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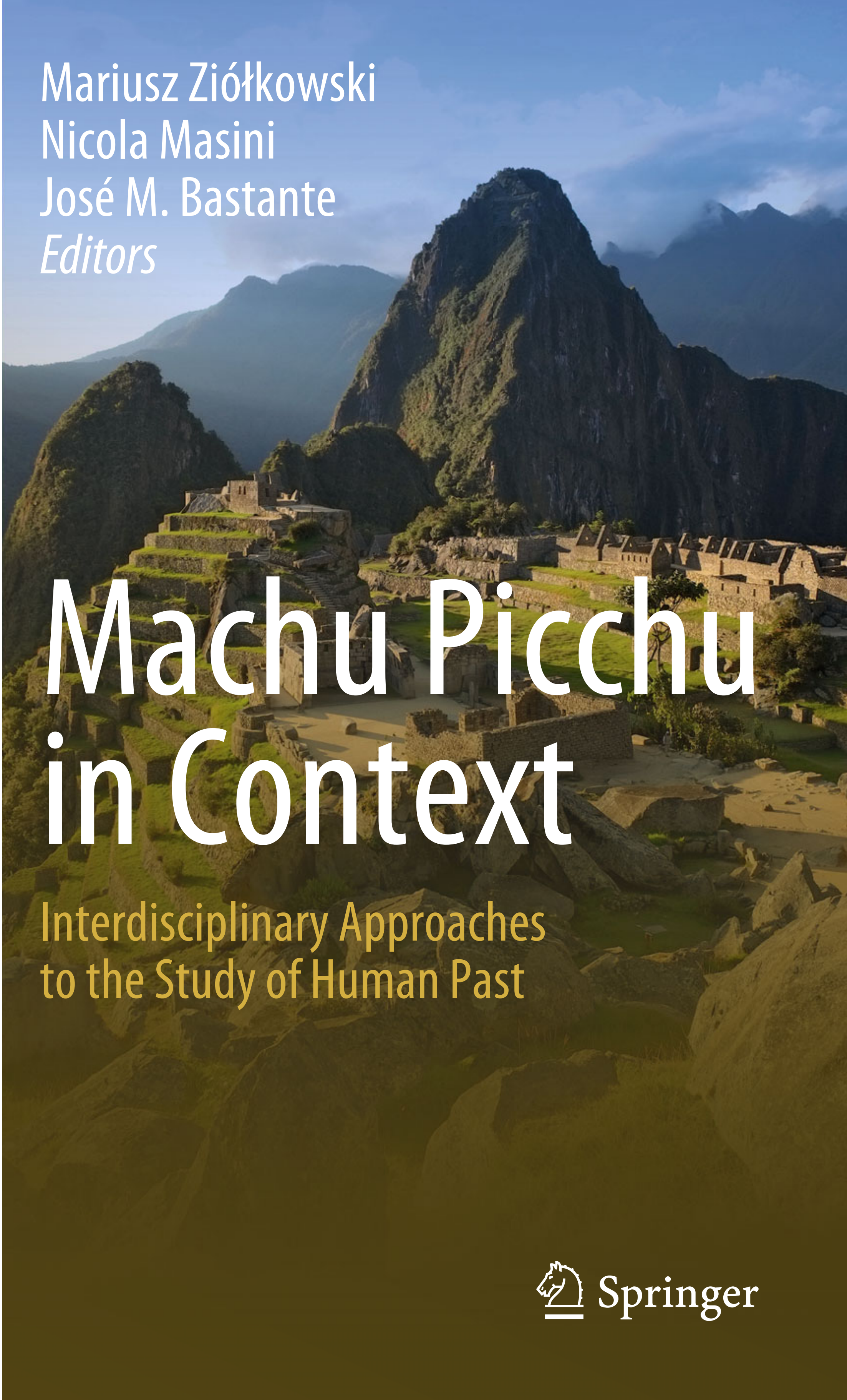
Machu Picchu in Context

Interdisciplinary Approaches to the Study of Human Past



Springer

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Foreword by Fernando Astete

The Historical Sanctuary—National Archaeological Park of Machu Picchu (SHM-PANM) is a mixed heritage site of Exceptional Universal Value, which must be protected, maintained and conserved as a priority. The fact that it is home to more than sixty archaeological monuments interconnected by a network of pre-Hispanic roads, and its harmony with the natural environment make it a place of exceptional beauty and an unlimited source of information for the different branches of knowledge. One of the most striking features of the area are the differences in altitude. In terms of minimum altitudes, at the eastern end of the SHM-PANM, the lower part of the Salapunku archaeological monument reaches 2,625 metres above sea level (masl), while at the western end, at the confluence of the Ahobamba and Vilcanota rivers, the altitude is 1,725 metres above sea level (masl). In reference to the maximum altitudes, in the south of the SHM-PANM, the snow-capped Salkantay reaches 6,271 masl and, in the northeast, the summit of Waqaywillka (Verónica) reaches 5,750 masl.

The Inka had a thorough knowledge of geography and the tutelary deities of the area, which allowed them to define a suitable area for the construction of the Machu Picchu llaqta and the other archaeological monuments in the region. In this way, a strategic location was determined from a religious and economic point of view, from where an extensive territory could be optimally administered and access to the enormous natural resources of the eastern chain of the Andes could be gained.

This llaqta has been habitually described as marvellous, extraordinary, fabulous, mystical and telluric, as the maximum expression of Inca architecture and engineering, the perfect symbiosis between human work and nature, among other appellatives, having been studied from the point of view of various disciplines.

In addition to the sacred geography in which it is immersed and the Vilcanota river surrounding it on three sides, the quality of the constructions in the *llaqta* is also a determining factor in defining its sacred character, as well as another element of utmost importance: water as a resource that reaches the nuclear area through a complex system of canalisation from the slopes of the Machu Picchu mountain.

In Andean construction rationality, architectural works are adapted to the topography of the terrain by terracing. This rationality is generally opposed to the contemporary conception, where it is generally preferred to achieve a more or less homogeneous surface to begin the construction process. The construction of the Machu Picchu llaqta required the participation of specialists in architecture, engineering and astronomy, as well as a great deal of manpower and thousands of man-hours for the work of preparing the land and transporting materials.

Inka architecture represents the original idea of what in modern times is known as organic architecture. That is to say, the Inka knew how to take advantage of the granite chaos of the site to build different types of structures for different purposes, such as ceremonial, housing and production enclosures, among others, by means of adequate stabilisation and protection of the slopes.

The processing, analysis, contrasting and cross-checking of all the information concerning the SHM-PANM disseminated from the different perspectives of the social and natural sciences since 1912, has allowed us to achieve a better understanding of the cultural development that took place in the area and the adjacent spaces; primarily about the origin and function of the llaqta of Machu Picchu, where most of the archaeological, conservation and restoration interventions have been carried out.

The SHM-PANM, and in particular the Machu Picchu llaqta within it, is the icon of our national identity and the best-known image of Peru worldwide. Therefore, the research and conservation work that is carried out is permanent and allows us to deepen our knowledge of the pre-Hispanic societies that developed in its area, as well as, through efficient management, to guarantee the proper enjoyment of this heritage asset, ensuring its integrity for future generations.

This publication is the result of a long collaboration between the Head of the PANM, led by myself and later by José Bastante, and the Centre for Andean Studies of the University of Warsaw, led by Dr Mariusz Ziółkowski. I am glad that Dr Nicola Masini and his team from the Consiglio Nazionale delle Ricerche in Italy have been invited to this fruitful international collaboration and have contributed with their valuable studies.

This book presents research carried out by different professionals under strict scientific standards and contributes to the clarification of numerous topics, some of which had not been addressed in previous studies. This type of publication brings us ever closer to a thorough understanding of the socio-cultural processes that took place in the area from the Late Formative period, through the Inka and Colonial periods, to the present day.

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Foreword by Ivan Ghezzi

The literature on the Incas, their empire, culture, architecture, infrastructure, and their other technical and technological achievements is vast. Yet, much less is known about the world-famous XVth century Machu Picchu site, located on a hilltop in the Urubamba River valley of Cuzco, Peru. The present volume, a compilation of eighteen papers covering a wide range of topics, helps fill that important gap.

This sample of the many multidisciplinary studies carried out at the Machu Picchu site is organised into three sections. Part I offers the context necessary to understand this settlement. It begins with the physiographic and environmental setting, which is considered a result of advanced environmental engineering techniques, as well as a sanctuary for the conservation of the park´s outstanding biodiversity. A chapter on the geological setting of the site, mainly granitoid bodies within the main rift system, details the important geomorphological risks in the surroundings of Machu Picchu, and a preliminary master plan for the mitigation and management of instabilities in its steep slopes. The next chapter compares and contrasts the "historical chronology", developed by John H. Rowe in 1945, and the absolute (radiocarbon) chronology to understand the expansion of the Inca state, using the brand-new calibration curves IntCal20 and SHCal20. In the following chapter, the Inca "building culture" is used to offer the context necessary to understand the architecture of Machu Picchu, whose building techniques are extremely complex and notable for their "almost perfect geometric and harmonic articulation". Finally, a systematic archaeoastronomical approach is applied to reveal alignments with a marked preference for orientations towards sunrise on the June Solstice from structures and architectural ensembles located in the main Machu Picchu site or its surroundings.

Part II consists of another five chapters related to the application of the natural sciences and technology to archaeological sites. Earth observation technologies applied to the study of cultural heritage in the first chapter demonstrates the great value of remote sensing to protect the natural and cultural landscape. The following chapter presents the results of the first archaeogeophysical research at Machu Picchu, derived from georadar and geomagnetic surveys, with the goal of exploring the subsoil in search of potential buried structures. Next, a chapter presents the advantages of airborne LiDAR technology to detect architectural and archaeological remains hidden under the forest cover of the sanctuary, especially when it is supplemented by close-range UAV platforms that allow for more detailed data collection in selected areas. The fourth chapter in this section presents a metrological study of the Machu Picchu citadel, applying the cosine quantogram method to the data provided by the 3D laser survey, with the aim of unveiling standards in the Inca measuring system. It identified two separate systems of Inca measures, based on different basic units. Finally, the results of the archaeological research performed at the Chachabamba site are presented and discussed.

Part III presents ten chapters with new data on archaeological and historical research performed on the site, as well as other related sites and infrastructure at the Machu Picchu National Archaeological Park. First, it presents the new archaeological and interdisciplinary research at the site, including a new sectorisation. Second, the archaeological and hydraulic research at the "water fountain" (phaqcha in Quechua language) of Chachabamba, to set the function of architectural solutions and modifications recorded at this site. Third, it presents results of the Underwater Archaeology program in the lakes situated near the piedmont of Salkantay mountain, where ritual ceremonies dedicated to the lakes were performed. Additionally, the pictographs (the so-called quillqas in Quechua) located at several rocky walls along the Lower Vilcanota basin, related to the Marcavalle Formative culture. It also contains an ethnohistorical study of post-Conquest documents on the site and its surroundings, which throws light on the evolution of land tenure and toponyms. Another chapter covers the chemical study of the biodeterioration of the stones composing the structures of Machu Picchu. The final chapter presents the logistics of Inca construction processes from data yielded by the study of four significant buildings at the site.

We warmly welcome this volume, which brings together detailed data and results from various interdisciplinary studies carried out at Machu Picchu over the last decade, with emphasis on the scientific and technological applications to archaeology, as an important contribution to the understanding of this magnificent World Heritage Site, and to the field of Inca studies in general.

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Introduction

Archaeology is today, like few other disciplines, in radical transformation and committed to overcoming any dichotomy between social and exact sciences.

The epistemological leap is evident.

The concept of science subsidiary to archaeology has long since passed. Archaeology today increasingly interprets the material evidence of the past, as components of complex natural and cultural systems, through interdisciplinary approaches that integrate it with other sciences such as physics, geography, geosciences, chemistry, remote sensing, geophysics and artificial intelligence.

Therefore, the way in which knowledge is acquired (ultimately the constitutive elements of the historical narrative) has been expanding. New questions arise, new horizons open up for research which, thanks to increasingly sophisticated methods and technologies, is able to penetrate more and more the historical depth and to allow a more precise reconstruction of the past.

Research is thus contributing centrality to global territorial approaches, passing from the priority of the site to that of the territorial and landscape context, with multidisciplinary and multifactorial interpretations of archaeological and geological records.

Hence the volume “Machu Picchu in context. Interdisciplinary approaches to the study of human past”which, starting from a consolidated (but in some cases fragmentary) state of the art of research, proposes an overall approach based on interdisciplinary integration and the use of the most advanced survey and imaging technologies, with particular attention to the relationship between Machu Picchu and its surroundings.

In this volume, we present to the public a series of recent interdisciplinary works on the Llaqta of Machu Picchu and its satellite sites, including Chachabamba, the Mirador of Inkaraqay and the Salkantay Mountain.

Such studies are the result of scientific cooperation between the National Archaeological Park of Machu Picchu (under the direction of Fernando Astete and Jose

Bastante[1]) and Centre for Andean Studies at the University of Warsaw[2] (directed by Mariusz Ziółkowski), to which the CNR has been added since 2016 through the ITACA Mission directed by Nicola Masini by CNR-ISPC.[3]

The National Park of Machu Picchu is covering an area of 37, 302 hectares. Its located in the valley of the Vilcanota–Urubamba river in the region of Cusco, province of Urubamba (Peru). The central part is a well-known agricultural, administrative and ceremonial complex of Machu Picchu. It is connected by a complicated road network with around 60 archaeological sites, which performed different functions, including agricultural and ceremonial ones. Understanding what the *llaqta* of Machu Picchu was itself, what functions it performer and how it developed depends not only on the study of the main centre, i.e. the Llaqta, but also on the research of its relation with surrounding satellite sites.

The Mirador de Inkaraqay is a small structure situated on the north, quite steep, slopes of Waynapicchu mountain. It is located in one of the zones of the Llaqta, at a distance of approximately 2 hour walk from the nuclear area. Architectural remains, which are quite well preserved, consist of three parallel walls placed perpendicularly to the steep slope of the hill. The lower wall serves as a retaining wall stabilising the footings of the building situated above. At the same time, it creates a narrow (ca. 1.75 m) platform facilitating access in front of the building. The middle wall is ca. 1.25 m wide and its façade is preserved to a height of ca. 3.5 m. The structure appears to be isolated from any habitation settlement and its small size suggests that it was used by a very small group of people. The previous research indicated that Mirador de Inkaraqay was a very precisely planed astronomic observatory, which permitted the observation of the rising Sun and the Pleiades.

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[1] The research undertaken in the Historic Santuary—National Archaeological Park of Machu Picchu is done in the framework of the Interdisciplinary Research Program of the Decentralized Directorate of Culture of Cusco/ Ministry of Culture of Peru.

[2] This research was started in the framework of the project: Function of the satellite archaeological sites in the vicinity of Machu Picchu: Inkaraqay and Chachabamba and the high mountain lakes on the foot of Nevado Salcantay (Peru), sponsored by a grant OPUS (number 2015/19/B/HS3/03557) from the National Science Centre of Poland. The research in Chachabamba was also sponsored in the framework of the project: Armakuna: ritual functions of the Inca "baths" in the Chachabamba ceremonial complex (Historic Sanctuary of Machu Picchu, Peru) by a Grant Preludium number 2015/19/N HS3/03626 from the National Science Centre of Poland. The logistic of the research of the Polish team was also supported by the Polish Ministry of Education and Science within SPUB grants./ The project was also attended by a group of Polish experts led by prof. Jacek Kościuk from the 3D Scanning and Modeling Laboratory at the Faculty of Architecture of the Wrocław Technical University. As part of the project, cooperation with other experts was also established: dr. Adine Gavazzi, an architect from the University of Genoa; prof. Giuseppe Orefici, archaeologist, an expert of rock art and the director of the Italian Centro Italiano Studi e Ricerche Archeologiche Precolombiane (CISRAP); prof. Alan Hogg, Director of the Waikato Radiocarbon Laboratory (New Zealand); prof. Andrzej Rakowski from the Department of Radioisotopes, Silesian University of Technology (Poland) and prof. Ewa Bulska, chemist, Director of Biological and Chemical Research Centre, University of Warsaw.

[3] Italian Mission includes also a research group of CNR-IMAA (directed by Rosa Lasaponara). Other italian experts by ISPRA-Italy (C. Margottini, D. Spizzichino) are among the coauthors of this book.

The Chachabamba archaeological site is located on an alluvial terrace on the left bank of the Vilcanota River at an average elevation of about 2172 m above sea level, at a distance of ca 3 hours walk. It is connected with the *llaqta* of Machu Picchu by the Inca trail running through the Wiñaywayna site. The site had a ritual function, as evidenced by the construction of 14 Inca baths used for ritual ablutions and the location of the sacred altar—*waka*, in the central part of the site.

The farthest (ca 6 to 10 hours of walk from the Lllaqta) area of studies are the lakes situated at an altitude superior to 4200 m asl, at the foot of the glacier covering Mt. Salcantay, one of the most important and sacred mountains of the Incas. The lakes were connected with Machu Picchu by a trail network. The area around the lakes was the object of the survey conducted both on land and under the water. A system of artificial platforms at the shores of Soqtacocha and Yanacocha lakes was identified. The discovery of these structures confirmed the assumptions about an important role of lakes in the Incas cosmovision rituals.

The book is divided into three sections.

The first section is focused on the Context including:

- the Physiographic and environmental setting (Spizzichino et al.) and Geological and geomorphological context of Machu Picchu (Margottini et al.)
- Machu Picchu in the context of the expansion of the Inca State, in light of the latest results from radiocarbon based chronological analyses (Ziółkowski et al.)
- an overview of Inca building culture with particular reference to Machu Picchu and the Urubamba Valley (Masini, Abate et al.)
- Astronomical observations at Machu Picchu: facts, hypothesis and wishful thinking (Ziółkowski & Kościuk).

The **second section** deals with **prospecting approaches and methods** based on novel earth observations sciences and survey technologies, including

- Open Big Earth Observation data and artificial intelligence for the study and preservation of UNESCO heritage: the case of Machu Picchu (Lasaponara et al.)
- New results from Archaeogeophysical investigations in Machu Picchu (Capozzoli et al.)
- LiDAR systems in architectural and archaeological research in the National Archaeological Park of Machu Picchu (Kościuk & Ćmielewski)
- The deveopment of standards in Inca measuring system(Kubicka & Kościuk)
- and, the multidisciplinaryInvestigation at the Chachabamba Archaeological Monument (Bastante, Sieczkowska, Deza).

Finally, the third section shows new results from archaeological and historical investigations on

- Machu Picchu (Bastante, Fernández, Astete) and the phaqcha from Chachabamba (Sieczkowska & Bastante) by means of interdisciplinary researches
- on the Lakes at the Foot of Salkantay Mountain based on Underwater Archaeolog. (Sobczyk et al.)

- Quillcas in the Historic Sanctuary-National Archaeological Park of Machu Picchu, a new line of evidence for the earliest occupancy of the lower Vilcanota basin (Echevarría López et al.)
- Machu Picchu National Archaeological Park by means of Ethnohistorical sources (Amado)
- biodeterioration of ancient structures in Machu Picchu by means of chemical studies (Bulska & Torres Eleguera)
- Inca construction process logistics applied to four structures in the Llaqta Machu Picchu (Kościuk & Bastante).

Nicola Masini
Mariusz Ziółkowski
José M. Bastante

Contents

Part I
Context

Chapter 1
Machu Picchu Physiographic and Environmental Settings

Daniele Spizzichino, Nicola Masini, Rosa Lasaponara, and Claudio Margottini

Abstract In this paper, we focus on the environmental and physiographic settings of Machu Picchu which is undoubtedly the result of advanced environmental engineering techniques. The Machu Picchu park is very rich in habitats and species diversity and preserves remarkable endemic and relict flora and fauna and for these reasons unanimously considered of global significance for biodiversity conservation.

Keywords Climate · Machu Picchu · Hydrological data · Land use · Habitats and species diversity

1.1 Introduction

In this paper we focus on the environmental and physiographic settings of Machu Picchu, the monumental masterpiece of architectural and landscape beauty, result of the Inca advanced environmental engineering techniques that are not fully understood still today.

In the Millenia and for diverse civilizations, the availability of resources, along with climate, environment, cultural, military and religious motivations have been the main factors that most influenced the choice of a place to build settlements and monuments.

The availability of building materials along with their characteristics and typology and the specific climate and environmental factors have generally conditioned the

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building techniques and technology construction, especially in places prone to geological and geomorphological hazards, as in the case of Machu Picchu. In particular, human activities are intimately intertwined with geomorphological processes and with the empirical capability of understanding and interpreting geomorphology contexts that in some cases allow to transform problems into opportunities. This ability to observe, analyse and interpret geomorphological landscapes was particularly developed by the pre-Hispanic civilizations in Southern America. Machu Picchu is an emblematic and extraordinary example of this attitude: the impressive terraces complement physically and aesthetically the magnificent granite rock structures among which it has been built. The monumental site is located between the mountains of Machu Picchu and Huayna Picchu, part of a large orographic formation, known as the Batolito Vilcabamba in the central Cordillera of the Peruvian Andes, and overlooks the left bank of the Urubamba Canyon, also known as Quebrada de Picchu. Declared as a World Heritage Site by UNESCO in 1983, Machu Picchu was officially rediscovered on 24 July of 1911, by the American explorer and archaeologist Hiram Bingham.

What did amaze Bingham, and does continue to amaze those who visit and study it still today, is the landscape in which the citadel is located that actually is unparalleled worldwide, as Bingham himself described it in his work ("I do not know any place in the world comparable to this"). It is located upon an upland at 2430 m.a.s.l.r., under which the Urubamba River flows, inside a park as wide as 32.592 Ha (325.92 km^2) on km 112 of the Qusqo-Quillabamba railway. The urban plan of the citadel extends for about seven hundred meters in the NE-SW direction on a plateau with a width of about five hundred meters with the exception of "Carretera Hiram". Every side of town is bordered by deep slopes (Fig. 1.1).

1.2 Site Location

The monumental complex of Machu Picchu (Lat. 13° 09′ South, Long. 72° 31′ West) is located on the top of a graben-like structure at 2.430 m.a.s.l., in the high Eastern Cordillera of the Peruvian Andean chain, and 500 m above the Urubamba river that cuts the Cordillera, approx. 80 km from Cuzco (Fig. 1.1). The Machu Picchu granitoid pluton, forming part of the larger "Quillabamba granite", is one of a series of plutons intruded along the axial zone of the high Eastern Cordillera Permo-Liassic rift system including a variety of rock types, dominantly granites and granodiorites (Mazzoli et al. 2009). Slope evolution of the area is mainly controlled by tectonic uplift, fluvial erosion operated by the Urubamba river, located at the toe of slopes, and by The monumental complex of Machu Picchu (Lat. 13° 09′ South, Long. 72° 31′ West), is located on the top of a graben-like structure at 2.430 m.a.s.l., in the high

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Fig. 1.1 Aerial photo view of Machu Picchu

Eastern Cordillera of the Peruvian Andean chain, and 500 m above the Urubamba river that cuts the Cordillera, approx. 80 km from Cuzco (Peru).

Machu Picchu (like most of the Quechua names of towns and different sites in the region) is a compound word which derives from macho = "old" or "ancient", and picchu = "peak" or "mountain"; therefore, Machu Picchu is often translated as "Old Mountain". The famous mountain which you see in the front, and appears in most of the classical views of the site, is named Huayna Picchu ("Young Mountain"). Because of its inaccessibility, the place (steep cliffs surrounded by the Urubamba river skirting the archaeological site) has always been considered as a possible military end of the citadel as well as to its possible religious character. Although numerous modern archaeologists are unwilling to consider Machu Picchu as a military citadel (due to the absence of a defense wall), the geographical position (isolated place) undoubtedly served as an excellent defense against a possible attack.

The choice of Machu Picchu site must have been made with great care, because it was, and still is, the ideal place to locate a centre for worship in a sacred mountain chain, starting at Salcantay (the *Apu*, or Great Spirit) and ending in Huayna Picchu.

Machu Picchu was probably constructed around 1450, at the height of the Inca Empire. It was abandoned less than 100 years later. According to the buildings discovered in the Inkan City, during its apogee, the population is calculated to have been about 1000 inhabitants. The mummies discovered by Bingham's expedition revealed that about 80% of Machu Picchu's population was constituted by women. This strongly supports the assertion that an important "Aqllawasi" (House of Chosen Women) stood here.

1.3 Weather Climate and Hydrological Setting

1.3.1 General Weather Climatic Setting of the Whole Area

The climate of the area has numerous contrasts and is characterized by the existence of different climatic zones (Fig. 1.2a, b).

Specifically:

- a hot band at altitudes lower than 2000 m above sea level;
- a moderate band for altitudes between 2000 and 3300 m;
- a cold band at altitudes between 3700 and 4800 m;
- a very cold band of perennial snow at altitudes higher than 4800 m.

Generally, the climate of the area is characterized by an alternation of a dry season (from April to August), a regular precipitation season (September to December) and three months of heavy and frequent rainfall (January to March).

The investigated area is classified as: B rainy; (o, i) dry autumn and winter; B′ tempered.

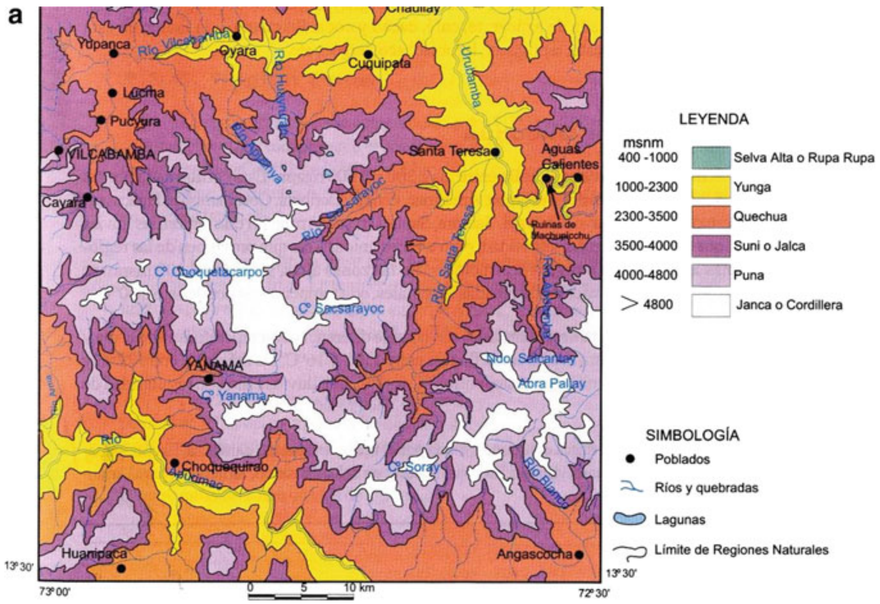


Fig. 1.2 (**a**) Map in Quillabamba e Machu Picchu Regions. (**b**) Climate classification national map. *Source* SENAMHI (2021)

b

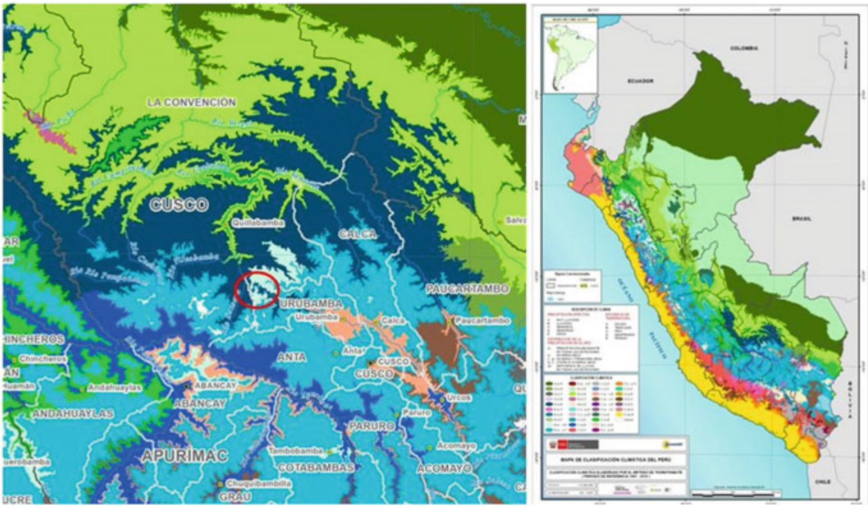


Fig. 1.2 (continued)

1.3.2 The Past Climate Estimated by Glaciological Measures

The past climate in the Historic Sanctuary of Machu Picchu could be reconstructed on the basis of literature data concerning the analysis of 2 cores of ice from the Quelccaya ice cap (Lat. 13° 56′ South, Long. 70° 50′ West, altitude 5670 m) located in the Andean Southern Peru, about 250 km south-east off Machu Picchu. Drilling has allowed the analysis of thick ice which covers a period of about 1500 years, with the identification of the annual changes in the visible layers of dusts, in the oxygen isotopes, in concentrations of fine particles and in the conductivity values: the annual depths so identified have been developed in order to obtain the estimated annual quantity of snowfall. The layers of the Quelccaya ice have therefore recorded the historical regional climatic situation of this sector of the Andes, and can be used in the analysis of the area climate trends. One sampled core represents the years from 470 to 1984, the other one from 744 to 1984. Therefore, it has been possible to reconstruct the sequence of wet and dry cycles between 470 and 1984, as shown in Table 1.1. (Thompson et al. 1985). The average depth of annual layers of ice, calculated over the period represented by the cores, is about 1.4 m: this value was estimated to be equal to an average annual rainfall of about 1990 mm of rain. The general weather pattern shows alternating dry and wet periods, summarized in Table 1.1 (Thompson et al. 1985), where the star indicates the extreme periods in which the average rainfall for both surveys is 20% higher or lower than the average (Fig. 1.3a, b).

Table 1.1 Alternating wet and dry periods from the analysis of ice cores taken on Quelccaya (Wright et al. 1999; INTERFRASI 2008)

Trend shown by the precipitation of the Quelccaya cores	
Wet periods	Dry periods
	540–560
	570–610*
610–650	
	650–730
760–1040	
	1250–1310*
1500–1720*	
	1720–1860*
1870–1984	

* The extreme periods in which the average rainfall for both surveys is 20% higher or lower than the average

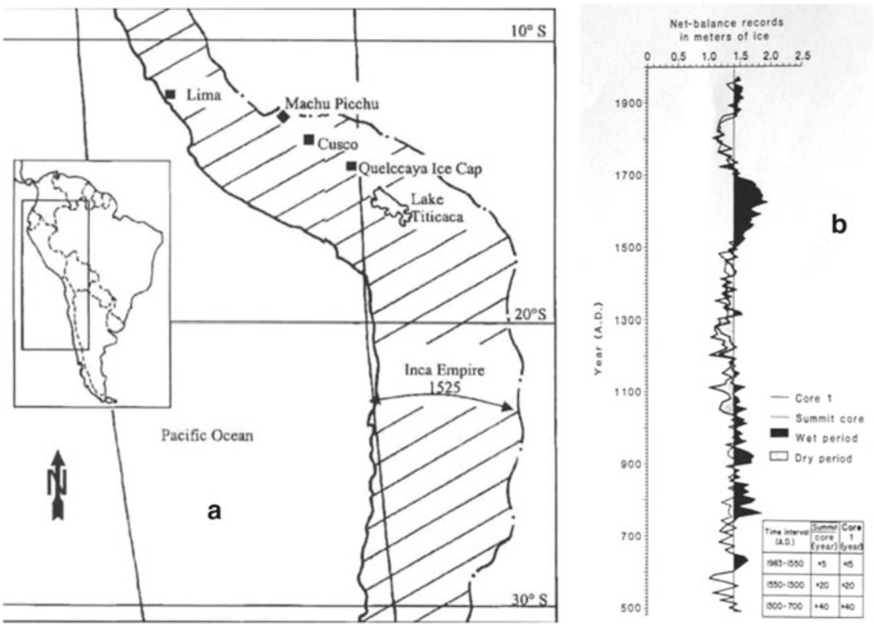


Fig. 1.3 (**a**) Extension of the Inca Empire at the time of the arrival of conquistador Pizarro in 1532, with the position of Quelccaya Glacier in relation to the sites of Machu Picchu, Lima, Cuzco and Lake Titicaca. (**b**) Reconstructed climate trends based on the analysis of the ice on Quelccaya (Andean area of Southern Peru) (Thompson et al. 1985). Map in Quillabamba e Machu Picchu Regions

In particular, the dry period between 1160 and 1500 has been particularly intense between 1250 and 1310, and a long wet period between 1500 and 1720, corresponding to a climatic phase extended over the entire planet, known as the "little ice age" (Thompson et al. 1985). At this stage, we have reached the highest values of precipitation in the area. Subsequently, we observe a period of drought characterized by minimum values in the depth of ice, between 1720 and 1860. In Fig. 1.4 (Wright and Zegarra 2000) such alternations of wet and dry periods are directly compared, and the rainfall pattern during the period of occupation of the Inca site of Machu Picchu. During the Inca occupation of the site, between 1450 and about 1540 (Fig. 1.5), the values of the ten-year average precipitation, evaluated on the levels of accumulation

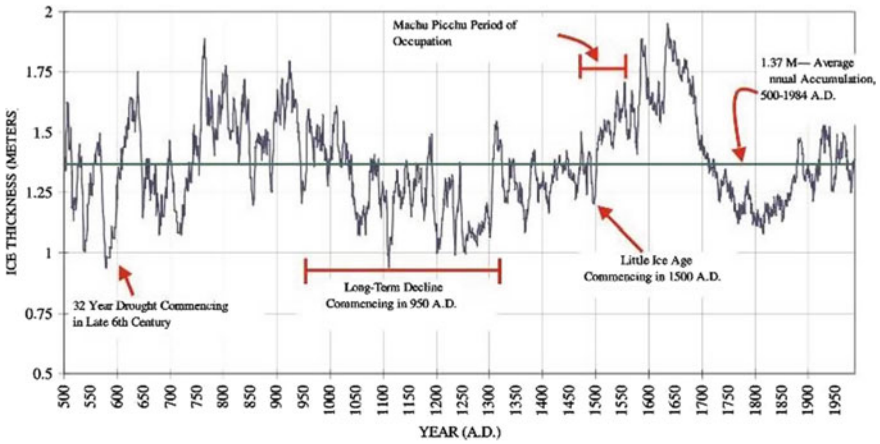


Fig. 1.4 Performance of the depth of snowfall on Quelccaya Glacier (Wright and Zegarra 2000)

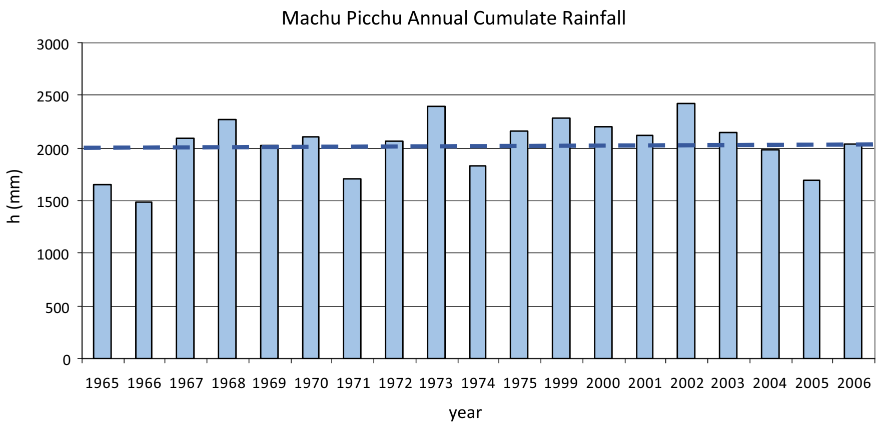


Fig. 1.5 Cumulative annual precipitation from three different meteo station in the sanctuary. Blue line is the Annual Average Rainfall (2035.7 mm/year). *Source* SENAMHI (2021)

Table 1.2 Ten-year average precipitation values, evaluated on the basis of the levels of accumulation of ice and in comparison with the average between 1967 and 1977 (Wright and Zegarra 2000; INTERFRASI 2008)

Average annual precipitation per decade during the Inca occupation of Machu Picchu	
Years	Rainfall (mm/year)
1450–1459	1770
1460–1469	1900
1470–1479	1830
480–1489	1770
1490–1499	1860
1500–1509	2020
1510–1519	2150
1520–1529	1980
1530–1539	2220
Average	1940
1967–1977	1960

of ice, have fluctuated between a minimum of 1770 mm/year and a maximum of 2220 mm/year, see Table 1.2 (Wright and Zegarra 2000). The same Table 1.2 also shows the average rainfall measured in the Historic Sanctuary in the period 1967 to 1977.

As shown below, the average rainfall measured between 1967 and 1977 is quite comparable with the average between 1450 and 1540 estimated on the basis of glaciological data, indicating that precipitation levels today are similar to those that occurred during the period of the Inca settlement in Machu Picchu.

For the actual period, climate data measured directly on site are available, still on the Quelccaya glacier system, between 1964 and 1977: the accumulation of these data indicates an average depth of 1.38 m ice equivalent to about 99% depth calculated in the long time. By analysing the comparison between the data on the depth of the Quelccaya ice cap (Fig. 1.5) and precipitation recorded in the current era, one can note that they correspond to 99% of the average value over the long term and that only 1% exceeded the precipitation values calculated for the time interval between 1450 and 1540. We can conclude that the average monthly and annual changes in precipitation for the current period are representative of the values of precipitation for the period of the Inca occupation of Machu Picchu. The ten-year averages of equivalent precipitation between 1450 and 1540 can be grouped into two phases:

- the first one, from 1450 to 1500, characterized by average rainfall around 1830 mm/year, about 8% lower than the long-term average (470 to 1984);
- the second one, from 1500 to 1540, with rainfall estimated at 2090 mm/year, 5% higher than the long-term average.

The rainfall pattern, then, shows that the hardest period for the area of Machu Picchu, after the building of the town, was during the so-called “little ice age”, with a maximum depth of ice on the cover of Quelccaya of approximately 1.95 m, corresponding to an average rainfall of about 40% higher than current levels.

1.3.3 Recent Rainfall Data

The site of Machu Picchu was monitored continuously between 1964 and 1977 by the National Service of Meteorology and Hydrology—SENAMHI (Cusco, Peru 2021); the monthly values of rainfall data collected are shown as follows, in Table 1.3

The synthesis of these data, displayed in Table 1.4, indicates that the area of Machu Picchu is characterized by a dry winter season (from May to August) and a rainy summer season (October to March) (Tables 1.4 and 1.5).

Three weather stations have recently been installed in the Sanctuary of Machu Picchu, by the National Institute for Natural Resources (INRENA 1998) in the towns

Table 1.3 Total monthly rainfall data sources (SENAMHI 2021)

Monthly rainfall (mm)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec	Annual
1964					48	24	23	54	71	58	108	216	
1965	231	301	248	139	0	23	52	27	191	142	103	201	1658
1966	242	272	148	58	32	2	23	30	37	171	225	248	1488
1967	287	286	396	115	47	7	63	83	114	293	108	289	2088
1968	350	399	353	107	31	30	132	81	65	197	313	210	2268
1969	254	260	309	263	59	111	15			141	159	280	
1970		329	288	268	108	28	79	34	108	160	118	283	
1971	286	347	256	161	20	37	16	70	24	120	115	247	1699
1972	381	227	344	187	63	2	32	94	92	118	262	263	2065
1973	301	449	380	311	30	24	42	121	169	118	195	258	2398
1974	258	356	214	258	20	27	65	126	102	178	79	142	1825
1975	268	368	309	148	124	86	22	42	113	166	212	303	2161
1976	276	260	399										
1977							52	32	132	121	223	198	
Average	285	321	304	183	49	33	47	66	102	153	171	241	1961
N. years	11	12	12	11	12	12	13	12	12	13	13	13	9
Min	231	227	148	58	0	2	15	27	24	58	79	142	1488
Max	381	449	399	311	124	111	132	126	191	293	313	303	2398

Table 1.4 Summary of rainfall data (1964–1977) sources (SENAMHI 2021)

Rainfall	Mm
Year average	1961
Year max	2398
Year min	1488
Average May–August	195
Average October–March	1473

of Wayllabamba, and Wiñaywayna Q'Oriwayrachina. The stations record hourly rainfall: Table 1.5 shows the summary of the total monthly amount. The observation period for these data is too short to make any statistical assessment (Fig. 1.6).

Directly from the SENAME meteo web portal last five years rainfall data were collected and plotted, in order to define some potential recent anomalies from past seasonal trend. The average rainfall data (monthly and yearly) seems to confirm the trend from previous decades (see Fig. 1.7). The present trend (2020–2021), with respect to last decade's cumulative rainfall distribution, is completely in accordance with the expected forecast (see Fig. 1.8).

1.3.4 Temperature Data

Concerning temperature, monthly mean data are provided by SENAMHI (2021), according to the measurement recorded between 1964 and 1977 (Table 2.6).

In summary, the climate in the area of Machu Picchu is temperate and there are no periods of frost. The temperature range is limited. In addition:

- The average minimum monthly temperature has been 8.2 °C (July).
- The average maximum monthly temperature has been 22.0 °C (August).
- The lowest monthly minimum temperature is 6.8 °C (July).
- The highest monthly maximum temperature is 23.4 °C (September)

1.3.5 Hydrological Data and Discharges

Data regarding discharge measurement and water quality at the primary distribution channel of the Citadel (Wright and Zegarra 2000) have been collected and preliminarily analysed: the flow is variable, ranging between 23 l/min and 125 l/minute, approximately 40,000 m^3/year. The comparison between wet and dry precipitation and the flow (Fig. 1.9) shows a significant change in flow during the season but always strictly linked with rainfall: this variability indicates that the flow comes from a relatively localized catchment area and is influenced by the variable seasonal rainfall.

Table 1.5 Summary of total monthly data in the localities of Wayllabamba, Wiñaywayna and Machu Picchu (SENAMHI 2021)

Year	Jan	Feb	Mar	Apr	May	June	July	Agu	Sept	Oct	Nov	Dec	Total
1965	230.5	301.3	247.9	139.3	0.0	22.7	52.4	27.3	190.6	142.1	103.2	200.9	1658
1966	242.3	271.7	148.4	58.0	32.1	2.2	23.1	30.0	37.0	171.2	225.0	247.7	1489
1967	286.8	285.8	396.3	115.3	46.9	7.0	62.9	83.1	114.2	293.4	107.7	288.9	2088
1968	350.4	399.1	353.1	107.1	31.0	30.3	132.4	80.6	65.4	196.9	313.3	209.8	2269
1969	254.8	260.1	308.9	262.8	59.0	110.7	15.2	66.4	97.7	141.4	159.4	280.0	2016
1970	297.1	328.8	287.7	268.4	108.1	27.8	79.2	34.0	107.8	160.0	117.8	283.2	2100
1971	286.1	346.8	256.3	161.2	20.2	37.2	16.0	70.0	24.3	120.3	115.2	246.5	1700
1972	381.1	226.7	343.7	186.8	62.8	2.2	31.8	94.1	91.9	117.6	262.3	262.9	2064
1973	301.1	449.2	380.0	311.3	29.7	23.8	42.3	121.0	169.2	117.8	195.1	257.8	2398
1974	257.5	355.8	213.9	257.7	19.5	26.6	64.7	126.3	102.0	177.9	79.2	142.3	1823
1975	268.1	368.4	308.8	148.1	124.4	86.2	22.2	42.4	112.8	166.3	211.9	302.6	2162
1999	430.90	476.50	302.60	227.60	189.10	28.10	33.90	16.60	116.50	119.60	148.30	193.2	2283
2000	395.40	339.50	265.10	207.20	75.30	132.20	36.00	125.20	142.50	183.50	113.20	191.6	2207
2001	292.00	308.80	393.30	93.50	81.50	98.80	61.50	50.60	94.40	155.70	230.10	262.5	2123
2002	212.70	358.50	359.50	282.80	43.10	65.20	144.10	50.70	121.50	231.40	193.50	364.5	2428
2003	310.40	333.90	463.90	154.40	70.80	53.50	39.80	87.90	88.80	113.20	135.70	295.8	2148
2004	350.80	320.20	213.20	160.30	78.80	43.70	145.90	92.50	70.40	141.10	143.20	225.8	1986
2005	160.70	314.10	278.00	146.60	26.50	2.00	45.20	14.00	65.40	188.20	141.90	314.5	1697
2006	335.60	215.00	381.20	211.60	35.00	109.00	36.50	48.70	44.10	157.20	204.20	260.6	2039
Average	297.1	329.5	310.6	184.2	59.7	47.9	57.1	66.4	97.7	162.9	168.4	254.3	2035.7

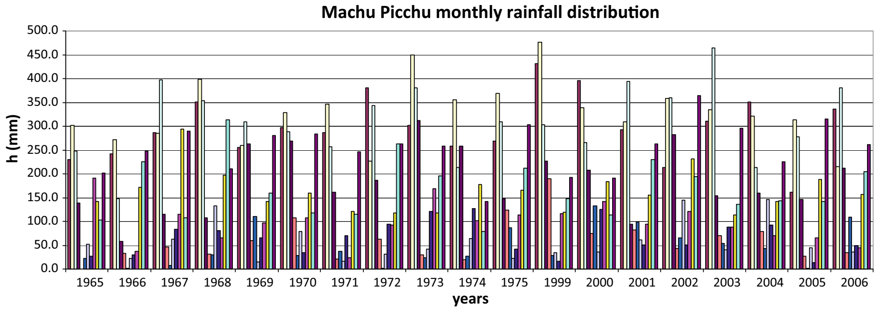
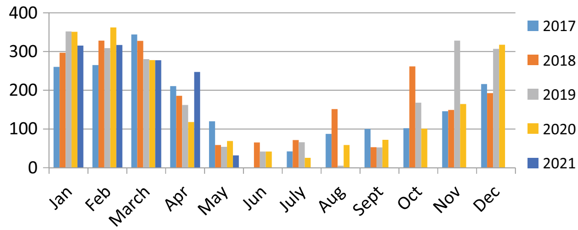


Fig. 1.6 Annual and monthly distribution of rainfall in the study area during the period from 1965 to 2006. *Source* SENAMHI (2021)

Fig. 1.7 Annual and monthly distribution of rainfall in the study area during the period from 2017 to 2021. *Source* SENAMHI (2021)



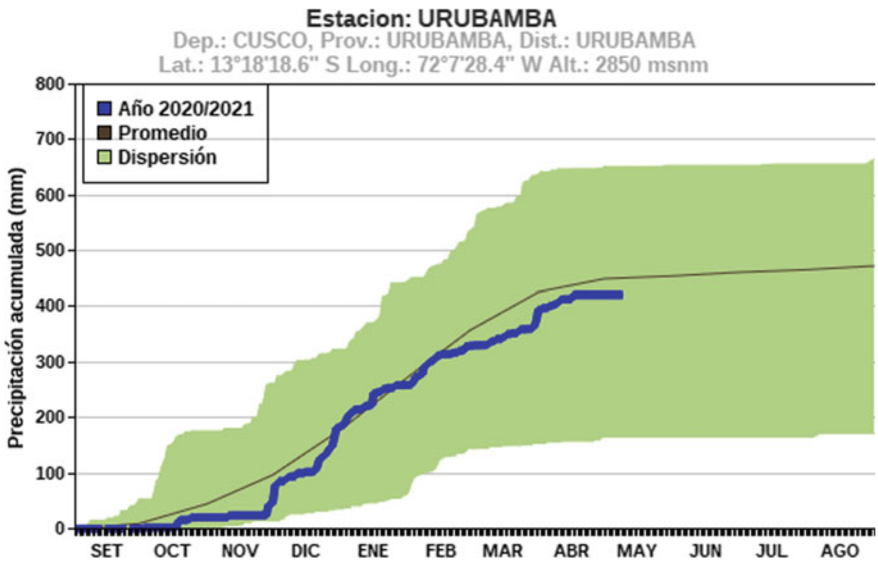


Fig. 1.8 Actual trend (2020 – 2021) with respect to last decade's cumulative rainfall distribution. *Source* SENAMHI (2021)

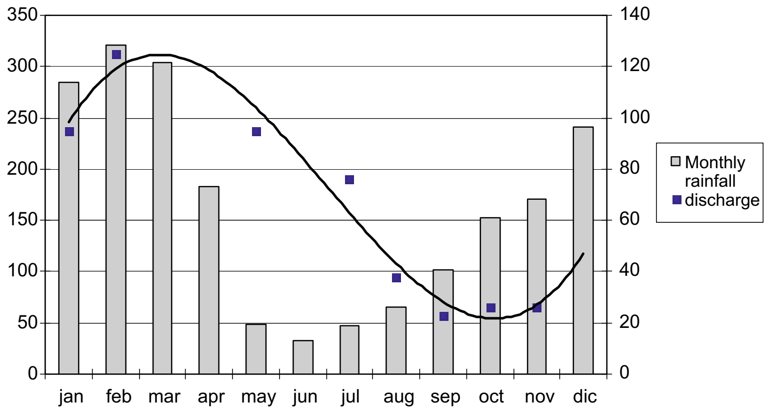


Fig. 1.9 Comparison between the average monthly precipitation (mm) and the flow rate of the Citadel of Machu Picchu (l/min). *Source* Wright and Zegarra (2000)

The following estimates of evaporation and evapotranspiration in the Historic Sanctuary (Wright and Zegarra 2000) have been provided:

- Average value for forested areas: 1760 mm/year;
- Average value for areas dedicated to agricultural activities: 1200 mm/year;
- Average value for the urbanized area: 600 mm/year.

Concerning the drainage method in the Citadel, on the basis of topography, soil type and vegetation cover, erosion and drainage holes of sub-surface potential, it has been estimated that about 90% of the annual water runoff produced by agricultural terraces was by infiltration, and the remaining 10% for surface runoff. On the contrary, in the urban area of Machu Picchu, the runoff reaches 60%, with 40% of infiltration. In any case, there was an efficient drainage system, both in urban areas and agricultural terraces, in order to avoid dangerous increases in the level of local groundwater.

1.3.6 Survey of Land Use Conditions

For a correct risk definition, jointly with a rigorous hazard assessment, a more detailed analysis of the exposed elements (at different scales of approach) must be implemented, considering also their value and their vulnerability, both in terms of loss (related to the occurrence of an event in a given area at a given time for a given intensity) and responsiveness to the solicitation from an external input (e.g. seismic, hydraulic, landslide). On such a basis, it was useful to produce a land use map (in the local area of investigation), as the first level of the elements exposed.

The basic data used for creating this map were:

- Plan Director of INRENA from 1999;

Table 1.6 Distribution of land use typologies

Typologies	Area (m^2)	Hectares (ha)	%
Sand	1173,264	117	0.03
Dense subtropical forest	2,322,509,153	232,251	57.60
Dense wet scrub	130,980,519	13,098	3.25
Rare wet scrub	792,219,180	79,222	19.65
Rocks	591,145,149	59,115	14.66
Water	74,943,929	7494	1.86
Archaeological site	119,437,617	11,944	2.96
Total	4,032,408,811	403,241	100

Source INRENA (1998)

- Aerial photos dating back to 2000, 1997, 1991, 1963, 1957, 1956;
- Quickbird satellite flight 2004.

The base layer information (INRENA 1998) has been updated and checked with the correct interpretation of ortho-photos and satellite images (Quickbird images). After the digitization and correction of land use zoning district the main land use typologies were summarized in Table 1.6.

The analysis of the information concerning land use shows the predominance of forests (subtropical forest, 58%) and shrubs (dense and often wet bush, 22%), followed by bare areas (rock, 15%) and archaeological sites (3%), river zones (2%). Bare areas are probably underestimated because of the steepness of rock walls (Figs. 1.10 and 1.11).

1.3.7 The Machu Picchu Reserve Area: Natural World Heritage Property

Machu Picchu is a mixed World Heritage property (namely both natural and cultural heritage) recognized for its outstanding cultural and natural values, being that it is very rich in habitats and species diversity and preserves remarkable endemic and relict flora and fauna and for these reasons unanimously considered of global significance for biodiversity conservation. Machu Picchu is located in the transition between the High Andes and the Amazon Basin ecosystems, and, therefore, it exhibits elements of both Andean and Amazonian ecosystems with nine life zones (as shown in Table 1.7) concentrated in a very short distance.

The diverse array of microclimates generated a very rich biodiversity concentrated in small size (around 38 thousand hectares) area, which hosts (among the others) riverine vegetation, humid and very humid low montane subtropical forests, humid evergreen and quasi-cloud forests, cultivated fields, terraces which have reverted to

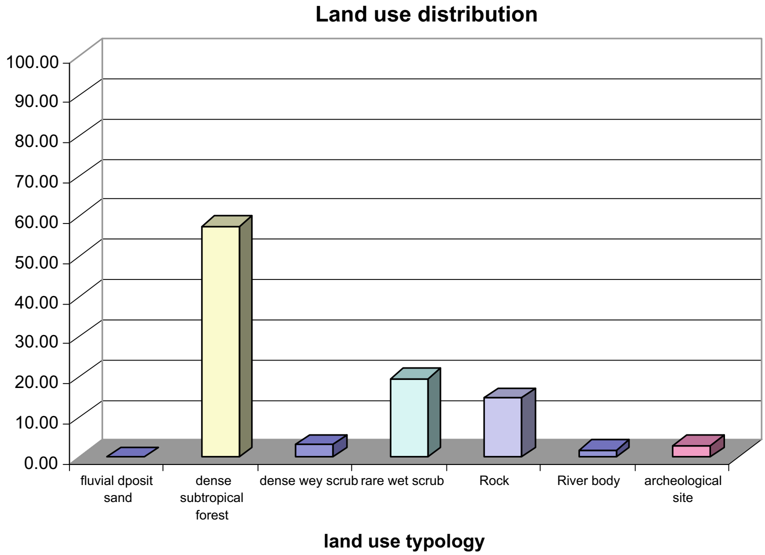


Fig. 1.10 Distribution of main land use typologies in the area

Fig. 1.11 Panoramic view of typical landscape

Table 1.7 Life zones distribution for the Machu Picchu reserve area

Life zone	Elevation (M)	Average Precip (mm)	Temp (°C)	% of area	Terrain
Subtropical humid forest	1850–3000	1950	15–18°	0.51	Flat to hilly
Subtropical humid low montane forest	2400–3000	1100	12–15°	3.67	Flat to hilly/steep
Subtropical very humid low montane forest	2000–3000	1950	12–15°	14.12	Flat to hilly/steep
Subtropical montane rainforest	3.000–3800	1900	6–12°	27.21	Sloping to steep
Subtropical very humid montane rainforest	3.000–3800	1500	6–12°	7.65	Sloping tosteep
Very humid subtropical subalpine paramo	3800–4400	1000	3–6°	12.43	Hilly to steep
Subtropical pluvial subalpine paramo	4.000–4400	1500	3–6°	13.73	Hilly to steep
Subtropical pluvial alpine tundra	4400–4900	1000	1.5–3°	13.71	Hilly to steep
Subtropical snow-capped peaks	>4600	900	<1.5°	7.5	Rugged

grass and secondary scrub or woodland, with above the ruins, bamboo, Polylepis and paramo grasslands. The Machu Picchu Reserve area (around 32,520 hectares) comprises the historical Sanctuary of Machu Picchu and its variety of micro regions gives rise to more than 700 species of butterflies and 400 species of birds among them the Andean Condor (considered to be sacred for the Peruvian people,) the Torrent Duck, the Hooded Siskin, the Green Jay and the Giant Hummingbird and the Cock-of-the-Rock (the national bird of Peru).

Therefore, the Outstanding Universal Value of the Inca City of the Historic Sanctuary of Machu Picchu has been recognized by UNESCO (among the other reasons /criteria) because:

(i) it is “a masterpiece of art, urbanism, architecture and engineering of the Inca Civilization” (Criterion (I).
(ii) “The property is part of a larger area unanimously considered of global significance for biodiversity conservation” Criterion (IX).

Since the time of the UNESCO inscription, concern was expressed about a diffuse ecosystem degradation due to (for example, but not only) the logging activities, firewood and commercial plant collection, poor waste management, poaching, agricultural encroachment, the introduction new species, increase of water pollution from both agro-chemicals in the Urubamba River and urban waste. To face these issues, significant efforts have been addressed as, the initiation of specific studies to investigate cultural and socio-economic aspects and improve knowledge on natural heritage in order to support and develop a Machu Picchu-Choquequirao Biosphere Reserve proposal.

In the framework of the cooperation between the Italian CNR and the Peruvian National Archaeological Park of Machu Picchu, a satellite based monitoring system has been ad hoc devised for Machu Picchu and currently implemented to be tested. In the recent decades, the availability of Earth Observation technologies for Cultural and Natural Heritage (CNH) is stepping into a golden age characterized by an increasing growth of both classical and emerging technologies for the study, documentation and preservation of the human past, archaeological landscape and environment. In the system devised and implemented for Machu Picchu satellite based analyses, including long time series of Landsat TM and Sentinel data (freely available from NASA and ESA, respectively) were performed in Google Earth Engine platform.

As a whole, in 2019 UNESCO (https://whc.unesco.org/en/soc/3926) considered resolved most of the issues.

1.4 Conclusions

In the present chapter, all the available information and data have been collected in order to provide a preliminary useful classification of the climate and vegetation setting. A specific study of the climate of the area has been carried out through the use of past glaciological measurements. These calculations have allowed defining climate setting for various time slots, thus making a preliminary comparison between past and present scenarios. Moreover, recent rainfall and temperature data obtained from literature and rain gauges have been collected and elaborated. It was already possible to define the current climate trends in terms of average rainfalls and temperatures. Finally, a preliminary analysis concerning main land use typology investigated in the study area has been conducted.

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References

Burger RL, Salazar RC (2008) Machu Picchu. Unveiling the Mystery of the Incas. ISBN: 9780300136456, 18 February, 240 pp

INRENA (1998) Plan Maestro del Manejo del Santuario Historico de Machupicchu. INRENA, Lima

INTERFRASI Project (2008) Satellite and ground based radar interferometer, integrated by GPS and other innovative equipments for monitoring archaeological sites in landslide areas: New technology for the safeguard of the INCA citadel of Machu Picchu (Peru). Final Report, 93 pp

Mazzoli S, Vitale S, Delmonaco G, Guerriero V, Margottini C, Spizzichino D (2009) 'Diffuse faulting' in the Machu Picchu granitoid pluton, Eastern Cordillera, Peru. J Struct Geol 31(11):1395–1408

SENAMHI (2021) http://www.senamhi.gob.pe/

Thompson LG, Moseley-Thompson E, Bolzan JF, Koci BR (1985) A 1500-year record of tropical precipitation in ice cores from the Quelccaya ice cap, Peru. Science 229(4717):971–973

Velasco AZ, Crousillat J (1999) Guía de Machu Picchu. Instituto de Estudios Peruanos; Università del Texas. ISBN: 9972510182, 9789972510182, 157 pp

Wright KR, Valencia ZA, Lorrah WL (1999) Ancient Machu Picchu drainage engineering. J Irrig Drain Eng 125(6):360–369

Wright KR, Zegarra AV (2000) Machu Picchu a civil engineering marvel. American Society of Civil Engineers, USA.

Chapter 2
Geological Setting and Geomorphological Hazards in Machu Picchu Area

Claudio Margottini and Daniele Spizzichino

Abstract The territory of the Inca Historical Sanctuary of Machu Picchu is characterized by granitoid bodies that had been emplaced in the axial zones of the main rift system. Deformation of the granite, caused by cooling and tectonic phases, originated 4 main joint sets, regularly spaced (few decimeters to meters).

Several slope instability phenomena have been identified and classified according to mechanism, material involved and state of activity. They are mainly related to rock falls, rock slides, debris flows and debris slides. Origin of phenomena is kinematically controlled by the structural setting and relationship with slope face (rock falls, rock slide and debris slides); the accumulated materials are the source for debris flow.

A preliminary master plan for mitigation and management of slope instabilities has been implemented. This includes a set of active, passive and mixed measures to reduce hazard or vulnerability, with a major attention to low impact solutions, possibly recovering local traditional techniques. Special attention has been posed to the Hiram Bingham Carretera, the unique way to access the site and where important debris flows have been identified.

Keywords Geology · Machu Picchu · Landslide

2.1 Introduction

The present chapter is mainly focused on the geological setting of the Machu Picchu archaeological area, starting from a regional approach through a more detailed analysis. Local geology as well as the geomechanical and structural setting were investigated. All the morphological processes and landslide typologies affecting the site were reported and described.

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The relationship between structural predisposing factors and geo-hazards was analyzed with the help of stability models implementation. A final master plan including landslide risk scenario and sustainable management of the site was reported.

2.2 Regional Geology

The territory of the Inca Historical Sanctuary of Machu Picchu is characterized by the outcropping of igneous rocks, essentially plutonic, which constitute the core of the Cordillera of Vilcabamba (Upper Permian–Lower Triassic). These intrusive bodies are generally WNO-ESE oriented and constitute the highest elevation of the Eastern Cordillera (Fig. 2.1). The study area is almost entirely interested by a plutonic body named batholith of Machu Picchu, as reported in Fig. 2.2: it is a huge intrusive triangular-shaped body mainly characterized by the presence of granite and, subordinately, by granodiorite and quartz-monzonite (Carlotto 1998; Carlotto et al. 1999). This intrusive mass has been dated ca. 24610 Ma (radionuclide dating based on Rb/Sr ratio). In the northern sector of the area, next to the major river catchments (e.g., Aguas Calientes River), the contact between the intrusive rocks and the quartzitic and metaquartzitic basement of the Sandia/Group of San Josè Formation (Ordovician) outcrops. The latter, in this sector, exhibits a microcrystalline dark gray-green facies, with a high degree of metamorphism due to the contact with the Permian pluton (Carlier et al. 1982; Jordanovski et al. 1987; Carlotto et al. 2007). Different petrographical rock associations can be found: macroscopically the batholith has a massive aspect, with a phaneritic texture, locally pegmatitic with visible crystals and mainly composed of orthoclase, plagioclase, quartz and hornblende (occasionally the presence of xenoliths of diorite can be found. Through the microscope, sienogranite, monzogranite, granodiorite, granomonzodiorite and, more rarely, quartz-sienite and alkaline granite can be found (Carlotto 1993, 1998; Carlotto et al. 2009).

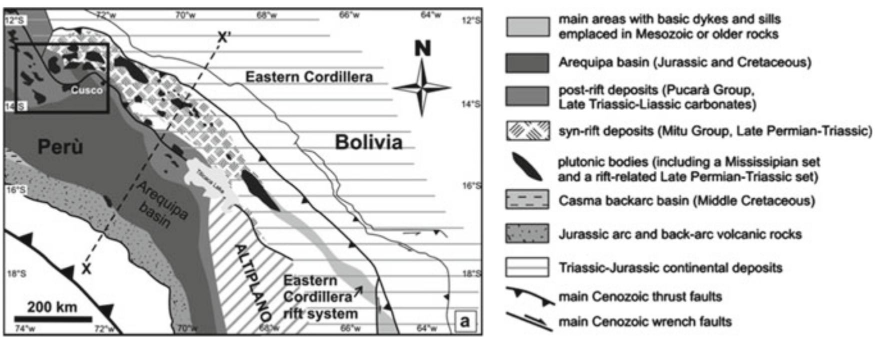

Fig. 2.1 Geological sketch map showing main Mesozoic elements of Peru and Bolivia (after Sempéré et al. 2002). The rectangle identifies the area described in Fig. 2.2

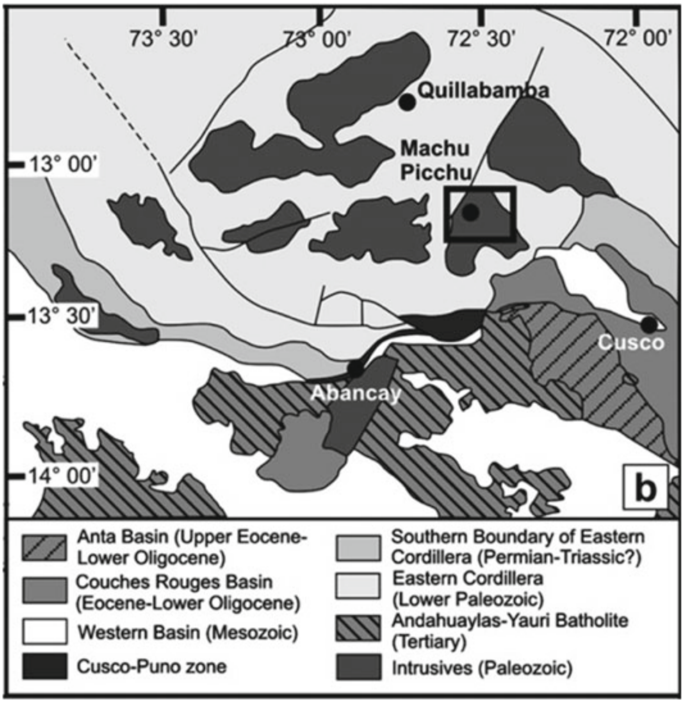

Fig. 2.2 Geological sketch map of the Cusco–Abancay area (after Carlotto 1998), showing the intrusive batholites (plutonic bodies) and the location of study area

From a lithological point of view, as a consequence, the setting of the area is dominated by igneous rocks and Palaeozoic basement, with Quaternary detritic-colluvial terrains sporadically outcropping along the main water streams: a general view is reported in Fig. 2.3. In particular, it is possible to recognize in detail the nature of the soil cover following weathering and geomorphological processes acting on the bedrock. Coarse-grained granodiorite is the lithological type which is widely affected by chemical weathering and, consequently, capable of producing thicker soil covers. The weathering process mainly occurs due to the limonitization of iron–magnesium bearing minerals (e.g., biotite and hornblende) whereas quartz, being stable, is the most diffused mineral in superficial terrains (Carlotto et al. 1999).

2.3 Local Geology

The bedrock of the Inca citadel of Machu Picchu is mainly composed of granite and subordinately granodiorite. The latter is mainly located in the lower part of the slopes (magmatic layering at the top). Locally, dikes of serpentine and peridotite are outcropping in two main levels; the former is located along the Inca trail, near

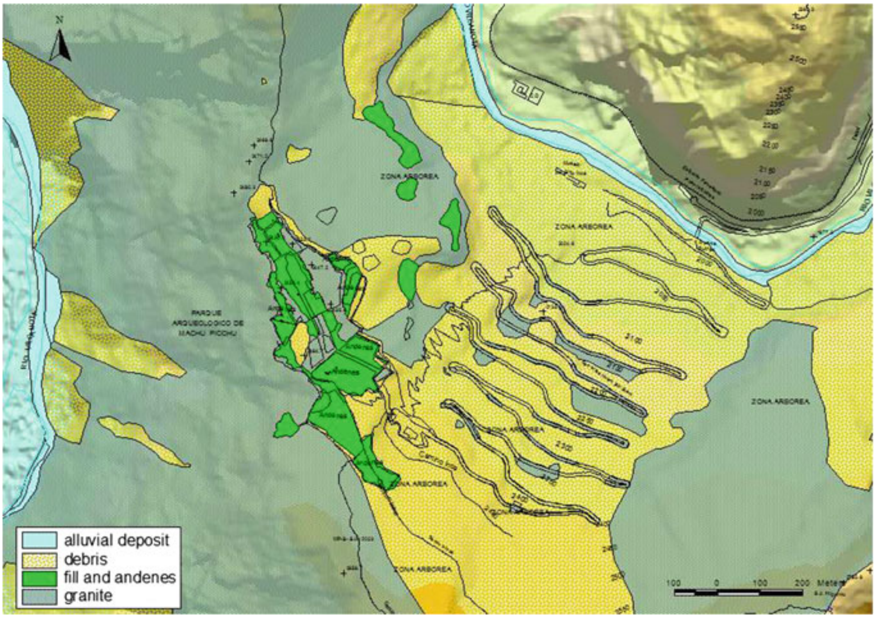

Fig. 2.3 Detailed geological map developed on GIS platform. Modified from Spizzichino (2012)

Cerro Machu Picchu (vertically dipping), the latter is located along the path toward "Templo de la Luna" in Huayna Picchu relief. Superficially, the granite is jointed in blocks with variable dimensions, promoted by local structural setting. The dimension of single blocks is variable from 10^{-1} to about 3 ~ 10 m^3. Soil cover, widely outcropping in the area, is mainly composed of individual blocks and subordinately by coarse materials originated by chemical and physical weathering of minerals. Part of the slopes exhibits debris accumulation as a result of landslide activity. Grain size distributions of landslide accumulation are closely related to movement types and evolution (Carlotto et al. 1999, 2007, 2009). Talus and talus cones are composed of fine and coarse sediments, depending on local relief energy.

Alluvial deposits outcrop along the Urubamba River and its tributaries. They are composed of heterometric and polygenic sediments that may be in lateral contact with the talus deposits. Anthropogenic fill and andenas, on top of Citadel, reflect the work of Inca urbanization and civilization in the area (Fig. 2.3).

Besides chemical weathering, past and present mechanical processes such as crioclastism, thermoclastism and gravitational phenomena (mainly acting on steepest rock slopes) produce thick and extensive debris and talus/alluvial cones. Very often, these types of soils are remobilized from their original place due to the present and past morphogenetic processes. The following superficial soils can be recognized in the whole area (INTERFRASI Project 2008):

- Alluvial fans, outcropping especially in the pedemountain zones where main rivers and tributary channels flow, composed of granitic pebbles immersed in a silty-clayey matrix (e.g., alluvial fans of Aguas Calientes and Aobamba);
- Moraine deposits, produced by glacial and fluvio-glacial processes, composed of pebbles, clasts and granitic blocks in clayey and silty matrix, in variable percentage and composition according to the characteristics of the glacial and fluvio-glacial where they have been deposited;
- Fluvial deposits, placed at various heights along the slopes and the main flood-valley water streams, formed by pebbles and blocks in a mainly silty matrix;
- Gravitational deposits, cone-shaped with intermediate slope angles between talus cone and alluvial cone, generated by remobilization of saturated soil covers due to the gravity process; they are composed of clasts and heterometric blocks, generally monogenic, with variable fraction and granulometry of the matrix which are the functions of the deposition area inside the talus/alluvial cone.

2.4 Geo-mechanical Setting

Geo-mechanical characteristics of the Machu Picchu slope-forming rocks outcropping in the study area have been reconstructed through geotechnical field techniques and laboratory tests (executed in Italy), on rock blocks. A rock mass classification and failure criteria (Hoek 2007, Hoek and Brown 1988; Hoek et al. 1992) have been implemented. In particular, the following activities have been carried out:

- Field survey implementation through scan line techniques in order to define and reconstruct the main geotechnical and geomechanical parameters and Index (e.g., RMR, GSI, and Q system);
- Strength and deformation parameters are collected starting from scientific and technical literature as well as from local technical report;
- Geo-structural analysis (orientation and characteristics of discontinuities);
- Sampling of blocks in the field for implementing laboratory analysis;
- Schmidt-hammer test on joint surfaces and intact rock block for in-situ analysis of UCS;
- Laboratory Point Load test to provide UCS data from sampled blocks and compare them with in-situ data.

The main results are reported in Tables 2.1 and 2.2.

Thanks to the two different survey analyses developed, the former with sampling and laboratory tests and the latter with direct-filed survey (Steffen, 1975), which are

Table 2.1 Synthesis of geotechnical parameters carried out from in-situ tests

Geological strength index GSI	Cohesion c' (Mpa)	Friction angle ϕ'	Elastic modulus E_m (GPa)	UCS from point load test (MPa)
65	0.3–0.4	40°	32.64	77.6

Table 2.2 Synthesis of geotechnical parameters carried out from laboratory tests

Unit weight (KN/m^3)	Wave velocity V_p (Km/s)	Wave velocity V_s (Km/s)	Elastic modulus $E_{sec}50$ (GPa)	UCS σ_1 (MPa) triaxial tests
25.9	3.4	1.82	27.2	79.95

possible to summarize the geomechanical parameters for the rock masses outcropping in the study area as follows (Tables 2.3 and 2.4):

- UCS values for weathered rock mass (obtained with in-situ Schmidt-hammer test) between 22 MPa (fractured) and 60 MPa (intact rock);
- Uniaxial compressive strength values by Point Load Test between 63 and 92 MPa;
- Unit Weight for the rock equal to 25.4 KN/m^3;
- JRC estimation through tilt test, between 4 and 8 and corresponding base friction angle between 37° and 51°;
- Rock mass belonging to a good quality class with an average RMR index equal to 71 and an average GSI index equal to 65;
- Cohesion values estimation between 0.30 and 0.40 MPa (Bieniawski 1989);
- Friction angle values estimation between 35° and 45° (Bieniawski 1989);
- Elastic modules value estimation between 19 and 57 GPA (Bieniawski 1989);
- Using Trunk and Honisch (1989) equation the friction angle values are comprised between 36.7° and 51° with an average value equal to 44°;

Using the Rockdata software and through the Hoek and Brown criteria, the following parameters were estimated and calibrated:

Table 2.3 Main parameters detected from laboratory: dry density (ρ_d), wave velocity (V_p and V_s), UCS (σ_f) and Young module (E_{sec50})

Samples	E_{dyn} (Gpa)	V dry	v ψMpa	V_p (Km/sec)	V_o (Km/sec)	$E_{sec}50$ (Gpa)
01	13.6	2.58	88.45	2.36	1.51	26.2
V1	27.6	2.59	54.1	3.92	2.01	28.9
V2	25.8	2.59	97 29	3.87	1.93	26.5
Average	22.33	2.59	79.95	34	1.82	27.20

Table 2.4 Geotechnical parameters and properties

	Density (KN/m^3)	Ed (MPa)	Kn (MPa}	v	Sigmaf (MPa)	Tensile strength (MPa)	II (°)	c (kPa)
Granite	23–25	80,000–90,000	20–100	0.15	50–250	7–13	33.5–40.5	220–355
Granodiorite	23–25	100,000–150,000	20–100	0.15	60–250	7–13	35–42	270–355
Superficial cover	25	–	–	–	–	–	32	270
Talus	18–25	–	–	–	–	–	34–38	0

- UCS = 60 MPa, GSI = 55, mi = 29 and D = 0.7 minimum cohesion equal to 1,53 MPa and friction angle equal to 43.4°;
- UCS = 80 MPa, GSI = 65, mi = 29 and D = 0.7 minimum cohesion equal to 2,16 MPa and friction angle equal to 49.8°;
- UCS = 100 MPa, GSI = 75, mi = 29 and D = 0.7 minimum cohesion equal to 3,213 MPa and friction angle equal to 55.1°;

The laboratory tests have provided the parameters reported in Table 2.3, while literature data provide the following parameters:

- Elastic modules values comprised between 10 and 15 GPa for the granodiorite and between 8 and 9 GPa for granite (lower than the laboratory values);
- Normal stiffness around 100 MPa for closed fracture;
- Normal stiffness around 20 MPa for opened and filled fracture;
- The average value for the Poisson module is equal to 0.15 with a load of more than 5 MPa;
- The Uniaxial compressive strength, always from literature data, varying from 49 to 98 MPa for the granite and from 58 and 156 MPa for the granodiorite;
- Tensile strength comprised between 7 and 13 MPa;
- Unit Weight varying from 23,5 and 25 KN/m3; average cohesion equal to 0.3 MPa and friction angle between 35° and 45°.

2.5 Structural Setting

2.5.1 Regional Structural Analysis

The general structural setting and the main elements, such as diaclases and fault planes, have deeply conditioned the geomorphological evolution of the Machu Picchu area. This is testified by the local hydrographic network characterized by a rectangular-shaped pattern with nearly orthogonal angles between the river Urubamba, the main channel of the catchment, and its major tributaries. Therefore, its morphology is strongly controlled by fault and joint sets such as the Machu Picchu and Huayna Picchu faults, named by the reliefs that those faults border, that form a NW–SE oriented graben-like structure where the Citadel is located. Since this area is located in the Eastern Andean Cordillera, characterized by a remarkable tectonic and seismic activities, the structural analysis is reputed as fundamental to reconstructing the geomorphological dynamics that is one of the main objectives of the research. The structural analysis has been carried out through the study of the available bibliography, the examination of aerial photos and a specific field mission survey. The morphology of the reliefs testifies the tectonic activity that has determined a general uplift of the area and the development of natural profiles of great interest and magnificence. Most of the slopes that exhibit a difficult accessibility, especially along the stream of the river Vilcanota, present an excellent exposition of the structural setting. The analysis performed have substantially confirmed the main

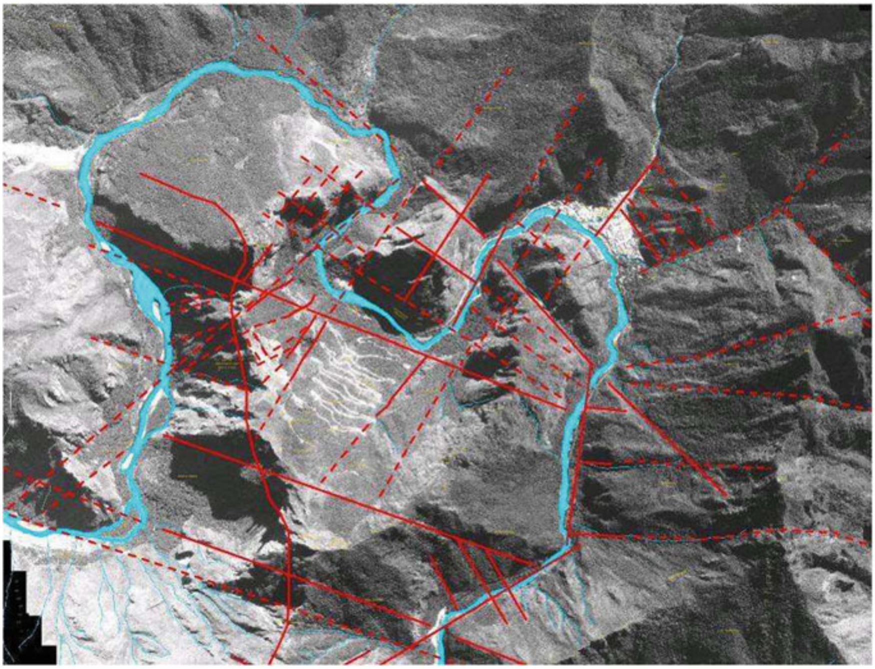

Fig. 2.4 Main tectonic lineation derived from aerial photo interpretation (Canuti et al. 2005)

tectonic lineations reported in bibliography and mainly oriented along the following directions: NW–SE, E–W and NNE–SSW. The NNE–SSW direction is very evident in the areas that surround the archaeological site of Machu Picchu. From aerial photo analysis, the two directions oriented NW–SE and NNE–SSW can be recognized in the form of two couples of conjugate joint sets (Fig. 2.4). Besides the above-mentioned main joint sets, the study area presents diaclases that contribute decisively to the definition of the reliefs morphology. The diaclases are originated by the contraction of the magma during the cooling phase as well as by straining consequently to the uplift and erosion of the deep valleys in the area.

The site investigation has reported a deep and general state of jointing in the rock mass outcropping in the study area. In particular, it has been evidenced that on the highest elevation of the investigated reliefs (Cerro Machu Picchu, Cerro Waynapicchu, Cerro Putucusi) and also inside the Citadel, chaotic accumulations of rock blocks, that in some cases have produced underground cavities, are outcropping.

The origin of these deposits can be associated to the weathering processes of granitic rock masses, deeply jointed due to tectonic activity, once uplifted and exposed to superficial dynamics (Kalafatovich 1963; Carlotto et al. 1999). The joints, initially originated by tectonic causes, have been successively affected by chemical–physical weathering with a consequent enlargement of joints and partial remobilization of the blocks. The great availability of jointed blocks, very often characterized by regular and smooth surfaces, also at high elevation, associated to recent morphogenetic processes (gravitational processes) can be defined as one of the main causes in the choice of this site for the foundation of Machu Picchu, confirming the intimate relationship between the availability of construction materials, strategic location and past/present slope dynamics (Carlotto et al. 2007, 2009).

2.5.2 Local Structural Analysis

It is well known that, in homogeneous plutonic rocks, strain tends to be partitioned and is mainly localized along shear zones. These of course have been extensively studied by many authors. Many of these studies stressed the importance of fluids and chemical softening leading to strain localization. Some of them also emphasized the role of brittle precursor structures in controlling shear zone nucleation. This seems to be very important also in our study area. The Machu Picchu granitoid pluton, as above-mentioned, is one of the series of plutons intruded along the axial zone of a Permo-Liassic rift system. As a result of strong tectonic inversion of the axial zone of the rift system, these granitoid plutons, forming part of the rift "roots," are now exposed at the highest altitudes. This provides a unique opportunity to analyze the effects, on these bodies, of the deformation associated with rift-scale tectonic inversion. The Machu Picchu granitoid pluton includes a variety of rock types, dominantly granites and granodiorites. In the area of the detailed study, the main plutonic body is a medium-grained granite with enclaves of more basic composition.

It shows little macroscopic evidence of deformation and metamorphism, and igneous relationships are well preserved. However, under the microscope, most country rock samples display variable metamorphic overprint of the primary minerals, with the typical alteration and partial replacement of plagioclase by sericite-calcite assemblages and of biotite by chlorite. The macroscopically most prominent deformation features typically consist of joints, organized in different sets (Mazzoli et al. 2009). However, some dominant sets can be recognized. These also coincide with the master joint sets. Joints are usually rather sharp, often less than 2–3 mm thick but may extend for many tens of meters. They generally show no evidence of cataclasis and also of alteration by fluid-rock interaction (in fact the typical bleached haloes are uncommon here). The master joint sets also control the main lineaments derived from aerial photo interpretation. Mafic dykes (lamprophyres) occur parallel to the main joint sets. This suggests that the joints formed early, most probably during cooling of the main plutonic body, and were intruded by late-magmatic dykes. The lamprophyres also show evidence of greenschist facies metamorphism and of shear along the contact with wallrock granite (Mazzoli et al. 2009). The joints appear also to form precursor structures controlling shear zone nucleation. Different types of shear zones have in fact been observed within the pluton: faulted joints (using a terminology by Wilkins et al. 2001), brittle-ductile shear zones and phyllonites showing a mylonitic fabric (Fig. 2.5).

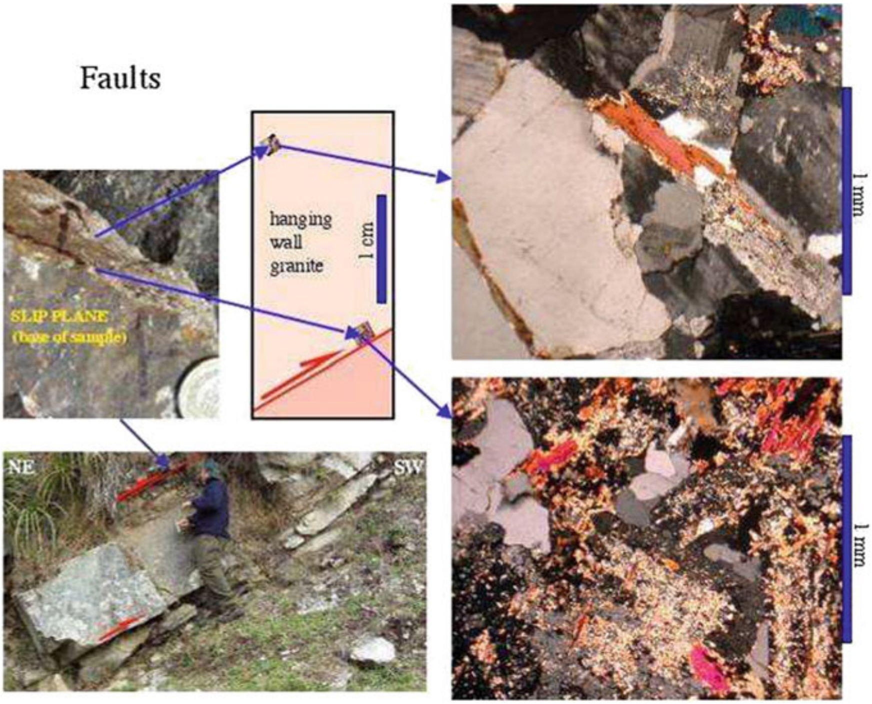

Fig. 2.5 Example of fault features: slip plane (upper and lower left) and thin section of a granite sampled in a shear zone (Mazzoli et al. 2009)

Faulted joints involve a simple fault-like reactivation of pre-existing joint surfaces, marked by quartz shear fibers, epidote and chlorite occurring along slip planes. The attitude of the slip planes is clearly the same as the main joint sets, confirming they originally belonged to the same group of structures. Reactivation of the three main joint sets occurs as follows: SW steeply dipping and NE moderately dipping planes are generally reactivated as reverse-sinistral oblique-slip faults, whereas NE trending vertical planes are characterized by dextral strike-slip. Paleostress analysis carried out from faulted joints from different sites shows dominant NE-oriented horizontal compression (Mazzoli et al. 2009). The results of stress inversion carried out for the whole fault population consistently show N60 trending horizontal compression (Fig. 2.6).

A straight foliation is sometimes associated with faulted joints, mainly in the compressional bridges between stepped terminations of en-echelon fractures. The fact that foliation is generally straight and inclined at about 45° to the bounding fracture segments suggests that the strain within the compressional bridges is rather low, and the offset on the bounding fractures is correspondingly small. Small (centimetric) displacements could actually be measured in outcrop (Wilkins et al. 2001). The wall-rock to faulted joints generally consists of apparently undeformed granite (Fig. 2.7), macroscopically showing no evidence of alteration by fluid-rock interaction.

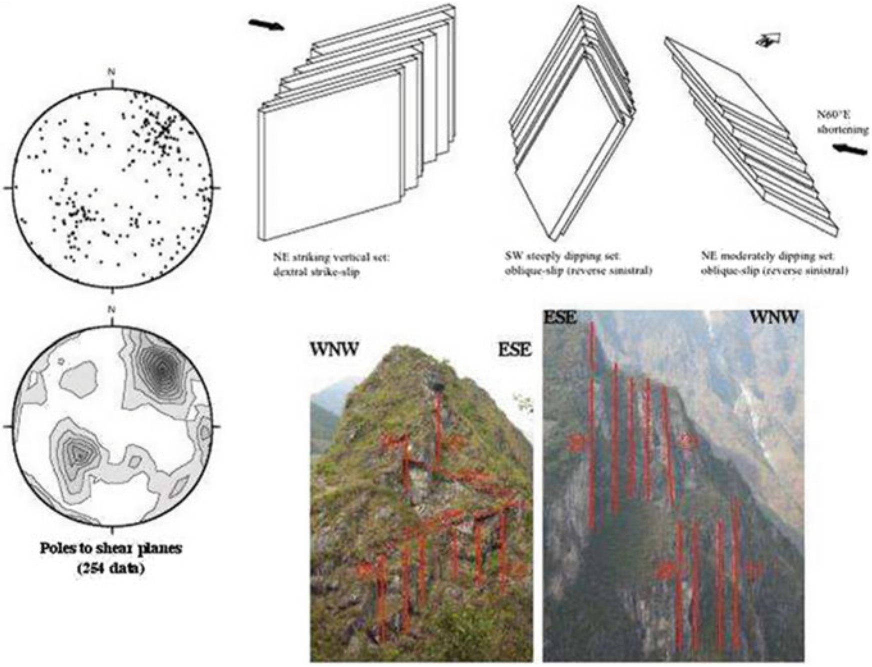

Fig. 2.6 Polar diagram reporting major shear planes orientation (left) and natural sections in Machu Picchu area with overlapping of joint/fault main sets (Mazzoli et al. 2009)

Under the microscope, wallrock granite shows no major differences, in terms of alteration and fabric development, with respect to country rock granite (Mazzoli et al. 2009).

Only in the very immediate vicinity of the slip plane, the breakdown of plagioclase and of iron–magnesium-bearing minerals becomes more intense. This appears to represent an incipient stage of reaction softening and development of phyllosilicaterich assemblages that are very important in more “mature” shear zones. Brittle-ductile shear zones consist of several centimeters to tens of centimeters thick bands of sigmoidally shaped foliation, typical of heterogeneous ductile shear zones, flanking the brittle precursor fracture, which also shows clear evidence of slip, consistent with shear zone kinematics (Spizzichino 2012). Ductile bands show a mylonitic fabric, including typical S-C structures and shear bands, and dynamic recrystallization of quartz dominated by subgrain rotation recrystallization. Several tens of centimeters thick phyllonites also occur within the study area, although they are less common. They show a mylonitic fabric, whereby the original mineral assemblage of the granite, dominated by quartz and plagioclase, has been replaced by one consisting of quartz, epidote-sericite and chlorite. These phyllonitic levels appear to represent more evolved shear zones that nucleated along the common brittle precursors, but underwent more intense reaction softening, allowing strain localization. In synthesis:

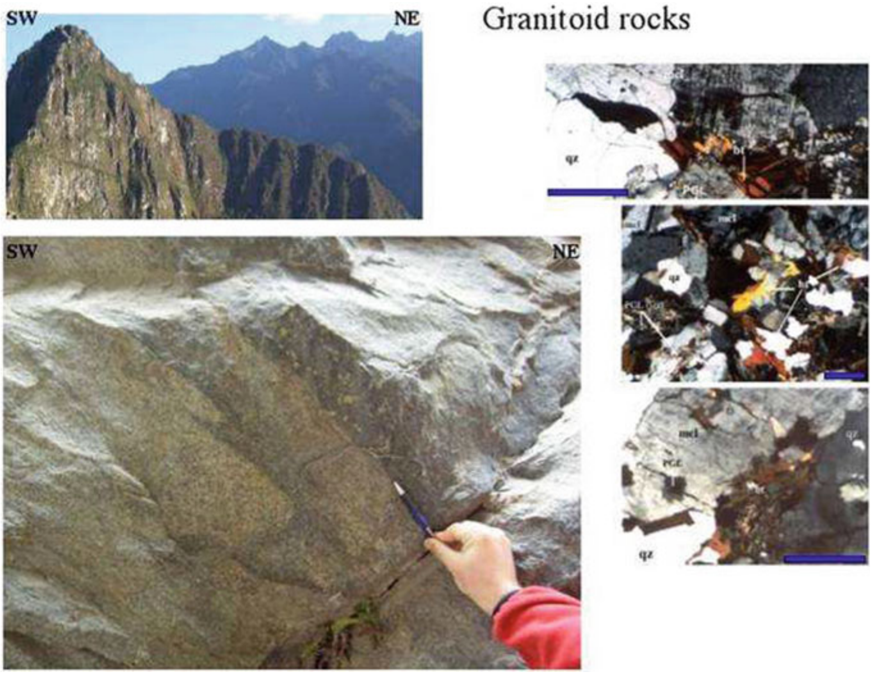

Fig. 2.7 Granitoid country rocks as they appear in the field (left) and at the microscope (right) (Mazzoli et al. 2009)

Shortening in the Eastern Cordillera rift "roots" was associated with tectonic inversion of the Permo-Liassic rift system. Within the Machu Picchu granitoid pluton, it produced widespread shear reactivation of primary joints (by a process that one might call "diffuse faulting").

Analysis of fault slip data indicates that shear reactivation of different joint sets is kinematically consistent with NE-oriented shortening. The studied area displays different stages of evolution, from (dominant) fault-like reactivation of pre-existing joints to (subordinate) "mature" shear zone development, apparently reflecting the influence of fluid infiltration along with precursor brittle fractures. Greenschist facies conditions for the deformation are indicated by the mineral assemblages. Both non reactivated and faulted joints commonly show little wallrock alteration by fluid-rock interaction and a lack of cataclasis. Brittle-ductile shear zones and thicker mylonitic phyllonites also developed along the same brittle precursor structures (being also kinematically consistent with NE-oriented shortening). Less than 1% of the shear zones consists of thick phyllonites (Mazzoli et al. 2009). This, together with little wallrock alteration and the lack of mineral-filled extension fractures and shear-related tension gashes, suggests minor dilatancy and limited fluid influx along precursor joints. Little fluid-rock interaction and minor reaction softening led to limited strain localization along individual ("weak") shear zones (Mazzoli et al. 2009). During

Andean shortening, strain has been accommodated by a form of "distributed shear" probably involving relatively small displacements occurring over a very large number of primary fractures, which form a pervasive network within the pluton. Therefore, even though strain localization occurs at the m scale, the km (or pluton) scale strain can be considered as essentially distributed.

The structural settings of terrains are finally related to the main following dip orientations/dipping surveyed in Machu Picchu surroundings (Figs. 2.8, 2.9 and 2.10):

- 30°/30° (in the Machu Picchu Hill);
- 30°/60°;
- 225°/65°;
- 130°/90°.

Secondary systems (e.g., 130°/45°, 315°/30° and 310°/45°) have also been surveyed in the area.

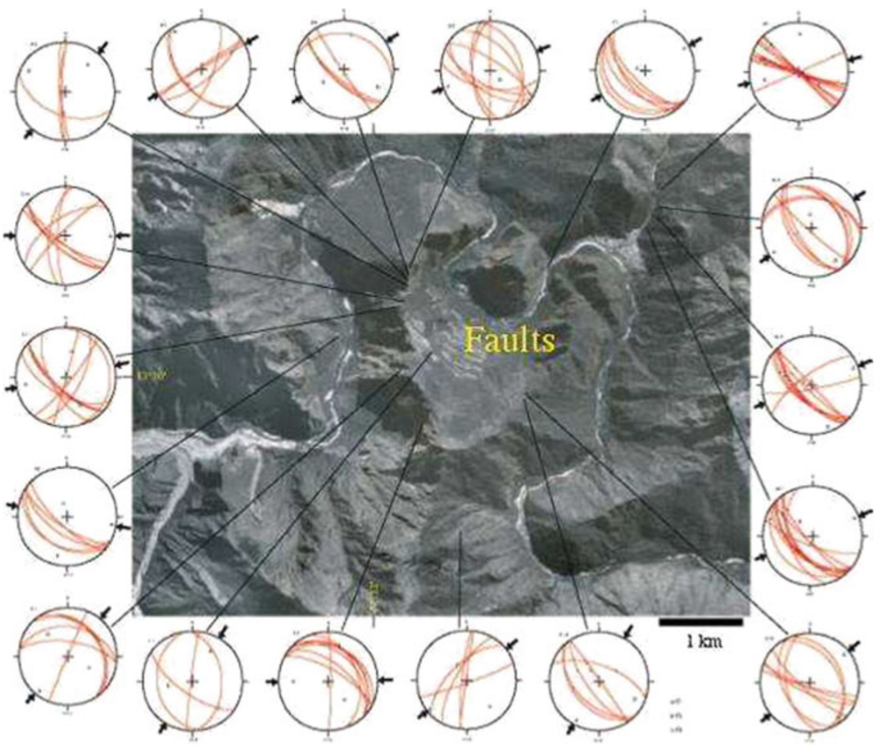

Fig. 2.8 Distribution of faults surveyed in Machu Picchu area. *Source* from INTERFRASI Project (2008)

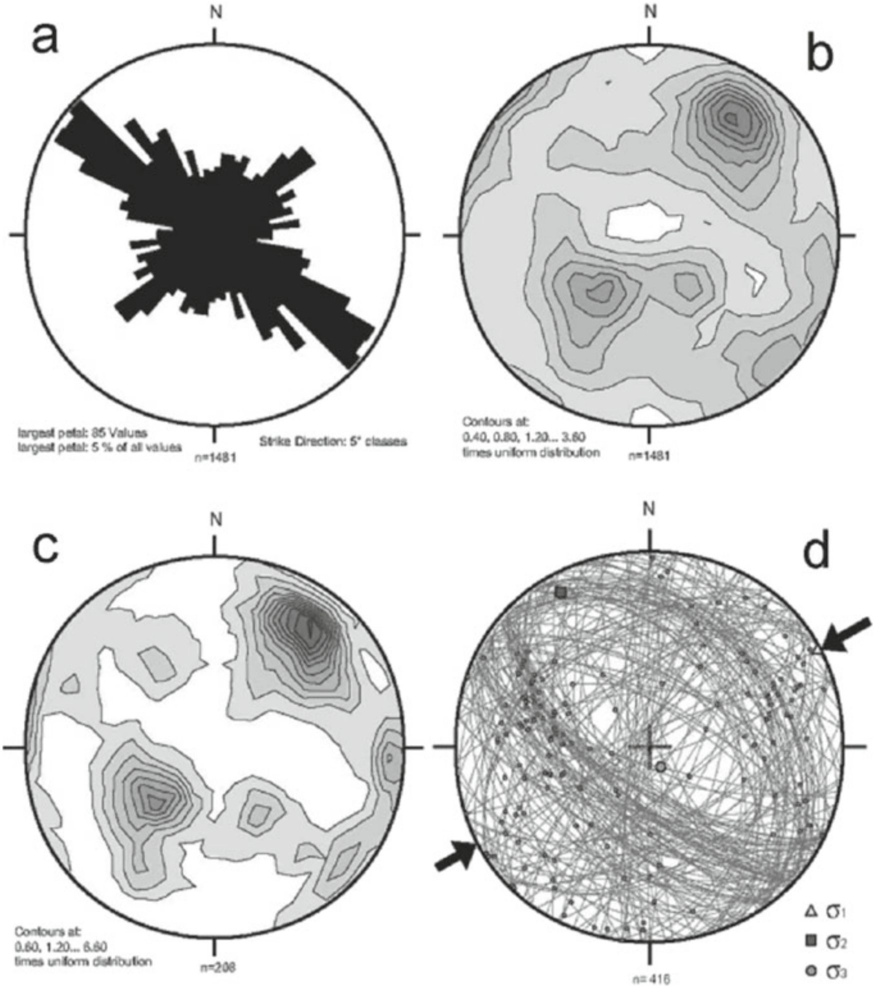

Fig. 2.9 Faults plot surveyed in Machu Picchu area (Mazzoli et al. 2009)

2.6 Geomorphological Features and Landslide Inventory

2.6.1 Landslide Classification

The landslide inventory in the study area has been implemented in order to define a general setting of the main typologies and processes acting along the slope. Specifically, the term "landslide" includes very different types and processes of slope movements. The commonly accepted classification after Cruden and Varnes (1996) respects these needs and defines five types of landslides: falls, topples, slides, spreads

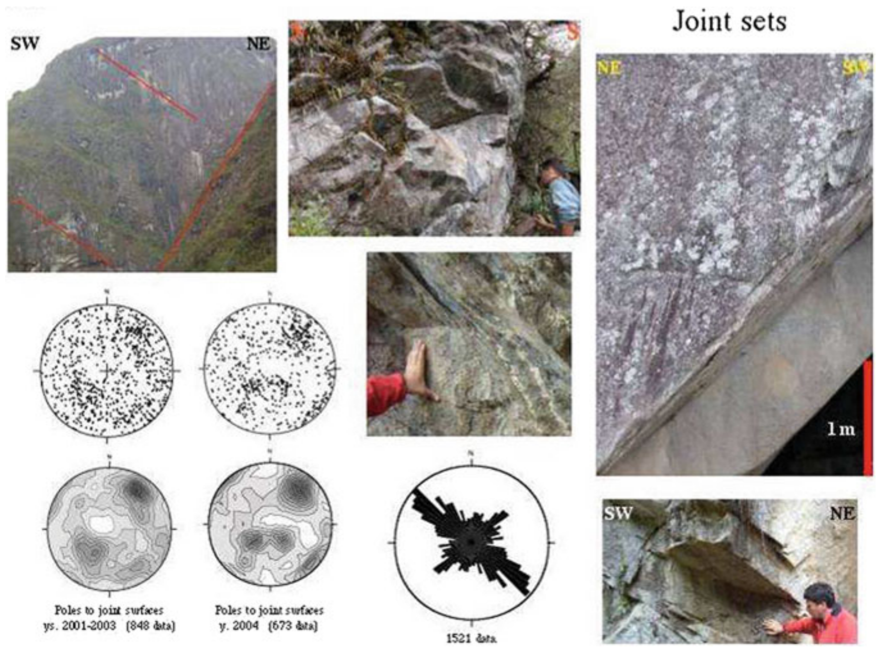

Fig. 2.10 Joints plot surveyed in Machu Picchu area (Mazzoli et al. 2009)

and flows. The classification in Table 2.5 combines these five types of movement with the material involved. Large and complex landslides often show several types within one site: rocks on a cliff may, e.g., spread and subsequently fall down, the resulting debris may slide or flow and include loose soil material (WP/WLI 1993). Landslides can also evolve in time and change from one type to another. A definition of the first move (e.g., rock fall) and the second move (e.g., rock flow or debris flow) is relevant for the process analysis. A clear definition of the different (subsequent or simultaneous) processes is also relevant for modeling and hazard assessment.

The landslides phenomena identified in the area are mainly classified as rock fall/topples, rock and debris slide and debris flows.

2.6.1.1 Rock Fall/topples

Rock falls cause severe damage due to their energy and speed ($v > 40$ m/s). It ranges from the fall of single stones (stone: Ø < 0.5 m, block: Ø > 0.5 m) to the collapse of large masses. The rare collapse of important masses as rock avalanches with huge volumes ($V > 1$ million m3) may result in disastrous damage. If a rock fall in preparation is detected in advance, its volume can be roughly predicted by means of field investigation. A detailed analysis can be done only by monitoring such as

Table 2.5 Classification of landslides (Hungr et al. 2013)

Type of movement	Rock	Debris	Earth
Fall	Rock fall	Debris fall	Earth fall
Topple	Rock topple	Debris topple	Earth topple
Rotational sliding	Rock slump	Debris slump	Earth slump
Translational sliding	Rock slide	Debris slide	Earth slide
Lateral spreading	Rock spread	–	Earth spread
Flow	Rock creep	Talus flow Debris flow Debris avalanche Solifluction Soil creep	Dry sand flow Wet sand flow Quick clay flow Earth flow Rapid earth flow Loess flow
Complex	Rock slide-debris avalanche	Cambering, valley bulging	Earth slump-earth flow

LIDAR or In-SAR scanning methods or by geophysical monitoring. A deformation analysis can also predict the moment of potential breakdown.

2.6.1.2 Sliding (Rotational and Translational)

The process of sliding is classified as rotational, translational or complex slides. In translational slides, the mass displaces along a planar surface of rupture. Very often translational slides are shallow and concern some meters only. This can happen especially in rock slopes with dip slope conditions (discontinuities run more or less parallel to the slope). A concave-shape of the rupture surfaces in cross-section may favor the instability, as in such sub-surface channels the sensitivity to hydrological changes is higher. Translational landslides can accelerate in short time, which means that they are more dangerous than rotational slides in general. For all kind of slides monitoring gives important hints about its mechanical behavior. Predicting speed evolution is difficult, but possible thanks to precise geological data.

2.6.1.3 Debris Flows and Shallow Landslides

Debris flows and shallow landslides triggered by heavy rainfall are frequent in the study area. They are characterized by moderate volumes (some thousands m3) and high speed (1–10 m/s). These phenomena are very dangerous and frequently cause damage, disruptions and fatalities. Shallow landslides mostly occur at slope inclinations ranging from 20° to 45° (Raetzo et al. 2002; Raetzo and Rickli 2007). Preventive monitoring of these processes is sometimes difficult as they start suddenly in case of extreme precipitation. The hydrogeologic conditions of a landslide mass are one of the main factors of high pore pressures and a sudden failure.

2.6.2 Rock Falls and Topples in the Area

Rock fall and topples surveyed in the area are triggered by the following causative factors (Fig. 2.11):

- Steep slopes (> 60°);
- Height energy relief (high vertical slopes).

The blocks susceptible to fall and toppling are often isolated and disarticulated from stable backslope by discontinuities, mainly vertical, of various origins: syngenetic thermal contraction, tectonics and post-orogenic detensioning (or tensile stress).

After the rock mass collapse, different processing of accumulation, depending on path and dynamic of fly (rolling, sliding and blasting), characterized the origins of reactivation phenomena. More in detail (in relation to accumulations mode) the

Fig. 2.11 Sub slope around the Historical Sanctuary of Machu Picchu

collapsed material may develop further in different movements depending on the state of fracturing, loss of cohesion, liquefaction and fluidization (Fig. 2.12).

The above-described process (rock fall in the upper and steepest part of the slope and remobilization of accumulated debris in the lower part) is not frequent because of the transportation and erosion activity of the Urubamba River (Fig. 2.13).

Fig. 2.12 Some examples of sources area of potential rock fall and toppling in the study area

Fig. 2.13 One of the main rock falls in the area along the railway from Aguas Calientes to Puente Ruinas

2.6.3 Rotational and Translational Slides in the Area

Translational slide is a downslope movement of rock and/or soil occurring mainly on planar or ondulating surfaces of rupture or on relatively thin zones of intense shear strain. As translational sliding continues, the displaced mass may break up, particularly if its velocity or its water content increase. The disrupted mass may then flow, becoming a debris flow rather than a slide. Translational slide often follows discontinuities such as faults, joints or bedding surfaces or the contact between rock and residual or transported soil. Translational slides on single discontinuities in rock mass have been called planar slides (Hoek and Bray 1977). The mode of movements depends in general on the orientation of the free surface of rupture relative to the discontinuities in the rock masses. Stepped rupture surface may result if two or more sets of discontinuities, such as bedding surfaces and some joint sets, penetrate the rock masses. This situation is frequent in the NE slope sector of the site in which one set of surfaces forms the risers of the steps and the other one forms the treads, crating and stepped slide (Kovari and Fritz 1978). In the specific situation of Machu Picchu site, the discontinuities are mainly constituted by:

- Shear surface, fault surface reactivated in shear, schistosity failure surface, characterizing phenomena from shallow (1–2 m) to deep (5–10 m);
- Contact surface between rock and weathered bedrock as well as between intact rock and soil cover (Fig. 2.14).

The source area is clearly detectable and strictly depends on a set of discontinuities which generated the displacement. The collapsed material may be located at different distances from the feed area and in different conditions compared to the original rock masses. Usually, the most fractured material is located far from the source area. The deposit is characterized, in the upper part, by the presence of a big rotated and tilted block, while in the lower part of the deposit the material is characterized by small sizes, due to the crushing and fragmentation along the traveled distance. The deposit

Fig. 2.14 Planar rock slide along Carrettiera Bingham

should be further interested by a new displacement or movements. Frequently eroded and transported away by hydro morphological dynamics when the final position is in the Urubamba River bed. The failure discontinuities constituted preferential paths for perennial or ephemeral groundwater movement into the slope. During meteorological extreme events, the increased pore pressure along discontinuities may decrease the stability condition of rock masses promoting sliding occurrences.

2.6.4 Debris Flow, Debris Avalanches and Shallow Landslide in the Area

Debris flows are often of high density, with over 80% solid by weight, and may exceed the density of wet concrete (Hutchinson 1988). They can move boulders whose diameter is as wide as several meters. The mode of flow often occurs during torrential runoff following exceptional rainfalls. Specifically, in the area, two main modes of flow have been classified:

- Debris flows (from very rapid to extremely rapid) of saturated non-plastic debris in a steep channel (Fig. 2.15);
- Debris avalanches (from very rapid to extremely rapid) shallow flow of partially or fully saturated on a steep open-slope (Fig. 2.15);

The above-mentioned modes, generally induced by gravity, are triggered and induced by the presence of water both as causative factor and as the plasticizing role in the displaced mass (Fanti et al. 2005; Puglisi et al. 2011). The involved material is constituted mainly by deposits at the toe of the slope and along the stream network.

These deposits are mainly constituted by:

- heterometric debris material (in which the coarse component with sand and gravel prevails);
- rock block (whose size is some m^3).

Fig. 2.15 Debris flow developed into the channel of the slope in the study area

Source areas often result from the accumulation of residual cover deriving from past events of different typology (slide and rock fall). The triggering areas are often close to the edge of the uphill crest at abrupt changes in slope which change the regularity and hill shape. The movement develops along the area corresponding to the contact between the debris soil cover and bedrock (Fanti et al. 2005; Puglisi et al. 2011). Rarely between intact and fractured rock masses. The upper shape of the failure surface, depending on the rheology of the rock mass, could be plane or circular. The failure mode in the triggering zone can be assimilated to both rotational and planar slides. The track area is mainly constituted by drainage systems and represents at the same time the feeding area (Fig. 2.16).

The material collapsed and flooded along the channel increases in size and magnitude, incorporating further material during the track. The velocity and impact energy increase from the top to the low part of the slope (Fanti et al. 2005; Puglisi et al. 2011). Debris flow, depending on the channel morphology and the liquid component of mobilized mass, can travel for a long distance (Hungr 2000; Hungr et al. 2001). In the landslide inventory map of the area (Fig. 2.18), the channels along the slope which are totally affected by debris flows from crest to floodplain are clearly individuated (Fig. 2.17).

More than 45 debris flows and debris avalanches have been collected and classified, both channelized (debris flow—Hungr et al. 2008) and on open-slope (debris avalanche—Hungr et al. 2008). Alluvial fans and cones are the main results of several pulse, connecting in a morphological sense the watersheds with floodplain. The potential mobilized mass can reach high velocity: rapid, very rapid and extremely rapid (more than 5 m/s).

Fig. 2.16 Different views of typical debris flow features in the study area

2.6.5 *The Landslide Inventory Map of Machu Picchu Sanctuary*

All the morphological processes and dynamics are mainly due to different combinations of structural settings and rheological conditions. As previously mentioned, the recurring phenomena in the area are:

- Falls/topples
- Slides
- Debris slide, debris flows and avalanches.

Fig. 2.17 Heterogeneity of debris flow (right) and debris avalanches (left) accumulation material

The aerial view of such landslides is reported in the following Fig. 2.18.

2.7 Structural Setting vs Slope Stability

The general morphological features of the area are mainly determined by the regional tectonic uplift and structural setting. As a consequence, kinematic conditions for landslide type and evolution are closely dependent on the above factors.

Several slope instability phenomena have been identified and classified according to mechanism, material involved and state of activity (Fig. 2.18). They are mainly related to the following: rock falls, rock slides and debris slides and debris flows. The area of the citadel has been interpreted as affected by a deep mass movement (Sassa et al. 2001, 2002) that, if confirmed by the present-day monitoring systems, it could be referred to a deep-seated gravitational slope deformation (DSGSD), probably of the type of the compound bi-planar sagging (CB) described by Hutchinson (1988). The

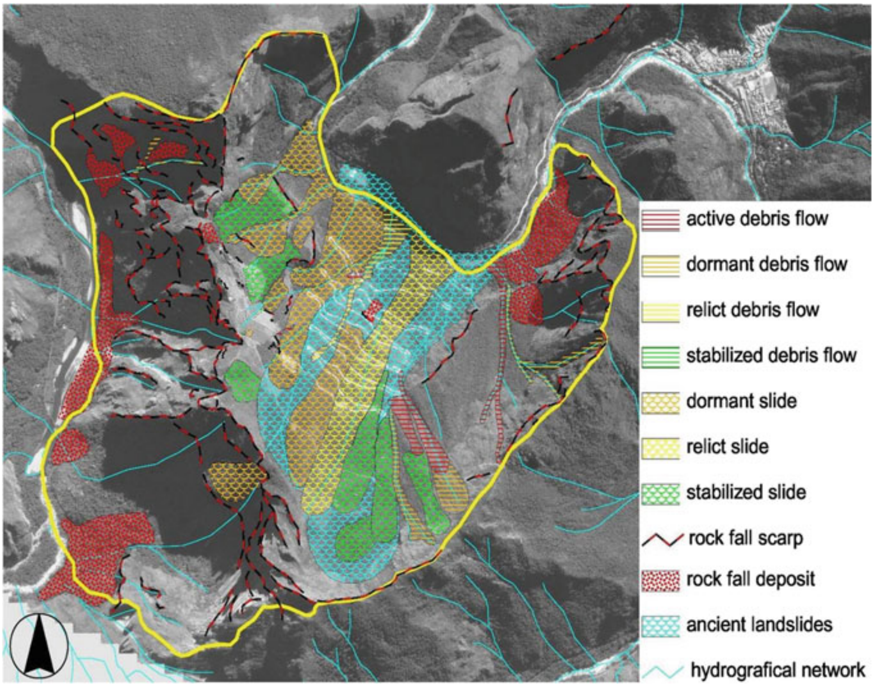

Fig. 2.18 Landslide inventory in Machu Picchu and surrounding areas. Modified from Canuti et al. (2008)

main trench with NW–SE trend, related to a graben-like structure, is located within the archaeological area and supports this hypothesis. Other trenches are elongated in the dip direction of the slope.

In the SW cliff, the local morphological depends on the intersection between the systems 225°/65° and 130°/90° which bounds lateral evolution. This kinematic condition causes high angle rock slide which very often evolves in rock falls. These are also conditioned by 30°/30° and 30°/60° systems which originate overhanging blocks. The SW slope exhibit some morphological terraces, regularly spaced, the origin of which it is still under investigation (fluvial erosion, sagging, joint, etc.).

The morphological evolution, in NE flank below the Inca Citadel, is constrained prevalently by the 30°/30° and 30°/60° systems and marginally the 225°/65° one; the intersection of the first two systems with slope face it is kinematically compatible with the occurrence of planar rock slides; the intersection of slope face with the 225°/65° is kinematically compatible with rock falls. Rock slides and rock falls may produce blocks with dimension variable from 10–1 to 102 m3.

Debris produced by rock slides and rock falls, as well as from weathering processes is periodically mobilized as debris slides and debris flow. A recent phenomenon occurred in 1995 along the "carrettera" Bingham. Debris slides and debris flows are characterized by an undifferentiated structure varying from chaotic blocks immersed on coarse sand matrix. The grain size distribution is mainly depending on the distance from the source areas and slope angle.

Finally, it is interesting to notice, on the NE side, the presence of a large debris accumulation, just below the citadel, presently being eroded by all around dormant slides. The accumulation is probably the result of an old geomorphological phenomena now stabilized, still not clear in its original feature. Anyway, the mass movements occurred their terraces (andenes) are founded over this accumulation area.

In order to define the most susceptible and prone to landslide areas, a detailed kinematic analysis has been implemented through the use of software Dips ® developed by Rockscience ®. The data set (more than 350 structural measures) has been implemented by analyzing dates that comes from past field survey and updating such dataset by new dates collected during the last 2009 field mission (Spizzichino 2012). All the data (Table 7.1) have been corrected and analyzed in order to define the main possible kinematic mechanism and to differentiate the study area in different sectors affected by specific types of failure mechanisms (Figs. 2.19 and 2.20).

The following figure is synthesizing the achieved results. Planar slides are kinematically possible (yellow zone) for dipping slope between 15° and 70° North. Falls and toppling are kinematically possible (gray zone) for dipping slope between 210° and 250° North and 0° and 25° North. In the figure also the area of "Carrettera" has been reported, where the most relevant phenomenon is debris flows.

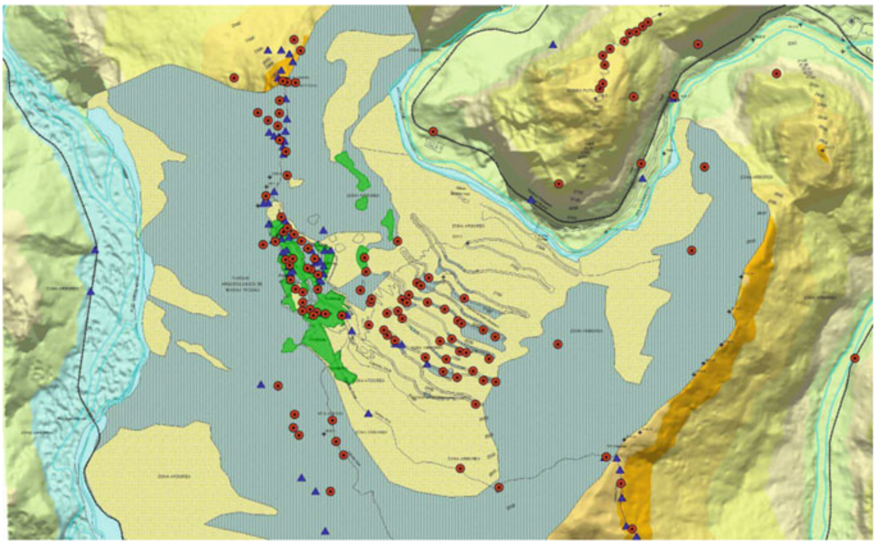

Fig. 2.19 Location of structural measure stations. Modified from Spizzichino (2012)

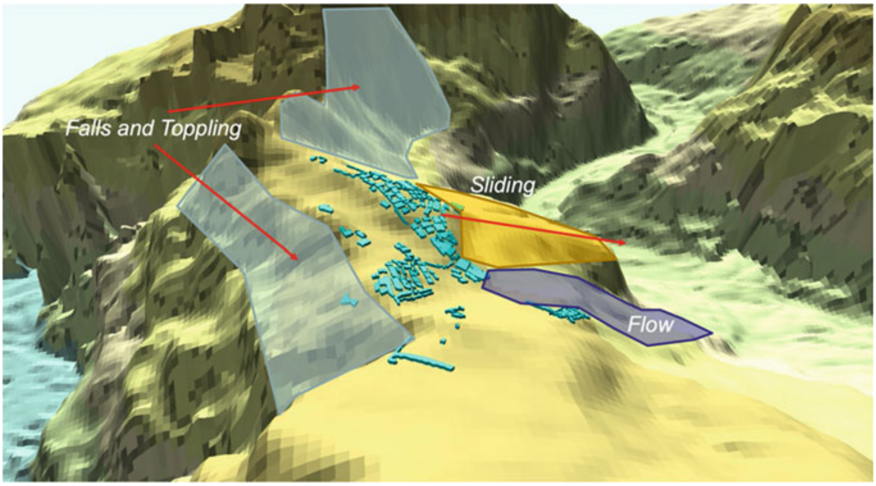

Fig. 2.20 Main processes affecting the upper Machu Picchu hillslope

2.8 Slope Stability Analysis

After the identification of the most prone areas from a geomorphological and kinematic point of view, a specific numerical analysis has been implemented on the areas which are most prone to collapse. More in detail, the potentially unstable areas are:

- The SW slope and the Wayna Picchu NE slope prone to rock fall phenomena;
- The NE slope of the citadel prone to planar slide.

After the definition of deformability and strength parameters of the involved rock masses, a slope stability analysis has been carried out, in order to define specific and residual landslide hazard conditions (Lembo Fazio et al. 1984). Regarding planar slides, two different scales of approach have been taken into consideration:

- A limited portion of the NE slope (unstable wedge, Fig. 2.21);
- The whole NE slope (Fig. 2.23).

In the first analysis, Mhor-Coulomb strength criteria have been adopted in case of limit equilibrium planar conditions. The analysis has been performed by using RocPlane software from RockScience®. Whereas, for the second approach, both Mhor-Coulomb criteria and Hoek–Brown strength criteria have been adopted for the entire rock masses, under the hypothesis of an equivalent continuum. The analysis has been performed by using FLACSlope software from ITASCA®.

In the NE sector, a potential unstable planar sliding has been detected by the presence of the following sets of joints: the first one parallel to the slope and the second one given by the average of two different sets of joints (dip 30°/slope 30°; dip 30°/slope 60°), from whose envelope the potential sliding stepped surface can be furnished (Fig. 2.21).

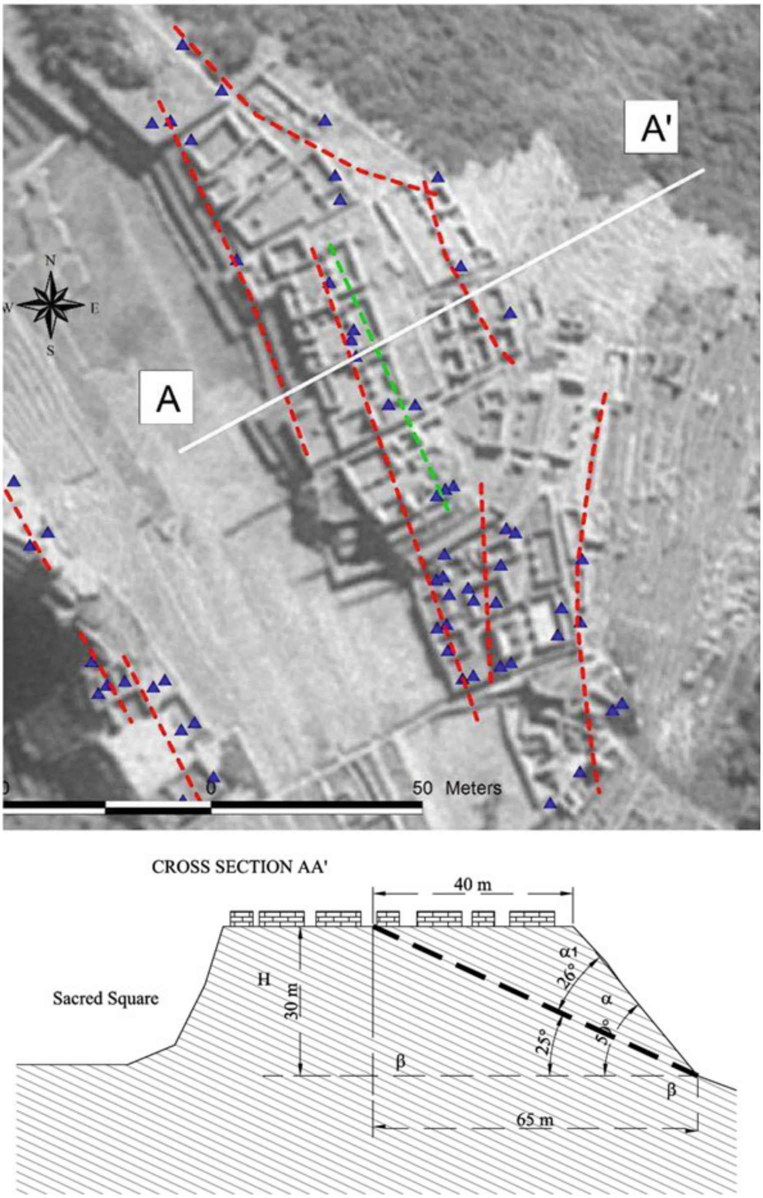

Fig. 2.21 Cross-section of potential unstable planar slide in the NE flank of the citadel adopted for the model. In the upper figure, blue triangles are cracks in structures, dashed red lines are deformation patterns and green line is a tension crack

The slope stability analysis has been implemented under the following hypotheses:

Planar sliding (static and dynamic1 conditions) in dry and saturated condition with the presence of a tension crack (Fig. 2.22);

Planar sliding (static and dynamic conditions) in dry and partially and fully saturated condition without the presence of a pre-fixed tension crack Fig. 2.22;

For the horizontal force, the acceleration value is equal to 0.25 g (INTERFRASI Project 2008).

The analysis has been performed by using Mohr–Coulomb resistance criteria (more conservative than Barton–Bandis and Hoek and Brawn criteria) and the following average geotechnical parameters for the discontinuities: fraction angle f' = 40°; cohesion c' = 305 kPa; unit weight g = 25.4 KN/m3.

The results, represented in Fig. 2.22 shows that the slope is at the limit of stability in dynamic conditions and saturation higher than 70%.

A finite-difference modeling code from Itasca® (2008) has been implemented in order to detect the safety factors along the NE section (Fig. 2.23), where a debris accumulation was detected and where the geophysical survey, with passive seismic stations (environmental noise), revealed low seismic velocity.

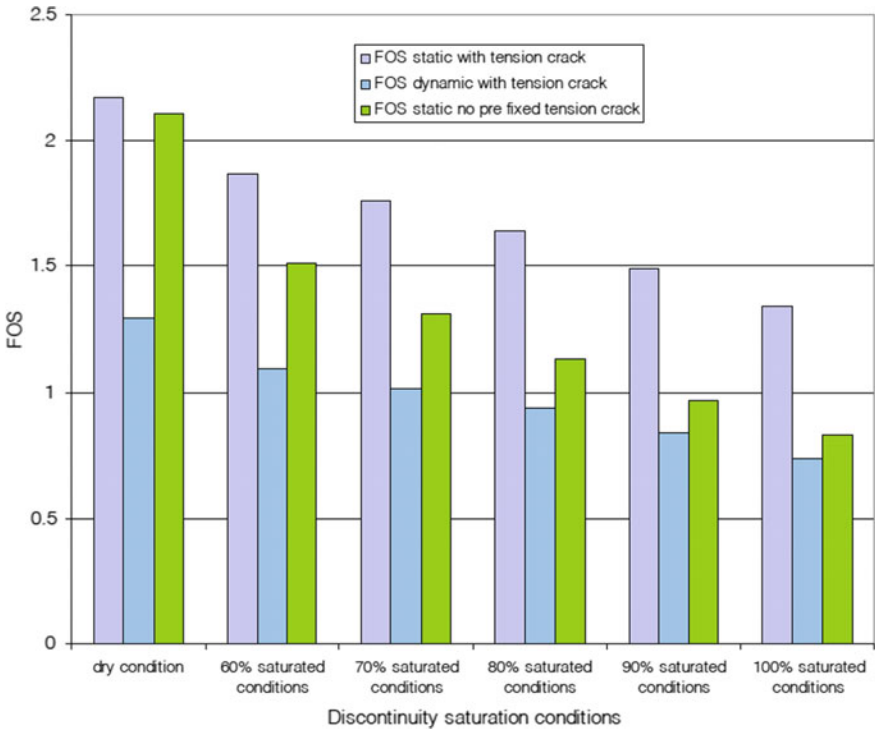

Fig. 2.22 FOS values for the different situations

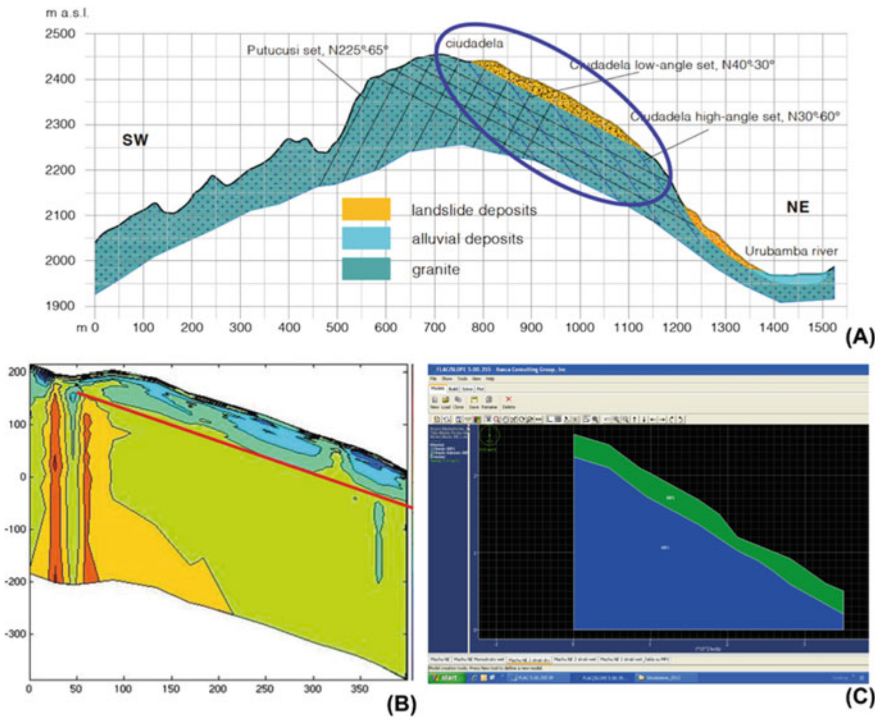

Fig. 2.23 NE Slope geological sections (A) (Spizzichino 2012). The numerical analysis has been implemented in a geological section (C) obtained by verification of strata with passive seismic velocity (B)

The analysis has been carried out by using a specific tool for the stability analysis (FlacSlope®), available with Flac® (Fast Lagrangian Analysis of Continua) software. For the cross-section implementation, two different schemas have been defined on the basis of the main results of field survey and noise environment elaborations.

The first schema assumes the slope characterized by a unique layer with resistance parameters between the minimum and maximum obtained by the analysis. The second schema assumes a double layer slope characterized by a minimum resistance parameter for the upper layer and a medium one for the lower. Under the hypothesis of an equivalent continuum, the stability analysis has been performed both by Mhor-Coulomb criteria (more conservative) and by Hoek–Brown generalized criteria. The FoS is always (dry and fully saturated conditions) greater than 1. The above-performed analysis confirms the substantial stability of the whole NE slope. A potential collapse due to a deep landslide is quite unlikely (at least in static conditions).

Boulders falling from rock slopes represent a natural evolution process of the slopes (in some cases, accelerated by human intervention), whose causes are multiple. For example, the movement of water into the discontinuity, the alteration caused by atmospheric agents (e.g., the pressure exerted by the presence of ice), vibrations induced by seismic activities or after an explosion, the flank erosion due to stream network evolutions, the action of plant roots and the changing in the stress state (digging activities or overloaded slopes) (Spizzichino 2012). After detachment, the motion of the rock blocks is characterized by the following steps:

- fly;
- impact on the ground;
- rolling;
- sliding and
- frequently, a combination of both.

  In order to perform a complete rock fall analysis, for Machu Picchu's most prone area, the following steps have been developed:
- source area definition (following the main results and indications from kinematic and geomorphological survey and analysis);
- typological section along the W-SW and E-NE slope (in order to take into account the interactions between theoretical paths and exposed elements, including trails);
- potential path simulation using Rocfall software from Rockscience®.

Selected source areas are reported in Fig. 2.24 on the basis of the field survey and kinematic analysis (Spizzichino 2012). Three areas along the W-SW slope and two others along the E-NE have been defined and implemented (Fig. 2.24). The selected profiles represent possible path interactions between different typologies of exposed elements (e.g., Intiwuatana, Main Temple, Inka Trail).

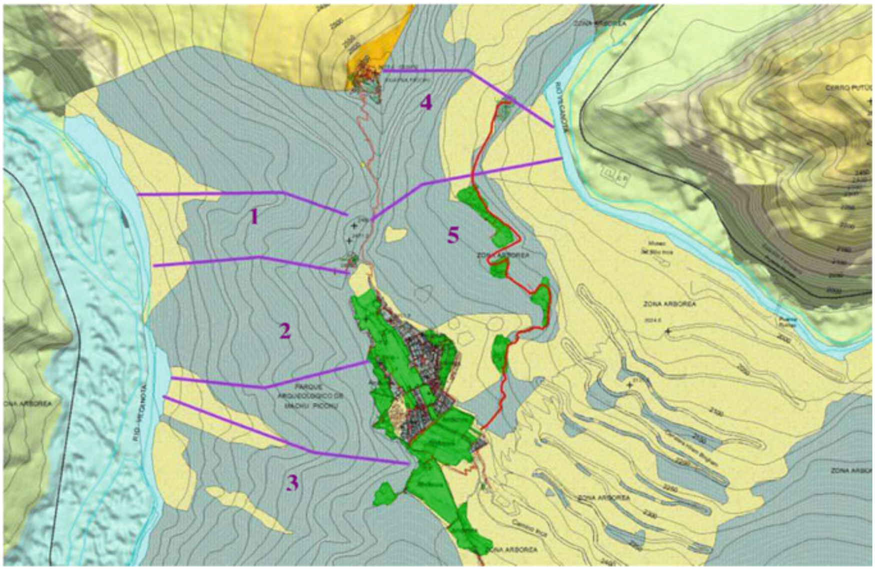

Fig. 2.24 Rock fall source areas and implemented profiles for the stability analysis

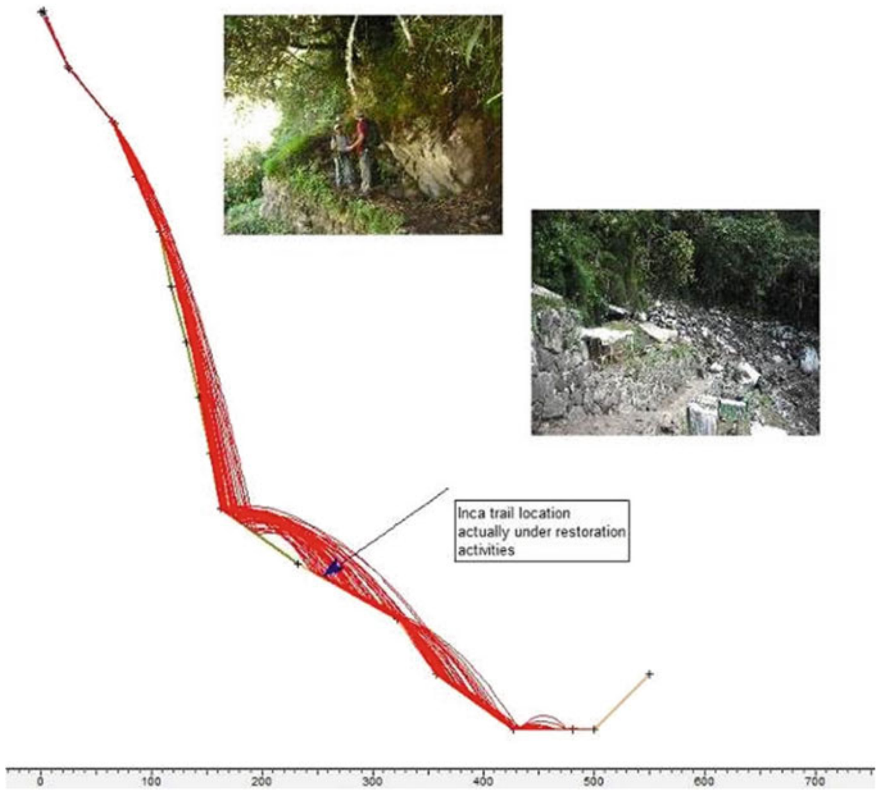

Fig. 2.25 Paths and main results of rock fall probabilistic analysis along profile number five of the E-NE slope

As an example, in the following figure it is possible to notice that, in the area 5, the possible collapse of boulders is impacting on the below Inca trail (Fig. 2.25).

2.9 Risk Scenario and Proposals for a Management Plan of Slope Instabilities

Modern risk management of landslides aims not only to protect short-term human interests but also to satisfy the needs of future generations and to preserve the natural and cultural heritage and landscape (Spizzichino 2012). The possibilities depend on several aspects. Therefore, protective measures or—in a more general way—hazard and vulnerability reduction measures may be roughly characterized as follows:

- Passive measures try to exclude people and vulnerable objects from dangerous zones. Such measures are mainly taken by planners rather than engineers and are based on extensive process studies, danger zone mapping and risk analyses. Usually, they do not contain structural measures. From the point of view of the natural landscape, they offer many advantages. Furthermore, they usually provide long-term safety. With respect to already populated areas and existing traffic lines, they are often difficult or even impossible to realize.

- Active measures influence the dangerous processes and mitigate natural hazards. They consist of structural and bio-engineering elements. Depending on the processes and the general protection concept, the actual measures may be located at some distance from the endangered objects (e.g., check dams, retaining walls and reforestation program in the catchment area of a torrent), or quite close to them (e.g., rock fall barriers immediately above a motorway). Depending on the safety requirements, temporary or permanent measures are installed. In the latter case, questions concerning their lifespan have to be considered, and control and maintenance schemes are of great importance. Active measures are generally less favorable as far as the natural environment is concerned. Accordingly, they have to be planned with great care and circumspection.
- In practice, a combination of active and passive measures is often employed. Comprehensive approaches may prove particularly efficient in cases of widespread settlements, where different objects may be protected by individually adapted structures. Such concepts often involve early warning systems as well as special design codes for new and already existing buildings.

In the present research, after having evaluated processes and dynamics acting along the archaeological park, landslides types and distributions, potential kinematic analysis (landslide susceptibility), assessed the stability conditions for the most prone areas through specific modeling and analysis, a preliminary management plan for the mitigation measures has been defined in order to take into account the above-depicted potential landslide risk scenario acting along Machu Picchu citadel.

To this purpose, a landslide hazard zoning was prepared, defining the most endangered areas for selected typologies of landslides. As already anticipated, the most landslide prone areas, classified according to different typologies and mechanism, seems to be (Fig. 2.26):

- W-SW and E-NE upper part of the slope for rock fall and toppling;
- E-NE slope for the rock planar slide;
- Carretera Hiram Bingham for the triggering of rapid shallows landslide (debris flows and debris avalanches).

Regarding rapid shallow landslide, it is important to underline that, although not treated by the analytical point of view in the present work, Hiram Bingham road is particularly affected by such phenomena. This area is one of the most vulnerable and, at the same time, strategic zones for tourist exploitation because it is the only access to the archaeological park.

Once identified the areas most prone to risk and their extension, a preliminary stabilization work, useful to reduce landslide hazard and risk, has been designed and defined. Every single measure was selected by taking into account the different types of phenomena.

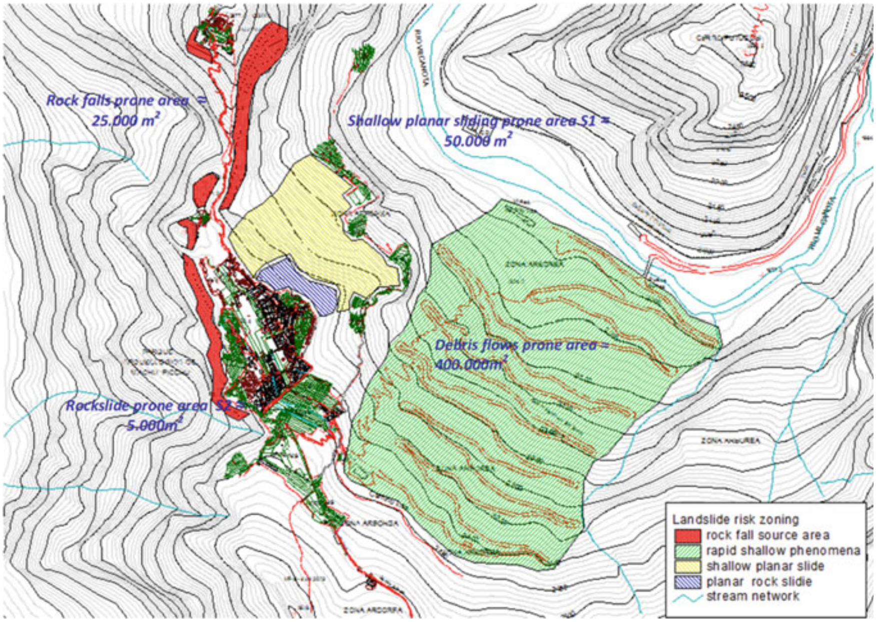

Fig. 2.26 Landslide hazard zoning for the archaeological park

More in detail, rock fall phenomena along the W-SW slope (red zone in previous maps), as already mentioned, the corresponding risk reduction for the exposed element in the upper part of the slope should be carried out by using the following operations:

- detailed scaling and survey of the unstable block along the slope (where possible);
- rock bolting.

The same approach could be applied to the preliminary design of mitigation measures in the upper part of E-NE slope affected by potential rock falls phenomena. The main difference is that, in this case, in addition to measures useful to avoid the problem reducing frequency (scaling and rock bolting), we have to plan mitigation works, such as catch fences, in order to reduce effect and magnitude (Hearn and Griffiths 2001). Special attention must be paid to all the zones interlinked with trail and rock falls path.

As a preliminary approach, the risk reduction of exposed elements situated in the upper part of the slope close to the tension crack (blue zone in previous maps) should be realized by adopting the following measures:

- local scaling and rock removal;
- drainage system restoration with low impact techniques;
- local rock bolting for the unstable blocks.

In that specific case, considering the main results of the stability model, rock bolting can be avoided and replaced only by an improvement of the drainage system in order to reduce the probable increase of pore pressure along the main joints and discontinuities. The drainage systems should be combined with a proper displacement monitoring system.

For the entire NE slope (yellow zone in previous maps) due to the absence of certain evidence against the possibility of triggering of a deep phenomenon by high-magnitude and disruptive effects (whose only mitigation would be a displaced monitoring system coupled to an early warning system), it is proposed to act by the same ancient Inka techniques more than five centuries ago through the realization of mixed terraces and drainage systems in order to consolidate and stabilized the slope (Fig. 2.27).

More in detail the works useful for the landslide risk reduction along the E-NE slope are summarized below:

- Scaling and rock material removed with the recovery of materials useful for andenas and terraces realization;
- Soft engineering local stabilizations with traditional techniques (andenas);
- Drainage systems implementation and improvement with traditional low impact techniques;
- Local rock bolting for the unstable blocks.

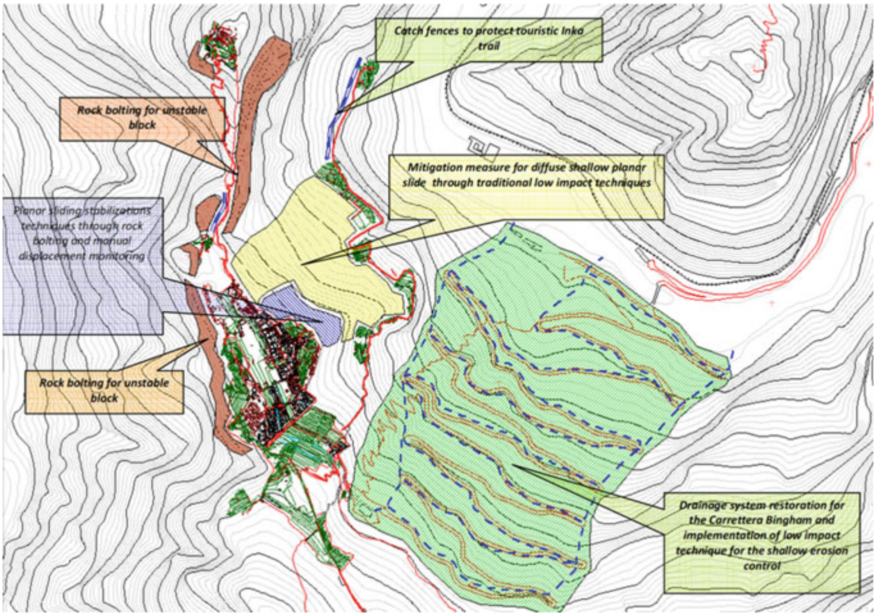

Fig. 2.27 Preliminary landslide mitigation measure zoning for the archaeological park

Concerning the unique way of access to the site (Hiram Bingham carretera), affected by frequent phenomena (mainly rapid and shallows landslide triggered by extreme events) (Fanti et al. 2005) in addition to a new regulation of the level of daily tourist accessibility (for more details, see the following chapter), we suggest every mitigation measure in order to improve the drainage capacity of the slope. This kind of mitigation measure will allow to reduce possible triggering by avoiding the pore pressure increase both in the upper and weathered part of the rock mass and in the debris soil cover. More in detail, we recommend that improved and adequate drainage systems are combined with sustainable low impact techniques with the aim of reducing and controlling the increasing soil erosion (small control wood and rock dam) especially in case of extreme events. The unstable block, if present, must be stabilized through local rock bolting.

2.10 Conclusion

In the present chapter, all the information concerning spatial landslide hazard (collected and developed during the research activity) have been summarized.

The final output is a landslide hazard zoning in GIS environment and a preliminary landslide zoning of potential mitigation measures in the archaeological park of Machu Picchu.

The latter is considered an important tool for addressing the management of local experts when dealing with the restoration of unstable or collapsed areas.

References

Bieniawski ZT (1976) Rock mass classification in rock engineering. Proc of the Symp "Exploration of rock Enginnering" 1:97–106

Canuti P, Margottini C, Mucho R, Casagli N, Delmonaco G, Ferretti A, Lollino G, Puglisi C, Tarchi D (2005) Preliminary remarks on monitoring, geomorphological evolution and slope stability of Inca Citadel of Machu Picchu (C101-1). Proceedings International Consortium on Landslides General Assembly, Washington, DC, pp 39–47

Canuti P, Margottini C, Casagli N, Delmonaco G, Falconi L, Ferretti A, Lollino G, Puglisi C, Spizzichino D, Tarchi D (2008) Monitoring, geomorphological evolution and slope stability of Inca citadel of Machu Picchu: results from Italian Interfrasi Project. In: Sassa K, Canuti P (eds) Landslide—disaster risk reduction. Springer-Verlag Berlin Heidelberg, 978-3-540-69966-8, pp 249–257

Carlier G, Grandin G, Laubacher G, Marocco R, Mégard F (1982) Present knowledge of the magmatic evolution of the Eastern Cordillera of Peru. Earth-Sci Rev 18(3–4) (Nov 1982):253–283

Carlotto V (1993) La geología en la conservacion del santuario historico de Machupicchu. seminario-taller internacional Arqueología del santuario histónacionaly sitio patrimonio mundial de Macupicchu: Estrado de cuestión y propuestas para un plan maestro

Carlotto V (1998) Évolution Andine et Raccourcissement au niveau de Cusco (13–16°S) Pérou: Enregistrement sédimentaire, chronologie, contrôles paléogéographiques, évolution cinématique. Tesis de Doctorado, Universidad de Grenoble, 158 pp, Grenoble

Carlotto V, Càrdenas J, Romero D, Valdivia W, Tintaya D (1999) Geologìa de los quadràngulos de Quillabamba y Machu Picchu. Boletìn No. 127, serie A: Carta Geologica Nacional, Lima, 321 pp

Carlotto V, Cárdenas J, Fidel F (2007) La Geología en la Conservación de Machupicchu. Boletín INGEMMET, Serie I Patrimonio y Geoturismo 1, 305 pp, Lima

Carlotto V, Cárdenas J, Fidel L (2009) La geología, evolución geomorfológica y geodinámica externa de la ciudad inca de Machupicchu, Cusco-Perú. Revista de la Asociación Geológica Argentina 65(4):725–747

Cruden DM, Varnes DJ (1996) Landslide types and processes. In: Turner AK, Schuster RL (eds) Landslides: investigation and mitigation. National Academy Press, Washington, DC, pp 36–75

Fanti R, Morelli S, Nocentini M, Vannucci P, (2005) Caratterizzazione geotecnica e valutazione delle condizioni di stabilità delle coperture detritiche nell'area archeologica di Machu Picchu (Perù). Giornale di Geologia Applicata 2:2010–2016. https://doi.org/10.1474/GGA.2005-02.0-30.0056

Hearn GJ, Griffiths JS (2001) Landslide hazard mapping and risk assessment. In: Griffiths JS (ed) Land surface for engineering practice geological society engineering geology special publication 18. London, pp 43–52

Hoek E, Bray JW (1977) Rock slope engineering, 2nd ed. The Institution of Mining and Metallurgy, London

Hoek E, Brown ET (1988) The Hoek-Brown failure criterion—a 1988 update. In: Curran JH (ed) Proc 15th Canadian Rock Mech Symp. Civil Engineering Dept, University of Toronto, Toronto, pp 31–38

Hoek E, Wood D, Shah S (1992) A modified Hoek-Brown criterion for jointed rock masses. In: Hudson JA (ed) Proc Rock Characterization, Symp Int Soc Rock Mech: Eurock '92. Brit Geotech Soc, London, pp 209–214

Hoek (2007) Practical rock engineering (2007 edition). http://www.rocscience.com. Last access on 15 June 2011

Hungr O (2000) Analysis of debris flow surges using the theory of uniformly progressive flow. Earth Surf Proc Land 25:1–13

Hungr O, Evans SG, Bovis M, Hutchinson JN (2001) Review of the classification of landslides of the flow type. Accepted for publication in Environmental and Engineering Geoscience, Dec 2000 (20 msp, 18 figs, 3 tabs)

Hungr O, Leroueil S, Picarelli L (2013) The Varnes classification of landslide types, an update. Landslides 11:167–194. https://doi.org/10.1007/s10346-013-0436-y

Hungr O, McDougallb S, Wisec M, Michael CM (2008) Magnitude–frequency relationships of debris flows and debris avalanches in relation to slope relief. Geomorphology 96(3–4):355–365

Hutchinson JN (1988) General report: morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. Proc 5th Int Symp on Landslides, Lausanne 1(July):3–36

INTERFRASI Project (2008) Satellite and ground based radar interferometer, integrated by GPS and other innovative equipments for monitoring archaeological sites in landslide areas: new technology for the safeguard of the INCA citadel of Machu Picchu (Peru). Final Report, 93 pp

Jordanovski L, Lee V, Manic M, Olumceva T, Sinadinovski C, Todorovska M, Trifunac M (1987) Strong earthquake ground motion data in EQINFOS: Yugoslavia. Part1. Dept Civil Engg University Southern California. Report No. 87-05

Kalafatovich C (1963) Geología de la ciudadela de Macchu Picchu y sus alrededores. Revista Universitaria 121:217–228. UNSAAC.

Kovari K, Fritz P (1978) Slope stability with plane, wedge and polygonal sliding surfaces. Symp 'Rock Mechanics related to Dam Foundations', Rio de Janeiro

Lembo Fazio A, Manfredini M, Ribacchi R, Sciotti M (1984) Slope failure and cliff instability in the Orvieto hill. 4th Int Symp on Landslides Toronto 2:115–120

Mazzoli S, Vitale S, Delmonaco G, Guerriero V, Margottini C, Spizzichino D (2009) Diffuse faulting in the Machu Picchu granitoid pluton, Eastern Cordillera, Peru. J Struct Geol 31:1395–1408. https://doi.org/10.1016/j.jsg.2009.08.010

Puglisi C, Falconi L, Lentini A, Leoni G, Prada CR (2011) Debris flow risk assessment in the Aguas Calientes village (Cusco, Perù). Second World Landslide Forum, Rome, 3–9 Oct 2011
Raetzo H, Lateltin O, Bollinger D, Tripet JP (2002) Hazard assessment in Switzerland—Codes of practice for mass movements. Bull Eng Geol Environ 61:263–268
Raetzo H, Rickli C (2007) Rutschungen. In: Bezzola GR, Hegg C (ed) Ereignisanalyse Hochwasser 2005. Teil 1—Prozesse, Schäden und erste Einordnung. Bundesamt für Umwelt BAFU, Eidg. Forschungsanstalt WSL. Umwelt-Wissen Nr. 0707, pp 195–210
Sempéré T, Carlier G, Soler P, Fornari M, Carlotto V, Jacay J, Ariste O, Neraudeau P, Cardenas J, Rosas S, Jimenez N (2002) Late Permian—middle Jurassic lithospheric thinning in Peru and Bolivia, and its bearing on Andean-age tectonics. Tectonophysics 345:153–181
Sassa K, Fukuoka H, Kamai T, Shuzui H (2001) Landslide risk at Inca's World Heritage in Machu Picchu, Peru. In: Proceedings UNESCO/IGCP Symposium on Landslide Risk Mitigation and Protection of Cultural and Natural Heritage, Tokyo, pp 1–14
Sassa K, Fukuoka H, Shuzui H, Hoshino M (2002) Landslide risk evaluation in Machu Picchu World Heritage, Cusco, Peru. In: Proceedings UNESCO/IGCP Symposium on Landslide Risk Mitigation and Protection of Cultural and Natural Heritage, Kyoto, pp 1–20
Spizzichino D (2012) Landslide risk assessment and management in the archaeological site of Machu Picchu inca citadel (Peru). PhD Thesis, University of Modena and Reggio Emilia, p 210
Steffen W (1975) Contribución al estudio biológico poblacional de Homalaspis plana y Cancer edwardsii en Mehuín. Rev Medio Ambiente 1(1):50–57
Trunk U, Honisch K (1989) Reported in "Engineering Rock Mass Classification". Bieniawski ZT
Wilkins SJ, Gross MR, Wacker M, Eyal Y, Engelder T (2001) Faulted joints: kinematics, displacement–length scaling relations and criteria for their identification. J Struct Geol 23:315–327
WP/WLI (1993) A suggested method for describing the activity of a landslide. Bull Int Assoc Eng Geol 47:53–57

Chapter 3
Machu Picchu in the Context of the Expansion of the Inca State: Between Historical and Radiocarbon Chronologies

Mariusz Ziółkowski, Jacek Pawlyta, Dominika Sieczkowska, and Andrzej Rakowski

Abstract This text presents the recent progress of studies on the phases of expansion of the Inca state, comparing the radiocarbon dates with the data resulting from the so-called "historical chronology" elaborated in 1945 by John H. Rowe. These analyses are based on available new calibration curves, as well as on the new delineation of the convergence zone boundary (ITCZ), published in 2021. The results confirm the hypotheses of different authors, that the Inca expansion in south and south-east direction occurred several decades before the date of 1471 AD resulting from the historical chronology. On the other hand, the same studies do not invalidate this traditional chronology of the Inca occupation of the territory of present-day Ecuador. In this general context, the beginning of the construction of the Llaqta of Machu Picchu also seems to date back to the first half of the fifteenth century. However, the construction of the Llaqta was apparently preceded by that of the nearby site of Choquesuysuy, coeval with the first phase of construction of the temple of Yurac Rumi in the Cordillera de Vilcabamba.

These interpretations of the results have the character of working hypotheses that will have to be confirmed by a more numerous series of radiocarbon dates.

Keywords Inca chronology · Machu Picchu · Archaeology · Radiocarbon dating

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3.1 Introduction

This study does not intend to give a definitive answer about the chronology of the construction of the Llaqta of Machu Picchu and the sites associated with this centre, in relation to the phases of expansion and remodelling, which experienced the Inca state. Our objective is rather to summarize the progress of research on these topics, and, if possible, to outline some directions to follow, among others for an ambitious project entitled “Chronology of Incan expansion in the Cordillera de Vilcabamba (Peru)” that we are starting. We hope that, in the next few years, this project will be able to provide important new elements to answer the questions mentioned at the beginning.

In the following lines, we will deal with the three main interrelated aspects to be taken into consideration when approaching this subject. These are:

1. The state of studies on the chronology of the imperial phase of the Inca state, in confrontation with historical, archaeological and radiometric data.
2. The advantages and limitations of the use of the radiocarbon method, in particular in relation to the ITCZ and the new calibration curves.
3. The position of Machu Picchu and the network of sites associated with it, within the process of expansion of the Inca State towards the “jungle belt” and the Amazon.

3.2 The Challenge of the “Historical Chronology” of the Inca Empire

Leaving open the question of the Inca ethnic group’s place of origin, it is assumed that during the period between the twelfth and thirteenth century AD, they established a kind of early state, with its centre in Cusco. By the end of the fourteenth /beginning of the fifteenth century, the Inca had taken over an area of approximately 100,000 km^2.

At the time of its greatest expansion, a century later, by AD 1530, the Inca Empire, called Tahuantinsuyu, stretched over a territory of more than one million square kilometres in area, covering partially or completely six current republics of South America; Peru, Bolivia, Ecuador, Colombia, Argentina and Chile, from the Pacific coast to the tropical forest, and from the Andamayo river in present-day Southern Colombia to the Maule river in Central Chile (Fig. 3.1). According to the most plausible modern estimates, Tahuantinsuyu was populated by 10 to 14 million inhabitants, among those Inca people as such inhabited the territories of several provinces of the current department of Cusco, Peru, and represented only about 3–5% of the total population of the Empire. In the peripheral provinces of the Empire the Incas made up only the upper stratum of the administration and the political, military and religious classes, as well as some specialized groups of Inca colonists (Szemiński and Ziółkowski 2018).

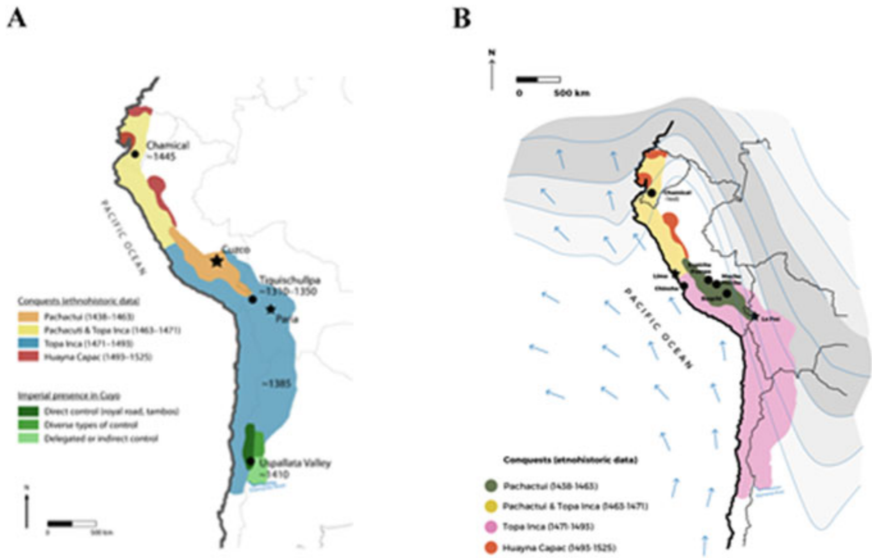

Fig. 3.1 (**a**) The Inca Empire (from Marsh et al. 2017). (**b**) The Inca Empire with analysed locations adapted from Marsh et al. 2017). Confidence intervals (±1σ, ±2σ, and ±3σ) of latitudinal positions of the Tropical Low-Pressure Belt (TLPB) are marked in grey, adapted after (Ancapichún et al. 2021)

Tahuantinsuyu had a complex infrastructure, a road network of about 40,000 km. long (Hyslop 1984), a system of administration and control established in administrative-religious imperial centers that, in all this immense territory, represented the centralized power of the Inca capital, Cusco. One of the important elements of the socio-territorial organization of the Inca Empire was the so-called royal estates, private properties of the sovereigns. Machu Picchu and the areas surrounding this site constituted precisely one of these private properties, attributed to Pachacuti Inca Yupanqui (Rowe 2003 [1986]).

The interpretation of the chronology and the phases of expansion, considered very rapid, rested on the so-called historical chronology proposed by John H. Rowe in 1945. According to this chronological scheme, based mainly on the Spanish chronicle of Miguel Cabello Balboa (1586), the imperial phase of the Inca State began with the ascension to power around AD 1438 of Pachacuti Inca Yupanqui, the ninth sovereign from the so-called traditional dynastic list. He and his successors, Tupac Inca Yupanqui and Huayna Capac Inca, extended the State first to the North-West of the capital city of Cusco to present-day Ecuador and then to the south-east and south to the territories of what is now Bolivia, Argentina and Chile.

According to this model, the reign of those three rulers calculated on the basis of data taken from chronicles, lasted ca. 100 years until the Spanish invasion in AD 1532 (Table 3.1 and Fig. 3.1a) (Rowe 1945; Marsh et al. 2017).

Table 3.1 Historical chronology of the Inca Empire cf. John H. Rowe (1945)

Year (AD)	Events
1438	Pachacuti deposes Viracocha, beginning of imperial conquest
1438–1471 (33 years)	Pachacuti ruled
1463	Pachacuti remains in Cuzco. Sons of Pachacuti including Topa Inca lead the army on campaigns of expansion
1471–1493 (22 years)	Topa Inca succeeds Pachacuti
1473	Chile conquered
1493–1525 (32 years)	Huayna Copac ruled
1525–1532 (7 years)	Huayna Copac dies, succeeded by Huascar, whose rule was contested by Atahuallpa
1532	Pizarro captured Atahuallpa in Cajamarca

Although the historical chronology was the most widespread it does not mean there were no contrary opinions about it. Some authors relying on a structuralist theorem, questioned the historical validity of all the Inca dynasty list and, by extension, rejected the possibility of any attempt to reconstruct the historical events of the pre-Hispanic period (Zuidema 1982). Without taking such an extreme position, Alan Covey summarized those more and more recurrent doubts about the reliability of the historical chronology as follows:

> Archaeological data and comparative historical evidence indicate traditional twelve-generation kinglist cannot be treated as a complete plausible account of Inka succession and chronology (…) Pachakutiq myth cannot explain the available evidence adequately, 1438 should not be used as a starting date for the Inka polity and history. (Covey 2006: 173–174)

3.2.1 *The Limitations of the Chronological Interpretation of Historical Sources*

Without going so far as to totally reject the reliability of the historical sources, it should be noted that the "historical chronology" was based on a somewhat superficial interpretation of the historical texts. Let's start with the analysis of the term "conquest", which in the historical sources is called the subjugation of a territory given the central power of the Cusquenians.

Taking as an example the case of the emblematic confrontation of the Incas with the Chancas, Amnon Nir observed that the analysis of the main dictionaries of the time reveals the existence, in Quechua and Aymara, of three equivalents of the Spanish term "conquistar" (to conquer), whose basic meanings are the following:

1. Llasa- refers to a conquest whose objective is to raid, plunder, rob and steal the enemy's resources.

2. Ati- evokes a conquest whose objective is to conquer, triumph, defeat and overcome the enemy in order to establish relations of subordination in a hierarchical political space.
3. Runa-cha- and its exact equivalent in Aymara Jaqui-cha- reflect a conquest whose objective is to convert the enemy into a "human being" (runa and jaqi designate human being, the former in Quechua, the latter in Aymara), that is, to incorporate him into the culture of the victors by forcing him to adopt their religion and assimilate their language, laws and form of government (Nir 2016: 129–130).

It is also necessary to take into consideration the different ways of classifying the conquests, depending on the persons of their authors: Inca in person or his captain(s). Moreover, the same territory could be conquered twice: by the sovereign and by his captains.

According to Nir, the type of "conquest" was conditioned by the person of the author:

– In regions conquered by only one of the Inca's captains, the nature of the conquest corresponds to the meaning of the verb llasa-; its object was thus to dispossess the enemy in order to control his resources and fill the Inca's empty warehouses.
– In the regions conquered by the Inca in person, as well as in those conquered and by the Inca and by his captains the nature of the conquest coincides with the sense of the verb ati-, which indicates that the object of such conquest was to defeat the enemy and establish with him relations of subordination (Nir 2016).

We can complete Nir's analysis by suggesting that only the conquest by the sovereign could correspond to the term runa-cha, since it implied a subsequent direct intervention of the imperial administration in the reorganization and management of the subjugated territory.

It is evident that each of these different (and often successive) forms of control of a given territory leaves other kinds of archaeological evidence, that are sometimes scarce.

But the problem lies not only in defining the type of control of a territory by the Incas but also in identifying on a personal level the authors of these different types of "conquests". Here came the problem of the system of attribution of personal names among the Incas.

3.2.2 The Question of the Personal Name Among the Incas[1]

It is well known that the so-called "personal names" under which the Andean people appear in the sources, constitute in reality a very heterogeneous set in which enter both titles and names of positions and/or professions, as well as some nicknames

[1] This issue has been analysed in more detail in: Ziółkowski (1997: 101–109). The following lines present the main conclusions of this analysis.

(sometimes derogatory) and proper names sensu stricto. But the separation of these three main groups is not easy; moreover, in certain contexts, one or the same individual could appear under different "names" and, at the same time, several individuals could share the same name and/or title. Let us briefly review some aspects of this problem, mainly in relation to the members of the Cuzco nobility, especially the Inca rulers.

Generally, each individual (regardless of sex) was named twice: at the age of about one year, during the *rutuchicu* (haircut) ceremony, when he or she received a "child's name" and a second time, when he or she reached maturity during the *huarachicu* (in the case of males) or *quicuchicu* (in the case of females) ceremony, when the "adult name" was attributed to him or her.[2]

However, it is noted that an individual could throughout his life be called with his "child's name" in particular if this was a "toponymic name" that is to say associated with the place of birth: it was the case, among others of Huascar Inca (Sarmiento de Gamboa 1906, Cap.63: 112) and Inca Paullu (Betanzos 1987, I p., Cap. XLV: 192).

Finally, when taking the supreme power, the Inca sovereign received his "official name", which rarely had anything to do with the "adult" name, as we can observe in the case of Atahuallpa: "Caccha Pachacuti Ynga Yupangue Ynga" (Betanzos 1987, Parte II, Cap. VI: 221)[3] The problem is that these names are rarely cited in the recount the life of the sovereigns: it seems that there was a kind of restriction on their use.[4]

Added to this is the already mentioned problem of differentiating a "personal name" from the title associated with specific functions or positions within the imperial socio-political organization. Szemiński has shown that this is the case of "Manco Capac", the supposed name of the founder of the Inca dynasty: it would actually be a title associated with the tradition of the Tiwanaku (Tiahuanaco) state (Szemiński 1994: 397 ff.). Regarding the Inca period, we have clear indications of a similar meaning (i.e.: name of an office) of, among others, "Capac Yupanqui", "Yamqui Yupanqui", "Auqui"; this would explain the appearance, generation after generation,

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[2] Regarding this last problem, let us note that some of the future Incas, before wearing the *mascapaycha*, bore names in which the combination "Cusi Huallpa" appears. For example, the future Huayna Capac was called Topa Cusi Huallpa, while Huascar Inca bore the name Titu Cusi Huallpa, the same as one of his predecessors, Yahuar Huacac (Sarmiento de Gamboa 1906, Chap.20, 56, 63: 50, 103, 112). What was the meaning of the difference in the first part of the name (Titu or Topa) and of the repetition of the second part (Cusi Huallpa)? Did this have something to do with the family affiliation of the mentioned Incas? (Ziółkowski, 1997: 103).

[3] For the subject of the present study it is also convenient to recall the name that was attributed to Pachacuti Inca Yupanqui: "Viracocha Ynga como le pusiese la borla en la cabeza le dijo: Yo te nombro para que de hoy y más te nombren los tuyos en las demás naciones que fuesen sujetas Pachacuti Ynga Yupangue Capac Indichuri que dice vuelta del tiempo Rey Yupangue hijo del sol el Yupangue es el Alacuña el linaje de do ellos son porque ansi se llamaba Mango Capac que por sobrenombre tenía Yupangue…" (Betanzos 1987, I.p. Cap. XVII: 83).

[4] This is clearly seen in the case of the Inca Sayri Tupac who changed his name in preparation for the departure from Vilcabamba: "Y cuando tomó la borla, antes que saliese de su tierra para venir a Lima, se mudó el nombre en Mango Capa Pachacuti Yupangue; y así estos dos nombres se han de entender ser todo uno." (Fernández "El Palentino" 1963, Parte II, Lib. III, Cap. V: 83). However, this name no longer appears in the account of the prince's life.

of successive “Capac Yupanqui”, “Chalco Yupanqui”, etc. It is quite evident that the use of such denominations was also highly contextual, that is to say: for a member of the Inca elite it was quite evident that a Capac Yupanqui associated with the Pachacuti Inca Yupanqui reign was not the same person as another Capac Yupanqui from the time of Huayna Capac. In the same way for someone versed in the history of Spain, the reference to the “Duke of Alba” (present actually even on brandy bottles) establishes in a clear and unequivocal way the association with the famous Spanish commander, don Fernando Alvarez de Toledo, third Duke of Alba (1507–1582). However, this is an obvious case of contextual use of the title, based on certain over-understood information, since individuals bearing the same title of “Duke of Alba” numbered more than ten, over a period of four centuries. For someone lacking such “contextual knowledge” related to Inca history (and this was the situation of most Spanish chroniclers in Colonial times), this kind of information provided by members of the Inca elite could lead to several identity confusions (Ziółkowski 1997: 109). This may be one of the causes of the problems we face when trying to attribute to a specific individual the merits of “conquest” or submission of this or that part of imperial territory: this problem is particularly noticeable in the case of actions carried out not by the Inca sovereigns themselves but by their commanders.

3.2.3 The “Dynastic Lists” of the Inca Rulers

Finally, we have to address a fundamental basic issue that has already been glimpsed in the initial part of this paragraph: did the Incas have the practice of recording events such as reigns of sovereigns, wars, etc. on a linear time scale based on astronomical phenomena (solar years, months, etc.)? Although in the case of the Mesoamerican cultures we have very tangible evidence in this respect, the Andean case is quite different, mainly because of the absence of pre-Hispanic material evidence comparable to the Mayan stelae with calendrical-historical inscriptions or the Mixtec or Aztec codices.

As far as the historicity of the Inca dynastic lists included in the chronicles written in the colonial period is concerned, the opinions of the specialists on the subject, mentioned at the beginning of this paragraph, are very divergent: from an acceptance, albeit critical (J. H. Rowe) to an outright denial (R. T. Zuidema).[5] And even if we were to accept the historicity of the sovereigns mentioned in these lists, would it be a monarchical or a diarchical model of power; in the latter case, with two parallel sovereigns representing the part of Hanan Cuzco and Hurin Cuzco, respectively

[5] See the critical summary of the positions that different authors have taken on the problem of the “mythical” or “historical” character of the “Inca kings” in Pärssinen (1992: 201ff). One of the most heated discussions on this subject centre around the interpretation of the chronicle of Fernando de Montesinos and his list of 105 “Kings of Peru”: see in this regard, among others, the studies by Hiltunen (1999) and Szemiński (2009).

(Tables 3.2 and 3.3) Without going into the details of this much-debated subject,[6] we note that the ages and duration of the reigns attributed, for example, by Guaman Poma de Ayala to the Inca rulers cannot correspond to a historical-chronological record as such,[7] but rather convey another type of information (Mróz 1984).

Table 3.2 The Inca rulers of Cusco (dates of reign are given based on the monarchical interpretation, according to which Manco Capac is considered the founder of one lineage of rulers. It does not include rulers intentionally omitted in the official tradition)

Manco Capac (Manqu Qhapaq Inqa)	Hurin Cusco Dynasty
Sinchi Roca (Zinchi Ruq'a)	
Lloque Yupanqui (Lluq'i Yupanki)	
Mayta Capac (Mayta Qhapaq)	
Capac Yupanqui (Qhapaq Yupanki)	
Inca Roca (Inqa Ruq'a)	Hanan Cusco Dynasty
Yahuar Huacac (Yawar Waqaq)	
Viracocha (Wira Qucha Inqa)	
Pachacutec Inca Yupanqui (Pachakuti Inqa Yupanki)	
Tupac Yupanqui (Thupaq Yupanki Inqa)	
Huayna Capac (Wayna Qhapaq) [1528? †]	
Huascar (Waskhar Inqa) [1528?–1532]	
Atahualpa (Ataw Wallpa) [1531?–1533]	
Tupac Huallpa (Tupa Wallpa) [1533]	
Manco Inca (Manqu Inqa) [1533–1544]	
Sayri Tupac (Sayri Thupa Inqa) [1544–1560]	
Titu Cusi (Titu Kusi Inqa) [1560–1571]	
Tupac Amaru (Thupa Amaru Inqa) [1571–1572]	

[6] The main source in support of the "diarchic" thesis is a fragment of Acosta's chronicle "Historia natural y moral …" (Lib. VI. Cap. 20, 1979: 306). See also the studies by Zuidema (1995: 223 ff.), Duviols (1979, 1980), and Regalado (1993).

[7] For example: "Este dicho Ynga [Cinche Roca Ynga] murió en el Cuzco de edad de ciento y cincuenta y cinco años" (Guaman Poma fol.89).

Table 3.3 The Inca rulers of Cusco (dates of reign are given based on the bi-dynastic interpretation, according to which Manco Capac is considered the founder of both dynasties. Two best-documented cases of rulers intentionally omitted in the official list [Urco Inca and Amaru Tupac] are included)

<table>
<tr><th>HANAN Cusco</th><th>HURIN Cusco</th></tr>
<tr><td colspan="2">Manco Capac (Manqu Qhapaq Inqa)</td></tr>
<tr><td>Inca Roca (Inqa Ruq’a)</td><td>Sinchi Roca (Zinchi Ruq’a)</td></tr>
<tr><td>Yahuar Huacac (Yawar Waqaq)</td><td>Tarco Huaman (Tarku Waman)</td></tr>
<tr><td>Viracocha (Wira Qucha Inqa)</td><td rowspan="2">Lloque Yupanqui (Lluq’i Yupanki)</td></tr>
<tr><td>Urco Inca (Urqun Inqa)</td></tr>
<tr><td>Pachacutec Inca Yupanqui (Pachakuti Inqa Yupanki)</td><td rowspan="2">Mayta Capac (Mayta Qhapaq)</td></tr>
<tr><td>Amaru Tupac (Amaru Thupaq Inqa)</td></tr>
<tr><td>Tupac Yupanqui (Thupaq Yupanki Inqa)</td><td rowspan="4">Capac Yupanqui (Qhapaq Yupanki)</td></tr>
<tr><td>Huayna Capac (Wayna Qhapaq) [1528? †]</td></tr>
<tr><td>Huascar (Waskhar Inqa) [1528?–1532]</td></tr>
<tr><td>Atahualpa (Ataw Wallpa) [1531?–1533]</td></tr>
<tr><td>Tupac Huallpa (Tupa Wallpa) [1533]</td><td rowspan="5">Don Juan Tampu Mayta Panaka</td></tr>
<tr><td>Manco Inca (Manqu Inqa) [1533–1544]</td></tr>
<tr><td>Sayri Tupac (Sayri Thupa Inqa) [1544–1560]</td></tr>
<tr><td>Titu Cusi (Titu Kusi Inqa) [1560–1571]</td></tr>
<tr><td>Tupac Amaru (Thupa Amaru Inqa) [1571–1572]</td></tr>
</table>

It seems that the Inca practice on this point could be even more complex, i.e. resulting from the parallel handling of two “chronological” systems. This is evident from a reading of the chronicle of Juan de Betanzos, which mentions “two different ages” attributed to Pachacuti Inca Yupanqui:

– one corresponding to one hundred and twenty years of life seems to have mainly a symbolic value;
– another related to the recording of the duration and fulfilment of certain tasks (work, military campaigns, festivities, etc.). According to this “parallel” evidence, Pachacuti Inca Yupanqui would have died “very old”, at the age of about ninety years, which seems more acceptable as a possible duration of the life of this sovereign (Betanzos 1987, Chap. XXIII–XXIX: 119–137).

This second type of record may have had its origin in the need to keep an accounting of the contributions made by different groups of tributaries of the Inca, while the first in certain considerations of a religious and astronomical nature.[8]

As we can see, even when we proceed to a more detailed analysis of the written records, we are left with a series of unknowns that make it difficult to establish the exact chronology of the expansion of the Inca state on pure historical basis.

3.3 New Approach: Chronology of Inca State Based on Radiocarbon Method?

Another important argument in favour of a remodelling (or even a total abandonment) of the "historical chronology" came in recent years with a series of studies based on radiocarbon dating.

3.3.1 Radiocarbon Dating Methods

Radiocarbon is one of the cosmogenic nuclides, which is formed during collisions between thermal neutrons and nuclei of nitrogen, in nuclear reaction ^{14}N (n, p)^{14}C. The global average production rate of ^{14}C is of the order of 2 atoms·cm^{-2}·s^{-1} (Castagnoli and Lal 1980) and strongly depends on the intensity of the cosmic ray flux (Usoskin and Kovaltsov 2012). These changes are due to changes in the intensity of the solar magnetic field, the interplanetary magnetic field and Earth's magnetic field, which modulate the flux of cosmic rays.

The freshly produced radiocarbon (^{14}C) is quickly oxidized to $^{14}CO_2$ and through several pathways enters terrestrial reservoirs such as the hydrosphere and biosphere. The atmospheric activity of radiocarbon is the result of equilibrium between cosmogenic production, radioactive decay and exchange with other reservoirs. The terrestrial biosphere exists in equilibrium of the radiocarbon concentration with the atmosphere, that is, the $^{14}C/^{12}C$ ratio of the troposphere stays approximately at the same level over time. The situation changes dramatically with the death of the organism, whereupon all of the metabolism functions stop and radiocarbon concentration in the tissue starts to decrease due to radioactive decay. If the initial level of radiocarbon concentration can be predicted, and if during the time the system was closed for carbon exchange, then by measuring the present ^{14}C concentration, its age, i.e., a period of time elapsed from its death, can be determinate, using the radioactive decay law.

The conventional radiocarbon age (CRA) of sample S is calculated using atmospheric ^{14}C concentration in 1950, a standard value set et 100% Modern Carbon

[8] The possible meaning of this 120-year number is explained elsewhere (Ziółkowski 1997: 228–230; 2015: 329–335).

(pMC) (Stuiver and Polach 1977) or 1 fraction modern carbon F (Reimer et al. 2004):

$$t = \frac{T_{1/2}}{ln2} ln(F_s), \tag{3.1}$$

or

$$t = -8033 ln(F_S), \tag{3.2}$$

and is reported in years before presents (BP, before 1950). In the equations F_S is ^{14}C concentration in fraction modern carbon with normalization to $\delta^{13}C = -25‰$ PDB (as an average value for C_3 plants), and $T_{1/2} = 5568$ years (Libby half-life). The actual radiocarbon half-life is 5730 ± 30 years (Godwin 1962), and is about 3% longer than this using for calculation, which is compensated during the calibration procedure. The time limit for this method is about 50 ka, and is determinate by its half-life (~9–10 half-lives).

3.3.2 Calibration Curve

Changes in radiocarbon concentration in the past are of great importance for radiocarbon dating method. This method based on the decay of the isotope of carbon of mass 14 (radiocarbon), and is very important to know how the radiocarbon concentration has changed in the past, and what is the present concentration in the sample. Radiocarbon concentration in the atmosphere is not constant in time and therefore to obtain a calendar age of the sample it is necessary to use the calibration curve (Reimer et al. 2020). It allows the determination of the interval in calendar years, which corresponds to the appropriate concentration of radiocarbon (radiocarbon age).

The differences in the concentration of radiocarbon between northern and southern hemispheres, force the creation of separate calibration curves for both hemispheres. Those curves in the youngest period were built on the basis of radiocarbon concentrations in tree rings from trees that were previously dated dendrochronological (Willis et al. 1960). Each point on the curve represents the mean average between 5 and 10 years (depends on period), which means that the amplitude of changes (rapid increase or decrease of the concentration of radiocarbon in the atmosphere) is shallower. However, in the new curve, IntCal20 and SHCal20 (Reimer et al. 2020; Hogg et al. 2020), many of the time period were substituted with one-year-resolution measurements based on annual tree rings. The selection of the appropriate calibration curve is dictated by the location of the sampling site in the relation to the ITCZ (Intertropical Convergence Zone—Marsh et al. 2018). In some cases, it is necessary to use both calibration curves with the appropriate percentages, determined by the time the location is under the influences of the air masses from the relevant hemisphere. The position of the ITCZ is presented in the Fig. 3.3 (after Ancapichún et al. 2021).

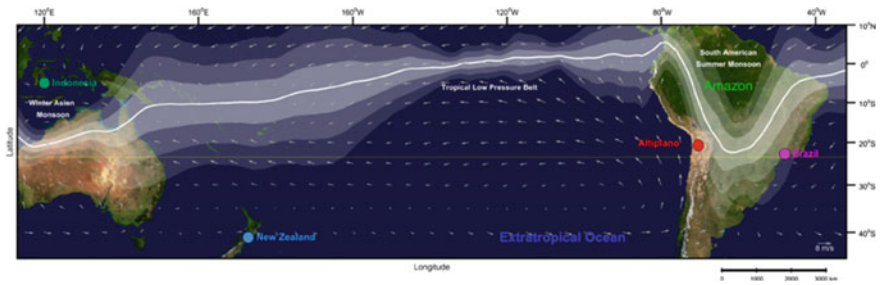

Fig. 3.2 Locations of Δ14C records used in our study: Altiplano (Polylepis tarapacana; 20°S, red dot, this study); Indonesia (Tectona grandis; 5° S, greendot; Hua et al. 2013); Brazil (Araucaria angustifolia; 22° S; magenta dot; Santos et al. 2015); and New Zealand (atmospheric measurements from Wellington; 41°S, blue dot; Turnbull et al. 2017). The white line represents the average (±1σ, ±2σ, and ±3σ) latitudinal positions of the Tropical Low-Pressure Belt (TLPB) drawn following 1949–2019 averaged austral summer (DJF) minimum sea-level pressure between 10° N and 35° S in the NCAR/NCEP reanalysis. White vectors show wind velocity and direction. The Tropic of Capricorn is shown with the yellow dotted line. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article, after Ancapichún et al. 2021.)

The location of the ITCZ during the austral summer is shown in Figs. 3.1b and 3.2. All analysed location, except for Chamical, are located completely below the marked line. This means that for samples from these sites, the southern hemisphere radiocarbon calibration curve (SHCal20) should be used for calibration. In the case of Chamical, it is possible to consider the influence of air masses from the northern hemisphere by using both the IntCal20 and SHCal20 calibration curves for calibration, but limiting the IntCal20 share to a few percent in total calibration.

Differences between IntCal20 and SHCal20 curves, in the period from AD 1000 to the present day (AD 1950) are shown on Fig. 3.4. Artificial radiocarbon dates (see Fig. 3.5) were created to analyse the differences in the range of calendar years calibrated using IntCal20, and SHCal20. In all three cases, the time intervals obtained using IntCal20 start much earlier than calibrated with SHCal20. The calibrated dates seem to be older than those calibrated using SHCal20 (Figs. 3.3 and 3.4).

3.3.3 Phases of the Expansion of the Inca State According to Radiocarbon Dating: Advances and Limitations of the Method[9]

It is true that the application of radiocarbon dating for the differentiation of the phases of formation and expansion of the Inca Empire was relatively limited. This was due to the preconceived idea that the Imperial period of the existence of the Inca State was

[9] The following lines use excerpts from an earlier study of ours: Ziółkowski et al. (2020).

so short (a century or less) that precise radiocarbon dating available in the 1980s or 1990s could not contribute much to the differentiation of the phases of its expansion. Other techniques, such as dendrochronology, were at that time practically irrelevant in the Andean region and only in recent years have begun to gain some importance (Ghezzi and Ródriguez 2015; Ghezzi et al. 2021a, b).

However, even with these limitations, a 1996 text based on the composite probability distribution of calibrated radiocarbon dates relating to the pre-Imperial and Imperial phases of the expansion of the Inka Empire, offers some interesting and novel conclusions.

This analysis showed that, at a rate of 68% probability, the pre-Imperial phase of the existence of the Inca state was placed between AD 1280 and 1396, while the expansive or Imperial phase between ca AD 1401 and 1518.

It turned out, as it happens, that the expansion of the Inca state began several decades before the "canonical date" of Ad 1438 (Fig. 3.5) resulting from the historical chronology (Adamska and Michczyński 1996).

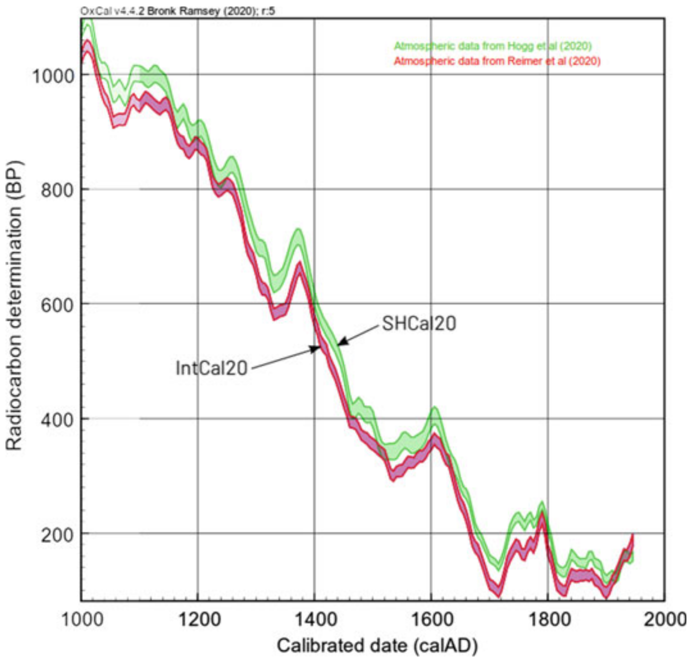

Fig. 3.3 Distribution of the discussed calibration curves (IntCal20 and SHCal20)

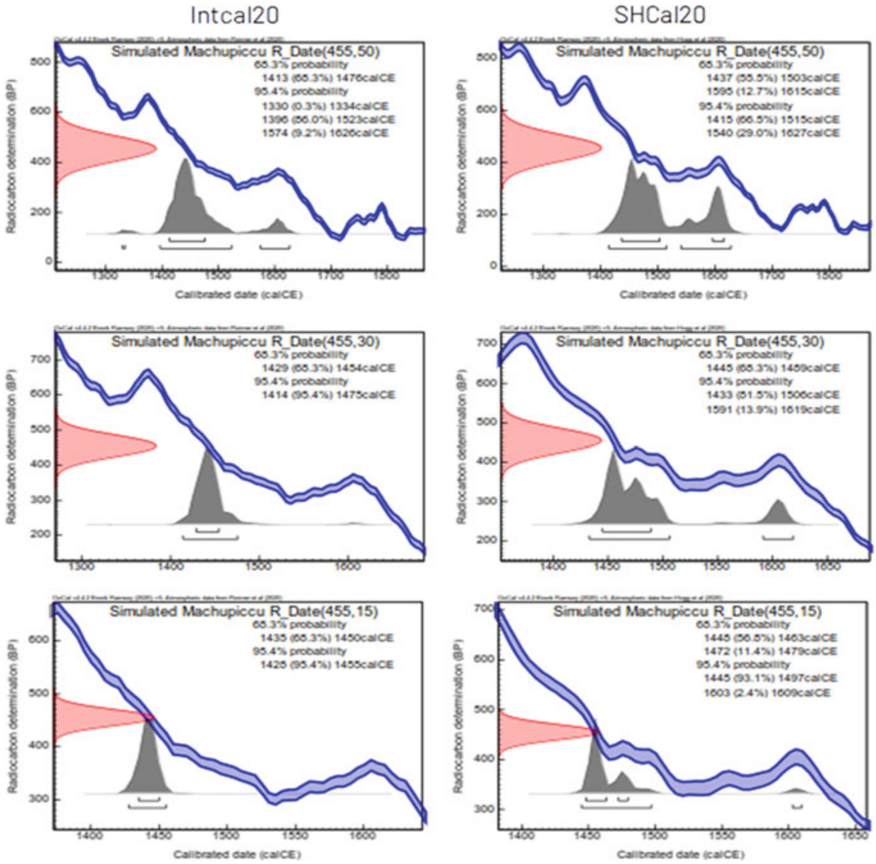

Fig. 3.4 Influence of IntCal20 and SHCal20 on calibrating Machu Picchu simulated dates of different uncertainties

An important step in challenging the "historical chronology" was undoubtedly the studies by Dennis Ogburn at the Inca site of Chamical in Ecuador. There, in an unquestionably Inca settlement, it was possible to differentiate a series of layers relating to different phases of the Inca occupation (Appendix 1). Based on the Bayesian analysis of the sequence of radiocarbon dating, Ogburn formulated the conclusion:

> Our chronology of Inca expansion can no longer be based on the historical accounts, and we should not be judging ^{14}C dates against the traditional chronology. Instead, we must base our chronology on ^{14}C dates, and evaluate the historical record in relation to them. ^{14}C dates will not provide the level of precision we might desire within the short span of the Inca Empire. But they can still provide a level of accuracy that is not possible within the framework of the historical account of Inca provincial expansion (…) We may be able to obtain dates of sufficient precision and accuracy to date the Inca incorporation of different provinces within a range of about 2 decades. (Ogburn 2012: 235)

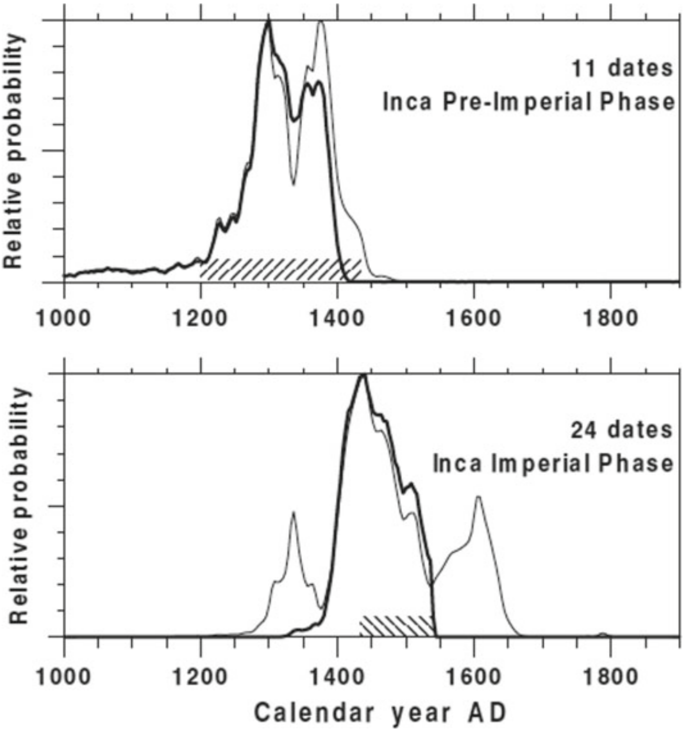

Fig. 3.5 Composed probability of calibrated radiocarbon dates for Inca Preimperial and Imperial Phase. Dashed areas show limits of phases established on the basis of the chronicles. Thin lines present probability distributions obtained from radiocarbon dates without additional data; thick lines show probability distributions obtained as a result of combining information. The statistical analysis of combined dates demonstrates that the Imperial Phase started around AD 1390–1400, before the period attributed to Pachacuti Inca Yupanqui (Adamska and Michczyński 1996)

Another argument in questioning the "historical chronology" as well as the traditional sequence of the expansion phases of the Inca Empire in Argentina was studied by Marsh et al. (2017). The Bayesian model based on 26 ^{14}C dates and 19 TL dates allowed the authors of the study to formulate the following conclusions:

> The emerging archaeological chronology of the Inca expansion confirms that dates in documentary sources are incorrect and strongly supports the argument to build an Inca chronology with radiometric dates and Bayesian models. Contrary to the traditional sequence of conquests, the southern expansion began first. Inca forces arrived in northern Argentina and Chile in the final decades of the fourteenth century. They probably arrived at the south-eastern edge of their empire in Mendoza at cal AD 1380–1430 (68% probability). At this point, the empire stopped expanding southward and occupied the area for the next 100–190 yr (68% probability). Conquering leaders then looked north and marched on Ecuador beginning cal AD 1430–1460 (68% probability). (Marsh et al. 2017: 20–21—Figure 3.1a)

Similar results were obtained with the analysis of 59 ^{14}C and 155 TL dates from different Inca sites in Chile. Apparently, the Inca occupation occurred almost

100 years before AD 1470, although differences between analysed regions exist (Cornejo 2014).

This served to elaborate a new isochronal map of the Inca expansion which is significantly different from the one based on the historical chronology (Fig. 3.1a).

3.3.3.1 Analysis Based on Recalibration According to New Curves

Let us now see what modifications can be made to this last model by applying the new calibration curves and re-calibrating the above-mentioned dates from Ecuador and Argentina accordingly. As we are analysing the problem of the beginning of the Inca presence in the fifteenth century or even earlier, we need not worry about the shape of the calibration curve in the sixteenth century which makes it practically impossible to define radiocarbon dates calibrated in that later period.[10]

Let us first look at the chronology of the site of Chamical (Ecuador). As we have pointed out above, in this case it is possible to consider the influence of air masses from northern hemisphere by using both the IntCal20 and SHCal20 calibration curves for calibration, but limiting the IntCal20 share to a few percent in total calibration.

Tables 3.5, 3.6 and 3.7 in Appendix 1 present a comparison of Ogburn's analysis based on the SHCal13/IntCal13 curves and the more recent analysis based on the IntCal20 and SHCal20 curves. Note that the application of the new curves has significantly changed the chronological position of the Chamical occupation stages identified by Ogburn. In general, they all turn out to be later than Ogburn's postulates. Limiting ourselves to the initial phase of the Inca presence at this site, we observe that it is located (at 68.3% probability) between 1445 and 1476 AD and between 1410 and 1496 AD (at 95.0% probability). It seems, that this result cannot therefore serve as a strong argument against the "historical chronology" according to which the Inca conquest of this part of the territory of present-day Ecuador would have taken place after AD 1463.

The situation with the dates from the Argentinean sites is more complex. First of all, it should be noted that Marsh and his collaborators used both radiocarbon and TL dates. Lacking complete information in the script presented by our colleagues (see Marsh et al. 2017) we were not in a position to reproduce the same analytical process. Therefore, we have limited ourselves to examine only some of the radiocarbon dates used by our colleagues in support of their postulate of an early Inca presence in the referred territory (see Fig. 3.1a). It should be noted, however, that the dates used by our colleagues have standard errors of more than 50 years (with the exception of two) and in some cases of the order of 80 or 130 years. Frankly speaking, this does not seem to us to be a firm basis for discussing the phases of Inca advance throughout the fourteenth and fifteenth centuries, not even with the support of an analysis based on a probabilistic calculation of an anterior–posterior relationship between the sites considered.

[10] See the discussion on this topic in Sect. 3.3.1.

For our comparative analysis in Appendix 2 we have chosen 6 radiocarbon dates of relatively good precision and from rather well-defined Inca contexts from five sites: Cienaga de Yalguaraz (UZ-2526/ETH-5319), Aconcagua (GX-19991, Beta-88785[11]), Cerro Penitentes (Beta-98941), Potrero Las Colonias (AA-66564) and Odisa (AA-90284)[12] (Marsh et al. 2017, Table 3.3: 11).

In any case, all these dates come from the same region of the Uspallata Valley. Therefore, they can be considered as corresponding to the same stage of the Inca occupation.

An analytical problem resulted from the two dates from the Aconcagua mummy. The difference between the age obtained on the basis of the collagen of the rib was more than 100 years later than the one based on the hair of the individual. This is difficult to explain as the infant was between 6 and 8 years of age. The authors of the study drew attention to a possible problem related to the preservation of collagen in the bones of infants, which could have caused this difference, and therefore the two dates should be considered equivalent (Marsh et al. 2017: 15). Without going into a detailed discussion of this issue we decided to perform 3 versions of a combined calibration:

Model AA—all 6 datings in one phase (Table 3.9, Fig. 3.11),
Model BB—5 datings in one phase without the from mummy bones (GX-19991) (Table 3.10, Fig. 3.12),
Model CC—dating from mummy bones and hair (GX-19991, Beta-88785) combined in one dating and then put together in one phase with the remaining 4 datings (Table 3.11, Fig. 3.13).

The results are presented in Appendix 2. Compared with those of Marsh et al. (2017) we note that although the beginning of the Inca presence in the Uspallata Valley has been slightly altered in relation to the thesis of these authors, it is still located in the first half of the fifteenth century (according to all three models), several decades before the date of post-1571, derived from the "historical chronology".

3.3.3.2 Camata (Moquegua): Another Case of Possible Early Inca Occupation

In reviewing some of the dating associated with Inca occupation we have come across the relatively little known case of Tambo de Camata in the Moquegua Valley (Dayton 2008). This is an Inca administrative centre, with a group of *collcas* (*qollqa*) or granaries. The excavations carried out in these structures revealed a complex stratigraphy, with well-defined Inca occupation levels. It has been possible to date

[11] "The two dates are from the child's rib collagen and hair (…). Given the high rate of collagen turnover in young bones, these dates should be equivalent, so they were combined prior to calibration" (Marsh et al. 2017: 15).

[12] The date comes from a human bone. The association of this burial with Inca-influenced pottery is somewhat uncertain (Marsh et al. 2017: 15).

samples taken from two *collcas* (CTQ1 and CTQ3), the results of the recalibration of these dates are presented in Appendix 3. Let us note that the temporal space of the beginning of the Inca installation corresponds according to the models elaborated to the period between AD 1391 and 1430 (at 68.3% probability) and between AD 1333 and 1442 (at 95.4% probability). It follows that the Moquegua valley was occupied by the Incas in the first half of the fifteenth century, i.e. several decades before AD 1471, the date resulting from the "historical chronology".

3.3.4 Back to Historical Sources and the Case of the Inca Occupation of the Chincha Valley

Although, as it was demonstrated above, some of the results of the new radiocarbon dating of different Inca sites scattered throughout the Empire seem to contradict the historical chronology, this does not mean that historical data lose all importance for the study of this subject. Radiometric data based on archaeological evidence also have their serious limitations for the reconstruction of historical processes, which we have presented above. By way of illustration: on the basis of the radiocarbon method alone, if not supported by historical data, it would have been very difficult, if not impossible, to establish the year AD 1532 as the date of the beginning of the Spanish Conquest of Tahuantinsuyu. The purely archaeological data relating to the initial phase of this process are very scarce, while radiocarbon dates would lack sufficient precision because of the above-mentioned shape of the calibration curve for this period.

A main contribution of the historical sources is that they provide detailed information about the different forms of occupation and control of a territory subjected to the Inca state; which is manifested among others in the diverse and heterogeneous archaeological manifestations of the Inca presence outside the so-called metropolitan territory, i.e. the region of Cusco and its region.

The Inca occupation of the Chincha Valley could serve as a case study for the comparison of historical sources and archaeological evidence (including radiometric dating), mainly thanks to a wealth of historical data from sources that served as a basis for the formulation of different models of the social, political and economic organization of the Chincha Valley (Fig. 3.6).

On the other hand, several archaeological projects have been carried out in the valley, in effect identifying, among others, a series of settlements and constructions from the Late Horizon period, some of which, such as the Huaca La Centinela, have been excavated (Wallace 1998; Santillana 1984). Unfortunately, for the reasons given above, the authors of these works have not considered it necessary or useful to take samples associated with the Late Periods (LIP and HT) for radiocarbon dating.[13]

[13] Among the numerous ethnohistorical and archaeological studies on this subject, let us note a few particularly relevant ones: (Bongers 2019; Sandweiss and Reid 2016; Nigra et al 2014; Tantaleán et al. 2013; Morris and Santillana 2007; Alcalde et al. 2002; Lumbreras 2001; Wallace 1998, 1991,

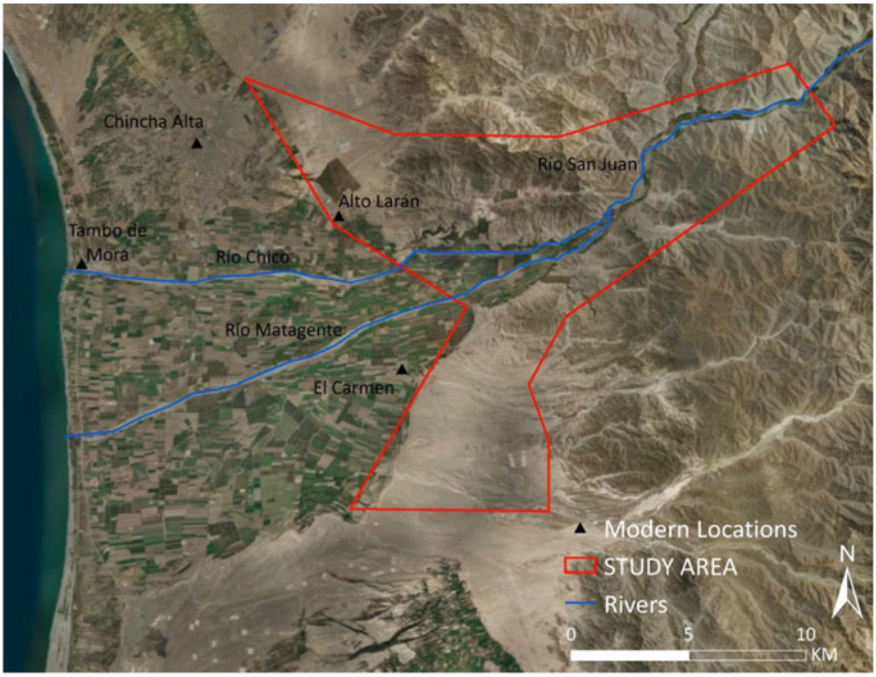

Fig. 3.6 The Chincha Valley (form Bongers 2019)

Regarding the chronology of the incorporation of this territory into the Inca Empire, a subject of main interest for our study, two antagonistic models have been formulated: one of a late "Inca conquest", around AD 1476, and another, of an early "Inca conquest", at the beginning of the fifteenth century AD. In his recent dissertation, Bongers synthesized these interpretative models in the form of a comparative Table 3.4 and pronounced himself in favour of the early chronology:

> All these lines of evidence support the following early placement model for the beginning of the south coast, outlined by Julien (2008). Capa Yupanqui was likely a younger brother of Pachacuti. He was ordered by Pachacuti to campaign on the south coast. Although whether Capa Yupanqui peacefully annexed the Chincha Valley remains debated, it appears that he may have successfully brought the Chincha Valley under Inca rule. This is because according to the 'Relación' (Crespo 1975, p. 93), local Chincha groups allegedly assigned a house (or palace) called 'Hatuncancha,' women, specialized workers, and agricultural fields to Capa Yupanqui after he left to continue his campaign. Therefore, it is plausible to argue that the Inca conquest of the Chincha Valley was initiated before AD 1476 and during the reign of Pachacuti, perhaps in the early to mid-15th century. For this study, I tentatively suggest that the Late Horizon (aka the Inca occupation) in the Chincha Valley is (AD 1400–1532). (Bongers 2019: 99–100)

1971; Sandweiss 1992; Santillana 1984; Crespo 1975; Rostworowski de Diez Canseco 1975; Menzel and Rowe 1966; Uhle 1924).

Table 3.4 "Overview of different written accounts that describe when the Inca annexation of the south coast occurred. This table is adapted from Julien (2008, p. 168)" (Bongers 2019)

	Cabello	Cieza	*Relacidn de Chincha*	Cobo
When the annexation occurred	During the rule of Thupa Inca, after the death of his father, Inca Yupanqui, about 1473	During the rule of Thupa Inca. A captain named Capa Yupanqui had been sent by his father, Inca Yupanqui, to annex the region, but had returned without success	During the rule of Capa Yupanqui, father of Thupa Inca, about 1408	During the rule of Inca Yupanqui, father of Thupa Inca
Who carried it out	Captains sent by Thupa Inca	Thupa Inca	Capa Yupanqui	A brother of Inca Yupanqui

Bongers has based his evaluation not only on a re-interpretation of historical sources but also on a series of highly accurate radiocarbon dates. Unfortunately, the latter does not come from stratigraphic contexts, but from organic material (mostly reeds) collected in burial contexts disturbed by the activity of *huaqueros*. The association of these contexts (and consequently of the samples taken from) to "pre-Inca" and "Inca phase", respectively, has been made on the basis of the architectural characteristics of these funerary monuments (*chullpas* and subterranean cists) as well as on the comparative analysis of mortuary practices. The author associates the decline in the use of cists and the rise in importance of the *chullpas* with the Inca occupation of the valley (Bongers 2019).

Taking this limitation into account, we have proceeded to a re-interpretation of these dates, based on the most recent calibration curves, described above. The results are presented in Appendix 4.

It follows that the transition phase corresponding to the abandonment of one funerary practice (cists) in favour of another (chullpas) is situated between AD 1380 and 1400. If this is really the effect of an Inca presence, this would mean that the occupation of the Chincha Valley by the Incas was almost a century earlier than would result from the "historical chronology". But this is a hypothesis that would have to be confirmed by other datings, this time from stratigraphic contexts.

By way of conclusion, we can point out that the study of the chronology of the Inca occupation of the Chincha valley presents interesting possibilities for the future. Such studies should first of all be based not on new excavations, but on the radiocarbon analysis of the organic samples from the previous works: this material is probably archived in the museum deposits.

3.4 The Advance of the Inca State in the Cordillera de Vilcabamba and the Chronology of the Construction of Machu Picchu

Inca expansion on the eastern slopes of the Andes and in the Amazonian lowlands, which constituted the part of the Inca Empire known as Antisuyu, was carried out somewhat differently than in the coastal and highland areas. This was due both to the ecological conditions of the area, which was very rugged, covered with dense vegetation and to the socio-political factors of the local populations, which were relatively unstratified and in most cases lacked centralized structures of power. This implied, on the part of the Incas, the implementation of instruments and practices based more on negotiations and political arrangements cemented by marriage alliances than on submission by force of arms. The latter form took place in some particular cases, and the corresponding *gestae* of the Inca protagonists were highly emphasized in the Inca historical tradition, but in reality, the Inca control of the Antisuyu was more of an indirect character.[14]

As an exception to this general rule, we can mention lands located relatively close to the metropolitan area of the Empire, particularly the valleys of Apurimac, Urubamba, Paucartambo and the Cordillera de Vilcabamba (Fig. 3.7).

Among these, the Vilcabamba area in particular was subject to intense penetration by the highland populations well before the Incas. In the Espíritu Pampa and Quillabamba areas, revealed the remains of a surprisingly large Wari occupation and, in the case of Espiritu Pampa, a set of elaborate Wari tombs (Fonseca Santa Cruz 2011; Fonseca Santa Cruz and Bauer 2013). With these remains it is becoming clear that the Wari established and maintained colonies in the eastern lowlands. In many ways this is not surprising since this region contained important resources, such as coca, and it lies relatively close to the Wari heartland (Bauer and Aráoz Silva 2015: 28).

After the end of the Wari influence, these areas continue to be intensively occupied, although the settlement pattern undergoes a significant change. During the Late Intermediate period (LIP): "the occupations are clustered on hilltops, many of which are fortified. There also appears to have been a shift from valley to highland resources in each of these areas. Furthermore, after each of these different regions fell under Inca control, settlements were re-established on the valley bottoms" (Bauer and Aráoz Silva 2015: 26). This settlement pattern was also observed in areas east of Vilcabamba in the Santa Teresa River valley region. One example is the site of Unnuyoc, where "35 structures of broadly circular ground-plan spread out along the ridge in small clusters for about half a kilometer" (Drew 1984: 361; Bauer and Aráoz Silva 2015: 26).

[14] The literature on the different forms of control by the Incas of these lands is abundant and we cite some relevant studies for this case: (Hemming 1970; Saignes 1981; Renard-Casevitz, Saignes and Taylor 1988; Tyuleneva 2020; Herrera Wassilowsky 2020; Beresford-Jones and Machicado Murillo 2020).

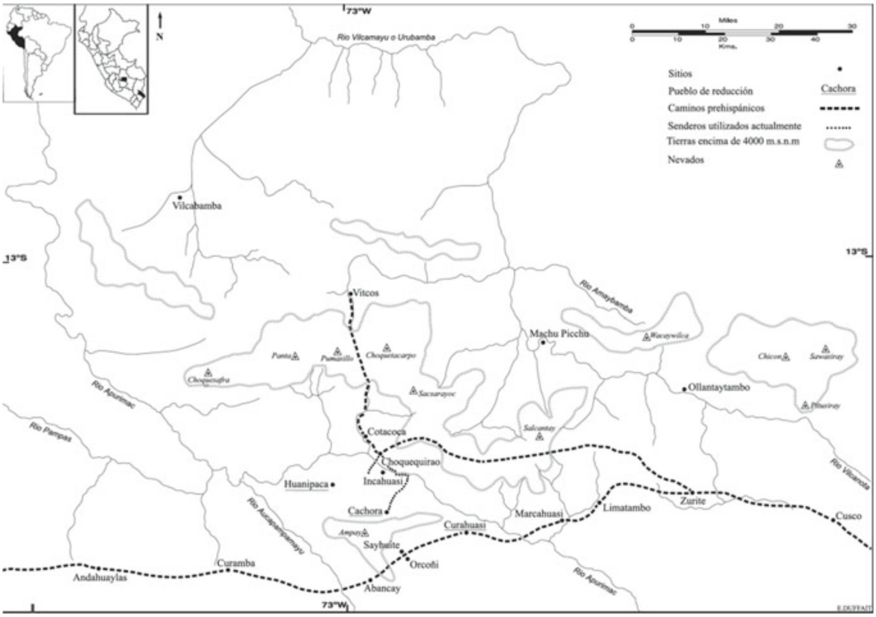

Fig. 3.7 Cordillera Vilcabamba area (from Duffait 2005)

The survey work carried out in the Apurimac valley testifies to a similar continuity of occupation of these lands throughout the LIP period and a similar settlement pattern, with the preferential occupation of land located at higher altitudes (Lecoq 2013; Saintenoy 2016). Analogous processes are observed further south, in the Cusco region (Covey 2008: 296–299). Here we can see the constitution of depopulated areas that serve as a buffer zone between the polities (Covey 2003: 72). This is the socio-political landscape that the growing Inca state will encounter.

3.4.1 *The Chronology of the Inca Settlements in Vilcabamba*

According to the historical sources, the region of Vilcabamba was one of the earlier Inca conquests during the reign of Pachacuti Inca Yupanqui.[15] There is, however, a certain discrepancy regarding the Inca protagonists of the conquest. According to Betanzos, these were the commanders sent by Pachacuti (Betanzos 1987, Parte l. Capítulo XIX: 133), while Cobo maintains that it was the Inca himself who met, in Pampacona, the chieftains of the Vilcabamba area, who agreed on terms for the submission of their territory to the Inca state. The chronicler emphasizes the importance of the discovery of the gold and silver mines that would have been made during

[15] See the Introduction at the beginning of this text.

this Inca entrance. The information that these began to be "worked" from that time onwards for the benefit of the Inca state seems to imply the installation of an adequate infrastructure (Cobo, lib. 12, cap. XII; 1890–1895, tomo III: 159–161).

Moving from the historical sources to the archaeological evidence, we find that, according to recent fieldwork in the area, after this initial moment, Vilcabamba became completely assimilated into the Inca administrative system, and was the object of great attention. This is attested to by the density of the road network (Hemming 1970: 16; Duffait 2013), the presence of major ceremonial and administrative centers at Chuquipalta and Rosas Pata, respectively, and the large, settled population and dense network of outposts on the Apurimac side of the Cordillera Vilcabamba (Bauer and Aráoz Silva 2015; Saintenoy 2016; Duffait 2013) with the monumental site of Choquequirao in the middle of it (Lecoq 2013).

As far as the antiquity of the Inca presence in this region is concerned, the date of the construction of the ceremonial site/temple of Yurac Rumi seems to be of particular importance. Bauer rightly argues that this was most probably one of the first Inca installations in the area. In the excavation he had carried out, a white granite gravel floor was found as a result of the carving of the rock:

> There is little doubt that the crushed white granite contained in these floors is the direct by-product of the Incas carving the many granite boulders that lie within the shrine complex. A carbon sample (AA 83415) collected from the upper crushed-granite floor in Unit P9 yielded an AMS radiocarbon date of 601 ± 34 B.P. A carbon sample (AA83416) collected from the crushed-granite floor in Unit P11 provided an AMS date radiocarbon age of 496 ± 51 B.P. These dates suggest that the shrine was built around AD 1400. (Bauer et al. 2015a: 70–71)

Separately, these dates appear somewhat different. But if we consider that most probably both are associated with the same event, i.e. the beginning of the carving of the rock, as the initial phase of the construction, and therefore we carry out a combined joint calibration of the two, we obtain the result AD 1401–1431 A (unmodeled) and AD 1409–1437 (modelled) at the probability of 68.3% (see Appendix 5).

This can be taken, with all due reservations, as a reference point for the dating of the Inca presence in the neighbouring territories and, consequently, for the determination of the temporal sequence of the establishment of the imperial infrastructure in this area.

But the situation is different with regard to the two phases of the destruction of the temple at the end of the existence of the neo-Inca state of Vilcabamba, in the second half of the sixteenth century. From historical sources, we know that the ceremonial structures of Yurac Rumi were burned in February/March 1570 by two Augustinian missionaries and their indigenous companions who had been recently converted to the catholic faith. Shortly after, the temple was partially renovated and then finally destroyed in June/July 1572 during the Spanish invasion which put an end to the existence of the Vilcabamba State. The authors of the excavation summarized the characteristics of the archaeological context, a vestige of this historical events, as follows:

> The recovery of various identifiable organic ceiling and roofing materials within a building with a known destruction date provided a unique investigative opportunity. We wanted to

examine how the dates of various plant species incorporated into the different parts of the roof correlated with each other, as well as with the known destruction date of the shrine. As a result, AMS measurements were run on a rope (AA83417 [1], AA83417 [2]), a batten (AA 83418 [1], AA83418 [2]), the outer layers of a roof support (AA83419 [1], AA83419 [2]), the grass thatch (AA83422), and carbon associated with the reoccupation of the structure (AA 83420, AA83421). (…) The burnt ceiling and roofing materials of the shrine also provided intriguing results. The sampled batten, roof support, and thatch all yielded very similar calibrated dates which clustered in the late-1400s to the mid-1500s.

These age estimations make sense if the shrine was established, as suggested by the dates from the granite floors, during the late 1300s to mid-1400s. However, the rope which was used to tie the thatch together provided surprisingly early dates. Our sample yielded calibrated probability dates in the late-1200s, suggesting that the rope; was more than 200 years older than the rest of the roof. Indeed, the results suggest that the rope may have even predated the Inca occupation of the Vilcabamba region. Contamination agents could have been introduced as a result of fiber preparation before the weaving of the rope, however, the Inca are not known to have used such agents. While it is possible that the Incas used older materials in the construction of the shrine, the dates of the rope seem excessively early, and we currently cannot fully explain the results. The precision of radiocarbon assays can be increased by using pooled means of different but related samples. In this study, the two samples from the reoccupation can be pooled together, as can the samples from the batten, the roof support, and the rope. The results of the pooling, presented in Figure 3.8, helps to illustrate how close the reoccupation dates are to the roof dates, and how much earlier the rope dates are. (Bauer et al. 2012: 200–201)

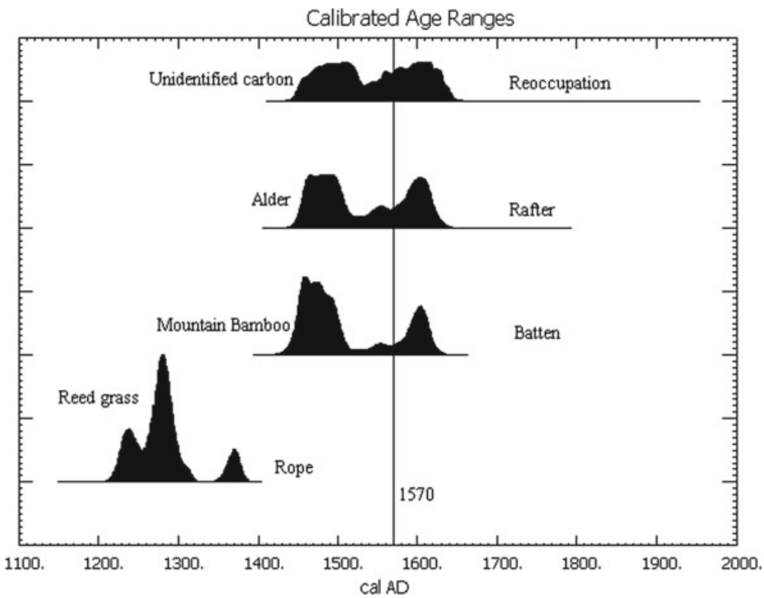

Fig. 3.8 Radiocarbon dates from Yurac Rumi using pooled means. According to: Bauer et al. (2012: 211)

Let us now see what modifications can be made to this model by applying the new calibration curves and re-calibrating, according to the latter, the dates cited above. For the sake of clarity, we have separated the dates into three groups which we will treat separately: the first corresponds to the granite floor, the second to the occupation stage which ends with the destruction of the temple of Yurac Rumi in February/March AD 1570 and finally the immediately subsequent stage of reconstruction and partial reuse of the ceremonial complex which ends with the second destruction, this time definitive, which probably occurred in June–July AD 1572. The question we are going to try to answer with this analysis is the same that Bauer et al. (2012) have formulated (but avoided answering concretely): to what extent can the radiocarbon dates coincide with the historical ones? In this precise case, it is a matter of defining, at least approximately and only on the basis of the analysis of radiocarbon dates supported by a stratigraphic component, the periods corresponding to the two destructions of the Yurac Rumi temple: the one in AD 1570 and the subsequent one in AD 1572. In order to homogenize the radiocarbon dating base, we have excluded from the analysis the two earliest dates corresponding to the rope (AA83417 [1], AA83417 [2]): for the subject of our interest, this chronological component was not essential.

The results shown in Appendix 5 (Table 3.17) are, frankly speaking, not very encouraging: because of the shape of the calibration curve throughout the sixteenth century, the dates associated with the two destructions are close, but only by a long way, to the historical dates of these events. To give just one illustrative example: the phase of reconstruction and reuse of the temple of Yurac Rumi, which lasted only two years (AD 1570–1572), from which come two medium-precision dates based on short-lived plants (AA 83420 and AA 83421), is associated (according to the unmodelled result) with a time period of around 100 years (at ca. 53.5%–56.4% probability) or ca. 200 years (at 95.4% probability). It should be noted that, due to the aforementioned shape of the calibration curve, these chronological estimates would not have improved significantly in the case of more precise dating, with a standard error of the order of 20–15 years. As we can see, despite the fact that we have 7 (or even 9 if we include the two from the rope) it is impossible to even approximate the historical dates of the event mentioned, i.e. the destruction of the temple of Yurac Rumi.

The conclusion is the one we have already formulated above: that for the sixteenth century corresponding to the final phase of the Inca Empire and the existence of the neo-Inca state of Vilcabamba, radiocarbon dating, not supported by historical dates, is of relatively little use for the elaboration of chronological sequences.

3.4.2 *Pre-Inca and Inca Settlement of the Lower Urubamba Valley: A Historical Chronological Overview*

While the Apurimac, Paucartambo and Amaybamba valleys testify to a significant density of settlement along the LIP and later during the Late Horizon, the situation in the Urubamba valley, particularly between approximately Cusichaca and the present-day town of Santa Teresa (Fig. 3.9) appears somewhat different. Survey work carried out in this area since the time of Hiram Bingham's Yale Expedition, and significantly expanded in recent years by the staff of the Machu Picchu National Park, has revealed

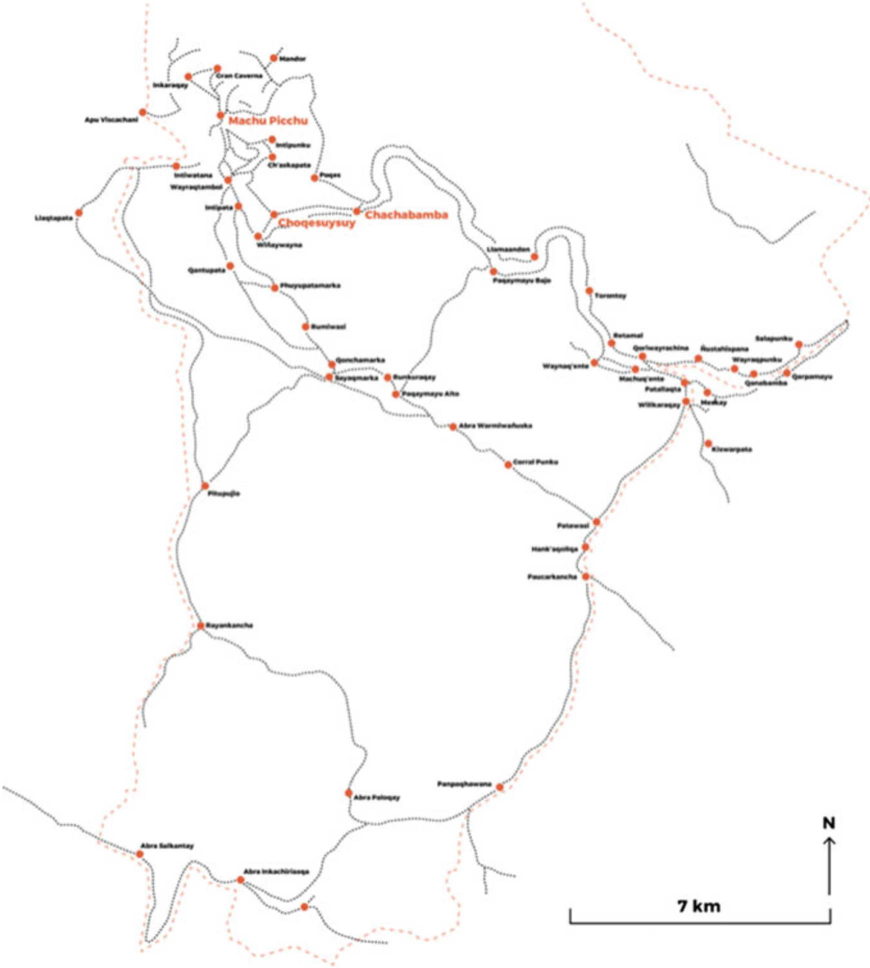

Fig. 3.9 The area of the National Archaeological Park-Historic Sanctuary of Machu Picchu with analysed sites marked in red (CEAC archives)

a relatively small number of settlements that can be associated with the LIP, and these are all on the right side of the Urubamba.[16] On the left side of the river, on the other hand, there was no evidence of settlements prior to the Inca presence, while 44 sites with rock art dated mainly to the LIP and HT (Astete et al. 2016) were revealed. It seems then that this area may have been the site of ritual activities but without a significant permanent population (Orefici 2017). The settlers would have arrived within the framework of the extensive building programme initiated by the Incas. Bauer suggests that the first stages of construction of Machu Picchu and its satellite sites may have originated at the same time as the beginning of the construction of the temple of Yurac Rumi in Vilcabamba, among others (Bauer et al. 2015b).

The question is then: when did this process of intense Inca activity begin in the region we know today as Machu Picchu? And to which Inca ruler can this initiative be attributed?

Here again we are faced with the problem of interpretation of the historical sources. Although the chronicles do not directly mention any works promoted by the Incas in that part of the valley, in the sixteenth-century documents concerning land ownership, both the conquest of this area and the ownership of the land thus gained are attributed to an "ynga yupangui" who is usually identified with Pachacuti Inca Yupanqui, the ninth ruler of the "traditional dynastic" list (Rowe 1990). Donato Amado in his recent and very detailed study on this subject confirms Rowe's findings and formulates the following conclusions:

> "According to the historical and legal documents of the sixteenth, seventeenth, eighteenth and nineteenth centuries, the following is proposed:

1. The present archaeological monument Machu Picchu, 'Llaqta de Machupicchu' or Machu Picchu Llaqta, was an Inca administrative, political and religious center of the Incas, from where, through an entire system of the Inca roads, control and management of the territorial space called Vilcabamba was developed,
2. The lands linked to the people were the lands destinated for the production of coca, from Intiguatana to the meeting of the Amaybamba, Vitcos or Vilcabamba river and the Yucay River,
3. The Lands of Intiguatana, as lands of the sun, the lands on the right bank from Tancac to Pomachaca or Amaybamba river, were the lands of the Inca, whose yield served for the worship of the mummies,
4. The terraces of Quentemarca belonged to the Inca State, the lands of Lucrepata or Huiñayhuayna for the cultivation of chili, peanuts, yuca, sweetpotato, all controlled and state-run, including the ceremonial centers such as Yuncapatamallauqasa, Yuncapata or Qantupata, Incarmana or Sayaqmarca, Salqantay, Yanatin and other apus of the village of Machupíccho." (Amado, in this volume).

But these observations do not provide an answer to the chronological problem of our interest:

[16] José M. Bastante, personal communication July 2021.

1. Although we are generally talking about the conquest of the mentioned part of the Urubamba valley by "ynga yupangui", at no time does this name appear in the form of "Pachacuti Inca Yupanqui". In the relation of 1568 cited by both Rowe and Amado there is even an apparent confusion (?) between "Inca Yupanqui" and "Topa Yupanqui", i.e. the son of Pachacuti Inca Yupanqui (Rowe 1990: 152).
2. It is noteworthy that in Betanzos' description of Pachacuti's entry into Vilcabamba the route followed by the Inca, both on the way there and on the return, passes through the Amaybamba and Choquechaca Bridge, but skirts the part of the Vilcanota valley below Tambo (Ollantaytambo). This apparently had not been at that early time a preferential communication route to the *selva*, which is corroborated by the noted scarcity of LIP settlements. From this, we can draw the conclusion that the submission by the "Inca Yupanqui" of the Vilcabamba region was prior to that of the part of Urubamba valley, which is nowadays the Machu Picchu National Park.
3. Rowe is of a different opinion in this respect: according to him, on his route to Vilcabamba the Inca passed precisely through the Urubamba valley, while the submission on his part of the Amaybamba valley was a later event (Rowe 1990: 143). However, Rowe relies in his chronological interpretation on late chroniclers, such as Murúa and Cobo, while the testimony of Betanzos, an early chronicler also very well informed (for family reasons) about the deeds of Pachacuti Inca Yupanqui, says the opposite.
4. Be that as it may, in the light of the evidence cited above, the date of 1438 as the beginning of the conquests by Pachacuti Inca Yupanqui has to be definitely rejected.

Let us now see what chronological precision radiocarbon dating can give us in this respect.

3.4.3 Radiocarbon Approach to the Chronology of the Construction Phases of the Llaqta of Machu Picchu and Some of Its Satellite Sites[17]

As we have stated in a recent article on this topic (Ziółkowski et al. 2020), Machu Picchu has not been intensively investigated by ^{14}C dating; there are only 7 ^{14}C dates

[17] The chronology of Machu Picchu was based to date mainly on the model of Rowe (1945), more exactly, on the evaluation of the reign of Pachacuti Inca Yupanqui between 1438 and 1471 AD. It was estimated that the construction of the Llaqta de Machu Picchu (the main site) could have been started about 10 years after the takeover by Pachacuti, that is around 1450 (Chavez Ballón 1971; Salazar 2004). According to the Authors who base their opinions on historical sources, Pachacuti would have ordered the construction of the so-called Llaqta de Machu Picchu and a series of satellite sites by 1450 AD (Chavez Ballón, 1971; Salazar 2004). This ceremonial and residential complex would have passed into the hands of the members of the Pachacuti clan (panaca), after the latter's death (Ziółkowski et al. 2020: 4).

on samples from a test pit excavated in 1983, and 5 more from human bone collected by the Peruvian Yale Expedition in 1912 and 1915 (Berger et al. 1988; Ajie et al. 1992). In 2017, as part of a Peruvian-Polish-Italian research project, 11 samples were taken and subsequently processed by the Waikato laboratory: three of these samples came from the Machu Picchu Llaqta, five from the Chachabamba site and three from the Choquesuysuy site (Bastante et al. 2017) (Fig. 3.9).

Because of the difficulties in establishing the exact stratigraphic correlation between the excavations of 1983 and those of 2017, as well as the significant divergences in radiocarbon dating methodology due to recent technological advances, we have decided to use for the subsequent analysis only the 11 dates based on the samples taken in 2017 (Fig. 3.10).

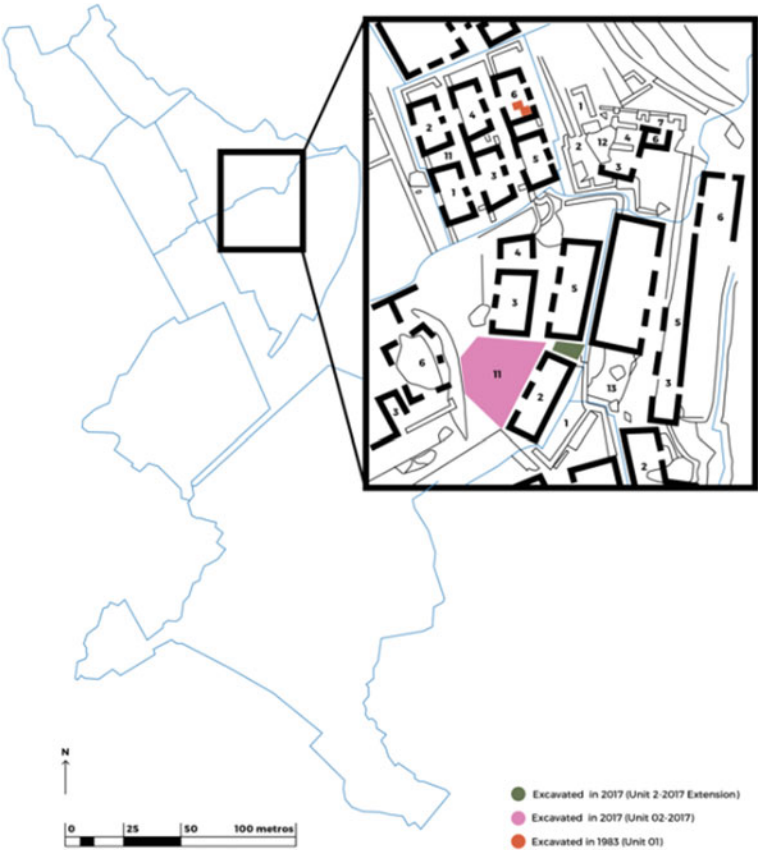

Fig. 3.10 The area of the llaqta of Machu Picchu with all UE marked (CEAC archives)

The calibrated ages of the 11 samples from Llaqta of Machu Picchu, Chachabamba, and Choqesuysuy were originally obtained using OxCal 4.3.2 (Bronk Ramsey 1995, 2001, 2009a, b). For calibration and modelling, the mixed SHCal13.14c and IntCal13.14c curves were used (Hogg et al. 2016; Ziółkowski et al. 2020: 8–9). We have recently recalibrated these dates with the new calibration curve SHCal20 (Hogg et al. 2020). We did not apply mixing of the southern and northern hemispheres radiocarbon calibration curves. The decision not to mix the curves was based on the recent publication about the modern location of ITCZ (Ancapichún et al. 2021). The results of both evaluations are presented in Appendix 6.

The subject of our interest is the moment of the beginning of the construction activity promoted by the Incas, and not the duration of the different phases of the subsequent occupation and re-modelling of the three ceremonial centres analysed: the Llaqta of Machu Picchu, Chachabamba and Choquesuysuy. Consequently, we have focused our attention on the problem of the very beginning of the Inca presence in each of the sites mentioned.

In the case of the Llaqta of Machu Picchu we had three radiocarbon dates, but we had to discard the oldest, Wk 48,116, because of its stratigraphic position, which suggests that it is an "outlier" (Ziółkowski et al. 2020: 11). Of the remaining two, Wk 46,936 is from an intrusive offering that cuts a floor of Inca occupation: therefore, the stratigraphically lower and the earliest is Wk 46935.

Our calibration gives, for the last, at 68.3% of probability, the span between AD 1439 and 1454, and at 95.4% that between AD 1429 and 1459. This must be for the moment (until we have more dates) considered to be the moment of the beginning of the first constructive phase of the Llaqta. This result is a few years later than the one resulting from the previous calibration with the curves SHCal13/IntCal13 (Ziółkowski et al. 2020), however, it is still somewhat earlier than the dates suggested on the basis of the "historical chronology".

The situation at Chachabamba is very similar: the earliest date associated with the first stage of the construction of the ceremonial fountains or *armakuna*, is Wk-46940, which, according to recalibration, corresponds, at 68.3% probability, to the span between AD 1438 and 1451, while at 95.4% to that between AD 1428 and 1455. This result is practically identical to that obtained for the Llaqta of Machu Picchu, which seems to indicate that these two centres began to be built simultaneously.

The case of Choquesuysuy is somewhat different, the oldest date, Wk-46933 gives 68.3% of probability the span between AD 1406 and 1425, while at 95.4% the one from AD 1399 to 1435. From this we can draw the conclusion, that the beginning of construction of this site was preceded by a few decades that of the Llaqta of Machu Picchu and Chachabamba. This may have been the first Inca ceremonial centre in this region.

However, given the limited number of dates on which we base our chronological estimates, they must be considered preliminary and treated with caution.

3.5 Conclusions

The conclusions resulting from the application of the new calibration curves as well as the new location of the ITCZ dividing line can be summarized in the following points.

1. As far as the questioning of the "historical chronology" is concerned, it turns out that the expansion of the Inca state towards the south and south-east, in the territories of present-day Argentina and southern Peru (as well as probably of northern Chile) occurred in the first half of the fifteenth century or even at the end of the fourteenth century. That is, several decades before the "canonical date" of AD 1571 established on the basis of John H. Rowe's "historical chronology" (1945).
2. On the other hand, the recalibration of the dates of the site of Chamical (Ecuador) does not invalidate the "historical chronology" as far as the moment of incorporation of these territories into the growing Inca State is concerned.
3. The shape of the new SHCal20 calibration curve throughout the sixteenth century makes any precise chronological estimation based on radiocarbon dating only practically impossible, whatever the precision of the latter. In the case of our interest, this concerns the final part of the existence of the Inca Empire and that of the Neo-Inca State of Vilcabamba.
4. Regarding the beginning of the construction processes of Machu Picchu and some of its satellite sites (Chachabamba and Choquesuysuy), the hypotheses formulated in our previous text (Ziółkowski et al. 2020) were confirmed: Machu Picchu apparently began to be erected in the first half of the fifteenth century in parallel with the site of Chachabamba. On the other hand, the site of Choquesuysuy, neighbouring Chachabamba, seems to correspond to an earlier construction stage at the beginning of the fifteenth century, thus preceding the two mentioned above.
5. The construction process of the ceremonial center of Yurac Rumi in the Cordillera de Vilcabamba, seems to be coeval with the beginning of the construction of Choquesuysuy.

Given the relative scarcity of radiocarbon dates from this region, these are working hypotheses, which will have to be verified by means of new high-precision dates from well-defined stratigraphic contexts.

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Appendix 1

See Tables 3.5, 3.6, and 3.7.

Table 3.5 Chamical site radiocarbon dates calibrated by OxCal 4.4.2 with SHCal20 / IntCal20: 95%/5% curves mixture. The OxCal script was based on the one published by Marsh et al. (2017)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13/IntCal13						**SHCal20/IntCal20**					
UGa-8801	410 ± 25	1450 1602	1496 1610	60.4 7.9	1441 1576	1515 1623	73.6 21.9	1459 1596	1503 1615	48.9 19.4	1452 1547	1513 1625	56.8 38.6
UGa-3457	450 ± 30	1435	1471	68.3	1421 1598	1500 1613	91.6 3.9	1446	1496	68.3	1435 1590	1507 1619	79.7 15.7
UGa-3458	450 ± 25	1435	1466	68.3	1426	1495	95.4	1447	1488	68.3	1441 1595	1504 1616	83.6 11.9
UGa-8803	440 ± 25	1441	1476	68.3	1431 1599	1500 1612	91.5 4.0	1451	1496	68.3	1445 1592	1505 1618	78.1 17.4
UGa-3459	410 ± 25	1450 1602	1496 1610	60.4 7.9	1441 1576	1515 1623	73.6 21.9	1459 1596	1503 1615	48.9 19.4	1452 1547	1513 1625	56.8 38.6
UGa-8802	380 ± 25	1461 1583	1514 1620	39.9 28.3	1453 1543	1525 1629	48.5 47.0	1486 1547	1513 1624	17.3 51.0	1462	1629	95.4
UGa-3460	300 ± 25	1521 1565 1626	1558 1567 1653	33.5 1.5 33.3	1507 1616	1595 1663	55.0 40.4	1518 1627	1540 1664	15.3 52.9	1508 1621 1785	1586 1669 1793	34.8 58.9 1.8

Table 3.6 Chamical site occupation as OxCal 4.4.2 model with SHCal20 / IntCal20: 95%/5% curves mixture. The model was based on the one published by Marsh et al. (2017)

Event name	Modelled (BC/AD)											
	From	To	%	From	To	%	From	To	%	From	To	%
	SHCal13/IntCal13						**SHCal20/IntCal20**					
Start Inca occupation	**1434**	**1460**	68.3	1416	1480	95.4	**1445**	**1476**	68.3	1410 1598	1496 1602	95.0 0.4
Span Inca occupation	0	28	68.3	0	51	95.4	0	33	68.3	0	64	95.4
Span Construction	0	12	68.3	0	24	95.4	0	14	68.3	0	29	95.4
End Inca occupation	**1456**	**1493**	68.3	1448	1518	95.4	**1471**	**1511**	68.3	1457 1605	1547 1620	93.2 2.2
AD 1463	1463	1464	68.3	1463	1464	95.4	1463	1464	68.3	1463	1464	95.4
Start Inca occupation	1434	1460	68.3	1416	1480	95.4	1445	1476	68.3	1410 1598	1496 1602	95.0 0.4
Difference	4	**29**	68.3	−17	48	95.4	−12	**19**	68.3	−138 −33	−134 54	0.4 95.0

Table 3.7 Calibration of combination of three radiocarbon dates from Chamical site. Calibration made in OxCal 4.4.2 with SHCal20 / IntCal20: 95%/5% curves mixture

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
UGa 8803	440 ± 25												
UGa 3457	450 ± 30												
UGa 3458	450 ± 25												
Chamical	Combine	1442	1460	68.3	1434	1485	95.4	1442	1461	68.3	1433	1488	95.4

Appendix 2

See Tables 3.8, 3.9, 3.10, 3.11, 3.12, and 3.13 and Figs. 3.11, 3.12, and 3.13.

Table 3.8 Mendoza occupation as obtained from radiocarbon and TL dates. Radiocarbon calibration was made using OxCal 4.4.2 software. Comparison is presented for used by Marsh et al. (2017) SHCal13 curve and new SHCal20 curve. The calibration was based on the model one published by Marsh et al. (2017). Missing dates in C-14 date column mean that the date comes from thermoluminescence dating

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
Cienaga de Yalguaraz													
GIF-4607	180 ± 80	1671 1755 1795 1831 1922	1748 1783 1816 1892 …	24.5 8.3 6.5 19.0 10.1	1633	…	95.4	1672 1752 1772 1797 1831 1922	1745 1767 1781 1821 1892 …	24.0 4.6 2.9 7.8 20.0 9.0	1632	…	95.4
UZ-2525/ETH-5318	485 ± 60	1411	1497	68.3	1395 1539	1517 1626	76.8 18.6	1414 1603	1498 1608	65.7 2.5	1395 1540	1516 1627	75.6 19.8
UZ-2526/ETH-5319	540 ± 55	1400	1450	68.3	1316 1382	1355 1496	8.8 86.6	1401	1451	68.3	1318 1385 1604	1355 1497 1607	10.0 85.2 0.3
UCTL-315		1378	1501	68.3	1320	1560	95.4	1378	1501	68.3	1320	1560	95.4
UCTL-321		1498	1581	68.3	1460	1620	95.4	1498	1581	68.3	1460	1620	95.4
GaK-7312	390 ± 90	1459 1535	1525 1627	28.6 39.7	1410 1739	1675 1798	90.8 4.6	1459 1524	1519 1628	25.2 43.0	1410 1736	1676 1800	90.1 5.4
UZ-2527/ETH-5320	420 ± 60	1449 1552 1575	1511 1558 1622	39.5 2.6 26.3	1435	1637	95.4	1450 1550 1579	1510 1560 1623	38.8 4.4 25.1	1436	1640	95.4
UCTL-322		1478	1561	68.3	1440	1600	95.4	1478	1561	68.3	1440	1600	95.4
Tambillos													

(continued)

Table 3.8 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
UCTL-302		1588	1671	68.3	1550	1710	95.4	1588	1671	68.3	1550	1710	95.4
Beta-26283	410 ± 70	1452 1547	1513 1623	32.0 36.2	1429	1649	95.4	1453 1547	1512 1625	31.4 36.8	1429	1651	95.4
UCTL-304		1283	1426	68.3	1215	1495	95.4	1283	1426	68.3	1215	1495	95.4
I-16637	290 ± 130	1478 1725	1697 1807	49.8 18.4	1453	…	95.4	1465 1482 1725	1468 1696 1809	0.6 48.5 19.1	1454 1905	1896 …	89.7 5.7
I-16908	300 ± 80	1500 1611 1740	1597 1674 1798	31.2 22.3 14.8	1454 1719 1836 1855 1926	1711 1813 1849 1882 …	69.5 20.5 1.0 2.2 2.2	1503 1615 1738	1596 1675 1799	30.1 21.4 16.7	1455 1719 1836 1865 1925	1710 1814 1860 1881 …	68.4 21.8 1.9 1.3 2.0

(continued)

Table 3.8 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
Beta-25221	770 ± 50	1229 1365	1302 1375	61.8 6.4	1211 1345	1324 1389	77.9 17.5	1228 1263 1363	1252 1301 1379	18.5 38.2 11.5	1214 1348	1324 1390	75.7 19.7
I-16907	310 ± 80	1496 1746 1781	1672 1757 1796	61.4 2.9 4.0	1450 1720 1837 1857 1928	1710 1812 1848 1880 …	73.8 17.8 0.7 1.5 1.6	1499 1611 1742 1764 1780	1601 1673 1755 1774 1798	35.3 22.5 3.2 2.4 4.9	1451 1719 1836 1865 1925	1710 1814 1855 1881 …	72.4 19.1 1.3 1.0 1.6
UCTL-306		1458	1561	68.3	1410	1610	95.4	1458	1561	68.3	1410	1610	95.4
UCTL-303		1458	1561	68.3	1410	1610	95.4	1458	1561	68.3	1410	1610	95.4
UCTL-301		1288	1411	68.3	1230	1470	95.4	1288	1411	68.3	1230	1470	95.4
Ranchillos													

(continued)

Table 3.8 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
Beta-62946		1052 1146	1080 1272	9.4 58.9	1026	1288	95.4	1053 1069 1149	1062 1081 1273	3.1 4.5 60.7	1025	1290	95.4
I-17003	220 ± 80	1647 1719 1836 1855 1926	1711 1812 1849 1882 …	19.7 31.5 3.2 6.8 7.1	1510 1622	1577 …	6.5 88.9	1648 1719 1836 1865 1925	1710 1813 1858 1881 …	19.2 32.6 5.8 4.2 6.4	1510 1560 1623	1550 1579 …	4.4 1.8 89.3
UCTL-317		1588	1651	68.3	1560	1680	95.4	1588	1651	68.3	1560	1680	95.4
Beta-69934	640 ± 50	1311 1379	1360 1405	45.3 23.0	1292	1422	95.4	1312 1382	1360 1407	45.9 22.3	1292	1423	95.4
Beta-69933	430 ± 50	1445 1582	1509 1620	46.4 21.9	1437	1628	95.4	1447 1586	1509 1621	46.4 21.9	1438	1629	95.4

(continued)

Table 3.8 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
I-17002	290 ± 80	1503 1615 1735	1592 1677 1799	27.1 22.3 18.9	1458 1718 1836 1924	1712 1814 1891 …	64.4 23.0 5.2 2.8	1505 1618 1734	1592 1679 1802	26.2 21.8 20.3	1458 1718 1835 1925	1711 1814 1885 …	63.8 24.3 4.8 2.5
I-17004	300 ± 80	1500 1611 1740	1597 1674 1798	31.2 22.3 14.8	1454 1719 1836 1855 1926	1711 1813 1849 1882 …	69.5 20.5 1.0 2.2 2.2	1503 1615 1738	1596 1675 1799	30.1 21.4 16.7	1455 1719 1836 1865 1925	1710 1814 1860 1881 …	68.4 21.8 1.9 1.3 2.0
UCTL-488		1438	1541	68.3	1390	1590	95.4	1438	1541	68.3	1390	1590	95.4
UCTL-499		1428	1531	68.3	1380	1580	95.4	1428	1531	68.3	1380	1580	95.4
UCTL-337		1548	1641	68.3	1505	1685	95.4	1548	1641	68.3	1505	1685	95.4
UCTL-785		1428	1531	68.3	1380	1580	95.4	1428	1531	68.3	1380	1580	95.4
UCTL-786		1508	1601	68.3	1465	1645	95.4	1508	1601	68.3	1465	1645	95.4

(continued)

Table 3.8 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
Tambillitos													
Beta-88786	540 ± 100	1316 1381	1357 1497	14.1 54.2	1289 1536	1524 1627	81.6 13.9	1318 1385 1604	1355 1497 1607	13.7 53.6 0.9	1289 1526	1519 1628	80.4 15.1
UCTL-787		1378	1501	68.3	1320	1560	95.4	1378	1501	68.3	1320	1560	95.4
Beta-88787	460 ± 80	1416 1576	1510 1622	49.4 18.8	1395	1645	95.4	1417 1551 1580	1510 1559 1623	47.8 2.6 17.9	1395	1647	95.4
UCTL-323		1508	1601	68.3	1465	1645	95.4	1508	1601	68.3	1465	1645	95.4
Agua Amarga													
Beta-261727	450 ± 50	1436 1591	1504 1615	54.7 13.6	1419 1537	1520 1627	65.2 30.2	1440 1595	1504 1616	54.1 14.1	1419 1537	1518 1628	63.7 31.7
UCTL 1725c		1375	1488	68.3	1322	1542	95.4	1375	1488	68.3	1322	1542	95.4

(continued)

Table 3.8 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
UCTL 1724c		1566	1649	68.3	1528	1688	95.4	1566	1649	68.3	1528	1688	95.4
UCTL 1726c		1513	1613	68.3	1466	1660	95.4	1513	1613	68.3	1466	1660	95.4
Aconcagua GX-19991 Beta-88785	370 ± 70 480 ± 40	1442	1496	68.3	1424 1576	1510 1622	79.7 15.8	1445 1604	1497 1607	65.6 2.6	1426 1550 1580	1510 1559 1623	76.3 0.8 18.3
Agua de la Cueva, AC-1563	470 ± 80	1410 1583	1508 1620	53.3 15.0	1329 1391	1335 1645	0.4 95.0	1410 1586	1509 1621	53.1 15.2	1328 1393	1337 1644	0.8 94.6
Cerro Penitentes, Beta-98941	550 ± 50	1400	1445	68.3	1317 1382	1355 1464	9.7 85.7	1401	1446	68.3	1318 1385	1355 1462	11.2 84.2
Potrero Las Colonias, AA-66564	569 ± 38	1398	1434	68.3	1323 1388	1346 1448	8.5 87.0	1399	1436	68.3	1324 1390	1347 1449	10.8 84.7
Odisa, AA-90284	529 ± 42	1413	1446	68.3	1391	1478	95.4	1413	1448	68.3	1327 1392 1472	1340 1464 1480	1.6 93.0 0.9

Table 3.9 Model AA. Results of radiocarbon dates recalibration and modelling for Argentina sites. SHCal20 calibration curve was used for recalibration. The chronological model was built as a sequence of two pall dates. No other additional constraints were applied

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	to	%
Samples from the Inca context													
GX-19991	370 ± 70	1488	1631	68.3	1440 1782	1672 1796	94.1 1.3	1425	1463	68.3	1410	1500	95.4
Beta-88785	480 ± 40	1425	1483	68.3	1409 1593	1505 1617	87.4 8.1	1426	1454	68.3	1412	1475	95.4
Odisa AA-90284	529 ± 42	1413	1448	68.3	1327 1392 1472	1340 1464 1480	1.6 93.0 0.9	1423	1447	68.3	1407	1455	95.4
UZ-2526/ETH-5319	540 ± 55	1401	1451	68.3	1318 1385 1604	1355 1497 1607	10.0 85.2 0.3	1421	1447	68.3	1402	1458	95.4
Cerro Penitentes Beta-98941	550 ± 50	1401	1446	68.3	1318 1385	1355 1462	11.2 84.2	1421	1446	68.3	1401	1455	95.4
Potrero Las Colonias AA-66564	569 ± 38	1399	1436	68.3	1324 1390	1347 1449	10.8 84.7	1417	1444	68.3	1402	1450	95.4
Modelled boundaries and spans													
Start of Argentina phase								1402	1437	68.3	1367	1448	95.4
End of Argentina phase								1430	1475	68.3	1418	1528	95.4

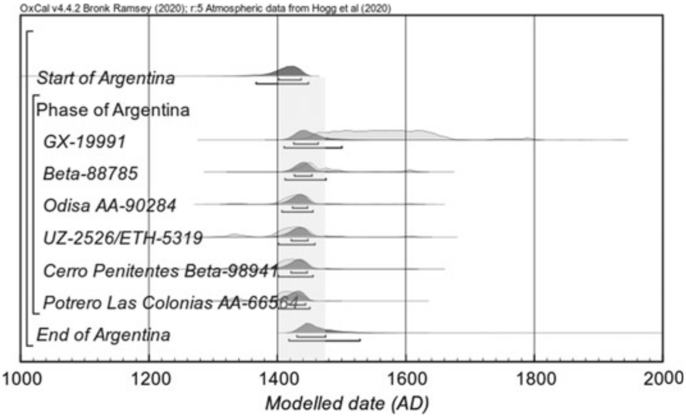

Fig. 3.11 Model AA. Results of radiocarbon dates recalibration and modelling for Argentina sites. SHCal20 calibration curve was used for recalibration. The chronological model was built as a sequence of two pall dates. No other additional constraints were applied. Grey bar represents the time range for the Inca phase (68% probability)

Table 3.10 Model BB. Results of radiocarbon dates recalibration and modelling for Argentina sites. SHCal20 calibration curve was used for recalibration. The chronological model was built as a sequence of two pall dates. No other additional constraints were applied

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
Samples from the Inca context													
Beta-88785	480 ± 40	1425	1483	68.3	1409 1593	1505 1617	87.4 8.1	1422	1447	68.3	1409	1459	95.4
Odisa AA-90284	529 ± 42	1413	1448	68.3	1327 1392 1472	1340 1464 1480	1.6 93.0 0.9	1419	1443	68.3	1407	1452	95.4
UZ-2526/ETH-5319	540 ± 55	1401	1451	68.3	1318 1385 1604	1355 1497 1607	10.0 85.2 0.3	1417	1443	68.3	1403	1453	95.4
Cerro Penitentes Beta-98941	550 ± 50	1401	1446	68.3	1318 1385	1355 1462	11.2 84.2	1418	1442	68.3	1404	1451	95.4
Potrero Las Colonias AA-66564	569 ± 38	1399	1436	68.3	1324 1390	1347 1449	10.8 84.7	1416	1440	68.3	1402	1448	95.4
Modelled boundaries and spans													
Start of Argentina phase								1400	1435	68.3	1371	1445	95.4
End of Argentina phase								1428	1458	68.3	1413	1488	95.4

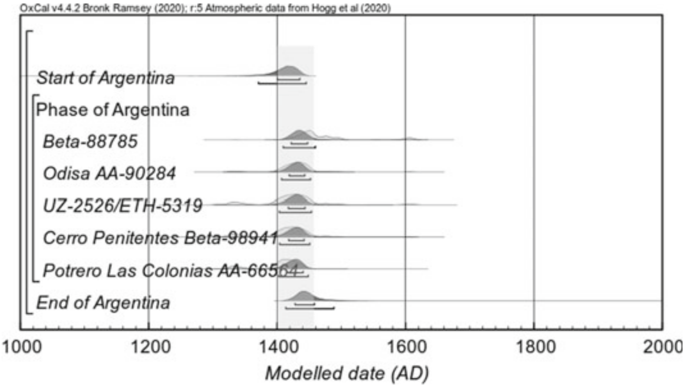

Fig. 3.12 Model BB. Results of radiocarbon dates recalibration and modelling for Argentina sites. SHCal20 calibration curve was used for recalibration. The chronological model was built as a sequence of two pall dates. No other additional constraints were applied. Grey bar represents the time range for the Inca phase (68% probability)

Table 3.11 Model CC. Results of radiocarbon dates recalibration and modelling for Argentina sites. SHCal20 calibration curve was used for recalibration. The chronological model was built as a sequence of two pall dates. No other additional constraints were applied

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
Samples from the Inca context													
Mummy GX-19991 Beta-88785	370 ± 70 480 ± 40	1445 1604	1497 1607	65.6 2.6	1426 1550 1580	1510 1559 1623	76.3 0.8 18.3	1430	1459	68.3	1416	1482	95.4
Odisa AA-90284	529 ± 42	1413	1448	68.3	1327 1392 1472	1340 1464 1480	1.6 93.0 0.9	1422	1447	68.3	1405	1455	95.4
UZ-2526/ETH-5319	540 ± 55	1401	1451	68.3	1318 1385 1604	1355 1497 1607	10.0 85.2 0.3	1420	1447	68.3	1401	1458	95.4
Cerro Penitentes Beta-98941	550 ± 50	1401	1446	68.3	1318 1385	1355 1462	11.2 84.2	1420	1446	68.3	1400	1455	95.4
Potrero Las Colonias AA-66564	569 ± 38	1399	1436	68.3	1324 1390	1347 1449	10.8 84.7	1416	1443	68.3	1400	1450	95.4
Modelled boundaries and spans													
Start of Argentina phase								1397	1436	68.3	1353	1449	95.4
End of Argentina phase								1433	1471	68.3	1420	1518	95.4

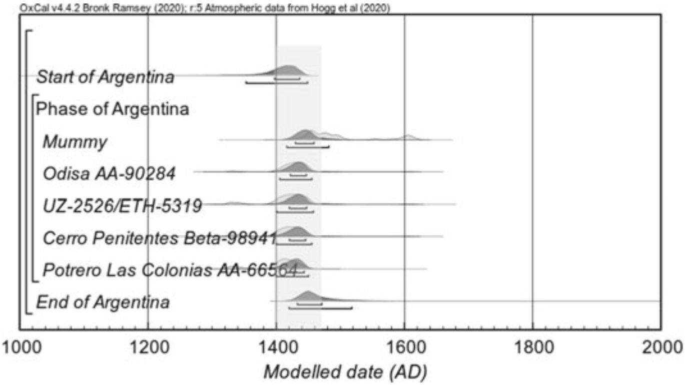

Fig. 3.13 Model CC. Results of radiocarbon dates recalibration and modelling for Argentina sites. SHCal20 calibration curve was used for recalibration. The chronological model was built as a sequence of two pall dates. No other additional constraints were applied. Grey bar represents the time range for the Inca phase (68% probability)

Table 3.12 Orders of Mendoza events. The probability that the event in the first column was prior to the event described in the column header. Recalculation was done in OxCal 4.4.2 based on Marsh et al. (2017) model and using SHCal13

	Initial Inca occupation of Cienaga de Yalguaraz	Funding of Tambillos	Funding o Ranchillos	Funding o Tambillitos	Initial Inca occupation of Agua Amarga	Cerro Aconcagua	Agua de la Cueva	Cerro Penitentes	Potrero Las Colonias	Odisa
Initial Inca occupation of Cienaga de Yalguaraz	0	0.5099	0.7417	0.5392	0.693	0.8131	0.7554	0.3814	0.3018	0.4404
Funding of Tambillos	0.4901	0	0.7451	0.5259	0.6568	0.7102	0.7017	0.3997	0.3545	0.4322
Funding of Ranchillos	0.25834	0.25492	0	0.28624	0.4085	0.4051	0.4686	0.21767	0.19566	0.23648
Funding of Tambillitos	0.4608	0.4741	0.7138	0	0.6507	0.7438	0.7111	0.3528	0.28805	0.4003
Initial Inca occupation of Agua Amarga	0.30697	0.3432	0.5915	0.3493	0	0.5522	0.5621	0.21801	0.17347	0.24824
Cerro Aconcagua	0.1869	0.28978	0.5949	0.25625	0.4478	0	0.5122	0.06437	0.030716	0.07585
Agua de la Cueva	0.24463	0.29827	0.5314	0.28889	0.4379	0.4878	0	0.15513	0.1111	0.18156
Cerro Penitentes	0.6186	0.6003	0.7823	0.6472	0.782	**0.9356**	0.8449	0	0.3956	0.5798
Potrero Las Colonias	0.6982	0.6455	0.8043	0.712	0.8265	**0.9693**	0.8889	0.6044	0	0.693
Odisa	0.5596	0.5678	0.7635	0.5997	0.7518	**0.9242**	0.8184	0.4202	0.30705	0

Table 3.13 Orders of Mendoza events. The probability that the event in the first column was prior to the event described in the column header. Recalculation was done in OxCal 4.4.2 based on Marsh et al. (2017) model and using SHCal13.Results of the recalibration of Marsh et al (2017) TL and C-14 dates are presented in Table 3.8. Results of remodelling of the order of occupation of the sites (Marsh et al. 2017) are presented in the Tables 3.9 and 3.10. Recalculation was done in OxCal 4.4.2 based on Marsh et al.'s (2017) model and using SHCal20. In the case of Mendoza only slight corrections to the chronology is visible after the application of SHCal13 radiocarbon calibration curve

	Initial Inca occupation of Cienaga de Yalguaraz	Funding of Tambillos	Funding o Ranchillos	Funding o Tambillitos	Initial Inca occupation of Agua Amarga	Cerro Aconcagua	Agua de la Cueva	Cerro Penitentes	Potrero Las Colonias	Odisa
Initial Inca occupation of Cienaga de Yalguaraz	0	0.5109	0.745	0.5313	0.6975	0.8159	0.7614	0.3851	0.29954	0.4454
Funding of Tambillos	0.4891	0	0.748	0.517	0.6588	0.7041	0.7041	0.4036	0.3564	0.4355
Funding of Ranchillos	0.25504	0.25205	0	0.27714	0.4072	0.3946	0.467	0.21698	0.19558	0.23517
Funding of Tambillitos	0.4687	0.483	0.7229	0	0.6592	0.7438	0.7185	0.3687	0.3013	0.4149
Initial Inca occupation of Agua Amarga	0.30252	0.3412	0.5928	0.3408	0	0.5422	0.5629	0.2203	0.17379	0.25019
Cerro Aconcagua	0.18409	0.29588	0.6054	0.2562	0.4578	0	0.5206	0.06686	0.029573	0.07889

(continued)

Table 3.13 (continued)

	Initial Inca occupation of Cienaga de Yalguaraz	Funding of Tambillos	Funding o Ranchillos	Funding o Tambillitos	Initial Inca occupation of Agua Amarga	Cerro Aconcagua	Agua de la Cueva	Cerro Penitentes	Potrero Las Colonias	Odisa
Agua de la Cueva	0.23863	0.2959	0.533	0.28155	0.4371	0.4794	0	0.15364	0.10765	0.18059
Cerro Penitentes	0.6149	0.5965	0.783	0.6313	0.7797	**0.9331**	0.8464	0	0.39	0.5814
Potrero Las Colonias	0.7005	0.6436	0.8044	0.6987	0.8262	**0.9704**	0.8924	0.61	0	0.6994
Odisa	0.5546	0.5645	0.7648	0.5851	0.7498	**0.9211**	0.8194	0.4186	0.30056	0

Appendix 3

See Table 3.14.

Table 3.14 Results of radiocarbon dates recalibration and modelling for Camata site. SHCal20 calibration curve was used for recalibration in OxCAL4.4.2 software. The chronological model was built as a sequence of two phases: pre-Inca phase > Inca phase. Dates within phases were also sequenced. No other additional constraints were applied

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
Samples from the Inca context													
AA73428-0096A	515 ± 35	1422	1451	68.3	1400	1462	95.4	1411	1438	68.3	1403	1450	95.4
AA73430-0299A CTQ1	558 ± 33												
AA73431-0508A CTQ1	560 ± 32												
CTQ1	R_Combine	1407	1431	68.3	1399	1442	95.4	1410	1430	68.3	1401	1442	95.4
Samples from the pre-Inca context													
AA73436-0261B	660 ± 32	1314 1382	1360 1395	53.1 15.2	1297	1401	95.4	1335 1376	1365 1400	26.8 41.5	1309	1404	95.4
AA73433-0759A	675 ± 33	1300 1342 1378	1326 1365 1392	28.6 25.0 14.7	1294	1396	95.4	1344 1374	1366 1398	23.5 44.8	1307	1402	95.4
Modelled boundaries and spans													
Start of Inca qollqa CTQ1-CTQ3								1391	1430	68.3	1333	1442	95.4
Span of Inca qollqa CTQ1-CTQ3								0	13	68.3	0	31	95.4

(continued)

Table 3.14 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
End of Inca qollqa CTQ1-CTQ3								1415	1450	68.3	1402	1497	95.4
Start of pre-Inca of qollqa CTQ1-CTQ3								1318 1329	1322 1394	3.0 65.2	1261	1401	95.4
Span of pre-Inca of qollqa CTQ1-CTQ3								0	16	68.3	0	49	95.4
End of pre-Inca of qollqa CTQ1-CTQ3								1351	1417	68.3	1311	1465	95.4
Start of qollqa CTQ1-CTQ3								1273	1388	68.3	938 1055	948 1399	0.5 95.0
End of qollqa CTQ1-CTQ3								1416	1506	68.3	1406 1767	1676 1772	95.1 0.3

Appendix 4

See Fig. 3.14 and Table 3.15.

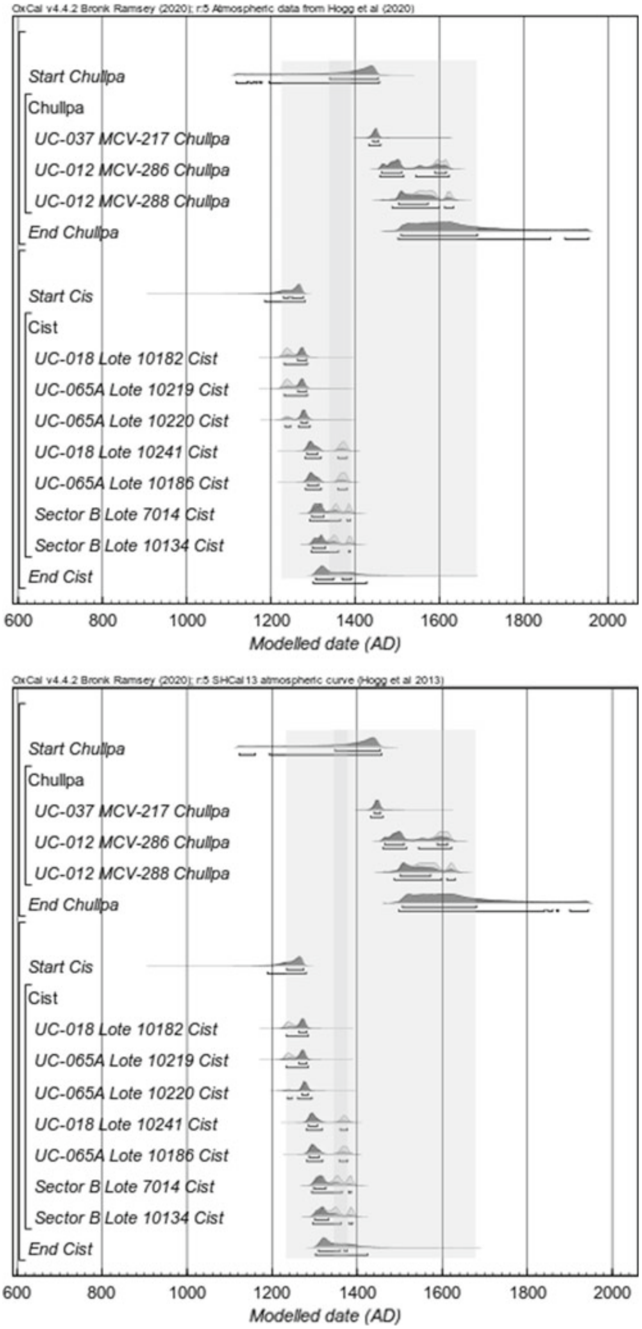

Fig. 3.14 OxCal 4.4.2 independent phase models for Chullpa and Cist samples from Chincha site. In the upper graph, there are modelling results obtained with SHCal20 calibration curve while in the lower graph the old SHCal13 was used. Grey bars represent 68% probability range for the phases duration. Darker shade of the bar represents overlapping of both phases

Table 3.15 Calibration of radiocarbon dates from Chincha site. OxCal 4.4.2 and SHCal20 calibration curve was used for recalibration

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
Sector B Lote 10,069	625 ± 15	1326 1390	1341 1401	36.9 31.4	1320 1386	1350 1406	54.3 41.1	1325 1392	1343 1401	45.3 23.0	1321 1387	1352 1406	60.9 34.6
Sector B Lote 9454	760 ± 15	1277	1291	68.3	1269	1300	95.4	1277	1293	68.3	1270 1363	1302 1380	87.4 8.0
UC-044 Lote 10,161	395 ± 15	1479 1588	1506 1617	31.7 36.6	1459 1547	1513 1624	45.6 49.9	1464 1481 1590	1470 1507 1619	5.7 28.9 33.7	1458 1547 1571	1513 1565 1624	46.7 5.5 43.3
UC-044 Lote 10,231	475 ± 15	1445	1455	68.3	1434	1464	95.4	1446	1457	68.3	1435 1472	1464 1479	93.5 1.9
UC-073 Lote 10,212	545 ± 20	1414	1435	68.3	1405	1444	95.4	1415	1436	68.3	1405	1445	95.4
UC-018 Lote 10,246	810 ± 15	1230 1261	1249 1277	35.9 32.4	1225	1280	95.4	1229 1266	1249 1278	43.0 25.2	1226	1281	95.4
UC-079 Lote 10,217	645 ± 15	1321 1386	1350 1395	54.0 14.2	1315 1380	1358 1401	70.9 24.6	1323 1389	1350 1394	58.4 9.9	1317 1383	1358 1400	72.4 23.0
UC-079 Lote 10,218	665 ± 15	1315 1336 1381	1329 1358 1391	20.6 32.1 15.5	1301 1375	1365 1395	73.4 22.1	1315 1337 1382	1329 1360 1393	18.8 33.0 16.5	1301 1379	1364 1396	74.3 21.2
UC-008 Lote 10,229	460 ± 15	1446	1463	68.3	1440	1485	95.4	1446	1462	68.3	1441 1604	1493 1607	94.8 0.6
UC-008 Lote 7016	350 ± 15	1510 1623	1576 1628	63.4 4.9	1502 1613	1594 1638	79.4 16.1	1510 1559 1623	1550 1581 1628	40.6 22.4 5.3	1504 1616	1594 1640	79.7 15.7

(continued)

Table 3.15 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
UC-008 Lote 10,230	465 ± 15	1445	1460	68.3	1440	1480	95.4	1445	1460	68.3	1438	1485	95.4
UC-008 Lote 7015	385 ± 15	1483 1576	1510 1622	23.5 44.8	1463 1540	1517 1625	32.7 62.8	1484 1550 1580	1510 1559 1623	21.9 5.8 40.6	1461 1540	1515 1627	33.0 62.4
UC-002 MCV-202	360 ± 15	1505 1536 1617	1520 1589 1627	12.6 47.6 8.1	1498 1608	1599 1633	80.2 15.2	1507 1540 1619	1517 1591 1627	9.0 51.3 8.0	1500 1611	1600 1636	80.9 14.5
UC-025 MCV-207	370 ± 15	1500 1542 1611	1515 1597 1625	11.8 45.1 11.4	1492	1630	95.4	1503 1545 1615	1513 1596 1625	9.8 48.6 9.8	1496	1630	95.4
UC-008 MCV-216	390 ± 15	1480 1582	1509 1620	27.7 40.6	1460 1540	1515 1625	38.4 57.0	1464 1481 1585	1470 1509 1622	4.1 26.5 37.6	1460 1545	1514 1625	39.7 55.8
Chullpa													
UC-037 MCV-217 Chullpa	485 ± 15	1441	1454	68.3	1433	1459	95.4	1441	1455	68.3	1434	1459	95.4
UC-012 MCV-286 Chullpa	390 ± 15	1480 1582	1509 1620	27.7 40.6	1460 1540	1515 1625	38.4 57.0	1464 1481 1585	1470 1509 1622	4.1 26.5 37.6	1460 1545	1514 1625	39.7 55.8
UC-012 MCV-288 Chullpa	360 ± 15	1505 1536 1617	1520 1589 1627	12.6 47.6 8.1	1498 1608	1599 1633	80.2 15.2	1507 1540 1619	1517 1591 1627	9.0 51.3 8.0	1500 1611	1600 1636	80.9 14.5
Cist													
UC-018 Lote 10,182 Cist	805 ± 15	1231 1262	1248 1279	29.9 38.3	1227	1282	95.4	1230 1266	1248 1280	38.5 29.8	1226	1284	95.4
UC-018 Lote 10,241 Cist	725 ± 15	1286 1363	1304 1377	41.9 26.4	1281 1356	1315 1382	57.5 38.0	1287 1362	1303 1380	31.4 36.9	1283 1358	1316 1383	49.9 45.6

(continued)

Table 3.15 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13						**SHCal20**					
UC-065A Lote 10,186 Cist	720 ± 15	1288 1362	1305 1378	36.4 31.9	1284 1356	1316 1382	52.8 42.6	1289 1362	1304 1381	28.7 39.5	1284 1356	1319 1385	47.7 47.7
UC-065A Lote 10,220 Cist	785 ± 15	1268	1286	68.3	1229 1261	1250 1291	13.8 81.7	1270	1287	68.3	1228 1265	1250 1292	24.2 71.2
UC-065A Lote 10,219 Cist	805 ± 15	1231 1262	1248 1279	29.9 38.3	1227	1282	95.4	1230 1266	1248 1280	38.5 29.8	1226	1284	95.4
Sector B Lote 10,134 Cist	665 ± 15	1315 1336 1381	1329 1358 1391	20.6 32.1 15.5	1301 1375	1365 1395	73.4 22.1	1315 1337 1382	1329 1360 1393	18.8 33.0 16.5	1301 1379	1364 1396	74.3 21.2
Sector B Lote 7014 Cist	675 ± 15	1305 1345 1378	1324 1362 1389	26.3 25.4 16.6	1300	1392	95.4	1303 1346 1380	1324 1362 1391	28.6 24.3 15.4	1296 1375	1370 1394	74.4 21.0

Appendix 5

See Tables 3.16 and 3.17.

Table 3.16 Recalibration of Yurac Rumi radiocarbon dates from the "granite" floor. Recalibration was made in OxCal 4.4.2 and SHCal20

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
Granite floor													
AA 83,416	496 ± 51												
AA 83,415	601 ± 34	1325 1391	1344 1420	23.1 45.1	1318 1385	1355 1436	34.8 60.6						
Granite floor	R_Combine	1401	1431	68.3	1327 1392	1339 1445	3.8 91.6	1409	1437	68.3	1397	1448	95.4

Table 3.17 Results of radiocarbon dates recalibration and modelling for Yurac Rumi site. SHCal20 calibration curve was used for recalibration. The chronological model was built as a sequence of two phases and combination of two radiocarbon dates: Granite floor > Occupation > Reoccupation. Dates within phases were also sequenced. No other additional constraints were applied

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
Samples from the reoccupation context													
AA 83,420	349 ± 52	1503 1615	1595 1642	53.5 14.8	1458	1663	95.4	1459	1533	68.3	1452 1619	1601 1622	95.1 0.4
AA 83,421	364 ± 52	1500 1611	1601 1633	56.4 11.8	1456	1652	95.4	1458	1533	68.3	1451 1615	1604 1618	95.0 0.4
Samples from the occupation context													
AA 83419_[2]	392 ± 51	1460 1548 1573	1512 1564 1624	30.0 8.4 29.9	1453	1639	95.4	1458	1495	68.3	1445 1586	1532 1618	91.0 4.4
AA 83419_[1]	426 ± 49	1449 1586	1509 1621	45.5 22.8	1441	1629	95.4	1456	1495	68.3	1441 1589	1517 1617	91.0 4.4
AA 83418_[1]	428 ± 52	1447 1584	1509 1622	45.0 23.3	1438	1630	95.4	1456	1495	68.3	1440 1587	1519 1618	90.8 4.6
AA 83,422	437 ± 52	1444 1588	1508 1620	48.3 20.0	1431	1629	95.4	1456	1495	68.3	1440 1590	1515 1617	91.2 4.3
AA 83418_[2]	441 ± 49	1445 1592	1505 1618	50.9 17.4	1428 1526	1519 1628	58.7 36.7	1455	1495	68.3	1440 1590	1514 1616	91.1 4.3
Granite floor													
AA 83,416	496 ± 51												
AA 83,415	601 ± 34												

(continued)

Table 3.17 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)						Modelled (BC/AD)					
		From	To	%	From	To	%	From	To	%	From	To	%
Granite floor	R_Combine	1401	1431	68.3	1327 1392	1339 1445	3.8 91.6	1409	1437	68.3	1397	1448	95.4
Modelled boundaries and spans													
Start of Yurac Rumi occupation								1441	1483	68.3	1405 1581	1504 1608	92.5 2.9
Span of Yurac Rumi occupation								0	28	68.3	0	77	95.4
End of Yurac Rumi occupation								1465	1511	68.3	1453 1595	1565 1630	89.8 5.7
Start of Yurac Rumi reoccupation								1440	1522	68.3	1394	1592	95.4
Span of Yurac Rumi reoccupation								0	19	68.3	0	64	95.4
End of Yurac Rumi reoccupation								1466	1563	68.3	1458	1650	95.4

Appendix 6

See Tables 3.18 and 3.19.

Table 3.18 Machupiccu and satellites radiocarbon dates results using SHCal13/IntCal13 mixed curve (Ziółkowski et al 2020) and comparison to recalibration with SHCal20 curve only. Recalibration for SHCal20 curve was made using OxCal 4.4.2

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13/IntCal13						**SHCal20**					
Machu Picchu sequence													
Wk-46935	490 ± 18	1430	1445	68.2	1420	1450	95.4	1439	1454	68.3	1429	1459	95.4
Wk-46936	441 ± 17	1444	1460	68.2	1439	1479	95.4	1451	1487	68.3	1450 1600	1500 1612	85.6 9.8
Chachabamba sequence													
Wk-48114	475 ± 19	1434	1450	68.3	1425	1455	95.4	1443	1458	68.3	1430	1484	95.4
Wk-46939	391 ± 15	1463 1601	1497 1611	54.0 14.3	1454 1590	1510 1619	68.4 27.0	1464 1482 1587	1469 1509 1621	3.6 27.3 37.5	1459 1546	1513 1625	40.9 54.5
Wk-48113	434 ± 19	1445	1468	68.3	1440	1490	95.4	1454	1496	68.3	1450 1595	1504 1616	79.1 16.4
Wk-46938	338 ± 18	1514 1539 1620	1529 1585 1631	14.2 43.6 10.5	1499 1613	1600 1640	77.7 17.7	1510 1560 1623	1550 1579 1640	38.3 14.4 15.5	1506 1619	1590 1645	73.5 22.0
Wk-46940	499 ± 15	1428	1441	68.3	1420	1446	95.4	1438	1451	68.3	1428	1455	95.4
Choquesuysuy sequence													
Wk-46933	567 ± 16	1400	1415	68.3	1328 1392	1340 1425	5.2 90.2	1406	1425	68.3	1399	1435	95.4
Wk-46934	423 ± 16	1450	1472	68.3	1445 1604	1493 1607	94.2 1.2	1458	1496	68.3	1454 1595	1504 1615	75.4 20.1

(continued)

Table 3.18 (continued)

Name	C-14 date (BP)	Unmodelled (BC/AD)											
		From	To	%	From	To	%	From	To	%	From	To	%
		SHCal13/IntCal13						**SHCal20**					
Wk-48115	209 ± 20	1666	1676	11.6	1656	1684	20.9	1672	1686	14.5	1664	1698	22.9
		1740	1798	56.7	1732	1804	71.6	1731	1782	45.4	1723	1811	72.2
					1943	…	2.9	1797	1805	8.4	1839	1842	0.3

Table 3.19 OxCal Modelling of Machu Picchu and satellites (Ziółkowski et al 2020) chronology calibration results using SHCal20 calibration curve

Name	Modelled (BC/AD)						Modelled (BC/AD)					
	from	to	%	from	to	%	from	to	%	from	to	%
	SHCal13/InCal13 mixed						**SHCal20**					
Machu Picchu sequence												
Start Machu Picchu	1308 1393	1348 1462	24.3 44.0	1308	1482	95.4	1192 1348	1204 1493	2.8 65.4	1188 1271	1263 1498	14.2 81.3
Machu Picchu phase												
Machu Picchu IV-III												
Start IV-III Sequence	1423	1478	68.3	1359	1520	95.4	1433	1490	68.3	1360	1540	95.4
Layer IV												
Wk-46935	1440	1477	68.3	1429	1520	95.4	1447	1488	68.3	1437	1532	95.4
Wk-46936	1447	1480	68.3	1441	1523	95.4	1455	1490	68.3	1448	1534	95.4
End Machu Picchu II	1450	1505	68.3	1443	1574	95.4	1457	1514	68.3	1449	1612	95.4
Machu First Picchu date	**1408**	**1477**	**68.3**	**1337**	**1509**	**95.4**	**1417**	**1495**	**68.3**	**1294**	**1530**	**95.4**
Machu Picchu date	1415	1526	68.3	1349	1594	95.4	1410	1550	68.3	1280	1716	95.4
End Machu Picchu sequence	1459 1600	1535 1638	45.8 22.4	1458	1638	95.4	1457 1837	1611 1849	65.8 2.4	1455 1753	1718 1853	81.3 14.1
Chachabamba sequence												
Chachabamba 1	1380	1505	68.3	1148 1225	1172 1528	1.7 93.7	1387	1511	68.3	1148 1228	1171 1528	1.7 93.7
Chachabamba phase												
Chachabamba VIII–III												

(continued)

Table 3.19 (continued)

Name	Modelled (BC/AD)						Modelled (BC/AD)					
	from	to	%	from	to	%	from	to	%	from	to	%
	SHCal13/InCal13 mixed						**SHCal20**					
Chachabamba VIII	1442	1502	68.3	1416	1529	95.4	1448 1474	1468 1510	25.4 42.9	1425	1531	95.4
Wk-48114	1448	1500	68.3	1437	1525	95.4	1452 1477	1469 1511	25.1 43.2	1445	1526	95.4
Chachabamba time interval VIII–VI	1460	1504	68.3	1445	1528	95.4	1465	1513	68.3	1452	1529	95.4
Wk-46939	1469	1506	68.3	1457	1530	95.4	1479	1517	68.3	1462	1532	95.4
Chachabamba end layer VI	1475	1513	68.3	1461	1537	95.4	1485	1520	68.3	1464	1539	95.4
Chachabamba III	1483	1521	68.3	1465	1550	95.4	1495	1527	68.3	1468	1562	95.4
Wk-48113	1485	1525	68.3	1468	1555	95.4	1499	1527	68.3	1478 1610	1560 1620	94.2 1.2
Wk-46938	1490	1530	68.3	1470	1565	95.4	1505	1530	68.3	1485 1621	1570 1635	93.5 2.0
Chachabamba end layer III	1491	1535	68.3	1471	1576	95.4	1506	1538	68.3	1485 1626	1584 1640	94.1 1.3
Wk-46940	1431 1493	1488 1501	61.7 6.6	1424	1536	95.4	1438	1489	68.3	1433	1532	95.4
Chachabamba first date	**1426**	**1497**	**68.3**	**1351**	**1538**	**95.4**	**1432 1502**	**1494 1506**	**65.9 2.3**	**1352**	**1534**	**95.4**

(continued)

Table 3.19 (continued)

Name	Modelled (BC/AD)						Modelled (BC/AD)					
	from	to	%	from	to	%	from	to	%	from	to	%
	SHCal13/InCal13 mixed						**SHCal20**					
Chachabamba date	1434	1544	68.3	1310	1676	95.4	1438	1550	68.3	1310	1691	95.4
End Chachabamba	1491	1595	68.3	1474 1838	1769 1863	93.8 1.7	1507	1601	68.3	1497 1847	1791 1879	93.3 2.1
Choquesuysuy sequence												
Choquesuysuy 1	1166	1459	68.3	866 958 977	953 962 1472	7.4 0.3 87.7	1183	1470	68.3	892 974 989 1010	965 980 1002 1485	6.4 0.5 1.0 87.5
Choquesuysuy phase												
Choquesuysuy IV-II												
start Choquesuysuy IV	1382	1471	68.3	1294	1527	95.4	1387	1481	68.3	1304	1533	95.4
Wk-46933	1405	1461	68.3	1397	1513	95.4	1410	1470	68.3	1404	1517	95.4
Time form Layer IV TPOQ to Inca Floor TPQ	1428	1487	68.3	1407	1534	95.4	1434	1500	68.3	1410	1561	95.4
Wk-46934	1455	1498	68.3	1447	1555	95.4	1462	1514	68.3	1454 1599	1569 1629	90.4 5.1
End Choquesuysuy Inca floor to occupation	1460	1538	68.3	1451	1665	95.4	1467	1559	68.3	1459	1688	95.4
Wk-48115	1667 1747	1696 1813	22.4 45.9	1656	1870	95.4	1675 1737	1702 1810	21.0 47.3	1667	1862	95.4

(continued)

Table 3.19 (continued)

Name	Modelled (BC/AD)						Modelled (BC/AD)					
	from	to	%	from	to	%	from	to	%	from	to	%
	SHCal13/InCal13 mixed						**SHCal20**					
Choquesuysuy first date	**1361**	**1480**	**68.3**	**1166**	**1531**	**95.4**	**1370**	**1490**	**68.3**	**1179**	**1534**	**95.4**
Choquesuysuy date	1360	1814	68.3	1074 2161	2155 2170	95.3 0.2	1372	1810	68.3	1097	2145	95.4
End Choquesuysuy	1678	2025	68.3	1672 2379 2393	2300 2388 2518	87.5 0.5 7.5	1686	2010	68.3	1679 2381	2292 2498	88.5 7.0

References

Acosta J (1979) Historia natural y moral de las Indias Pasta blanda. Fondo de Cultura Económica; Edición 2

Adamska A, Michczyński A (1996) Towards radiocarbon chronology of the Inca State. ANDES, Boletin de la Misión Arqueológica Andina 1:35–60

Ajie HO, Kaplan IR, Hauschka PV, Kirner, D, Slota PJ Jr, Taylor RE (1992) Radiocarbon dating of bone osteocalcin: isolating and characterizing a non-collagen protein. Radiocarbon 34(3):296–305

Alcalde Gonzales J, Del Aguila Chavez C, Fujita Alarcón F, Retamozo Rondón E (2002) "Plateros" precoloniales tardíos en Tambo de Mora, Valle de Chincha (siglos XIV–XVI). Anales del Museo de América 10:43–57. Madrid

Ancapichún S, De Pol-Holz R, Christie DA, Santos GM, Collado-Fabbri S, Garreaud R, Lambert F, Orfanoz-Cheuquelaf A, Rojas M, Southon J, Turnbull JC, Creasman P (2021) Radiocarbon bomb-peak signal in tree-rings from the tropical Andes register low latitude atmospheric dynamics in the Southern Hemisphere. Science of the Total Environment 774. https://doi.org/10.1016/j.scitotenv.2021.145126

Astete F, Bastante J, Echevarría López GT (2016) Quilcas en el Santuario Histórico de Machupicchu-Parque Arqueológico Nacional de Machupicchu: análisis y perspectivas arqueológicas. Revista Haucaypata 62–86

Bastante J, Astete F, Fernandez A (2017) Informe Programa de Investigaciones Arqueológicas e Interdiciplinaras en el Santiario Histórico de Machupicchu, Informe Final de Excavaciones temporada de 2017 para casos de llaqta de Machupicchu, Chachabamba, Choquesuysuy; Ministerio de Cultura Cusco (manuscript)

Bauer BS, Aráoz Silva M (2015) Settlement patterns and excavations in the Vitcos region. In: Bauer BS, Fonseca Santa Cruz J, Aráoz Silva M (eds) Vilcabamba and the archaeology of inca resistance. The Cotsen Institute of Archaeology Press, Los Angeles, pp 26–41

Bauer BS, Aráoz Silva M, Burr GS (2012) The destruction of the Yurac Rumi Shrine (Vilcabamba, Cusco Department). Andean Past 10:195–211

Bauer, BS, Aráoz Silva M, Quave K (2015a) The Yurak Rumi Shrine complex. In: Bauer, BS, Fonseca Santa Cruz J, Aráoz Silva M (eds) Vilcabamba and the archaeology of Inca Resistance. The Cotsen Institute of Archaeology Press, Los Angeles, pp 42–75

Bauer, BS, Fonseca Santa Cruz J, Aráoz Silva M (2015b) Vilcabamba and the archaeology of Inca Resistance. The Cotsen Institute of Archaeology Press, Los Angeles. https://escholarship.org/uc/item/3xk2n538

Beresford-Jones D, Machicado Murillo E, (2020) Crossing frontiers: perspectives from the various disciplines. In: Pearce AJ, Beresford-Jones DG, Heggarty P (eds) Rethinking the Andes–Amazonia divide: a cross-disciplinary exploration. UCL Press

Berger R, Chohfi R, Valencia Zegarra A, Yepez W, Fernandez Carrasco O (1988) Radiocarbon dating Machu Picchu, Peru. Antiquity 62:707–710

Betanzos J De (1987) [1551] Suma y Narración de los Incas. Transcripción, notas y prólogo de María del Carmen Martín Rubio. Ediciones Atlas, Madrid

Bongers JL (2019) Mortuary practice, imperial conquest, and sociopolitical change in the Middle Chincha Valley, Peru (ca. AD 1200–1650). PhD dissertation at the University of California, Los Angeles

Bronk Ramsey C (1995) Radiocarbon calibration and analysis of stratigraphy: the OxCal program. Radiocarbon 37(2):425–430

Bronk Ramsey C (2001) Development of the radiocarbon program OxCal. Radiocarbon 43(2A):355–363

Bronk Ramsey C (2009a) Bayesian analysis of radiocarbon dates. Radiocarbon 51(1):337–360

Bronk Ramsey C (2009b) Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51(3):1023–1045

Cabello Balboa M (1951) [1586] Miscelánea antártica, una historia del Perú antiguo, Valcarcel LE (ed). Universidad Nacional Mayor de San Marcos, Instituto de Etnología, Lima
Castagnoli G, Lal D (1980) Solar modulation effects in terrestrial production of carbon-14. Radiocarbon 22(2):133–158. https://doi.org/10.1017/S0033822200009413
Chavez Ballón M (1971) Cusco y Machu Picchu. Wayka, Revista del departamento de antropología de la Universidad del Cusco 4–5:1–4
Cobo B (1890–1895) Historia del Nuevo Mundo. Publicada por primera vez con notas y otras ilustraciones por Marcos Jiménez de la Espada, 4 vols. Sociedad de Filósofos Andaluces, Sevilla
Cornejo L (2014) Sobre la cronología del inicio de la imposición cuzqueña en Chile. Estudios Atacameños. Arqueología y Antropología Surandinas 47:101–116
Covey RA (2003) The Vilcanota Valley (Peru): Inca state formation and the evolution of imperial strategies. PhD dissertation at the University of Michigan
Covey RA (2006) Chronology, succession, and sovereignty: the politics of Inca historiography and its modern interpretation. Comp Stud Soc Hist 48(1):169–199
Covey RA (2008) Multiregional perspectives on the archaeology of the Andes during the Late Intermediate Period (c. AD 1000–1400). J Archaeol Res 16(3):287–338. https://doi.org/10.1007/s10814-008-9021-7
Crespo JC (1975) La relación de Chincha (1558). Hist Y Cult 8:91–104
Dayton CL (2008) Late prehistoric and modern irrigation agriculture in Torata, Peru. PhD dissertation at the Boston University
Drew D (1984) The Cusichaca project: aspects of archaeological reconnaissance—the Lucumayo and Santa Teresa Valleys. In: Kendall A (ed) Current archaeological projects in the Central Andes. BAR International Series 210. BAR, Oxford, pp 345–375
Duffait E (2005) Choquequirao en el siglo XVI: etnohistoria e implicaciones arqueológicas. Bulletin de l'Institut français d'études andines 34(2). https://doi.org/10.4000/bifea.5467
Duffait E (2013) Les routes incas de Machu Picchu et Vilcabamba. Pouvoir et mémoire dans des Andes péruviennes. L'Harmattan, France
Duviols P (1979) La guerra entre el Cuzco y los chancha: ¿historia o mito? Revista de la Universidad Complutense. ISSN 0210-7872, Nº. 117 (Ejemplar dedicado a: Economía y sociedad en los Andes y Mesoamérica)
Duviols P (1980) Algunas reflexiones acerca de las tesis de la estructura dual del poder incaico. Historica 4(2). Pontificia Universidad Católica del Perú
Fernández El Palentino D (1963) [1571] Primera y segunda parte de la historia del Perú. Crónicas del Perú, vols. I–II. Biblioteca de Autores Españoles, tomos, Madrid, 154–155
Fonseca Santa Cruz J (2011) El rostro oculto de Espíritu Pampa, Vilcabamba, Cusco. Arqueología Iberoamericana 10:5–7
Fonseca Santa Cruz J, Bauer BS (2013) Dating the Wari remains at Espiritu Pampa (Vilcabamba, Cusco). Andean Past 11:Article 12
Ghezzi I, Rodríguez R (2015) Primera serie dendroarqueológica en los Andes Centrales: resultados preliminares de Chankillo, Casma. Bulletin de l'Institut Français d'Études Andines 44(1):1–21
Ghezzi I, Rodríguez R, Hogg A, Manning S (2021a) Cronología de alta precisión del "Observatorio Solar Chankillo y su Centro Cermonial" mediante fechados de radiocarbono y dendrochonologia. Conference paper at Simposio Internacional de la Cronología Andina, July 22
Ghezzi I, Mabres A, Rodríguez, R, Cruz G, Salazar P, Hogg A, Boswijki G, Manning S (2021b) Fechados 14C de alta precisión de eventos El Niño (ENSO) de Chankillo. Conference paper at Simposio Internacional de la Cronología Andina, July 23
Godwin H (1962) Half-life of radiocarbon. Nature 195(984). https://doi.org/10.1038/195984a0
Guaman Poma de Ayala P@@ (1615/1616) Nueva corónica y buen gobierno. København, Det Kongelige Bibliotek, GKS 2232 4°. www2.kb.dk/elib/mss/poma/
Hemming J (1970) The conquest of the Incas. A Harvest Book, HB 258
Herrera Wassilowsky A (2020) Changing Andes–Amazonia dynamics: El Chuncho meets El Inca at the end of the Marañón corridor. In: Pearce AJ, Beresford-Jones DG, Heggarty P (eds) Rethinking the Andes–Amazonia divide: a cross-disciplinary exploration. UCL Press

Hiltunen, J (1999) Ancient Kings of Peru. The reliability of the chronicle of Fernando de Montesinos; correlating the dynasty lists with current prehistoric periodization in the Andes. Bibliotheca Historica 45. Helsinki:Suomen Historiallinen Seura

Hogg A, Southon J, Turney C, Palmer J, BronkRamsey C, Fenwick, P, Boswijk G, Boantgen U, Friedrich M, Helle G, Hughen K, Jones R, Kromer B, Noronha A, Reinig F, Reynard L, Staff R, Wacker L (2016) Decadally resolved lateglacial radiocarbon evidence from New Zealand Kauri. Radiocarbon 58(4). https://doi.org/10.1017/RDC.2016.86

Hogg A, Heaton T, Hua Q, Palmer J, Turney C, Southon J, Bayliss A, Blackwell P, Boswijk G, Bronk Ramsey C, Petchey F, Reimer P, Reimer R, Wacker L (2020) SHCal20 Southern Hemisphere calibration, 0–55,000 years cal BP. Radiocarbon 62

Hua Q, Barbetti M, Rakowski A (2013) Atmospheric radiocarbon for the period 1950–2010. Radiocarbon 55(4):2059–2072. https://doi.org/10.2458/azu_js_rc.v55i2.16177

Hyslop J (1984) The Inka road system. Academic Press, San Francisco and New York

Julien C (2008) On the beginning of the late horizon. Ñawpa Pacha 29(1):163–177. https://doi.org/10.1179/naw.2008.29.1.007

Lecoq P (2013) Can the Inca site of Choqek'iraw be considered an agro-pastoral calendar? Ñawpa Pacha 33(1):43–69

Lumbreras L (2001) Uhle y los asentamientos de Chincha en el siglo XVI. Revista del Museo Nacional de Lima, pp 13–88, t. XLIX

Marsh EJ, Kidd R, Ogburn D, Durán V (2017) Dating the expansion of the Inca empire: Bayesian models from Ecuador and Argentina. Radiocarbon 59(1):1–24

Marsh EJ, Bruno MC, Frits SC, Baker P, Capriles JM, Hastorf CA (2018) IntCal, SHCal, or mixed curve? Choosing a ^{14}C calibration curve for archaeological and paleoenvironmental records from tropical South America. Radiocarbon 60(3):925–940. https://doi.org/10.1017/RDC.2018.16

Menzel D, Rowe JH (1966) The role of Chincha in late pre-Spanish Peru. Ñawpa Pacha 4:63–76

Morris C, Santillana J (2007) The Inka transformation of the Chincha capital. In: Variations in the expression of Inka power. Dumbarton Oaks, Washington, DC, pp 135–163

Mróz M (1984) A numerical interpretation of the chronicle of Huamán Poma de Ayala. Anthropológica. No 2 (Año 1984). Pontificia Universidad Católica del Perú

Nigra B, Jones T, Bongers J, Stanish C, Tantalean H, Perez K (2014) The Chincha Kingdom: The archaeology and ethnohistory of the late intermediate period South Coast, Peru. Backdirt Annual Review of the Cotsen Institute of Archaeology at Ucla, December 2014

Nir A (2016) Reconstrucción histórica del ciclo de guerras entre los incas y los chancas. In: Szemiñski J, Curatola M (eds) El Inca y la Huaca. La Religión del Poder y el Poder de la Religión en el Mundo Andino Antiguo. Pontificia Universidad Católica del Perú-Fondo Editorial, Lima, pp 121–154

Ogburn D (2012) Reconceiving the chronology of Inca Imperial expansion. Radiocarbon 54(2):219–237

Orefici G (2017) Informe de Arte Rupestre en el Parque Arqueológico Nacional de Machupicchu. Manuscrito Archivos del Centro de Estudios Andinos de la Universidad de Varsovia en el Cusco

Pärssinen M (1992) Tawantinsuyu. The Inca State and its political organization. PhD dissertation, Studia Historia 43. Societats Historica Findandiae, Helsinki

Regalado L (1993) La sucesión incaica. Aproximación al mando y poder entre los Incas a partir de la crónica de Betanzos. Fondo Editorial de la Pontificia Universidad Católica del Perú. Lima.

Reimer PJ, Brown TA, Reimer RW (2004) Discussion: Reporting and calibration of post-bomb 14C data. Radiocarbon 46(3):1299–1304. IntCal04: Calibration Issue, Guest editor Paula J Reimer. https://doi.org/10.1017/S0033822200033154

Reimer P, Austin W, Bard E, Bayliss A, Blackwell P, Bronk Ramsey C, et al. (2020) The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radiocarbon 62(4):725–757. https://doi.org/10.1017/RDC.2020.41

Renard-Casevitz FM, Saignes T, Taylor AC (1988) Relaciones entre las sociedades amazónicas y andinas entre los siglos XV y XVII. Los piedemontes orientales de los Andes centrales y meridionales: desde los Panatagua hasta los Chiriguano. In: Al Este de los Andes. Tomo I,Éd

iteur: Institut français d'études andines, Abya-Yala Collection, Lima. https://doi.org/10.4000/books.ifea.1631
Rostworowski de Diez Canseco M (1975) Pescadores, artesanos y mercadores costeños en el Perú prehispánico. Revista del Museo Nacional de Lima 41:311–350
Rowe JH (1945) Absolute chronology in the Andean area. American Antiquity 10(3):265–284
Rowe JH (1990) Machu-Picchu a la luz en documentos del siglo XVI. Historica 14(1)
Rowe JH (2003) [1986] Machu Picchu a la luz de documentos del siglo XVI. In: Rowe JH (ed) Los Incas del Cuzco. Siglos XVI–XVII–XVIII. INC–Región Cusco, pp 117–126
Saignes T (1981) El piedemonte amazónico de los Andes meridionales: estado de la cuestión y problemas relativos a su ocupación en los siglos XVI y XVII" Bull. Institut français d'études andines Tomo X(3–4):141–176
Salazar LC (2004) Machu Picchu: mysterious royal estate in the cloud forest. In: Burger RL, Salazar LC (eds) Machu Picchu: unveiling the mystery of the Incas. Yale University Press, pp 21–48
Sandweiss D (1992) The archaeology of Chincha fishermen: specialization and status in Inka Peru. Bulletin of Carnegie Museum of Natural History 29–
Sandweiss D, Reid D (2016) Negotiated subjugation: maritime trade and the incorporation of Chincha into the Inca Empire. J Isl Coast Archaeol 11(3):311–325. https://doi.org/10.1080/15564894.2015.1105885
Saintenoy T (2016) Arqueología de las *Llaqtas* del Valle del Apurímac: Contribución al estudio de la territorialidad de las comunidades aldeanas serranas en los Andes Prehispánicos. Chungará (Arica) 48(2). http://dx.doi.org/10.4067/S0717-73562016005000014
Santillana JI (1984) La Centinela: Un Asentamiento Inka Chincha. Rasgos Arquitectónicos Estatales y Locales. Revista Arqueología y Sociedad nº 10. UNMSM. Lima–Perú
Santos G, Linares R, Lisi C, Tomazello M (2015) Annual growth rings in a simple of Panańá pine (Araucaria angustifolia): toward improving the 14C calibration curve for the southern hemisphere. Quat Geochronol 25:96–103. https://doi.org/10.1016/j.quageo.2014.10.004
Sarmiento de Gamboa P (1906) [1572]. Geschichte des Inkareiches (Historia Indica). Edición de Richard Pietschmann. Abhandlungen der Königlichen gesellschaft der wissenschaften zu Göttingen. Philologisch-historische klasse. Neue folge VI(4). Weidmann, Berlin
Stuiver M, Polach H (1977) Discussion reporting of 14C data. Radiocarbon 19(3):355–363. https://doi.org/10.1017/S0033822200003672
Szemiński J (1994) Wira Quchanmanta kamasqanmantawan. De Wira Quchan y de su creación. Bet Shemesh, Madrid
Szemiński J (2009) Un ejemplo de larga tradición histórica andina: Libro 2º de las Memorias antiguas historiales y políticas del Piru redactado por Fernando de Montesinos. Iberoamericana, Madrid; Vervuert colección "Tiempo emulado", Frankfurt
Szemiński J, Ziółkowski M (2018) Mitos, rituales y política de los Incas. Ediciones El Lector, Arequipa
Tantaleán H, Stanish C, Zegarra M, Pérez K, Nigra B (2013) Paracas en el valle de Chincha: Nuevos datos y explicaciones. Boletín de Arqueología PUCP, pp 31–56
Turnbull JC, Mikaloff Fletcher SE, Ansell I, Brailsford GW, Moss RC, Norris MW, Steinkamp K (2017) Sixty years of radiocarbon dioxide measurements at Wellington, New Zealand: 1954–2014, Atmos. Chem Phys 17:14771–14784. https://doi.org/10.5194/acp-17-14771-2017, 2017
Tyuleneva T (2020) The Amazonian Indians as viewed by three Andean chroniclers. In: Pearce AJ, Beresford-Jones DG, Heggarty P (eds) Rethinking the Andes–Amazonia divide: a cross-disciplinary exploration. UCL Press
Uhle M (1924) Explorations at Chincha. University of California Publications in American Archaeology and Ethnology
Usoskin IG, Kovaltsov GA (2012) Occurrence of extreme solar particle events: assessment from historical proxy data. Astrophysics J 757:92. https://doi.org/10.1088/0004-637X/757/1/92
Wallace DT (1971) Sitios Arqueológicos del Perú: Valles de Chincha y de Pisco. Arqueológicas 13. Museo Nacional de Antropología y Arqueología, Lima

Wallace DT (1991) The Chincha roads: economics and symbolism. In: Trombold CD (ed) Ancient road networks and settlement hierarchies in the New World. Cambridge University Press, pp 253–263

Wallace DT (1998) The Inca compound at La Centinela, Chincha. Andean Past 5:5–33. Cornell University. Latin American Studies Program, Cornell

Willis EH, Tauber H, Münnich KO (1960) Variations in the atmospheric radiocarbon concentration over the past 1300 years. Radiocarbon 2:1–4

Ziółkowski M (1997) La guerra de los wawqis: los objetivos y los mecanismos de la rivalidad dentro de la élite inka, siglos XV–XVI. Colección Biblioteca Abya-Yala 41

Ziółkowski M (2015) Pachap unancha. El calendario metropolitano del Estado Inca. Sociedad Polaca de Estudios Latinoamericanos – Ediciones El Lector, Arequipa

Ziółkowski M, Bastante Abuhadba, J, Hogg A, Sieczkowska D, Rakowski A, Pawlyta J, Manning S (2020). When did the Incas build Machu Picchu and its satellite sites? New approaches based on radiocarbon dating. Radiocarbon, 1–15. https://doi.org/10.1017/RDC.2020.79

Zuidema T (1982) Myth and history in ancient Peru. In: Rossi I (ed) The logic of culture. Bergin and Garvey, South Hadley, MA, pp 150–175

Zuidema T (1995) El Sistema de ceques del Cuzco la organización social de la capital de los Incas. Fondo Editorial de la Pontificia Universidad Católica del Perú

Chapter 4
Machu Picchu in Context: The Inca Building Culture

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Abstract Even today, and certainly in the past, the infrastructures built by Inca engineers appear extremely complex, even in their almost perfect geometric and harmonic articulation. The imposing structures incorporating stone blocks weighing several tons seem beyond the reach of men, whose level of technology never reached the Iron Age. Stone was undoubtedly the most widely used building material in prestigious architecture, including religious one, and in infrastructure, as well as playing a fundamental role in religiosity directly linked to the deities of the earth and the mountains. This work aims to be the first approach to a resume of the history of stone in the Inca empire, through the analysis of edited texts and original contributions of the authors, from the quarry to the fitting, through the description of practices, methods, processing techniques and labour management.

Keywords Inca building techniques · Architecture · Machu Picchu · Quarrying techniques

4.1 Introduction

One of the most relevant aspects of the Inca civilisation is the finely worked stone architecture. The high technical expertise achieved by the Incas in the masonry constructions is the result of a technological and cultural millennial evolution that

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began, before 1000 BCE, at Cerro Sechin (Fig. 4.1a), whose amazing architecture is characterised by large refinely dressed stones and engraved with bas-reliefs. Then it was perfected in Chavin de Huantar (800–500 BCE), where well-joined cut-stone masonry widely developed (Fig. 4.1b). Refined construction solutions are found in Pukara, from the Early Intermediate Period, where the architecture is embellished with elaborate cut-stone masonry and carved stelae (Protzen and Nair 1997). With the Tiahuanaco culture cut-stone construction reached higher levels from a technical and artistic point of view (Fig. 4.1c), thus becoming the main reference point for Inca architecture and building culture (Posnansky 1945; Protzen and Nair 1997).

Many scholars have often questioned the reasons that have favoured the development of advanced technical knowledge, in particular in hydraulic engineering and masonry structures, despite the tools and the technologies at their disposal, limited compared to contemporary civilisations of other continents (iron was unknown to the Incas as well as the wheel was never used for practical purposes) and not superior to coeval or previous pre-Hispanic cultures of the American continent (Protzen 1983; Wright et al. 1999).

In particular, what arouses wonder and amazement is the advanced level in the techniques of extraction, transport and processing of stone blocks, and their installation to form refined and statically effective masonry structures.

Fig. 4.1 **a** Cerro Sechin; **b** Chavin de Huantar; **c** Tiwanaku. Photos by N. Masini

The difference with the other Andean cultures that preceded the Incas is that they improved and expanded on a large scale logistic, road and hydraulic infrastructures that would allow them to control, govern, manage natural resources (moreover in different ecosystems) of the largest empire developed in South America before the arrival of the Spaniards. Such massive infrastructure system was also the basis of the victorious military which in a few decades led the Inca to conquer large regions of the coast, the sierra and part of the forest, from current Ecuador to Chile.

Historians and scholars date the expansion of the Inca (pre-empire and empire) to a period between the end of the thirteenth century, and the arrival of the Spanish conquistadors at the second quarter of the sixteenth century (1532) (McEwan 2008; Hemming 2012; D'Altroy 2014; Szemiński et al. 2018).

The pan-Andean Inca empire of the Late Horizon (1400–1572) was probably the result of a very long cultural evolution that took place in South America (central Andes) during the previous centuries. The pre-incaic organisation of the state must have been organised around two capitals, with their respective zones of power: (i) Tiahuanaco, near Lake Titicaca, which controlled parts of Peru, Bolivia, Chile and Argentina; (ii) Wari, which controlled the sierra area and the Peruvian coast. The bipartite division of power in the American Southwest changed with the collapse of the Wari culture, between the eighth and ninth centuries, which was survived by the Tiahuanaco culture, albeit in decline, until the twelfth century (Szemiński et al. 2018).

The period between the decline of Wari and Tiahuanaco and the Inca Empire proper was a period of transition, marked by political and cultural fragmentation, albeit imbued with a collective pan-Andean sentiment, which was later echoed in the Inca Empire itself.

The story of the Inca and the rise of their empire, like all stories of ancient civilisations, is full of myths and legends. Studies of the history of this people are based on a constantly debatable chronology of thirteen emperors (or sovereigns), proposed by Rowe, from the legendary Manco Capac to the last emperor, Atahuallpa (Rowe 1946, 1960; Brundage and Toynbee 1963).

To date, this accepted version has been revised by numerous scholars who have produced new hypotheses on the basis of historical data, oral traditions and archaeological data (Ogburn 2012; Marsh et al. 2017; Ziółkowski et al. 2020).

The origin of the Inca is narrated in several legends reported in the sources and reconstructed by scholars of Peruvian history and ethnography (Guamàn Poma de Ayala 1615, 1992, 1967, 2006; Garcilaso de la Vega 1987; Rostworowski 2000; Betanzos 2008).

There are many traditions about the origin of the Incas and some are linked to the city of Tiahuanaco from where they migrated to Cuzco area. This first phase, considered proto-imperial, is linked to the *Killke* culture. In the fifteenth century, and later in the sixteenth, Inca politics reached a mature imperial phase, with a pan-Andean characteristic and an extension throughout southwest America. The expansion of the Inca Empire proper was very rapid and is confirmed by archaeological and historical data. Probably between the end of the fourteenth and the beginning of the fifteenth century, a few decades before the reign of Emperor Pachacuti, as attested by archaeological analyses carried out at several sites of the empire in Peru, Argentina, Chile and Ecuador (Ziółkowski et al. 2020). During this period, they move to a "historical" level with what will be remembered as the most important Inca emperor: Pachacuti (1438–1471) (Bonavia 2000; Sarmiento de Gamboa 2001).

Recent studies on the chronology of the emperors have also revised the classical tradition of the thirteen sovereigns for a more extensive list, depicting a diarchic-based way of government, according to the traditions of the central Andes. According to the general custom of the Andes, all authority was always divided between two persons with complementary functions, belonging to the dynasty of Hanan Cusco and Hurin Cusco, although at the time of the Spanish conquest only one sovereign (Hanan dynasty) governed the empire (Szemiński et al. 2018).

Much of the success in both the conquest and government of the Inca empire was due to the ability to create an efficient control and administrative system (Protzen and Batson 1993).

The Inca emperors administered an empire of over 15 million inhabitants, from Ecuador to Chile (Fig. 4.2). The official and administrative language of the empire was the quechua of the Cuzco territory, but hundreds of languages were also spoken, until the period of the Spanish conquest, when quechua became the common language. Most Andean peoples had a triple awareness of cultural belonging: (i) cultural and religious belonging linked to ceremonial centres (*llaqta* o *marka*); (ii) ethnicity; (iii) belonging to a nation or empire.

The territory of the empire, called *Tawantinsuyu*, was divided into four (*tawa*) quadrants (*suyu,* deriving from the verb suyuni, meaning to divide up an obligation) and Cusco, in the middle, was the capital (Julien 2009). Some important centres assumed the status of provincial capitals and were equipped with all the infrastructure necessary to govern the territory, such as administrative structures, sanctuaries dedicated to the sun, facilities, and services. The division was functional not only for the administrative organisation of the empire but also for the management of workers, goods and products. The interference of the imperial administration in the local government of the provinces varied and depended mainly on their strategic, economic and productive importance, and on the number of inhabitants (Julien 1988).

The Tawantinsuyu included extremely diverse areas, by altitude above sea level and latitude. These were divided by the Inca into three well-defined ecological and cultural niches: (i) Yunga, from the coast to 2500 m above sea level, included the population living between the sea and the river valleys, and the tropical forested lands and humid climate of the Andes; (ii) Quechua, between 2500 and 3800 m above sea level represented the temperate zone; and (iii) Puna, the high mountain areas above 3800 m. Agriculture was the main activity in the Yunga and Quechua areas, with a preference for maize; while the Puna area was dedicated to livestock breeding (llamas and alpacas) and the cultivation of certain types of plants suited to that ecosystem. In the Andes, every family and every institution kept provisions for the lean years. The rhythms and labour requirements in the different climatic zones were established by specialised agronomists (*chakra kamayuq*). Work was agreed upon by institutions in negotiations with representatives of social groups.

Fig. 4.2 Map of the Inca Empire. Reworked from Szemiński et al. (2018)

Work was managed in three different ways: symmetrical exchange between equals (*ayni*); participation in a particular work for the benefit of a particular individual or institution in exchange for food and prestige (*mink'a*); corvettary work, carried out in shifts by members of the community, e.g. to cultivate the personal land of a lord (*mit'a*). The mit'a system provided the necessary labour to fulfil roles in the service of the state or the Inca lords. The services of craftsmen working on behalf of the state, such as potters, goldsmiths, miners, carpenters, were ensured by establishing them in cities dependent on the central power. Payment was often in goods or land,

and craft work could in some cases alternate with being a farmer or soldier. The displaced and resettled populations were called *mitmaq* (Rostworowski 2000).

In the Andes, villages gravitated around religious and administrative centres that also functioned as storage and redistribution centres for raw materials. Conservation of resources was imposed by the central authority for the sole purpose of storing goods needed for imperial reserves, while the *surplus* of individual producers was used for exchange.

Both storage and redistribution were organised to be part of official ceremonies involving the population and the workers, praising their role for the benefit of the state.

In order to make this strategy work, it was necessary to move huge amounts of people, goods and materials across the empire. The solution to these problems was a massive programme of building infrastructures, which would allow (i) an easy movement from the coast to the sierra, from the sierra to the jungle, from North to South, by buildings paved roads and bridges; (ii) the military and religious control of the territory through the construction of monumental palaces, fortresses, temples; (iii) the redistribution and storage of goods and commodities by means of a network of warehouses, stores and facilities; and (iv) the production of primary goods such as food, agricultural products and water (agricultural terraces, fountains, canals, settlements, new towns) (Hyslop 1984; Ogburn 2004a; Bray 2013; Castro et al. 2019). In particular, the enormous effort of the Inca engineers was spent on monumental works of architecture, agricultural terrace systems (*andenes*), quarries and *caminos* (road system), carried out with a great expenditure of labour force and building materials (stone, wood, plant/animal fibres and metal) (Agurto Calvo 1987; Protzen and Batson 1993).

Even today, and certainly in the past, the infrastructures built by the Inca engineers appear extremely complex, albeit in their almost perfect geometric and harmonic articulation. The impressive structures incorporating blocks of stone weighing several tons seem beyond the reach of men whose level of technology never reached the Iron Age. Stone was undoubtedly the most widely used building material in prestige architecture, including the religious one, and infrastructure, as well as playing a fundamental role in religiosity directly linked to the deities of the earth and mountains. For the Inca people, there was a close relationship between the use of the natural landscape and human actions. Both aspects of the relationship between man and nature (monumental and religious) were used by the Inca emperors to manifest their power and standardise the empire with a single culture and style. With particular reference to imperial architecture, with limitations in the provinces imposed for available labor. The Incas were not interested in modifying, for example, the housing architecture.

Although the Incas knew the adobe technique, used above all on the coast (e.g. Paradones near Nasca) and occasionally also in the *sierra* (e.g. Raqch'I, central wall of the Temple of Wiracocha), stone was essential to the public architecture built for the manifestation of the Inca power.

The types of architecture were adapted to the characteristics of stone, assuming unique aspects and connotations depending on: (i) solidity, form and organisation of spaces; (ii) monumentality; (iii) beauty and durability (Schama 1995; Rostworowski de Diez Canseco 2000; Dean 2010).

In order to standardise the style and monumentalise cities, temples and fortresses, the Incas created a complex system of management of building stone based on extraction sites (quarries), working sites, infrastructure for transporting the stones and management of the labour force (Protzen 1983).

The following chapter deals with the Inca building culture by framing it in the context of a systemic approach to buildings, in its technological, socio-economic implications and in the ability to observe the environment and natural resources.

This discussion is divided into four sub-paragraphs relating, respectively, to four phases of the construction chain process.

i. Quarrying activities: from the criteria for selecting the stone to the tools used to extract it and break it up;
ii. The handling and transportation: focusing on the devices and techniques for transporting and lifting building stones;
iii. The cutting and dressing: with particular reference to the methods and tools used for these operation;
iv. The fitting and laying: focusing on the technique and devices used by the Incas to achieve the extraordinary fit between stones?

4.2 Inca Building Culture

The fine masonry used in temples, palaces and monumental buildings are a distinctive feature of Inca architecture. In particular, what makes the masonry construction techniques original, thanks to the influence and cultural heritage of the Tiwanaku civilisation, are the precision in fitting the stone, the stone working characterised by the refined carving and high or low relief surfaces of the stone blocks.

These features characterise the most important monuments and buildings of the Inca capital of Cuzco, and several llaqta in the Urubamba valley, such as Ollantaytambo, Machu Picchu.

The cultural homologation process implemented in the conquered regions by the Incas invested also the construction techniques. This favoured the widespread use of stone also along the coast (we cite above all the ceremonial centre of Pachacamac and Paredones in the Nasca valley), although in these territories the most commonly used technique was the adobe widely practised in smaller sites.

In order to build their “stone empire” (palaces, temples, infrastructures), the Incas had to manage an enormous amount of work involving a large number of workers, employed in several extraction sites, and equally involved in transport and construction. Labour was in fact the first element in the building of monumental centres, as well as in the selection, extraction, dressing and fitting of stone. For this reason, the Incas were very focused on population management, redistributing the conquered populations in different productive regions of the empire (Ogburn 2013).

Considering the technological level of the Inca empire, the labour force was the first and greatest asset for the execution of large-scale works. The labour force within the production cycle of building stone was of two types, according to literary sources: (i) under compensation, (ii) as a task related to *mitmaqkuna* (Béjar 2003).

In the first case, the state foresaw the use of specialised figures for complex tasks (*kamayoq*). The status was hereditary and there were figures like carpenters (*quiro camayoc*), quarrymen (*rumita chicoc*), and builders (*pirca camayoc*) (Guamàn Poma de Ayala 1615, 1967; Rostworowski de Diez Canseco 2000), as well as specialised architects whom, according to literary sources and recent archaeological studies, designed and built the prestigious structures such as the Temple of the Sun, the city of Cuzco and the fortress of Sacsahuaman, before and probably also during the reign of Pachacuti and his son (Protzen and Batson 1993; Betanzos 2008; Ziółkowski et al. 2020).

The second case, the Mitmaqkuna (from mitima meaning outsider, foreigner, newcomer, one who has been relocated) can be explained by keeping in mind the concepts of conquest, the need to ensure the political control by cultural homogenisation and the exploitation of forced labour of groups of people resettled (from one province to another), along with the Incan economic system (Cobo and Hamilton 1979; Davidson et al. 2021).

The Inca empire was not based on a monetary system for exchange and remuneration, so, in order to ensure tribute to the state, labour was used as a reasonable exchange in the system of *mit'a*. Under this system, people were obliged to work several months (one or two) a year for the state, and the revenue was collected by the state as tribute (Guamàn Poma de Ayala 1615, 1992; Protzen and Batson 1993).

The provision of building material (stone) was a complex operation, as it was for every ancient civilisation. The places where the material was found, the sites where it was worked were not always close to each other. This required an adequate and complex organisation by the state.

The production of building stone included a number of operations such as: (i) the selection of the quarry, the stone to be quarried, the transport and the storage of the raw material; (ii) the dressing of the stone, the transport and the storage of the dressed material; (iii) the fitting of the stones for building masonry structures. Although in some cases dressing did not necessarily take place in situ, in most cases operations took place in several locations, by thousands of workers, supervised by specialists, imperial inspectors (Agurto Calvo 1987; Kaufmann et al. 2006; Pigeon 2011).

4.3 Stones, Quarries and Quarrying Activities.

The first step in finding construction material was to install the quarry or quarries, i.e. to choose the site on the basis of certain factors such as: (i) type of stone to be extracted; (ii) accessibility; (iii) possibility of installing facilities; (iv) setting up transport infrastructure (ramps and roads) (v) and in some cases setting up dressing sites for partial processing of products.

The stones used in Inca architecture had to respect certain requirements, depending on the type of construction to be built. In the case of monumental, religious and representational structures, the Incas preferred to use the same type of resistant rock in their masonry. This practice has been observed in Ollantaytambo, Cusco and Ingapirca by Protzen (1983) and Ogburn (2013). In the case of ephemeral or temporary constructions, different types of stone were also used often by composing them with fieldstones (Protzen 1983; Ogburn 2013).

Inca architecture required blocks of different sizes, with homogeneous characteristics, resistant to the stresses produced once fitted. In most cases, the Incas used volcanic, or igneous stone, either intrusive or effusive, because of its chemical-physical and mechanical properties. The stones most commonly used by the Incas, in accordance with the geo-lithological composition of the Peruvian territory, were the Yucay limestone, green Sacsayhuaman diorite porphyry, black andesite, granite and rhyolite and limestone (Kaufmann et al. 2006). In some cases basalt, sandstone and quartzite were also used (Agurto Calvo 1987) (Fig. 4.3).

The mining of granites, basalts, diorites, andesites and rhyolites is documented in a number ancient quarries such as Rumiqolqa, Huaccoto, Cojitambo, Yucay, Cuzco, Kachiqhata, and Machu Picchu (Heizer and Williams 1968). The deposits of volcanic or igneous stone, as well as those of limestone, offered the possibility of quarrying large blocks with homogeneous properties. The type of building stone was carefully selected, and the fitting site was not always close to the quarry. In addition, the material for the construction of the buildings could come from one or more quarries.

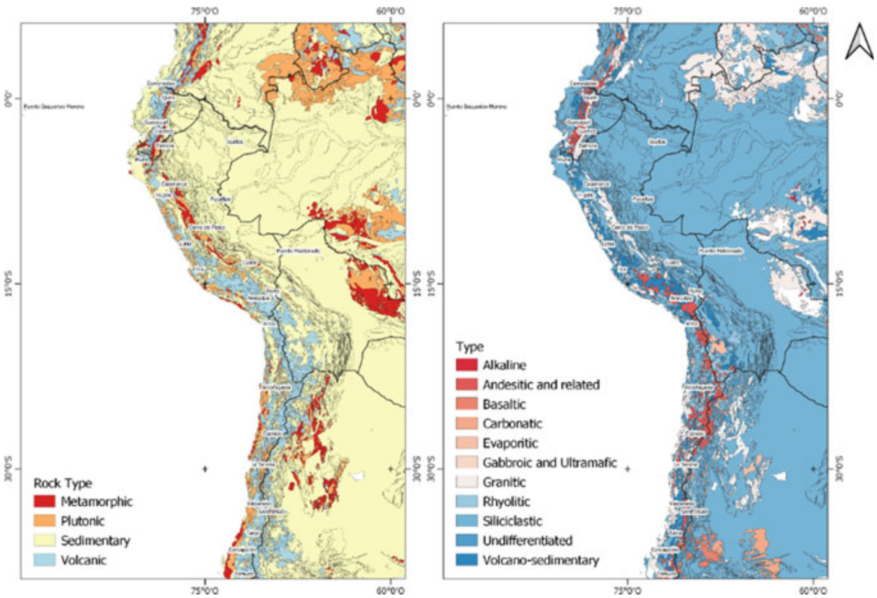

Fig. 4.3 Geological Map of South America: general rock type and specific type. Reworked by the authors from Gómez et al. (2019)

The importance given to the right type of stone was such that it justified supplying sites that were far away or difficult to reach (Protzen and Batson 1993). In some cases, the quarries were divided into sectors, which provided stones of different types (Protzen 1983). The division of the quarries into sectors probably also depended on a different functionality of themself. In the quarries of Kachiqhata and Rumiqolqua, several structures have been identified to define different quarters such as that of the supervisors or administrators (e.g. *Soqamarka*), that of the quarryman (e.g. *Muyupata* and *Nawinpata*), as well as buildings probably useful for storage and for an initial dressing operation to reduce the material to be transported to the fitting site (Protzen 1983).

Apart from pragmatic and practical aspects (type of stone, construction, logistics), stone quarrying in the Inca world was also closely influenced by cultural and religious concepts (Dean 2010). The choice of which and how many stones to use, and which buildings to construct, was obviously a well-targeted choice, useful to send a message of power and belonging to an elite, as well as a close relationship with the deities (Gasparini and Margolies 1980). Above all, we mention the megalithic structures of Sacsaihuaman where the extraordinary dimensions and formal and constructive characteristics of the blocks were not only functional to static and defensive reasons but were also linked to the will to flaunt power and ability to dominate the surrounding territory. In addition, Inca elites manifested their power and leadership abilities through the management of human (labour force) and natural resources (Trigger 1990).

The location of the quarry in relation to the construction site (fitting) was crucial as the activity of transporting the blocks was labour-intensive, without technologically advanced equipment such as the iron and the wheel unknown to the Incas. In some cases, the primary stone used for construction was quarried on site, as in the case of Machu Picchu, where several outcrops of fractured granite rocks show clear traces of mining and cutting. Other quarries have been found by archaeologists as that located at North East of Plaza Principal (Bastante 2016). In the latter regard, the recent discovery of hammerstones during excavations in the Plaza Principal, as well as geophysical and remote sensing analyses at the site, have suggested the hypothesis of the existence of a quarry phase for the extraction of stone, before the creation of the ceremonial plaza.

In other cases, the quarry could be several kilometres away, as in the case of Kachiqhata and Ollantaytambo (4 km), or in the case of Rumiqolqa and Cuzsco (35 km). The stone could also travel many kilometres, as attested to by the more than five hundred blocks from Rumiqolqa found in Ecuador: more than 500 blocks weighing over 700 kg each (Ogburn, 2004b). A constant relationship, however, is the presence of quarries along the major routes of the Inca road, usually within 1 to 2 km of the road route (Ogburn 2013).

The size of the quarry areas can be deduced mainly by the traces on the landscape of quarrying activity such as ramps, slides, roads, quarry steps, pits, by the facilities useful for the work, the processing waste and by the presence of abandoned processed blocks. For large quarries, such as Rumiqolqa, Cojitambo and Kachiqhata, the area involved ranged from 30–40 ha (Cojitambo) to 200 ha (Rumiqolqa). Alongside the large quarries, smaller or localised extraction sites had to coexist, such as the 10 m diameter shafts in Acacana (Ecuador), which were useful for the construction of small to medium-sized structures at the Incapirka and Tambo Blanco sites (Ogburn 2013).

The operation of the quarries was ensured by different types of facilities useful for quarrying activities. The position and type of structure was closely linked to the type of quarry itself, the topography of the area and the type of processing to be carried out in situ. Scholars agree on the absence of a precise pattern in the arrangement and organisation of the structures useful for quarrying, and therefore the lack of a formal and organisational standard, contrary to what has been observed for the organisation of the labour force and masonry. Among the facilities useful for quarrying activities there had to be: (i) accommodation for the workers, although it was possible that many of them moved from settlements close to the quarry; (ii) facilities for storing water and food for the workers; (iii) facilities for preliminary processing of the material and its storage; (iv) ramps and paths useful for moving men and stones (Betanzos et al. 1996; Cieza De Leon 2015; Cieza de León 2021). However, these structures are not easy to identify. In some cases, such as the Machu Picchu site, no specific structures dedicated to the accommodation of the stone workers, or ad-hoc roads for the transport of the blocks have been found. The service facilities for the quarry activities were probably temporary, set up during the period of activity and then removed or reused for other purposes (Wright et al. 1999; Ogburn 2013). Instead, most of the infrastructure was found and identified on quarry sites with a medium to long distance from the construction site. This is the case of Cojitambo, Rumiqolqa and Kachiqhata (Protzen 1983; McEwan 2008; Ogburn 2013). There was also no lack of places and structures within the quarry sites dedicated to the burial of men (*chullpa*), such as those identified in the Kachiqhata quarry (Protzen and Batson 1993).

Quarrying is a crucial activity of the entire stone construction chain with implications and effects also on the organisation of the Inca state, due to the expenditure of both skilled and unskilled labour force that it required. Stone could be found in different ways, in different types of quarries. The latter were of two types: (i) opencast, and (ii) surface quarries (Protzen 1983).

The opencast quarries involved the detachment of blocks from the bedrock. Such quarries were for example the quarries of Rumiqolqa and Cojitambo, used by the Inca for building material in Cusco and Tomebamba (Ogburn 2013). This operation required a large labour force and could be carried out in several ways:

i. extraction of outcropping stone by mechanical separation from the bedrock (Béjar 2003);
ii. mining of the rock at depth by means of a system of pits and tunnels (Protzen 1983).

These extraction methods had a strong impact on the landscape, giving the quarry its classic stepped and cavities appearance, such as in the case of Rumiqolqa quarry, which supplied the andesite for the construction of Cuzco, during the Pachacutec empire. For this reason, Rumiqolqa was considered the main quarry in the Inca state.

It is part of the archaeological complex of Piñipampa, in the district of Andahuaylillas, about 32 km from Cusco. Geomorphologically, the quarry corresponds to an outcropping andesite zone, with a lava flow forming the so-called *lengua* that runs Northeast of Piñipampa. More than 500 facilities are present near the extraction sites, associated with the life and activity of the quarrymen. Even today, toponyms name the several sites (quadrants) where lithic material was extracted: Jahuacollayniyoc, Huascahuascan, Qomerqocha, Torrebaulchayoc, Parisniyoc, San José, Puca Cantera, Qakapunco, Bandohuajana, Tucuchayoc and others. The Rumiqolqa quarry shows very old phases of occupation, starting from 1000 B.C., and was used for the extraction of basaltic andesite and obsidian during the Ancient Horizon and the Early Intermediate Period. Work in the quarry during this period must have been managed in part by the Inca state, as shown by the discovery of public structures in the quarry, such as ceremonial and administrative centres, in the Iglesiachayoc sector, and described in literary sources (Sarmiento de Gamboa 2001; Béjar 2003).

The stone was extracted by mechanical separation of the stone from the bedrock, creating a characteristic quarry landscape made up of more or less regular steps, while internal movements between the different sectors were permitted by ramps, roads and slides (Vargas 2013). In this quarry there is also a pit, called Llama Pit by Protzen due to the presence of two petroglyphs with a llama. The pit is 100 m long, 60 m wide and 20 m deep (Protzen 1983). The type of stone extracted from the pit mirrors the pattern of pit and gallery quarries, where the rock layers vary with depth due to the natural weathering of the rock. Protzen identified three qualities of rock: (i) the first layer of porous stone; (ii) a second layer of light grey or light brown rock, compact but highly fractured; and (iii) a dense dark grey stone, good for construction (Protzen 1983).

The most common quarrying techniques were of two types: (i) the first based in digging channels for the detachment of the block from the bedrock following fracture lines, using wedges, bronze bars and levers, (ii) the second consisting in drilling holes using bronze chisels and tools into which wooden wedges were inserted, to be expanded with water, or levers, to force the detachment of the block (Protzen, 1983; Protzen and Batson, 1993) (Fig. 4.4).

Signs of these techniques can also be seen in some of the blocks in Ollantaytambo, while some bronze quarry tools are kept in the museum in Lima. Another technique observed on the blocks is the detachment of one piece of stone from another through the use of a "collar", as Protzen defines it. The practice consists of digging out a portion of stone until a detachment between the parts is achieved. This practice was observed in the Kachiqhata quarry, in the *Nawinpata* and *Ranrakural* sectors, within blocks and retaining walls. The practice of splitting was not very common in the case of large blocks, however, it was widely used for the production of small blocks (60 to 200 cm length, 20 to 80 cm width, and 20 to 50 cm height) (Protzen and Batson 1993).

The second quarrying strategy used by the Incas was surface quarrying. This operation involved collecting blocks already outcropping or completely detached by landslides, rockfalls, weathering, and glacial activity. These quarries often made it possible to recover large megalithic blocks, as in the case of the Kachiqhata quarry,

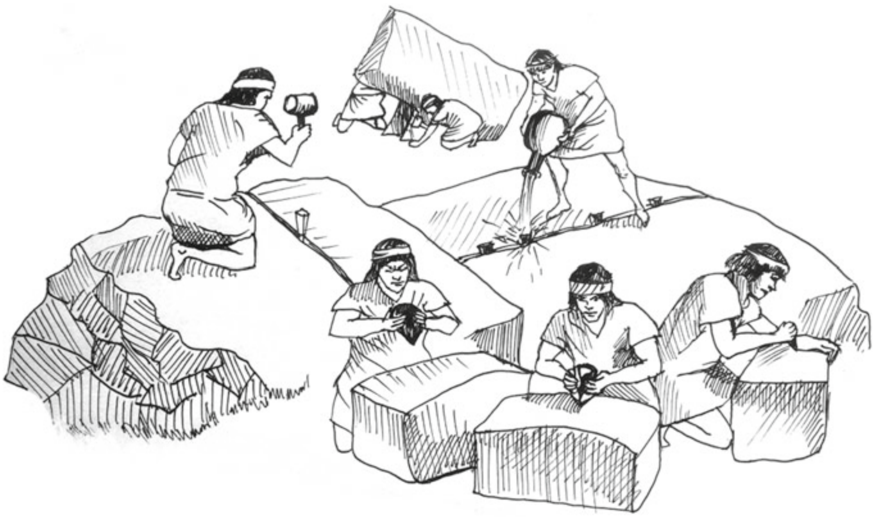

Fig. 4.4 Stone cutting techniques. Redrawn by Anna Kubicka from Kaufmann et al. (2006)

which provided the rose megaliths of Ollantaytambo, selected from a large rockfall on the side of the mountain (Ogburn 2013).

The Kachiqhata quarries are located along the Urubamba river, a few kilometres southwest of the Ollantaytambo site. The quarries were planted on two large rockfalls of a granite mountain, called Negra Buena. The quarries were first described by Squier in 1863 and then deepened by Protzen (Protzen 1983). The quarry is reached by a system of ramps, arriving at the river, and then at the stone deposit. The quarry has a series of paths and roads for the connection between the various sectors: North, South and West. The roads are slightly inclined (8–12°) and wide enough for the passage of blocks and people (4 to 8 m). The roads and ramps are made directly into the mountainside, regularised, and supported by retaining walls varying in height from 1 to 10 m. Wherever possible, the ramps were replaced by a slide such as the one in the northern sector which reaches the river, 250 m long and inclined at about 40° (Protzen 1983; Protzen and Batson 1993). Workshops for stone pre-processing (reduction) and temporary storage were set up in Kachiqhata. The large megalithic blocks were transported to special areas, where they were first rough-hewn to reduce their weight and even out the surface. Protzen identifies at least three such points, distributed in the West, South and North sectors. In particular, one of these processing points is stockpiled is strategically located at a ramp joining the North and South quarries. The areas show a large ground distribution of small fragments of lithic material (rose and red granite), result of preliminary roughing activity (Heizer and Williams 1968; Ogburn 2013).

Similar activity must have taken place near Cuzco, in the Huaccoto andesite quarry, where the extraction took place both from the lava flow and from the bedrock. Some examples of surface quarries linked to glacier activity are the Labrashcarrumi quarry in Ecuador and the Cajón Tambo quarry used for the construction of the Ingapirca site in Cañar (Gomis 2003). Usually, many blocks were divided on site into smaller or regularised blocks before transport.

The size of the quarried stones differed according to their use tone and the object to be built. Agurto Calvo proposes the following classification for the stone blocks into:

i. Small blocks, with dimensions not exceeding 20 cm (e.g. 20 × 20 × 20 cm), and a weight not exceeding 24 kg;
ii. Medium-sized blocks, ranging in size from 20 to 40 cm, and weighing between 50 and 72 kg;
iii. Large blocks, with dimensions ranging from 40 to 80 cm (e.g. 40 × 60 × 80 cm), and a weight of 420 to 570 kg;
iv. Very large blocks, from 80 cm to 1.6 m (e.g. 0.6 × 0.8 × 1.6 m), weighing 1,700 to 2,300 kg;
v. Cyclopean blocks, ranging in size from 1.6 to 7 m (e.g. 2 × 3 × 6 m) and weighing from 80,000 to 110,000 kg (Agurto Calvo 1987);

Studies, surveys and archaeological excavations carried out into Inca quarries have revealed the existence of special tools for quarrying activities, useful when extracting and working the material. Predominantly, stone and bronze tools as well as wooden boards were used, as in all pre-Iron Age civilisations. Bronze wedges and levers were found within the quarries and, together with their wooden counterparts, perishable and not found, they were used for the detaching and carving/drilling of blocks and stones. Hammerstones were certainly used and were found by Protzen, intact or in pieces, within the sites of Kachuqhata, Rumiqolqa, Waquoto and Pisaq (Protzen 1983). However, a small number of these tools have been found in the Kachiqhata quarry, mainly in the storage areas of'Incaraqay e Ñawinpata. This seems to be explainable given the unusual and perhaps valuable nature of some tools, which were therefore owned and kept by the workers.

During the recent excavations in Machu Picchu, conducted by Bastante in the Plaza Principal, the discovery of some hammerstones suggested the hypothesis of quarrying and working phases of the stone in situ, useful for the construction of the structures and preceding the reorganisation of the plaza as a ceremonial place. Archaeologically, this practice is widespread in any pre-industrial civilisation, where the intrinsic value of a work tool is such that the tool itself is carefully guarded (Outwater 1959; Protzen and Batson 1993). Hammerstones were formed using river cobbles, due to their rounded shape, and were of different materials, such as: (i) diorite, (ii) basalt, (iii) rhyolite, (iv) quartzite, (v) porphyritic trachyte, (vi) hematite. In some cases, these materials were not present on site, which shows how these tools were stored and transported. In the case of Hammerstones made of hematite, an iron oxide, both in the sources and in modern language the term used to identify the tool is similar: *hihuana* or *hihuaya* (Garcilaso de la Vega 1987; Protzen and Batson 1993).

The hammers could vary in weight from 2 to 8 kg. They were used during the quarrying process to separate the blocks from the bedrock, and likewise to break large blocks into smaller ones (Protzen 1983).

4.4 Transporting

One of the main problems associated with quarrying and, consequently, processing and setting stone was short, medium and long-distance transport. Transport is still one of the problems affecting any kind of movement of goods and must have been even more acute for ancient populations, who lacked the technology and means to move heavy objects. Most ancient societies overcame these difficulties at the cost of enormous efforts in terms of engineering and labour force. The previous paragraph describes how the Incas shaped the landscape to create ramps and paths for the movement of people and goods, both within the quarries themselves and between the quarries and the construction sites. However, the effort to transport, move and work on the blocks required hundreds, if not thousands, of people. In case of very large blocks, the number of people employed to transport them is certainly overestimated by the literary sources. For example, according to Garcilaso de la Vega (1987) tens of thousands of workers were employed in the transport of stone and the construction of the Sacsayhuamàn fortress.

However, reasonably this number should be around 2,000 man-units, after installing the towing systems (ropes and poles) and reducing the friction of the block with the ground (Protzen and Batson 1993).

The transport activity was certainly influenced by the type and size of the blocks, as well as the distance to the construction site. In the case of small and medium blocks, the activity could be carried out by one or more men supported by the use of panniers, baskets or haulers. Transporting the large blocks, or cyclopeans, was a much more complex and costly operation (Fig. 4.5).

The ways in which blocks were dragged are described in literary sources (Protzen and Batson 1993):

> *"Solian traer estos indios a fuerza de brazos unas piedras muy grandes, tirandolas con muchas cuerdas largas de bejuco i enequen,..., i son tan grandes que quince yuntas the bueyes no las trajeran […]"* (lib. 3, cap. 63) (Gutiérrez de Santa Clara 1905) [These Indians carried very large stones with the force of their arms, wrapping them with long cords of liana and enequen..., and they were so large that fifteen pairs of oxen could not have carried them […]].
>
> *"[…] llevabanlas arrastrando a fuerza de brazos con gruesas maromas; ni los caminos por donde las llevaban eran llanos, sino sierras muy asperas, con grandes cuestas por do las subian y bajaban a pura fuerza de hombres […]"* (lib. 7, cap. 27) (Garcilaso de la Vega 1987) [They carried them by dragging them by force of arms with big ropes. Nor were the roads were taken flat, but rather rugged mountain ranges, with great slopes upon which they were raised and lowered by the sheer force of men.]

Transport could be carried out in two ways: (i) by dragging, and (ii) by rolling (Agurto Calvo 1987).

i. The first method was dragging the blocks over their base, lubricating the sliding surfaces with wet clay. Examples of this type are evident in the road between Rumiqolqa and Ollantaytambo. In the case of Huaccoto, however, the main roads of the quarry are covered with river pebbles: rounded rocks useful to

Fig. 4.5 Transporting stone. Guamàn Poma de Ayala (1992)

facilitate the sliding of the blocks (Ogburn 2013). In some cases, the stones had a convex base to facilitate sliding. The drag marks are visible on several blocks, left by the friction between the stone and the road for hundreds or thousands of metres. Protzen identified several drag or shove marks on the blocks in Ollantaytambo. These marks are composed of parallel striations, on a smooth surface, and are also found on blocks abandoned along the road. In some cases, the blocks have these striations on two sides, a sign that the block itself was rotated during transport perhaps to overcome an obstacle (Protzen and Batson 1993).

ii. The second method consisted in rolling the blocks above wooden trunks, using drag ropes and other trunks as levers (Agurto Calvo 1987). Stone rollers are also attested in Inca settlements including Machu Picchu.

The Inca moved the large blocks, securing them with vegetable fibre ropes and using human strength to move them. The blocks were dragged up and down the ramps. The system provided for a net of ropes that secured the block to the workers both in its front and rear, so as to drag and hold, if necessary, at the same time. Confirming this method are the protuberances, gouges and grooves of different sizes and shapes that can be observed on the abandoned blocks or on the fitted blocks. Protzen identified five categories of these protuberances, which he classifies with the letters A to E. In all cases, these protuberances seem to be useful either for the insertion of levers or for the lodging of ropes, for the transport and the positioning during the construction phase. Cyclopean blocks had large protuberances, often parallel to the length of the block, to allow for better anchoring (Fig. 4.6).

4.5 Cutting, Dressing and Fitting

The stones had to undergo further work after being quarried. These probably received an initial cutting and dressing immediately after extraction, in an area adjacent to the quarry site, in order to reduce the material to be transported to the construction site where they were further processed. Cutting and dressing, or partial dressing, are established for some locations such as the Rumiqolqa quarry. The tools used for these operations were similar to those used for quarrying: mainly hammerstones of various sizes. These tools are usually smaller in size than those used for quarrying. In addition to the signs of hammering, there are also clear traces of other tools such as drills and blades on the cut blocks. The blocks were placed on earthen ramps to be worked more comfortably (Protzen 1983).

Stone cutting was a complex activity involving the detachment of parts of the rock to form other blocks for use. This activity left clearly identifiable traces on the embedded rock that negatively show the shape of the extracted block. These marks, called panlike or cuplike because of their shape, can be observed both in blocks found inside the quarries and in large blocks used for masonry, as in the case of the Main Temple and the Temple of the three Windows in Machu Picchu (Astete 2008) (Fig. 4.7a, b) and the Temple of the Sun in Ollantaytambo (Fig. 4.7c).

Most of this activity took place in the quarries themselves, as evidenced by the processing waste (dust, fragments, flakes and chips) produced by the reduction of larger blocks in the quarry of Rumiqolqa (Menotti 1998; Ogburn 2013).

Dressing or partial dressing, on the other hand, was intended to give the block a similar appearance to that which it would finally take on when assembled in the masonry. Dressing was done by hammering or tapping the faces of the block with small hammers and was completed by finishing the edges. There again, the activity produced a large amount of debris, mainly dust and chips, smaller in size than the

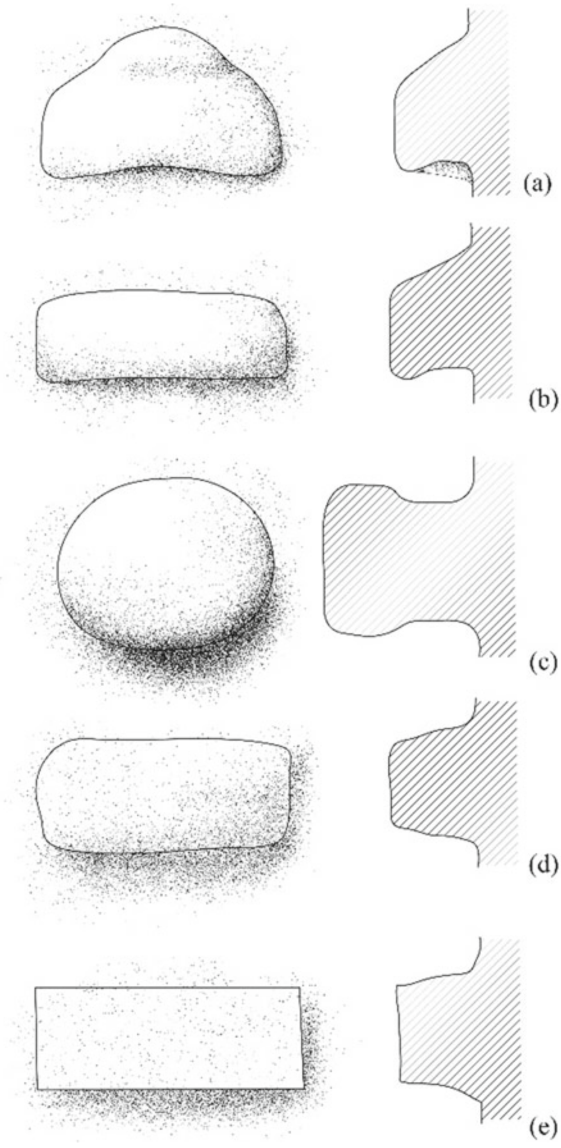

Fig. 4.6 Types of protuberances identified by Protzen. Reworked by the authors from Protzen and Batson (1993)

cutting. This debris is still found at the base of impressive Inca structures, such as the First Wall and the Wall of Ten Niches in Ollantaytambo, a sign that the dressing operation was completed at the same time as the fitting. The dressing operations left pillowlike (*almohadillado*) marks on the face of the blocks, i.e. the classic tapped appearance. It is also probable, judging by the marks found, that the Inca workers carved into the surface of the blocks to create an outline and guidelines for further

Fig. 4.7 Marks of extraction from larger blocks, visible at Machu Picchu in **a** the Temple of the three windows and **b** Main Temple and **c** in the Temple of the Sun in Ollantaytambo. Photos by the authors

processing, which gave the block its final shape for the fitting (Protzen and Batson 1993).

Fitting is the operation of placing the stones in order to create a wall. The Inca stonemasons were masters at this and their masonry was extremely precise in the way the blocks were joined together, being mainly dry masonry (i.e. without mortar). The bedding of the blocks took place in a schematic and systematic manner, leading block by block to the construction of the wall. Usually, the growth of the masonry took place with the bedding of the basal blocks (on the lower row) starting from one corner, until the opposite corner was reached. The vertical development of the masonry was mainly achieved by cutting the stones of the lower row so that they would fit perfectly with those of the upper row (a negative replica) and, at the same time, by thinning the structure as the height increased. The same procedure was used for the lateral joining of the blocks, where the contact surfaces were well worked and attuned for a perfect fit (Outwater 1959). The work of smoothing and bevelling to make the blocks fit together perfectly was probably achieved using an abrasive medium (sand), water, and a stone as a smoothing tool. Probably, the blocks were smoothed and joined before installation, so as to have a perfect positive–negative pair, before the weight of the stone had to be lifted (Agurto Calvo 1987). As noted by some scholars, a technique practised by the Incas to better match the stones within the masonry was the use of wedge-stones (*piedra-cuña*) (Harth-Terré 1964; Protzen 1983). These stones were used by the Incas to solve joining problems: (i) to fill the narrow space between two megalithic blocks which were to have to move them several times to produce perfect fit by "doing and testing",; (ii) when the work started from two sides and the last stone could have been inserted only frontally. Its specially formed front surface overlapped the neighbouring blocks and thus it masked all inaccuracies in fitting.

Wedge-stones offered Inca architects the possibility of filling these gaps, being worked to fit on at least three sides (two sides and the lower one) of the structure. These were inserted frontally into the masonry, creating a perfect fit. Examples of the use of this type of solution can be seen in the walls of Cuzco, Qorikancha and the stone of the Twelve Angles in Calle Hatunrumiyoq, in the walls of Saqsahuaman and in the Temple of the Sun at Ollantaytambo. In addition, the Inca architects used in some cases mechanical joining practices between the stones, through the use of metal clamps. The use of this expedient is clearly visible in the T-shaped marks left above the stones, such as those observed at Ollantaytambo and Cuzco (Protzen and Batson 1993). In addition, the protuberances on many of the larger blocks suggest that they played a key role in the fitting operations. It is possible that they were used to anchor ropes or levers, and it is probable that they were employed as props placed on the visible face to allow the rotation of the block during placement, preventing the whole face from generating friction with the ground and facilitating movement operations (Agurto Calvo 1987).

Inca architects used stone worked in different ways in their architecture. Agurto Calvo (1987) and other scholars have identified and classified some basic types of stonework (Fig. 4.8):

i. Natural: field stones collected and used without processing (Fig. 4.8a).
ii. Roughing: the result of roughing out stones to equalise their dimensions before the fitting (Fig. 4.8b).
iii. Edging: correspond to lithic units cut in a pre-established form, with a high number of percussions (Fig. 4.8c).
iv. Carving: are the most worked and time-consuming stones. Their surface is well worked and polished and they are used in architecture for the construction of regular and harmonious works (Gavazzi 2020) (Fig. 4.8d).

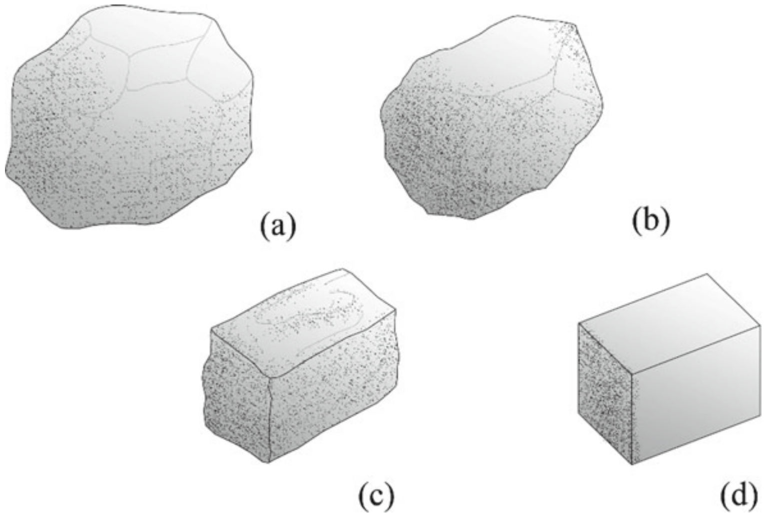

Fig. 4.8 Basic types of stonework. Reworked by the authors from Agurto Calvo (1987)

The finish of the exposed face and the edges of each block could, however, undergo a different degree of processing that characterises the type and the texture of wall: (i) natural; (ii) roughened; (iii) rounded or padded; (iv) convex; (v) bevelled; (vi) plan or polished (Fig. 4.9; see also Fig. 4.10).

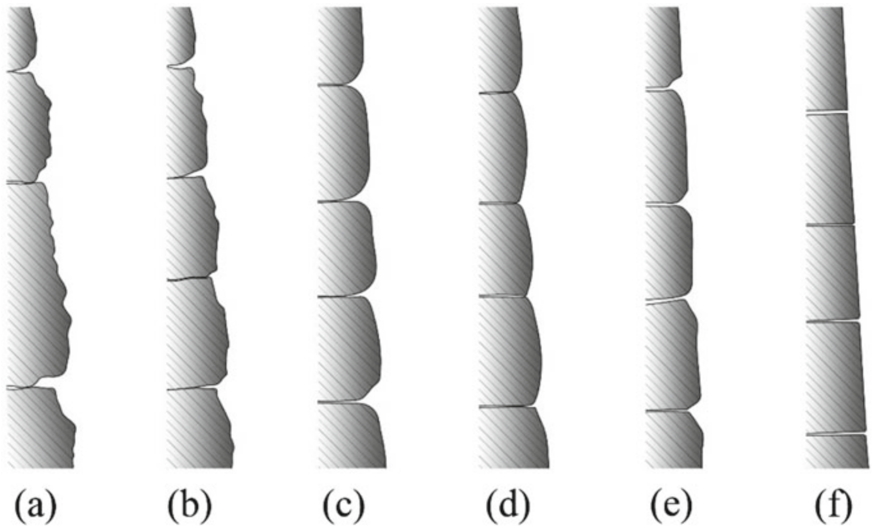

Fig. 4.9 Exposed face type: **a** natural, **b** roughened; **c** rounded or padded; **d** convex; **e** bevelled; **f** plan or polished. Reworked by the authors from Agurto Calvo (1987)

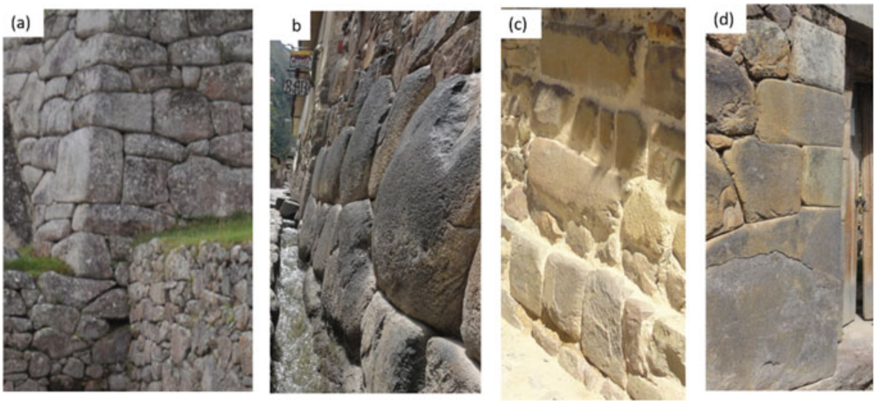

Fig. 4.10 Example of exposed face type. In Machu Picchu: **a** Natural/roughened (wall below) and bevelled (wall at the top); in Ollantaytambo **b** Convex; **c** bevelled; **d** plan. Photo by Nicola Masini

4.6 Masonry

Monumental administrative, military or religious buildings are certainly among the most impressive features of the product left by the Inca people. However, the Inca construction methods were varied and in most cases did not involve such an enormous effort as can be seen in the capital Cuzco or at the sites of Machu Picchu and Ollantaytambo. The symmetry and order observed in monumental constructions, a symbol of the power of the Empire, was not reflected within the walls of facilities and common or low-level buildings.

In fact, in most cases, Inca structures were built using (i) unworked or semi-worked fieldstones and argillaceous mortar, (ii) adobes and/or tapia. This reflected the status of the occupants or the role of the structure itself (Moorehead 1978).

Structures created using fieldstones and clay mortar are usually one- or two-floor structures, with walls ranging in thickness from 60 cm to 2.7 m in exceptional cases. The construction scheme involved the use of well-crafted and well-bonded stones at the corners and at the ridge of the walls, so as to ensure greater stability (with particular reference to the horizontal components of the thrusts), while in the central parts of the wall the stones were bound together with clay mortar. The stones arranged on the face of the wall could be arranged in regular rows (coursed) or in a less orderly manner (uncoursed). This was related to the shape, size and level of workmanship of the stone. Mainly, in coursed masonry, the stones were of a similar shape and weight, whereas in uncoursed masonry there was no scheme or stones selection (Gasparini and Margolies 1980).

The second type of mid- to low-level structure was built of adobe and tapia, also considered composite walls. Adobe is clay moulded to create unbaked bricks, in the mixture of which there is a certain amount of animal (e.g. fur) and vegetable fibres (e.g. straw, hay, grass) by reducing material shrinkage and the resulting micro-cracks. Adobe, being unfired clay, is greatly affected by humidity and the disintegrating action of water which causes it to dissolve or melt. For this reason, the Inca engineers used this type of masonry in conjunction with a base of mortared stone masonry. The stone base was usually 1.0 to 1.5 m high, enough to block the capillary rise of moisture from the ground and to protect the adobe from the rain-splash reflected on the ground. The walls were sloped inwards and covered by overhanging roofs to protect the adobe from the direct impact of rain. The fitting of the adobe was often done in a regular manner, using adobe bricks of equal size, alternating between headers and stretchers. This type of masonry obviously required periodic maintenance due to weather and water damage to the adobe (Moorehead 1978; Protzen and Batson 1993).

The Inca architects, also, adopted various solutions in their architecture made up prevalent of stone blocks (drywalls), which have been analysed in the past by scholars in order to create a typological seriation, particularly for the city of Cuzco and other important archaeological sites (Ollantaytambo, Machu Picchu, Tiwanaku) (Harth-Terré 1964; Gasparini and Margolies 1980). The idea behind the typological classification involved the analysis of certain characteristics of the stones used and the masonry built:

i. The characteristics of the material making up the masonry;
ii. the type of working (cutting and dressing) to which the stone has been subjected;
iii. the way in which the stones are arranged and placed within the masonry (fitting);

Following this criterion, scholars have drawn up general categories and subcategories to identify variations. The macro-categories identified are: (i) rustic type (*tipo rustico*), (ii) cell type (*tipo celular*), (iii) crimped type (*tipo engastado*), (iv) regular type (*sedimentary type*) and (v) cyclopean type (*tipo ciclopeo*) (Agurto Calvo 1987) (Fig. 4.11).

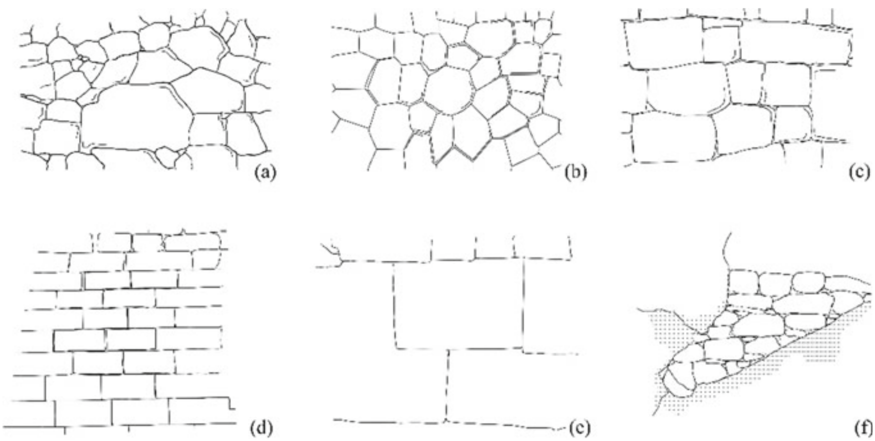

Fig. 4.11 Masonry macro-categories: **a** rustic type (*tipo rustico*); **b** cell type (*tipo celular*); **c** crimped type (*tipo engastado*); **d** sedimentary type or regular type (*tipo sedimentario*); **e** cyclopean type (*tipo ciclopeo*); **f** carved stones

i. The rustic type consists predominantly of fieldstones, with no particular emphasis on finishing and dressing. The stones were laid one on top of the other filling the gaps with earth, clay or smaller stones. The stones used were not uniform in size and could vary from small blocks to medium-large blocks, as well as the type of stone, which could be sandstone, limestone or volcanic. The same principle is used in the colour matching between the various stones, to which no particular attention was paid. Little or no work was done to make the various elements that made up the masonry fit together. Also serving a structural function (e.g. cornerstones) were roughly worked. The rustic type was mainly used for the construction of retaining walls, in andenes, terraces, farmhouses (*chujillas*), and facilities (Fig. 4.11a).

ii. The cell type is masonry whose elements are organised in such a way as to recall the pattern of cellular growth or an organic structure. It is a type of uncursed wall whose stones shape is polygonal, with five or six sides, and its dimensions vary from 20 cm to 1 m. Compared to the rustic type, builders paid more attention to selecting certain types of stone (andesite and limestone), which were also uniform in colour (dark, grey-white, rose). The surface of the blocks on the face side is polished, slightly convex. The apparatus of the finished wall has the appearance of an ordered grid, with connecting midpoints that give it its typical cellular structure. As in the case of the rustic type, the cell type also has reinforcements in the load-bearing joints (corners and jambs) obtained through the use of rectangular parallelepiped stones. This type of masonry was used for terracing, retaining walls, andenes and channels (Fig. 4.11b).

iii. The crimped type is probably the most observed drystone walling in Inca architecture. It consists mainly of large stones that are joined together perfectly by careful cutting, dressing and fitting. The size of the stones can vary, up to 2 m, while the material used was mainly durable stone: andesite, diorite and basalt. The colour of the masonry was closely linked to the type of stone used. The use of stones of different sizes did not allow a perfect development on horizontal lines as opposed to the sedimentary type (Fig. 4.11c).

iv. The regular and/or sedimentary type takes its name from the arrangement of the blocks, arranged in regular rows, which reminds us of sedimentary or stratified geological formations. The stones used in the construction of this type of architecture are very regular, of the same type and very similar shapes, bedded in order to create an orderly and harmonious effect, In most cases, limestone, andesite, diorite and basalt are used. The shape of the stone can be: trapezoidal, rectangular or tetrangular. The blocks are usually finely worked, with a rusticated, convex, flat and bevelled profile. This allowed the architects to compose the structure in an orderly manner, both in horizontal and vertical rows. The blocks were either denticulated or interlocking. The facade finish is in most cases polished or smooth. Often, for both structural and aesthetic reasons, the corners were reinforced with large blocks, larger than those used in the central part of the masonry. This type of masonry was used for public buildings and high-class houses, and in some cases to build canals or other structures, throughout the Inca Empire (Fig. 4.11d).

v. The cyclopean type includes structures created using very large stones of more than 3 m in size. This type of structure was a symbol of the power of the Inca empire to manage its workforce and to find advanced engineering solutions to the problem of extraction, transport, dressing and fitting. The stone used is generally limestone or andesite, in the colours white–grey, grey and rose. Before being placed, the stones were worked and finished for a perfect fit. The exposed parts are generally quite smooth, due to the polishing given by the workers and, of course, the effect of the weathering. This type of masonry is used in exceptional apparatus, such as defence walls, bastions and fortifications of sacred places. It can be found in several sites, including Sacsayhuamán and Ollantaytambo, and seems to have been inspired by the ancient building tradition observed in Tiwanaco (Agurto Calvo 1987) (Fig. 4.11e).

Another particular type of "masonry" used by the Incas was the practice of integrating outcrops into masonry or monumentalising them (Fig. 4.11f). This practice can be observed mainly in religious contexts and derives from the Incas' concept and relationship with Pachamama (Mother Earth). This practice consisted of building around large carved outcrops or living rock that were entrusted with a meaning related to the sacred world. The masonry built was therefore adapted to the topography of the land and rock, trying to minimise the visual impact of man-made alterations, but perfectly blending the relationship between man and nature. Examples of this practice can be found in major sacred sites such as in the Machu Picchu complex, in the Temple of the Sun or Tower, at the base of the Temple of the Condor, partly in Intihuatana and in the Temple of the Moon in Huayna Picchu (Dean 2010; Astete 2020).

In addition to load-bearing masonry, Inca construction techniques included the construction of equally important building elements and construction details, such as: (i) foundations, (ii) openings and niches, (iii) floors, and (iv) roofs (Protzen and Batson 1993; Wright et al. 1999; Astete 2020).

The foundation work of the structures was certainly one of the main moments in the construction. The foundations were created in trenches 30 to 50 cm deep below the ground level, in which dry stones or stones bound with mortar were laid. The bedrock was worked so that the foundation stones adhered perfectly to it. The foundation wall could be 10 to 15 cm thicker than the exposed wall. In some cases, the wall was built without a foundation, directly on the carved bedrock (Wright et al. 1999).

The structures built by the Incas had some openings consisting mainly of doorways and windows, as well as small blind niches.

Doorways were generally placed on one of the long sides of the buildings, unless this was impractical. They were trapezoidal in shape with often rounded corners. As literary sources suggest, the Incas did not use doors panels to close openings (Fig. 4.11a). Windows were also integral elements of Inca masonry. These were generally very small, quadrangular in shape (Gasparini and Margolies 1980; Protzen and Batson 1993) (Fig. 4.11b).

Niches were a very common element in Inca architecture. The niches were usually built between 1.2 and 1.5 m high and were distributed symmetrically, along a line, on each wall of the building. The niches could also be arranged in several rows. Their shape was quadrangular or trapezoidal with a height of 90 cm, a depth of 40 cm and a base of about 50 cm. They were usually architraved elements, the lintel of which consisted of a large stone. The construction of the niche in the wall probably took place in an orderly process. Once the workers had built the row of the niche base, the niches corners were constructed and then the masonry space between them was completed (Fig. 4.13) (Niles 1987). The use of the niches was probably related to housing objects, sacred and ceremonial elements, or purely ornamental, as in the case of the external niches (Protzen and Batson 1993; Astete 2020) (Fig. 4.12c).

The ground-floor floors were usually made of tamped earth. The floors of the upper floors, on the other hand, were light, supported by beams of circular cross-section and made of a weave of wood and fibre, probably mixed with clay and other materials. The Inca built roofs out of perishable materials (e.g. wood, fibres, ropes) which have not survived to date. The roof was very tapered, with gabled pitches and a slope from 50 ÷ 53 (many examples in Cusco) to 65 degree (for example in Ollantaytambo).

The span of the roof structure was relatively small, about 2.8–4.5 m, and in exceptional cases could reach up to 11 m (Agurto Calvo 1987). Some scholars have proposed a specific function for each detail of the particular configuration of the gable and eaves. The notches at the base of the gable walls serve to accommodate a base purlin, which is located on the outer crown of the long walls. The inner projections receive the roof frame made of tripods made of round timber. The depth of the recess in the crown of the gable walls accommodates the thickness of the purlins, leaving the upper part of the purlins flush with the outer crown. The purlins, supported on tripods, are fixed to horizontal pegs in the inner crown. The eyebolts in the outer ring

Fig. 4.12 **a** Doors, **b** windows and **c** niches at Machu Picchu. Photograph by the authors

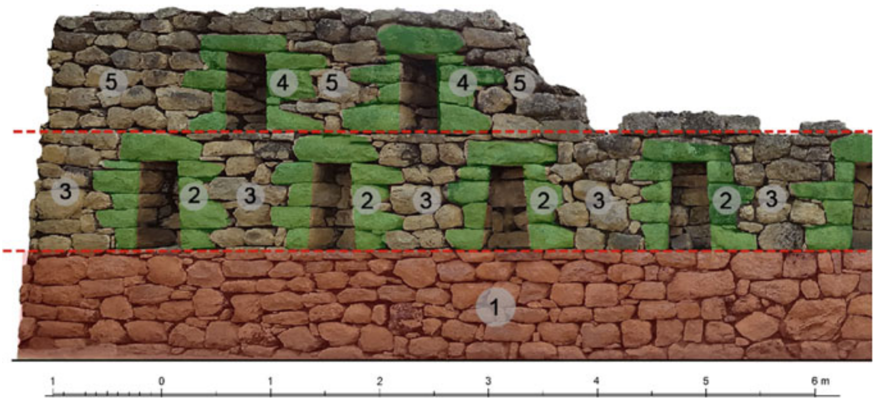

Fig. 4.13 Machu Picchu: the wall of the Great Kallanka in Sector 5D. Numbers correspond with subsequent technological phases of the wall erection process. *Source* Kubicka (2019, p. 143, Ryc. 98)

are used to tie a mat stretched over the purlins. The mat receives the scaffolding, which is sewn to it. The outer pegs provide an anchorage for the matting and stuffing to the eaves, preventing the wind from blowing the roofing material away (Lee 1988a, b; Protzen and Batson 1993; Nair et al. 2018) (Fig. 4.14). The type of roof depended on the type of underlying structure. For this reason, there were many different types of roofs, based on the number of columns, supporting timbers and the type of joints. An accurate classification was made by Agurto Calvo (Agurto Calvo 1987).

4.7 Conclusions

This chapter dealt an overview on Inca building culture, with particular reference to Urubamba Valley and Machu Picchu, framed in the context of a systemic approach to buildings, in its technological, socio-economic implications.

The articulation of the overview is based on the diverse phases of the construction process (from quarrying activities techniques to the transporting and lifting building stones, from the cutting and dressing to fitting and laying of stone blocks), highlighting the specificities of the single phases, and at the same time the reciprocal connections, as part of a building culture.

The approaches used so far by scholars are based on critical surveys and comparative analyses of construction techniques which, as a whole, make it possible to address the theme of construction culture in a broader framework of relations with Inca culture, society and technologies.

Important steps forward can be made with:

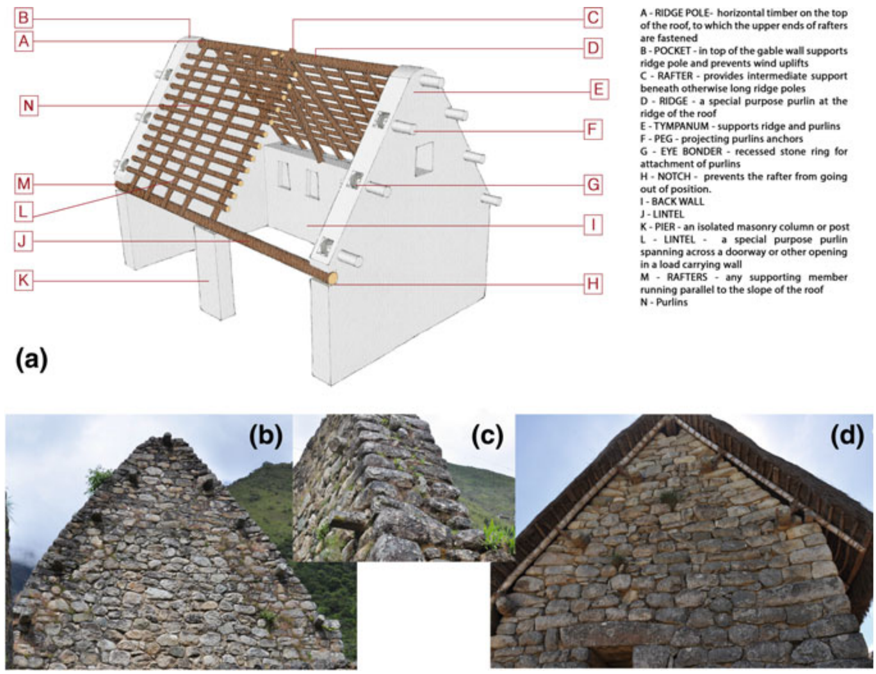

Fig. 4.14 (a) Scheme of the roof structure; (b) Wall tympanum including stone pegs with the anchor function for overhanging purlins; (c) Details of stone pegs; (d) Building with the complete covering of the mantle composed of compacted straw and small rafters

i. analytical approaches based on archaeological applications of architecture, using the Harrys method, as proposed in this volume by Koscuk and Bastante (2021),
ii. archaeometric investigations aimed at identifying the loan quarries,
iii. close-range imaging/remote sensing approaches for the detailed study of stone working techniques,
iv. and aspects connected with the design and execution of the works, including the identification of metrological relationships, such as the one based on the cosine quantumgram method, developed and presented in this volume by Kubicka and Kościuk (2021)

References

Agurto Calvo S (1987) Estudios acerca de la construcción, arquitectura y planeamiento incas. Capeco, Lima

Astete F (2008) Proceso constructivo de la ciudad inka de Machupicchu. 13–21

Astete F (2020) Llaqta de Machupicchu: sacralidad y proceso constructivo. In: Astete F, Bastante JM (eds) Machupicchu. Investigaciones interdisciplinarias. GD Impactos, Miraflores - Lima, pp 313–325

Bastante JM (2016) Investigaciones Interdisciplinarias en la Llaquta de Machupicchu. Arqueología y Sociedad 267–276. https://doi.org/10.15381/arqueolsoc.2016n32.e13326

Béjar IS (2003) La cantera inca de Rumiqolca, Cusco. Boletín de Arqueología PUCP, pp. 407–417

Betanzos J de (2008) Suma y narración de los incas. Echo Library, Middlesex TW11 [England]

de Betanzos J, Hamilton R, Buchanan D (1996) Narrative of the Incas, 1st edn. University of Texas Press, Austin

Bonavia D (2000) The origin of the Incas and the Chanca question. In: Bákula C, Bonavia D, Laurencich Minelli L, et al. (eds) The Inca world: the development of pre-Columbian Peru, A.D. 1000 - 1534. University of Oklahoma Press, Norman, pp 133–147

Bray TL (2013) Water, ritual, and power in the Inca Empire. Lat Am Antiq 24:164–190

Brundage BC, Toynbee AJ (1963) Empire of the Inca. University of Oklahoma Press, Norman

Castro J, Vallejo LE, Estrada N (2019) The optimal design of the retaining walls built by the Incas in their agricultural terraces. J Cult Herit 36:232–237. https://doi.org/10.1016/j.culher.2018.09.013

Cieza De Leon P de (2015) L'impero degli Incas = El señorío de los Incas. Quodlibet, Macerata

Cieza de León P de (2021) Segunda parte de la crónica del Perú, que trata del señorio de los Incas Yupanquis y de sus grandes hechos y gobernacion. Independently published

Cobo B, Hamilton R (1979) History of the Inca Empire: an account of the Indians' customs and their origin, together with a treatise on Inca legends, history, and social institutions

D'Altroy TN (2014) The Incas, 2nd ed. Wiley-Blackwell, Chichester, West Sussex; Malden, MA

Davidson R, Fehren-Schmitz L, Llamas B (2021) A multidisciplinary review of the Inka imperial resettlement policy and implications for future investigations. Genes 12:215. https://doi.org/10.3390/genes12020215

Dean C (2010) A culture of stone: Inka perspectives on rock. Duke University Press, Durham, NC

Garcilaso de la Vega (1987) Royal commentaries of the Incas and General history of Peru. 1: ..., 1. paperback print.-1987. University of Texas Press, Austin

Gasparini G, Margolies L (1980) Inca architecture. Indiana University Press, Bloomington

Gavazzi A (2020) Tecnomorfología de la llaqta inka de Machupicchu. Materiales, métodos y resultados del levantamiento arquitectónico y paisajístico. In: Astete F, Bastante JM (eds) Machupicchu. Investigaciones interdisciplinarias. GD Impactos, Miraflores - Lima, pp 353–381

Gómez J, Schobbenhaus C, Montes NE (2019) Geological Map of South America At a Scale of 1: 5M. Servicio Geológico Colombiano

Gomis D (2003) Prospección y excavaciones en la cantera de Cajón Tambo (provincia de Cañar). Rev Antropol 17:37–67

Guamàn Poma de Ayala F (1992) Conquista del regno del Perù. Sellerio, Palermo

Guamàn Poma de Ayala F (1615) Nueva corónica y buen gobierno

Guamán Poma de Ayala F (1967) Historia gráfica del Perú. Lima

Guamán Poma de Ayala F (2006) The first new chronicle and good government, abridged. Hackett Pub. Co, Indianapolis

Gutiérrez de Santa Clara P (1905) Historia de las guerras civiles del Perú (1544–1548) y de otros sucesos de las Indias. V. Suárez

Harth-Terré E (1964) Técnica y arte de la cantería incaica. Garcilaso, Cuzco, Perù

Heizer R, Williams H (1968) Archaeological research in Peru and Bolivia. National geographic society research reports for 1963. National Geographic Society, Washington, DC, pp 127–134

Hemming J (2012) The conquest of the Incas

Hyslop J (1984) The Inka road system. Academic Press, Orlando

Julien C (2009) Inca worldview. In: Raaflaub KA, Talbert RJA (eds) Geography and ethnography. Wiley-Blackwell, Oxford, UK, pp 128–146

Julien CJ (1988) How Inca decimal administration worked. Ethnohistory 35:257. https://doi.org/10.2307/481802

Kaufmann HW, Kaufmann JE, Hook A (2006) Fortifications of the Incas: 1200–1531. Osprey, Oxford

Kościuk J, Bastante J M (2021). In a search for Inca construction process logistics. Case studies of four structures from the Llaqta Machupicchu

Kubicka A (2019) Zastosowanie metody cosine quantogram do analizy metrologicznej kompleksu Machu Picchu/Application of a cosine quantogram method in the metrological analysis of the Machu Picchu settlement. Phd, Faculty of Architecture, Wrocław University of Science and Technology

Kubicka A, Kościuk J (2021). In a search for standards in Inca measuring system, in this volume

Lee VR (1988a) The lost half of Inca architecture. Lee, Wilson, Wyo

Lee VR (1988b) A study of function, form and method in Inca architecture. Lee, Wilson, Wyo

Marsh EJ, Kidd R, Ogburn D, Durán V (2017) Dating the expansion of the Inca Empire: Bayesian models from Ecuador and Argentina. Radiocarbon 59:117–140. https://doi.org/10.1017/RDC.2016.118

McEwan GF (2008) The Incas: new perspectives. W.W. Norton, New York

Menotti F (1998) The Inkas: last stage of stone masonry development in the Andes. Archaeopress, Oxford, UK

Moorehead EL (1978) Highland Inca architecture in Adobe. Ñawpa Pacha: J Andean Archaeol: 65–94

Nair S, Archila S, Hastorf CA (2018) The lost half of Andean architecture: eighteenth-century roofing traditions and enviromental use at chinchero, Perù. Lat Am Antiq 29:222–238. https://doi.org/10.1017/laq.2018.4

Niles SA (1987) Callachaca: style and status in an Inca community. University of Iowa Press

Ogburn D (2004) Power in stone: the long-distance movement of building blocks in the Inca Empire. Ethnohistory 51:101–135. https://doi.org/10.1215/00141801-51-1-101

Ogburn D (2013) Variation in Inca building stone quarry operations in Peru and Ecuador. In: Tripcevich N, Vaughn KJ (eds) Mining and quarrying in the Ancient Andes. Springer, New York, NY, pp 45–64

Ogburn DE (2012) Reconceiving the chronology of Inca imperial expansion. Radiocarbon 54:219–237. https://doi.org/10.2458/azu_js_rc.v54i2.16014

Ogburn DE (2004) Evidence for long-distance transportation of building stones in the Inka Empire, from Cuzco, Peru to Saraguro, Ecuador. Latin Am Antiq 15:419–439. https://doi.org/10.2307/4141586

Outwater JO (1959) Building the fortress of Ollantaytambo. Archaeology 12:26–32

Pigeon G (2011) Inca architecture: the function of a building in relation to its form

Posnansky A (1945) Tihuanacu: The cradle of American man. J.J. Augustin, New York

Protzen J-P (1983) Inca Quarrying and stonecutting. Ñawpa Pacha: J Andean Archaeol: 183–214

Protzen J-P, Batson R (1993) Inca architecture and construction at Ollantaytambo. Oxford University Press, New York

Protzen J-P, Nair S (1997) Who taught the Inca Stonemasons their skills? a comparison of Tiahuanaco and Inca Cut-Stone Masonry. J Soc Archit Hist 56:146–167. https://doi.org/10.2307/991281

Rostworowski de Diez Canseco M (2000) Estructuras andinas del poder: ideologia religiosa y politica. IEP, Lima

Rostworowski M (2000) The Incas. In: Bákula C, Bonavia D, Laurencich Minelli L, et al. (eds) The Inca world: the development of pre-Columbian Peru, A.D. 1000 - 1534. University of Oklahoma Press, Norman, pp 143–188

Rowe JH (1946) Handbook of South American Indians. In: Steward JH (ed). Smithsonian Institution, Washington DC.

Rowe JH (1960) Tiempo, Estilo y Proceso Cultural en la Arqueologìa Peruana. Instituto de Estudios Andinos, Berkeley

Sarmiento de Gamboa P (2001) Historia de los Incas. Miraguano Ed, Madrid

Schama S (1995) Landscape and memory, 1st ed. A.A. Knopf: Distributed by Random House, New York

Szemiński J, Ziółkowski MS, Wachtel N (2018) Mitos, rituales y política de los incas, Primera edición. Ediciones El Lector, Arequipa, Perú

Trigger BG (1990) Monumental architecture: A thermodynamic explanation of symbolic behaviour. World Archaeol 22:119–132

Vargas S (2013) Tecnología Prehispánica Tecnologías de la Construcción de Viviendas y Sistema vial

Wright KR, Zegarra AV, Lorah WL (1999) Ancient Machu Picchu drainage. Engineering. https://doi.org/10.1061/(ASCE)0733-9437(1999)125:6(360)

Ziółkowski M, Abuhadba JB, Hogg A, et al (2020) When did the Incas build Machu Picchu and its satellite sites? New approches based on radiocarbon dating. Radiocarbon: 1–15. https://doi.org/10.1017/RDC.2020.79

Chapter 5
Astronomical Observations at Machu Picchu: Facts, Hypothesis and Wishful Thinking

Mariusz Ziółkowski and Jacek Kościuk

Abstract The aim of this text has been the evaluation of the hypotheses, formulated by various authors, on the possible astronomical function of seven structures and architectural ensembles located in the Llaqta of Machu Picchu and its immediate vicinity: the Temple of the Sun, the Room of the Mortars, the cave of Intimachay, the Temple of Condor, the Intihuatana, the Mirador de Inkaraqay, the River Intihuatana as well as the site of Llactapata. Apart from the Room of the Mortars, whose astronomical function was revealed to be dubious, the remaining six ensembles present well-documented evidence of astronomical alignments, with a marked preference for orientations towards sunrise on the June Solstice, and the demarcation of a fixed number of days around this phenomenon. Two structures, namely Intimachay and the Mirador de Inkaraqay, meet instrument requirements for precision observations, but of different types. The latter structure, provided with two observation tubes, a unique case in Inca architecture, seems to have been designed for observations of the Pleiades and Venus at its maximum elongation, in the frame of a multiannual cycle. Intimachay, on the other hand, was used for observations of the cycles of the Sun and the Moon.

Keywords Inca astronomy · Inca architecture · Machu Picchu · 3D laser scanning

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5.1 Introduction

Before starting the analysis of the possible astronomical function of some structures of the Llaqta of Machu Picchu and its satellite sites, we have to emphasise a thematic restriction that we have imposed on our work. The explanation of our position seems important, especially in the context of the recent publication of Steven Gulldberg, who presented a comprehensive overview of Inca astronomy, devoting much attention to the Llaqta of Machu Picchu and some of its satellite sites (Gullberg 2020). It is that we will limit ourselves to the discussion of the mainly technical aspects of the structures analysed, with the aim of proving (or rejecting) the feasibility of certain types of astronomical observations by the Incas, postulated by other authors and/or resulting from our own work on the subject. On the other hand, we will neither engage in discussions about the location of the Llaqta of Machu Picchu in its geographical environment and the possible symbolism of constituent elements (rivers, snow-capped peaks, etc.) of the latter nor about the alleged symbolic "long-distance" relationship of the Llaqta with Vilcanota (Magli 2009) nor about the symbolism of the parts of the eponymous site in terms of Inca cosmology, etc. These topics, undoubtedly of much interest and relevance, have been profusely debated by other authors. A detailed discussion of their postulates would go far beyond the limits of this chapter.[1] However, it seems appropriate to point out some issues addressed in the mentioned studies, which are important for the technical aspects of our interest. First of all, the design of the Llaqta in relation to the cardinal points is a matter discussed by Johan Reinhard (2007) in his well-known study:

"A careful look at the geographical location of Machu Picchu reveals that it is not only at an ecological centre between the mountain highlands and the forest lowlands, but it is also located among the most sacred mountains of the region. In addition, it is virtually encircled by the sacred Urubamba River, which flows generally in a southeast to northwest direction, replicating the passage of the sun. At key times of the Inca calendar the sun rises and sets behind snow-capped mountains, which are still considered powerful deities today. The Southern Cross, centre of the Milky Way, the celestial river in Inca thought, lies in juxtaposition with Salcantay, one of the most sacred mountains of the Incas and directly connected to Machu Picchu. Sacred mountains lie in the four cardinal directions from the site" (Reinhard 2007, 130). Reinhardt also postulates that some of these mountains were represented by certain components of the same Llaqta, both natural (the Sacred Rock) and artificial (Intihuatana). Similar postulates have been formulated, on the basis of convincing arguments, in the case of other ceremonial centres, such as Pariacaca (Astuhuamán Gonzáles 2007, 24 et seq.).

[1] In particular by Johan Reinhard (2007) and by Steven Gullberg (2020).

Regarding the topographical-astronomical relationship of different sites around the Llaqta, let us note Steven Gullberg's suggestion related to the site of Llactapata: "The Llactapata ridge can be seen from Machu Picchu, five kilometres across the gorge below. Well over 100 structures have been found engulfed by the cloud forest. The Llactapata Sun Temples kept clear and exhibits distinct solar orientation. The Llactapata Sun Temple, the River Intihuatana at the base of the gorge, and the Sacred Plaza of Machu Picchu all lie on the axis of the June solstice sunrise/December solstice sunset (…). A ceremonial channel beginning at the central door of the Sun Temple points across the River Intihuatana to the Sacred Plaza (…). On the horizon beyond is where the Sun rises on the June solstice and also points near to the heliacal rise of the Pleiades" (Gullberg 2020, 814).

To conclude these introductory remarks, it is necessary to specify what we understand by the term "astronomical functions" of the structures to be analysed below? We will repeat what we have already emphasised several times in our previous studies (Astete Victoria et al. 2017; Ziółkowski 2015; Ziółkowski and Kościuk 2018) that when discussing devices used for tracking the movement of celestial bodies, two different categories of arrangements are considered:

- Those, due to religious and ceremonial reasons, aimed at an approximate orientation towards the rising or setting of the sun (or another celestial body) at some important moment in its annual transition across the horizon. In these cases, precision of astronomical observation is not so important but rather creating a visual effect for the masses of the faithful gathered in spacious plazas in the main ceremonial centres (Aveni 1981; Ziółkowski 2015).
- Those, which may be called "precise astronomical instruments", intended for the use by a few priest-astronomers, as mentioned in some sources (Sarmiento de Gamboa, Anónimo 1906, 151–152; Astete Victoria et al. 2017; Ziółkowski and Kościuk 2018).

In the following lines we will analyse from this perspective the following structures and architectural ensembles of the Llaqta of Machu Picchu and some of its satellite sites (Fig. 5.1): Torreón (the Temple of the Sun), Sala de los Morteros (the Room of the Mortars), the cave of Intimachay and a unique architectural structure on the northern slopes of Huayna Picchu—El Mirador de Inkaraqay (Fig. 5.2).

These are not all the structures of the Llaqta Machu Picchu and its surroundings, about which astronomical hypotheses have been formulated,[2] but we have focussed on the analysis of those structures for which we have 3D measurements and orientations based on our own surveys, observations and calculations. However, we will also refer, albeit more briefly, to three important structures such as the Temple of Condor

[2] Among these are the "Temple of the Condor" (Westerman 2005) and the "Intihuatana de Urubamba" (Gullberg and Malville 2014).

(Fig. 5.1), the River Intihuatana as well as the site of Llactapata (Fig. 5.2). The limitation of our comments in this case results mainly from the lack of comparative data from our own field studies.

Fig. 5.1 Llaqta Machu Picchu and the places discussed in the text (elaborated by J. Kościuk)

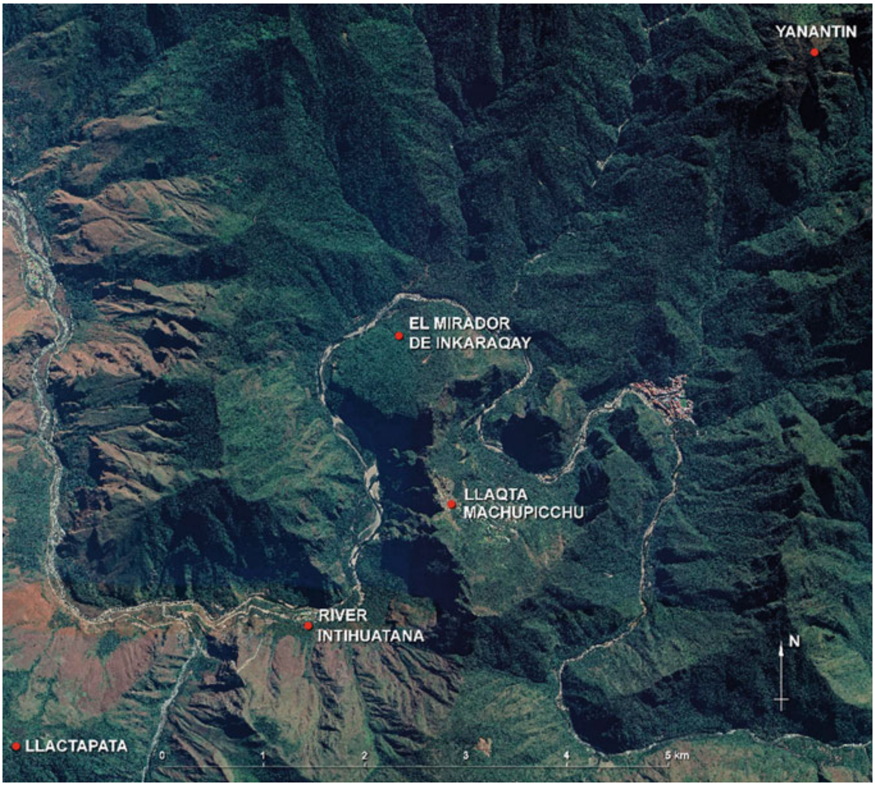

Fig. 5.2 Satellite sites around Llaqta Machu Picchu as discussed in the text (drawn on GoogleEarth photo by J. Kościuk)

5.2 Methodology

From the point of view of research methodology, we must answer some basic questions here—what kind of astronomical observations are we dealing with:

- gnomonic,
- horizontal,
- zenithal?

- In case of the horizontal and gnomonical observations of the Sun, we must take into account what moment was particularly important for the Inca astronomers?
  - the first ray of the rising Sun,
  - the appearance of the middle of the Sun disk above the horizon,
  - or the entire Sun disk visible above the horizon?

In turn, regarding the fieldwork methodology and necessary subsequent analysis, we must consider the following aspects:

How accurate is the plan of the analysed building?
By what method and with what accuracy was it oriented relative to the true north?
How precisely was the orientation of the building linked to the orientation of the horizon?
Finally, when analysing existing publications, we must pay attention to how consistent the text and accompanying drawings are

The buildings and structures described in this chapter, for which there are more or less convincing arguments about their potential astronomical function, may have served gnomonic, horizontal and zenithal observations. Unfortunately, we have no data to firmly state what moment of the Sun path was particularly crucial for the Inca astronomers in case of each particular structure. This, however, at least in some situations, could be deduced from the analysis of the building itself by determining for which moment the given astronomical "instrument" is useful, or the most precise.

The input data that we use in the analyses presented here is the result of a 3D laser scanning project carried out in cooperation with the Machu Picchu National Archaeological Park. Already in 2012, we set up a detailed geodetic network on Machu Picchu consisting of 59 measurement stations. Angle and distance to each of the visible points were measured from each of these stations using Leica TCRP1203 totalstation. In order to increase the accuracy, angular measurements were made twice, each time in two opposite positions of the lunette. The tachymetric data obtained in this way were adjusted using the least-squares method.

Additionally, static GPS measurements were done on 8 points lying across the entire area. Based on the four reference points[3] of the official geodetic network, these data were also aligned using the least-squares method. The rigid survey network was then transformed (rotation and translation) from the local coordinates system into the global geodetic UTM18S coordinates. The maximum errors were in a range of 20 mm or less.[4]

In 2012, 3D laser scanning of the central part[5] of Machu Picchu also began.[6] Initially, a scanner of the Machu Picchu Park Directorate (Leica ScanStation 2) was in use, and in the following years (2014–2015),[7] courtesy of Leica Geosystems Poland, we used the Leica ScanStation C10 scanner. Finally (2016–2018), we brought to the site our own Leica P40 instrument. More than 350 scan stations were completed,

[3] They were points: Placa 149, Placa 150, Placa 167 and Placa 186.

[4] All geodetic measurements were made by a team led by Bartłomiej Ćmielewski.

[5] That is, within the limits available for visiting by tourists. The entire area of the Machu Picchu National Archaeological Park is over 300 km^2.

[6] This part of the scanning project was coordinated jointly by the architect of the Machu Picchu Park—César Medina Alpaca and Jacek Kościuk.

[7] From that moment on, the entire scanning project was in the hands of Jacek Kościuk.

thus covering all the essential areas and buildings. Whenever possible, referencing to the aforementioned survey network has been done by placing HDS targets directly on the network points. In the areas from which no such points were visible, cloud to cloud registering has been used with the least-squares method to minimise possible errors which did not extend 1 cm over the whole site. In the few cases when the errors turned out to be bigger, weighting was used.

Since the general orientation of the whole project was based on global geodetic WGS-84 coordinates, for archaeoastronomical analysis, it was necessary to introduce an adjustment for the true north—the greed convergence correction. It was calculated with the help of Walls Project Editor v2 and for Machu Picchu lying within UTM 18S Zone, whose central meridian is 69°W, resulted in −0.56° adjustment.

Although the whole project is not finished yet, the data derived from 3D laser scanning were intensively used for the presented below archaeoastronomical analysis. All the plans and sections are directly derived from the 3D point cloud, while all the computer simulations of the Sun impact were made on 3D mesh models based on the scanning results.

As for the more precise orientation of particular buildings and linking it to the orientation of the horizon, direct Sun observations were used. The totalstation was set in front of the building, and several characteristic points were measured on the horizon (horizontal and vertical angles) and on the building itself (both the angles and the distance). For the last, often HDS targets for 3D laser scanning were used as the reference. From the same totalstation location, up to 20 positions of the Sun were measured in 1–2 min intervals and the true north direction was calculated with the help of Stellarium or Cartes du Ciel software alternatively. Finally, still using the same tripod position, the totalstation was replaced with a digital camera mounted on a panoramic head, and several overlapping pictures of the horizon were shot.

In most cases, we received good compatibility between our measurement and the official plan of Machu Picchu kindly provided by the Park Direction. The differences did not exceed +/−0.16° and must be explained mainly by the necessary simplification of the general plan of Machu Picchu, which did not take into consideration all the local irregularities of the sloping and often curved walls. For the processing of the data and the reconstructions of the images of the sky at the time of the construction and functioning of this Inca site (about fifteenth century AD), we have used the software Cartes du Ciel 4.0 and Stellarium v. 0.16.0. With this instrumental basis, let us now examine the structures and architectural ensembles mentioned above. We will start with the Torreón, as this is the building that has been the subject of numerous interpretations concerning its possible astronomical function.

5.3 The Torreón or the Temple of the Sun

The Torreón[8] (Fig. 5.3) is built on top of a pile of big granite blocks that are the characteristic features of the whole geomorphology of Machu Picchu.[9] The whole structure consists of two distinct parts: the lower part, often referred to as the Tumba Torreón, and the upper part, which will be the main subject of the following analysis.

The lower part occupies an irregular cave-like space between large lumps of granite wedged against each other. The gaps between the granite blocks are filled with the fine ashlar, Cusco-style masonry in which several trapezoid niches are arranged (Fig. 5.3b). In some parts, the natural rock has been carefully carved in the form of stepped ledges, platforms and prisms.

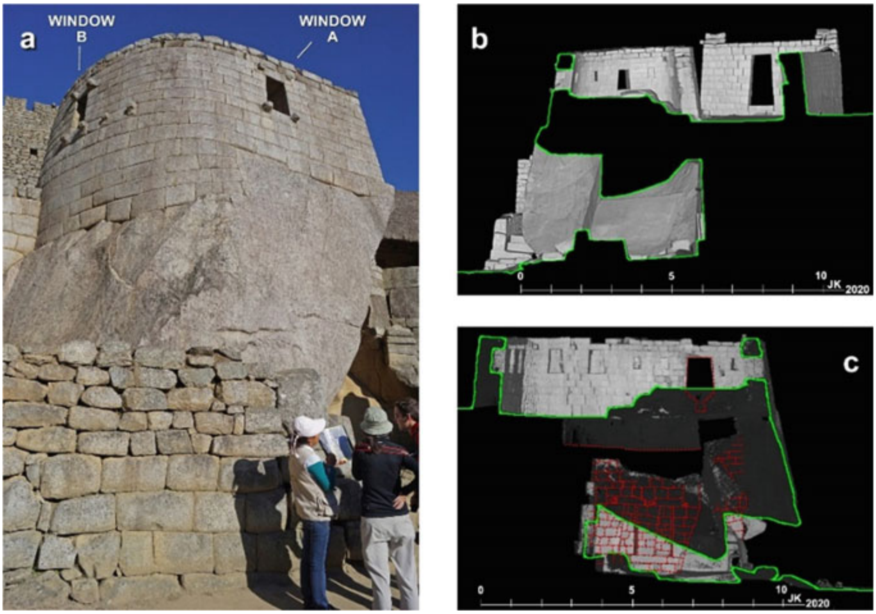

Fig. 5.3 The Torreón of Machu Picchu. **a** The Torreón as seen from the east, **b** vertical section across Window A looking south, **c** vertical section across Window A looking north (photo and drawings by J. Kościuk)

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[8] In the following lines we are using extensive excerpts from our recently published detailed study of possible astronomical orientations at the Torreón (Ziółkowski and Kościuk 2020).

[9] It is worth mentioning that some scientists see this as one of the reasons that this place was chosen by Inca builders (Canuti et al. 2009, 256).

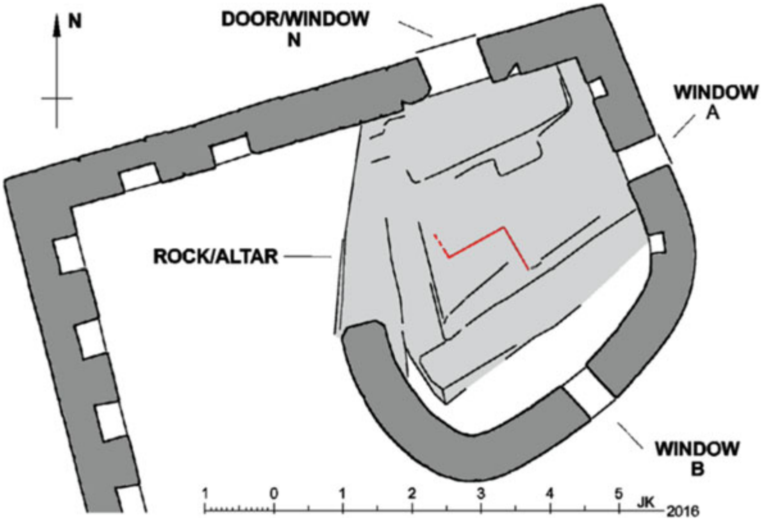

Fig. 5.4 The upper part of the Torreón according to 3D laser scanning results. The Z-like sharp edge on the top of the altar is marked in red (elaborated by J. Kościuk)

Fig. 5.5 Panoramic view of the upper part of the Torreón (photo J. Kościuk)

The upper part of the Torreón (often referred to as the Temple of the Sun) is built over oblong, artificially shaped rock (Fig. 5.3a). It is surrounded by probably the best ashlar masonry one can find on Machu Picchu. The top of the rock is carved with several steps, horizontal platforms, seats(?) and sharp edges[10] forming a Z-like figure (Fig. 5.4). It is usually interpreted as an altar, or more often described as the rock/altar.

In the walls surrounding the rock/altar, there are nine niches embedded (Fig. 5.5). The main feature of the upper part of the Torreón is a system of three openings in the walls pointing to characteristic directions—the east, south-east and north. The eastern opening (Window A) has on its outer face elements that are unusual for this location.

[10] Today heavily damaged.

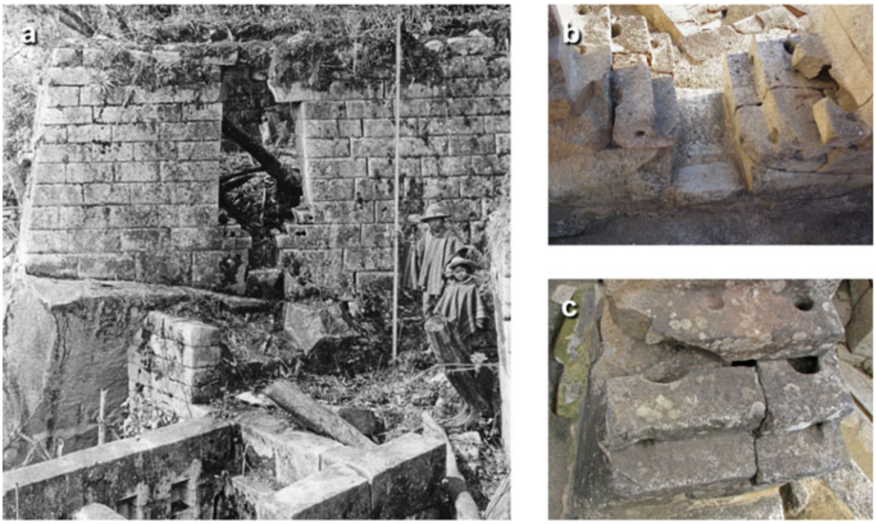

Fig. 5.6 Door/Window N of the Torreón. **a** The northern facade of the Torreón as seen on September 22nd, 1911 (photo by H. Trucker, in: Machu Picchu. Catálogo de la colección 2011, 171); **b** the lower part of Door/Window N as seen from the south (photo by J. Kościuk); the western jamb of Door/Window N as seen from the east (photo by J. Martusewicz)

Four pegs are carved in stone blocks around the window corners (Fig. 5.3a). Such elements are usually interpreted either as protrusions for the easy lifting of heavy blocks, or pins for attaching ropes stabilising the roof truss, or finally—particularly when placed above niches inside the buildings—as pegs to hang mats protecting the contents of niches. None of these interpretations convincingly fit this case. The outer face of the south-eastern opening (Window B) is even more peculiar—there are six such pegs, and four of them are arranged in a horizontal line below the window (Fig. 5.3a). While their function is equally debatable, Dearborn and White (1983) offered in this case a compelling, it seems, explanation for the presence of the two additional pegs in the lower row. They assume that these are a remnant (window sill) of a planned, and ultimately moved more to the west, window. Since the curvature of the wall differs significantly in these two places, the already made and installed sill would have been useless for the window's new location. It was probably easier to leave it in place and carve out a new block for the new window sill. Nevertheless, the mystery of the pegs around the window corners remains unsolved.

The last opening—the northern one—is the most difficult to interpret (Fig. 5.6). It is severely damaged and has proportions and a location more typical for a door than a window. The state of preservation, particularly of its lower part and the western jamb, does not allow for a reliable reconstruction. Neither its general dimensions nor the level of the threshold (or the sill) is clear. Therefore, it will be further referred to as Door/Window N. At the bottom part of this opening, there are several blocks with holes drilled in their vertical and horizontal faces. An association with a window in the facade of the so-called "Room of the Stars" in Coricancha may easily be imposed here (Ziółkowski and Kościuk 2018, 11, fig. 4). However, it may also be that these blocks come from an earlier, demolished building.[11]

5.3.1 The Plan of the Torreón and Its Orientation Towards True North and the Horizon

When comparing the plan of the Torreón resulting from 3D laser scanning with plans published by our predecessors (Fig. 5.7), we noticed several discrepancies concerning the shape of the building itself, the positions of the windows and the orientation of these elements relative to true north (Table 5.1).

Although the outline of the building does not play such an essential role in this case, the position of the window openings and their orientation towards north is of fundamental importance for further analyses.

To a large extent, the differences we found are due to the different methods and measuring techniques used by particular researchers. However, it is puzzling that the oldest of the plans analysed here, prepared in 1929 (Müller 1929, 1972), shows a high degree of compliance with the current measurements made with the use of modern equipment and software. This is also true of the plans made for the Hiram Bingham expedition by US Army topographers in the early twentieth century (Bingham 1912, 1930).[12]

For some reason, whose origin we do not know, the data differ between the different authors and sometimes in the same publication. This is revealed when comparing information provided in the texts with those on the plans (Table 5.2).

[11] In the Inca times, as all the stones surrounding Door/Window N seem to be in the same place as in the times of Hiram Bingham. Another peculiarity can be found on the inner face of this wall of the Torreón—west of Door/Window N. One of the ashlars can be easily pulled out from the wall, and behind it, there is a small hiding place—a kind of a "cache" (Ziółkowski and Kościuk 2020, 12–13, fig. 7).

[12] Due to the very low quality of the copies that were available to us, we could not include them in this text.

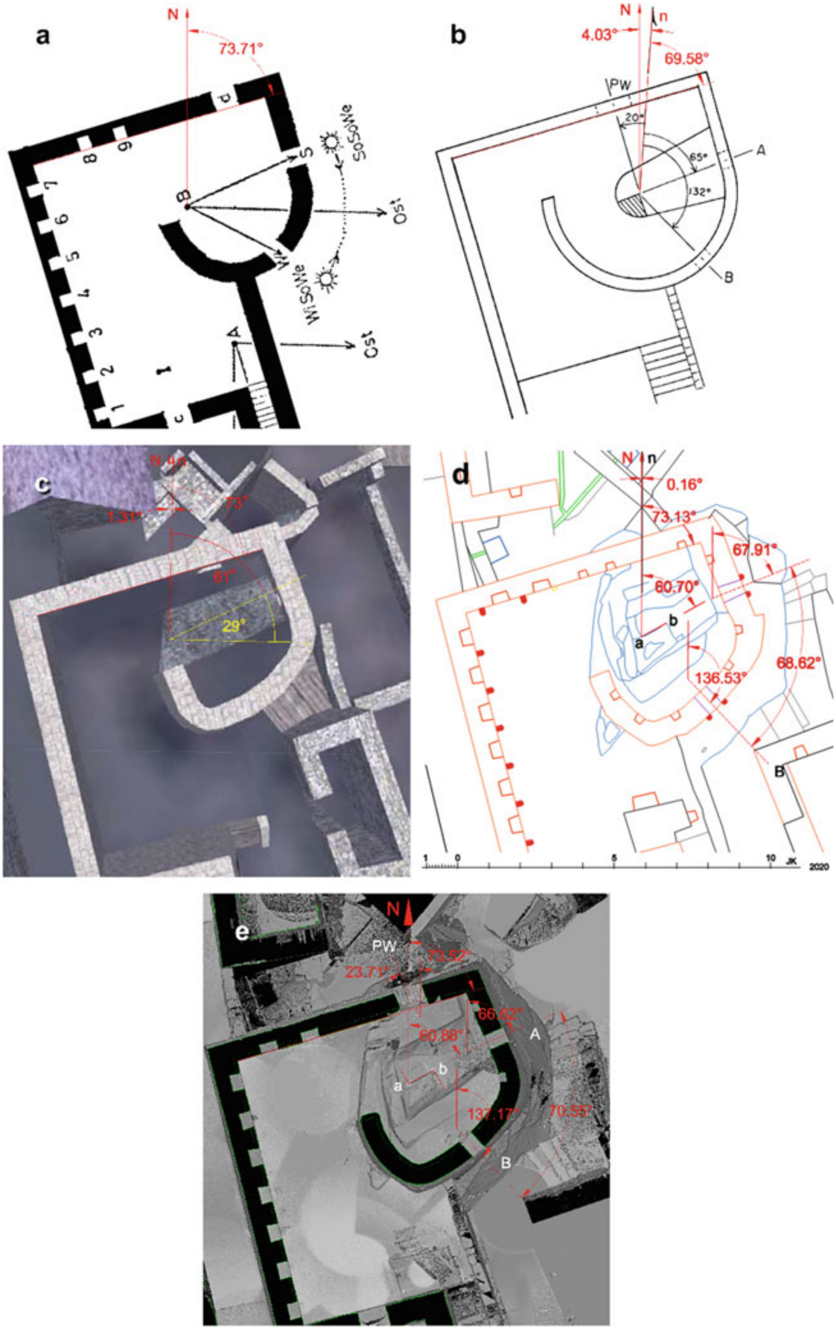

Fig. 5.7 Differences in Torreón orientation. Sources: **a** Müller (1972, 28, Abb.13); **b** Dearborn and White (1983, S41, Fig. 4); **c** Klokočník et al. (2012, slide 21); **d** Machu Picchu Park official plan 2015 (courtesy of Dirección Desconcentrada de Cultura, Cusco); **e** 3D laser scanning plan 2012–2016 (elaborated by J. Kościuk)

Table 5.1 Torreón orientation according to various authors (elaborated by J. Kościuk)

	Angle	Müller (1972)	Dearborn and White (1983)	Kokocnik et al. 2013	Machu Picchu Park plan 2015	3D laser scan 2012–14	Difference Müller/3D laser scan 2012–2014	Difference Dearborn and White 1983/3D laser scan 2012–2014	Difference Kokocnik et al. 2013/3D laser scan 2012–2014	Difference Machu Picchu Park plan 2015/3D laser scan 2012–2014
Plan	PW-A	–	85.0°	–	–	90.33°	-	– 5.33°	-	-
	PW-B	–	152.0°	–	–	160.88°	-	– 8.88°	–	–
	A-B	–	67.0°	–	68.62°	70.55°	-	– 3.55°	–	– 1.93°
Orientation	n–N	0.00°	4.03°	1.31°	0.16	0.00°	0.00°	4.03°	1.31°	0.16°
	N-wall-n	73.71°	69.58°	73.0°	73.13°	73.52°	0.58°	– 3.94°	–0.52°	– 0.39°
	n-PW	–	20.0°	–	–	23.71°	–	– 3.71°	–	–
	n-A	–	65.0°	–	67.91°	66.62°	–	– 1.62°	–	1.26°
	n-B	–	132.0°	–	136.53°	137.17°	–	– 5.17°	–	– 0.64°
	n-ab	–	65.0°	61.0°	60.70	60.58°	–	4.42°	0.42°	0.12°

Legend: PW—the axis of Door/Window N; A—the axis of Window A on Fig. 5.7e; the axis of Window B on Fig. 5.7e; N-wall—the northern wall of the Torreón; N—true north as on a 3D laser scan plan; n—true north as on the plan on Fig. 5.7e; ab—the edge on the rock/altar between points “a” and “b” on Fig. 5.7e.

Table 5.2 Solstice orientation according to various authors (compiled by J. Kościuk)

Source	Alignment method	Alignment of the straight edge cut into the rock/altar		June solstice alignment for ca. 1500**
		Degree from N in the text	Degree from N on the drawing	
Müller, 1972	Direct Sun observations	64.50	63.74	64.50
Dearborn and White, 1983	Direct Sun observations	65.00	64.97	65.00
Dearborn and Schreiber, 1986	Direct Sun observations	65.00	57.63	65.00
Klokočník et al. 2012	Magnetic compass	61.00	63.68	61.00
Machu Picchu Park plan 2015*	GPS	–	61.07	–
3D laser scan 2012–2014*	GPS corrected with direct Sun observations	60.91	60.91	61.32

* UTM grid convergence was applied as calculated by WALLS Project Editor v2.0 for 13° 9′ 52″ S. 72° 32′ 44″; h = 2447 m; UTM grid convergence = 0.56°; ** for Klokočník et al. (2012) at ca. Hz = 14.6°; for 3D laser scan 2012–2014 at Hz = 14°; there are no available data for the other authors

A set of photos of the Torreón shot with digital, GPS-equipped cameras were used for the test. The exact GPS time stamp was read from the EXIF header of each photo, and the angles of incidence of sunlight were calculated in Stellarium for that exact moment. These values were then used to illuminate the 3D model of the Torreón resulting from laser scanning and oriented according to “our” north. Comparison of the obtained images with the original photos showed virtually no differences (Fig. 5.8). They would show up, especially in the case of small, single spots of sunlight, if the orientation of the 3D model in relation to true north was wrong by more than 3°.

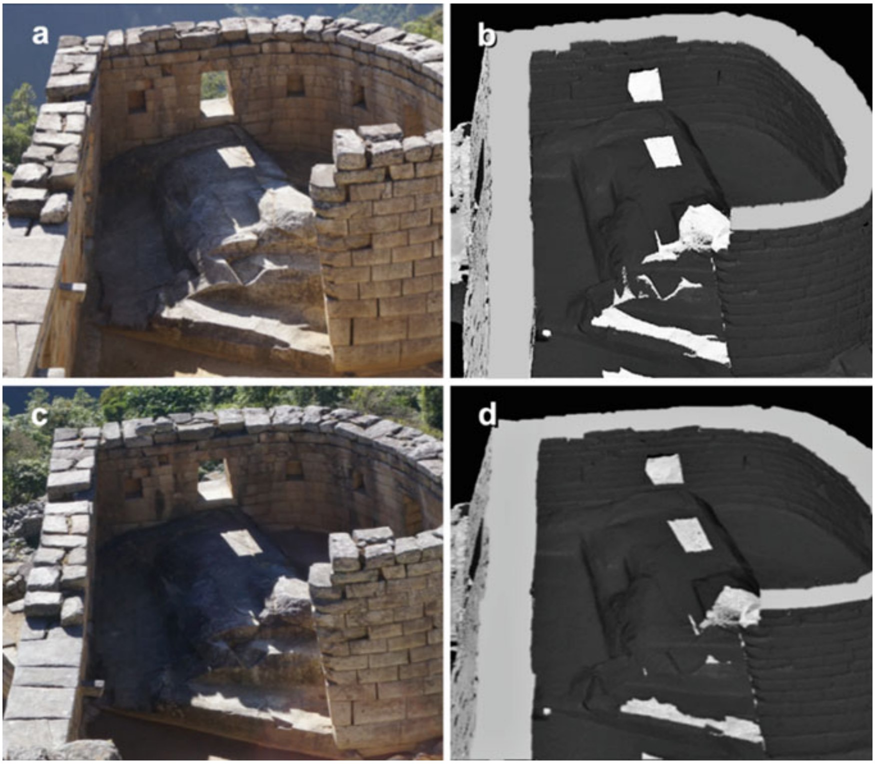

Fig. 5.8 Comparison of shadows on photos with recorded GPS time stamps with simulations on the Torreón 3D model (photos and simulations by J. Kościuk); **a** photo from July 26th, 2012 (GPS time stamp 13:37:19, local time 8:37:19); **b** computer simulation on the 3D model for sunlight angles of incidence calculated for July 26th, 2012, 8:37:19 with Stellarium software; **c** photo from July 6th, 2017 (GPS time stamp 13:37:19, local time 8:37:19); **d** computer simulation on the 3D model for sunlight angles of incidence calculated for July 6th, 2017, 8:37:19 with Stellarium software

Final confirmation of the correct orientation of Torreón was obtained; thanks to two series of photos taken by Jose Bastante on June 21 and 23, 2021. The verification procedure was the same as before. For the three most characteristic photos, the time stamp was read from the EXIF header and the azimuth position and sun altitude were calculated for each of these time moments. As before, the obtained angular data were used to illuminate the virtual 3D model, with the difference, however, that this time the focus was on the central part of Torreón where the Z-like sharp edge is engraved on the top of the rock/altar. The obtained high correspondence between the photos and the computer simulation fully confirmed the correctness of the orientation of Torreón (Fig. 5.9).

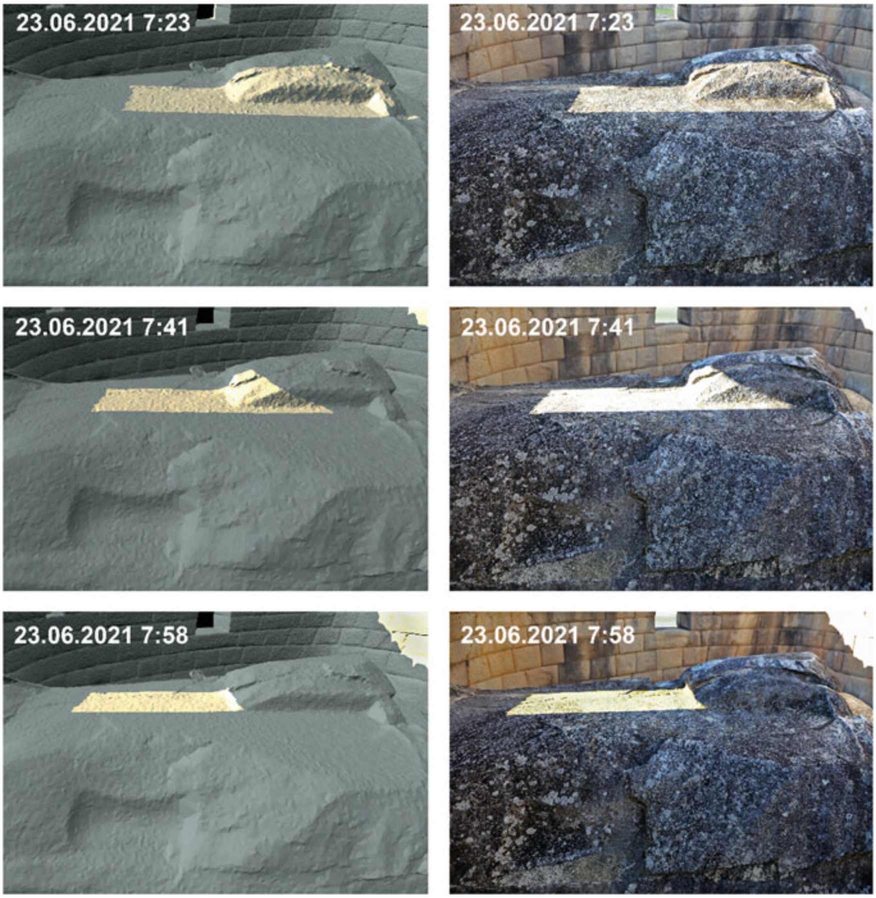

Fig. 5.9 Comparison of shadows on photos with recorded GPS time stamps with simulations on the 3D model of the Torreón's rock/altar. Left column—computer simulations (angles of sunlight incidence calculated with Cartes du Ciel 4.0 by M. Ziółkowski; computer simulations by J. Kościuk). Right column—original courtesy of José Bastante

5.3.2 The Torreón as Astronomical Observatory—Summary of Existing Hypotheses

Several hypotheses regarding possible astronomical functions have been formulated about the Torreón, especially in relation to the chamber in its upper part. All these interpretations are based on the orientation of the three openings (Window A, Window B and Door/Window N) in the walls of the upper part of the structure. Three of these hypotheses concern different methods of solar observations:

- horizontal, for the observation of the sunrise on the solstices of June and December (Müller 1972),

- gnomonic, with the use of the shadow of a plumb line in relation to the line on the rock/altar (Dearborn and White 1983),
- gnomonic—of the simultaneous entry of sunlight in February and October through both windows (A and B) as anticipation of the sun's passage through the local zenith (Dearborn and Schreiber 1986).

An additional fourth hypothesis concerns the possibility of stellar observations through Windows A and B and perhaps Door/Window N. We will analyse each of these hypotheses, assessing their reliability by confronting them with the properly orientated 3D digital model of the Torreón. The model was used to reproduce and analyse all possible horizontal and gnomonical observations postulated by our predecessors. The astronomical calculations for these analyses were made with the use of Cartes du Ciel v. 4.0 and Stellarium v. 0.16.0 software.

5.3.2.1 Horizontal Observations of the Sunrise at the Solstices

Undoubtedly the first (in chronological order) archaeoastronomical hypothesis concerning the Torreón was formulated by the German astronomer Rolf Müller in 1929 (Müller 1929), which was expanded and furnished with additional observations later (Müller 1972). As both studies were published only in German, they did not have the dissemination they deserved—instead they were almost entirely ignored by the main archaeoastronomical studies of Machu Picchu.[13]

Müller's hypothesis is presented in the form of an oriented plan (Fig. 5.7a) and a brief description.[14] It is noteworthy that Müller did not pay much attention to the carved rock/altar in the central part of the structure's main room (Fig. 5.10).

Our comparative analysis confirmed Müller's observations that indeed, there is a place within the structure, located in front of the western part of the rock/altar, from which the sunrise can be observed at the two solstices six months apart: that of June through Window A and that of December through Window B (Fig. 5.11).

However, the intersection point of the sunlight from the June and December solstices lies neither on the floor of the room nor on any of the walls. It is "suspended" in space, about 40 cm above the first western step of the rock/altar and about 20 cm from the nearest wall face. This makes direct observation from there somewhat impractical. Instead, the gnomonic observation of the sunlight in this place would be more likely, but as already indicated above, there is no element (lines, niches or protrusions) that could have served as a precise marker, in particular for the sunrise on the December solstice.

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[13] For this reason, the merit of initiating archaeoastronomical studies at Machu Picchu is commonly and erroneously attributed to Dearborn and White: "The first investigations of astronomy at Machu Picchu were performed in 1980 by Earthwatch teams led by David Dearborn and Ray White (1982, 1983, 1989)" (Malville 2015, 885).

[14] For an English translation of the most important part cf (Ziółkowski and Kościuk 2020, 17).

Fig. 5.10 The carved rock/altar in the central part of the main Torreón room as seen from the north. Window B is visible in the rear (photo by J. Kościuk)

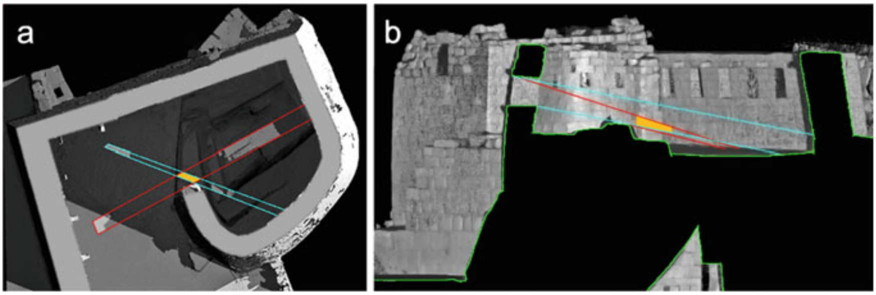

Fig. 5.11 The area (marked yellow) from which the sunrise can be observed at both solstices (elaborated by J. Kościuk); **a** horizontal plan; **b** vertical section along the December solstice direction

Concluding: Müller's postulate of the possibility of the horizontal observation of the sunrises at both solstices from the same place within the Torreón is theoretically possible, but not very practical, because of the limitations imposed by the spatial arrangement of both the windows and the surrounding walls.

5.3.2.2 The Supposed Gnomonic Observations of the June Solstice Sunlight on the Rock/Altar

This second hypothesis focusses on the carved rock/altar inside the Torreón and the supposed observations of sunlight illuminating it in a particular way at sunrise on the June solstice. The corresponding study, accompanied by some measurements, was started in 1980 by David Dearborn and Raymond White.

The authors published several texts in which they presented their hypothesis with different precision degrees (White 1981; Dearborn and White 1982, 1983; Dearborn and Schreiber 1986). The most detailed description is included in the 1983 text; therefore, we will refer mainly (but not exclusively) to that one. Here, particular attention is paid to a carved line (the "edge") in the rock/altar (Dearborn and White 1983, 39–40).[15]

Further on, the authors propose the existence of a plummet hanging on a device tied to the protrusions on the outer side of Window A. The shadow of the plumb line at sunrise would have established an angle with a sharp edge cut into the rock/altar and oriented towards the June solstice. This way, the temporal distance to that event could have been calculated (Dearborn and White 1983, 42). In any case, the authors are firmly convinced that the Torreón tower was designed for precise solar observations:

> (…) the Torreón is designed for use as a precise instrument for observing the June solstice. In addition to this, it could be used to observe constellations and the approach of the zenith passage date. (Dearborn and White 1982, 253)

Leaving the discussion about possible stellar observations aside for the moment, let us look more closely at the factors put forward by the authors in support of the hypothetical reconstruction of the conditions of gnomonic observations in the main room of the Torreón.[16]

As we pointed out at the beginning of this chapter, the main problem we faced in our comparative analysis was the noticeable difference in the orientation measurements towards Window A presented in the subsequent publications. Another problem is that the authors do not precisely explain what moment of sunrise they are referring to—to the first visible rays on the horizon or the rise of the entire solar disk?

In any case, our colleagues' hypothesis deserved a detailed analysis, which we carried out using the 3D model mentioned above. In conclusion, we can confirm that the illumination of the rock/altar surface in the circum-solstitial period cannot be doubted. However, the hypothesis that the carved edge might have been used for precise observations needs further discussion.

First of all, the carved edge is relatively short (ca 90 cm), and its edges, in their present state of preservation, are far from regular, which today limits its potential use as a source to draw up precise conclusions. Secondly, this hypothesis would imply that a device hung outside the window (in a wooden frame?) on the pegs. For obvious

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[15] The authors suggest a similarity of the layout (and function) of the rock/altar of the Torreón with the Intihuatana of Pisac (Dearborn and White 1983, 24–25).

[16] Also some pictures of the projection of sunlight on the rock/altar in periods near the June solstice were presented as a support for this hypothesis. But is to be noted that the dates and times at which these photos were taken are not precisely indicated. The one published in 1983 with the shadow cast by a plummet carries only the comment that it was taken "a week after the solstice" (Dearborn and White 1983, 42, fig. 5). In the same text, there is information that the technique for predicting the moment of the solstice was tested by the authors between July 5th and 9th, 1980, but this information is accompanied only by a graphic scheme and not by pictures (Dearborn and White 1983, 43, fig. 6). In the photo published in 1986 in which no scales or plummet shadows are visible, there is only the comment that it represents the situation "on a day near the solstice" (Dearborn and Schreiber 1986, 23).

reasons, there are no physical traces of such an artefact. Also, no single mention exists in historical records about the use by the Incas of such an instrument for astronomical observations. Similar doubts concerning the accuracy of solar observations in the Torreón have also been expressed previously by other authors (Aveni 1988; Hyslop 2014; Malville 2015, 885–886).

5.3.2.3 Gnomonic Observations of Sunlight Simultaneously Entering Windows a and B in February and October, as Anticipation of the Passage of the Sun Through the Local Zenith

Dearborn and White (1983) also formulated this hypothesis as a complement to their previous analysis of horizontal observations in the June solstice period. The authors state that for about five days on both sides of the zenith passages through Machu Picchu (February 14th and October 29th), the sun enters at sunrise through Windows A and B simultaneously (Dearborn and White 1983, 46).[17]

To verify this hypothesis, we used the same 3D digital model as for the case study of the orientation of Window A towards the sunrise on the June solstice (Fig. 5.11).

Results of our 3D simulations led to the conclusion that the simultaneous entry of sunrays through Windows A and B in the period surrounding the sun's passage through the local zenith is a proven fact—the authors were right in their hypothesis. However, their assumptions have to be modified somewhat:

- The view from the two windows does not intersect along a 4° segment of the horizon between azimuths 99° and 103°, but in a space, corresponding to ca. 6°, between azimuths 98.7° and 104.85°.
- The periods of visibility of the incoming rays through both windows are not symmetric in length when related to the day of the Sun's passage through the local zenith. In the case of the passage through the zenith on February 14th, the visibility of the two rays projected into the room begins about 12 days before the event, on February 2nd, and continues until February 20th. In the second zenith passage, on October 29th, the situation is reversed: the period of visibility of sunlight from both windows before the event is approximately 7 days, and after it, 12 days. This asymmetry results from the particular shape of the horizon in the segment corresponding to the intersection of sightlines from Windows A and B.
- The shapes of the patches projected in the morning of the Sun's passage through the local zenith differ. What can be seen is the change in the visibility of both patches and their respective dimensions (Fig. 5.12)[18]

[17] A slightly less detailed description is presented in the previous work of these authors (Dearborn and White 1982, 253).

[18] Another result of our analysis is that during the 3–4 days around zenith transition, the sunlight that enter Window A illuminates a part of the interior wall of the room where a type of "cache" is located—a detail that appears when a loose stone is taken out of the wall (Ziółkowski and Kościuk 2020, 22).

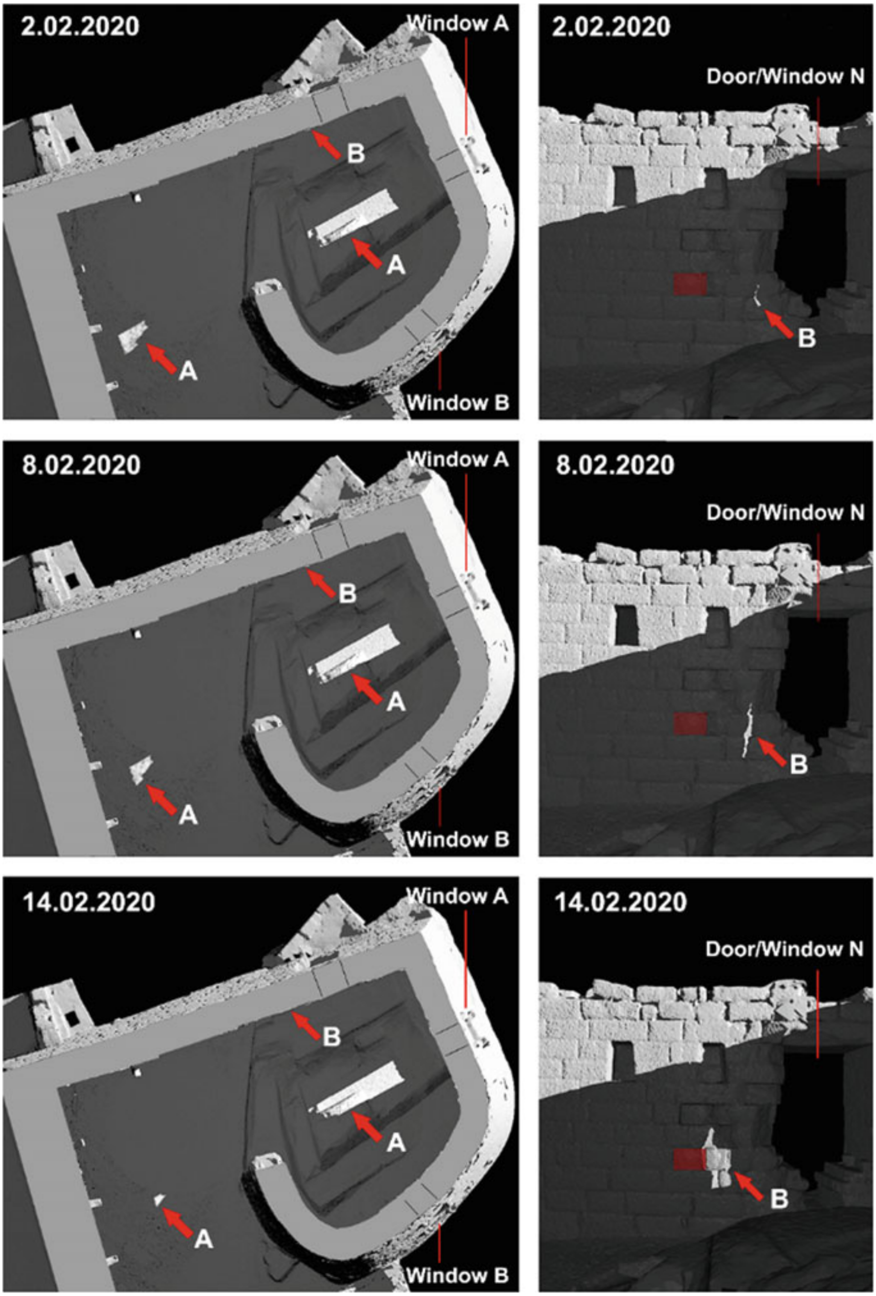

Fig. 5.12 Simulations of the sunlight passing simultaneously through Windows A and B in the period around the local zenith transition. Full solar disk over the horizon is taken as the simulation moment (calculations by M. Ziółkowski; computer simulation by J. Kościuk); Left column—plan of the Torreón; right column—view of the northern wall of the Torreón around Door/Window N sunlight passing through Window B; The place of the “cache” is marked in red; A—sunlight spots entering through Window A; B—sunlight spots entering through Window B

5.3.2.4 The Possibility of Stellar Observations from the Torreón

Some authors have hypothesised that apart from the observations of the Sun from the main room, observations of some stars important within the Inca (or more generally Andean) cosmovision were also made. In this case, the proposals made in this respect have to be examined in terms of four factors:

- the general orientation of the window
- the shape and height of the horizon visible through that particular window,
- the position of the supposed observer, not only in terms of his exact location within the perimeter of the room but above all in terms of the height from which the observations are made,
- the likely date of observation, since unlike solar observations, because of the effect of the precession of Earth, the present positions of stars cannot be projected 500 years back.

Hypotheses formulated around each of the three openings of the upper room of the Torreón will be analysed separately.

Window A

According to several authors, this window could be used (in parallel to the observations of the sunrise on the June solstice) for the observation of the heliacal rising of the Pleiades—a group of stars significant in the Andean cosmovision for the prediction of the harvest of the forthcoming year (Dearborn and White 1983, 40). Salazar Garces also adds the Hyades and the star Aldebaran (α Tau) to the list of stars that could be viewed from this window (Salazar 2014, 176). None of the cited authors specify from which exact location such observations could be made.

The main line of sight through Window A can be either of the following:

- the geometric centre of the window,
- looking along the carved edge of the rock.

Both orientations differ by 5.74° (Fig. 5.7e), but the most critical limitations result from the observer's position in relation to the height of Window A. A person of medium height (160 cm), standing in front of this window, will not see the horizon or the sky but the hillslope. Someone kneeling on the SW side of the rock/altar, with his/her head placed on its surface, will be able to glimpse the sky just below the window sill. The visible portion of the sky will then be in the range of only 1.5° vertically (Fig. 5.13a) and about 7° horizontally (Fig. 5.13b).[19]

[19] From 62.9° to 70.2° when the observer looks along the axis of Window A, and from 59.3° to 66.5° when the observer looks along the edge carved on the rock.

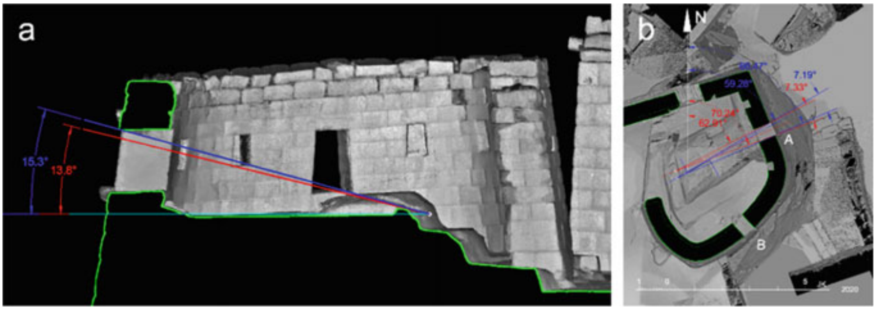

Fig. 5.13 Simulation of the sky's visibility over the horizon for an observer kneeling in front of the rock (elaborated by J. Kościuk); **a** vertical extension of visibility (red line—angle at which the eastern horizon is visible; blue line—range of visibility limited by the upper edge of Window A); **b** horizontal extension of visibility (red line—looking alongside the axis of Window A; blue line—looking alongside the edge carved on the top of the rock/altar)

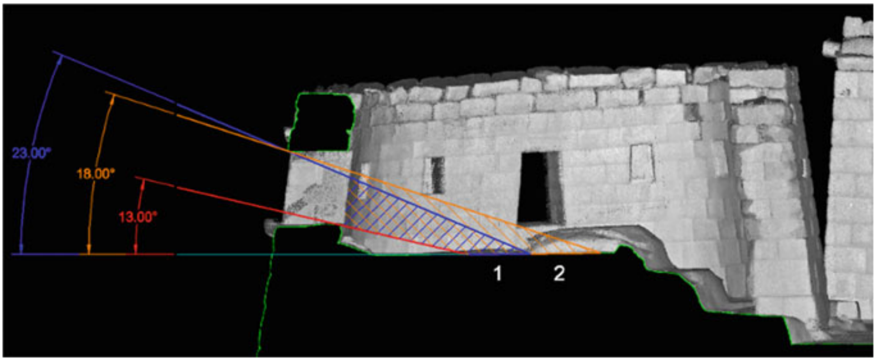

Fig. 5.14 Simulation of the sky's visibility over the horizon for an observer lying on the rock in zone 1 and 2 (elaborated by J. Kościuk); Red lines—visibility range limited by the bottom edge of Window A (for both observation zones); blue lines—visibility range limited by the upper edge of Window A for an observer in zone 1; orange lines—visibility range limited by the upper edge of Window A for an observer in zone 2

This does not constitute a privileged situation for observing entire constellations, as one can hardly see a star or groups of stars, such as the Pleiades, with an observation time of not more than 6 minutes resulting from the vertical extension of the sky strip reduced to only 1.5°.

Finally, one has the best observation conditions when lying on the rock, with his/her head close to the window, and looking upwards. In such a situation, the observer would have a wide strip of the sky for observation—no less than 15° horizontally and from 5° to 10° vertically depending on exact observer position (Fig. 5.14).

Considering these limitations, we reconstructed, using Cartes du Ciel 4.0 software, the conditions of visibility through Window A, principally of the Pleiades, for 1450 AD and 1500 AD—the two moments indicated by Dearborn and White. It should be noted that in 1450 AD, visibility of the Pleiades would have been very limited—only part of the group would have appeared next to the left window jamb. Taking Taygeta (19 Tau) as a reference and a height of the horizon of 14°, we observe that this star is rising at 62°19′ azimuth, which would have been invisible because the door jamb obscures it. The situation improves if the observer moves slightly south and looks along the edge carved on the top of the rock. In this case, the whole Pleiades group would be practically in the centre of his/her field of vision.

In 1500 AD, because of the terrestrial precession, when looking along the geometrical axis of Window A, the observer would no longer have been able to see the Pleiades (Taygeta rising at 62.12° would have been behind the window jamb) while still being able to observe the group from the second position looking along the edge (Fig. 5.13b).

Contrary to Salazar Garces's postulate, Aldebaran (α Tau) and the Hyades would not have been visible in either 1450 AD or 1500 AD (Salazar 2014, 176) from either observation point. All these stars, and many others, would have been well visible in both 1450 AD and 1500 AD from the observer's position lying on the altar rock in zone 1 or 2 (Fig. 5.14). Then the celestial band determined by declinations between 60.5° and 72.5° and vertical range between 13° and 23° would have been within eyeshot.

Window B

As regards Window B, Dearborn and White put forward the following interpretation of its possible function:

> The band of sky visible to such an observer lies approximately within the declination strip $-57° < \delta < -37°$. This strip is well outside of the ecliptic plane, and so solar, lunar and planetary phenomena cannot be observed directly (straight) through Window B. (…) The Inca people recognised the dark lanes or clouds along the Milky Way, as well as the stars in their constellation mythology. The "Llama" is a dark region stretching from Scorpio to α and β Centauri (which form the Llama's eyes), and it rises through Window B. (…) Other objects which could be observed to rise through Window B include the stars Llamacnawin (α and β Centauri) and Pachapacariq Chaska (Canopus), as well as the dark clouds or constellations Unallamacha (the Baby Llama) and Machacuay (the Snake) …. (Dearborn and White 1983, 45).[20]

Unfortunately, the authors have not pointed out in their schematic plan of the Torreón (Dearborn and White 1983, 41, fig. 4) where the observer should be sitting precisely, which leaves room for doubt when determining the visible strip of the sky.

[20] In a later study, Salazar Garces also places special emphasis on the possibility of observing the tail of Scorpio (Salazar Garces 2014, 176).

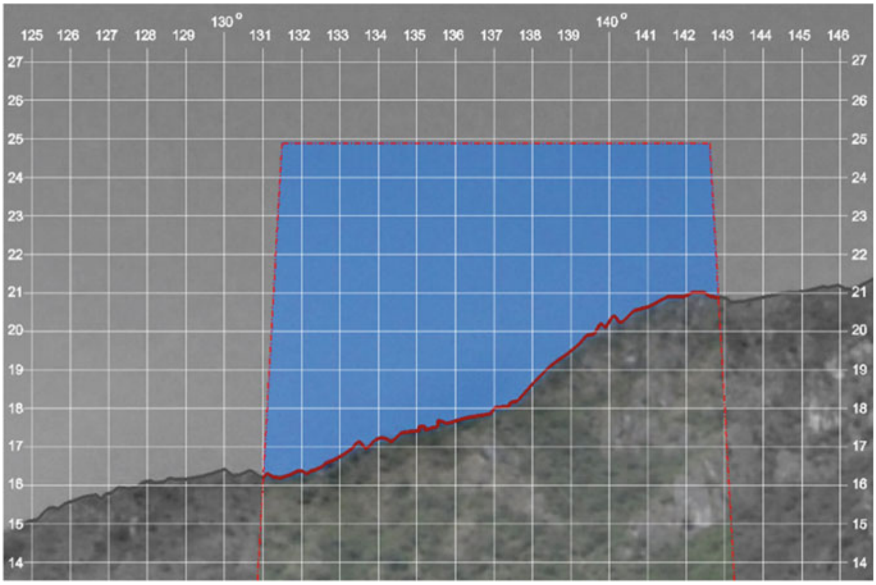

Fig. 5.15 The extent of the horizon as seen through the upper part of Window B from the position probably indicated by Dearborn and White (elaborated by J. Kościuk)

Following the description cited above, in our reconstruction, we have opted for a seated observer with his/her back to the altar rock and looking out along the axis of Window B. In this case, the visible part of the sky would cover approximately 14° of the horizon (Fig. 5.15).

We also reconstructed visibility conditions through Window B for stars and parts of the Milky Way in 1450 AD that were indicated by the authors. The stars Llamacñawin (α and β Cen) were rising above Machu Picchu mountain at the azimuth of ca. 148° and 147°, respectively. Therefore, to an observer sitting in the place described by Dearborn and White, they would be invisible, as they would be hidden by the window jamb. This limitation also concerned the dark stains in the Milky Way. On the other hand, the rising of Canopus (α Car) on the horizon above Machu Picchu mountain could be seen at the azimuth of approximately 141.5°.

The observation that Dearborn and White considered as being of particular interest is related to the rising of the tail of Scorpio (Dearborn and White 1983, 45). However, this description is a commentary on a figure that is somewhat difficult to interpret (Dearborn and White 1983, 44, fig. 7).

According to the reconstruction we made, about ten days before the June solstice in 1450 AD, a few minutes before the sunset, the tail of Scorpio's first stars was rising. However, from the place postulated by Dearborn and White, only two of them could be seen, Sargas (θ Sco) and η Sco, at about 130.67° azimuth, while the left window jamb hid the remaining stars of both the tail and the entire constellation of Scorpio.

To get better visibility corresponding to 20° horizontally, as postulated by Dearborn and White, an observer would have needed to sit closer to Window B (ca. 65 cm from the foot of the wall). From there, about an hour after sunset on the June solstice day, he/she would have been able to see almost the entire tail of Scorpio, but already at an altitude of 34°–38°, not just above the horizon.

To summarise: although changing the place of observation from the altar stone to a part closer to the window would have allowed some of the stellar observations mentioned by Dearborn and White, it does not seem that the design of this part of the Torreón was conditioned by astronomical considerations—at least, not for precise observations.

Door/Window N

Regarding this opening, some hypotheses have been formulated about the possibility of observing circumpolar stars. The most detailed (albeit somewhat imprecise) is Salazar Garces's proposal (Salazar Garces 2014, 175–176). It should be noted that the view through Door/Window N was limited by the roof of a house built opposite it. This seems to indicate that the visibility of a clear horizon was not the builders' primary intention.

The conditions of observation from two points that we have tentatively chosen are somewhat different:

- The star Deneb (α Cyg) could not have been seen because it was hidden by the window sill.
- The setting of the tail of the Big Dipper might have been visible; however, the period of perceptibility of these stars was shorter because of the reduced vertical width of the band of sky due to the Door/Window's trapezoid shape. Nevertheless, at least in theory, this situation allowed a more accurate observation of the stars in relation to sunrise and sunset times throughout the year

5.3.3 Conclusions

It appears that the observations of the sun postulated by both Müller (1929, 1972) and Dearborn, White and Scheiber (Dearborn and White 1982, 1983; Dearborn and Schreiber 1986) were possible but without the degree of accuracy required for a precise "astronomical" instrument. Therefore, we can assume that the entry of sunlight from Window B and in particular from Window A at different times of the year (in the case of the latter window—at the period around the June solstice) may have served more for ritual purposes than for astronomical calculations. Consequently, contrary to the postulates of the authors mentioned above, we disagree with the thesis that the Torreón was a precise solar observatory.

As far as stellar observations are concerned, which are dealt with in detail by the scholars cited above and by Salazar Garces (2014), these were in some cases possible (for example, the heliacal rising of the Pleiades through Window A). However, the interior arrangement of the upper room of the Torreón was apparently not designed with this particular function in mind. To summarise: we can take as established evidence that the builders of the Torreón designed the building according to some solar orientations, but without the purpose of erecting an astronomical observatory as was apparent in the cases of Intimachay and Inkaraqay.

5.4 Intihuatana as Astronomical Device—Summary of Existing Hypotheses

It is without a doubt the most emblematic structure of Machu Picchu. This is a type of stone altar, located in a room located on top of a rocky prominence, the highest place of the so-called Religious Sector (Figs. 5.1 and 5.16). The name Intihuatana had been attributed by Bingham, because of certain similarity with a similar monument, so named, in Pisac (Bingham 1930, 52). Incidentally, there is some disagreement about the origin of the name "Intihuatana" (literally a Quechua term meaning "place where the sun is tied"). It is not mentioned before 1856, when Clement Markham made a reference to a monument in Ollantaytambo:

> (…) a dizzy point, on which is placed a huge block called the Ynti-huatana, or place for observing the sun. (Markham 1856, 181; Rowe 1946, 329, note 39)

Twenty years later, Squier attributes this term both to the monuments in Ollantaytambo and Pisac (Squier 1877, 492, 524–530). The absence of this term in the sources and dictionaries of the colonial period could indicate that it is a modern term, introduced by scholars. But on the other hand, Markham himself declares that the name had been communicated to him as a toponym by the inhabitants of the area, which seems to indicate rather an Andean origin of the term.[21]

As far as the possible astronomical function of this and other "Intihuatanas" is concerned, the prevailing opinion among specialists is that it did not perform, contrary to popular opinion,[22] the function of gnomon to determine dates on the solar calendar (Uhle 1908, 329–330; Rowe 1946, 329; Dearborn and Schreiber 1986, 35–36; Reinhard 2007, 67).

[21] This was apparently also Rowe's opinion (Rowe 1946, 329).

[22] For example, Rolf Mueller (Müller 1929, 185).

Fig. 5.16 Intihuatana of Machu Picchu (photo by J. Kościuk)

However, this does not totally rule out its possible astronomical function: if not directly as a measuring instrument, at least as a marker for horizontal observations. This interpretation of the Intihuatana would be supported by historical sources. In the description of the system of horizontal observations from the main square in Cusco, the anonymous author specifies that the device included both the pillars visible on the horizon and a place of observation, specifically indicated by a type of pillar in the same square:

> Es ansí, que, para tomar el punto del Sol, entre los dos pilares de en medio tenían otro pilar en medio de la plaça, pillar de piedra muy laborada, de vn estado en alto, en vn paraje señalado al propósito, que le nombrauan Osno, y desde alli tomauan el punto del Sol en medio de los dos pilares, y estando ajustado, hera el tiempo general de sembrar en los valles del Cusco y su comarca. (Anónimo 1906, 151)

Reinhard draws attention to the role of Intihuatana as the focal point of the location of Machu Picchu in the supposed sacred space, conditioned by the mountains, objects of ancestral worship:

> It is significant that, viewed from the Intihuatana at Machu Picchu, sacred mountains are in alignment with the cardinal directions. The Veronica range lies to the east, and the sun rises behind its highest summit at the equinoxes (…). Huayna Picchu is due north (…). A line of snowcapped peaks of the Pumasillo range is to the west, the sun setting behindthe highest summit (246°) at the December solstice and the equinox line crossing (p.63) its northern end (…). The massif of Salcantay lies to the south, its highest summit being at an azimuth of precisely 180°. Salcantay is not visible from the Intihuatana, but it is visible from the summits of Huayna Picchu and Machu Picchu peak (…). The Intihuatana was, therefore, at a central point from which sacred mountains were in alignment with the cardinal directions and where significant celestial activity took place. (Reinhard 2007, 63–66)

Dearborn and White have more precise ideas about the type of solar observations that could be made from the Intihuatana in reference to supposed pillars located on the San Miguel Ridge, on the Western horizon:

> The dates when the sun would appear to set beyond the pillars are April 29 and May 3 in the late fall, and August 10 and 14 in the late winter. These dates correspond closely with the Festival of Santa Cruz (May 1–3). (Dearborn and White 1982, 257–258)

The problem is that the surveys carried out by the American team during the field work in the San Miguel Ridge did not reveal the existence of any type of construction as pillars (Dearborn and Schreiber 1986, 35), so this hypothesis, although interesting, for the moment lacks archaeological confirmation.[23]

Apparently, the only astronomical orientation of Intihuatana, confirmed by archaeological data, is the one with the site of Lllactapata which we will discuss below.

5.5 Sala de los Morteros (the Room of the Mortars)

5.5.1 Introduction

The Sala de los Morteros (Fig. 5.17) has already been the subject of our larger study (Kościuk and Ziółkowski 2020). So we limit ourselves here only to the essential facts and our conclusions.

[23] In 1998 Fernando Astete and Johan Reinhard found a huanca or standing stone on this ridge, but this object is invisible from the Intihuatana (Jose Bastante A., personal communication, November 2020).

Fig. 5.17 Panoramic view of the Sala de los Morteros (photo by J. Kościuk)

Discussing the Sala de los Morteros' possible astronomical significance, it is crucial answering four fundamental questions similar to that already formulated in the case of the Torreón. First, whether the current position of both bowls that have given their name to the building is original and to what extent the surrounding buildings have been preserved in a condition that allows the reconstruction of their original form? If the answer is yes, do the shape and position of the two circular bowls have any astronomical significance at all? If it is so, then whether the Sala de los Morteros was an actual observatory, with similar functions to Intimachay (Ziółkowski et al. 2013) and the Mirador de Inkaraqay (Astete Victoria et al. 2017); or did it serve only to achieve some form of visual effect during ceremonies perhaps performed there? Alternatively, is the astronomical significance of the orientation purely accidental, having no actual relation to any astronomical phenomena?

It will not be possible to answer the above questions without relying on detailed data on both the building itself and its immediate surroundings. This input data and the verification and analysis methods are analogues to these described in the case of the Torreón.

5.5.2 The Current State of Cuarto de los Morteros and the Sala de los Morteros

The Sala de los Morteros located within a bigger complex, the so-called Industrial District or the Cuarto de los Morteros (Fig. 5.18), is another building, next to the Torreón, the Intihuatana and the so-called Temple of the Condor that is of great interest not only to tourists but also scientists.

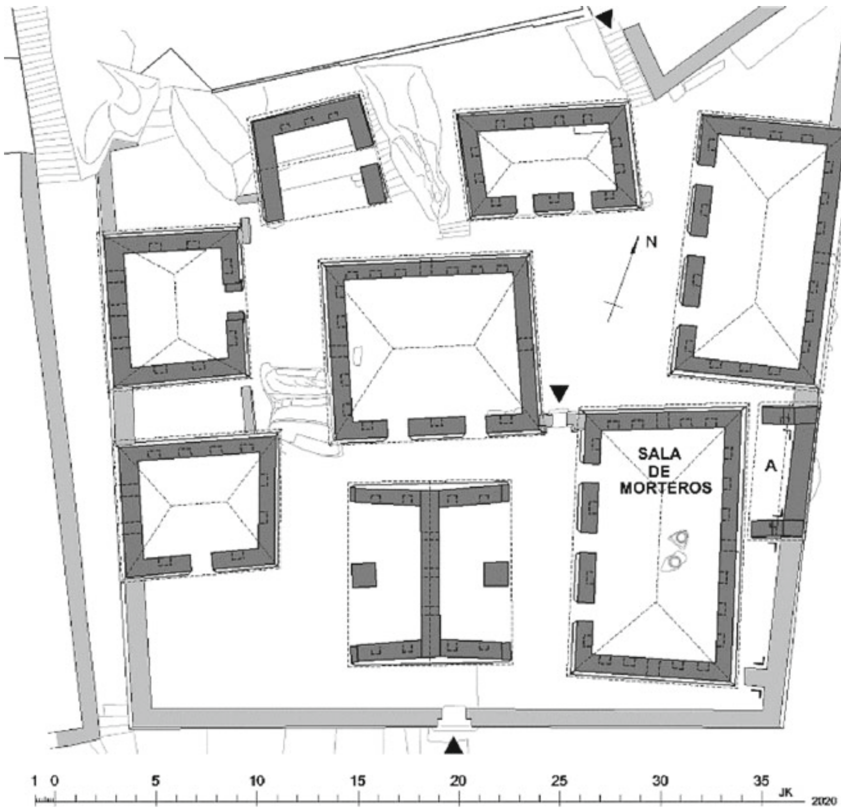

Fig. 5.18 Top view of the Cuarto de los Morteros in the eastern part of Machu Picchu (elaborated by J. Kościuk). Dark grey—roofed buildings; light grey—enclosure walls; blue lines –gutters draining water from the roofs; the L-shaped marks east of the Sala de los Morteros represent walls erected during the same construction phase

The whole complex consisting of ten edifices delimited by an enclosure can only be accessed from two directions: from the south through a double-jamb door and from the north by steps descending from a small courtyard located further to the north. The analysis of the Cuarto de los Morteros external facades and wall corners of Building 6 (Fig. 5.18) located to the east of the Sala de los Morteros strongly suggests that the complex was planned as one project although it was not erected in one construction phase.

The first of our questions that is whether both the "mortars" are still in their original positions has been already thoughtfully researched by Eulogio Cabada Hildebrandt (2008, 42–46), who, despite Hiram Bingham's expedition photos showing some digging activity around the stones (Fig. 5.19), argues strongly that the Bingham expedition did not move both “mortars”. In 1933–1934 there were other excavations carried out around both the stones (Fig. 5.20), but, in this case, the explorers do not report lifting or moving them.

The Sala de los Morteros’ present state does not differ very much from that Bingham had found it (Fig. 5.19). The spacious interior measures approximately 8.15 by 13.5 m[24] and is decorated with 18 niches. Three windows are pointing to the north, east and south. The lower sections of the surrounding walls (up to the niches’ full height) show much better quality stonework than the upper-most rows of stones. One may even have the impression that the building was finished—if at all—in a hurry.[25]

Fig. 5.19 The Sala de los Morteros in 1912 (Bingham 1913, 469)

[24] The exact measures are 8.15 (8.17 for the opposing side) by 13.05 (13.85) meters.

[25] The same can be said for other buildings in this sector.

Fig. 5.20 Excavations around the "mortars", led by Luis E. Valcárcel V. in 1933–1934 Source: (courtesy of Dirección Desconcentrada de Cultura, Cusco)

Fig. 5.21 Traces of red plaster in the niche of building 6 (photo by J. Kościuk)

Many indications suggest that all the buildings of Cuarto de los Morteros have been once roofed (Kościuk and Ziółkowski 2020). Still preserved triangular gable walls in building 9/10 and 6 (Fig. 5.18) give the direct indication that the thatches were intended there. In case of other buildings, we only have indirect evidence of roofs' existence. These are red plaster traces inside buildings 1, 2, 4 and 8 (Fig. 5.21) and rows of stones alongside the outer facades of buildings 4 and 5 suggesting a type of gutter into which water flowed from the roofs (the blue lines on Fig. 5.18). Since the gutters also run along the shorter walls of some of the buildings without triangular gable walls, it may indicate that hipped roofs existed there. The lack of rainwater drainage from inside the buildings may serve as an additional argument favouring roofs' existence. Considering all these indications, one may conclude, as opposed to J. McKim Malville opinion (2015, 888–889), that also the Sala de los Morteros and building 6 neighbouring from the east were initially thatched (Fig. 5.22). The latter conclusion is fundamental in view of the possible astronomical function of the Sala de los Morteros.

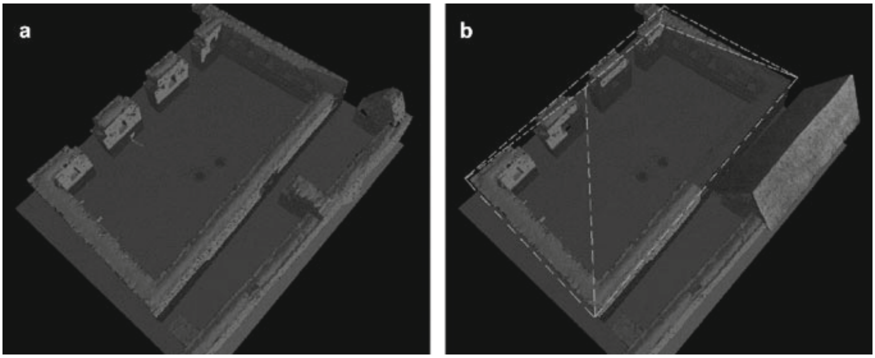

Fig. 5.22 A tentative reconstruction of roofs on the Sala de los Morteros and Building 6 (drawing by J. Kościuk). **a** The present condition of the building; **b** roof reconstruction proposal

5.5.3 The Plan of the Sala de los Morteros and Its Orientation Towards True North

Further important questions concern the Sala de los Morteros plan's accuracy and its orientation towards the true north. As already mentioned, the plan and orientation analysis were based on the same data set and methods as in the case of the Torreón.

There also an additional set of photos of the Sala de los Morteros shot with GPS-equipped digital cameras was used to verify orientation (Kościuk and Ziółkowski 2020). No significant differences between the original photos and 3D computer simulations were found, thus confirming the plan orientation's accuracy (Fig. 5.23). However, some minor differences between the results of the 3D laser scan and the plan published by Cabada Hildebrandt (2008, 33, lam. 04) have been noticed (Table 5.3).

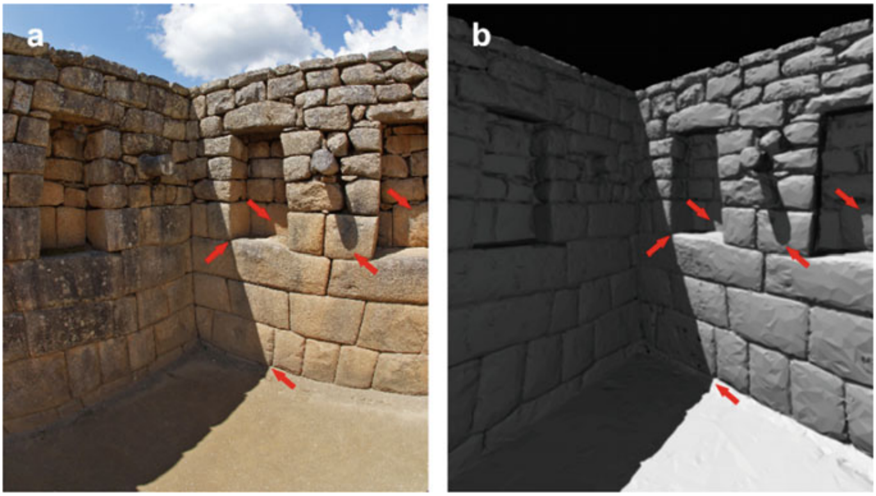

Fig. 5.23 The south-eastern corner of the Sala de los Morteros. Comparison of shadows on photos with recorded GPS time stamps against simulations on a 3D model (photos and simulations by J. Kościuk). **a** photo from August 20, 2016 at 11:14:40 AM as read from the GPS time stamp in the EXIF header; **b** shadow simulation on the 3D model for Az = 21.167° and Alt = 62.940° as reconstructed in Stellarium 0.16.0

Table 5.3 The basic data related to the dimensions and orientation of the Sala de los Morteros (elaborated by J. Kościuk)

Data	Cabada Hildebrandt[a]	Kościuk and Ziółkowski[2]	Difference
Sala de los Morteros coordinates	13°09′23″ 72°32′34″	13°09′48″ 72°32′21″	+ 0°0′25″ −0°0′13″
Sala de los Morteros inner dimensions	Medium 6.50 × 11.75 m	Medium 6.43 × 11.70 m	−0.07 ÷ +0.05 m
The azimuth of the eastern wall of the *Sala de los Morteros*	16°	16.59°	+0.59°
The azimuth of the mortars' centres	ca. 360°	356.8°	+3.2°
June 21 at 7:21:11 AM*	Az 61.88°	Az 61.21° Alt 14.44°	+0.67° –
December 21 at 8:00:00 AM*	Az 109.58°	Az 109.57° Alt 35.18°	+ 0.01° –
March 21 at 7:17:35 AM*	Az 85.42°	Az 83.90° Alt 22.47°	+1.52° –

[a]Cabada Hildebrandt 2008, 54; Kościuk and Ziółkowski (calculated using Stellarium 0.16.0 for 13°09′48″ and 72°32′21″ coordinates)

5.5.4 The Sala de los Morteros as an Astronomical Observatory: Existing Hypothesis and Its Verification

Eulogio Cabada Hildebrandt (Cabada Hildebrandt 2008) published the very detailed and well-documented hypothesis concerning the astronomical significance of the Sala de los Morteros. The most important conclusions he summarises at the end of his study:

From the direct observation (…) and (…) the previous analyses (…), the following conclusions are drawn:

- The relationship between the window and the southern rocky disc (…) presents the necessary conditions to function as a marker of the winter solstice (…).
- The possibility (…) of a column, seated on the (…) is not discarded.
- The relationship between the window and the northern stone disc (…) presents the necessary and sufficient condition to function as a marker of the equinoxes (…).
- Finally, the various attempts to determine the North, from the known azimuths, end up in an alignment very close to the discs' centres, which allows us to deduce that such alignment was planned (Cabada Hildebrandt 2008: 62, translated from Spanish by M. Ziółkowski).[26]

Although we are fully convinced of the accuracy of the author's measurements and models and the precision and excellent temporal record of the photos that document the analysed solar events, some doubts however arise. They can be as follows:

- Are the solar events, which can be observed today, result from a planning process intended to achieve such a calendar function, or are they circumstantial effects of incidental building orientation?
- Even if we accept that the arrangement of the two "mortars" in relation to the eastern window of the room was premeditated and responded to specific astronomical considerations, was this a device for precision observations, or was it just an orientation intended to achieve some symbolic effect?

The following subchapters will try to answer these two fundamental questions.

[26] For full translation of this passage consult Kościuk and Ziółkowski (2020).

5.5.4.1 Comparison of the Sala de los Morteros with Some Known Cases of Devices Serving for the sun's Observations

The historical sources and available archaeological material well-document the practise of gnomonic observations of the sun in the Andean region (Bauer and Dearborn 1995, 55–56; Fink 2009; Ziółkowski 2015, 219–223). The testimony of Sarmiento de Gamboa [1532–1592], a Spanish explorer and astronomer, can be an excellent example of the gnomonic type of observations that once were to have existed near Cuzco (Sarmiento de Gamboa 1906, Chap. 30 [1572]).[27]

Also, at least three structures on Machu Picchu could serve as examples of these observational techniques: Intimachay (Ziółkowski et al. 2013); the Mirador de Inkaraqay (Astete Victoria et al. 2017) and as we demonstrated above, to some degree also the Torreón. The typical elements of such gnomonic devices are scales (lines in the case of a meridian) or stripes (in the case of sundials), serving as a reference grid for the observed sun's rays at a given time of day and/or year. Despite their size (ca. 40–45 cm for the inner diameter) and high finish quality, no lines or stripes were found marking the temporal succession of sunlight falling on both discs. Further on, in all known so far Inca architecture, there are no other examples of mortars-like instruments that were ever attributed as astronomical instruments. In this context, the use of both "mortars" as instruments for gnomonic observation becomes questionable and will require further verification.

However, a different interpretation of such round vessels, although not confirmed in the Andean, pre-Columbian world, is possible. If filled with water or other liquid, they could serve as mirrors reflecting the sunrays, i.e. as reflective gnomons. Such an observation technique was known in the Old World, and the Copernicus' Table of the Equinoxes from the Olsztyn Castle (Poland) is a good example here (Colomboni 1669, 640; Przypkowski 1973; Szubiakowski and Włodarczyk 2018; Dzieciątkowska 2013). However, an attempt at an interpretation in this direction faces another obstacle. In order to guarantee the proper precision of observation, the diameter of the reflecting vessel should be relatively small—in the case of the Copernican Table of the Equinoxes as well as in the models described in Copernicus' manuals, it not exceed 4 cm (Szubiakowski and Włodarczyk 2018, 182–183). This tendency

[27] For English translation consult Bauer and Dearborn (1995, 37).

to reduce the sun's beam's size at crucial moments of the sun's annual route can also be observed in other examples of Inca astronomical instruments known to us—in Intimachay (Ziółkowski et al. 2013, fig. 8, 400) and the Mirador de Inkaraqay (Astete Victoria et al. 2017, 20, fig. 14), and to some degree also in the Torreón (Ziółkowski and Kościuk 2020, 22, fig. 14). In the case of our "mirror-mortars", exactly the opposite is true. For use as reflective gnomons, their diameters are disproportionately large.

5.5.4.2 Critical Analysis of the Hypothesis of the Astronomical-Calendric Function of the "Mortars"

Despite all these doubts, let us analyse Cabada's hypothesis in detail using our 3D model based on laser scanning and oriented precisely to the astronomical north.

On September 23rd, the sun's rays, passing through the eastern window, actually fully illuminate the northernmost "mortar" (Fig. 5.24a—middle row). The whole spectacle lasts for about 40 min, from 7:54 AM till 8:34 AM. A good agreement with Cabada's observations, additionally confirmed by cross-photos (Fig. 5.25), we also received for the June solstice—the sun's rays illuminated the southern half of the other "mortar", from about 8:28 AM until about 9:08 AM (Fig. 5.24b).

However, we must remember that in the past, as evidenced by the triangular gable walls preserved to this day (Fig. 5.22a), building 6 was covered with a roof (Fig. 5.22b). When this fact is taken into account, the situation changes completely—during June solstice day, no sun's rays could have been falling onto the southern "mortar" (Fig. 5.24c). This way, we can attribute astronomical function to only one of the "mortars" (the northern one) illuminated during equinox days. What, then, was the purpose of the southern "mortar"? A situation in which only one of them can be used for astronomical observations, and even so with some doubts, dramatically weaken the credibility of the hypothesis about the astronomical function of the Sala de los Morteros.

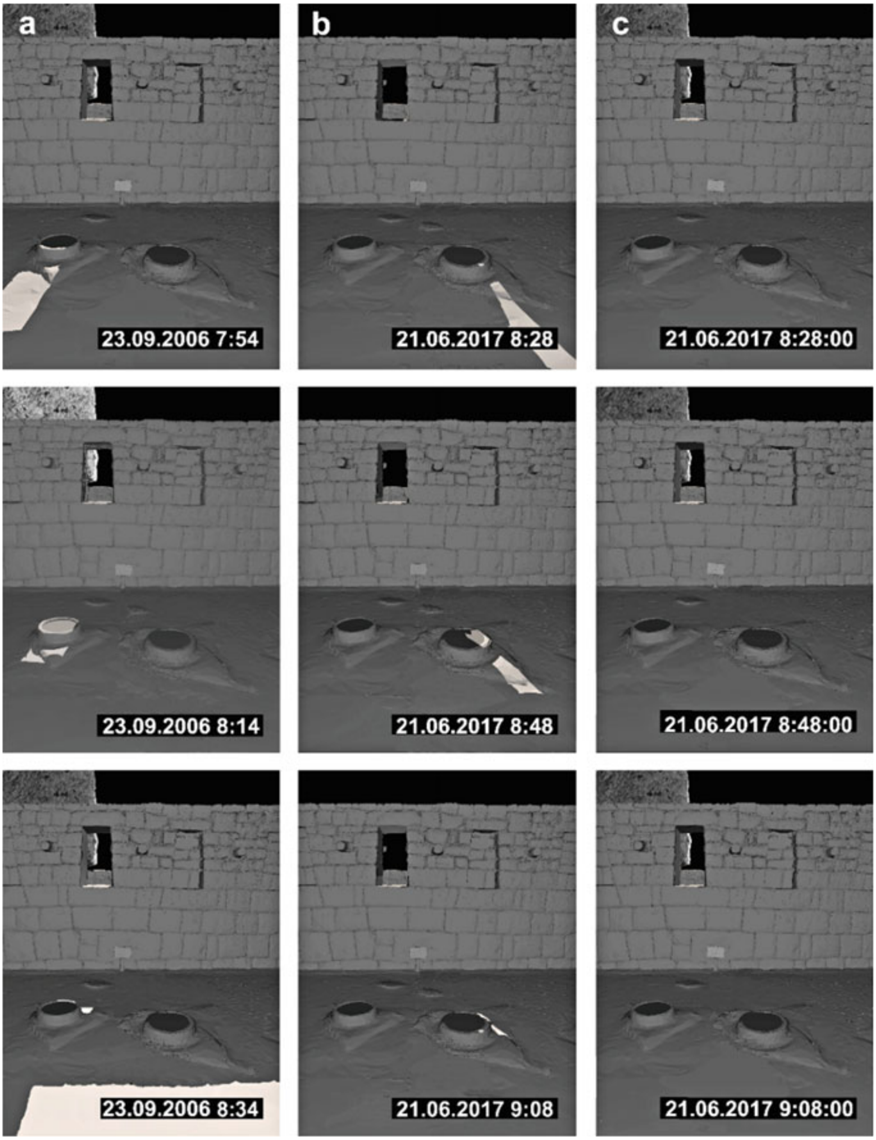

Fig. 5.24 Computer simulations using a 3D model for the sun's rays falling on the "mortars" in the Sala de los Morteros (elaborated by J. Kościuk); **a** on the day of the equinox; **b** during the June solstice (no roof over Building 6); **c** during the June solstice (with a roof over Building 6)

Fig. 5.25 The Sala de los Morteros on the June 21, 2017 (photo by D. Sieczkowska)

Let us now assume that indeed only the northern bowl served such observations, and additionally, in the absence of any markers determining the positions of the sun's rays, it was a reflective gnomonic type of observations. Where then, on the days of the equinoxes, would the reflected sun's rays fall? Computer simulation on a 3D model indicates that the sun's first rays peeking into the bowl's interior will be reflected on the top of the room's opposite western wall (Fig. 5.26a). As the sun rises above the horizon, the reflection of its rays from the surface of the liquid in the vessel will move to the thatched roof above the building (Fig. 5.26b, c). This does not create favourable conditions for astronomical observations, let alone for observations that precisely mark the days of the equinoxes.

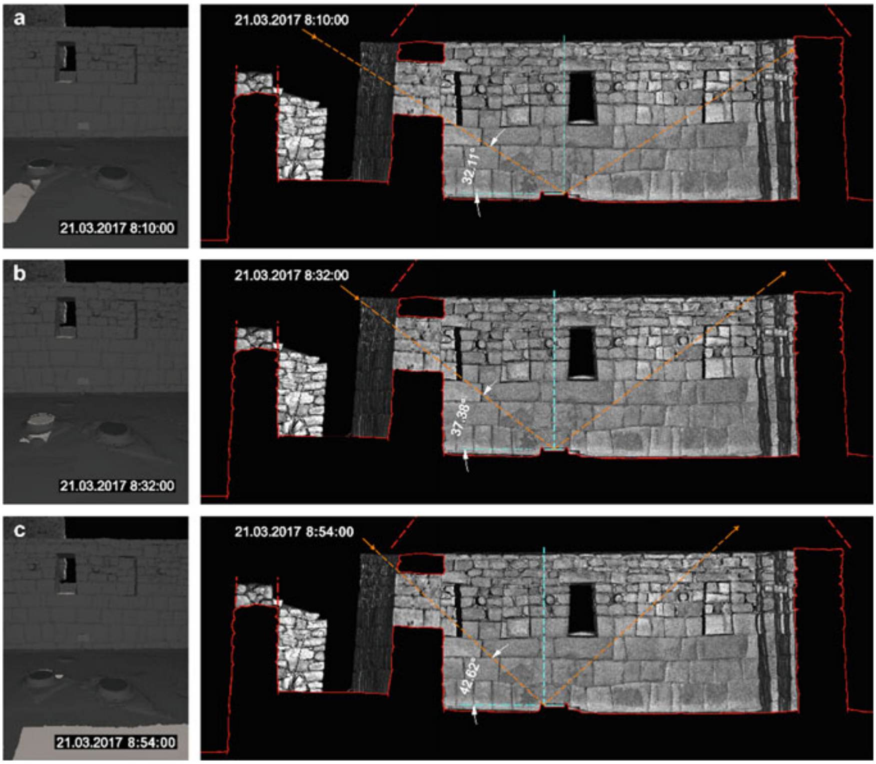

Fig. 5.26 Computer simulations using a 3D model for the sun's rays reflected from the northern "mortar" on June solstice day (elaborated by J. Kościuk); **a** at 8:10 AM on June 21, 2017; **b** at 8:32 AM on June 21, 2017; **c** at 8:54 AM on June 21, 2017

5.5.5 *Conclusions*

Although, at first sight, Eulogio Cabada Hildebrandt's hypothesis about the Sala de los Morteros calendar-astronomical function seems convincing, the analyses presented above multiply further doubts instead confirming it. Therefore, we are inclined to reject his postulates. The reasons behind this can be summarised as follows:

– the presence of roofs exclude the southern “mortar” to be ever illuminated at solstice or equinox days;
– the lack of any markers (lines or stripes) exactly marking the position of the sun’s rays in these most characteristic moments of the solar year makes the entire instrumentation unsuitable for precise astronomical observations;
– none of “mortars” is likely to serve as a reflective gnomon;
– the roof over the Sala de los Morteros rendered observations of the sun’s zenith passage over Machu Picchu impossible;
– the roofed buildings on the western side of the Sala de los Morteros prevent sunlight from this direction to illuminate the “mortars” through any of the three entrance doors.

In these circumstances, even any ceremonial function for the “mortars” related to the solar events might be questionable. Therefore, their original purpose cannot be clearly explained in light of the facts available. Perhaps they served for much more prosaic function than astronomical observations or rituals associated with astronomical events.

5.6 The Temple of the Condor

The Temple of the Condor is a group of structures located in the Hurin part of the Llaqta of Machu Picchu to the south of Intimachay (Figs. 5.1 and 5.27a). The central part of the complex consists of a small square bordered by two rocks between which is located the entrance to three small caves: two natural and one partially modified by the Incas.[28] The shape of these rocks is reminiscent of the wings of a bird in flight. This interpretation is corroborated by a relief in the shape of a bird’s head, carved into the rock surface on the square in front of the caves entrance.

An archaeoastronomical interpretation of this complex and the adjacent architectural structures (Fig. 5.27b) has been developed by James Westerman (2005). According to this scholar, the Incas, through the construction of buildings bordering the plaza on the NE side, achieved the effect of “allow the sun to only beam into the centre cave entrance at certain specific times of the year” (Westerman 2005: 347).

[28] The archaeological work in this sector was carried out by Alfredo Valencia Zegarra. (Valencia 1995, cited according Westerman 2005, 341, 347). Important comments on the astronomical interpretation were also provided by the latter and by Fernando Astete Victoria (Westerman 2005: 341).

Those correspond to "April 20th to 24th and August 16th to 20th. Due to the roof lines which existed during Inca times on the two buildings which form the gap, and the overhang of the suspended boulder above the cave, these would have been the only times of the year when the sun would have been visible in the caves" (Westerman 2005, 343).

The mentioned periods would coincide with the times of the passage of the Sun through the so-called antizenith (of Cusco and Machu Picchu), according to Tom Zuidema, symbolically important phenomena in the Inca rituals associated with agriculture (Zuidema 1991; Westerman 2005, 343–344).

We have analysed Westerman's model based on our field data (Fig. 5.28). It turns out that the illumination of the entrance to the caves and the relief with the condor's head indeed occurs in the periods postulated by Westerman. However, given the lack of elements such as marks to accurately follow the sun's rays movement, it seems that, as in the case of the Torreón, the astronomical orientation of the Condor temple served more for ritual purposes and not for precise observations. It should also be noted that in any case, this ceremonial complex would be one of the few known in the Inca environment, oriented in directions associated with the passage of the sun through the antizenith.[29]

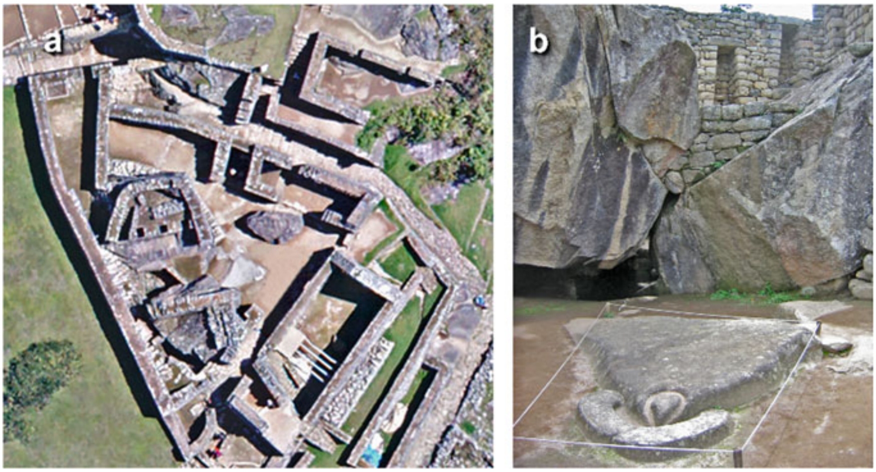

Fig. 5.27 The Temple of the Condor site**; a** the site orthoimage (courtesy of the DDC-Cusco); **b** "The Condor" petroglyph and the cave behind (photo by M. Ziółkowski)

[29] It has not been possible to identify with certainty such orientations at other Inca sites (Bauer and Dearborn 1995; Zawaski and Malville 2007/2008; Ziółkowski 2015, 186ff). The cases of Sahuite, Llaco and Moray, postulated in Zawaski's earlier work (Zawaski 2007), concern landscape elements but without any particular artificial signage (pillar, cairn, etc.) and are therefore not very convincing.

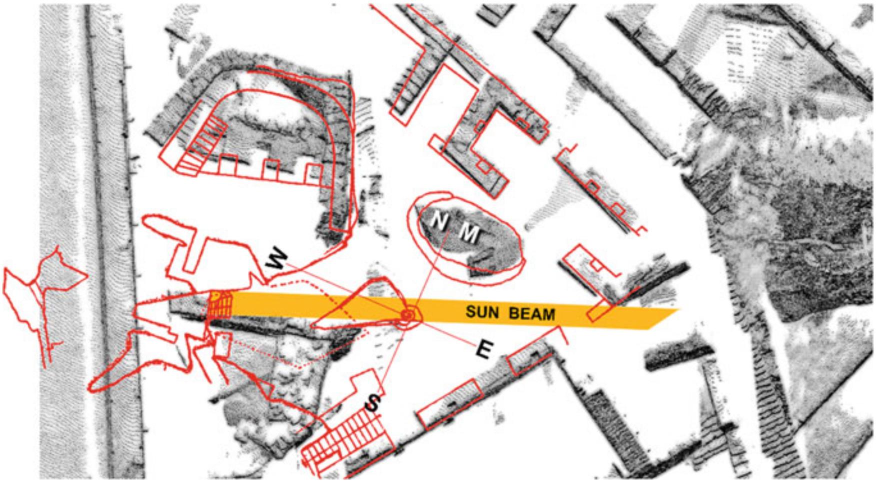

Fig. 5.28 The Temple of the Condor. Red—Westerman's plan (2005, 347, Fig. 7); Grey—results of 3D laser scanning (elaborated by J. Kościuk)

5.7 The Intimachay Cave

Intimachay is a small cave situated on the eastern terraces of Machu Picchu (Fig. 5.1). This natural cavity (Figs. 5.29 and 5.30) has been intentionally reshaped to serve for some ceremonial activities, among these of an astronomical nature.

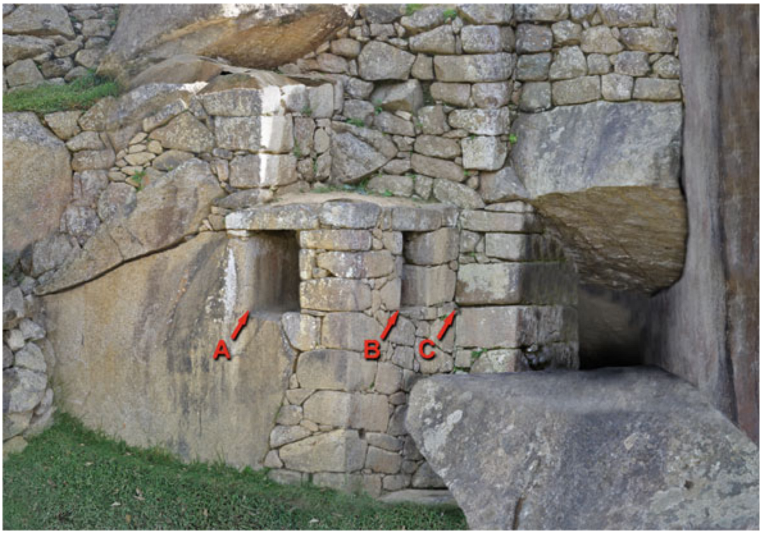

Fig. 5.29 The Intimachay cave as seen from the north-east (photo by J. Kościuk). A—the Eastern Widow; B—the Northern Widow; C—vertical joint between the 1st and 2nd building phases

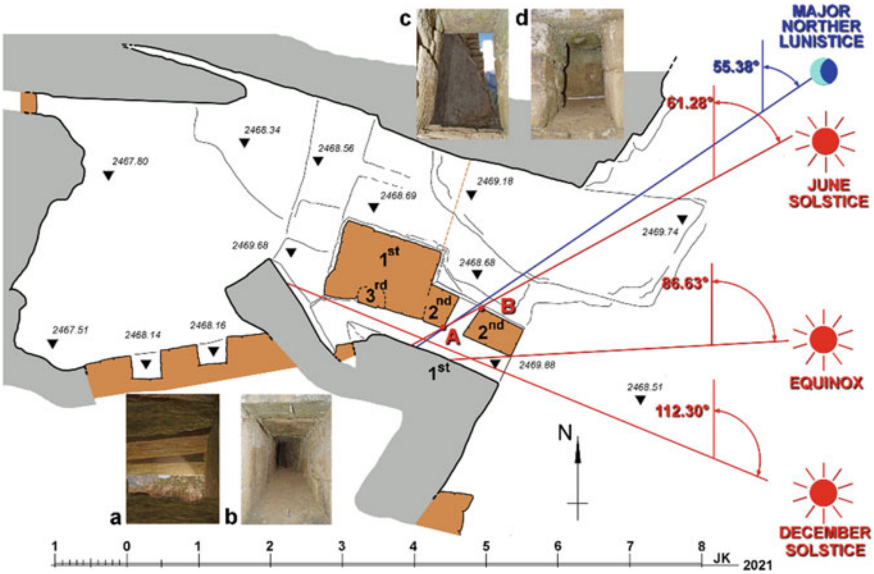

Fig. 5.30 The Intimachay cave. Grey—natural rock; brown—stone masonry (drawing and photos by J. Kościuk); **a** the eastern tunnel as looking east; **b** the eastern tunnel as looking west; **c** the northern tunnel as looking north; **d** the northern tunnel as looking south; 1st, 2nd, 3rd—technological building phases; A, B—corners of the northern tunnel delimiting the width of the light (of the Sun and the Moon) passing through the Northern Window

This last aspect has been the object of several investigations. The first archaeoastronomical study written by Dearborn White and Schreiber (1986) stands out there. They presented the hypothesis that this construction fulfilled the function of an observatory of the sunrise on the December solstice. The observation would be made by a type of tunnel or tube constructed by the specially carved natural rock and adjacent walls that form the ceiling and the northern wall of the structure. The outer opening of this tunnel, the Eastern Window (Fig. 5.29A), is oriented towards the sunrise on December solstice (Dearborn et al. 1987). A more recent study by Ziółkowski et al. (2013), based on a precise 3D model of the cave, oriented with a precision ±/−2 arc minutes in relation to the astronomical north, confirmed this hypothesis, but at the same time completed it by demonstrating the importance of a lateral opening—the Northern Window (Fig. 5.29B). This window had not been taken into account by our predecessors in their analysis.

As this last aspect had already been the subject of detailed publications (Ziółkowski et al. 2013, 402–403; 2015, 900–905; Ziółkowski 2015, 232–239; 2020, 12–13), in this place we will only summarise the conclusions of our work on the subject:

- A ray of the rising Sun falling diagonally through the Eastern Window during the Equinox will be visible through the Northern Window against made of dark streaks “scale” on the N-wall of N-E tunnel (Fig. 5.30).

- A beam of the rising Sun during June Solstice will fall through the Northern Window and will also light up the tunnel wall in part covered by mentioned above “dark streaks” (Fig. 5.30 top).
- Significant to this chapter’s main subject, a ray of the Moon rising at the Major Northern Lunistice (Fig. 5.30) will also fall through the Northern Window (Ziółkowski et al. 2013, 402–403).

Two further aspects must be mentioned, however. The first concerns the place chosen to erect this astronomical observatory. In the complicated configuration of the mountain ranges surrounding Llaqta Machu Picchu and taking into account the equally complicated topography of Llaqta itself, the problem of finding a place from which to observe both solstices[30] and the moment of equinoxes is not trivial even with the use of modern principles of descriptive geometry and computer tools. The chosen place should also be adequate to the planned building layout, which is an additional challenge in the so-called “granite chaos” of Llaqta’s natural topography.

The second important aspect concerns the use of the site’s potential for the construction of an astronomic observatory. In previous considerations, we emphasised an important, characteristic feature of buildings that were to serve as devices for precise astronomical observations. It was a tendency to minimise the angle within which a given astronomical phenomenon is observable. This principle is clearly visible in the case of Intimachay.

Towards the east, the pass between two hills and a kind of “rear sight” at the western end of the observation tunnel limited the horizontal visibility. In turn, the Eastern Window lintel, the horizon line and the “rear sight” located on the western end of the observation tunnel limited the vertical direction’s visibility to a bit more than the sun’s angular diameter disc (Fig. 5.30a). Therefore, on December 21st, not only the sunspot’s size falling on the rock surface behind the western end of the observation tunnel was very small but also the whole spectacle lasted only a bit longer than one minute. This constitutes perfect conditions for precise observations.

In the case of the north-facing observation tunnel, the range of horizontal visibility was limited on the left side by a sloping wall constructed from well-shaped stone blocks and on the right side by the edge of the observation window (Fig. 5.29c). The range of horizontal visibility, in this case, is slightly greater due to the need to take into account the angular difference between the June solstice and Major Northern Lunistice, which for these latitudes is 5.25°. The mountain’s slopes visible on this section of the horizon, and the Northern Window lintel limited the vertical range of visibility.

[30] Since at these latitudes the angular difference between the Major Northern Lunistice and the June Solstice is less than 6°, lunistice orientation played a minor, albeit not negligible, role in the search for an optimal location for the observatory.

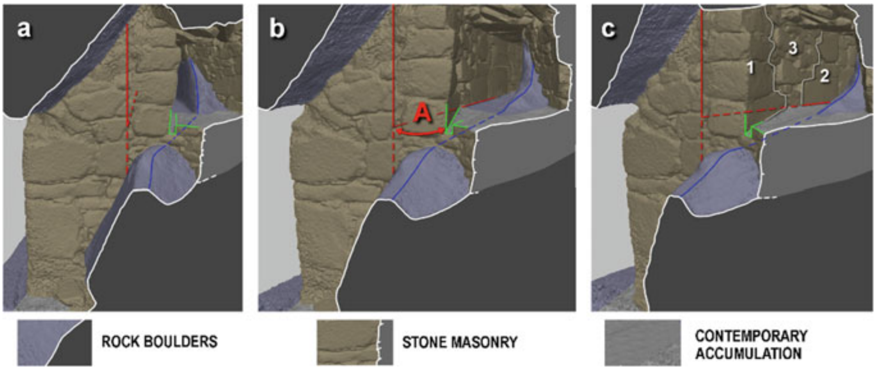

Fig. 5.31 The western end of the eastern observation tunnel (photo and drawing by J. Kościuk). Green lines—"rear sight"; red lines—the direction of the tunnel's northern side-wall projected from its eastern end; blue lines—the ridge of a rock boulder; 1, 2, 3—subsequent construction phases; A—correction of the tunnel's corner due to the construction constraints

In July 2017, M. Pakowska and J. Kościuk surveyed the eastern tunnel interior using the structured light scanner Artec Eva and short-range digital photogrammetry. With a high degree of confidence, the new data allowed us to reconstruct the main construction phases of the Intimachay observatory. It seems that in the first step, a large rock boulder forming the lintel of the cave entrance (Fig. 5.29) has been secured by a massive pillar (Fig. 5.30). Here, builders had to solve a significant construction problem. The entire pillar was built against the sloping face of the rock. The northern corner of the tunnel's western end and, if following the direction of December solstice, would be then on the rock slope (Fig. 5.31a), thus creating a risk of the entire construction slipping. The south-west corner of the pillar (Fig. 5.31 green lines) was therefore moved more to the south (Fig. 5.31b), behind the rock's ridge (Fig. 5.31 blue lines). A kind of "rear sight" has been arranged there (Fig. 5.31 green lines). Together with rising the pillar mentioned above, the eastern observation tunnel has been cut into the rock's sloping surface at the eastern front of the cave (Fig. 5.32).

As the second step, the framing of both observation windows was completed. The Eastern Window received its northern limit, and the Northern Window has been set up in a way to comply with several constraints:

- Corners A and B of the northern observation tunnel (Fig. 5.30) were to be set up in a way to ensure that the light-beam falling into the observation tunnel during the June solstice and the Major Northern Lunistice (of the Sun the Moon, respectively) was very narrow (Fig. 5.32).
- To avoid the risk of the entire construction slipping (since it has been built against the sloping face of the rock) the corner B of the northern observation tunnel (Fig. 5.30) should be set up over the rock shelf with some overlap (Fig. 5.32).

- The eastern window's northern extent should guaranty that the light of the Sun rising over the eastern horizon during the December solstice will enter inside the eastern observation tunnel.
- The northern face of the eastern observation tunnel has to be parallel to the December solstice direction.

As a result, the directions of the northern face of the eastern observation tunnel built in the first and second phases did not coincide with each other and intersected at an obtuse angle. The resulting gap was filled with less careful masonry in the third construction phase (Fig. 5.31c).

To summarize, we can state that despite many construction constraints, the builders took particular care to construct this "astronomical instrument" as precisely as possible. This concerns two main factors: a precise orientation towards important directions (equinox, both solstices and the Major Northern Lunistice) and minimising the angle within which a given astronomical phenomenon is observable.

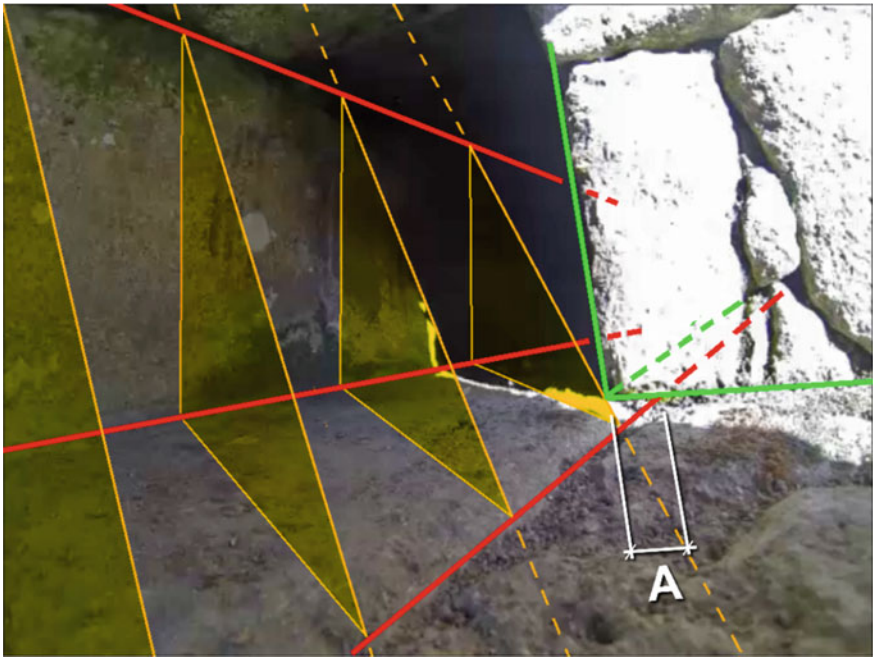

Fig. 5.32 The inside of the E-W observation tunnel. Note the sun-dagger entering the eastern tunnel at the moment of the June solstice when the full Sun disk is already above the horizon line (photo by J. Bastante, drawing by J. Kościuk). Red lines—the eastern tunnel's edges forming its bottom and southern wall; orange lines and triangles—simulation of the cut-out part of the rock; green lines—corner of the northern observation tunnel; A—the rock-shelf overlap

5.8 Llactapata

Llactapata is an important ceremonial Inca site located to the west of Llaqta Machupicchu, outside Machu Picchu Park's limits, but close to the old Inca trail that tourists take on an alternate route to reach the eponymous site (Fig. 5.2). The site had been located and briefly described by Hiram Bingham in 1912. However, the first archaeoastronomical research was carried out there as late as 2003 (Malville et al. 2004, n/a, Malville 2015; Gullberg 2019; Reinhard 2007).

The limitation of our review of this research and the formulated results from the fact that we have not carried out our own fieldwork at Llactapata. Therefore, we do not consider ourselves competent to judge the hypotheses made by others unequivocally. We limit ourselves to examine only some factors related to the orientation of some structures of the Sector I (Bingham) of Llactapata about what the mentioned Authors postulated the following:

> The site that Bingham had located (Sector I) extends some 90 m along the hillside and contains seven buildings, two courtyards, and two ceremonial corridors. The corridors open to an azimuth of approximately 65.6o on the north-eastern horizon and provide views of the rising sun on June solstice, the rising of the Pleiades, and Machu Picchu itself. The longer corridor, which is 2.5 m wide, 33 m long, has no side doors or side passages, implying its function as a ceremonial passageway. The precise centre of the corridor is difficult to establish because of irregular walls, but its length frames a window of approximately 4o along the horizon. On the 6o elevated horizon the first gleam of sunrise on June solstice has an azimuth of 64.2o. The Pleiades star cluster covers approximately 1o on the sky, and in A.D. 1500 it rose close to the centre of the horizon window, at an azimuth of approximately 66o. On June solstice, the Pleiades was a harbinger of sunrise, appearing on the horizon perhaps fifteen minutes ahead of the sun. (Malville et al. 2004)

In the latter publication, some data regarding the corridor's orientation and the conditions for observing sunrises and Pleiades were slightly modified: "When observing from the corridor's rear, a field of view is created extending 4.3° along the horizon. In 1500 AD, the June solstice Sun rose at an azimuth of 64.3°, while the heliacal rise of the Pleiades ranged from 64.9° to 65°" (Malville et al. 2006 quoted in Gullberg 2019).

We investigated these results using the Cartes du Ciel 4.0 software and arrived at similar results.[31] Indeed, on the June solstice 1500 AD, when looking alongside this corridor towards the East, the sunrise was seen at an azimuth of ca 64 13′. This corresponds almost exactly to the calculations of Malville and his Colleagues. Likewise, the rise of the Pleiades in 1500 AD was visible on the horizon, between approximately the azimuths 64°44′ (Taygeta, 19 Tau) and 65°13′ (Alcyone, η Tau),[32] which

[31] Our analysis are based on: plans published by Malville et al. (2004, 14, fig. 1, 15, fig. 2, 18, fig. 5) and Gullberg (2020, 291, Fig. 9.45); the horizon line as seen from Llactapata (on Google Earth Pro); the plan of a part of the Llactapata Sector I prepared by the personnel of the Park of Machu Picchu. We are grateful to the archaeologist José Bastante, the Director of the Park, for providing us with this last document.

[32] As the reference we took the moment when all that group of stars was visible over the horizon, but not the rise and place of each particular star of this constellation.

is quite close to the values of 64.9° and 65.0° postulated by the Authors mentioned above. The only discrepancy we note on the evaluation of the exact moment of the Pleiades' rise in relation to that of the Sun:

- on the days of the June solstice itself (ca. 9–11 June 1500 AD, according to the Julian calendar), this group of stars did not rise "fifteen minutes" before the sunrise, but around 3:54 am, i.e. about 2 h and 20 min before the event in question,
- the real "heliacal rise" of the Pleiades, which preceded the sunrise of ca. 15 min, actually took place a month before, around May 9th, 1500.

The second aspect that we try to evaluate is the supposed "cross orientation" between Sector I (or Bingham) of Llacatapa and some constructions in Machu Picchu itself. In their subsequent publications Malville and Gullberg described this proposal as follows: "Llactapata, rediscovered in 2003 (Malville et al. 2004), lies some 5 km to the southwest of Machu Picchu and appears to have been part of an extended, interconnected ceremonial centre. (…) A stone-lined channel leads from the double-jamb doorway of Llactapata toward the Sacred Plaza of Machu Picchu, making explicit the close connection between these places. (…) The east-facing wall of the Coricancha was covered with plates of high quality gold" (Malville 2015, 880–881). If the east-facing wall of Llactapata had adornments similar to those of the Coricancha, reflections of June solstice sunrise from its gold plates would have been a spectacular sight at Machu Picchu (…) Adjacent to the Plaza is the Sacristy, one of the most beautifully crafted rooms of Machu Picchu. A bench at the rear of the room faces December solstice sunset and possible reflections of June solstice sunrise from the walls of Llactapata" (Malville 2015, 881–885; see also Gullberg 2020, 295).

Due to the lack of archaeological data, we cannot pronounce ourselves in favour or against the existence of the "gold plates" on Llactapata's walls. The photos published by the mentioned authors (Malville 2015, 884, fig. 68.6; Gullberg 2020, 296, fig. 9.51) supporting the thesis of general intervisibility between Llactapata and Machu Picchu sites are convincing, but this is mainly due to the topographical situation of the region under investigation and the locations of both sites. However, the available measurements, plans and photos do not allow for a conclusive answer if, and to what extent, the planning and construction of particular buildings (for example, of the mentioned Sacristy on Llaqta Machupicchu) were conditioned by the desire to interconnect both sites at the level of orientation and visibility. This issue deserves a more detailed study in the future.

5.9 River Intihuatana

Among the ceremonial sites close to the Llaqta Machupicchu, the so-called "River Intihuatana" (Fig. 5.33) stands out. It is a group of carved rocks, platforms, fountains, basins, caves, platforms and architectural structures (including a circular tower) located in the Urubamba valley some 10 kms downstream from Machu Picchu (Fig. 5.2) or, more precisely, from the "Puente Ruinas".

The site, identified by Hiram Bingham in 1911, is not as well-known as its namesake, the Intihuatana of the Llaqta Machu Picchu. Its most extensive description is that recently published by Steven Gullberg (2020). As we know this important complex only very superficially, in the following lines we will quote some of Gullberg's observations on the subject:

> It is located at S13°10.54′ and W72°33.44' at 1819 masl on a hillside between PeruRail switchbacks near a hydroelectric complex. (…) The principle element of the shrine is a rock carved with steps and tiers. The adjacent upslope section of the sanctuary contains two water basins aligned east–west and has an elaborately engineered water fountain that is situated over a small cave. Eastward of these granite carvings are the remains of several support structures and a tower attached to a large boulder with a second cave beneath. The area exhibits agricultural terraces, but they are presently engulfed by trees. (Gullberg 2020, 272–275)

Fig. 5.33 The River Intihuatana (photo by M. Ziółkowski)

Gullberg also notes the existence of a long-distance "line of sight", corresponding to a solstitial axis, of which Intihuatana seems to be a focal point: "This is a solar axis formed between the horizon points of the June solstice sunrise and December solstice sunset, which also includes Llactapata's Sun Temple and Machu Picchu's Sacred Plaza. It remains possible that the River Intihuatana's location (…) may have been part of a ceque connecting Machu Picchu with Llactapata. It is also a possibility that the precise geographic location of the River Intihuatana at the junction of such axes was intentional and that this may be an example of the power and status of this huaca" (Gullberg 2020, 255). The scholar also postulates an equinoctial orientation for the structure called "Torre" in the River Intihuatana complex (Gullberg 2020, 288).

As we have not conducted our own works at this site, we are not in a position to evaluate Gullberg's postulates. However, it is worth noting that if indeed River Intihuatana played such a prominent role as a focal point, which conditioned the location of the main Inca sites in this area (including the Llaqta Machu Picchu), it could be that the River Intihuatana was a ceremonial centre erected by the Incas even before the Llaqta. These questions could be answered only by further detailed researches on this important ceremonial centre.

5.10 El Mirador de Inkaraqay

Mirador, or El Mirador de Inkaraqay, is a small complex located on the northern slopes of Huayna Picchu (Fig. 5.2). The site was discovered in 1982 by Fernando Astete Victoria, and from the beginning, due to the specific characteristics of the structure, it was considered a kind of observatory (Reinhard 2007). However, the verification of this possible function did not begin until 2012 when the Peruvian-Polish team formed by personnel of the Machu Picchu National Park and scientists from the Centre of Andean Studies of the University of Warsaw in Cusco started the investigations on the site. The results of these studies have already been widely disseminated in several publications, so here, as in the case of Intimachay, we will limit ourselves only to a summary presentation of the main conclusions of the research already published (Astete Victoria et al. 2017).

The architectural remains of El Mirador de Inkaraqay consist of three parallel walls placed perpendicularly to the steep slope of the hill (Fig. 5.34). The lower wall serves as a retaining wall to stabilise the foundations of the building above. Simultaneously, it creates a narrow platform (about 1.75 m) for easy access in front of the building. The central wall is about 1.25 m wide, and its facade is preserved up to a height of about 3.5 m. The carefully executed stone masonry is of the pseudo-curved type with slightly depressed joints. On the back of this wall, two series of niches are extant. Three of them, about 1.6 m high, begin directly above the floor of the building. They are about 70 cm wide. The central niche and the northernmost niche have two observation openings. Analysis of the construction process suggests that the wall was planned according to these openings' appropriate location and orientation.

It should be noted that the openings have been made with great care and are structurally well thought out (Fig. 5.35). Both were made and oriented precisely. The architectural analysis shows that they could not fulfil any other function than that of observation.

However, it should be noted that according to the data from the excavation carried out in this building in 2012, it seems that it was abandoned during the construction process, i.e. it was never finished. This conclusion is based on the lack of any cultural stratum, which could testify to its occupation. The absence of stone blocks, which would necessarily have been accumulated inside the building if only the rear wall had collapsed, is another indication (Delgado Villanueva 2012, 212–216). To this, we can also add the missing architrave above the southern entrance with double door-jambs. Such a massive element, even when collapsed, is likely to remain in close vicinity of the door. Another puzzling fact is that only two of the three big niches have observation openings, although all three are extant to the full height. Such asymmetry is atypical for Inca architecture.

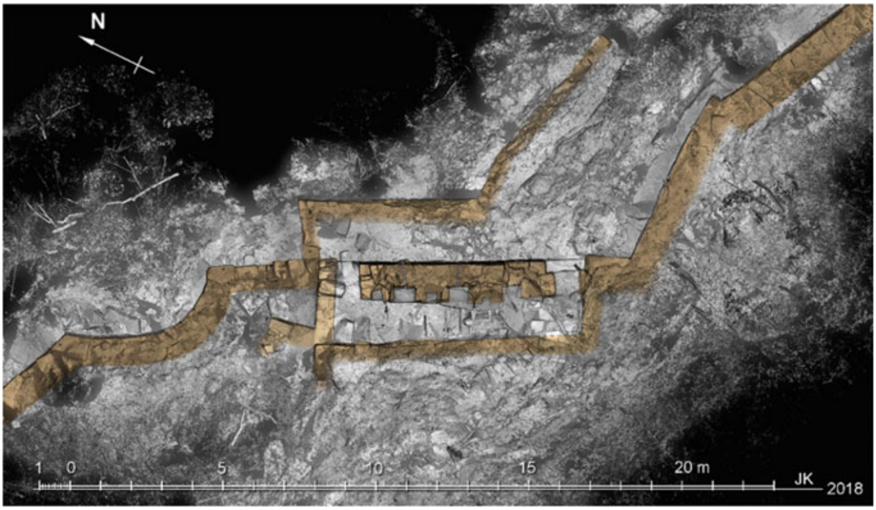

Fig. 5.34 El Mirador de Inkaraqay plan resulting from 3D laser scanning (drawn by J. Kościuk)

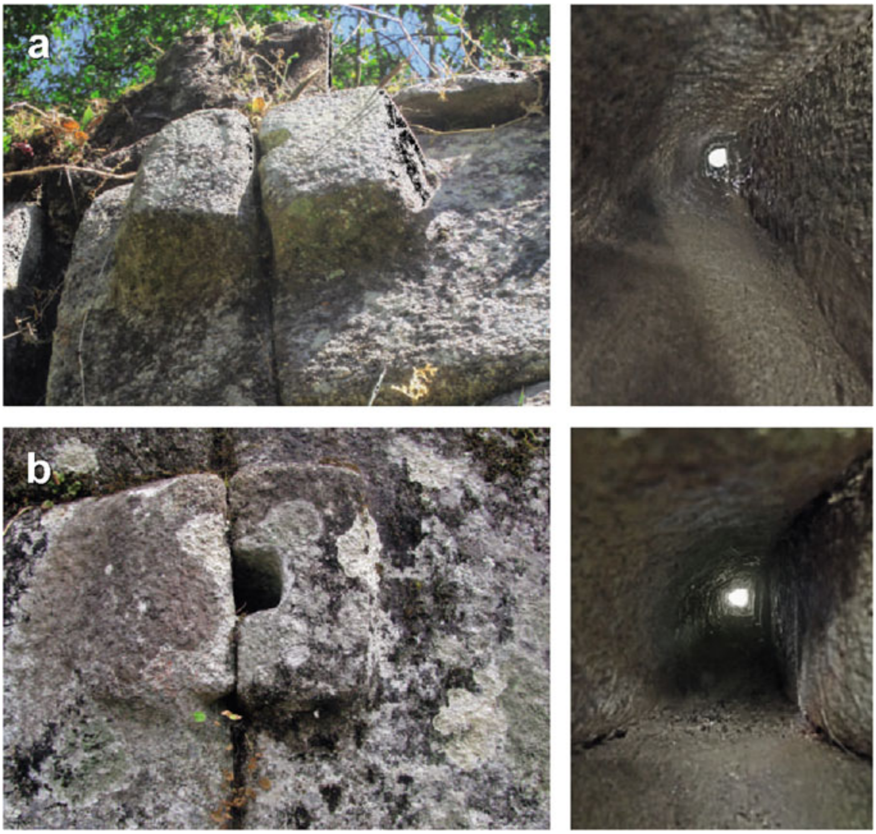

Fig. 5.35 The observation openings (photos by M. Ziółkowski). **a** The northern observation opening as seen from the outside (left) and inside of the main wall (right); **b** the southern observation opening as seen from the outside (left) and inside of the main wall (right)

We are then confronted with an unfinished building, which obviously does not facilitate its interpretation. However, we can still sum up several observations and formulate some hypotheses concerning the possible astronomical significance of this building:

- On-site observations conducted on June 20–21, 2014 confirmed the results of earlier simulations on the 3D model (based on 3D scanning) —during the June solstice, the sunrise is visible through the northern opening directly above the Yanantin peak (Fig. 5.36). This phenomenon is visible not only through the northern but also the central opening. However, observation with the naked eye is possible only in the initial phase of the phenomenon; once the entire solar disk is above the horizon, its glow is too blinding. One can hypothesise that in this particular case, this opening was used not for horizontal but gnomonic observation, following a ray of sunlight falling on the back wall of the structure. We can assume that if there was plaster on it (which was typical in the Inca buildings of this status), this observation could be aided by specific signs made in it.

- We noticed that the southern opening covers an arc of the horizon vision matching to the movement of the Sun between the declinations of approximately 21°06′ to 23°26′, corresponding to period between May 25th and July 17th, 2020, that is, for about 52 days,[33]
- The northern opening covers a section of the horizon approximately between declinations + 22°38′ and + 27°00′, so it goes 3°34′ beyond the sun's extreme position in the June solstice. The movement of the sun can be followed through this tube between approximately June 5th and July 6th, 2020,[34] i.e. for about 31 days.
- As the consequence of such orientation of both openings, the simultaneous entry of the sun's rays through both openings could serve to refine the demarcation of a period of about one month (ca. 30 days) around the Solstice.
- The Moon could be observed both directly and gnomonically through both tubes. Although one of the directions, towards sunrise at the June Solstice, corresponds to what is called the "median lunistice", other, typically lunar orientations, such as the major or minor lunistices, cannot be observed. Thus, the lunar observatory's role seems doubtful, at least when analysing the unfinished shape of the structure.
- The unique form of the openings (long tubes), which have no parallel in any other Inca construction of astronomical character, seems to be designed for another, specific kind of observations. Tubes like those allow for fine-tuning the direction of observation and reducing the impact of the "parasite lights", particularly at times close to sunrise or even after it. This could be used to observe with greater precision the heliacal rise of stars (or planets), particularly the Pleiades. According to our reconstruction (Fig. 5.35), around 1470 AD, through both openings, one could observe the rising of this group of stars in a very particular position in relation to the Yanantnin mountain: they seem to "climb" its southern slope (Astete Victoria et al. 2017).
- We have also considered the possibility of observing other stars. However, although, for example, Arcturus (α Boo) or Hamal (α Ari) were visible in the directions delimited by the tubes, it is not clear whether it was important in the Inca cosmovision and astronomical practise (Astete Victoria et al. 2017, 22).

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[33] In the Julian calendar, this would correspond to the period between May 16th and July 8th, 1470 AD.

[34] In the Julian calendar, this would correspond to the period between May 27th and June 29th, 1470 AD.

- There remains for consideration another possibility that we have already raised previously, but only in a general way. Through the northern tube, one can observe certain positions of Venus above a very characteristic topographical feature on the N slope of the Yanantin mountain situated on the outskirts of the sun's path at the azimuth 54°30′, which in this case approximately corresponds to a declination of +27°00′ (Fig. 5.35a).[35] In its eight-year cycle, Venus rises in this part of the sky alternately every 3 and 5 years, during its period of visibility as Evening Star. Thanks to the combined effect of its greater elongation and the tube's optical characteristics, it might also be observed in the daytime.[36] A discussion of the possible role of such diurnal observations of Venus in its Evening Star phase will be offered in the general conclusions subchapter.

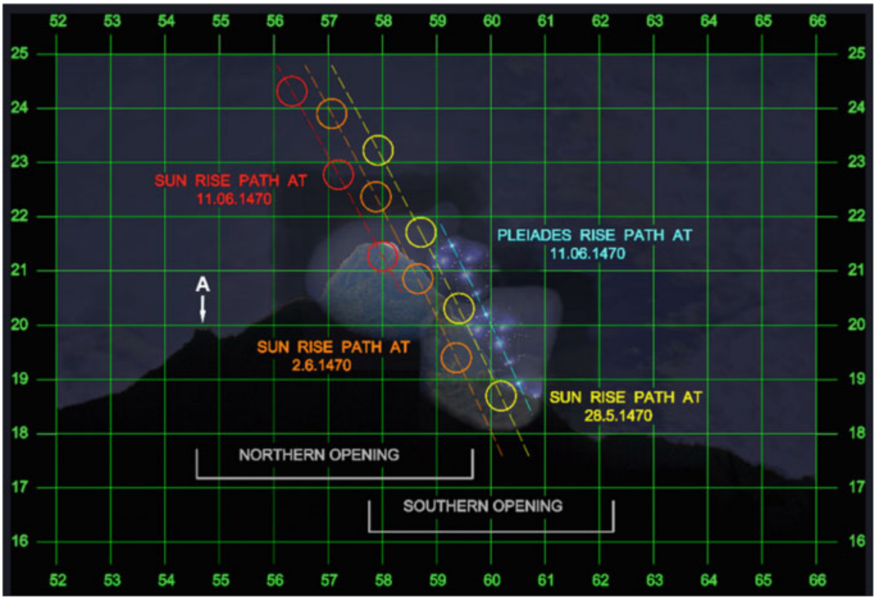

Fig. 5.36 Reconstruction of the conditions for observing the sky through both openings showing view fields alongside their principal axes (reconstructed by M. Ziółkowski and J. Kościuk using Cartes du Ciel 3.08 and Stellarium 0.16.0 software). The lower scales (in grey) show the maximum range of visibility from each opening when changing the position of the observer's eye. JSSR in 1470 AD (the approximate year of the building construction) is marked in red. The Pleiades' heliacal rising is represented in blue. A—a characteristic topographical feature on the N slope of the Yanantin mountain

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[35] We have advanced the possibility of Venus observations in this part of the horizon in our 2017 text (Astete et al. 2017, 22).

[36] This much more elaborated version of our initial hypothesis the result of an important contribution of Professor Tomasz Bulik (Institute of Astronomy, University of Warsaw). For example, between 1450 and 1500 AD, this phenomenon occurred in the following periods: April 1454, May 1457, April 1462, May 1465, April 1470, May 1473, April 1478, April 1481, April 1486, April 1489, April 1494 and April 1497 (Tomasz Bulik, personal communication, March 30th, 2021).

In any case, a specific characteristic of the Mirador de Inkaraqay, shared with the Intimachay cave, is very evident. Both structures were planned and erected for the exclusive purpose of astronomical observation, carried out by a select group of people, which is confirmed by the reduced dimensions of these architectural complexes. In the final section of this chapter, we will try to compare these structures with other monuments of possibly similar function.

5.11 General Conclusions

The aim of this text has been the evaluation of the hypotheses concerning the possible astronomical function of some structures and architectural ensembles located in the Llaqta of Machu Picchu and in the immediate vicinity of it. These were: El Torreón (the Temple of the Sun), Sala de los Morteros (the Room of the Mortars), the cave of Intimachay, the Temple of Condor, the Intihuatana, El Mirador de Inkaraqay, the River Intihuatana as well as the site of Llactapata.

5.11.1 Results

Of these seven, one, the Sala de los Morteros, appears not to have at all been designed for astronomical observation purposes. The illumination effects, which are observed today, of the two mortars in particular at sunrise at the Equinoxes seem to be a fortuitous effect, due to the structural changes of this complex since the Pre-Hispanic period, especially the lack of roofs on the buildings. In the digital reconstructions, which take into account these changes, the mentioned effects disappear completely in case of one of the “southern” and become unconvincing as far as the second (“northern”) is concerned, and that for lack of any traces of marks or signs for tracking the changes in the position of the sun’s ray. Therefore, we have to reject the hypothesis that this ensemble fulfilled the function of a solar observatory calendar.

Two other structures, namely the Intihuatana of the Llaqta of Machu Picchu and the River Intihuatana may have served as sites for horizontal observations. However, in the case of the Intihuatana of the Llaqta, it has not been possible to identify any type of artificial signalling on the horizon, which could have served to refine such observations. The main phenomena observed from that structure, such as sunrises and sunsets at the solstices, rises and culminations of groups of stars, etc. can only be followed in relation to distinctive natural elements of the surrounding landscape, such as hilltops, etc. This may have been important for the Incas within the general framework of their cosmovision, but they could hardly have been precise observations. These same assessments concern the River Intihuatana, although in this case it cannot be excluded that the observations, in particular the "solstitial axis" postulated by Steven Gullberg, might have been made in relation to some structures in Llactapata and the Llaqta of Machu Picchu: “This is a solar axis formed between the horizon points of the June solstice sun-rise and December solstice sunset, which also includes Llactapata's Sun Temple and Machu Picchu's Sacred Plaza" (Gullberg 2020, 255).

Nor can we exclude the possibility of astronomical observations in reference to other points on the horizon or of zenithal observations at the structure known as the "Tower" located within the River Intihuatana complex. These issues deserve to be addressed in future fieldwork. However, for the moment also in the case of this complex, we lack evidence that the documented astronomical orientations could have had any other purpose than a purely ritual-symbolic one.

The site of Llactapata, located to the west of the Llaqta of Machu Picchu, has only been mentioned in our text, for lack of our own work there. However, it is worth noting the very precise orientation of one of the main structures towards sunrise at the June solstice, and the important role this may have played in the rituals probably performed in this ceremonial complex.

The function of two of the other structures analysed, the Torreón at Machu Picchu Picchu and the Temple of the Condor, may have been similar. The Torreón has been analysed in detail in a separate study (Ziólkowski and Kościuk 2020), given the complexity of the hypotheses formulated around its possible function as a "precision observatory". It has been possible to confirm the intentionality of the orientation of the windows to follow the movement of the sun's rays in the periods around the solstice, as well as in those close to the dates of the sun's passage through the zenith of Cuzco (and/or the local zenith). Likewise, from certain particular observation positions within the structure, the movements of some groups of stars, important within the framework of the Andean cosmovision of that time (and even today), such as the helical rising of the Pleiades or of the tail of the Big Dipper, could be followed. However, it is worth noting that given its architectural characteristics, the Torreón does not seem to have been designed to facilitate observations other than those of a symbolic-ritual nature, since the existence of some mobile devices for that purpose is not supported by historical or archaeological data. In short—in the process of planning and erecting this structure, astronomical considerations were most probably taken into account, but without the aim of achieving a high precision of the associated orientations.

The case of the Temple of the Condor is similar: the orientation towards the sunrise in the timespan of about 5 days neighbouring the passages of the sun through the antizenith of Cuzco and Machu Picchu (April 20th to 24th and August 16th to 20th) seems to be well-proven (Westerman 2005), however, the characteristics of the complex do not seem to have been designed as an astronomical instrument. On the other hand, it should be noted that this would be the only Inca structure known to date, oriented towards sunrise on dates close to the so-called antizenith passages of the Sun.

Two structures remain to be examined, Intimachay and the Mirador de Inkaraqay which, as we postulated at the end of the previous section, do seem to fulfil the necessary conditions to be considered as astronomical instruments of precision. But it remains to be established, for what practical purpose were the observations made in these structures? To answer this question, we have to refer also to these few examples from other parts of Tahuantinsuyu, where the existence of similar kind of instruments has been evidenced.

5.11.2 Some Comparative Cases

Although several dozens of Inca sites, from various parts of the Inca Empire, have been analysed at an archaeoastronomical level, with different degrees of accuracy (and seriousness…), there are few examples of structures erected for the purpose of precise observations. For the subject of our study, three of these are of particular importance: the sucancas of Urubamba, the structures of the Puncuyoc site (Vilcabamba) and the supposed sucancas located in the Tikani range on the Island of the Sun (Titicaca).[37]

5.11.2.1 The Sucancas of Urubamba and Quispiguanca, the Palace of Huayna Capac

The two pillars located on the hill to the east of Quispihuanca, the palace of Huayna Capac in the Urubamba valley, have only recently been the subject of archaeoastronomical studies.[38] The results of the work of Zawaski and Malville are worth mentioning:

"The pillars are on a ridge known as Cerro Sayhua. Although sayhua means "marker" in Quechua, the purpose of these pillars had not been publicised until our observations. Measurements of the pillars and palace were made by taking multiple sunsights with a Wild T-2 theodolite and GPS. As viewed from the north-eastern point in the courtyard, the azimuth of the midpoint of the towers is 56°I4′; the mean altitude of the pillars is 24°1′. (…) Although the courtyard of the palace is large, greater than 2 ha in area, it may not have been used for it may not have been used for

[37] Another structure of a similar kind could be "La Horca del Inca", located on the top of a hill south of the city of Copacabana (Bolivia). According to Osvaldo Rivera and Juan de la Cruz Zapata, this device, together with certain holes in the surrounding rocks, constituted a type of observatory, which made it possible to follow, throughout the year, different solar phenomena, especially the June solstice and the equinoxes (Rivera 1984; Zapata 1983). This hypothesis, apparently recognized as reliable by other authors (Bauer and Stanish 2001, 244–246) has subsequently been severely questioned by Gonzalo Pereira Quiroga, who does not give the "Horca del Inca" any astronomical function confirmed with any certainty (Pereira Quiroga 2011; Ziółkowski 2015, 189–190). It is also necessary to mention the cave of Amarumarca-huasi (called also Lacco) near Sacsayhuaman (Cusco), as a possible "precision instrument for zenithal observations of the Sun and the Moon. The shape of this cave seems to be suitable for such observations, thanks to the existence of a vertical conduit above a type of stone altar carved into the bedrock. However, the lack of an artefact (stone tube, plate with a hole of a suitable diameter, etc.) at the mouth of this conduit does not allow us to establish the degree of accuracy of such observations (Gullberg and Malville 2011, 104–109; Ziółkowski 2015, 244–248).

[38] The actual proof of this interest is the partial reconstruction of one of the pillars.

public ceremonies. (…) The pillars are built of shaped sandstone blocks that match the composition of the ridge. They stand 35.3 m apart on either end of a built-up terrace. They are located along an azimuth of 101.5° on the ridge at an elevation of approximately 3,860 m. When viewed from Quespiwanka, the separation of the towers is 0.59°. The easternmost tower has a height of 4.3 m and a base of 1.5 × 3.3 m; the base of the partially restored western tower is similar. (…) The June solstice sunrise can be viewed outside the northern and southern walls of the palace [of Quespiwanca]" (Zawaski and Malville 2007/2008, 24–25).

Accepting that the observation site was indeed the one suggested by Zawaski and Malville, we note that the angular dimension of the space between the pillars barely exceeds the diameter of the Sun disc, which meets the requirements of a precise observation. We have a similar situation at the site of Puncuyoc in Vilcabamba.

5.11.2.2 Puncuyoc and Inca Huasi, Ceremonial Complex in the Puncuyoc Range, Vilcabamba

The Puncuyoc/Incahuasi ceremonial complex has been described in detail, principally by White (1984–1985)[39] and Vincent Lee (1985), but in the following lines we will limit ourselves to summarising the archaeoastronomical research carried out at this site by Bernard W. Bell (2011). According to this researcher, the observations made at this site were of two types:

- Horizontal, of the sunrise on the June Solstice, is marked by two piles of stones located on the summit of a hill, a phenomenon observed from a ceremonial stone platform. Bell has been able to establish that the angular distance between these piles corresponds to that of the diameter of a solar disc (Bell 2011, 103), which resembles the situation described above of the Urubamba pillars.[40]
- Gnomonic, of the sun's rays entering through the door of the Incahuasi complex, located below: "From the same platform looking south into the interior of the Incahuasi via a second story opening one can see the same sunrise light beaming through the doorway and crossing the centre of its sill to strike the back wall of a man-sized niche" (Bell 2011, 107).

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[39] White presents a summary of references to this site in the works of other authors (White 1984–1985, 128–130).

[40] However, Bell highlights the difference in the construction and finishing of these two sucancas: "These piles of stones are similar to trail markers or apacheta cairns found at mountain passes in the Andes and stand in stark contrast to the carefully fitted stonework of the Incahuasi. The stone markers are not fitted, shaped, or worked in any discernible way. If at one time they had been covered with plaster (as was the Incahuasi), no clear trace remains visible today. Instead, the stones were simply carefully stacked one on top of the other. The top of each cairn consists of a large triangular stone rising from the lichen-encrusted pile beneath it, with its sharp end pointing skyward" (Bell 2011, 106–107).

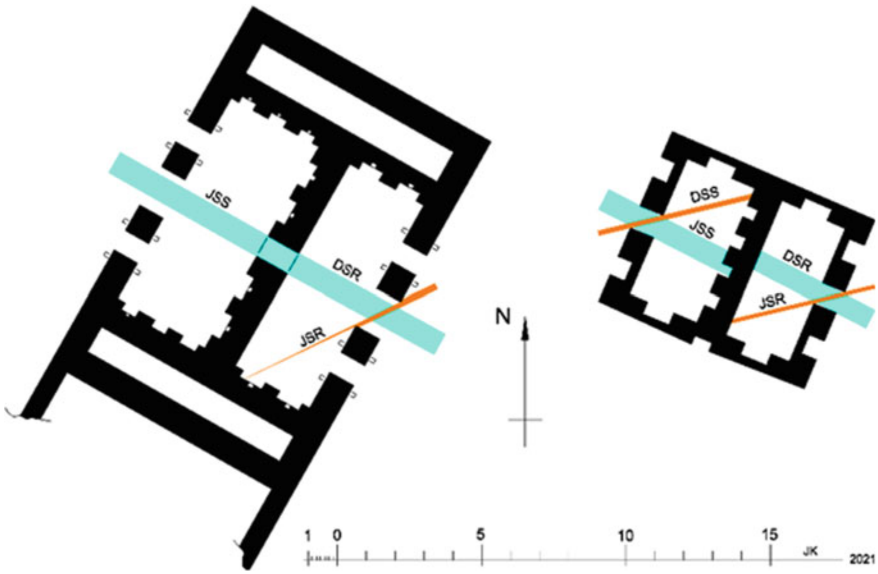

Fig. 5.37 Comparison of the plans of the structure at Punkuyoc (left) with that of the "Guard Room" at Ingapirca (right). Note the similarity in design and orientation, apparently with the aim of illuminating the inner wall of the structures alternately throughout the year: the west room at the time of the June solstice, the east room at the time of the December solstice. It is also noteworthy that one of these structures is located in the Cordillera de Vilcabamba, Peru, while the other in Cañar, Ecuador, which seems to testify to the application, in two different and distant locations, of the same architectural-astronomical model (drawing by Jacek Kościuk)

The observations at Incahuasi would be made by observing the rays of the rising sun in the period of about 40 days around the June solstice. On the other hand, at the December solstice only a narrow ray of the sun would fit inside the structure (see figure). It is noteworthy that the very shape of this structure as well as the technical aspect of the observation are similar to those at the Ingapirca site (Fig. 5.37) in the province of Cañar (Ecuador), described by one of us (Ziólkowski and Sadowski 1991). This coincidence seems to testify that such a model of ceremonial/astronomical structure was part of the repertoire of the Inca architects, and could have been replicated in different ceremonial centres throughout the Tahuantinsuyu.

5.11.2.3 The Tikani Sukankas

The structures in question are related to a ceremonial plaza located in front of the Sacred Rock (Titikala), on the Island of the Sun in Lake Titicaca. The observations made there were of two types; one of the sunrise over the Sacred Rock at the time of the June solstice and another, in the same period, but of the sunset between two sucancas (or pillars) located in the Tikani range at a distance of 600 m from the plaza. Apparently, in both cases, a selection of the group of attendees/observers of these phenomena was noted. According to David Dearborn, Mathew Seddon and Brian Bauer, the plaza was reserved for members of the elite, while ordinary people could take part in the ceremonies and observe the Sun from a platform outside the sacred precinct. The scholars made a series of measurements from a central point in the "elite" square to determine the orientation of the sucancas (Fig. 5.38). They noted that the distance between the foundations of those structures, about 30 m, corresponds to an angular spacing of about 2.75° (Fig. 5.39). However, no precise location for the observations is indicated and the chosen reference point is arbitrary (Dearborn et al. 1998, 250–256).

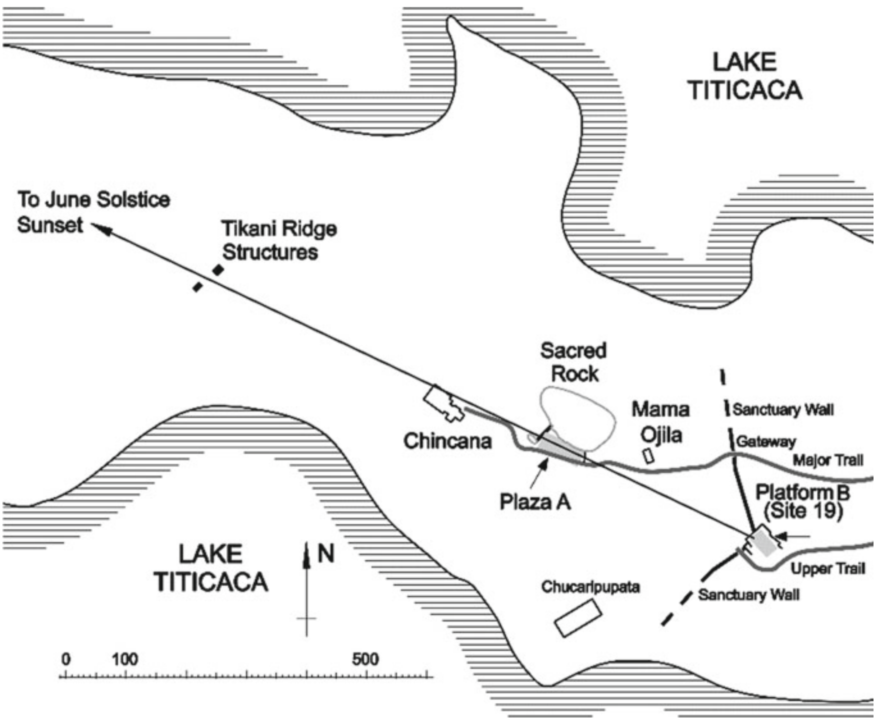

Fig. 5.38 The Sacred Rock (Titikala) on the Island of the Sun, with the adjacent plaza, and a platform (Site 19) adjoining the sanctuary wall. People standing in the plaza or on the platform can see the June solstice sunset between two structures located on the Tikani ridge (drawing by Jacek Kościuk on the base of Dearborn et al. 1998, 249 fig. 7)

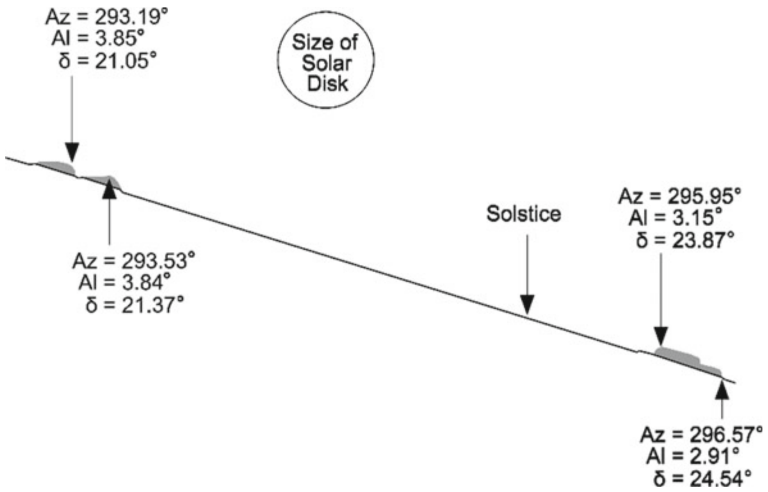

Fig. 5.39 Schematic plan of the location of the two structures on Tikani Ridge, as seen from the centre of the plaza adjacent to the Sacred Rock (compare Fig. 5.36). The description of the movement of the sun between the structures is presented in the text (elaborated by Jacek Kościuk on the base of Dearborn et al. 1998, 253 fig. 12)

Although in this case it is also, as in the cases described above, the observation of the Sun in the solstitial period, there are some differences that should be highlighted:

- First, it is the observation of the sunset and not of the sunrise as in most of the structures previously analysed.
- Secondly, it remains to explain why the angular distance between the two Tikani sucancas is 2.75°, while in the case of both the Urubamba and Puncuyo sucancas it barely exceeded the diameter of the solar disc. In Tikani there are no topographical restrictions that would have prevented locating the pillars closer to each other, so the question arises, what was the practical purpose of distancing them?

In this respect we can advance the hypothesis that it was not only a matter of determining an exact orientation and a punctual event but also of marking a period in the year, delimited by the moments of the Sun's entrance between the sucancas, its advance, subsequent return and exit outside the sucancas. On the basis of the measurements presented by the above-mentioned studies we have calculated that the Sun's entrance from the S side between the sucancas occurs on May 26th, and its exit from this space on July 17th, respectively,[41] which corresponds to a period of about 52 days. Let us also note that by 1500 AD in the space between the pillars at about 1 degree of distance from the south pillar the sunset of the Pleiades could be observed, a phenomenon considered important in the system of the Andean cosmovisions.

[41] By 2020, according to the Julian calendar, between May 16/17th and July 6/7th, 1500 AD, respectively.

5.11.3 About the Function of Intimachay and the Mirador de Inkaraqay

In the case of the former, it is clear that it could have been mainly for gnomonic observations of the Sun and the Moon, apparently throughout the year, mainly through the north window. The complex and elaborated modification of the parameters of the latter, most probably in function of the need to refine the observations, should be emphasised. The possible presence of a graduation on the inner wall of the conduct, opposite the side window, made it possible to follow the movement of the Sun throughout the year and also to define the position of the Moon at the major lunistice (and possibly also at the minor lunistice), within the framework of the 18.61 year cycle.

On the other hand, the structure could not be used for observations of planets and stars, except in a very restricted part of the horizon, looking through the eastern tube from inside the cave.

It is noteworthy that in Intimachay, the system was based on the orientation not only of the main axes but also (or above all) of the diagonals, determined by the corners (external and internal) of the observation windows. This characteristic is also observed in the cases cited above, of Inkahuasi in Punkuyoc and Ingapirca (Ecuador) as well as, although with a variant, in the case of the two tubes of Inkaraqay.

Because of the presence of two observation tubes, the latter structure is unique and has no known parallel among Inca constructions. Like Intimachay, it could be used for gnomonic observations, as well as for horizontal observations of the Sun and the Moon, but in comparison with Intimachay it had a more reduced repertoire of phenomena. It should be noted that the characteristic of the tubes and their orientation apparently allowed to determine, by the movement of the sun's rays, two periods around the June Solstice: one of approximately 30–31 days of duration and the other of about 52 days. The latter corresponds to the time of the sun's movement between the sucancas or pillars at the sanctuary of the Sacred Rock on the Island of the Sun. Let us remember, that a period of similar length, though not as precisely established, was also postulated to be related to the orientation of some structures in the temple of Coricancha in Cusco.[42]

As we have already stressed, the unique form of the openings (long tubes) allows for fine-tuning the direction of observation and reducing the impact of the "parasite lights", particularly at times close to sunrise or even after it. This could be used to observe with greater precision the heliacal rise of stars (or planets), particularly the

[42] Tom Zuidema postulates the importance of a fixed period of 55 days around the June solstice (Zuidema 2015). Although this exact duration has not been demonstrated to correspond to the orientations at Coricancha, the examples cited from the Mirador de Inkaraqay and the Tikani sukankas compel us to consider as possibly important period of approximately this duration centered on the June solstice. For more details about the hypothesis of the astronomical function of Coricancha see Ziółkowski and Kościuk (2018).

Pleiades, for the purpose of forecasting next year's harvests.[43] But what is particularly remarkable is that the reduced sky brightness observed by such a tube allowed the daytime observation of a planet as bright as Venus at (or near) its maximum elongation, in its Evening Star phase (sic!).

It has been hypothesised previously that the war activity of Inca ruler seems to manifest a certain association with the visibility cycle of Venus: the Inca personally attended the battle only when Venus was visible as the "Evening Star", while he was absent (delegating the effective command of the army to his "generals") during the periods of Venus' visibility as the "Morning Star" (Ziółkowski 2015, 333). We can then tentatively advance the hypothesis that the diurnal observations of Venus may have been associated with some rituals directly related to the Sapan Inca.

In concluding these remarks on the analysis of the supposed astronomical instruments of the Incas, we cannot overlook the deficiency of one category of sources of particular importance: calendar inscriptions and astronomical/calendar computation systems such as we have so abundantly evidenced for Mesoamerican cultures. Although we have reliable data about the function of quipus, there are very few objects that we can, with a high degree of probability, identify as "astronomical-calendar quipu".[44] A potentially promising research direction for the future could be the search, in the quipus, for cycles of durations postulated by the analysis of architectural structures.

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[43] The subject of observing Pleiades and other groups of stars for predictive purposes has been widely discussed in other texts (Zuidema and Urton 1976; Urton 1981, 1982; Ziółkowski 2015, 226–230).

[44] The literature on the subject is not very abundant, for some basic data see Nordenskiöld (1925), Urton (2001) and Ziólkowski (2015, 37–38).

to highlight the fundamental contribution of Tomasz Bulik in the elaboration of the final version of the hypothesis concerning the observations of Venus in the Mirador de Inkaraqay.

References

Astete Victoria F, Ziółkowski M, Kościuk J (2017) On Inca astronomical instruments: the observatory at Inkaraqay – El Mirador (National Archaeological Park of Machu Picchu, Peru). Estudios Latinoamericanos 36(37):9–25

Anónimo (1906) Discurso de la sucesión y gobierno de los Yngas. In: Maurtua V (ed) Juicio de límites entre el Perú y Bolivia, vol. 8, Lima, pp 149−165.

Astuhuamán Gonzáles CW (2007) Pariacaca: un oráculo imperial andino. In: Ensayos en Ciencias Sociales 2; Premio Nacional en Ciencias Sociales, UNMSM. Facultad de Ciencias Sociales. Instituto de Investigaciones Histórico Sociales, Lima, pp 15–54

Aveni AF (1981) Horizon astronomy in Incaic Cuzco. In: Williamson RA (ed) Archaeoastronomy in the Americas. A Ballena Press/Center for Archaeoastronomy Cooperative Publication, Los Altos, College Park, pp 305−318.

Aveni, AF (1988) On seeing the light: a reply to here comes the sun by Dearborn and Schreiber. Archaeoastronomy: Journal of the Center for Archaeoastronomy 10: 22–24

Bauer BS, Dearborn DSP (1995) Astronomy and empire in the ancient Andes: the cultural origins of Inca sky watching. University of Texas Press, Austin

Bauer BS, Stanish C (2001) Ritual and pilgrimage in the ancient Andes: the Islands of the Sun and the Moon. University of Texas Press, Austin

Bell BW (2011) Decoding and Inca observatory: solar alignments at Puncuyoc. Ñawpa Pacha: Journal of Andean Archaeology 31:101–116. https://doi.org/10.1179/naw.2011.31.1.101

Bingham H (1912) The Yale Peruvian expedition: preliminary report. Geogr J 39(3):235–241

Bingham H (1913) In the wonderland of Peru: the work accomplished by the Peruvian expedition of 1912, under the auspices of Yale University and the National Geographic Society. National Geographic Magazine XXIV(4), April 1913

Bingham H (1930) Machu Picchu, a citadel of the Incas; report of the explorations and excavations made in 1911, 1912 and 1915 under the auspices of Yale University and the National Geographic Society. London, H. Milford, Oxford University Press, Memoirs of the National Geographic Society, no. 1.

Cabada Hildebrandt E (2008) Calendario solar de Machupicchu y otras incógnitas. Gráfica Retai S.A.C., Lima.

Canuti P, Margottini C, Casagli N, Delmonaco G, Falconi L, Fanti R, Ferretti A, Lollino G, Puglisi C, Spizzichino D, Tarchi D (2009) Monitoring, geomorphological evolution and slope stability of Inca Citadel of Machu Picchu: results from Italian INTERFRASI project. In: Sassa K, Canuti P (eds) Landslides—disaster risk reduction. Springer, Berlin, Heidelberg, pp 249–257. https://doi.org/10.1007/978-3-540-69970-5_14.

Colomboni AM (1669) Prattica gnomonica, o vero tauole, con le quali ciascuno ageuolmente può far da sè gli horologi da sole orizontali, verticali, e riflessi di qualsiuoglia grandezza. Calcolate à grado per grado di declinatione murale per sei altezze di polo, cioè da gradi 40. sino à 45. Domenico Barbieri eredi, Bologna. Internet source: http://www.internetculturale.it/jmms/iccuviewer/iccu.jsp?id=oai%3Awww.internetculturale.sbn.it%2FTeca%3A20%3ANT0000%3AMILE034792&mode=all&teca=MagTeca+-+ICCU&fulltext=1

Czerner R, Martusewicz J (2012) The results of research conducted by the polish archaeological and conservation mission sent by the Ministry of Culture and National Heritage and Ministry of Foreign Affairs (Republic of Poland) in the area of the archaeological park of Machu Picchu (Peru). Estudios Latinoamericanos 32:131–191

Dearborn D, White R (1989) Inca observatories: their relation to the calendar and ritual. In: Aveni AF (ed) World archaeoastronomy. Cambridge University Press, Cambridge, pp 462–469
Dearborn DSP, White RE (1982) Archaeoastronomy at Machu Picchu. In: Aveni AF, Urton G (eds) Ethnoastronomy and archaeoastronomy in the American tropics. Annals of the New York Academy of Sciences, vol. 385, New York: New York Academy of Sciences, pp 249–259
Dearborn DSP, White RE (1983) The Torreon at Machu Picchu as an observatory. Archaeoastronomy 5:37–49
Dearborn DSP, Schreiber KJ (1986) Here comes the sun: the Cuzco-Machu Picchu connection. Archaeoastronomy J Cent Ar-Chaeoastronomy 9:15–37
Dearborn DSP, Schreiber KJ, White RE (1987) Intimachay: a December Solstice observatory at Machu Picchu, Peru. Am Antiq 52(2): 346–352
Dearborn DSP, Seddon MT, Bauer BS (1998) The sanctuary of Titicaca: where the sun returns to earth. Lat Am Antiq 9(3):240–258
Dearborn DSP, Bauer BS (2015) Island of the sun: elite and non-elite observations of the June Solstice. In: Ruggles CLN (ed) Handbook of archaeoastronomy and ethnoastronomy. Springer Science+Business Media New York, pp 883–896
Delgado Villanueva CW (2012) Informe final del proyecto de investigación arqueológica ciudad inka 2011, con excavaciones sectores I,II,III, V Andenes Orientales 01 e Inkaraqay. Dirección Desconcentrada de Cultura Cusco, Direcciòn del Parque Arqueológico de Machupicchu.
Dzieciątkowska J (2013) Badania konserwatorskie tablicy Mikołaja Kopernika na zamku w Olsztynie. In Badań S (ed) Tablica astronomiczna Mikołaja Kopernika na zamku w Olsztynie Olsztyn: Muzeum Warmii i Mazur, pp 91–96
Fink R (2009) Eventos solares en tres relatos de origen y fundación y las representaciones de la deidad solar inca. Revista Andina 48:9–55
Gullberg S (2009) The cosmology of Inca huacas. PhD thesis, James Cook University. Internet source: http://eprints.jcu.edu.ay/10346.
Gullberg S (2019) Inca astronomy: Horizon, light, and shadow. Astronomische Nachiichten 340:23–29
Gullberg S (2020) Astronomy of the Inca empire, historical & cultural astronomy. Springer Nature Switzerland AG, Cham
Gullberg S, Malville JM (2011) The astronomy of Peruvian huacas. In: Orchiston W et al. (eds) Highlighting the history of astronomy in the Asia-Pacific region, astrophysics and space science proceedings. Springer Science+Business Media, New York, pp 85–118
Gullberg S, Malville JM (2014) The River Intihuatana: Huaca Sanctuary on the Urubamba. Mediter Archaeol Archaeom 14(3):179–187
Hyslop J (2014) Inka settlement planning. University of Texas Press. Kindle Edition: Chapter 8: Orientation and Alignment: Astronomical Concerns; Subchapter: Windows, Light, and Shadow Casting at Machu Picchu
Kendall DG (1974) Hunting quanta. Philos Trans R Soc Lond Ser A, Math Phys Sci 276(1257): 231–266
Klokočník J, Kostelecký J, Hanzalová K (2012) Astronomical-Solar Orientation of Inca Features in Yurac Rumi, Machu Picchu and Ollantaytambo, Peru. Presentation at SEAC 2012 Conference, Lubliana 24–29 September 2012. Internet source: http://www.asu.cas.cz/~jklokocn/PPT_Ljubljana_YuracRumi_etc_Klokocnik_etal_2012.ppt (accessed 12 November 2020)
Kościuk J, Ziółkowski M (2020) Sala de los Morteros at Machu Picchu: another precise astronomical instrument of the Incas. Estudios Latinoamericanos, in print.
Kubicka A (2019) Zastosowanie metody cosine quantogram do analizy metrologicznej kompleksu Machu Picchu/Application of a cosine quantogram method in the metrological analysis of the Machu Picchu settlement. PhD Thesis. Faculty of Architecture, Wrocław University of Science and Technology, Wrocław.
Lebeuf A (1995) Astronomía en Xochicalco. In: González N, De la Fuente B, Wimer J (eds) La acropolis de Xochicalco. Instituto de Cultura de Morelos, Cuernavaca, pp 211–287
Lee V (1985) Sixpack Manco: travels among the Incas, [the author], Wilson, Wyoming

Magli G (2009) At the other end of the sun's path: a new interpretation of Machu Picchu. Nexus Netw J 12(2):321–341. https://doi.org/10.1007/s00004-010-0028-2
Malville JM (2015) Machu Picchu. In: Ruggles CLN (ed) Handbook of archaeoastronomy and ethnoastronomy. New York: Springer, 2015, pp 879–891
Malville JM, Thompson H, Ziegler G (2004) El observatorio de Machu Picchu: Redescubrimiento de Llactapata y su templo solar. Revista Andina 39:11–50
Markham C (1856) Cuzco: a journey to the ancient capital of Peru; with an account of the history, language, literature, and antiquities of the Incas. And Lima: a visit to the capital and provinces of modern Peru; with a sketch of the viceregal government, history of the republic, and a review of the literature and society of Peru. Chapman & Hall, London. Internet source: https://archive.org/details/cuzcojourneytoan00markrich.
Müller R (1929) Die Intiwatana (Sonnenwarten) im alten Peru mit 8 Abbildungen und 6 Figuren, Baessler-Archiv. Beitäge zur Völkerkunde, Band XIII (Alfred Maass, ed.), Berlin 1929, pp 178–187. Internet source: https://www.digi-hub.de/viewer/fullscreen/1500547264653/492/.
Müller R (1972) Sonne, Mond und Sterne über dem Reich der Inka. Springer-Verlag Berlin, Heidelberg
Nordenskiöld E (1925) Calculations with years and months in the peruvian quipus. Comparative Ethnographical Studies, n° 6, Goteborg
Pakkanen J (2001) Deriving ancient foot units from building dimensions: a statistical approach employing cosine quantogram analysis. In: Burenhult G, Arvidsson J (eds) Archaeological informatics: pushing the envelope, proceedings of the 29th CAA conference 2001, pp 501–506
Pereira Quiroga G (2011) La Horca del Inca – an astronomical observatory? In: Ruggles CLN (ed) "Oxford IX" international symposium on archaeoastronomy proceedings IAU symposium No. 278, pp 128–134
Przypkowski T (1973) Tablica doświadczalna Kopernika w Olsztynie. In: Kopernik na Warmii. Życie – działalność naukowa – środowisko, Jasiński J et al. (ed) Olsztyn: Stacja Naukowa Polskiego Towarzystwa Historycznego and OBN im. W. Kętrzyńskiego, pp 215−235
Reinhard J (2007) Machu Picchu: exploring an ancient sacred center. Cotsen Institute of Archaeology, University of California, Los Angeles
Rivera O (1984) La Horca del Inka. Arqueología Boliviana, INAR, La Paz 1: 91–106
Rostworowski de Diez Canseco M (1978) Mediciones y Cómputos en el Antiguo Perú, Cuadernos Prehispánicos No 6, Seminario Americanista, Universidad de Valladolid, Valladolid.
Rowe JH (1946) Inca culture at the time of the Spanish conquest. In: Steward JH (ed) Handbook of South American Indians, Bureau of American Ethnology, Bulletin 143, vol. II, Washington pp 183–330
Salazar Garces E (2014) Astronomia Inka. Arqueoastronomía & etnoastronomía. Museo Andres del Castillo, Lima
s.n. (sine nomine) (2011) Machu Picchu. Catálogo de la colección. Lima, p 171, (Photo: Herman Trucker)
Sarmiento de Gamboa P (1906 [1571]) Segunda Parte de la Historia General Llamada Índica. In: Pietschmann R (ed) Geschichte des Inkareiches von Pedro Sarmiento de Gamboa, Abhandlungen der Königlichen Gesellschaft der Wissenschaft en zu Göttingen, Philologisch-Historiche Klasse, Neue Folge, Band VI nº 4. Weidmannsche Buchhandlung, Berlin
Squier EG (1877) Peru: Incidents of Travel and Exploration in the Land of the Incas. Harper & Brothers, New York. Internet source: https://archive.org/details/peruincidentsoft00squi/page/n9/mode/2up?view=theater
Szubiakowski J, Włodarczyk J (2018) The Solar Dial in the Olsztyn Castle: its construction and relation to Copernicus. J Hist Astron 49(2):158–195
Taylor G (1980) Rites et traditions de Huarochiri: manuscrit quechua du début du 17 siécle. L'Harmattan, Paris
Uhle M (1910 [1908]) Datos para la explicación de los Intihuatanas. Memoria presentada al Congreso Internacional de Americanistas, Viena 1908. Revista Universitaria, Año V, 1: 325–332
Urton G (1981) At the crossroads of the earth and the sky. University of Texas, Austin

Urton G (1982) Astronomy and calendrics on the coast of Peru. In: Aveni AF, Urton G (eds) Ethnoastronomy and archaeoastronomy in the American tropics. New York Academy of Sciences, New York, pp 231–247

Urton G (2001) A calendrical and demographic tomb text from Northern Peru. Lat Am Antiq 12(2):127–147

Westerman JS (2005) Inti, the condor and the underworld: the archaeoastronomical implications of the newly discovered caves at Machu Picchu, Peru. In: Fountain JW, Sinclair RW (eds) Current studies in archaeoastronomy: conversations across time and space. Carolina Academic Press, Durham NC, pp 339–352

White R (1981) Field expedition to Machu Picchu. Archaeoastron J Cent Archaeoastron 4(2)

White S (1984–1985) Preliminary site survey of the Punkuyoq range, Southern Peru. Ñawpa Pacha: J Andean Archaeol 22/23:127–160

Zapata, J de la Cruz (1983) Alineaciones Líticas con Ortos y Ocasos Solares y Lunares Medidas en el Observatorio del Cerro Kesanani (4000 msnm). Departamento de Física, Universidad Mayor de San Andrés, La Paz

Zawaski MJ (2007) Archaeoastronomical survey of Inca sites in Peru. Unpublished MA Thesis, Department of Earth Sciences, University of Northern Colorado, Greeley

Zawaski MJ, Malville JM (2007/2008) An Archaeoastronomical Survey of Major Inca Sites in Peru. Archaeoastronomy 21:20–38.

Ziółkowski M (2015) Pachap vnancha. El calendario metropolitano del Estado Inca. Arequipa, Ediciones El Lector

Ziółkowski M, Sadowski RM (1991) Investigaciones arqueoastronómicas en el sitio de Ingapirca, Prov. de Cañar, Ecuador. In: Archeologia e Astronomia, Colloquio Internazionale, Venezia 3−6 Maggio 1989, A cura di Manuela Fano Santi, Rivista di Archeologia Supplementi 9:151–162

Ziółkowski M, Kościuk J, Astete Victoria F (2013) Astronomical observations at Intimachay (Machu Picchu): a new approach to an old problem. In: Šprajc I, Pehani P (eds) Ancient Cosmologies and Modern Prophets: Proceedings of the 20th Conference of the European Society for Astronomy in Culture. Ljubljana: Slovene Anthropological Society, pp 391–404

Ziółkowski M, Kościuk J (2018) Astronomical observations in the Inca Temple of Coricancha (Cusco)?: a critical review of the hypothesis. Teka Komisji Architektury, Urbanistyki i Studiów Krajobrazowych, Lublin 14(1): 7–33

Ziółkowski M, Kościuk J (2020) The Torreón of Machu Picchu: an astronomical observatory? Teka Komisji Architektury, Urbanistyki i Studiów Krajobrazowych, Lublin 16(4): 7–31. https://doi.org/10.35784/teka.2451

Ziółkowski M, Bastante Abuhadba J, Hogg A, Sieczkowska D, Rakowski A, Pawlyta J, Manning S, (2020) When did the Incas build Machu Picchu and its satellite sites? New approches based on radiocarbon dating. Radiocarbon, First View, Cambridge University Press, pp 1–15. Online edition: https://www.cambridge.org/core/journals/radiocarbon/article/when-did-the-incas-build-machu-picchu-and-its-satellite-sites-new-approches-based-on-radiocarbon-dating/10254F52B68EAC0960DB85D91BB66593

Zuidema RT (1991) Inca observations of the solar and lunar passages through Zenith and Anti-Zenith at Cuzco. In: Williamson RA (ed) Archaeoastronomy in the Americas, A Ballena Press/Center for Archaeoastronomy Cooperative Publication, Los Altos, College Park, pp 319−342

Zuidema RT (2015) Ceque System of Cuzco: A Yearly Calendar-Almanac in Space and Time. In: Ruggles CLN (ed) Handbook of archaeoastronomy and ethnoastronomy. Springer Science+Business Media, New York, pp 851–863

Zuidema RT, Urton G (1976) La constelación de la Llama en los Andes Peruanos. Allpanchis Phuturinqa, Cusco 9:59–119

Part II
Prospecting Machu Picchu and Urubamba Valley. New Results from Earth Observations Sciences and Technologies

Chapter 6
Open Big Earth Observation Data and Artificial Intelligence for the Study and Preservation of UNESCO Natural and Cultural Heritage: The Case of Machu Picchu

Rosa Lasaponara, Nicodemo Abate, Carmen Fattore, and Nicola Masini

Abstract In recent decades, the availability of Earth Observation technologies for cultural and natural heritage is stepping into a golden age characterized by an increasing growth of both classical and emerging technologies for the study, documentation and preservation of the human past, archaeological landscape and environment. This work focuses on the use of free tools such as Google Earth Engine for processing big data acquired from satellite platforms (Landsat 7 and 8) on large spatial and temporal scales, for the protection and preservation of natural and cultural heritage. In particular, the analyses were conducted within the area of the Machu Picchu natural park. Through the use of machine learning, artificial intelligence, and statistical operations, the following were calculated: the impact of damaging fires such as wildfires through automatic identification and perimeter of the burnt area and calculation of Fire Severity, as well as changes in vegetation (loss and gain) over the twenty-year period 2000–2020. The results demonstrated how remote sensing can be a fundamental tool in the monitoring, management, and protection of the natural and cultural landscape.

Keywords Earth observation technologies · Remote sensing · Big data · Open data

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6.1 Introduction

In the recent decades, the availability of Earth Observation technologies (from satellite, aerial and ground) for cultural and natural heritage (CNH) is stepping into a golden age characterized by an increasing growth of both classical and emerging technologies for the study, documentation and preservation of the human past, archaeological landscape and environment (Lasaponara and Masini 2017; 2020; Masini and Lasaponara 2017). In particular, today archaeologists and CNH decision makers are more aware of the potentiality of Earth Observation (EO) technologies in terms of reduction of costs and time for investigations and benefits for supporting conservation strategies thanks to the:

(i) improvement in spectral and spatial resolution of sensors, evermore useful for site discovery as well as for archaeological landscape and environment.
(ii) availability of multiscale, multi-temporal, and multi sensor data useful to investigate changes due to human activity in areas of cultural interest and with high natural value as, for example, biodiversity.

Earth observation data provide important and useful spatial and temporal information that can be used to make better decisions, design policies, and address problems that range in scale from local to global, costs go down, quality increases, and data become increasingly available for important everyday applications. Moreover, the huge availability of satellite data and satellite derived parameters enable to monitor changes in a diverse range of environmental sectors. Nevertheless, despite the potential of EO technologies, still today the applications of RS data in operational applications are a difficult task. To move from science to application there are gaps to be filled and needs to be addressed. To improve the use of satellite data specific protocols and quantitative evaluations of accuracy and reliability are needed for diverse steps of data processing from the data management to data processing and interpretation.

The main critical challenge is still today a lack of correspondence between the great amount of data available from diverse technologies (satellite, aerial, ground RS) and effective methods to extract useful information for knowledge improvement and long-term site monitoring.

These intriguing challenges can be faced today by exploiting open big data and free cloud tools as for example Google Earth Engine (GEE). It is a portal that allows end users to consult and work in cloud simultaneously with dozens and dozens of different datasets (such as, for example, those from NASA and ESA) for a collection of over forty years of data on a global scale. Undoubtedly, today the availability of big and open satellite data jointly with cloud resources offers big opportunities and big challenges, relevant for multi- and inter-disciplinary studies as documentation and preservation of the human past, archaeological landscape and environment.

In accordance with available technologies, one of the major challenges related to Big data is related to analytics i.e., the analyses and knowledge extraction from enormous amount of data (Fig. 6.1).

In other words, Big data processing and storing are challenging but, it is really important to highlight that they exist only to serve the knowledge extraction. To this

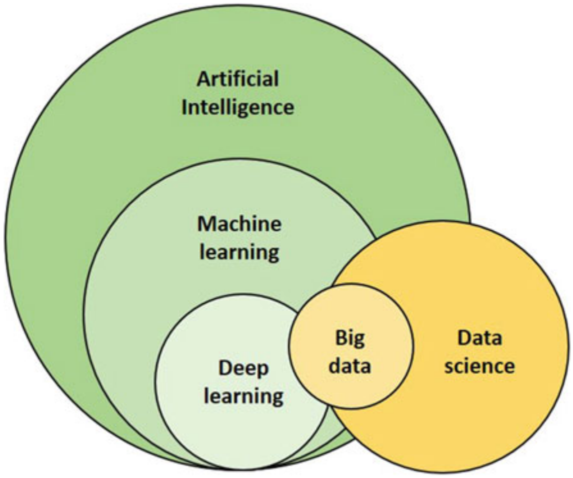


Fig. 6.1 Interrelational scheme of AI (including machine learning, deep learning), data science, and big data

aim, several tools for automatic extraction of features are available today in open and commercial software and also on cloud-computing service, such as GEE.

Nevertheless, it is important to highlight that AI, as machine learning (ML) and deep learning (a subfield of machine learning, see Fig. 6.1), is not a new approach, but originated during the second half of the twentieth century (Friedberg et al. 1959; Friedberg 1958; Samuel 1959).

However, to date the AI approach has been re-discovered and improved for new applications in several fields (e.g. Earth Observation, medicine). Recently, In November 2020 a dedicated Workshop was focused on Big Data and Artificial Intelligence for Earth Observation highlighted the advances achieved in this field as for example a of set 4 promising analytics tools deployed to improve:

(i) Earth Observation data mining for classification, allowing users to refine their query by iteratively specifying a set of relevant and non-relevant images.
(ii) Deep Learning for Change Detection on time series for optical and radar Earth observation data. The tools provide generic change detection maps for every couple of respectively optical and SAR images.
(iii) Semantic search and indexation on the output of the Earth observation library and non-image data, to allow users to make requests using multi-criteria.
(iv) Data fusion techniques to merge data that came from various sources, enabling to combine multiple image sources for classification.

All of the diverse aspects ranging from the research and innovation to the application issues, namely from the science to services, must to be tackled by the scientific community in conjunction with the "end uses needs" to ensure an effective and reliable applicability of EO data, information, and products today available free of charge. This paper aims to illustrate two different methods of monitoring high-impact events in the Machu Picchu Natural Park area, obtained by using satellite data and artificial intelligence to map vegetation loss and fire-affected areas.

The archaeological site of Machu Picchu stands 2,430 m above sea-level, in the middle of a tropical mountain forest, in an extraordinarily beautiful setting. It was probably the most amazing urban creation of the Inca Empire at its height; its giant walls, terraces, and ramps seem as if they have been cut naturally in the continuous rock escarpments. The natural setting, on the eastern slopes of the Andes, encompasses the upper Amazon basin shelters a remarkably diverse array of microclimates and, therefore, a very rich diversity of flora and fauna, included in a larger area considered extremely important for global biodiversity conservation. Machu Picchu also offers a safe habitat for several endangered species: among these, the spectacled bear (Oso de anteojos), one of the most interesting species in the area, deserves a particular mention. Other animals that populate the area are the dwarf fawn, the otter, the long-tailed weasel, the ocelot cat (a kind of small mountain cheetah), the boa, the cock of the Andean rocks, the Andean condor with more than 420 species of birds, about 377 species of butterflies, 15 of amphibians and 25 of reptiles, of which 9 are types of lizards and 16 snakes.

In Machu Picchu the natural vegetation is typical of a low and humid mountain forest of the subtropical region with various species of palms and several tree species as alyss, white cedar, cinchona, yanay, and laurel; as well as woods of ounce, queñua, and tasta. The protected area is surrounded by a buffer zone exceeding the size of the property and the surrounding valleys are cultivated, as before and after the construction of Machu Picchu, in a harmonious man-earth productive relationship.

For all the UNESCO properties, since the time of inscription, site managers are asked to carefully monitor the site in order to prevent changes and mitigate risks, as for example, those related to ecosystem degradation through logging, firewood and commercial plant collection, waste management, poaching, agricultural encroachment, pollution, and pressures derived from broader development in the region due to the expected tourist fluxes. In the case of Machu Picchu, its location in a high altitude, the extreme topography and weather conditions might increase the overall risks due to susceptibility to natural disasters. Satellite tools may profitably support the systematic monitoring needed to comply with protected area legislation and plans and to prevent degradation issues (Agapiou et al. 2020).

6.2 Methodology

Over the years, there have been a large number of space-borne missions that have been provided enormous amounts of remotely sensed data with continuous improvements in the radiometric, spectral and spatial resolutions which led to the possibility of using satellite data for studying temporal evolution of environmental and manmade systems on short, medium and long time scales. So that in the last decades, there has been a large increase in the use of EO in various applications for several reasons, among them: (i) technological improvements, (ii) availability of user–friendly software for data processing, (iii) increasing interest in studying the dynamics of environmental changes (iv) the large use of multi-temporal satellite data in an ever increasing number of strategic and challenging applications and (v) the availability of free of charge of long-term satellite time series.

Moreover, in recent years, a significant increase in software and hardware technologies has been achieved for processing satellite data, and this is particular relevant in the era of Big-EO Data (Lasaponara and Masini 2020).

Frequently, complex processes that are particularly expensive in terms of storage and computing resources are delegated to third-party services that allow you to operate directly on the cloud, without having to invest economic resources in high-performance personal computers.

One of the absolute most popular tools used in recent studies is Google Earth Engine (GEE). It is an open source tool made available by Google through registration. It is a portal that allows us to consult and work simultaneously with dozens and dozens of different datasets for a collection of over forty years of data on a global scale (Kumar and Mutanga 2018). GEE is a powerful high-performance computing tool, it is accessed and controlled through a web-based accessible application programming interface (API) and there is an associated web-based interactive development environment (IDE) that allows quick prototyping and visualization of results (Tamiminia et al. 2000).

Available datasets include satellite data acquired by several missions, such as: (i) MODIS (Moderate Resolution Imaging Spectrometer); (ii) ALOS (Advanced Land Observing Satellite); (iii) Landsat series; and (iv) Sentinels. These are complemented by other useful/ancillary data, such as: (i) DTMs (Digital Terrain Models); (ii) shape files; (iii) meteorological data; and (iv) Land Cover (Arévalo et al. 2020; Lemoine and Léo, 2015; Horowitz 2015; Sazib et al. 2018).

GEE, in addition to making operations with several types of sensors extremely easy, allows the same way and time to work with petabytes of data and has changed the concept of work and analysis in the field of Remote Sensing, and to the big-data approach to the issues. GEE in recent years has been successfully used in many of the disciplines involving EO techniques due to its potential, and the number of papers on the topic has increased exponentially (Wang et al. 2020).

Several satellite platforms are currently in orbit and capture a wide variety of data, thus enabling multi-temporal, multisensor, and multiscale analyses, that can be promptly processed in pen cloud platform resources, as GEE, which enormously facilitates the access manipulation, analysis, and visualization of geospatial data without the need for supercomputers (Tamiminia et al. 2000) and, above all, without having to download huge quantities (petabytes) of data. Moreover, GEE archives are updated with new satellite acquisitions and also with ancillary geospatial information and maps as land use land cover, topography, meteorological records, and socio-economic dataset (Amani et al. 2020; Gorelick et al. 2017).

For these reason several initiatives have been developed using GEE, as, for example, Global Forest Watch (http://globalforestwatch.org), which enable us to monitor the situation of forests around the world in real time obtained processing millions of satellite images collected in 40 years and made freely available by the United States Geological Survey, the American geological agency (Hansen et al. 2013).

Table 6.1 Landsat 7 ETM+ Bands (https://landsat.gsfc.nasa.gov/)

Name	Resolution (m)	Wavelength (μm)	Description
B1	30	0.45–0.52	Blue
B2	30	0.52–0.60	Green
B3	30	0.63–0.69	Red
B4	30	0.77–0.90	Near infrared
B5	30	1.55–1.75	Shortwave infrared 1
B6	30	10.40–12.50	Thermal infrared
B7	30	2.08–2.35	Shortwave infrared 2

The use of Google Earth Engine (GEE) for the analysis of large-scale satellite imagery has become quite common in recent years. As discussed, the portal provides several ready-to-use datasets (complete with band information, atmospheric correction, cloud mask). The provided dataset are updated on a regular basis, a few days after their official release by the relevant space agencies.

For this study, long time series of Landsat 7 ETM+ (Table 6.1), and Landsat 8 OLI (Table 6.2) multispectral data were ad hoc processed in GEE platform and analyzed for a part of National Archaeological Park Machu Picchu (PANM).

Optical remote sensing for vegetation has been traditionally carried out by using vegetation indices, which are quantitative measures, based on vegetation spectral properties that attempt to measure biomass or vegetative vigor. The use of GEE and vegetation indices, as well as that of artificial intelligence and machine learning

Table 6.2 Landsat 8 OLI Bands (https://landsat.gsfc.nasa.gov/)

Name	Resolution (m)	Wavelength (μm)	Description
B1	30	0.435–0.451	Ultra blue
B2	30	0.452–0.512	Blue
B3	30	0.533–0.590	Green
B4	30	0.636–0.673	Red
B5	30	0.851–0.879	Near infrared
B6	30	1.566–1.651	Shortwave infrared 1
B7	30	2.107–2.294	Shortwave infrared 2
B8	15	0.52–0.90	Panchromatic
B9	15	1.36–1.38	Cirrus
B10	30	10.60–11.19	Thermal infrared
B11	30	11.50–12.51	Thermal infrared

(ML), has also recently been used for the analysis of natural events with high impact on the landscape such as fires, landslides, and floods (Arruda 2021; DeVries et al. 2020; Mahdianpari et al. 2018; Mutanga and Kumar 2019).

The strength of a cloud-based computing system, which includes ready-to-use and up-to-date datasets, is the ability to use computing power without having to download large amounts of data locally, in some cases no longer available on space agency hub.

Although the landscape of Machu Picchu is not optimal for analysis with optical data, due to the mountains and frequent clouds, the tool was successfully tested in two cases, both on a large spatial scale (3000 ha). However, the first caste study is on a couple single-time events, while the second one is based on a wide temporal scale analyses:

(i) the automatic identification, perimeter, and evaluation of the fire events occurred in 2013 and 2017, previously analyzed using Landsat 8 satellite (Chohfi 2018).
(ii) the analysis of twenty years of Landsat data (2000–2020) for the understanding of vegetation changes in the forested area.

6.2.1 Automatic Identification, Perimeter, and Evaluation of Wildfires Using Satellite Data, Machine Learning (ML), and Google Earth Engine GEE

The analysis of events with a strong impact on the landscape has always been one of the main issues of EO, particularly in the context of a strong natural and cultural value such as UNESCO sites. Thanks to constantly updated satellite data, the use of powerful calculation tools, and the use of ML, it is now possible to identify events (e.g. fires, landslides, floods) in near-real time or real time, a factor linked to the rate of update (revisit time) of the satellite data themselves. Usually, the free optical (multispectral or hyperspectral) data made available by space agencies have a periodic update ranging from 5–6 days for the Compernicus Programme Sentinels (Fabre et al. 2020) to 16–17 days for NASA's Landsat constellation (Acharya and Yang 2015). This element has made this type of data to be very useful and efficient in identifying events (Bar et al. 2020; Caballero et al. 2019; Pulvirenti et al. 2020).

On the other hand, the study can also be done backward in time, having access to data already published in the bibliography and at the same time to satellite data stored in online datasets, as in the case of those present in GEE. This opportunity is of great importance for the study of methodologies to be applied to individual events, as it allows for reliable feedback on the results obtained from the methodology on the basis of analyses conducted by other scholars, government agencies or research institutes. Furthermore, it offers the possibility of refining the method in order to be able to project it on new events in the future.

This study includes two events that occurred at the end of August 2013 and between July 20th and 24th, 2017, and affected the southwestern sector of Machu

Picchu District, in the confluence of the Urubamba and Ahobamba rivers, the same area affected by another event in 1988.

Using the available geographic and temporal data, a rectangular buffer area (30 × 30 km) was calculated from the Machu Picchu site. Landsat 8 satellite imagery search dates were set to calculate pre-fire and post-fire images, according to the literature on the subject (Quintano et al. 2018), and an optimal image was identified pre- and post-each event. Respectively: (i) 14th August 2013 and 30th August 2013; (ii) 8th July 2017 and 24th July 2017.

The process involved several operations, all carried out automatically by GEE, from processing to exporting the output, once the coordinate of interest (the Machu Picchu park), the buffer area in which to search for satellite data and the pre-event and post-event dates have been entered. The operations carried out as part of the automatic identification and extraction of burned areas can be summarized according to the diagram in Fig. 6.2.

GEE provides several dataset of Landsat data. The dataset 'LANDSAT/…/C01/T1_SR' was used for this study, which includes the already processed images of all useful radiometric and geometric corrections. The first operation produced was to apply a mask function for the clouds and create (i) RGB natural color (B4, B3, B2) compositions, and (ii) RGB atmospheric penetration (B6, B5, B4) compositions (Fig. 6.3).

Then, the NIR and SWIR bands, for each pre-event and post-event image, were mathematically combined (6.1) into a vegetation index useful for the identification of burned areas: normalized burn ratio (NBR) (Miller and Thode 2007)

$$\frac{(\mathrm{Nir} - \mathrm{SWIR})}{(\mathrm{Nir} + \mathrm{SWIR})} \tag{6.1}$$

To enhance the visibility of the area affected by the fire, the pre-event (t0) and post-event (t1) NBR indices were combined to obtain a delta (Δ), which is useful to show the differences between the two acquisitions (6.2) (Lasaponara et al. 2018; Pepe and Parente 2018).

$$\Delta\mathrm{NBR} = \mathrm{NBR}_{t0} - \mathrm{NBR}_{t1} \tag{6.2}$$

The ΔNBR is considered one of the best performing products for the identification of burned areas and for the characterization of Fire Severity, i.e., the damage produced by the present vegetation. Then, the ΔNBRs obtained (2013 and 2017) were classified using a machine learning (ML) unsupervised classification (Khairani and Sutoyo 2020), useful for the creation of a binary map (i) burned, and (ii) unburned (Fig. 6.4).

Of course, unsupervised binary classification is not limited to selecting the pixels present within the area of the event, but it also selects a small amount of noise as individual pixels or in small groups, scattered throughout the area of interest. To reduce the number of false positives by isolating the burned area, an edge detection function (canny edge) was used only on pixels classified as burned, so as to trace their contours. Each contour was then vectorized and the area in hectares was calculated

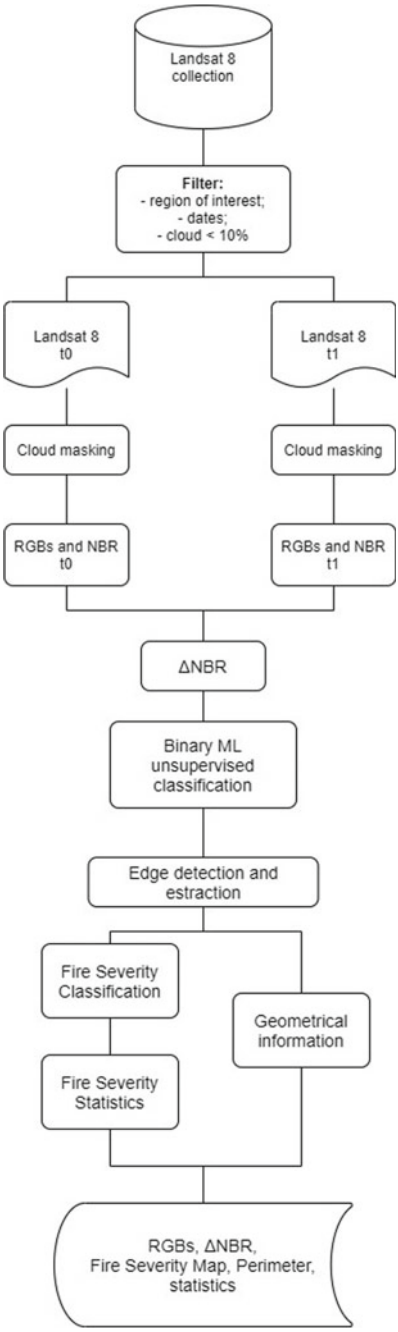


Fig. 6.2 Burned area identification flowchart for Landsat 8 images

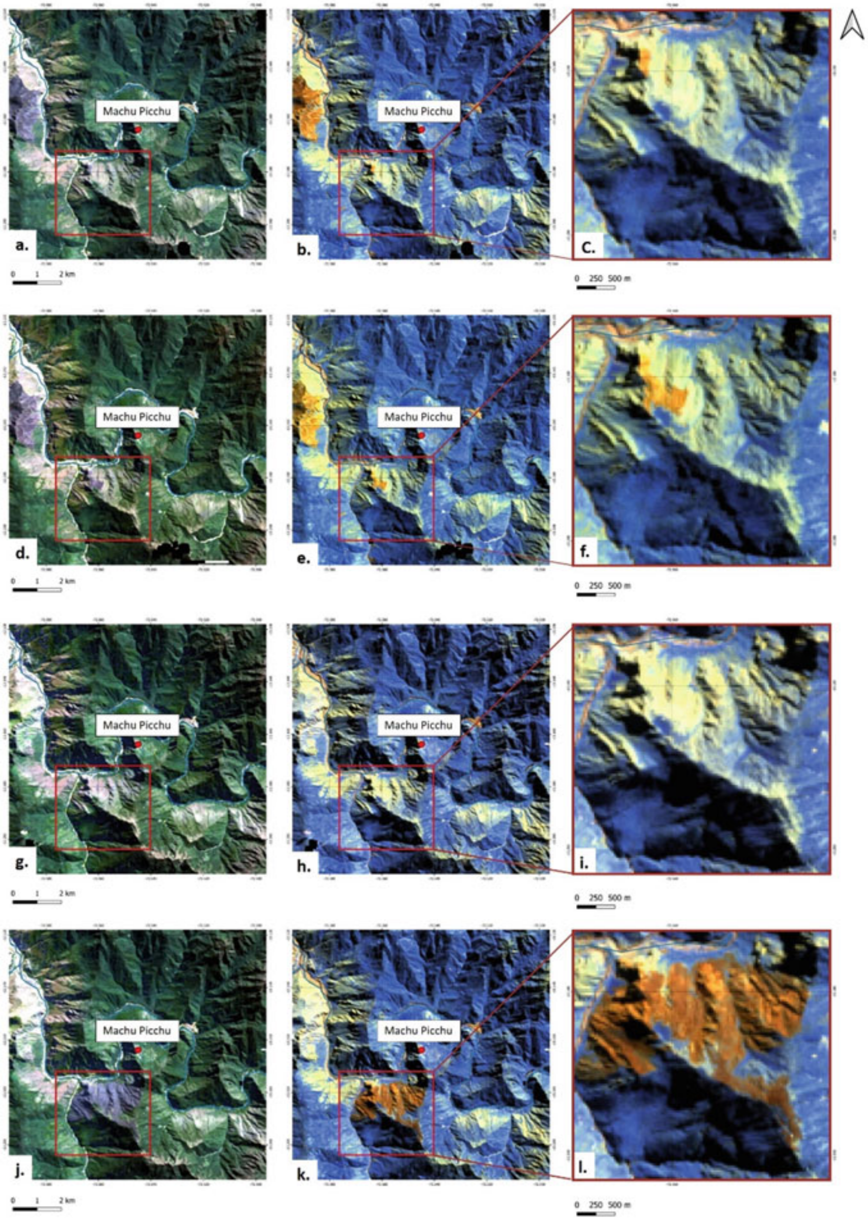


Fig. 6.3 Landsat imagery of the area of interest: **a** RGB (4–3–2) pre-event (2013 July 29); **b**, **c** RGB (6–5–4) pre-event (2013 July 29); **d** RGB (4–3–2) post-event (2013 August 30); **e**, **f** RGB (6–5–4) post-event (2013 August 30); **g** RGB (4–3–2) pre-event (2017 July 8); **h**, **i** RGB (6–5–4) pre-event (2017 July 8); **j** RGB (4–3–2) post-event (2017 July 24); **k**, **l** RGB Composition (6–5–4) post-event (2017 July 24)

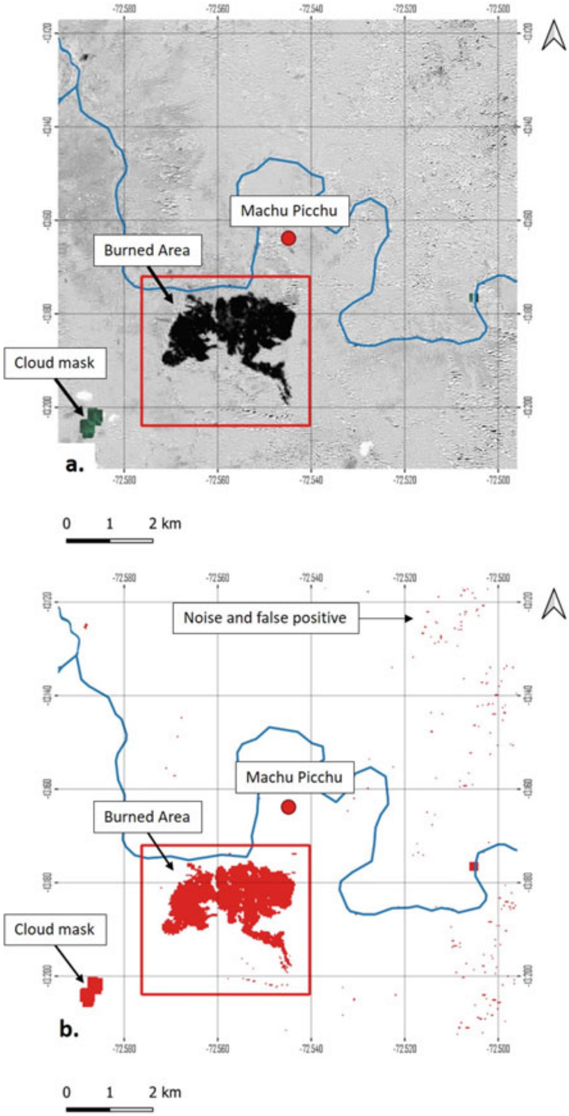


Fig. 6.4 **a** ΔNBR of the 2017 event; **b** burned-unburned binary classification of the 2017 event, useful for automatic extraction of the perimeter area of the event

for each polygon created. The polygons, stored in a FeatureCollection, were sorted in descending order, to apply a selection based on area size (ha), isolating the largest one, representing the event area, and eroding the smaller ones. Through this process the area of the event has been isolated and its perimeter vectorized in a completely automatic way (Fig. 6.5).

In addition, in order to observe fire damage to vegetation, USGS (United States Geological Survey) proposed thresholds were applied (Table 6.3) to calculate burn severity (Candra et al. 2020; Davies et al. 2010; Keeley 2009).

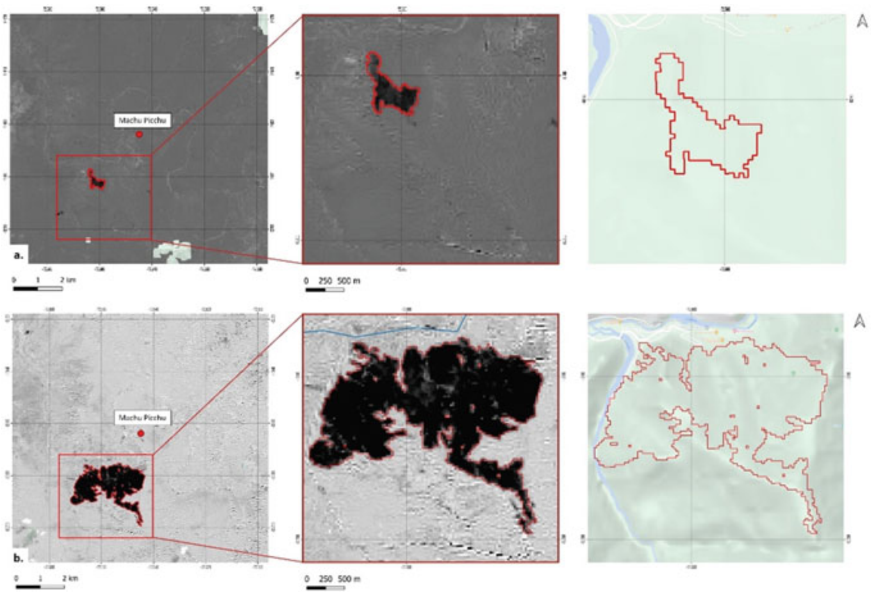


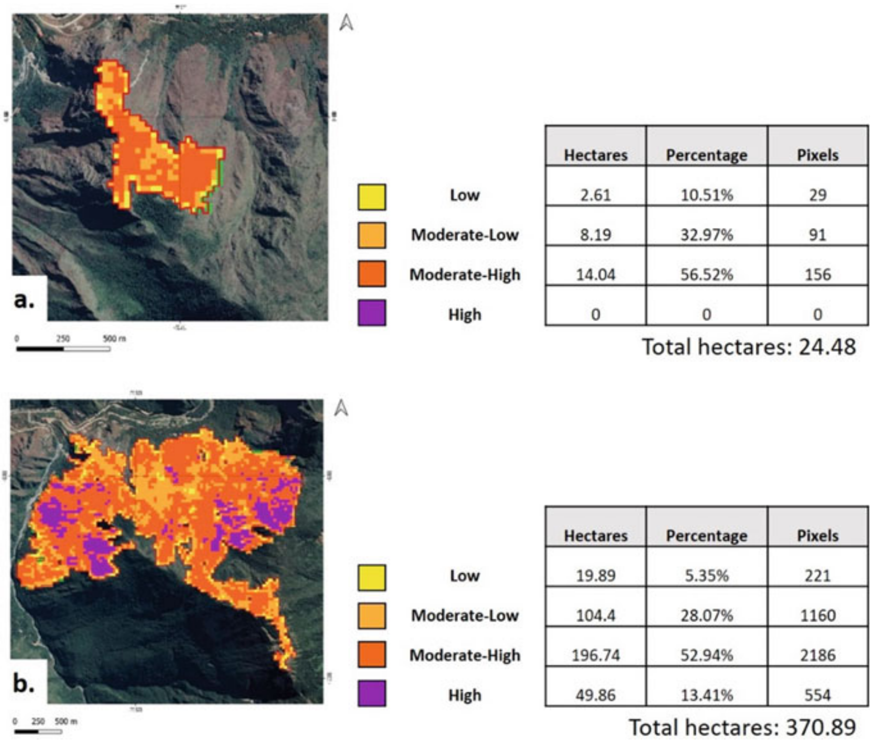
Fig. 6.5 Automatic identification and extraction via machine learning of the fire event: **a** 2013; **b** 2017

Table 6.3 ΔNBR burn severity thresholds according to the United States Geological Survey (USGS) categorization

ΔNBR	Burn severity
≤−0.25	High post-fire regrowth
−0.25 to –0.1	Low post-fire regrowth
−0.1 to 0.1	Unburned
0.1–0.27	Low-severity burn
0.27– 0.44	Moderate-low severity burn
0.44–0.66	Moderate-high severity burn
>0.66	High-severity burn

Burn severity or fire severity is the degree of burn caused by fire to vegetation, the amount of vegetation burned, and the percentage of dead vegetation. This can be subdivided into degrees, calculable and classifiable through the use of some indices and Δ images, and each degree indicates a more serious level of destruction, starting from low, up to high (Keeley 2009).

Through this system and the potential of GEE, it was possible to obtain in an automatic and fast way (less than a minute of calculation time) all the described outputs and statistics on the area affected by the fire, such as hectares, severity classes, and their extension, finding a reliable similarity with the published data on the same events (aa). According to published data, (i) the 14th August 2013 event extended over 21 ha, and (ii) the July 8th 2017–July 24th 2017 event extended over



a.	Hectares	Percentage	Pixels
Low	2.61	10.51%	29
Moderate-Low	8.19	32.97%	91
Moderate-High	14.04	56.52%	156
High	0	0	0

Total hectares: 24.48

b.	Hectares	Percentage	Pixels
Low	19.89	5.35%	221
Moderate-Low	104.4	28.07%	1160
Moderate-High	196.74	52.94%	2186
High	49.86	13.41%	554

Total hectares: 370.89

Fig. 6.6 Perimeter, vectorization, and analysis of event statistics, all obtained automatically: **a** 2013; **b** 2017

347 ha. The differences in size observed between what is calculated in the literature and what is automatically computed by the system produced in GEE are likely to be attributed to the pixels on the edges of the burned area and to the size of the unscaled pixel itself with pan-sharpening (Fig. 6.6).

6.2.2 Analysis of Large Multi-temporal and Spatial Landsat Datasets for the Semi-automatic Analysis of Vegetation Changes in the Forested Area

In addition to the single event and a few couple of images, vegetation at large spatial and temporal scales was studied using the power of GEE and Landsat sensors and the use of vegetation indices to understand dynamics over time. For the vegetation analysis in the area of the archaeological site of Machu Picchu, Landsat images and vegetation indices, from 2000 to 2020, were used, calculating a rectangular buffer area of 3000 ha from the coordinates of the archaeological site.

Understanding the state of health of the vegetation has always been one of the main issues in the field of Earth Observation applied to natural and cultural heritage, and it is even more important in the case of large natural heritages (parks and reserves) surrounding the important UNESCO sites, such as Machu Picchu. The vegetation, in fact, can be affected by anthropogenic or natural events with a strong negative impact, such as those often observed on a global scale as deforestation, uncontrolled urban sprawl, fires, pests, climatic events of extraordinary power and not always the damage left by these events are immediately perceptible. Earth Observation techniques and remote sensing are fundamental tools for understanding the dynamics of landscape development and changes in land cover/land use (LC/LU) (Hasmadi et al. 2009), and scholars are focused in understanding what are the most performing methods and procedures for this purpose, such as (i) the use of vegetation/humidity indices to emphasize certain spectral features in the case of multispectral and hyperspectral optical sensors; (ii) the use of Synthetic Aperture Radar (SAR) sensors to understand changes in LC/LU; (iii) the use of powerful classifiers and the use of artificial intelligence to analyze and classify features and identify changes in image series; (iv) the development of powerful onboard or cloud-based systems for processing Big Data (Chuvieco 2008).

The operations carried out for the analysis of vegetation trends and dynamics during the period 2000–2020 followed the flowchart shown in Fig. 6.7.

The health of the vegetation is usually identified starting from indices (mathematical combination of individual bands acquired by satellites) that enhance certain spectral characteristics. The vegetation indices operate by contrasting intense chlorophyll pigment absorption in the red band of the electromagnetic spectrum against the high reflectance of leaf mesophyll in the near infrared band. The simplest form of vegetation index is simply a ratio between two digital values from these two spectral bands. The most widely used index is the normalized difference vegetation index (NDVI) (Jiang and Huete 2010; Rouse et al. 1974) (6.3).

$$\frac{(\mathrm{Nir} - \mathrm{Red})}{(\mathrm{Nir} + \mathrm{Red})} \tag{6.3}$$

NDVI is used to identify vegetation health by measuring the difference of the infrared reflectance with that of the visible red band. NDVI provides information about the spatial and temporal distribution of vegetation communities and vegetation biomass. High values of the vegetation index identify pixels covered by substantial proportions of healthy vegetation (Justice et al. 1985). NDVI is indicative of plant photosynthetic activity and has been found related to the green leaf area index and the fraction of photosynthetically active radiation absorbed by vegetation. Therefore, variations in NDVI values and in general in vegetation indices are indicative of variations in vegetation ongoing trends and dynamics.

The assessment of Vegetation dynamical processes requires investigations performed at different temporal and spatial scales, from local up to regional level. In such a context, satellite technologies can be profitably used for investigating the dynamics of vegetation in terms of type and status of vegetation cover and ongoing

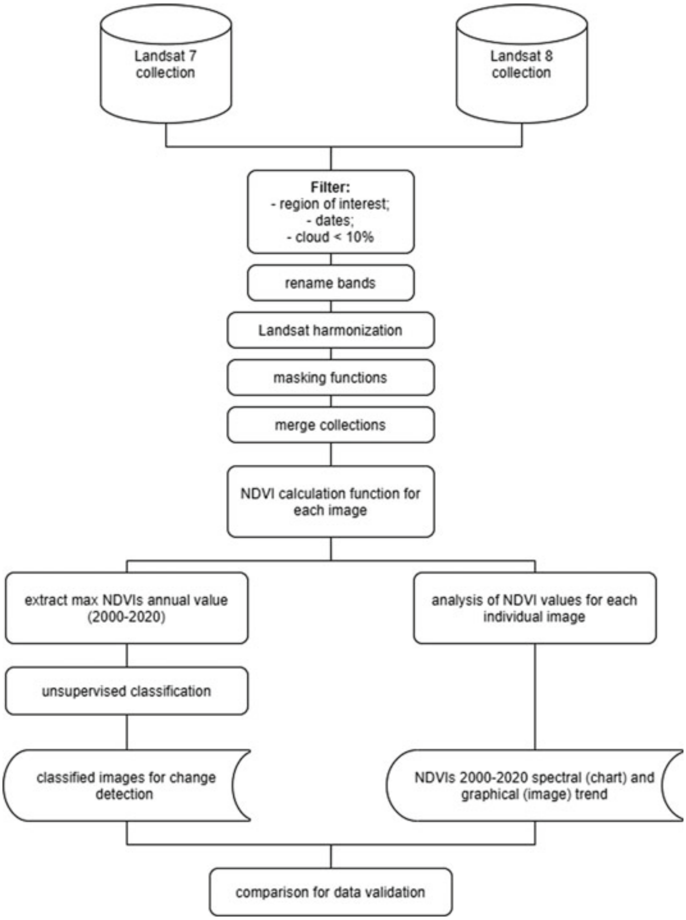


Fig. 6.7 Perimeter, vectorization, and analysis of event statistics, all obtained automatically: **a** 2013; **b** 2017

changes is a key issue for the management of ecosystem functionality and for implementing effective strategies to mitigate disturbance phenomena as drought, wind, storm, fire on environment and ecosystems. Vegetation dynamical processes are very difficult to study since they affect the complex soil–surface–atmosphere system, due to the existence of feedback mechanisms involving human activity, ecological patterns, and different subsystems of climate (Telesca and Lasaponara 2010). The use of satellite time series along with statistical analysis techniques can be helpful in understanding the functional characteristics of vegetation dynamics and enable the reporting of ongoing trends at a detailed level (Telesca 2007).

According to Google Earth Engine databases, available documentation, and reference literature, the first step to be able to work simultaneously and correctly with the different Landsat data (7, 8) over time was to harmonize the datasets, and improve the dataset temporal continuity. In the context of satellite data analysis, particularly when several sensors are used, this procedure has proved useful in the past to increase the number of data to be analyzed and make them consistent with each other (Savage et al. 2018; Vogeler et al. 2018).

Landsat 7 and 8 sensors acquire similar bands, which, however, only partially intersect (Irons et al. 2012; Roy et al. 2014, 2016), and in order to use all the data, harmonization by a linear transformation of the spectral space of ETM to OLI is required, using coefficients found in the literature (Roy et al. 2016).

In addition to harmonization, the creation of a single images collection to access all data simultaneously over time was useful. In order to prepare and create a single images collection, some functions were necessary:

(i) renaming individual bands, so that bands with different numbers but similar wavelengths were aligned to the same name (e.g. L7 B1 renamed to 'Blue'; L8 B2 renamed to 'Blue');
(ii) apply the harmonization function with its coefficients;
(iii) apply masking functions to pixels classified as cloudy, snowy, and shadowy, using the appropriate mask bands (Zhu et al. 2015).

The functions, written in Javascript, were then applied to the image collections Landsat 7 and 8, within the GEE datasets, after having preliminarily filtered them by cloudiness (<40%), estimated quality (9) and geographical area (30 × 30 km buffer around Machu Picchu). Then, the now edited individual collections were merged into one huge collection of 2000–2020 images to be analyzed simultaneously. However, the number of images was reduced due to the high cloudiness of the area during most of the year, for a total of 113 useful satellite images.

Once the reference dataset was established, using a calculation function, GEE was able to apply the function to each element of the image collection, in the parallel computing sense, operating a normalized difference between the NIR and Red bands.

In order to avoid problems in the creation and analysis of NDVI images such as: (i) presence of noisy elements caused by clouds, and (ii) discontinuities between the images composing the mosaic due to the difference in phenological status of the vegetation in two contiguous Landsat swaths; the 'quality mosaic' function was used to create the mosaics. This function allows the maximum NDVI value to be taken for each pixel in the interval considered, thus avoiding problems related to the presence of shadows, clouds, or climatic events affecting the vegetation.

GEE as a powerful calculation engine made it possible to obtain in a few seconds, for each year 2000–2020 (01–01 to 31–12) (i) RGB images with average pixel value; (ii) RGB images with the quality mosaic function (maximum pixel value based on maximum NDVI); (iii) NDVIs with maximum value for each pixel in the collection; (iv) statistics on the images produced; and (v) intra- and infra-collections statistics.

Using this powerful and free tool, it was possible to obtain an overview of the state and evolution of the vegetation over a period of twenty years, without downloading and processing data locally. The NDVIs herein produced were used to monitor vegetation in the area of interest, in accordance with the literature on the issue (Forkel et al. 2013; Schmid 2017). NDVIs, in fact, processed according to the theory of maximum values per pixel along the time series considered, year by year, have highlighted changes in the development and presence of vegetation, with very different values between images, where a change has occurred. Usually, a low value is given for the small city of Aguas Calientes as well as for the Urubamba River that flows downstream of the Machu Picchu site. These values, while identifying a low presence of vegetation in the area, are nevertheless constant in the images due to the constant presence of the elements that generate them such as water and buildings. However, small changes were observed along the banks of the Urubamba, due to normal change in climate and weather conditions between years. However, major changes were identified in different portions of the area of interest. To avoid manual and optical identification by an operator, artificial intelligence is commonly used to classify images and changes between images. Classification is a data mining operation that groups pixels into classes according to their characteristics and value (pixel-based classification), or groups pixels into objects (object-based classification). GEE allows to produce several types of classification: (i) supervised classification (Richards 2013) and (ii) unsupervised classification (Arthur and Vassilvitskii 2007).

The difference between the two procedures is that in supervised classification the operator has to provide a training dataset in order to instruct the algorithm to recognize the pixels; whereas in the second case, the classifier, exploiting the potential of artificial intelligence and machine learning (ML), groups the pixels into classes autonomously (Fattore et al. 2021).

A K-means unsupervised classification function was used applied to annual NDVIs, obtained using maximum value for each pixel in the collection to avoid the strong impact of clouds and shadows on classification (Figs. 6.8 and 6.9).

The unsupervised classification was made by establishing three classes: (i) non-vegetated; (ii) seasonally influenced vegetation; (iii) forest. The rationale behind the classes was:

(i) Non-vegetated: areas with the presence of watercourses (Urubamba River), built-up areas or areas where no vegetation was ever recorded during the year;
(ii) Seasonally influenced vegetation: areas where there is the presence of canopy that cannot be classified as forest, which undergoes a strong seasonal change;
(iii) Forest: forest area.

This system allowed the classification of the images in a fully automatic way, with the possibility of detecting changes in the vegetated and forest areas in different years.

A similar, albeit more complex, tool has been developed on a global scale using the potential of GEE to monitor changes in forest areas, using satellite and ancillary data. Global Forest Watch (GFW), in fact, is a tool designed to monitor forest loss-gain on a global scale, using Landsat data and is fully integrated within GEE (Hansen et al. 2013). GEE offers the possibility to retrieve data from GFW and analyze it for the area of interest, obtaining information and statistics about the gain and loss of vegetation from 2000 to 2020, within the areas classified as forest (Fig. 6.8).

In addition to identifying changes in the land cover, GEE allowed to plot the value of the pixel(s) over the twenty years considered, image by image, in order

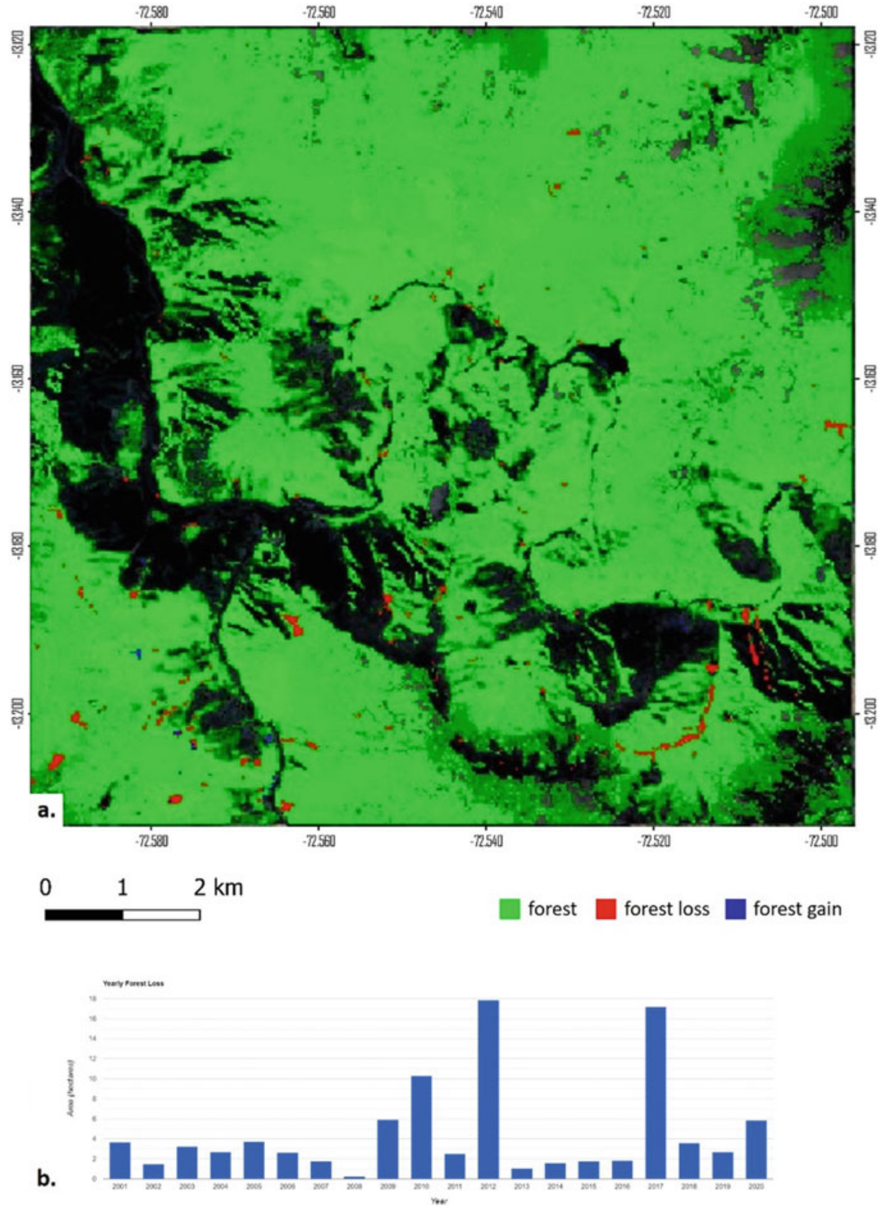


Fig. 6.8 Data and statistics obtained using the Global Forest Watch system in GEE: **a** Image with Forest Land Cover Type and identification of areas of forest lost (*red*) and gained (*blue*) from 2000 to 2020; **b** Graphical representation of information contained in a

to understand the trend of the index value, and therefore of the vegetation, in the area of interest. This type of analysis is particularly useful for understanding the events that have occurred in a specific place or restricted area, and for dividing the 'extraordinary' events that have affected a pixel from the ordinary ones related to the seasons and weather conditions.

The analysis starts by calculating the values of the vegetation indices (NDVI in this case) over the entire time series considered. The first step was to calculate a chart of the NDVI value of the pixel(s) over time, using linear regression to estimate a linear trend model over time (6.4):

$$\text{xt} = \beta 0 + \beta 1\text{zt1} + \beta 2\text{zt2} + \cdots + \beta \text{q ztq} + \text{wt} \tag{6.4}$$

where $\beta 0 + \beta 1\text{zt1} + \beta 2\text{zt2} + \cdots + \beta \text{q ztq}$ are unknown fixed regression coefficients, and wt is a random error or noise. This model is useful for detrending data and reducing stationarity along the time series (Shumway and Stoffer 2017).

The linear model was useful in estimating periodicity and creating a harmonic model. Periodicity is the repetition of an event over time (6.5). A cyclic event repeats in time and "*a cycle as one complete period of a sine or cosine function defined over a unit time interval*" (*Idem*):

$$\text{xt} = \text{Acos}(2\pi\omega\text{t} + \varphi) \tag{6.5}$$

where for $t = 0, 0, \pm 1, \pm 2, \ldots, \pm n$, ω is a frequency index, defined as a cycle per unit time with A the amplitude of the function and φ the phase (6.6):

$$\begin{aligned} \text{pt} &= \beta 0 + \beta 1\text{t} + \text{Acos}(2\pi\omega\text{t} - \varphi) + \text{et} \\ &= \beta 0 + \beta 1\text{t} + \beta 2\cos(2\pi\omega\text{t}) + \beta 3\sin(2\pi\omega\text{t}) + \text{et} \end{aligned} \tag{6.6}$$

Setting ω = 1 and using least squares regression, was possible to fit the model to the time series and produce an harmonic model and a fitted model. These analyses are very useful in understanding exceptional changes in pixel values and open up possibilities for large-scale spatial and temporal analysis not possible outside of cloud processing engines such as GEE. In order to be able to compare the value of the pixels with the value of the same pixels in the previous images (t_0, t_1, t_2, t_n), it was necessary to make the same collection of images interact twice, creating what can be defined as a lagged collection, which incorporates a large amount of data.

With the necessary precautions, due to the geographical location of Machu Picchu which does not allow for particularly high-performance optical acquisitions (Landsat 7 and 8), the images allowed to observe the negative and positive changes in some pixels over the twenty years considered. Significant changes, in agreement with what was recorded in the forest area classifications and by the GFW system, were graphically observed in the clear spots of the image, while they are found at the deviation of several consecutive minimum and maximum points from the harmonic value (Fig. 6.9).

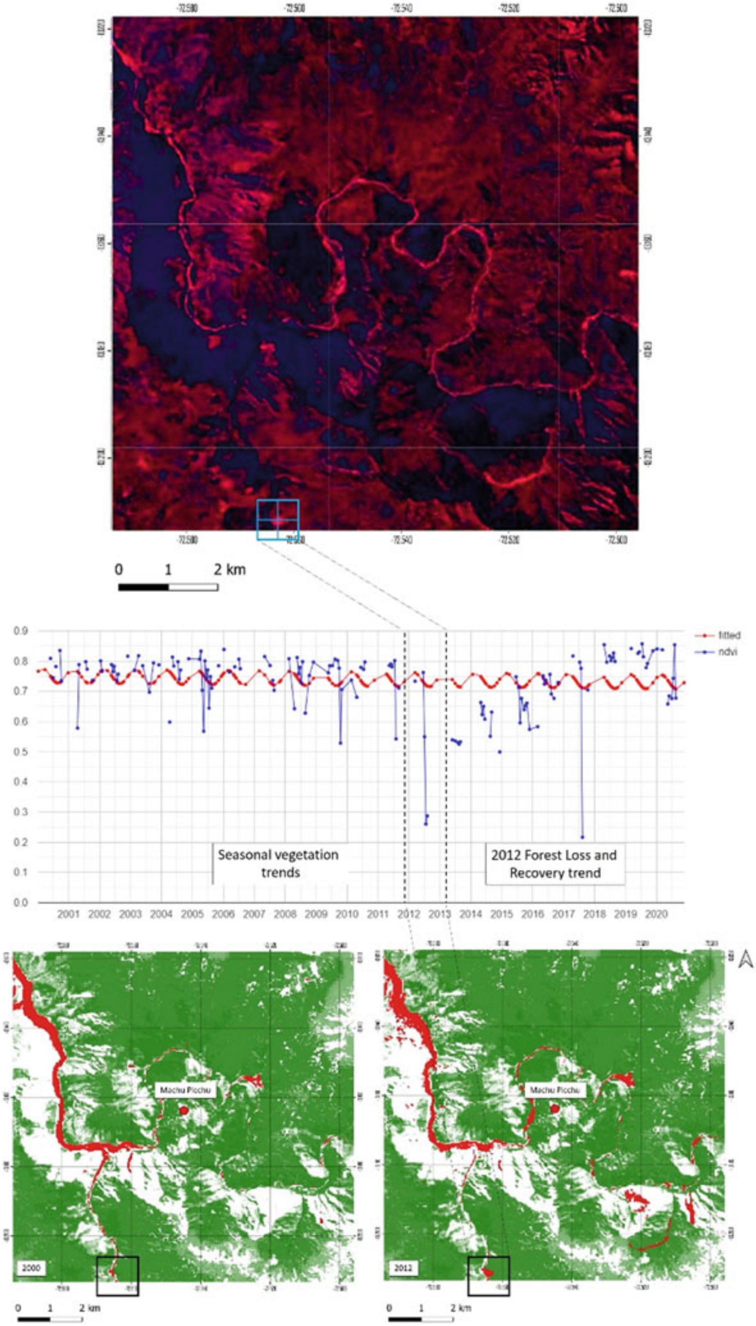


Fig. 6.9 Analysis of vegetation trends in the study area and identification of pixel value changes, to identify a loss of vegetation, in accordance with GFW. Below are the results of the unsupervised K-means classification

Trend analysis over very long time series are useful; however, a great strength of GEE is the possibility to operate with petabytes of data, allowing simultaneous trend analysis of all pixels in the area of interest, transforming the point-in-time analysis into a large-scale temporal analysis.

6.3 Result

This work shows the potential of EO techniques applied to large-scale spatial and temporal analysis in CNH contexts. Analyzing individual data (or couples of data) to identify risk and damage events for the NCH is well researched in the literature, while using cloud-based systems to process is a quite new system, thanks to the contribution of tools such as Google Earth Engine and Amazon.

The cases considered show two examples of the potential of these tools, and the ease and immediacy with which results can be obtained, through the use of well-defined methodologies.

The study of fire events is a central issue in the monitoring and analysis of large natural settings, such as for Machu Picchu Park (PANM), since it allows to understand the real damage reported by vegetation, in terms of extent and severity. This information is also useful to (i) formulate hypotheses about the causes of the event itself, and (iii) consider long-term damage in terms of vegetation loss, atmospheric emissions, and hydrogeological risk.

Using GEE and Landsat satellite imagery, it was possible to quickly calculate the two events that occurred in 2013 and 2017. These events, as already specified, were taken as a model to test the tool, which returned excellent outputs automatically (Fig. 6.6), comparable to those obtained by other research in the past (Chohfi 2018). In this methodology, a fundamental role is played by the ML operations that allow in a fully automatic way to discriminate through pixel clusters, the burned areas from the unburned ones, and vectorize them, without human action.

The method used for the single past case can be easily reapplied using the satellites revisit time to create a system of constant monitoring of the environment that allows to identify in near-real time the presence of fire events, and to obtain all the necessary information to implement measures of damage containment to avoid snowball effects. This tool can be integrated and used for continuous monitoring of areas of interest, providing a tool that is based on data sets and not a single pair.

In fact, the use of Big Data and long series of images is one of the strengths offered by GEE as observed in the case of the analysis of vegetation trends.

In this case, the results obtained clearly show a correspondence between the classification of the single image and the immediate identification, on a 20-year series, of vegetation changes (Figs. 6.8 and 6.9), from both a geometric and a spectral point of view. The tool, in this case, used NDVI as index, which is useful for understanding the health of the vegetation. However, this index is only one of many that can be produced using combinations of spectral bands, which have other purposes and utilities. The ability to use the same tool (GEE), with a simply editable code, is a strength for

EO technologies because, with minimal effort, allows the tool to be reused for other analyses, on large spatial and temporal scales, such as: (i) LC/LU; (ii) shoreline change study; (iii) water stress study; (iv) movement trends of permanent and seasonal water bodies; (v) floods; (vi) salinization; (vii) parasites; (vii) urban expansion.

GEE also provides the possibility to use multiple datasets, implementing ancillary data for analysis. This possibility makes this methodology scalable in terms of spatial resolution (e.g. Sentinel-2), but also applicable on a global scale and to any context.

Moreover, the importance of being able to work with long series of data is, moreover, strictly connected with the possibility of knowing the past but above all of being able to predict the future thanks to the use of the computing power of GEE and the use of mathematical models, statistics and artificial intelligence.

6.4 Conclusion

Since the 1970s, Landsat data have been the availability and have supported early satellite-based mapping analyses, even if despite the early successful applications, the limited spatial resolution compared to aerial photographs prevented and limited the use of satellite data compared to aerial surveys. Later, in the 1990s–2000s, the interest in global assessment and analyses pushed the use of medium to coarse resolution. Subsequently, around 2000s, the availability of very high resolution satellite data such IKONOS (1–4 m), Quickbird (0.6–2.4 m) provided improved technical capabilities with increased spatial detail (Ban et al. 2013; Del Frate et al. 2015).

Nevertheless, the cost of new acquisitions of VHR scenes along with the sparse coverage of archived data limited their diffusion for historical time series analyses and still today medium resolution (20–30 m) datasets such as Landsat remain the best compromise between the availability of historical data sets and spatial detail. In particular, the Landsat Thematic Mapper (TM), Enhanced ThematicMapper Plus (ETM+) and Operational Land Imager (OLI) satellite systems have been and are the most widely used tools for time series analyses for their extensive and accessible archives also available for free in a wide range of environments.

Big data has emerged in the past few years providing opportunities to improve and/or enable research and decision support applications with unprecedented value for digital CNH and archaeology. The possibility to fast analyses relatively large, varied and rapidly changing huge quantities of data has sped up the work during the diverse phases of application ranging from survey, mapping, documentation, exploitation, and monitoring at diverse spatial and temporal scales of interest, from landscape down to local level scale.

Actually the full exploitation of data provided by diverse sensors (from aerial, space and ground acquisition) requires the integration of all the available information (in digital and non digital format). This can be achieved within a GIS environment and the use of suitable software technologies for the management of huge amount of data (big data), as well as the integration, elaboration, exploitation and publication of heterogeneous data sources. These issues can be addressed by a Web-GIS platform, based on open source components (i. e. open standards, metadata and open source architectures), that can enable a "friendly" use of big data. Nevertheless the management, archiving of big data and their time series requires new approaches and concepts in the development of infrastructures and low cost effective technologies.

There is, therefore, no doubt that in the next future, EO big data will significantly change the scientific approach, data analysis, and methodologies for CNH also considering that these technologies are non-invasive, very reliable, and useful not only to investigate cultural landscapes, but also to support preservation and management of CNH properties and historic sites. As a whole, we can highlight that today advanced low cost technologies are available and, therefore, the critical point is to create easy access tools to these technologies and products as well as to assure interoperability in order to face needs not only for research, planning and monitoring purposes but also for sustainable exploitations of resources and educational purposes.

References

Acharya T D, Yang I (2015) Exploring Landsat 8. Int J IT Eng Appl Sci Res (IJIEASR) 4(4): 4–10.

Agapiou A, Lysandrou V, Hadjimitsis DG (2020) Earth observation contribution to cultural heritage disaster risk management: case study of Eastern Mediterranean open air archaeological monuments and sites. Remote Sens 12:1330

Amani M, Ghorbanian A, Ahmadi SA, Kakooei M, Moghimi A, Mirmazloumi SM, Moghaddam SHA, Mahdavi S, Ghahremanloo M, Parsian S, Wu Q, Brisco B (2020) Google earth engine cloud computing platform for remote sensing big data applications: A comprehensive review. IEEE J Sel Top Appl Earth Obs Remote Sens 13:5326–5350

Arévalo P, Bullock EL, Woodcock CE, Olofsson P (2020) A suite of tools for continuous land change monitoring in Google Earth Engine. Front Clim 2: 576740.

Arruda VLS (2021) An alternative approach for mapping burn scars using Landsat imagery, Google Earth Engine, and deep learning in the Brazilian Savanna. Remote Sens Appl: Soc Environ 22: 100472.

Arthur D, Vassilvitskii S (2007) K-means++: The advantages of careful seeding. In Proceedings of the Eighteenth Annual ACM-SIAM Symposium on Discrete Algorithms, New Orleans, LA, USA, 7–9 January; Society for Industrial and Applied Mathematics: 1027–1035, Philadelphia, PA, USA.

Ban Y, Gong P, Chandra G (2013) Global land cover mapping using Earth Observation satellite data: Recent progresses and challenges. ISPRS J Photogramm Remote Sens 103:1–6

Bar S, Parida BR, Chandra Pandey A (2020) Landsat-8 and Sentinel-2 based Forest fire burn area mapping using machine learning algorithms on GEE cloud platform over Uttarakhand, Western Himalaya. Remote Sens. Appl Soc Environ 18: 100324.

Caballero I, Ruiz J, Navarro G (2019) Sentinel-2 satellites provide near-real time evaluation of catastrophic floods in the West Mediterranean. Water 11:2499

Candra DS, Phinn S, Scarth P (2020) Cloud and cloud shadow masking for Sentinel-2 using multitemporal images in global area. Int J Remote Sens 41:2877–2904

Chohfi RE (2018) Burnt Areas by Forest Fires Occurring Near the Machupicchu Ruins in Peru Detected by Multitemporal Landsat Satellite Images: 1988, 2013 and 2017. https://doi.org/10.13140/RG.2.2.36535.83364

Chuvieco E (ed.) (2008) Earth observation of global change. The role of satellite remote sensing in monitoring the global environment, Springer Netherlands, Heidelberg.

Davies G, Smith A, MacDonald A, Bakker J, Legg C (2010) Fire intensity, fire severity and ecosystem response in heathlands: factors affecting the regeneration of Calluna Vulgaris. J Appl Ecol 47(2):356–365

Del Frate F, Pacifici F, Schiavon G, Solimini C (2015) Use of neural networks for automatic classification from high-resolution images. IEEE Geosci Remote Sens 45(4):800–809. https://doi.org/10.1109/TGRS.2007.892009

DeVries B, Huang C, Armston J, Huang W, Jones JW, Lang MW (2020) Rapid and robust monitoring of flood events using Sentinel-1 and Landsat data on the Google Earth Engine. Remote Sens Environ 240: 111664.

Fabre S, Elger A, Riviere T (2020) Exploitation of Sentinel-2 images for long-term vegetation monitoring at a former ore processing site. Int Arch Photogramm Remote Sens Spatial Inf Sci XLIII-B3-2020, 1533–1537.

Fattore C, Abate N, Faridani F, Masini N, Lasaponara R (2021) Google Earth Engine as multi-sensor open-source tool for supporting the preservation of archaeological areas: the case study of flood and fire mapping in Metaponto, Italy. Sensors 21: 1791.

Forkel M, Carvalhais N, Verbesselt J, Mahecha MD, Neigh CSR, Reichstein M (2013) Trend change detection in NDVI time series: effects of inter-annual variability and methodology. Remote Sens 5:2113–2144

Friedberg R (1958) A learning machine: Part, 1. Ibmjournal 3(2):2–13

Friedberg R, Dunham B, North T (1959) A learning machine: Jbrt 2. IBM J Res Dev 3(3):282–287

Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R (2017) Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sens Environ 202:18–27

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG (2013) High-resolution global maps of 21st-century forest cover change. Science 342:850–853

Hasmadi M, Pakhriazad HZ, Shahrin MF (2009) Evaluating supervised and unsupervised techniques for land cover mapping using remote sensing data. Geogr: Malays J Soc Space 5(1): 1–10

Horowitz FG (2015) MODIS daily land surface temperature estimates in Google Earth Engine as an aid in geothermal energy siting. In Proceedings of the World Geothermal Congress 2015, Melbourne, Australia, 19–25 April 2015.

Irons JR, Dwyer JL, Barsi JA (2012) The next Landsat satellite: The Landsat data continuity mission. Remote Sens Environ 122:11–21

Jiang Z, Huete A (2010) Linearization of NDVI based on its relationship with vegetation franction. Photogramm Eng Remote Sens 76(8):965–975

Justice CO, Townshend JRG, Holben BN, Tucker CJ (1985) Analysis of the phenology of global vegetation using meteorological satellite data. Int J Remote Sens 6(8):1271–1318

Keeley JE (2009) Fire intensity, fire severity and burn severity: a brief review and suggested usage. Int J Wildland Fire 18:116–126

Khairani NA, Sutoyo E (2020) Application of K-means clustering algorithm for determination of fire-prone areas utilizing hotspots in West Kalimantan Province. Data Base Adv Inf Syst 1:9–16

Kumar L, Mutanga O (2018) Google Earth Engine applications since inception: usage, trends, and potential. Remote Sens 10:1509

Lasaponara R, Tucci B, Ghermandi L (2018) On the use of satellite Sentinel 2 data for automatic mapping of burnt areas and burn severity. Sustainability 10:3889

Lasaponara R, Masini N (2020) Big earth data for cultural heritage in the Copernicus era. In: Hadjimitsis D et al. (eds) Remote sensing for archaeology and cultural landscapes. Springer Remote Sensing/Photogrammetry. Springer, Cham

Lasaponara R Masini N (2017). Preserving the past from space: an overview of risk estimation and monitoring tools. In: Masini N, Soldovieri F (eds) Sensing the past. From artifact to historical site. Springer International Publishing, pp 61–88. https://doi.org/10.1007/978-3-319-50518-3_3

Lemoine G, Léo O (2015) Crop mapping applications at scale: Using Google Earth Engine to enable global crop area and status monitoring using free and open data sources. In Proceedings of the

2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Milan, Italy, 26–31 July 2015, pp 1496–1499
Mahdianpari M, Salehi B, Mohammadimanesh F, Homayouni S, Gill E (2018) The first wetland inventory map of newfoundland at a spatial resolution of 10 m using Sentinel-1 and Sentinel-2 data on the Google Earth Engine cloud computing platform. Remote Sens 11:43
Masini N, Lasaponara R (2017) Sensing the past from space: approaches to site detection. In Masini N, Soldovieri F (eds). Sensing the past. From artifact to historical site. Springer International Publishing, pp 23–60. https://doi.org/10.1007/978-3-319-50518-3_2
Miller JD, Thode AE (2007) Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sens Environ 109:66–80
Mutanga O, Kumar L (2019) Google Earth Engine applications. Remote Sens 11: 591
Pepe M, Parente C (2018) Burned area recognition by change detection analysis using images derived from Sentinel-2 satellite: The case study of Sorrento Peninsula, Italy. J Appl Eng Sci 16:225–232
Pulvirenti L, Squicciarino G, Fiori E, Fiorucci P, Ferraris L, Negro D, Gollini A, Severino M, Puca S (2020) An automatic processing chain for near real-time mapping of burned forest areas using Sentinel-2 data. Remote Sens 12:674
Quintano C, Fernández-Manso A, Fernández-Manso O (2018) Combination of Landsat and Sentinel-2 MSI data for initial assessing of burn severity. Int J Appl Earth Obs Geoinf 64:221–225
Richards JA (2013) Supervised classification techniques. Remote sensing digital image analysis. Springer, Heidelberg, pp 247–318
Rouse JW, Haas RH, Schell JA, Deering DW, Harlan JC (1974) Monitoring the vernal advancements and retrogradation (greenwave effect) of nature vegetation. NASA, Washington, DC, USA.
Roy DP, Kovalskyy V, Zhang HK, Vermote EF, Yan L, Kumar SS, Egorov A (2016) Characterization of Landsat-7 to Landsat-8 reflective wavelength and normalized difference vegetation index continuity. Remote Sens Environ 185:57–70
Roy D P, Wulder M, Loveland T, Woodcock C, Allen R, Anderson M., ... Zhu Z (2014) Landsat-8: Science and product vision for terrestrial global change research. Remote Sens Environ 145: 154–172.
Samuel AL (1959) Some studies in machine learning using the game of checkers. IBM J Res Dev 3:211–229
Savage S, Lawrence R, Squires J, Holbrook J, Olson L, Braaten J, Cohen W (2018) Shifts in forest structure in northwest Montana from 1972 to 2015 using the Landsat archive from Multispectral Scanner to Operational Land Imager. Forests 9(4):157
Sazib N, Mladenova I, Bolten J (2018) Leveraging the Google Earth Engine for drought assessment using global soil moisture data. Remote Sens 10:1265
Schmid JN (2017) Using Google Earth Engine for Landsat NDVI time series analysis to indicate the present status of forest stands. https://doi.org/10.13140/RG.2.2.34134.14402/6
Shumway RH, Stoffer DS (2017) Time series analysis and its applications. Springer International Publishing, Berlin, Germany
Tamiminia H, Salehi B, Mahdianpari M, Quackenbush L, Adeli S, Brisco B (2000) Google Earth Engine for geo-big data applications: A meta-analysis and systematic review. ISPRS J Photogramm Remote Sens 164:152–170
Telesca L (2007) Time-clustering of natural hazards. Nat Hazards 40: 593–601.
Telesca L, Lasaponara R (2010) Analysis of time-scaling properties in forest-fire sequence observed in Italy. Ecol Model, Elsevier 221(1):90–93
Vogeler JC, Braaten JD, Slesak RA, Falkowski MJ (2018) Extracting the full value of the Landsat archive: inter-sensor harmonization for the mapping of Minnesota forest canopy cover (1973–2015). Remote Sens Environ 209:363–374
Wang L, Diao C, Xian G, Yin D, Lu Y, Zou S, Erickson TA (2020) A summary of the special issue on remote sensing of land change science with Google Earth Engine. Remote Sens Environ 248: 112002.

Zhu Z, Wang S, Woodcock CE (2015) Improvement and expansion of the Fmask algorithm: Cloud, cloud shadow, and snow detection for Landsats 4–7, 8, and Sentinel 2 images. Remote Sens Environ 159:269–277

Chapter 7
New Results from Archaeogeophysical Investigations in Machu Picchu

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Abstract The ITACA Mission of the CNR, in collaboration with the University of Warsaw and the PIAISHM from 2017 to 2019, conducted for the first time in Machu Picchu an interdisciplinary survey project aimed at exploring the subsoil for archaeological purposes with remote sensing and geophysics. Excavations carried out by the PIAISHM in 2016 opened new questions to which the geophysical investigations have attempted to provide an answer. This chapter shows and discusses the results mainly based on georadar surveys, integrated in some cases with geomagnetic prospecting, that on the one hand have highlighted the effectiveness of the approach, on the other hand have brought to light information (albeit indirect, being geophysical anomalies) on the presence of potential buried structures, linked to human frequentation phases preceding the architectural evidences. The exploration of the subsoil

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made it possible to characterize the stratigraphy both for archaeological and geotechnical purposes, as in the case of the Principal temple, providing some useful data to understand the cause-and-effect mechanisms of the structural failure affecting the same temple.

Keywords Archaeogeophysics · Machu Picchu · Ground Penetrating Radar · Magnetometry · Resistivity method

7.1 Introduction

In Southern America, the use of geophysics for archaeological prospection started in the first decade of the 2000s. The most popular geophysical techniques used for preventive archaeological research, have been geomagnetometry (GM), Ground Penetrating Radar (GPR), and Electrical Resistivity Tomography (ERT), selected according to the expected characteristics of both buried archaeological features and soils.

GM, based on the measuring and recording of spatial variations in the Earth's magnetic field, has been mainly used to detect and map (i) ring ditches of the prehistoric sites in the lowlands of the Llanos de Moxos in the Bolivian Amazonia (Prümers 2006) and (ii) buried earthen city walls of the ceremonial center of Pachacamac in Peru (Lasaponara et al. 2017; Pozzi-Escot et al. 2018).

GPR, based on the analysis of radar signal reflection in the presence of subsoil discontinuities, has been generally exploited to detect: (i) stone masonry structures, as those in andesite identified in Tiwanaku (Henderson 2004), and (ii) naturally dried-earth settlements, from the Formative age in the northwest of Argentina to the colonial period in Patagonia (Bonomo et al. 2010; Lascano et al. 2003). GPR has been also fruitfully employed in Peru for the characterization of looted areas in Ventarron (Lasaponara et al. 2014).

Although Machu Picchu has been studied from multiple points of view, from historical-ethnographic aspects to archaeological research (Bastante 2017), from hydraulic engineering (Wright et al. 1997) to geology, geomorphology (Carlotto and Cárdenas 2009; Margottini and Spizzichino 2014), and deep geophysics, however very little has been done on the shallow geophysical characterization for archaeological purposes.

Recently, some geophysical prospections have been performed in Chachabamba, in Urubamba valley, in the Historic Sanctuary of Machu Picchu (Masini et al. 2018). The investigations have been aimed to explore the anthropic shallow subsoil, for the detection of expected buried structures and canals, as well as to experiment and validate an archeogeophysical approach in the perspective to reapply in other sites with similar characteristics of the Urubamba valley, including Machu Picchu.

In Chachabamba, a large variety of archaeological features, such as walls, canals, morphological changes of terraces, stoneblocks have been identified, thus validating an integrated geophysical approach, based on GPR and GM, which has been applied in Machu Picchu (Masini et al. 2018).

This chapter shows and discusses the main results obtained with the integrated and combined use of GPR, ERT, and GM performed in different areas of Machu Picchu for supporting the archaeological research. The geophysical prospections have been performed by the Italian scientific mission ITACA of CNR, in the context of multidisciplinary studies conducted in cooperation with Polish archaeological mission of Warsaw University and Archaeological National Park.

The cooperative use of the different methodologies characterized by different resolution and depth of investigation has allowed to characterize the first meter of subsoil highlighting its complexity due to coexistence of anthropic structures and geological conditions that have influenced the history of the entire site. The integration of different methodologies has provided a fundamental tool to reduce the uncertainties regarding the interpretation but it was not always fully achievable. Indeed, small areas or areas enclosed between buildings are little investigable with ERT and MAG and only GPR is exploitable in these conditions; while, where open areas are present, the comparison and integration of all techniques is widely desirable.

7.2 Methodology

The use of geophysics for archaeological purposes represents the most useful approach to identify and reconstruct ancient scenarios still buried and unknown. Further, the application of different geophysical methodologies can support other types of remote sensing techniques for detecting the traces of the past that predates the ones which are known and observable (Keay et al. 2014). The success of its application in the archaeological field is due to the capability of some methodologies to observe and highlight some anomalies in the physical behavior of the subsoil due to the presence of objects or structures of archaeological interest. The methodologies that have most success for the archaeological issues are the ones belonging to the near surface geophysics, which includes the methodologies able to investigate, in a noninvasive way, small-scale features in the first meters of the subsurface (Rizzo and Capozzoli 2019).

However, each method is characterized by limits and potentialities and their use should be carefully evaluated depending on the characteristics of the investigated structures and the site-properties. Indeed, electromagnetic methods are not particularly effective in high conductive soils, while in dry or less-conductive scenarios can give detailed information until to considerable depths. Magnetometric methodologies in urban scenarios are hardly penalized for the presence of metallic objects imputable to the modern building materials but in rural areas provide high quality information in a short time. Electric methods are less used for archaeology for the limited resolution offered by the method, but their applications can give amazing insights for understanding geological and morphological evolution occurring in the investigated site (Masini et al. 2017). It is evident how the use of a multimethodological and multisensory approach deeply increases the possibility to obtain high quality imaging of the subsoil (Capozzoli et al. 2020a, 2020b; Campana and Piro 2009; Piro et al. 2003).

However, the contribution of the geophysics does not end solely to detected buried features but rather, provides useful information to reconstruct the paleomorphological scenarios present before the realization of ancient settlements or also identify the possible cause of the abandonment of the site. Further, previous excavation activities not adequately documented could be effectively detected in noninvasive way. These aspects are particularly important for the activities carried out in the site of Machu Picchu where, exploiting most effective geophysical methodologies for archaeological purposes, geological and archaeological aspects are investigated enriching the scientific speculation.

Indeed, analyzing the results obtained by the use of geophysics in this site four main targets are reached:

(1) Detection of buried structures, supposedly belonging to different historical phases of the site;
(2) Characterization of the shallower layers constituting the subsoil partially interested by the works of reshaping;
(3) Identification of areas interested by geological instability phenomena;
(4) Detection of areas subject to previous excavations.

Through an extensive plan of geophysical investigation, 13 different areas located in the archaeological site of Machu Picchu were investigated with the use of the geophysical methodologies.

7.2.1 Ground Penetrating Radar (GPR)

GPR is a geophysical active technique based on the emission and propagation of electromagnetic (e-m) waves in a medium also including subsoil conserving buried archaeological remains. The variation of physical parameters as electrical conductivity, magnetic permeability, and dielectric permittivity, causes variations of the electromagnetic impedance of the investigated materials and several reflections of the e-m signal introduced into the ground are generated. The subsequent reflection signals due to the presence of anomalies give the possibility to identify objects buried into the ground and enable the physical characterizations of the material through which they propagate (Catapano et al. 2019).

GPR systems are generally constituted by a timing unit that controls the transmission and reception of the e-m signals. This component provides the synchronization of the signals and is linked both to the unit used for visualizing and recording the data and to the antennas that generate and record the signal. As regarding the characteristics of the signal in term of resolution and depth of investigation, a fundamental role is played by the operating frequency of the antenna. Generally, GPR systems work at the frequencies ranging between 0.01 GHz and 2 GHz. The antennas with the lower frequencies are suitable for geological studies where the required resolution is lower, but it is essential to reach great depths of investigation. Antennas operating between the frequencies of 200 and 600 MHz provide a good compromise between resolution and depth of investigation; their use is surely adequate for archaeological issues. The high frequencies (>1 GHz) are more adequate for engineering issues where a great resolution is required but the thickness of the elements investigated is limited.

GPR measurements are generally taken in different positions along defined lines and the corresponding radargrams are obtained. The basic element of a GPR acquisition is called trace (A-Scan) that provides a one-dimensional information defined by a certain number of samples that are representative of the electromagnetic behavior of the investigated medium. A set of traces generates the radargram that is the two-dimensional representation of the GPR data (B-Scan). By the interpolation of more intersecting B-Scans, also acquired according to different orientations, it is possible to define a 3D-representation of the GPR data (C-Scan). The use of the B-Scan and C-Scan representations is particularly important for archaeological feature detection because it allows to identify the stratigraphy of the subsoil and the presence of alignments due to buried structures (Ludeno et al. 2018; Capozzoli et al. 2020a, 2020b).

In Machu Picchu an extensive plan of investigation with GPR was performed using a time domain, IDS manufactured, TH DUAL-F HI-Mode GPR system equipped with a single fold dual frequency antenna, allocated into a shielding box, whose nominal central frequencies are 200 MHz and 600 MHz. 20 traces at the second are acquired and a marker is placed every meter to make possible the geographical editing of the acquired data. The trace-increment was fixed to 0.01 m while the time-increment was 0.1 ns and 0.3 ns for the 600 and 200 MHz antennas, respectively. The samples constitute the single trace are 512 and no gain function or bandpass filter are applied during the acquisition phases.

Data are processed with the use of a processing chain based on the sequent steps:

- Data editing, for assigning the spatial information to the data;
- time gating, for reducing the noise due to the interface air-ground below the antenna;
- amplitude normalization, consisting of the de-clipping of saturated (and thus clipped) traces by means of a polynomial interpolation procedure;
- linear gaining, for improving the quality of the signal at greater depths;
- bandpass butterworth filtering, to reduce the information collected to unknown frequencies;
- diffraction migration, for collapsing hyperbolas after the evaluation of the electromagnetic velocity obtained with the direct analyses and the hyperbolas fitting method.

After the application of this processing chain, the radargrams are used to create a 3D representation of the most relevant anomalies present in the subsoil with the support of the GPR-Slice software (Goodman 2017).

7.2.2 Magnetometric Measurements (GM)

GM is a passive geophysical method based on the mapping of the magnetic field to identify areas where the geological structure of the subsoil or the presence of buried bodies locally modify the Earth magnetic field (Telford et al. 1990). It is widely used in a great variety of applications which range from large-scale geological mapping thought to small-scale investigation such as those related to non-destructive archaeological explorations.

The possibility to scan large areas in a short time, the easy field operations, and the relative intuitive data processing, make the GM investigation an optimal tool for a preliminary survey of an area of potential archaeological interest (Aitken et al. 1958; Fedi et al. 2009).

Depending on the target of a GM survey, different acquisition strategies can be adopted. When targeting to shallow buried structure or remains, the pseudo-gradiometric measurements, which consist in the simultaneous measurements of the magnetic field at two different positions (heights), are usually preferred to the total field measurements (Telford et al. 1990). The pseudo-gradiometric allows to filter out the Earth magnetic field and the geological contribution leaving only the remanent magnetism and the induced magnetization-related anomalies. The induced magnetization is linked to the magnetization of a material as a response to the Earth's Magnetic field; the remanent magnetism, on the other hand, is the result of several processes such as thermal or chemical alterations.

In an archaeological framework, these anomalies usually range from few nT (1–20 nT) for remains up to thousands of nT for fired structures (hearths, kilns, crockery, pottery) and ferrous objects (Piro et al. 2007). The shape and the amplitude of the magnetic anomalies depend on the characteristics of the buried body (both in terms of its geometry, location, and magnetic properties) and by the geomagnetic latitude of the surveyed area (Tite, 1972). The measured field is, in fact, the vector sum of the earth's magnetic field (with amplitude, inclination and declination variable site by site) and the field created by a local feature which, in case of induced magnetization, is strongly connected to the earth's magnetic field.

Magnetic surveys are usually performed in open areas walked following equally spaced transects along which magnetic data are collected. This leads to the creation of the magnetic maps. The spatial resolution of the survey is function of the spacing between the transects and of the sampling frequency used to collect data along the lines. Whereas the maximum dimension of the maps only depends on instrumental limits (battery and memory), the acquisition of magnetic data in small areas is usually avoided. The extend of an anomaly depends, in fact, not only by how big and magnetizable/magnetized the generating body is but also by its depth. The deeper it is, the more extended will be its related magnetic anomaly. It derives that a small magnetic map could be not able to depict the whole extension of the anomalies and be hence poorly informative.

As a standard processing procedure, the following steps are usually adopted in analyzing magnetic map:

i. pass-band filter, to remove high or low frequency components;
ii. despike made using a uniform weighted window to search for and leave out outlier valued replaced by the mean;
iii. destripe to remove the striping effect between grids caused by directional effects;
iv. Kringing interpolator with a linear variogram to highlight the main geomagnetic linear anomalies.

In Machu Picchu, GM data were collected using a Grad601-Bartington system. The system includes a data logger, a battery, two Grad-01-1000 l sensors mounted on a rigid carrier bar. The instrumental sensitivity is ±1 nT (nano Tesla). Calibration is performed on-site prior to acquisition through an automated procedure which allows to correct possible misalignment in the sensors measurements. The gradiometer data were collected in unidirectional mode, along parallel profiles 1 m apart and at a 0.2 m sampling interval.

7.2.3 Resistivity Method (ERT)

The geoelectrical method is an active geophysical method which allows to image the subsurface electrical resistivity distribution. An electrical current is injected into the subsurface by means of a couple of electrodes (current electrodes) and the associated electrical potential drop is measured on the surface by using a couple of electrodes (potential electrodes). The measured potential drops are related to the injected currents via the apparent resistivity and the geometrical factor K ($\Delta V = \rho\_a/K\ I$). K is a function of the relative distances between the current and the potential electrodes which, according to their disposition, can be arranged in several different ways said "geoelectrical array configurations". Whereas, theoretically, the electrodes can be placed in any position on the surface, fixed and regular dispositions are usually adopted in a geoelectrical measurement. The most used arrangements are named Dipole–Dipole, Wenner, Schlumberger, Wenner-Schlumberger, and Pole-Dipole (Telford et al. 1990). Each of these arrangements is characterized by a different investigation depth, vertical and horizontal resolution, and Signal to Noise ratio. According to the target of the survey, a specific array can be preferred. In noisy areas, for example, the Wenner array could be preferred due to its higher Signal to Noise ratio. Dipole–Dipole is usually preferred to highlight the presence of vertical discontinuity within the subsoil etc. A complete description of the array characteristics can be found in several geophysical textboox (i.e. Telford et al. 1990). When performed along a transect line (the most common arrangement), geoelectrical measurements are often called Electrical Resistivity Tomography and generates section of the subsurface resistivity distributions. Detailed reviews on basic principles of ERT and its numerous practical applications can be found in Loke et al. (2013) and Revil et al. (2012). It is just worth to note that the investigation depth and the resolution directly depend on the electrode spacing. Increasing the electrode spacing, the investigation depth becomes greater but the resolution decreases.

In the archaeological framework, ERT is often used to highlight the presence of electrical anomalies within the subsoil which could be connected with the presence of buried structures. In this context, where the resolution plays a more relevant role than the investigation depth, it is common to perform ERT survey with sub metrical electrode spacing and to prefer the Dipole–Dipole electrical array due to its sensitivity to the presence of vertical discontinuities (Capozzoli et al. 2015, 2020a, 2020b).

In Machu Picchu, ERT data were collected by using a SyscalPro 48Ch (Iris Instruments), able to control simultaneously up to 48 electrodes, connected to multielectrode cables with electrode spacing of 0.5 m. This configuration normally allows to acquire data along profile with a maximum length of 23.5 m and with an investigation depth up to ~4 m. When it is necessary to cover longer distances, the roll-along technique can be applied. All the geoelectrical data have been inverted by using the commercial software RES2DInv (Loke and Barker 1996).

7.3 Context, Study Area, and Aims

The monumental complex of Machu Picchu (Lat. 13° 09' South, Long. 72° 31' West) is located on the top of a graben-like structure at 2.430 m.a.s.l., that separates the Vilcabamba and Urubamb rivers, between the slopes of the Machu Picchu and Huayna Picchu hills, in the high Eastern Cordillera of the Peruvian Andean chain, approx. 80 km from Cusco (Peru) (Fig. 7.1a).

The Machu Picchu granitoid pluton, forming part of the larger "Quillabamba granite", is one of a series of plutons intruded along the axial zone of the high Eastern Cordillera Permo-Liassic rift system including a variety of rock types, dominantly granites and granodiorites (Mazzoli et al. 2009). Slope evolution of the area is mainly controlled by tectonic uplift, fluvial erosion operated by the Urubamba river, located at the toe of slopes, and by the geomechanical-structural settings of slope forming materials (Fig. 7.1b, c). The local bedrock of the Inca citadel of Machu Picchu is mainly composed of granite and subordinately granodiorite. Granodiorite is mainly located in the lower part of the slopes (magmatic layering at the top). Superficially, the granite is jointed in blocks with variable dimensions, promoted by the local structural setting. More in detail, local substrate often consists of large irregularly-piled granite boulders (granitic chaos) over which the urban area was built. Soil cover, widely outcropping in the area, is mainly composed of individual blocks and subordinately coarse materials originated by chemical and physical weathering of minerals. Part of the slopes exhibit debris accumulation as a result of past and present landslide activity. Talus and talus cones are composed of fine and coarse sediments, depending on the local relief energy (Spizzichino 2012). Anthropogenic fill and terraces (Andenes), on the top of the Citadel, reflect the work of Inca activities in the area (Canuti et al. 2008, 2009).

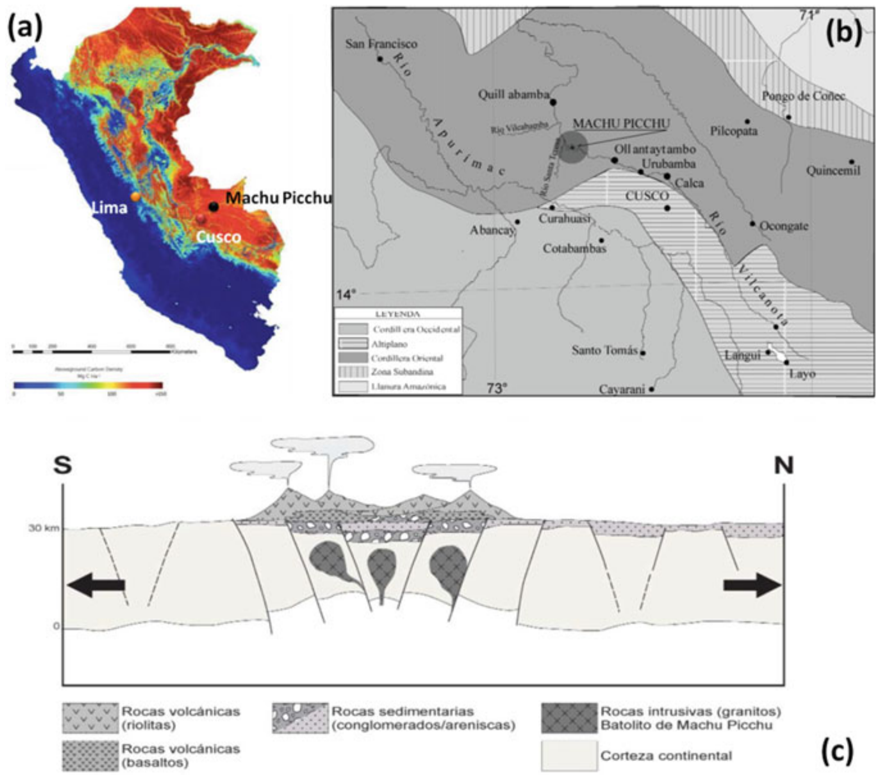

Fig. 7.1 (**a**) Location of Cusco and Machu Picchu. (**b**) Machu Picchu location overlooking three rivers. It is settled on Eastern Cordillera of the Andes Eastern, surrounded by other environmental setting such as Western Cordillera, Plateau (where Cusco is located), Amazon plain and, Sub-Andean area. (**c**) Geological section of the region

Machu Picchu was built in the first decade of the fifteenth century, as recently proved by radio carbon dating (Ziółkowski et al. 2020), and abandoned in the sixteenth century, after the conquest of the Inca empire by the Spaniards. It was lost up to its re-discovery in 1911 made by Hiram Bingham, who, was searching for Vilcabamba, the last refuge of the Incas until the fall of the Empire in 1572 (Bingham 1913; Bastante 2017; Moseley 1992). The first archaeological excavations were performed in 1912 by the Yale Peruvian Expedition and directed by Bingham (1913, 1922). The results of these excavations, recorded in the field diary of the engineer Ellwood Erdis and recently studied by Bastante (2017), allowed us to argue that Machu Picchu was an administrative, political and religious center of utmost importance during the Late Horizon (fifteenth century). It played an important role for the cultural interaction and a strategic setting for the exchange of products between the Amazonian jungle, Andean mountain and coastal shoreline (Bastante et al. 2020).

The monumental site of Machu Picchu (also known as llaqta), masterpiece of architectural and landscape beauty (Fig. 7.2a) developed along a nortwest-southeast axis (see Fig. 7.2b), and is divided in two large sectors: (i) the agricultural one to the southeast side, made up of terraces (andenes), mostly used for the slope stabilization and corn cultivation; and (ii) the urban sector, on the northeast, used as a residence, places of worship and warehouses, where the main civil and religious activities took place. The whole site is characterized by a dense network of roads, stairways, and water channels. The urban sector, as common in the typical Inca town, is divided in

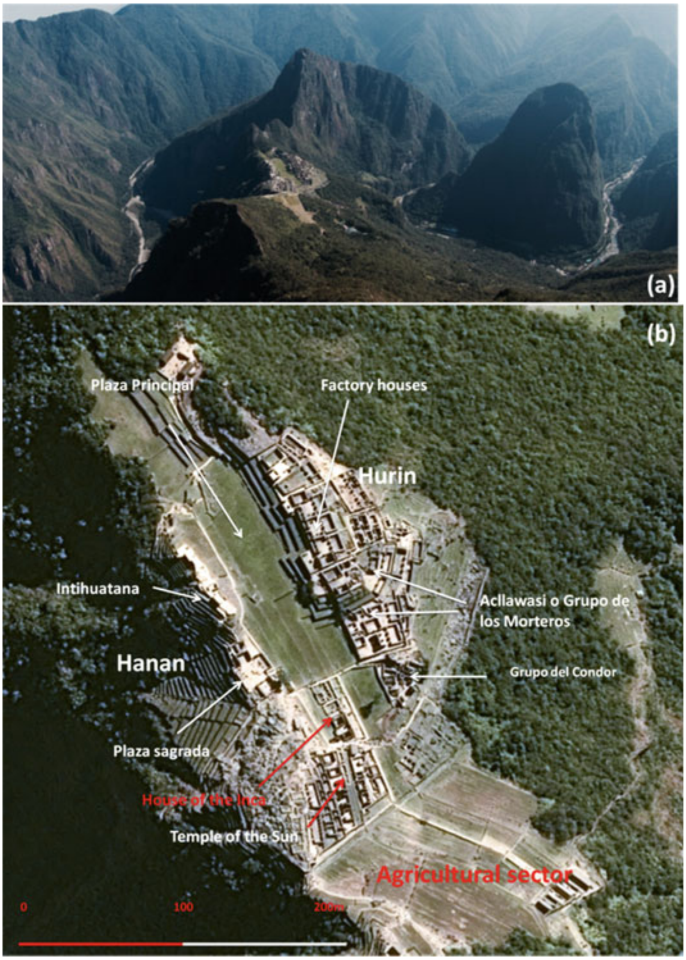

Fig. 7.2 (**a**) Landscape view of Machu Picchu (courtesy by Jose Bastante). (**b**) GeoEye satellite-based map of Machu Picchu which puts in evidence the main sectors of Machu Picchu: the agricultural sector at South and the urban sector at North, in their turn divided in two subsectors the Hanan (to the west) and Hurin (to the east) with in between the ‘Plaza Principal’

two parts: the upper (to the west), named Hanan and the lower (to the east), known as Hurin (Gasparini and Margolies 1980; Hyslop 1990).

The Hanan includes the Plaza Sagrada, the Temple of the Sun, and the House of the Inca (Fig. 7.2b). The Plaza Sagrada is composed by a set of constructions, including the Temple of the Three Windows and the Main Temple, set around a square courtyard. All of those structures that stand out with the top level stone masonry are surmounted by a pyramid complex, on the top of which is the Intihuatana stone (Fig. 7.2b), whose presence was only related, in the Inca vision, to places considered sacred (according to some scholars as Reinhard 1991; Moseley 1992).

The Hurin is characterized by the typical trapezoidal shaped doorways, windows, and niches in the walls set around small rectangular squares, called kancha. In particular it is composed of three large kanchas, arranged symmetrically and communicating with each other, including housing and workshops overlooking the Plaza Principal (Fig. 7.2b). Hurin also includes a large building complex with one entrance door, suggesting that it was the Acllahuasi (or 'house of chosen women') of Machu Picchu, dedicated to religious service and fine crafts; and the Temple of Condors, characterized by some caves with evidence of ritual use and a large carved stone in the center of a large patio in which many believe they see a representation of a condor.

The geophysical investigations are performed on different areas of the archaeological site of Machu Picchu (see Fig. 7.3). Considering the characteristics of the areas investigated, the integration and combined use of the different methodologies was not always done. In particular, as shown in Fig. 7.3, seven areas with limited sizes are investigated with only the use of GPR (yellow coloured areas in figure), an area (Sector D) was investigated with the use of only ERT, while two different areas (Plaza E2 and Plaza D) were investigated with the use of all the methodologies. The areas in red and in green, finally, are investigated, respectively, only with MAG and MAG coupled to GPR.

7.4 Results

7.4.1 Intihuatana

The Intihuatana is a little square characterized by the presence of a monumental ritual stone, supposedly linked to the astronomic clock or calendar of the Inca people (Fig. 7.4). The target of this investigation was the characterization of the shallower layers of the subsoil and identification of critical anomalies for the vulnerability of the structure. For these reasons only GPR data have been collected in two orthogonal directions.

Figure 7.5 shows the radargrams acquired at the frequency of 200 MHz. The radargrams exhibit several reflections immediately close to the slope which delimits the area investigated. This behavior well-matches with the hypothesis that this area

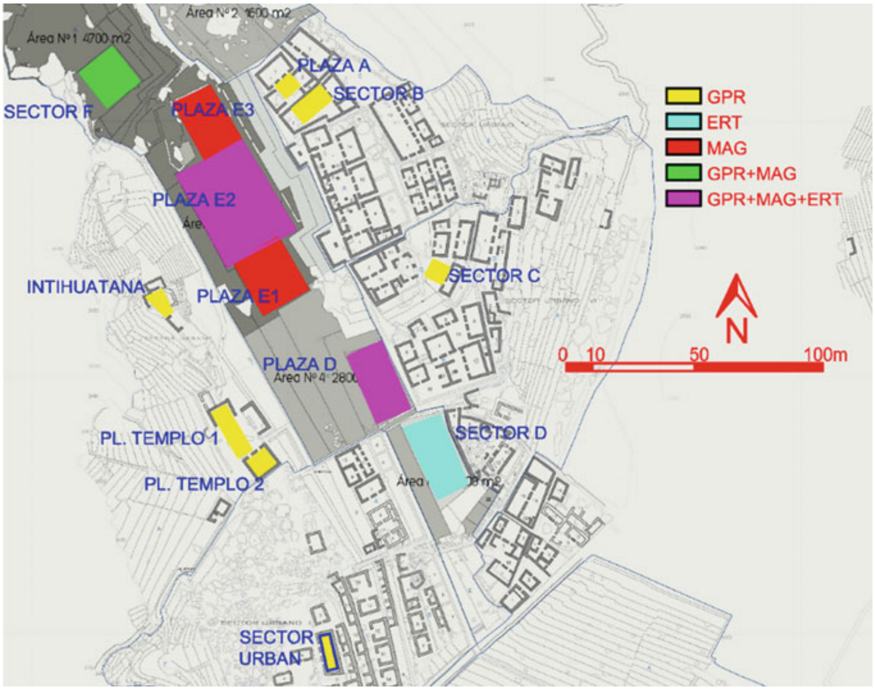

Fig. 7.3 Localization of the sites investigated with GPR, ERT and MAG

Fig. 7.4 GPR data-acquisition at the Intihuatana site

is affected by erosional phenomena. The anomaly A1 is placed near the slope, but also the other anomalies A2, A3, and A4 denote the presence of discontinuities in the subsoil associable to the geological conditions of the area. Similar reflections are observed on the opposite side of the area, where the radargrams F5, F6, and F7 end. The black arrows highlight the presence of discontinuities in the rock that the altar was built on. All the radargrams are characterized by a linear anomaly placed in

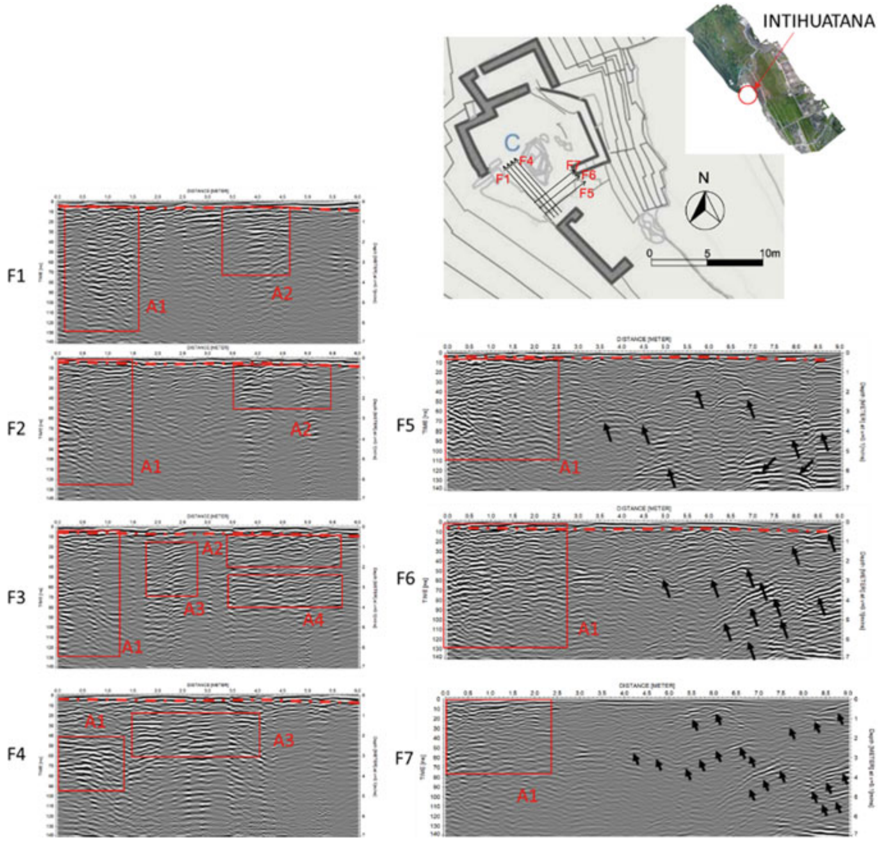

Fig. 7.5 Radargrams acquired in Intihuatana with the indication of the main punctual reflections (black arrows) and the areas characterized by erosional phenomena (red boxes)

the first 0.5 m supposedly associable to the original floor of the site. The reflections placed immediately under the hypothesized floor permit to suppose the presence of a not homogenous soil before the realization of the existing structures. The acquired data do not show strong attenuation effects affecting the radar signal, indicating that the acquisitions are made in dry conditions or directly in contact with the bedrock.

In conclusion, considering the geological processes interesting the area, the recorded reflections are the visible result of the physical alteration of the rocks as well as the possible presence of incipient failures on the slope.

Fig. 7.6 Two sites investigated in Hurin: sector A (on the left) and sector C (on the right)

7.4.2 Hurin Sectors A, B, and C

In this area, geophysical prospections were performed for analysing a large architectural complex placed at the northeast side of the archaeological site, dominated by three large *kanchas*[1] arranged symmetrically and communicating with each other. Its covers, of identical invoice, overlook the main square of Machu Picchu. It includes housing and workshops (see Figs. 7.2b, 7.3, and 7.6).

In this context, three sectors, named A, B and C (for their localization see Fig. 7.3), have been investigated only with GPR. The target of the investigation performed in this area is to identify the presence of buried structures belonging to previous construction phases. All the investigated areas are characterized by regular and plan surfaces with no obstacles for collecting the GPR data (see Fig. 7.6).

7.4.2.1 Sector A

The area investigated, a small patio (courtyard) enclosed between ancient buildings (Fig. 7.6, left), was investigated with several profiles acquired every 0.5 m in two perpendicular directions (see top Fig. 7.7).

Radargrams highlight the presence of a shallow inclined reflective layer in the first meter, supposedly due to the leveling work occurring in the area (green arrows in figure). Below this layer, strong reflections characterize the subsoil up to the depth of about 3 m. These reflections could be related to the reshape works of the site; however, considering their spatial distribution, it cannot be excluded that other constructive phases, more ancient, have been encountered. Indeed, red arrows identify reflections associable to the presence on an ancient floor, at about 1–1.5 m depth, subsequently filled with homogeneous soil (dashed yellow rectangle). At the opposite side, chaotic reflections are recorded (dashed blue rectangle) apparently due

[1] The *kancha* is the Inca basic architectural unit characterized by a rectangular plan commonly composed of three walls; it is also a set of enclosures with three or more rectangular structures around the courtyard (Hyslop 1990, 17).

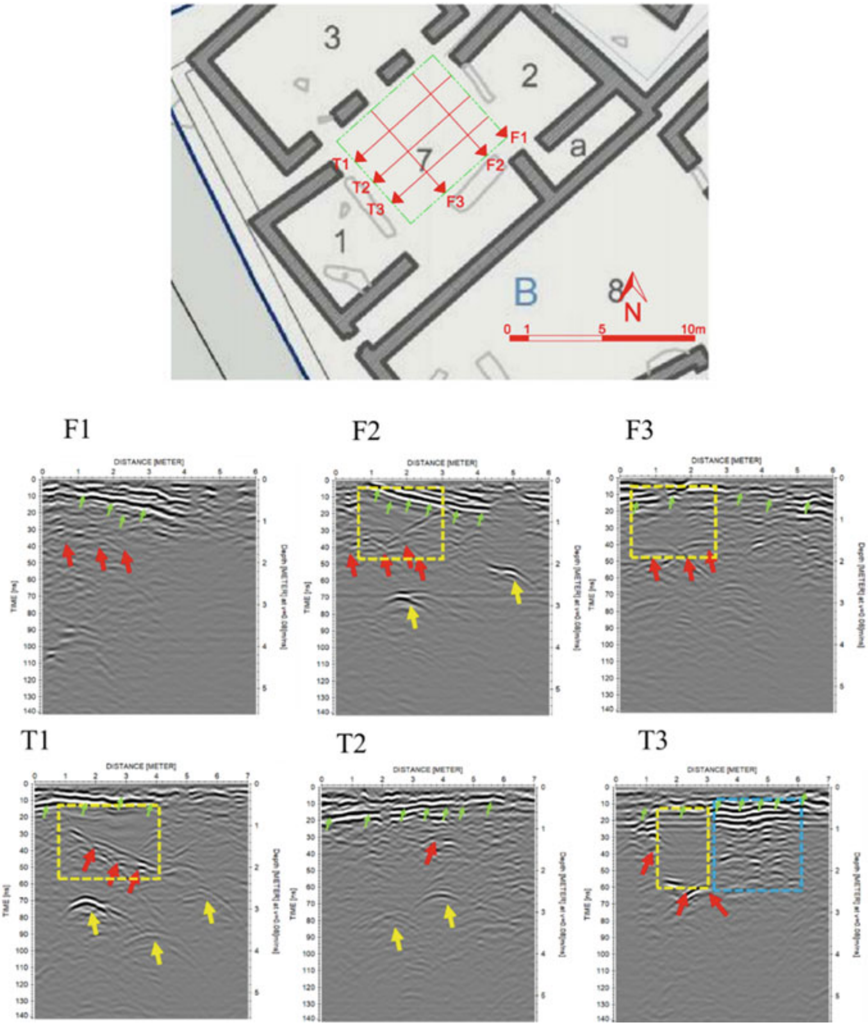

Fig. 7.7 Radargrams acquired in correspondence of the courtyard of sector A with indication of the main anomalies detected

to a less compacted soil. Strong reflections are, further recorded at a depth greater than two meters supposedly due to the presence of the fractured rocks (yellow arrows).

Plotting the reflections in 3D view it is possible to detect some anomalous areas that seem to suggest the presence of two ancient structures placed between the depths of 0.9 m and 2 m (top of Fig. 7.8). The 3D reconstruction of the higher amplitude reflections highlights the structure placed at the northeast edge of the investigated area (yellow arrows in Fig. 7.8).

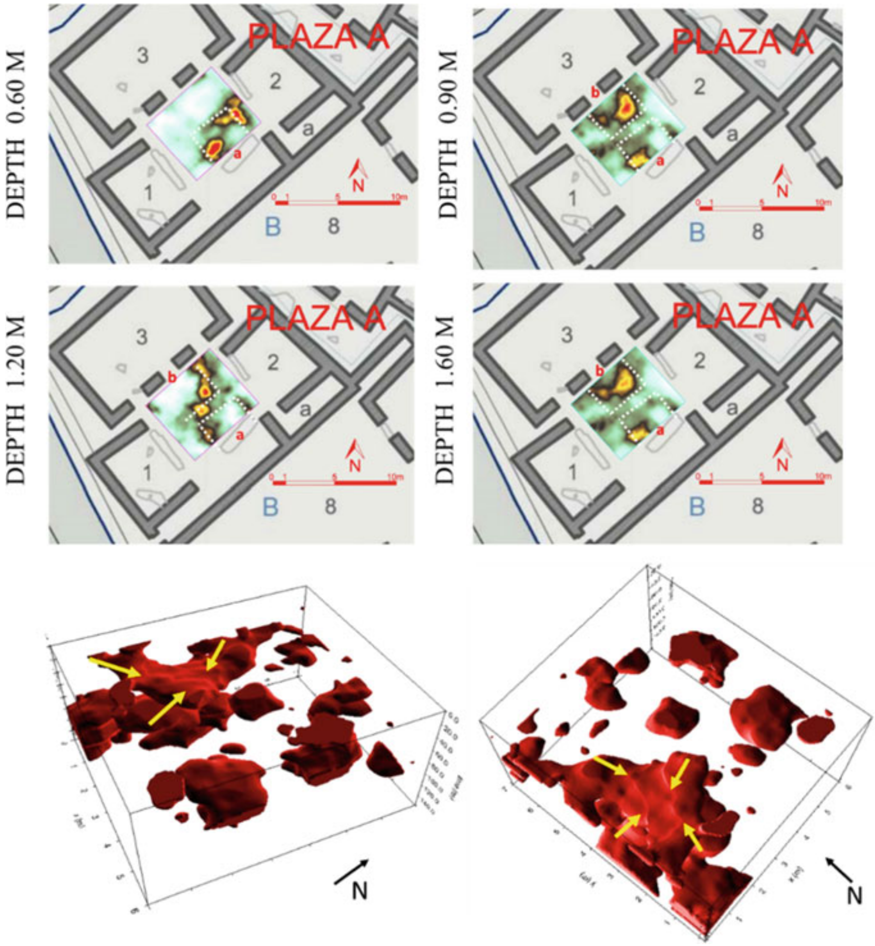

Fig. 7.8 Depth slices acquired in correspondence of the patio A (at the top) and 3D representation of the higher amplitude reflections (at the bottom)

7.4.2.2 Sector B

This sector is placed in contiguous to the patio of sector A and was investigated with profiles acquired in two perpendicular directions placed every 0.5 m. As indicated in Fig. 7.9, it is possible to identify some interesting anomalies in the first two meters of depth, likely due to the presence of a buried structure or an excavation area placed close to the southwest corner of the area. The other reflections (yellow arrows) are imputable to the geological condition of the site and are supposedly associable to isolated and fractured rocks similarly to the ones highlighted in the sector A.

The depth slices extracted by the 3D volume of the area clearly highlight the presence of two anomalous areas placed at the southwest corner of the area (named

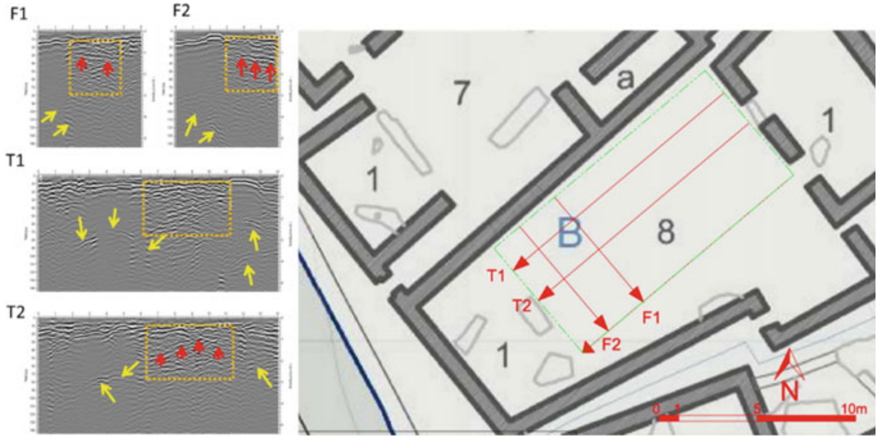

Fig. 7.9 Radargrams acquired in Sector B (near Sector A) with indication of the most remarkable anomalies

A and B) that could be associated to a different construction phases of the adjacent buildings (Fig. 7.10).

Figure 7.10 provides to identify the two anomalous zones that seem to suggest, considering their shape and extension, two well-organized buried structures where the first one (A) is placed at a depth ranging between 0.5 m and 1.5 m, and the second one (B) at a depth of approximately 2 m.

The 3D visualization shown in Fig. 7.11 is a further valid aid in the interpretation of the reflecting bodies A and B, placed in different areas and depths, reasonably referable to two distinct construction phases.

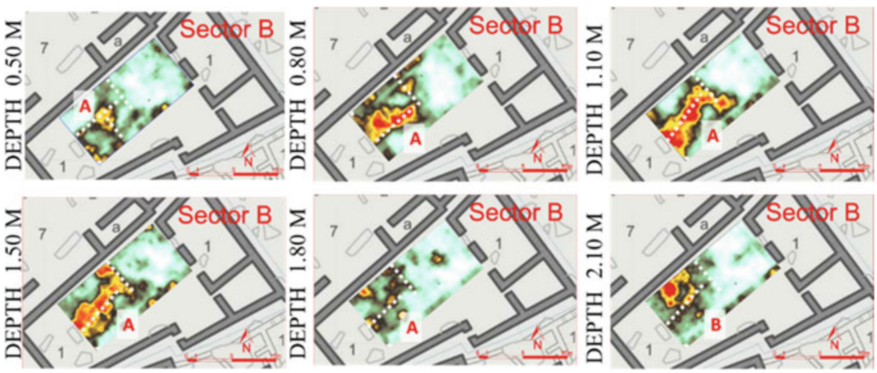

Fig. 7.10 Depth slices of Sector B with identification of the most interesting alignments (white dashed lines)

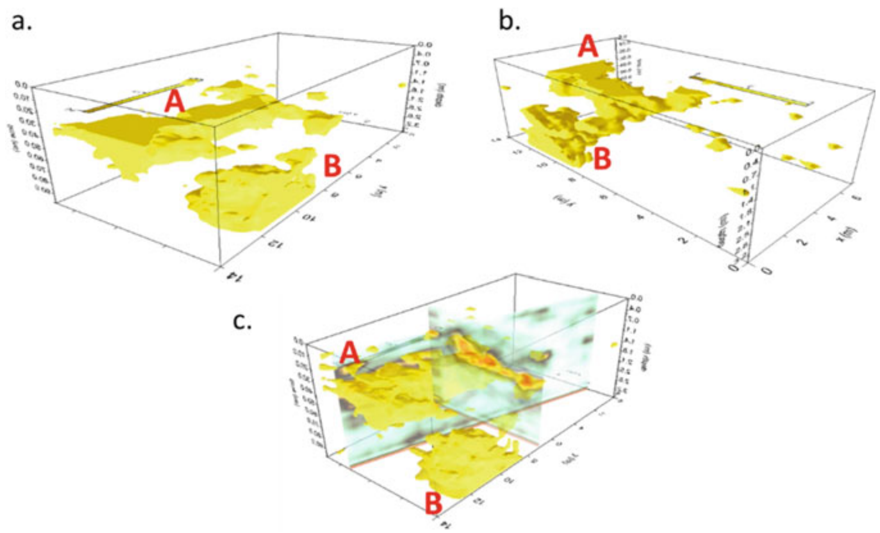

Fig. 7.11 3D reconstruction of the two anomalies detected in the sector B

7.4.2.3 Sector C

At the foot of the workshop district, a small enclosure, named C (or UE2 by the archaeologists) was investigated with profiles equi-spaced 0.5 m in two perpendicular directions. Two are the most interesting anomalies highlighted by 3D GPR imaging (see time slices in Fig. 7.12). One (named a in Fig 7.12), linearly oriented, is visible from the depth of 0.50 m to the depth of 0.90 m. The second anomaly (called b, in Fig. 7.12), is characterized by a semi-circular shape and is placed at a greater depth (ranging between 1.2 m and 1.5 m). The excavation unit UE2 conducted by Bastante et al. (2021) confirmed the archaeological interest of the geophysical reflectors. The linear one is referable to accumulations of stones. The circular one is related to the accumulation of lithic elements referable to a rainwater evacuation zone (as found from the UE2) and modern intentional cutting in order to extract silty-sandy material for the preparation of mortar. Such features are better visible from the 3D representation of the higher amplitude reflections (Fig. 7.13).

At South of the investigated area another reflector is visible. The excavations put in evidence a wall of irregular masonry joined with mud mortar as a claw and attached to the foundation built to give greater stability to the north wall of the enclosure.

The presence of reflectors at a greater depth than that investigated by archaeologists and referable to probable wall structures, leaves open the hypothesis of a different spatial distribution of this enclosure.

According to the archaeological record this space, located at the convergence of two roads and close to the entry toward the top complex characterized by a waka (probably represents the Putukusi mountain), could have gathered a considerable

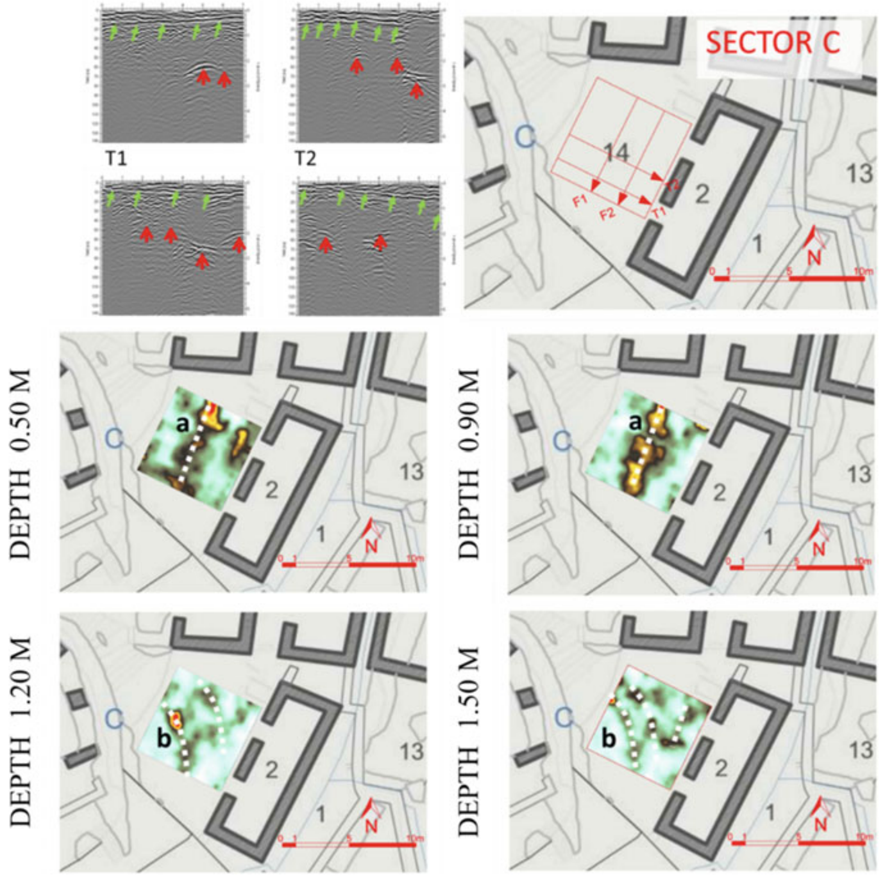

Fig. 7.12 Radargrams (at the top) and depth slices obtained in the Sector C (at the bottom) with indication of the most interesting anomalies

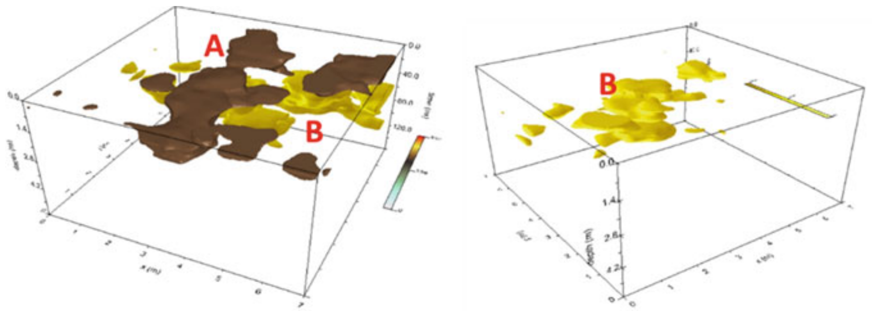

Fig. 7.13 Anomalous reflections placed at the two different depths (on the left) with the highlighting of the only deeper one (on the right)

number of participants in ceremonial events, that would not be allowed to enter the upper complex (Bastante et al. 2021).

7.4.2.4 Plaza Sagrado—Sector 1: Main Temple

The Plaza Sagrada (Sacred Square) is a group of buildings arranged around a square patio destined to different rituals. It includes the Temple of the Three Windows, whose walls of large polygonal blocks were assembled like a puzzle, and the Main Temple (Fig. 7.14), made of more regular blocks, which it is believed that it was the main ceremonial site of the *llaqta*. Attached to the latter is the so-called "house of the priest" or "chamber of ornaments". There are indications that the general complex was not completed.

As regards the Main Temple, one of the three walls (*wayranas*) is affected by a in-plane deformation phenomenon with sliding and rotation of the granite squared blocks.

Results of GPR prospection, shown in Fig. 7.15, allow to identify a number of local and continuous reflectors which open challenging questions on the cause of these reflectors. A strong reflection, located in the northeast corner of the three-sided room (labelled with A1 Fig. 7.15), seems to be connected to the simultaneous presence of rocky elements and ground fills (at a depth greater than 1 m) that appear to have been created to fill gaps near the deformed wall. Such inhomogeneity of the subsoil, nearby the deformed wall, could be related to the structural instability of the Main Temple.

Fig. 7.14 GPR investigation at the Main Temple of the Sacred Plaza

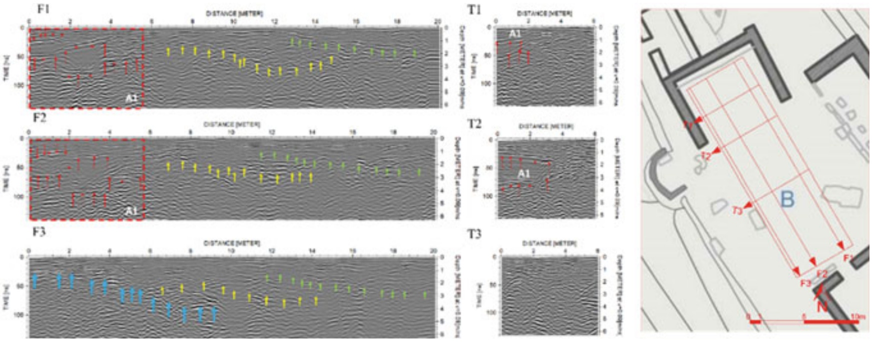

Fig. 7.15 Longitudinal and transverse radargrams acquired at the Main Temple with indication of the most interesting anomalies

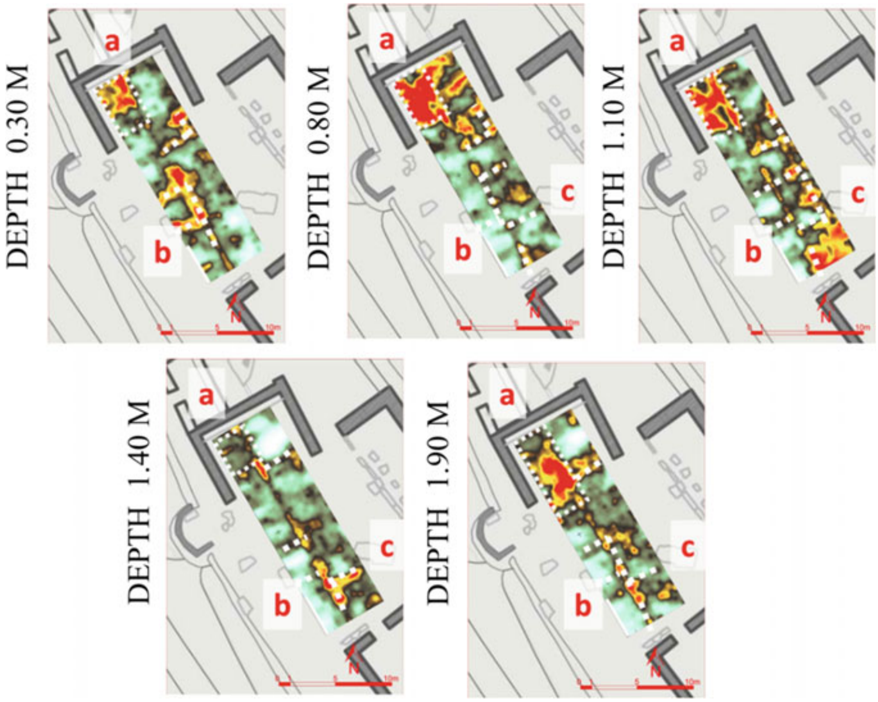

Fig. 7.16 Depth slices acquired in plaza Templo with indication of the three anomalies a, b, c supposedly due to the presence of ancient structures

Further, three sub-horizontal and parallel reflective layers (indicated in Fig. 7.15 with blue, yellow and green arrows) placed at different depths, are recognizable and could be due to the reshaping of the area that occurred in different historic phases.

The depth slices shown in Fig. 7.16 allow to identify the area affected by inhomogeneity near the northwest side, with dimensions equal to 2.5 × 4 m. Further, the time slices exhibit several linearly aligned features in the two directions of the Temple, NW–SE and NE-SW, respectively. They are visible from 30 cm to 1,90 m of depth and could be reasonably referable to buried structures and shallow drainage canals.

Figure 7.17 shows the 3D visualization which: (i) confirms the hypothesis of the electromagnetic behavior nearby the three walls, linked to the presence of voids and structures placed in the first 2–3 m of subsoil, and (ii) depicts the strongest linear reflectors referable to buried walls.

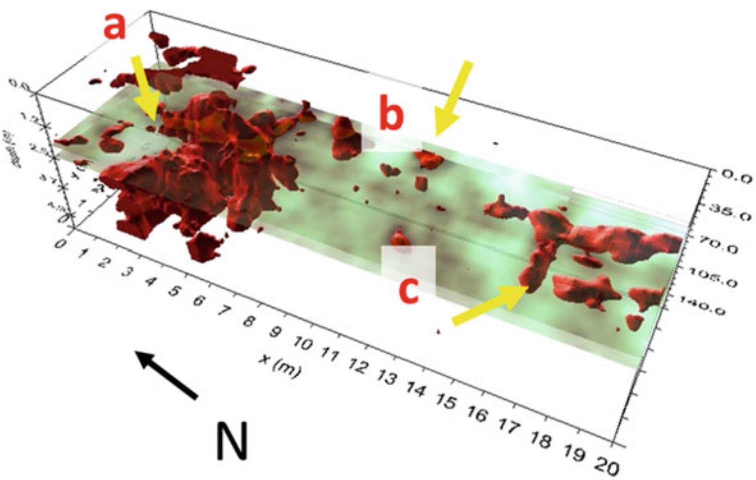

Fig. 7.17 3D reconstruction of the three anomalies characterizing Plaza Templo

7.4.2.5 Plaza Sagrado—Sector 2

GPR data are acquired every 0.5 m in two perpendicular directions in the ancient house placed at the south of the Main Temple. Data shown in Fig. 7.18 are characterized by the presence of a reflective layer placed in the first meter of depth (highlighted with yellow arrows) and some strong chaotic reflections (red arrows) characterizing the northwest corner of the investigated area. Results seem to indicate the presence of a subsoil poorly compacted or rocks hardly fractured.

Depth slices exhibit high amplitude reflections distributed, in particular, along to the west wall of the investigated house (Fig. 7.19). The reflections could be associated both to the foundation structures of the building and to the voids potentially present under the floor.

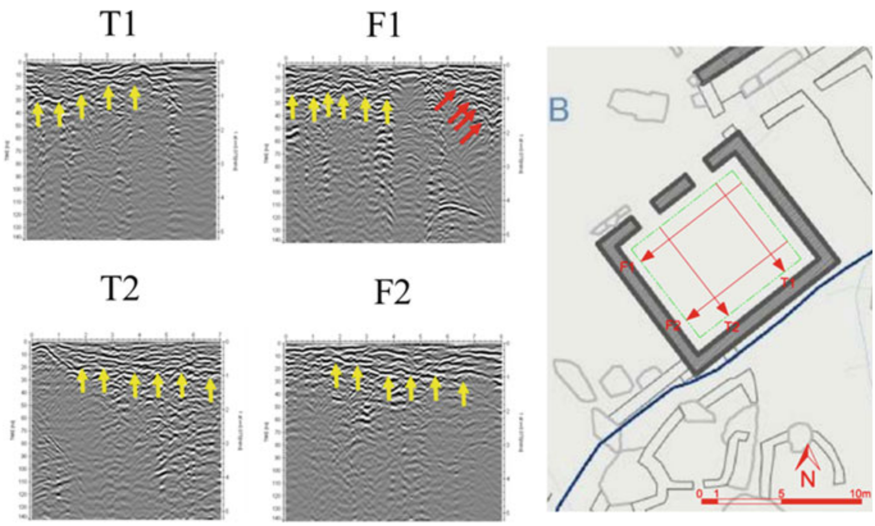

Fig. 7.18 Radargrams acquired near Plaza Templo with their interpretation

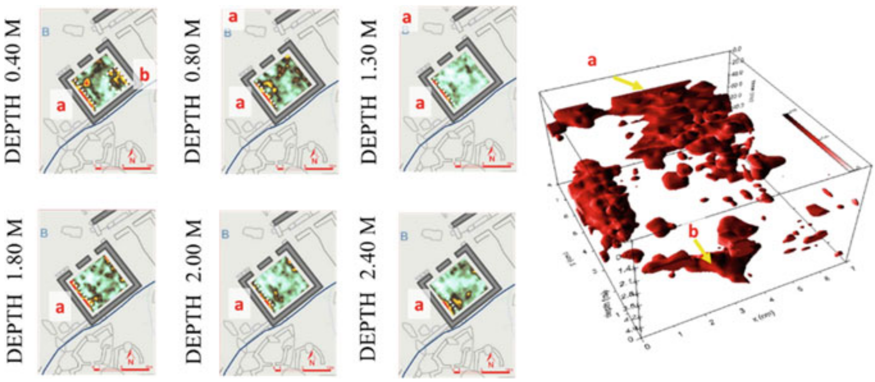

Fig. 7.19 Depth slices acquired in the southern house of Plaza Sagrada (on the left) and 3D reconstruction of the highest amplitude reflections (on the right)

7.4.2.6 Plaza D (Urban Area)

This area is placed at the foot of the main squares of the archaeological site and is characterized by the presence of a small fence at the southwest edge. The site is bordered by terraces and one of the main path that links the ceremonial areas (Fig. 7.20).

MAG results are presented in Fig. 7.21. As for all the magnetic surveys carried out near the equatorial latitude, the mean amplitude of the induced vertical magnetic anomalies retrieved in Plaza D is generally small. On the west side of the investigated

Fig. 7.20 Plaza D, the area is bordered by the typical terraces of the site

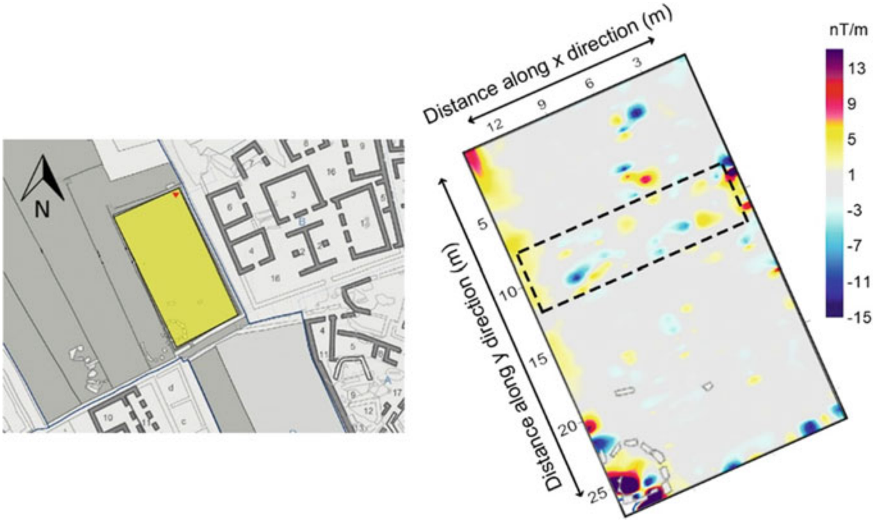

Fig. 7.21 MAG results obtained in the Plaza D. On the left, the yellow rectangle shows the location of the surveyed area. The red triangle in the upper right corner marks the position x = 0, y = 0 of the MAG map shown on the right side of the figure

area, the results are affected by the presence of a terrace wall (see right side of the area in Fig. 7.20) whose presence leads to an increase of the recorded magnetic field. Easily recognizable in the magnetic map is also the trace induced by the stone circle in the lower left corner of the area. Both the wall and stone circle effects on the MAG survey have to be considered as “noise” and hence not relevant from an archaeological point of view.

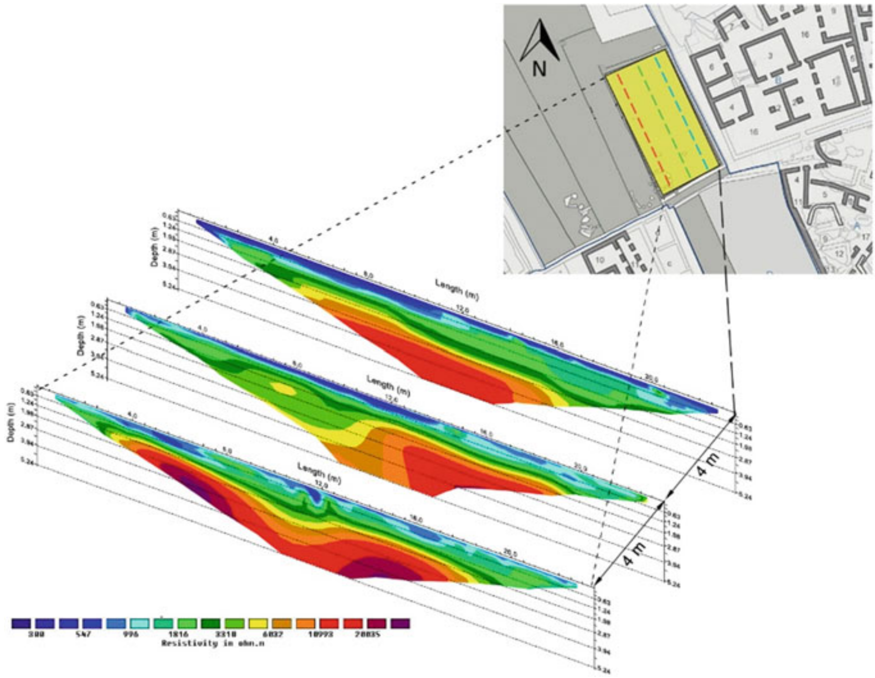

Fig. 7.22 ERT results obtained in the Plaza D. On the top, the yellow rectangle shows the location of the surveyed area and the three ERT profiles. The ERT results are shown in the lower part of the figure

Relevant features, on the other hand, can be considered the presence of several dipolar MAG anomalies most of which aligned parallel to the shorter side of the area and highlighted in Fig. 7.21 by the dashed rectangle.

ERT surveys in Plaza D were performed along three transect lines (see Fig. 7.22). The retrieved resistivity values show a quite relevant variability both in depth and along profiles of the electrical structure of the subsoil. The resistivity distributions and the geological knowledge of the area seems to suggest the presence of three main electrostrata:

- a shallow one, characterized by resistivity values up to ~1000 Ω·m; which can be associated to the soil cover;
- an intermediate one, characterized by resistivity values ranging from ~1000 Ω·m to 5000 Ω·m, associable to the granitic chaos, composed of soil and of what is called "granitic chaos", a mix of batholitic fragments of different size linked to the weathering of the batholitic rocks
- a deep one, characterized by resistivity values larger than 5000 ~ Ω·m, associable to the batholitic bedrock.

The westernmost ERT profile (red dashed line in Fig. 7.22) shows the bedrock presence at different depth along the profile. It seems to deepen toward the South with a pronounced depression in the middle of the profile. It has to be noted that the ERT survey does not have the resolution to show the exact shape of the bedrock profile.

The ERT profile in the middle of the Plaza (green dashed line in Fig. 7.22) shows a relevant layer, in terms of thickness, of granitic chaos in the northern part of the section. Starting from 12 m along profile, the in depth electrical distribution changes and a possible step in the batholitic bedrock seems to be present.

Finally, the easternmost ERT profile (cyan dashed line in Fig. 7.22) shows, again, the presence of batholitic bedrock generally deepening Southward with a stepdown at around 12 m along profile.

GPR data acquired for investigating the area have allowed to identify the interesting reflective areas mainly placed at the north side of the map. The radargrams acquired in this area (Fig. 7.23) have allowed to identify the possible presence of two highly reflective layers that could be associable to the presence of two ancient floors belonging to two distinct historic phases of the site as highlighted in Fig. 7.20. In particular, the first one is placed at the depths ranging between 0.50 and 1.50 m (blue arrows) while the second one is detected between the depths of 2 and 3 m (red arrows). The presence of a gap between the two phases is also detected in the radargram F1 (yellow arrow) that indicates supposedly a variation occurred in the past, when maybe for ceremonial needs the square, originally divided in two little rectangles, was expanded to the actual sizes.

The depth slices located in the first 2 m of the subsoil and shown in Fig. 7.24 highlight some reflections that seem to suggest the presence of structures irregular or collapsed which not necessarily are developed according to linear schemes (anomalies A, B and C). The 3D reconstruction, indeed, shows the not homogeneous behavior of the subsoil characterized by a lot of reflections due to the leveling works of the area and do not provide useful information for the identification of archaeological alignments.

7.4.2.7 Sector D

A single ERT survey was carried out in the area to investigate the subsoil stratigraphy that allows to detect the possible presence of resistivity anomalies due to caves linked to the complex of the Temple of the Condor. The ERT location and result are shown in Fig. 7.25. The color scale and the resistivity value—lithology association are the same adopted in presenting the ERT results in Plaza D. From the survey interpretation, it seems that the topsoil cover, extending up to a depth of ~1.5 in the Northern sector of the tomography, is thicker than in the Plaza D. From the sharp resistivity variation observed below the topsoil stratum, it seems that the extension of the granitic chaos is limited to few tens of centimeter. In the deeper part of the survey, the batholitic bedrock appears to be not fractured and generally competent.

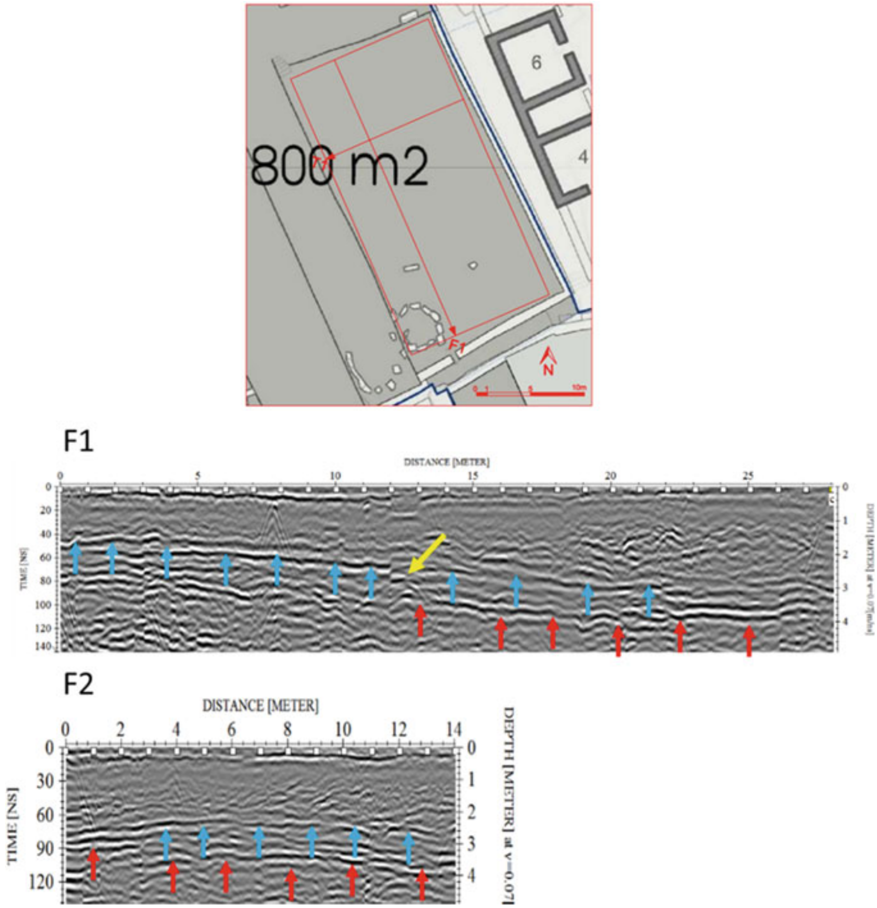

Fig. 7.23 Radargrams acquired in correspondence of Plaza D with indication of the most interesting reflections present in the first 4 m of subsoil

The presence of cavities can not be neither confirmed or excluded due to lower resolution of the ERT survey in its deeper part (where the cavity should be expected) and due to the low resistivity contrast between the very resistive batholitic bedrock and the equally resistive air-filled cavities.

7.4.2.8 Hanan Urban Zone: Sector at Southwest

The site investigated is surrounded by walls and placed at the top of a cavity not accessible (indicated in official maps as recinto 2, Conjunto 14, Sector I). It has

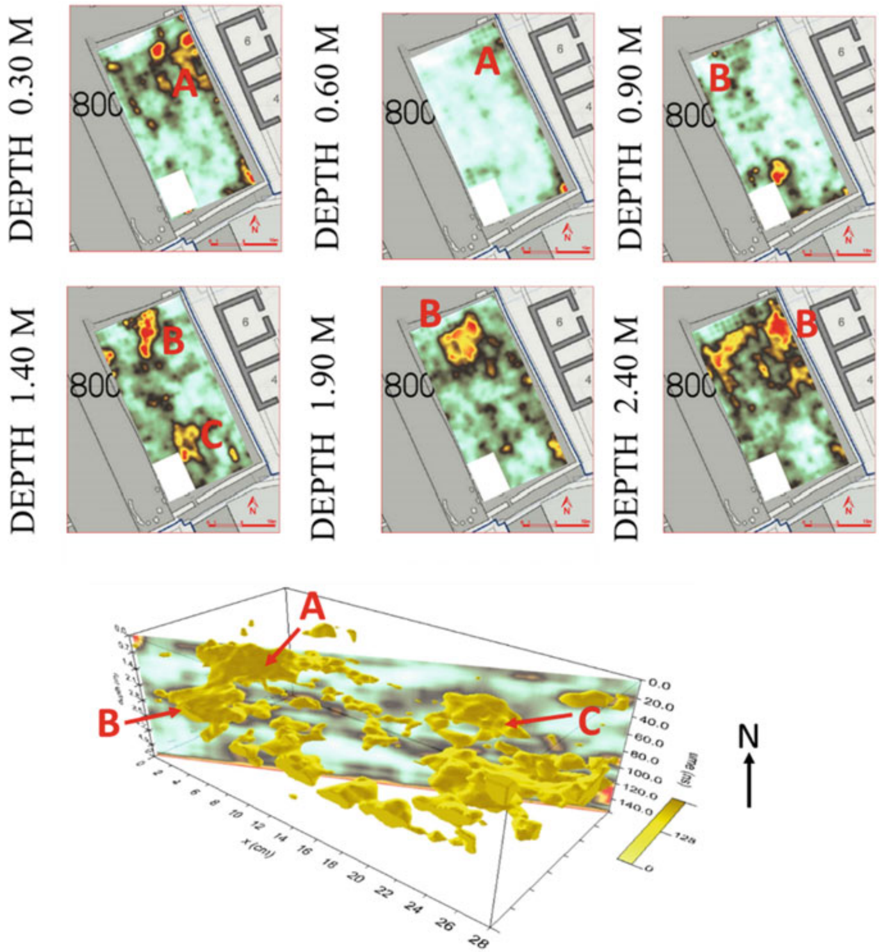

Fig. 7.24 Depth slices and 3D reconstruction of Plaza D with indication of the main anomalies

already been investigated by French researchers who, using electromagnetic equipments, announced that they had found a hidden chamber that could possibly house the tomb of Pachacuti Inca Yupanqui (!).

Therefore, it was decided to include this area as well to characterize the subsoil and identify any buried presence of archaeological interest.

Radargrams have been acquired every 0.5 m in only one direction and results, shown in Fig. 7.26, highlighting the presence of reflections distributed on two main parallel layers at increasing depth supposedly associable to two different phases of the construction. These sub-horizontal reflective layers are limited between 9 m e 11 m where no reflection is recorded (yellow rectangle); maybe this area is filled with homogenous material that has provided a good compaction of the subsoil.

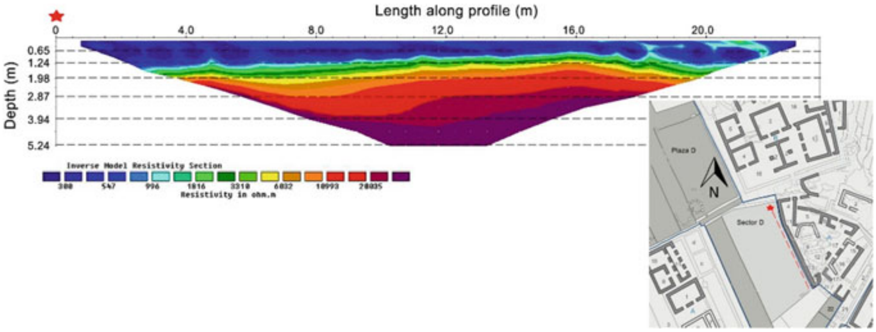

Fig. 7.25 ERT obtained in the Sector D. The red dashed line on the map shows the survey location. The red star indicates the location of the electrode 1 (beginning of the ERT)

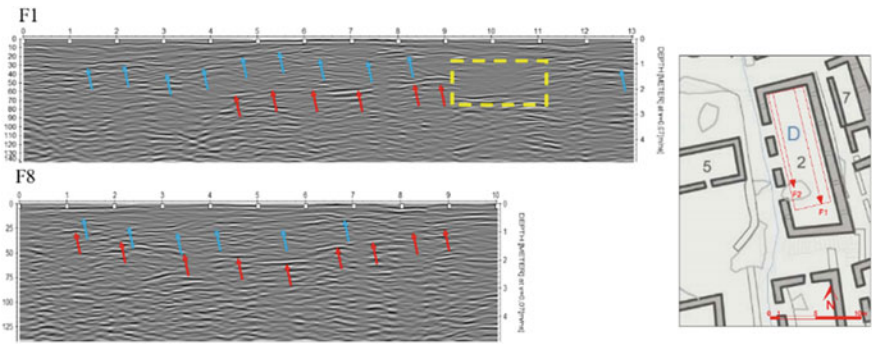

Fig. 7.26 Radargrams acquired in the investigated house with identification of the main anomalies

The reflective nuclei identified in Fig. 7.27 are potentially linked to the discontinuities present in the subsoil; this is also in agreement with the presence of a little cave characterizing the investigated area and observable at the bottom of the building (see Fig. 7.28).

7.4.2.9 Sector F

Sector F is located at the foot of the Sacred Rock and was investigated with GPR and MAG. GPR acquisitions have been carried out every meter in two perpendicular directions. Results showed a strongly reflective layer placed at a depth ranging between 1.5 m and 2.5 m that represents likely the bedrock or an anthropic layer well compacted and realized for leveling the areas (red arrows in radargrams plotted in Fig. 7.29). Inside the hypothesized bedrock, some punctual reflections have been detected (yellow arrows) corresponding to fractured rocks or altered areas where rocks are extracted for the quarrying activities. It is also identifiable the presence

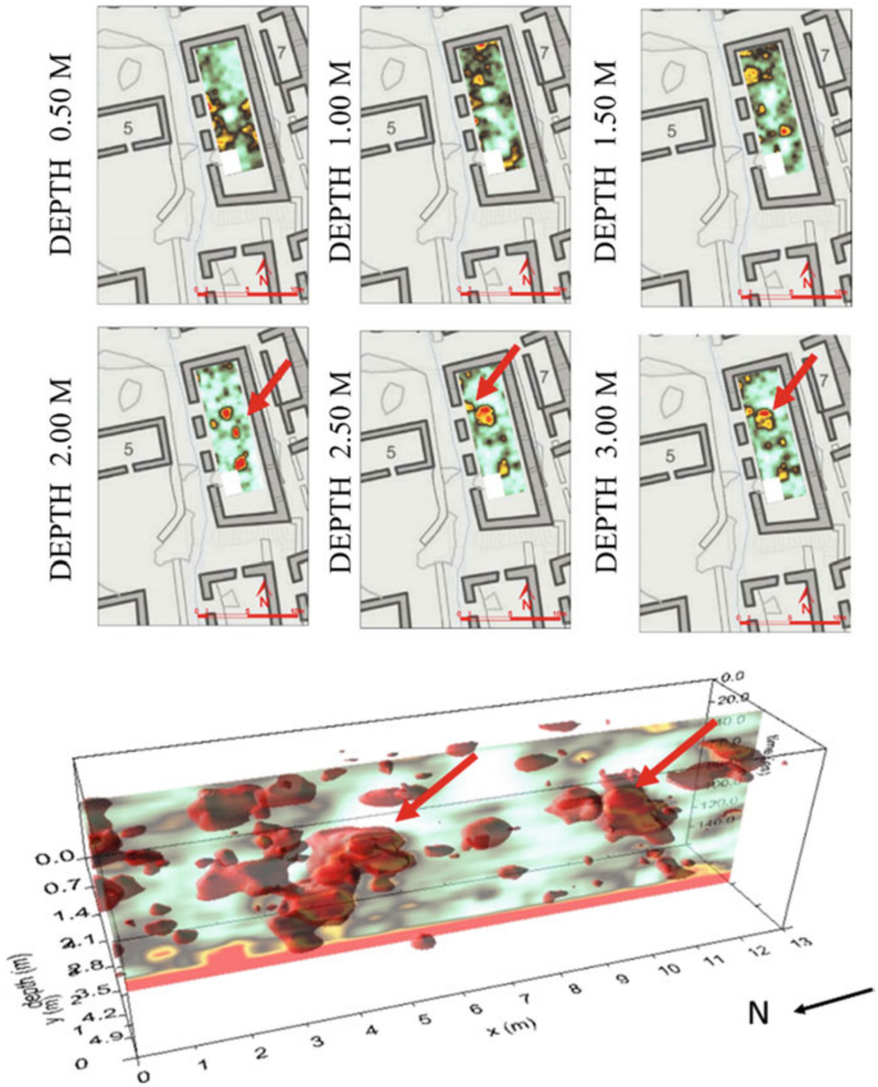

Fig. 7.27 Red arrows show reflections apparently associable to the fractured rocks and a not homogeneous subsoil also hosting a little cave

of a gentle slope in direction southwest able to convey the water outside the place supplying the drainage water necessities.

Figure 7.30 shows the presence of few anomalies in the first meters investigated and the only remarkable results obtained in this area are related to the identification of the reflective layer corresponding to the leveling works realized in the area after supposedly the quarrying activities as highlighted by the 3D representation.

Fig. 7.28 The closed "cave" under the building placed in Sector Urbano

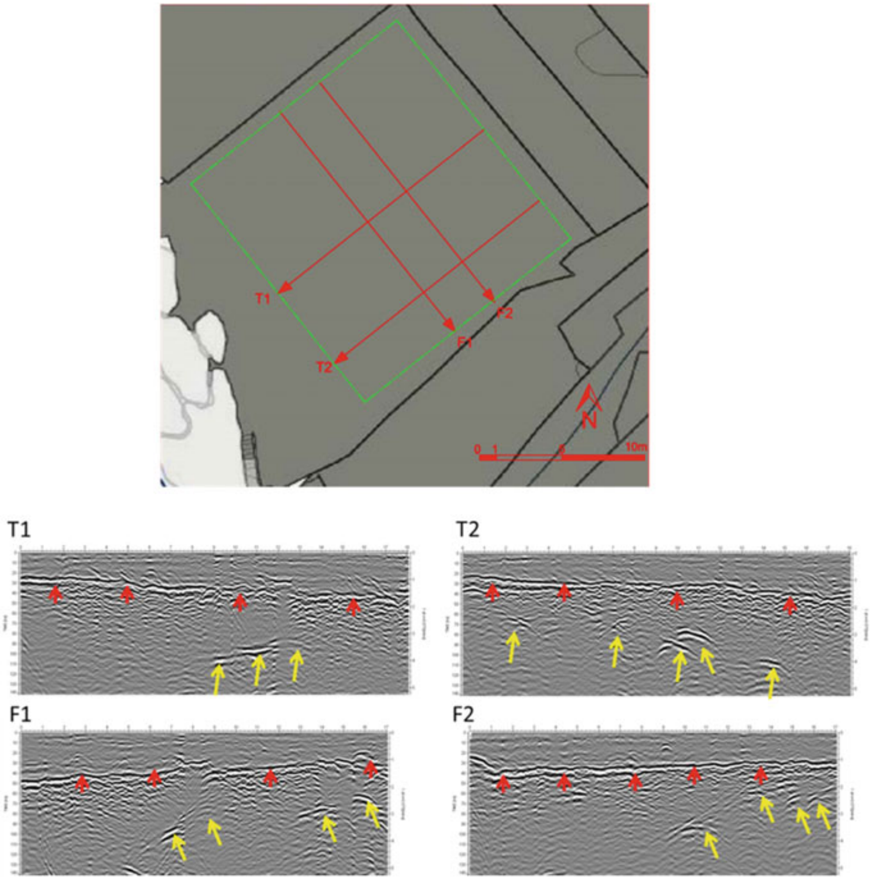

Fig. 7.29 Radargrams acquired in correspondence of the Plaza F with indication of the main anomalies

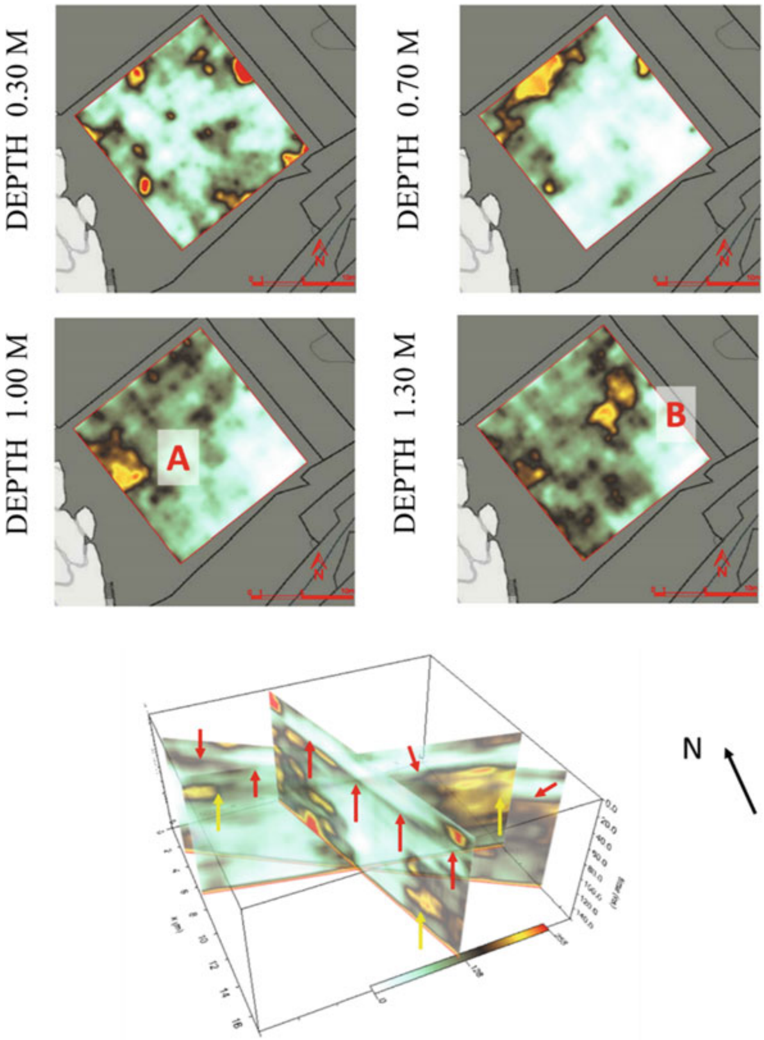

Fig. 7.30 Depth slices acquired in the Plaza F (on the left) and 3D representation of the main reflections (on the right)

MAG results are presented in Fig. 7.31. On the right side of the investigated area, the elongated positive magnetic anomalies can be associated, as in Plaza D, to the presence of a large batholitic block which is part of the perimeter walls. All the magnetic dipolar anomalies located on the edges of the map can be associated with fragments of batholitic rocks placed on the surface of the investigated area. No clear alignment can be observed supporting the GPR conclusion about the presence of buried structures.

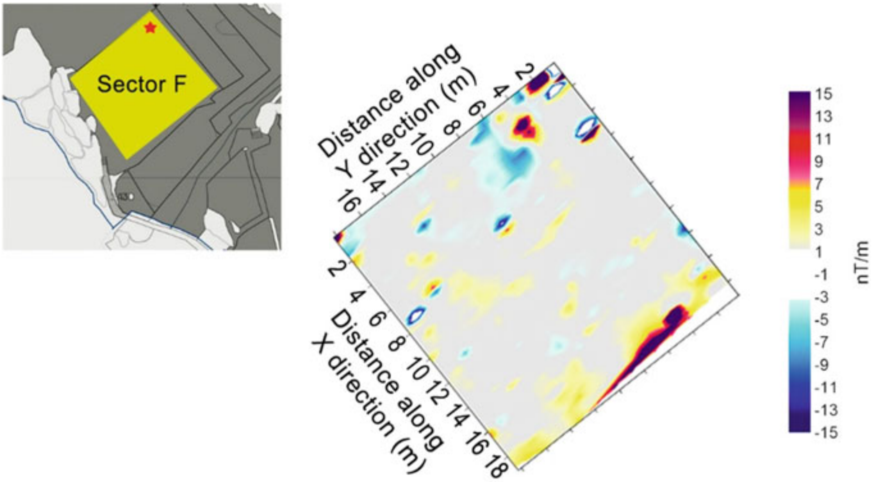

Fig. 7.31 MAG results obtained in the sector F

7.5 Conclusions

For the first time Machu Picchu subsoil has been investigated by geophysical methods in order to explore and characterize the anthropic layers and identify elements of possible archaeological interest.

The approach, based on the integration between GPR, MAG, and ERT methods, has proved highly effective in discriminating different phases of human frequentation. Despite the archaeological evidence is characterized by a homogeneous and coherent architectural facies and style, the anthropic features and layers highlighted by geophysics demonstrate a construction history that evolved in more building phases.

In particular, the results of geophysics highlight the presence of different phases of constructive, including rethinking linked to the change in functional needs and to problems related to erosive phenomena.

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References

Aitken MJ, Webster G, Rees A (1958) Magnetic prospecting. Antiquity 32:270–271
Bastante JM (2016/2017) Los trabajos de las Expediciones Peruanas de Yale en la Llaqta de Machupicchu. Estudios Latinoamericanos 36/37:27–67

Bastante JM, Astete F, Fernandez A, Usca AI (2020) Estado de la cuestión: historia y arqueología de la llaqta de Machupicchu. In: Astete F, Bastante J (eds) Machupicchu Investigaciones Interdisciplinarias. Ministerio de Cultura del Peru, GD Impactos, Miraflores—Lima, vol I, pp 141–236

Bastante JM, Fernandez A, Astete F (2021) Machu Picchu: interdisciplinary researches. In this Book

Bingham H (1913) In the Wonderland of Peru. Natl Geogr 24:387–573

Bingham H (1922) Inca Land: explorations in the highlands of Peru, 2nd edn. Houghton Mifflin, Boston

Bonomo N, Osella A, Ratto N (2010) Detecting and mapping buried buildings with Ground-Penetrating Radar at an ancient village in northwestern Argentina. J Archaeol Sci 37:3247–3255

Campana S, Piro S (2009) Seeing the unseen—geophysics and landscape archaeology. CRC Press, London, UK, p 376. ISBN 978-0-415-44721-8

Canuti P, Fanti R, Margottini C, Spizzichino D (2008) Effects of landslides on Machu Picchu Cultural Heritage—Proceedings of The First World Landslide Forum 18–21 November, Tokyo, Japan, pp 411–416

Canuti P, Margottini C, Casagli N, Delmonaco G, Falconi L, Ferretti A, Lollino G, Puglisi C, Spizzichino D, Tarchi D (2009) Monitoring, geomorphological evolution and slope stability of Inca citadel of Machu Picchu: results from Italian Interfrasi Project. In: Sassa K, Canuti P (eds) Landslide—disaster risk reduction. Springer Verlag Berlin Heidelberg, 249–257 pp (978-3-540-699668)

Capozzoli L, Caputi A, De Martino G, Giampaolo V, Luongo R, Perciante F, Rizzo E (2015) Electrical and electromagnetic techniques applied to an archaeological framework reconstructed in laboratory, Advanced Ground Penetrating Radar (IWAGPR), 2015 8th International Workshop on Advanced Ground Penetrating Radar, IEEE, 7–10 July, Firenze. https://doi.org/10.1109/IWAGPR.2015.7292655

Capozzoli L, De Martino G, Capozzoli V, Duplouy A, Henning A, Rizzo E (2020a) The pre-Roman hilltop settlement of Monte Torretta di Pietragalla: first results of the geophysical survey. Archaeol Prospect. https://doi.org/10.1002/arp.1793

Capozzoli L, Catapano I, De Martino G, Gennarelli G, Ludeno G, Rizzo E, Soldovieri F, Uliano Scelza F, Zuchtriegel G (2020b) The discovery of a buried temple in Paestum: the advantages of the geophysical multi-sensor application. Remote Sens 12:2711

Carlotto V, Cárdenas JLF (2009) La geología, evolución geomorfológica y geodinámica externa de la ciudad inca de Machupicchu, Cusco-Perú. Revista de la Asociación Geológica Argentina 65(4):725–747

Catapano I, Gennarelli G, Ludeno G, Soldovieri F, Persico R (2019) Ground penetrating radar: operation principle and data processing. In: Wiley Encyclopedia of Electrical and Electronics Engineering. Wiley, Hoboken, NJ, pp 1–23

Fedi M, Cella F, Florio G, La Manna M, Paoletti V (2017) Geomagnetometry for Archaeology in Sensing the Past, Masini N, Soldovieri F (eds). Springer, Berlin/Heidelberg, Germany, pp 203–230

Gasparini G, Margolies L (1980) Inca Architecture. Indiana University Press

Goodman D (2017) GPR-SLICE v7.0 Ground Penetrating Radar Imaging Software

Henderson KK (2004) Ground-Penetrating Radar at Tiwanaku, Bolivia. Unpublished Master's thesis. Department of Anthropology, University of Denver, Denver

Hyslop J (1990) Inka settlement planning. University of Texas Press, Austin, TX

Keay SJ, Parcak SH, Strutt KD (2014) High resolution space and ground-based remote sensing and implications for landscape archaeology: the case from Portus, Italy. J Archaeol Sci 52:277–292. https://doi.org/10.1016/j.jas.2014.08.010

Larson DO, Lipo CP, Ambos EL (2003) Application of advanced geophysical methods and engineering principles in an emerging scientific archaeology. First Break 21:51–62

Lasaponara R, Leucci G, Masini N, Persico R (2014) Investigating archaeological looting using satellite images and GEORADAR: the experience in Lambayeque in North Peru. J Archaeol Sci 42:216–230. https://doi.org/10.1016/j.jas.2013.10.032

Lasaponara R, Masini N, Pecci A, Perciante A, Pozzi Escot D, Rizzo E, Scavone M, Sileo M (2017) Qualitative evaluation of COSMO SkyMed in the detection of earthen archaeological remains: the case of Pachamacac (Peru). J Cult Herit. https://doi.org/10.1016/j.culher.2015.12.010

Lascano E, Osella A, de la Vega M, Buscaglia S, Senatore X, Lanata JL (2003) Geophysical prospection at Florida Blanca archaeological site, San Julián Bay, Argentina. Archaeol Prospect 10:175–192

Loke MH, Barker RD (1996) Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. Geophys Prospect 44:131–152

Loke M, Chambers J, Rucker D, Kuras O, Wilkinson P (2013) Recent developments in the direct-current geoelectrical imaging method. J Appl Geophys 95:135–156

Ludeno G, Capozzoli L, Rizzo E, Soldovieri F, Catapano I (2018) A microwave tomography strategy for underwater imaging via Ground Penetrating Radar. Remote Sens. https://doi.org/10.3390/rs10091410

Margottini C, Spizzichino D (2014) How Geology Shapes Human Settlements. In: Bandarin F, van Oers R (eds) Reconnecting the city. The historic urban landscape approach and the future of urban heritage. Wiley Blackwell, Chichester, vol 95, pp 135–156

Masini N, Capozzoli L, Chen P, Chen F, Romano G, Lu P, Tang P, Sileo M, Ge Q, Lasaponara R (2017) Towards an operational use of Remote Sensing in Archaeology in Henan (China): Archaeogeophysical investigations, approach and results in Kaifeng. Remote Sens 9:809. https://doi.org/10.3390/rs9080809

Masini N, Capozzoli L, Romano G, Sieczkowska D, Sileo M, Bastante J, Astete VF, Ziolkowski M, Lasaponara R (2018) Archaeogeophysical based approach for Inca archaeology: overview and one operational application. Surv Geophys. https://doi.org/10.1007/s10712-018-9502-2

Mazzoli S, Vitale S, Delmonaco G, Guerriero V, Margottini C, Spizzichino D (2009) Diffuse faulting in the Machu Picchu granitoid pluton, Eastern Cordillera, Perù. J Struct Geol 31:1395–1408. https://doi.org/10.1016/j.jsg.2009.08.010

Moseley ME (1992) The Incas and their ancestors: the archaeology of Peru. Thames and Hudson, New York

Piro S, Goodman D, Nishimura Y (2003) The study and characterization of Emperor Traiano's Villa (Altopiani di Arcinazzo, Roma) using high-resolution integrated geophysical surveys. Archaeol Prospect 10:1–25

Piro S, Sambuelli L, Godio A, Taormina R (2007) Beyond image analysis in processing archaeomagnetic geophysical data: case studies of chamber tombs with dromos. Near Surface Geophysics 5(6):405–414

Pozzi-Escot D, Oshiro MDJ, Romano G, Lasaponara R, Capozzoli L, Masini N (2018) Traces in the desert: use of new technologies for conservation and study of the Pachacamac sanctuary—Lima, Peru, Heritage Science, https://doi.org/10.1186/s40494-018-0230-1

Prümers H (2006) Improntas de esteras en ceramica prehispanica del sitio Bella Vista (Depto. Beni, Bolivia) Actas III Jornadas Internacionales sobre Textiles Precolombinos. In: Solanilla Demestre V (ed) Departament d'Art de la Universitat Autonoma de Barcelona—Institut Catala Iberoamericana, Barcelona, pp 207–212

Reinhard J (1991) Machu Piccu. El Centro Sagrado, Instituto Machu Picchu, Cimagraf, Lima

Revil A, Karaoulis M, Johnson T, Kemna A (2012) Review: Some low-frequency electrical methods for subsurface characterization and monitoring in hydrogeology. Hydrogeol J 20

Rizzo E, Capozzoli L (2019) Integrated Geophysical Techniques for Archaeological Remains: Real Cases and Full Scale Laboratory Example, Chapter 13 in El-Qady G, Metwaly M (eds) Archaeogeophysics. Springer International Publishing AG, part of Springer Nature. https://doi.org/10.1007/978-3-319-78861-6_13

Spizzichino D (2012) Landslide risk assessment and management in the archaeological site of Machu Picchu Inca citadel (Peru). PhD thesis in Earth System Sciences: Environment, Resources and Cultural Heritage at University of Modena and Reggio Emilia (XXIII Cycle)

Spizzichino D, Margottini C, Puzzilli L (2013) Landslide risk assessment and management in the archaeological site of Machu Picchu (Peru). In: (a cura di): Bilotta E, Flora A, Lirer S, Viggiani C, Geotechnical Engineering for the Preservation of Monuments and Historic Sites. Taylor & Francis Group, London, ISBN: 978-1-138-00055-1, Napoli, 30–31 May 2013

Telford W, Geldart L, Sheriff R (1990) Applied Geophysics (2nd ed.). Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781139167932

Wright KR, Kelly JM, Valencia Zegarra A (1997) Machu Picchu: ancient hydraulic engineering. J Hydr Engrg, ASCE 123(10):838

Ziółkowski M, Abuhadba JB, Hogg A, Sieczkowska D, Rakowski A, Pawlyta J, Manning SW (2020) When did the Incas build Machu Picchu and its satellite sites? New approaches based on radiocarbon dating. Radiocarbon 1–15. https://doi.org/10.1017/RDC.2020.79

Chapter 8
Possibilities of Using LiDAR Systems in Architectural and Archaeological Research in the National Archaeological Park of Machu Picchu

Jacek Kościuk and Bartłomiej Ćmielewski

Abstract Against the background of basic information on airborne laser scanning (ALS) use in the detection of architectural and archaeological relics hidden under the forest cover, two cases of using LiDAR in research conducted in the Archaeological Park of Machu Picchu are discussed. The obtained results are compared with selected examples of similar studies. Particular emphasis was placed on the potential scope of application and expected results of aeroplane-based LiDAR and UAV-based LiDAR. A potential strategy for further application of the ALS survey in the Machu Picchu Park research was also proposed.

Keywords Remote sensing · ALS · LiDAR · UAV · Machu Picchu · Inca architecture

8.1 Introduction

From at least the first decade of the twenty-first century, LiDAR (acronym form "light detection and ranging", or "laser imaging, detection, and ranging") has become one of the standard remote sensing techniques for collecting spatial data for archaeological purposes. It has several advantages over other technologies: the ability to cover a large area in a short time with an acceptable resolution, centimetre accuracy, and, first of all, the capacity to penetrate forested areas and record the topography of the bare ground. Therefore, LiDAR proved particularly successful in searching for archaeological and architectural remains hidden under dense vegetation. The use of LiDAR in archaeology earned extraordinary publicity due to spectacular discoveries in Central America—Caracol in Belize (Chase et al. 2010), legendary *La Ciudad*

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Blanca in the La Mosquitia region of Honduras jungle (Papas 2013), Izapa pre-Columbian kingdom in the Mexican state of Chiapas alongside the border with Guatemala (Rosenswig and López-Torrijos 2018), or over 60,000 Mayan sites in Guatemala (Horn III and Ford 2019; Thompson 2020). LiDAR survey also significantly changed our understanding of the Angkor site in north-western Cambodia (Evans et al. 2013, 2015). Recently, two papers were also published on the use of LiDAR in the Machu Picchu Archaeological Park (Fletcher et al. 2020; Ćmielewski et al. 2021). They will be analysed later in this chapter.

8.2 LiDAR Technology in Short

The effectiveness of LiDAR in detecting architectural and archaeological relics hidden under the canopy of trees is based on its ability to register successive reflections of the laser pulse from sequential obstacles (Fig. 8.1).

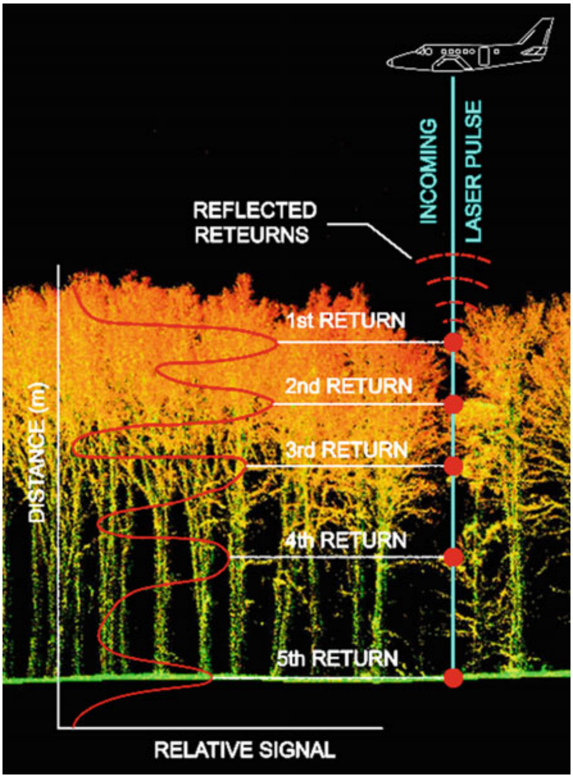

Fig. 8.1 The principle of multiple reflections registration by LiDAR. Drawing by J. Kościuk

Several advanced technological solutions are behind this feature. The first is, of course, the LiDAR sensor itself, whose technical specification (range, pulse rate, accuracy, horizontal and vertical field of view, beam footprint, number of reflections registered) has a significant impact on final results. However, unlike terrestrial laser scanning (TLS), the source of the laser impulses (and the receiver of returning signals) move all the time. Therefore it is crucial to know, with the highest possible accuracy, where the sensor, which is usually flown over 180 km/h (or around 30 km/h in case of UAV mounted LiDAR) sending laser pulses (at sampling rates usually higher than 150 kHz) and receiving reflected returns, is at the specific moment. Two solutions came together to solve this problem.

The first is the Global Navigation Satellite System (GNSS), the second is a set of high precision gyroscopes constituting the core of the Inertial Measuring Unit (IMU). GNSS receivers can record date and time, X, Y, Z position, course and speed, while IMU units will provide additional data about pitch, roll and yaw of the flying platform. These data combined with readings from the ground GNSS reference station will serve to estimate the flight trajectory. The accuracy of the flight trajectory estimation can be further improved by precise satellites positions data published by the International GNSS Service (Sośnica et al. 2020). After georeferencing the data captured by the LiDAR sensor into the flight trajectory, one finally gets the 3D point cloud data, which are the primary source for any further analysis (Fig. 8.2).

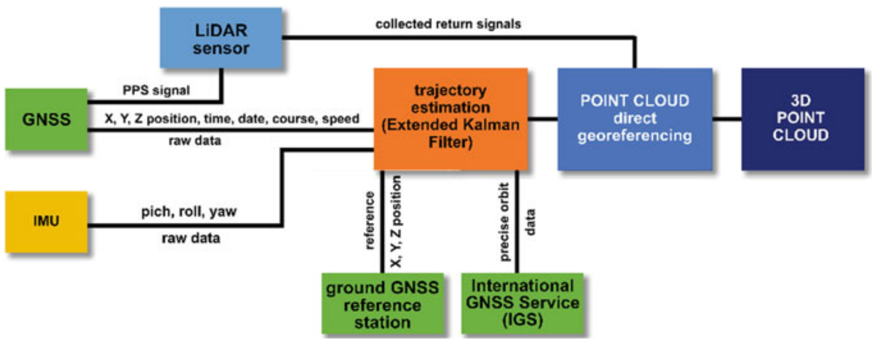

Fig. 8.2 Main steps of the LiDAR data acquisition and processing. Elaborated by J. Kościuk

8.3 LiDAR 3D Point Clouds Processing for Archaeological Purposes

However, before the 3D point cloud can be efficiently used, some preparatory steps are necessary. In most cases, the first would be cleaning the 3D cloud from unwanted points. They may include parts of the cloud outside of the interest scope or points representing the various forms of noise. The noise definition will depend on the specifics of the project and planned analyses. This can be, for example, 3D cloud points that are distant from their neighbours above (or below) a predetermined value, points with too low reflection intensity value, or vice versa; the so-called intensity oversaturated points.

Usually, the following step includes 3D point cloud classification. Depending on the type of LiDAR sensor used, or more precisely, from the number of subsequent reflections registered by the sensor, the classification process may include only differentiation between "ground points" and the rest (in the case when only two reflections were registered), or much more sophisticated distinctions, between "ground points", buildings, low, medium and high vegetation (when more returning reflections were registered).

In most cases, for the applications we are considering, i.e., using LiDAR data to detect archaeological or architectural relicts hidden under a tree canopy, it is enough to separate the part of the 3D point cloud representing reflections from the ground surface (Fig. 8.3a). The situation changes when, among the relics hidden

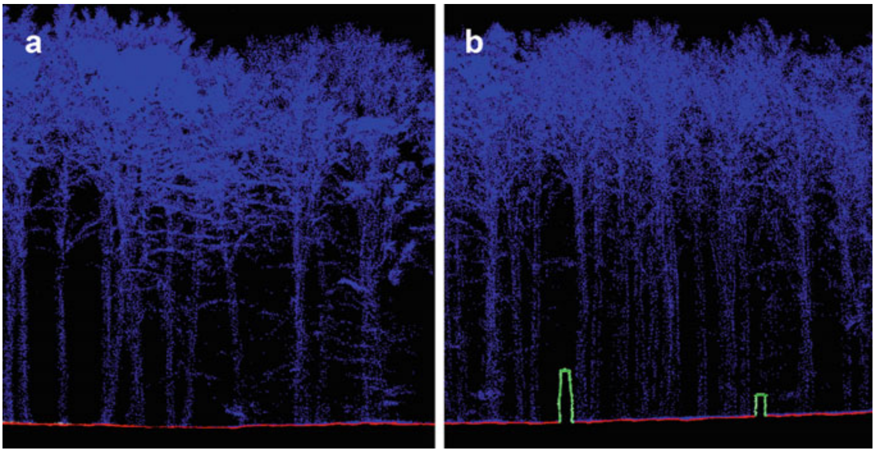

Fig. 8.3 Examples of 3D point cloud classification: (**a**) two classes only (in red—ground points class, in blue—all other points, (**b**) three classes (in green—building constructions). Elaborated by J. Kościuk

under the forest cover, there are clearly distinguishable (by strictly defined width, usually vertical faces and height in relation to the surrounding ground) fragments of walls, or even entire buildings. Then it is necessary to separate at least one more class—building constructions (Fig. 8.3b).

From this point on, there are two possible ways to further proceed with the 3D point cloud. The first involves transforming the 3D point cloud into a triangulated irregular network (TIN) and visualise the resulting 3D model in one of the programs (for example, Bentley MicroStation) that allow the so-called thematic re-symbolisation. This path, although relatively simple and not requiring specialised software, has

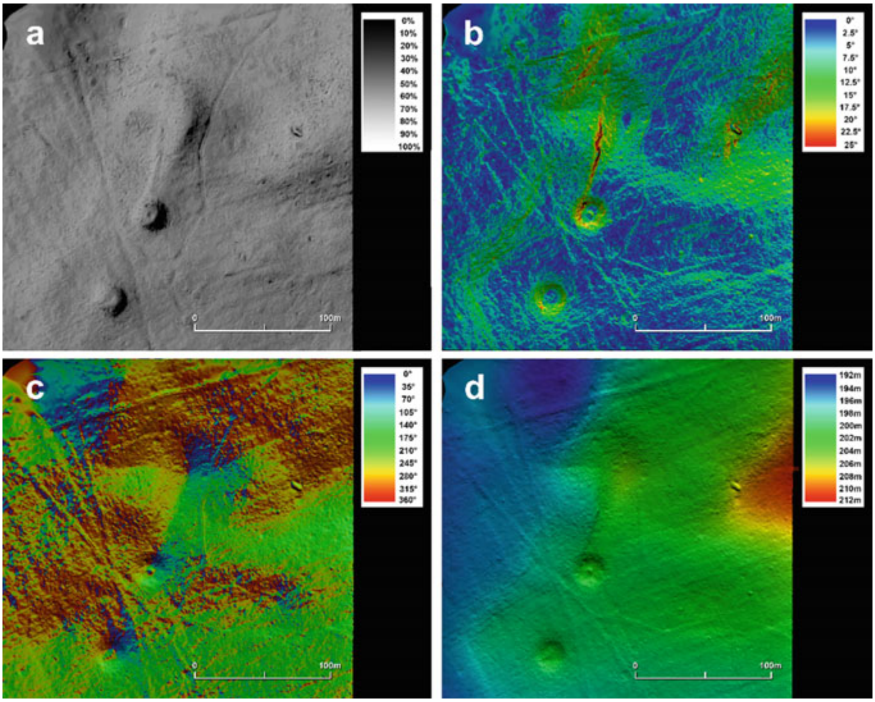

Fig. 8.4 Uniradze/Poland (burial mounds site). Examples of different TIN model visualisation modes (thematic re-symbolisation): (**a**) unidirectional hill-shading; (**b**) slope inclination; (**c**) sky visibility; (**d**) hypsometry. *Source* LabScan3D archives; elaborated by J. Kościuk

severe limitations—the number of possible 3D model visualisation modes is usually restricted to the most rudimentary ones:

– Unidirectional hill-shading, usually with a possibility to set up azimuth and height of the light source (Fig. 8.4a),
– Slope inclination (Fig. 8.4b),
– Sky visibility or openness (Fig. 8.4c),
– Insolation,
– Hypsometry (Fig. 8.4d).

Additionally, in a CAD 3D environment, usually, one can generate contour lines and break lines from TIN models. However, such a way does not allow for a comprehensive analysis of spatial data and most often permits the detection of only the most apparent anomalies related to the relics sought. A more advanced way is to work on Digital Elevation Models (DEM), or depending on the case, on Digital Surface Models (DSM). The first represents the bare-ground surface, while the second also includes objects like plants and buildings. Both DEM and DTM are usually generated in a GIS environment (for example, ArcGIS, QGIS, SagaGIS).

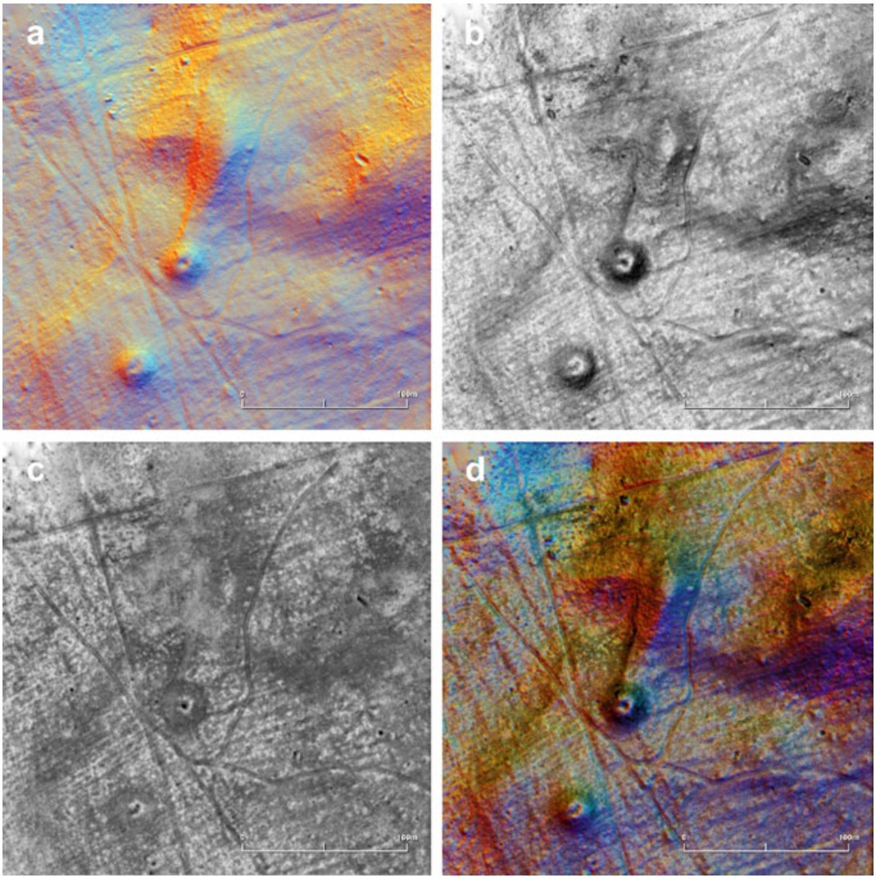

Fig. 8.5 Uniradze/Poland (burial mounds site). Examples of different DEM analytical modes in RVT software: (**a**) multidirectional hill-shading; (**b**) anisotropic Sky-View factor; (**c**) sky illumination; (**d**) multidirectional hill-shading and slope gradient (RVT Mixer). *Source* LabScan3D archives; elaborated by J. Kościuk

Preparing a DEM opens the way to a larger pool of analytical tools built into individual GIS packages and specialised tools that have found wider application in the detection of archaeological relics. One such tool is Relief Visualisation Toolbox v.2.0 (RVT), a standalone application that further processes the DTM files. Here, the choice of analytical tools is much wider and includes:

- Unidirectional hill-shading (Crutchley and Crow 2009, 41),
- Multidirectional hill-shading up to 64 azimuth directions (Fig. 8.5a),
- Principal Component Analysis (PCA) of hill-shading (Devereux et al. 2008, 472),
- Slope gradient (Bennett et al. 2012, 47; Challis et al. 2011, 285),
- Simple local relief model,

– Sky-View factor, and Anisotropic Sky-View factor (Zakšek et al. 2011, 402; Kokalj et al. 2011) (Fig. 8.5b),
– Openness (negative and positive),
– Sky illumination (Fig. 8.5c),
– Local dominance.

This wide availability of different visualisation modes improves the chance of searched archaeological remains detection (Challis et al. 2011, 288; Bennett et al. 2012, 47). However, due to the diverse nature of the features in the given study area, there is no rule of thumb indicating the best method. A certain help offers the Mixer built into the RVT, allowing for combination (with a certain degree of transparency) up to five different basic visualisation modes (Fig. 8.5d).

Such a wide range of analytical tools makes the use of LiDAR technology in archaeology, both on the aeroplane and drone platforms, more and more common. This is evidenced by the growing number of research, and consequently, publications on the use of LiDAR in prospecting heavily forested areas. Only recently, these issues have also become the subject of the Virtual Webinar held at Dumbarton Oaks from June 16 to July 28, 2021.[1]

8.4 LiDAR in the Machu Picchu Archaeological Park

As already mentioned, two papers have been recently published on the application of the LiDAR in the Machu Picchu Archaeological Park research (Fletcher et al. 2020; Ćmielewski et al. 2021). Although both articles cited here concern the use of LiDAR for researches in the Machu Picchu Park, they differ, among the others, in the main study aim, its extent, the sensors used, and the flying platform. These differences result in difficulties in direct comparison and assessment of the obtained outcomes, so a brief summary of both articles is essential at this point.

However, it should be stated that Machu Picchu is not the only place in Peru where LiDAR has been used to detect architectural and archaeological relics. In the case of large-scale surveys with aeroplanes, Adine Gavazzi (2014) work should be mentioned here. In turn, concerning the use of LiDAR on the drone platform, the recent publication on Kuelap in the Peruvian Chachapoya in the Amazonas department (VanValkenburgh et al. 2020) should be noticed (Fig. 8.6). However, in both cases, the topographic conditions are entirely different than in the Machu Picchu Archaeological Park. The forest cover occurs only sporadically, and the detected architectural relics are large-scale objects, as in the case of Lima, or walls at least one meter wide and several meters high, as in the case of Kuelap (Fig. 8.6). Therefore, both represent an entirely different remote sensing problem.

[1] https://www.doaks.org/research/pre-columbian/scholarly-activities/hidden-landscapes-of-the-past-uncovering-the-ancient-world-through-lidar.

Fig. 8.6 Ruins of Kuelap. (**a**) GoogleEarth image of the site as on 20.11.2014; (**b**) results of UAV-based LiDAR survey. *Source* VanValkenburgh et al. (2020, p. S82, Fig. 5, modified)

8.4.1 Helicopter-Based Machu Picchu LiDAR Survey

In 2016 the Machu Picchu Archaeological Park authorities commissioned LiDAR survey, which covered 50 square kilometres of the Park itself and the surrounding area alongside the Urubamba Valley. The survey has been conducted by a consortium called the Peru Lidar Project[2] and executed by the Horizons Peru, the Lima-based company. The Leica ALS 70 sensor was installed on a helicopter platform flown at an altitude of 2000 m magl. The LiDAR survey specification assumed a density of 25–30 points/sqm. The LASTools software (Hug et al. 2004) has been used for sorting and filtering, while further image processing and display were done with the ArcGIS tool.

In 2020, in the monography of the latest interdisciplinary researches on Machu Picchu (Astete and Bastante 2020), the first preliminary results of this survey were published (Fletcher et al. 2020). The study concentrates on the general topography of this highly rugged terrain (Fig. 8.7). Particular emphasis is placed on the identification of agricultural terraces and pre-conquest roads. This resulted in valuable data, although, as the authors themselves admit, due to the challenging topographic conditions for flight and very dense tropical forest cover, the resulting bare-ground cloud

[2] Cf. www.facebook.com/mplidar/.

density does not allow to distinguish the details of many structures—for example, of the so-called Mandor Wall (Fletcher et al. 2020, 384).

However, the obtained data turned out to be adequate for the detailed topographical analysis of the terrain (Figs. 8.7, 8.8). They included twenty groups of terraces systems distributed among eight sites within the surveyed area. They were that of Intipunku, Intipata (Fig. 8.9), Choqesuysuy, Chachabamba, Wiñay Wayna, Phuyupatamarka, Sayaqmarka, Runkurakay and the core site of the Llaqta de Machupicchu. The main research aim was to resolve the question of whether the different terracing systems show significant relationships with the terrain configuration and if there are any preferences (inclination, altitude and microclimate, sunlight, accessibility to routes, visibility, water supply) in choosing slopes for terracing (Fletcher et al. 2020, 387–391).

Fig. 8.7 3D topographic image of the coverage area of the LiDAR survey. *Source* Fletcher et al. (2020, p. 384, Fig. 1)

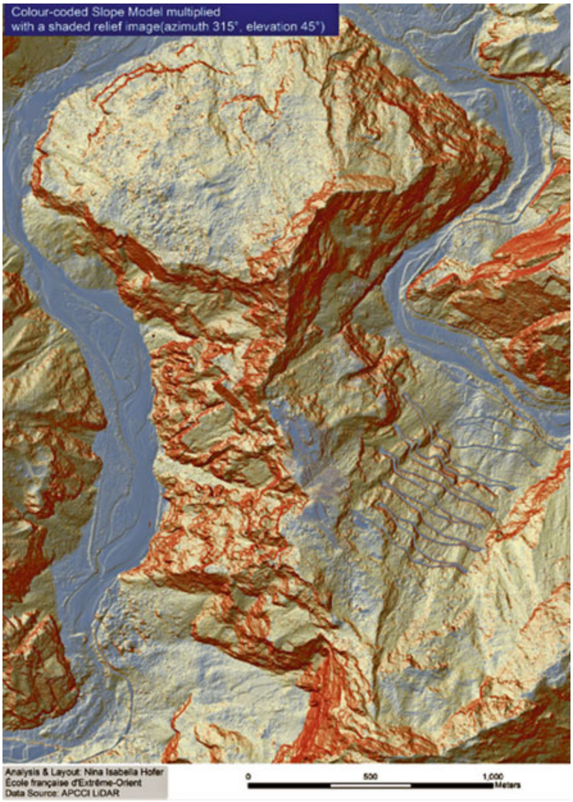

Fig. 8.8 Processed LiDAR data for the central part of the Park (Llaqta de Machupicchu) showing differences in the slope inclination: from flat (blue), through moderate (yellow), to the steepest slopes shown in red. *Source* Fletcher et al. (2020, p. 386, Fig. 6)

The Authors concluded that this LiDAR data are well suited as the starting point to solve these questions. As proof, they offer several detailed analyses of particular sites and the first general synthesis (Fletcher et al. 2020, 390, Fig. 12). Despite such interesting results, the entire project has become a source of sceptical opinions regarding the possibility of using LiDAR mounted on crewed aircraft in the conditions of the Machu Picchu Park (VanValkenburgh et al. 2020, S77). These unjustifiable opinions may result from overly aroused expectations as to the results of LiDAR prospecting under these conditions, which might be associated with a lack of understanding of all technical aspects of this technology and misinterpretation of the project's main aim. Assessment of LiDAR use for the Machu Picchu Archaeological Park survey will be discussed in more depth in the last part of this chapter. Before that, however, let us look at the results of two UAV-based LiDAR surveys regarding the same area.

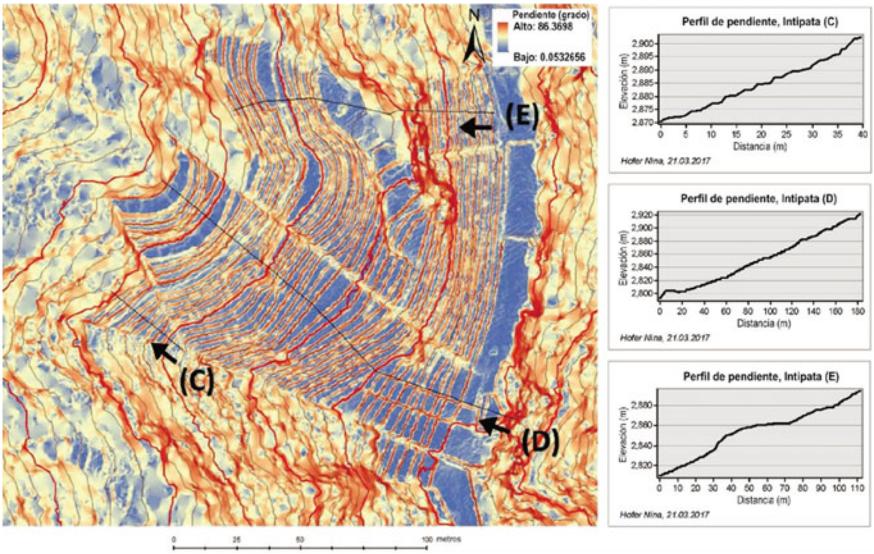

Fig. 8.9 Example of detailed topographical analysis of terracing system in Intipata showing differences in the slope inclination: from flat (blue), through moderate (yellow), to the steepest slopes shown in red. *Source* Fletcher et al. (2020, p. 388, Fig. 8, modified)

8.4.2 UAV-Based Machu Picchu LiDAR Survey

Already mentioned text of Ćmielewski et al. (2021) discusses potential contributions to mapping sites in the Machu Picchu Park by the LiDAR constructed at the 3D Scanning and Modeling Laboratory. This prototype system includes a Velodyne VLP-16 laser scanner combined with a dual-frequency NovAtel OEM615 GNSS receiver, a survey-grade antenna and an IMU STIM300 manufactured by Sensonor. The technical specifications are summarised in Table 8.1. All the sensors (Velodyne VLP-16, GNSS receiver and IMU), together with an AAEON microcomputer for collecting and storing the data, were assembled in an aluminium box fixed by quick-release mount to a professional heavy-duty camera coupling plate (Fig. 8.10).

The platform to fly the entire system was the octocopter assembled from commercially available parts (frame Tarot T960, motors type 5008, and propellers 1855 from Tarot). As an autopilot, Pixhawk 2.1 from Profi CNC was used. The six-cell Li-Ion batteries, of 12.5 Ah capacity each, as the power source (for both the LiDAR and the UAV), enabled a 9.6 kg lifting capacity system to fly at the altitude of ca. 2500 masl for around 17 min. In practice, it corresponds to covering with LiDAR data 200,000 to 250,000 sqm of the terrain. Since the system had only one survey-grade GNSS antenna, a kinematic alignment was used to guarantee the correct azimuth. Therefore, additional equipment included a ground station with a dual-frequency

NovAtel OEM615 GNSS receiver and a GNSS antenna for differential trajectory processing. The total cost of all components did not exceed 20,000 US$, which is less than a quarter of commercial off-the-shelf LiDAR-UAV systems of a corresponding technical specification.

Table 8.1 The technical specifications of the components

Laser sensor—Velodyne VLP-16	
Number of diodes	16
Horizontal field of view (as mounted on the drone)	30° (+15° to −15°)
Measurement range	up to 100 m
Measurement accuracy	±0.03 m
Number of returns	2
GNSS sensor Novatel OEM615	
Horizontal GNSS/IMU accuracy	0.010 m
Vertical GNSS/IMU accuracy	0.020 m
IMU sensor—Sensonor STIM300	
IMU attitude for roll and pitch	0.006°
IMU attitude for yaw	0.019°

Fig. 8.10 Example the LiDAR system assembled at LabScan3D and used in the study. Photo by J. Kościuk

This LiDAR-UAV system was used in the 2018 and 2019 research seasons for surveys at Inkaraqay and Chachabamba sites—both already covered by the helicopter-based LiDAR data. Four flights were executed for each of the two sites. In the case of Chachabamba surveyed in 2018, the data covered about 930 m long and 200–400 m wide terrain along the left bank of the Vilcanota (Fig. 8.11). The

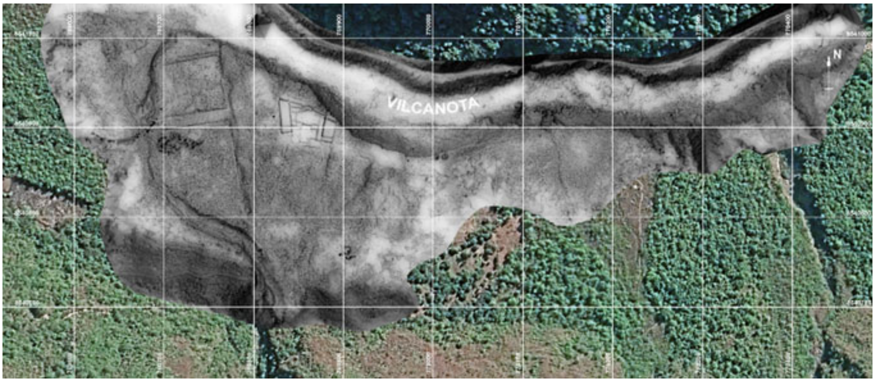

Fig. 8.11 LiDAR-UAV survey results (slope gradient) at the Chachabamba archaeological site with the Google Earth image used for the background. Elaborated by B. Ćmielewski

summarised flight time was between 1 to 1.5 h for each site, and the data were processed at the back office after the field season was completed

At Inkaraqay, where the data were collected in 2019, the 350 m wide surveyed strip runs for about 1350 m alongside the same bank of Vilcanota (Fig. 8.12).

In both cases, the main goal of the LiDAR survey on the drone platform was to accurately locate the already known relics of Inca architecture hidden in dense rainforests. However, from the results of last years field prospection, we know that there are still other pieces of Inca building activity evidence in these hard-to-reach areas. Unfortunately, besides such specular examples as the astronomical observatory of El Mirador de Inkaraqay (Astete et al. 2017), they often represent only fragments of separate walls, sometimes of inferior building quality, preserved in not more than two or three courses of stone blocks emerging from the ground.

These still not fully surveyed parts of the Park are essential to understand the function of its particular areas, but until now, they have drawn relatively little attention. The main reasons are technical and logistical problems of surveying very rugged, covered by rainforest areas, which are difficult to access using traditional terrestrial exploration techniques. Therefore, it was assumed that as a result of the LiDAR data analysis, it would be possible to identify and precisely locate new, previously unknown relics.

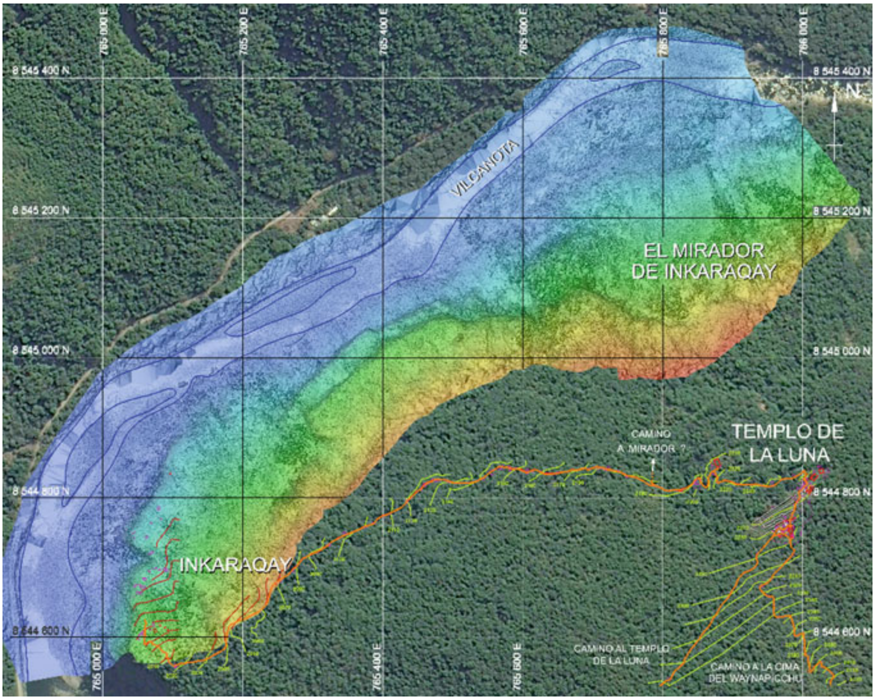

Fig. 8.12 LiDAR-UAV survey results (unidirectional hill-shading combined with hypsometry) on the Inkaraqay archaeological site with the Google Earth image used for the background (elaborated by B. Ćmielewski) and the plan of the Inca road between Huayna Picchu and Inkaraqay prepared by the Machu Picchu National Archaeological Park's surveyors (courtesy DDC-Cusco)

Indeed, in the case of Chachabamba, the analysis of these data allowed not only to verify the exact location of the already known relics (Fig. 8.13) but also to identify another, shedding new light on the functioning of this ceremonial complex (Fig. 8.14). Significant was the discovery of the exact course of the channels supplying water to ritual baths. During the following field-work season in summer 2019, all these results were verified on-site using the Locus Map Pro application running on a smartphone equipped with a built-in GPS sensor.

Since the UAV-LiDAR survey at the Inkaraqay archaeological site took place during the summer 2019 field-work season, the data has been compiled and analysed in the back office during winter 2019/20. In the next step, the preliminary interpretations derived from the LiDAR survey should be loaded into a portable GIS system to be validated on the field. Unfortunately, the world pandemic situation deprived the authors of verifying the obtained results in the field. Therefore, the anomalies detected between the proper Inkaraqay archaeological site and the El Mirador de Inkaraqay should be treated cautiously. Nevertheless, they shed new light on the location of El Mirador.

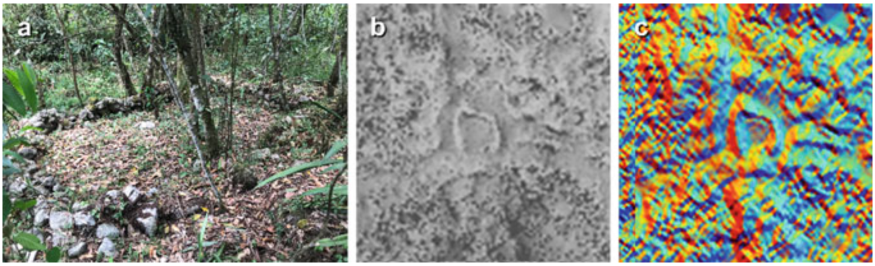

Fig. 8.13 An example of the relics of Inca building (ca. 6.5 m in diameter; walls ca. 0.8 m wide, and less than. 0.4 m high) detected in Chachabamba; (**a**) the current state of preservation (Photo by D. Sieczkowska); (**b**) visualisations of LiDAR data using the positive openness algorithm (Elaborated by B. Ćmielewski); (**c**) visualisations of LiDAR data using the multidirectional hill-shading algorithm (Elaborated by B. Ćmielewski)

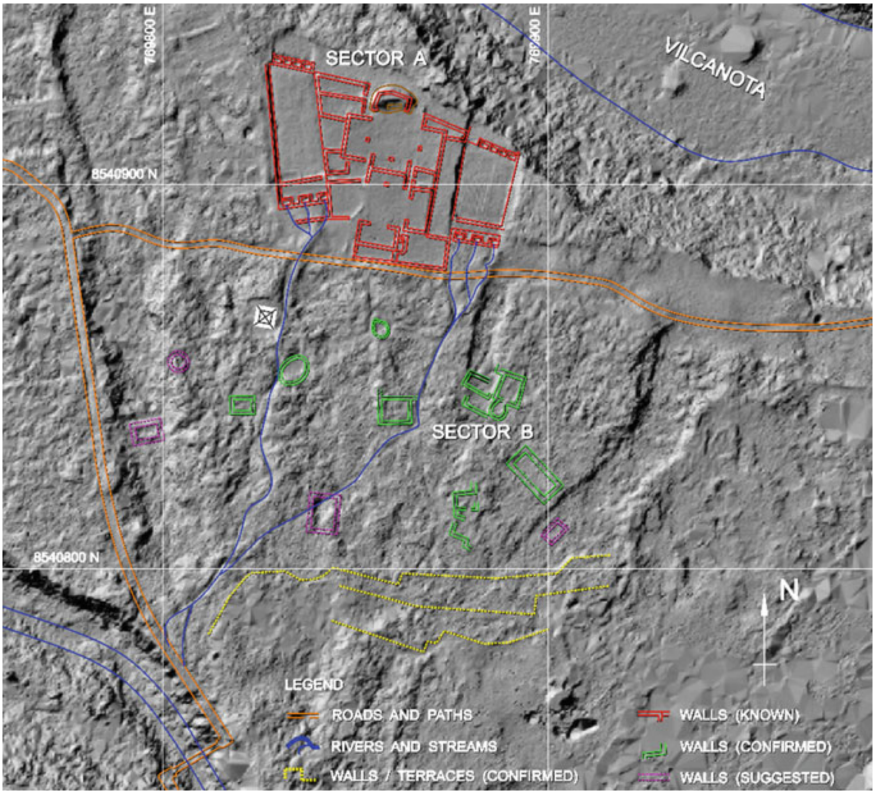

Fig. 8.14 Visualisation and interpretation of LiDAR survey from Sectors A and B of the Chachabamba archaeological site. *Source* LiDAR data processing by B. Ćmielewski; edited and drawn by J. Kościuk

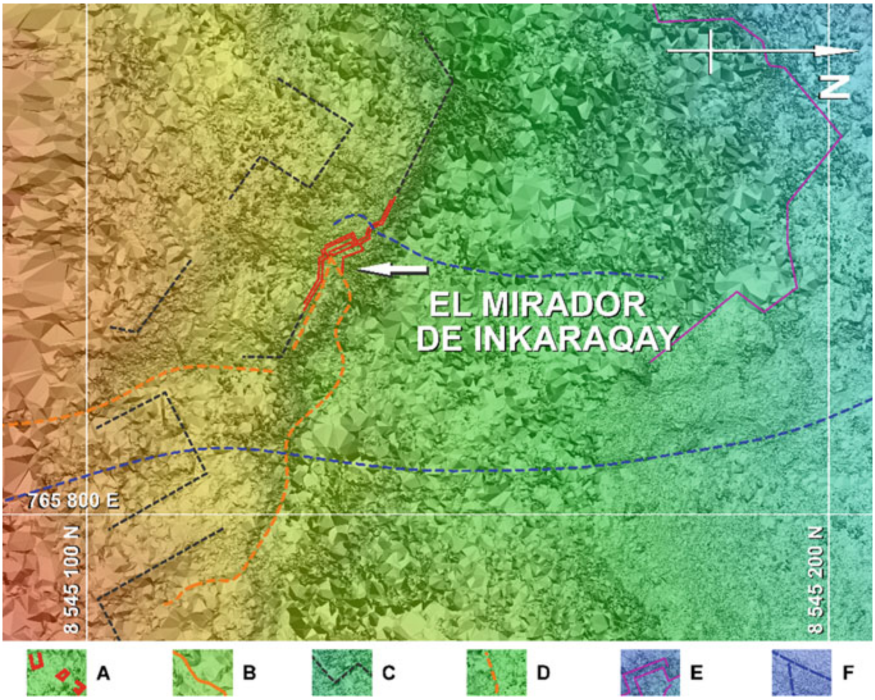

Fig. 8.15 Results of the LiDAR survey over the El Mirador de Inkaraqay archaeological site: (**a**) Inca walls and buildings already mapped by the terrestrial survey; (**b**) Inca paths known from the terrestrial survey; (**c**) features of unrecognised character (terraces or sharp terrain faults); (**d**) suggested Inca paths; (**e**) rock cliffs' sharp edges; (**f**) rivers and periodic streams. *Source* LiDAR data elaboration by B. Ćmielewski; edited and drawn by J. Kościuk

The first observation is that the slopes exposure changes there for almost 90° compared to the more westerly located area (Fig. 8.15). Therefore, it must have been the decisive factor in choosing this very place for the astronomical observatory of El Mirador de Inkaraqay meant to perceive the June solstice at an azimuth of approximately 58°.

An analysis of the terrain relief exposed after filtering the tree canopy revealed numerous terrain faults with an orthogonal orientation. At the edge of one of these natural rock faults, the El Mirador de Inkaraqay observatory was built. Until now, during on-site studies, it has been possible to trace in the jungle about 40 running meters of the entire complex's front wall, 10 m of which belong to the observatory proper. The LiDAR data analysis shows that the lateral walls may extend further for about 30 m to the northwest and another 12 m to the southeast. Reaching these points, the natural rock fault turns inwards and runs for another 15 or 20 m. The front part, culminating in the centrally located observatory, would then be about 80 m long. The entire arrangement seems to emphasise the natural rock fault to give a more monumental character.

An entirely new image of the site emerges from LiDAR data. The whole El Mirador de Inkaraqay complex must have been much more monumental than one would have previously assumed, especially if we assume that the slope on which the observatory is located was not covered with forest in Inca times. Then, the entire site, as seen from the river valley, appeared as a manifestation of imperial power and might expressed through monumental forms of architecture and the natural landscape.

8.5 Assessment of LiDAR Use for the Machu Picchu Archaeological Park Survey

8.5.1 Helicopter-Based LiDAR Survey

Let us start this assessment by comparing obtained results with other projects carried out in similar (to a certain extent) conditions. This analysis will start from projects where LiDAR has been mounted on crewed aircraft and then move to UAV-based LiDAR projects.

The density data obtained by the helicopter LiDAR survey of Machu Picchu Archaeological Park does not differ considerably from that of already mentioned sites in Belize (Prufer et al. 2015; Thompson 2020) and Izapa archaeological site (Rosenswig and López-Torrijos 2018). They are summarised in Table 8.2.

For Belize, the smallest anomalies detected (Classic Maya house mounds) varied from 20 to 275 m^2 or between 20 and 40 m in diameter, as in the case of the household plazuelas. All were elevated for not less than 1.2 m above the surrounding terrain. Even with such a low resolution as 1.1 ground points/m^2 (Table 8.2), it still gives from several dozen to several thousand points for the anomaly sought.

Table 8.2 Comparison of return signals for aeroplane-based LiDAR data

Site	Average 3D point cloud density	
	All returns [pts/m^2]	Ground class only [pts/m^2]
Machu Picchu National Archaeological Park (data courtesy to the Park authorities)	4.75[a]	1.3 ÷ 1.4
Uxbenká /Belize (Prufer et al. 2015)	20.1	2.7
Maya regions of Belize (Thompson 2020)	–	1.1 ÷ 5.3[b]
Izapa archaeological site (Rosenswig and López-Torrijos 2018)		1.4 ÷ 4.3[b]

[a]calculated for a sample from the football field located in the centre of Machu Picchu Pueblo, so, an area not covered with vegetation, with a flat surface well reflecting the laser pulses
[b]Higher values are for areas with no or less vegetation

Although the terraces located on the Machu Picchu Archaeological Park slopes vary in size, they are usually much bigger than 3.5 m by 15 m, and vertical spacing between subsequent terraces is rarely less than 1 m. Assuming 3D point density on the ground only as 1.3 pts/m^2 (Table 8.2), it gives a minimum of about 70 well-spaced vertically points in the 3D cloud in the worst case for the smallest terraces. This density turned out to be sufficient for the comprehensive analysis of terrace systems (Fletcher et al. 2020, 387–391).

To summarise, we can state that in the Machu Picchu Park case, results of using LiDAR mounted on helicopter do not differ drastically from other projects in areas covered with dense tropical jungle. Especially, when considering the specific terrain with its narrow valleys and local differences in relative heights of more than 1000 m. Therefore, for flight safety, the helicopter often flew at the limits of the Leicsa ALS 70 LiDAR's range, which for HP model varies between 2500 and 3500 m AGL depending on the configuration. The expectations that under these conditions, obtained results will allow for the identification of single walls hidden in the jungle were a little exaggerated.

8.5.2 UAV-Based LiDAR Survey

The already mentioned LiDAR-project in Kuelap (VanValkenburgh et al. 2020) will serve as a reference point for evaluating the results obtained in Chachabamba and Inkaraqay sites. Table 8.3 shows the resulting density of returns signals for these three projects.

Table 8.3 Comparison of return signals for UAV-based LiDAR data

Site	Average 3D point cloud density		
	All returns [pts/m^2]	Ground class only [pts/m^2]	Ground class + 0.5 m [pts/m2]
Inkaraqay (Ćmielewski et al. 2021)	ca. 513	10.6	25.3
Chachabamba (Ćmielewski et al. 2021)	ca. 219	13.2	72.2
Kuelap (VanValkenburgh et al. 2020)	ca. 2000	Not stated	–

In the Kuelap project, our attention attracts an awe-inspiring 2000 pts/m^2 density of return signals. Despite this, the Authors seems to be disappointed that this data density "…does not appear to be high enough to resolve fine differences in masonry and individual building blocks on either the site's monumental walls or the walls of smaller domestic structures" (VanValkenburgh et al. 2020, S82). As in the case of helicopter-based LiDAR performance evaluation, such expectations are too high. At a density in a range of 2000 pts/m^2, the average 3D point spacing is around 2.2 cm—far not enough to record clearly joints between particular blocks in the walls. This would require the TLS method instead, as the Authors rightly point it in the following lines.

One should also consider the technical limitations of Velodyne VLP-16 (Table 8.1) and unavoidable errors in determining the precise trajectory of the moving sensor. Our experience shows that even in the optimal conditions when driving car-mounted Velodyne VLP-16 at a distance of ca. 10 m from the building's façade, it is difficult to obtain a clear picture of each stone block (Fig. 8.16).

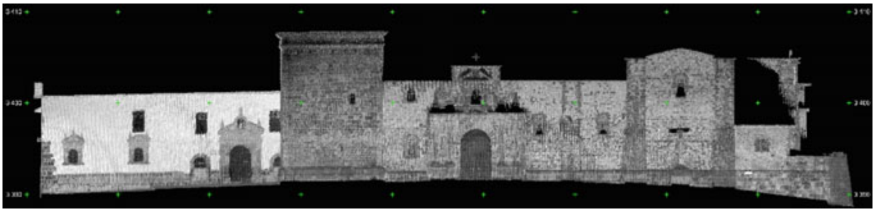

Fig. 8.16 The lower part of the façade of the Corikancha temple in Cusco recorded with a Velodyne VLP-16 sensor mounted on a car during two passes at 30 km/h speed at the distance of ca. 10 m from the façade. *Source* Archives of LabScan3D

The relics of Inca walls preserved in Chachabamba represent mostly scattered fragments of walls hardly exceeding 5 m in length, preserved at the height of 1–2 layers of stones (0.5 m on average). With a wall thickness of less than one meter, such relics give much fewer return signals compared to the situation in Kuelap. The size and scattered character of Chachabamba relicts are also much more difficult to isolate from the background signals. In Chachabamba and Inkaraqay conditions, most wall relics are covered with a dense layer of lianas and lichens. For this reason, an additional class to the filtration process has been introduced—"the ground class + 0.5 m" (Table 8.3). This raised the resulting 3D points density to 25 $\div$ 75 pts/m^2—enough to detect such difficult to capture anomalies (Fig. 8.13).

On this basis, one can assume that the density in the range of 75 $\div$ 100 ground-pts/m^2 might be sufficient to detect most of the sought relics in this area. It is further confirmed by the fact that in the case of the Inkaraqay project, the density in a range of 25 ground-pts/m^2 permitted only for recognition of detailed terrain topography (including details of agricultural terraces) and identification of places where anomalies possibly associated with archaeological relicts might be located.

Last but not least remains the question of the quality and reliability of the obtained data. At this stage of the research, and after only two attempts at applying the UAV-LiDAR survey in Machu Picchu Park, it is too early to formulate general conclusions. Further on-site verification of data is still necessary, but this part of the research has not yet been completed due to the outbreak of the pandemic.

8.5.3 Helicopter-Based Versus UAV-Based LiDAR Survey in the Conditions of Machu Picchu Park

Before we start to compare the results of the helicopter-based and UAV-based LiDAR surveys, it is important to point into important differences between both technologies. A good part of them lies in the technical specification of equipment (sensors) used and the setting of scanning parameters. However, in the conditions of the Machu Picchu Park, an equally important factor are differences in sensors trajectory. All these aspects will influence the resulting density of ground points. The last statement is generally valid for all ALS surveys over forested areas, even on flatlands. Tests of the constructed by us AUV-LiDAR systems carried out on Uniradze burial-mounds site in northern Poland proved that low budget, drone-based LiDAR systems could deliver much better results in searching for small relicts than high-altitude LiDAR surveys with the most advanced ALS systems (Fig. 8.17).

The experience to date shows that, for LiDAR mounted on an aircraft platform, one should expect certain mean ground point density limits below tree cover. In the case of UAV-LiDAR surveys, the density can easily be increased by using repetitive cross survey flights. Once the UAV operator team is in the field, repeating the flight is only a matter of additional time and available batteries to power the drone and LiDAR.

In the case of Machu Picchu Park, aeroplanes or helicopters must fly at an altitude high enough to avoid the danger of neighbouring mountains peaks—in the example discussed there, the flight altitude was 2000 m AGL. This guaranteed better than in the case of drones visibility of GNSS satellites resulting in more precise data for the sensor trajectory, but at the same time, greater distance from the ground surface results in a more significant error in determining the X, Y, Z position of the point from which the laser pulse was reflected (Kellner et al. 2019). The size of the laser beam footprint, usually bigger in the case of aircraft-mounted LiDARs, is also essential.

In the case of UAV-based LiDAR flying usually $50 \div 80$ m AGL, the impact of errors in trajectory positioning is smaller, the footprint is also smaller, but the visibility of the satellites becomes important. At a low flight altitude, the surrounding hills will limit the number of visible satellites, and even those visible will not always be in positions that guarantee precise trajectory coordinates—the effect referred to as the dilution of precision. The following real case example of drone flight planning will be a good illustration there (Figs. 8.18 and 8.19).

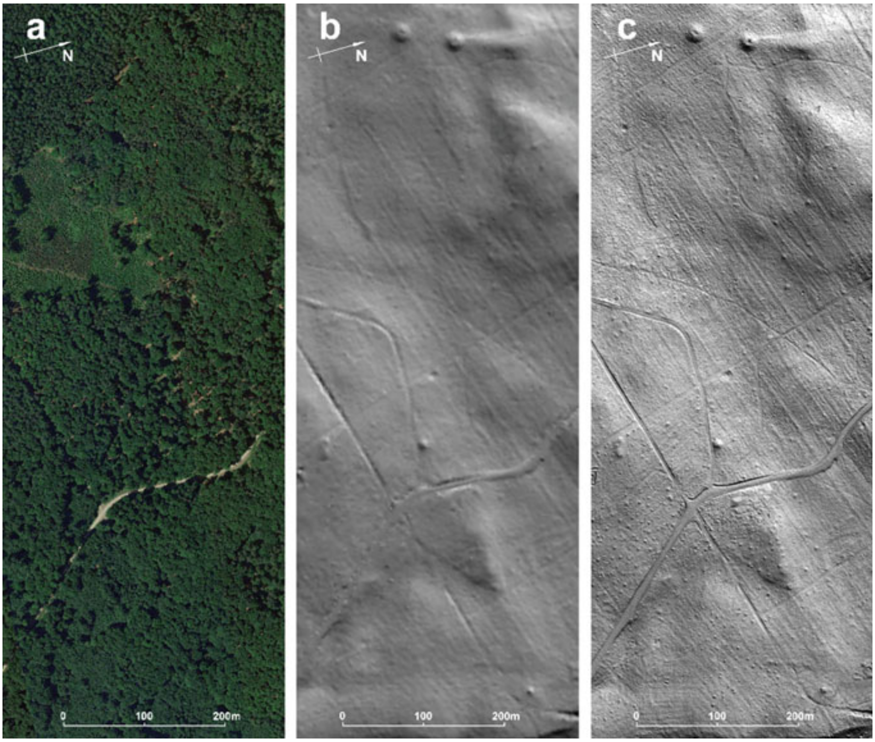

Fig. 8.17 Tests results of UAV-LiDAR systems carried on Uniradze burial-mounds site in northern Poland: (**a**) RGB image of the site (*Source* Google Earth); (**b**) hillshaded data from a high-altitude ALS (*Source* The National Geodetic and Cartographic Resources Poland); (**c**) hillshaded data from tested UAV-LiDAR system (*Source* Archives of LabScan3D)

Additionally, flights favourable weather conditions (no rainfall, wind speed below 30 km/h) do not always coincide with the moments when an optimal number of satellites (at least 6) is visible above the horizon, so the optimal flight window is often limited to a couple of hours.

As we can see (Figs. 8.18 and 8.19), in this particular place and on this particular day, the optimal time for the flight is only about one hour, from 9:30 till 10:30 a.m. (local time) for GNSS receivers (the drone antenna and the reference station) following only two satellite systems. With an increased number of followed GNSS systems, this time interval will expand—in this particular case matching the optimal weather conditions window (Fig. 8.18).

Since at this altitude, even with special propellers, the flight time for a battery-powered drone will hardly exceed 12 min, there is still enough time to fly four missions (if one has enough battery packs for replacement). Depending on the local conditions, the four flights may cover up to 1 km^2 of the terrain.

This leads us to another constatation—battery-powered UAVs have a remarkably short time of flight. Adding to this the restrictions concerning large capacity lithium batteries transportations and restrictions in entering the country with drones and high-tech sensors, the use of battery-powered drones becomes logistically complicated.

Also, finding places that will guarantee clear sightlines during the flight and at the same time safe taking off and landing is often also problematic in the case of the Machu Picchu Park topographic conditions.

Despite all these problems, in the case of relicts hidden below the tree canopy on steep slopes, the UAV-based LiDARs have, besides the already mentioned better ground point density, one more advantage over maned LiDAR carriers. The angles of incidence of the laser beam on the vertical planes of the walls (α_w and $ß_w$) and on the sloping ground surface (α_g and $ß_w$) are more favourable when using drones (Fig. 8.20). This dependence, resulting in greater energy of the return pulses, significantly impacts chances to detect the sought relics and adequately record the ground surface.

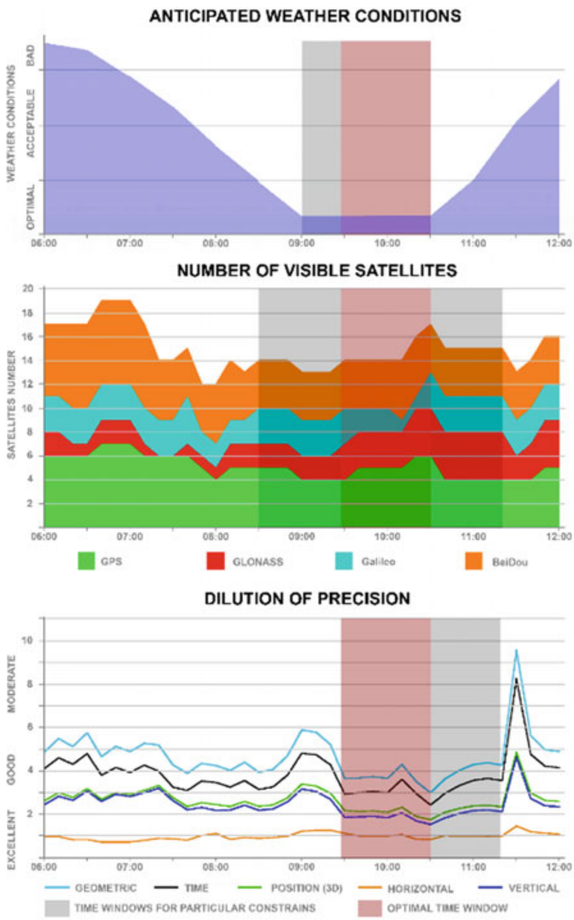

Fig. 8.18 The real case drone flight plan for the Inkaraqay site at July 6, 2021 Calculated by J. Kościuk

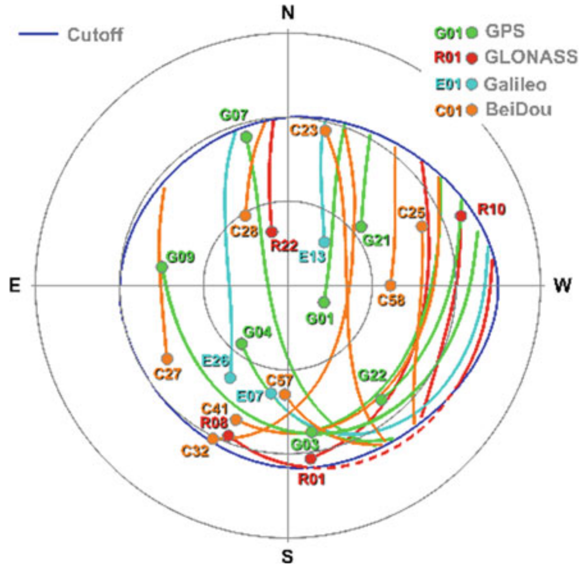

Fig. 8.19 Sky-plot for the planned drone flight for the Inkaraqay site on July 6, 2021, 0:00 ÷ 5:00 UTC. Calculated by J. Kościuk

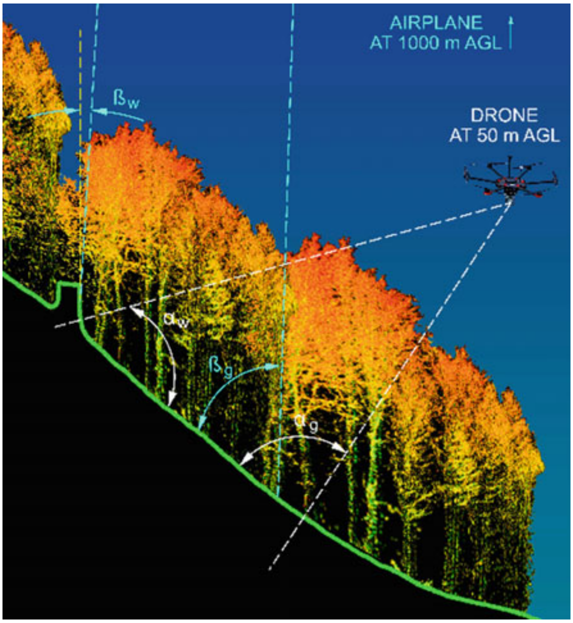

Fig. 8.20 Angles of incidence for the sensor trajectory at 50 m AGL and 1000 m AGL. Note that $\alpha_g > ß_g$ and $\alpha_w > ß_w$. Elaborated by J. Kościuk

Comparison of crew-maned to drone-based LiDAR flights would be incomplete without discussing the acquisition cost of such surveys. In the case of crew-maned ALS surveys, they differ depending on the country, but in the years 2012–2015 for which synthetic data were published (at least in the USA) a trend towards a slight decrease in prices has been noticed (Sugarbaker et al. 2017, 7, table 3). The average cost per square kilometre for forty-seven QL2 quality levels (as defined by Heidemann 2014) ALS acquisitions was about 87 US$, for an average project size of ca. 7350 km^2.

With an almost 100 times smaller acquisition area in the case of Machu Picchu Park, unit costs per square kilometre will be much higher. This is especially true when considering that the nearest ALS service provider is in Lima, so at a distance of at least 500 kms in a straight line across rugged mountains. The authors do not know the financial details of this project, but certainly, apart from the cost of data elaboration, a significant part of the entire budget was the charge for the flight to the Machu Picchu area and the return to the base in Lima.

In turn, surveying with a UAV platform equipped with a LiDAR, GNSS, and IMU devices allows for more detailed data collection in selected areas, limited to a few or a dozen square kilometres, when searching for the small relics of buildings hidden under the tree canopy, especially where the terrain makes it challenging to operate helicopters or planes. According to our experience, this method of ALS data acquisition is especially suitable for distant from any airfields, small (up to a few square kilometres) forested areas, where LiDAR mounted on an aircraft could be economically and logistically unjustified.

Thus, the problem is not in assessing the strengths and weaknesses of both technologies but in the correct answer to "where and what for" questions. Just as there is no, as underlined by the authors of research in Belize (Thompson 2020), one universal method for analysing and visualising LiDAR data for the identification of archaeological features hidden between the tree canopy, there is also no one ALS data acquisition method, adequate in all cases. Each case, depending on the nature of the terrain and density of vegetation cover, and above all, on the nature of the anomalies sought (overall size, height relative to the surrounding terrain, dimensions and geometrical shape), may require different acquisition methods and different, most detective methods of data elaboration. So instead of juxtaposing the weaknesses and strengths of both ALS technologies on forested areas, we will present in a tabular form (Table 8.4) an attempt to answer the already asked question "where and what for".

It should be emphasised that the above list is neither exhaustive nor binary. It only outlines the general rules, and the recommendations can differ in specific, unusual situations.

Table 8.4 Ranges where ALS on manned and UAV platforms have the most significant application potential

Aeroplane-based LiDAR systems	UAV-based LiDAR systems
Large-budget projects	Low-budget projects
Large-scale surveys on tens, hundreds or even thousands of square kilometres of the terrain inaccessible for terrestrial surveys	Small-scale surveys limited to a few or a dozen or so square kilometres of the terrain inaccessible for terrestrial surveys
Searching for large-scale anomalies of tens or hundreds square meters—at least one meter higher (or 1 m lower) than the surrounding ground, when the ground points density of 1 ÷ 5 pts/m^2 is sufficient	Searching for small and narrow anomalies of a few square meters, particularly relicts of walls only slightly (0.20 till 1 m) elevated above the surrounding ground when the ground points density of minimum 50 ÷ 75 pts/m^2 is essential
Surveys over flat or moderately mountainous lands—no narrow valleys, no relative terrain heights exceeding 1000 m	Surveys over mountainous and rugged lands—narrow valleys, steep slopes, relative terrain heights exceeding 1000 m
When the angle of incidence of the laser beam is not so crucial for detecting the anomalies sought	When the angle of incidence of the laser beam plays an essential role in detecting the sought anomalies

8.6 Conclusions and Proposed Strategy for the Continuation of the Machu Picchu Park ALS Survey

The general conclusion drawn from this study is that for this type of research, surveying with a UAV platform equipped with LiDAR, GNSS and IMU devices can be seen as a supplementary method to enrich data from aircraft based long-range LiDARs. It allows for more detailed data collection in selected areas, limited to a few or a dozen square kilometres, when searching for the small relics of buildings hidden under the tree canopy, especially where the terrain makes it challenging to operate helicopters or planes. Both technologies can complement each other by increasing the survey resolution in the areas of particular interest. Along with the currently observed dynamic development of hardware and software, LiDAR-UAV systems will be even more popular in the coming years.

This probably also applies to research planned in the Machu Picchu Archaeological Park. Therefore, it seems essential to outline a potential strategy of using ALS in the conditions of Machu Picchu Park, even if the current, limited experience is considered insufficient to draw definitive conclusions.

The ALS survey from the helicopter platform fulfilled its primary aim of providing data to build a detailed model of the terrain topography enabling further studies on the terrace system, hydrological relations or landslide hazards. This general survey can be successfully extended to the Park's entire area and continued along the Vilcabamba Valley, both east and west of Machu Picchu. It can provide equally essential data for other areas not covered by the current survey. In a much longer time perspective, repetition of such surveys may be considered to monitor human inducted and natural changes in the terrain topography.

The data obtained from high-altitude ALS can also serve for autonomous BLOS flights control. The resolution of this data is much greater than usually used for this purpose 30m-resolution DEM generated by the Shuttle Radar Topography Mission (SRTM).[3] This data will also be particularly important as a basis for determining particularly interesting places for which more detailed surveys using UAV-based LiDAR systems can be considered. As proofed by Chachabamba and Inkaraqay cases, these might be the regions around satellite archaeological sites surrounding Llaqta Machu Picchu and areas located along the already known Inca roads or those just detected by high-altitude ALS. It might be beneficial to synchronise such drone-based surveys with the current activities of the Park. The presence of the Park personnel on the ground during drone-based LiDAR surveys will be essential for establishing the ground control points, setting up the GNSS base station and monitoring the flight lines.

The possibilities and strategy of using ALS in Machu Picchu research outlined here do not, of course, exhaust all possible applications. These are determined by, on the one hand, financial possibilities and, on the other, the ingenuity of researchers.

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[3] https://earthexplorer.usgs.gov/.

Bibliography

Astete VF, Bastante AJM (eds) (2020) Machupicchu. Investigaciones Interdisciplinarias. Tomo I, Cusco 2020

Astete VF, Ziółkowski M, Kościuk J (2017) On Inca astronomical instruments: the observatory at Inkaraqay—El Mirador (National Archaeological Park of Machu Picchu, Peru). Estudios Latinoamericanos 36/37:9–25.

Bennett R, Welham K, Hill RA, Ford A (2012) A comparison of visualization techniques for models created from Airborne Laser scanned data. Archaeol Prospect 19:41–48. https://doi.org/10.1002/arp.1414

Challis K, Forlin P, Kincey M (2011) A generic toolkit for the visualization of archaeological features on airborne LIDAR elevation data. Archaeol Prospect 18:279–289. https://doi.org/10.1002/arp.421

Challis K, Kokalj Z, Kincey M, Moscrop D, Howard AJ (2008) Airborne LIDAR and historic environment records. Antiquity 82:1055–1064

Chase, AF, Chase DZ, Weishampel JF (2010) Lasers in the jungle: Airborne sensors reveal a vast Maya landscape. Archaeology 63(4):27–29

Ćmielewski B, Sieczkowska D, Kościuk J, Bastante José M, Wilczyńska I (2021) UAV LiDAR mapping in the Historic Sanctuary of Machupicchu: challenges and preliminary results. Wiadomości Konserwatorskie, J Heritage Conservation (in print)

Crutchley S, Crow P (2009) The light fantastic: using airborne LIDAR in archaeological survey. English Heritage Publishing, Swindon

Evans DH, Fletcher RJ, Pottier Ch, Chevance J-B, Soutif D, Boun ST, Sokrithy I, Darith E, Tina T, Samnang K, Cromarty Ch, De Greef S, Hanus K, Bâty P, Kuszinger R, Ichita S, Boornazian G (2013) Uncovering archaeological landscapes at Angkor using LIDAR. Proc Nat Acad Sci 110(31):12595–12600. https://doi.org/10.1073/pnas.1306539110

Devereux BJ, Amable GS, Crow P (2008) Visualisation of LIDAR terrain models for archaeological feature detection. Antiquity 82:470–479

Evans DH, Hanus K, Fletcher RJ (2015) The story beneath the canopy: an airborne lidar survey over Angkor, Phnom Kulen and Koh Ker, Northwestern Cambodia. In: Traviglia A (ed) Across Space and Time, Papers from the 41st Conference on Computer Applications and Quantitative Methods in Archaeology, 25–28 March 2013. Amsterdam University Press, Perth, pp 38–46

Fletcher RJ, Hofer N, Mudbidri M (2020) Avances preliminares de la investigación con lidar en Machupicchu. In: Victoria FA, José Miguel BA (eds) Machupicchu. Investigaciones interdisciplinarias. Tomo I, Cusco, pp 383–392

Gavazzi A (2014) Lima. Memoria prehispánica de la traza urbana. Lima.

Heidemann HK (2014) Lidar base specification (ver. 1.2, November 2014). U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 67 p 24. https://doi.org/10.3133/tm11B4

Horn III Sherman W, Ford A (2019) Beyond the magic wand: methodological developments and results from integrated Lidar survey at the ancient Maya Center El Pilar. Star: Sci Tech Archaeol Res 5(2):164–178. http://doi.org/10.1080/20548923.2019.1700452

Hug C, Krzystek P, Fuchs W (2004) Advanced LIDAR data processing with LASTtools. Internet source: https://www.researchgate.net/publication/228347125_Advanced_lidar_data_processing_with_LasTools

Kellner JR, Armston J, Birrer M, Cushman KC, Duncanson L, Eck C, Falleger C, Imbach B, Král K, Krůček M (2019) New opportunities for forest remote sensing through ultra-high-density Drone Lidar. Surv Geophys 40(4):959–977

Kokalj Ž, Zakšek K, Oštir K (2011) Application of sky-view factor for the visualisation of historic landscape features in LIDAR-derived relief models. Antiquity 85:263–273

Pappas S (2013) Ruins of Lost City May Lurk Deep in Honduras Rain Forest. Live Sci 5.

Prufer KM, Thompson AE, Kennett DJ (2015) Evaluating airborne LiDAR for detecting settlements and modified landscapes in disturbed tropical environments at Uxbenká, Belize. J Archaeol Sci 57:1–13. https://doi.org/10.1016/j.jas.2015.02.013

Rosenswig RM, López-Torrijos R (2018) Lidar reveals the entire kingdom of Izapa during the first millennium BC. Antiquity 92(365):1292–1309. https://doi.org/10.15184/aqy.2018.166

Sośnica K, Zajdel R, Bury G, Bosy J, Moore M, Masoumi S (2020) Quality assessment of experimental IGS multi-GNSS combined orbits. GPS Solutions 24:54. https://doi.org/10.1007/s10291-020-0965-5

Sugarbaker LJ, Eldridge DF, Jason AL, Lukas V, Saghy DL, Stoker JM, Thunen DR (2017) Status of the 3D Elevation Program, 2015, Open-File Report 2016-1196. U.S. Geological Survey, Reston, Virginia. https://doi.org/10.3133/ofr20161196

Thompson AE (2020) Detecting Classic Maya Settlements with Lidar-Derived Relief Visualizations. Remote Sens 12(17):2838. https://doi.org/10.3390/rs12172838

VanValkenburgh P, Cushman KC, Castillo Butters LJ, Rojas Vega C, Roberts CB, Kepler Ch, Kellner J (2020) Lasers without lost cities: Using Drone Lidar to capture architectural complexity at Kuelap, Amazonas, Peru. J Field Archaeol 45(sup1.):S75–S88. https://doi.org/10.1080/00934690.2020.1713287

Zakšek K, Oštir K, Kokalj Ž (2011) Sky-view factor as a relief visualization technique. Remote Sens Nat Cult Heritage 3:398–415. https://doi.org/10.3390/rs3020398

Chapter 9
In a Search for Standards in Inca Measuring System

Anna Kubicka and Jacek Kościuk

Abstract Using the cosine quantogram method, the authors carry out a metrological study of Llaqta Machupicchu**.** The introduction presents a synthetic review of the literature and emphasises the reliability of the initial data for any metrological analysis. The presented research was based on the results of the 3D laser survey. In part presenting the research methodologies and methods used, attention was drawn to the difficulties associated with the typical Inca architecture inclination of external walls and most often inaccessible for direct laser measurements level of building foundations, on which building plan might have been initially laid out. Llaqta Machupicchu metrology studies were expanded by comparative material from the Coricancha Temple in Cusco, Chachabamba archaeological site and El Fuerte de Samaipata in Bolivia. The research results indicate the existence of two separate systems of Inca measures based on different basic units. The authors also present a preliminary interpretation of the obtained results.

Keywords Machu Picchu · Inca architecture · Inca metrology · Cosine quantogram

9.1 Introduction

Let us start from a well-known quotation from the chronicle of Juan de Betánzos describing the Inka's personal involvement in planning and delineating the Coricancha Temple:

"After that, they left the place, where he and his people were and, at the place where the temple was to be built, Inca Yupanque himself with his own hands took

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the cord, measured and laid out the plan of the temple of the Sun. He measured the stones for building this temple, after which the people of nearby towns worked the stones pointed out to them until there were enough to build this temple. Along with these stones they brought everything else necessary for this temple. On arrival they went to work on it just as Inca Yupanque had designed and imagined it. He always supervised the work himself along with the other lords." (Translated and edited by Roland Hamilton and Dana Buchman 1996, 45 from Palma de Mallorca manuscript).

How to understand this text? From the reference to the measurements of stones for the temple construction, we can conclude that the cord served to determine not only a general layout of the building but also single stones. Therefore, it must have had a strictly defined length based on smaller, precisely defined units. Do we have any material evidence of the existence of such a measuring system? To answer the last question, we must approach the problem of Inca metrology. Several authors have already published names of basic measurement units used by the Incas and estimations of their length in metric system (Table 9.1).

Table 9.1 Basic Inca measuring units as reconstructed by different authors

Unit	Reconstructed length [cm]						
	Bennet (1949)	Rostworowski (1960)	Agurto (1987)	Baudin (2003)	Müller (1929/1972)	Rowe (1946)	Farrington (1984)
yuku	12–15	10–12	16			12–14	
k'apa		21	18.2–21			20	
chaqui			25–30				
khococ	45		40–45			45	
sikya	81	81	76–83.5			81	80.75
rikra		162	153.5–166.1	160–162		162	161.5
waska			646				646
?					7.3		

What kind of data was taken as a base to reconstruct those measures? Generally, two approaches are present there. The first can be called anthropometric—when the known names of incaic measuring units are fitted to different models of idealised human body proportions (Bennet 1949; Rostworowski 1960; Agurto 1987; Baudin 2003). The second approach is based on the measurements of existing buildings and searching for repetitive units of measure (quantum) representing the length of hypothetical measuring unit used by the Inca builders (Müller 1929, 1972; Rowe 1946; Farrington 1984). If so, what was the source of the measurements: published plans or direct measurements? If the last, then on the level of foundations, on the original level of use, or on any arbitrarily selected height? A further division may distinguish between general studies where measurements were collected from many different sites and then analysed as one group (Farrington 1984) or the case studies of particular sites or even particular buildings (Farrington 2013). Finally, what was the measurement technology? What was its accuracy? The answers to the above questions are fundamental. In this respect, one should also notice a different approach represented by Lee (1996), who seeks proportions between different parts of buildings instead: "… there seems little doubt that proportional ratios were important and perhaps determining concepts in laying out the floor plans of Inca buildings" (Lee 1996, 13–14).

Leaving for a moment the methodology used by the mentioned authors, we have to consider perhaps an essential question:

- did the Incas have a standardised measurement system and any equivalent physical model, such as known from ancient Egypt royal cubit bars (Fig. 9.1),
- or was the system based on the anthropometric dimensions of a particular individual, which necessarily meant that the basic units, although named identically (for example *rikra*), differed from one construction to another?

As far as it seems, there was no strictly defined standard of measure in Inca culture. Instead, the system was based on specific dimensions of the human figure that differ between specific individuals. However, some of the authors dealing with Inca metrology (Table 9.1) suggest that that wooden or metal stick was used to delimit the shorter measurements and a cord or rope, called *ñañu waska* (de González Holguín 1608), for longer dimensions, as described in already quoted Betánzos' testimony.

Returning to the main topic, we want to emphasise that in metrological studies, two factors are very important:

- the quality (the accuracy) of the data and
- the methods of interpretation.

Fig. 9.1 Egyptian royal cubit. *Source* http://root.projetrosette.info/assets/Textes/facSimile/193/Coudee_Maya.jpg

Building archaeology, especially metrology studies, requires input data of high reliability and accuracy. The final result of the research depends to a large extent on the quality of the data and its interpretation. Today, we have measurement technologies much more accurate than those available even 20 years ago. Its application allows not only to verify previous findings but can lead to entirely new discoveries. The following examples should be understood not as a criticism of other researchers but only as evidence of the benefits of new measuring techniques not available for our predecessors. Let us use the Coricancha Temple, partly reconstructed after the earthquake of 1950, as an example of how, and in which way, different factors and different methodological approaches may influence the final results of metrological studies.

A good understanding of the examined building structure constitutes one of the most critical factors. It is crucial for any metrological studies that we are dealing only with the original walls. As it is not always so obvious which walls were reconstructed and how far they follow the original design, some additional studies on the building and all available archival sources are necessary. The so-called Room of Stars in Coricancha may serve as an example (Fig. 9.2). Any metrological studies not considering which parts are original and which were reconstructed may end up with false, or at least not very accurate, results.

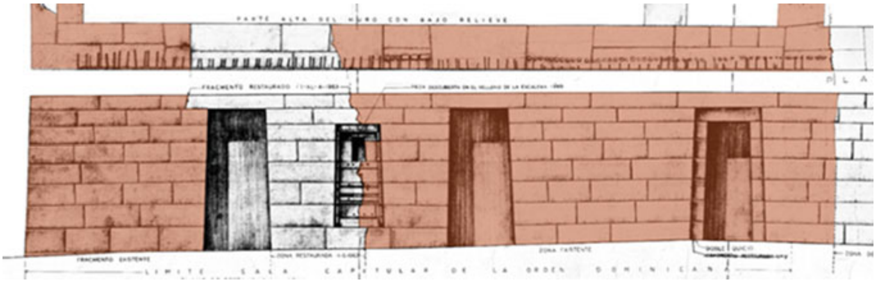

Fig. 9.2 The eastern facade of the "Room of the Stars" as drawn by Oscar Ladrón de Guevara in July 1960 during his work on Coricancha restoration. We colour the original walls in red, and reconstructed parts are left in grey. *Source* Private archive of D. César Ladrón de Guevara

The case of Coricancha illustrates well also the importance of measurements accuracy. In 2011 and 2014, a group led by Sławomir Święciochowski from the Centre of Pre-Columbian Studies at Warsaw University (CEAC) and the Laboratory of 3D Laser Scanning and Modeling at Wroclaw University of Science and Technology (LabScan3D) completed a 3D scan of the whole temple (Ziółkowski and Kościuk 2018). Let us now compare the results of Coricancha's perimeter wall measurements with those published by Ian Farrington's well-known monography of Cusco (Farrington 2013, 170). Aside from the printer's devil probably interfering with referencing particular measurements to particular walls, our 3D laser scan data differ from 1 to 4 m if compared with Farrington data (Table 9.2, Fig. 9.3). This, however, should be not be understood as a critique but only as an exemplification of and impact of modern measuring instruments on metrological studies.

Table 9.2 Comparison of Coricancha perimeter wall measurements

Wall[a]	Farrington (2013)	EAC & LabScan3D (2014)
	length [m]	length [m]
N1	74.30 (probably E)	84.58
N2	–	87.61
E	41.90 (probably S1)	70.57
S1	?	41.03
S2	–	85.61
W1	85.60 (probably N1)	69.34
W2	–	87.70

[a] As on Fig. 9.3

Fig. 9.3 Results of Coricancha EAC and LabScan3D laser survey. Drawing by J. Kościuk

In the same book, Farrington also published basic dimensions of R2 and R3 Coricancha buildings (Farrington 2013, 167). He expressed this data in *rikra* units of 1.615 m (Table 9.3), resulting from his earlier studies based on a generalisation of hundreds of measurements from different archaeological sites (Farrington 1984).

Table 9.3 Farrington estimation of Coricancha's R2 and R3 buildings dimensions

Coricancha buildings[a]	Units	External length	External width	Internal length	Internal width
R2	metres[b]	13.10	5.03	11.50	4.20
	rikra 1.615 m	*8.11*	*3.11*	*7.12*	*2.60*
R3	metres[b]	14.51	10.00	12.95	8.05
	rikra 1.615 m	*8.98*	*6.19*	*8.02*	*4.98*

[a]As on Fig. 9.3; [b]As in Farrington (2013, 167, table 7.1)

Table 9.4 Cosine quantogram estimation of Coricancha's R2 and R3 buildings dimensions

Coricancha building	Units	External length	External width	Internal length	Internal width
R2	metres[a]	13.10	5.03	11.50	4.20
	rikra 1.626 m	*8.06*	*3.09*	*7.07*	*2.58*
R3	metres[b]	14.51	10.00	12.95	8.05
	rikra 1.626 m	*8.92*	*6.15*	*7.96*	*4.95*

[a]As on Fig. 9.3; [b]As in Farrington (2013, 167, table 7.1)

In the introductory chapters of his Cusco monography, Farrington points to the cosine quantogram method (Kendall 1974, 231–266; Pakkanen 2001, 501–506) as the tool he used for metrological analyses of hundreds of melodiously collected data (Farrington, 2013, 66). He also evaluates the cosine quantogram method as the most adequate and promising for metrological studies in building archaeology. So, let us apply the cosine quantogram method only to R2 and R3 Coricancha buildings as measured by Farrington. The reconstructed *rikra* will be instead 1.626 m (Table 9.4) and not 1.615 m. The difference is small, but if the measurements are again expressed in *rikra* units, the results better fit round numbers. A small sample (only eight measurements) is a severe limitation there, resulting in relatively low, therefore not the entirely conclusive value of cosine quantogram function.

We are fully convinced that Farrington's estimations of *rikra* based on so many measurements and the cosine quantogram method are correct. The example of R2 and R3 Coricancha buildings only demonstrates how results based on single case studies of particular buildings may differ from conclusions based on a much broader set of data.

However, the problem is even more complicated since our 3D laser scanning results indicate that R2 and R3 buildings are rather of a trapezoidal than the rectangular shape (Fig. 9.3), thus inflicting another difference in metrological estimations. Now, *rikra* reconstructed from TLS measurements (Table 9.5) is 1.645 m, what again demonstrates the influence of measurement accuracy on metrological estimations (Fig. 9.4).

Table 9.5 EAC and LabScan3D estimation of Coricancha's R2 and R3 buildings dimensions

Coricancha building	External E length [m]	External W length [m]	External N length [m]	External S length [m]	Internal E length [m]	Internal W length [m]	Internal N length [m]	Internal S length [m]
R2	13.29	13.11	6.06	6.04	11.64	11.49	4.19	4.21
R3	14.49	14.89	10.03	10.04	12.69	12.97	8.06	8.07

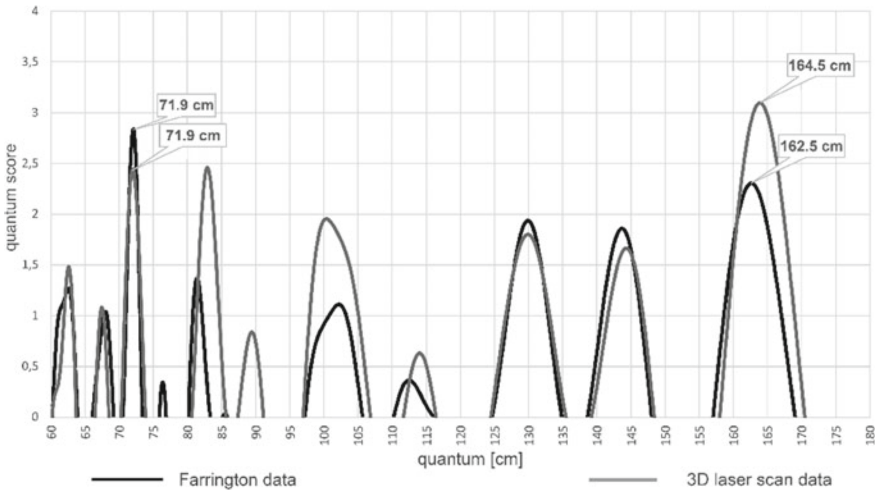

Fig. 9.4 Results of *rikra* estimation for R2 and R3 Coricancha buildings when using cosine quantogram method on Farrington and 3D laser scan data. Elaborated by J. Kościuk

The difference between our results and the previous reconstruction of *rikra* length is now more than 2 cm, and at the same time, the sample is twice as big, so the results are more reliable as the cosine quantogram function reaches the value of 3.0, which is estimated as the minimum level to be considered (Fig. 9.4). However, it should be underlined that we measured the length of the walls at the lowest available level—not necessarily the level on which Incas used to define the layout of their buildings. Since the Inca walls are always battered, the level on which one measures the building's plan plays an important role.

One more intriguing observation is a pick of cosine quantogram function at 72.2 cm (Fig. 9.4). This fits surpassingly well Müller's tenfold multiplication of estimation for Torreón niches and Intihuatana measurements. In his later publication (Müller 1972, 29), which is essentially republishing of his much earlier work (Müller 1929), he offers the same measurements, but now with an additional comment:

> The arithmetical evaluation, which I cannot go into here, aimed to determine the most probable value of the measuring unit was calculated from 54 equations with 2 unknowns. According to this evaluation, one can assume that the builders of Machu Picchu used a basic unit of 7.3 cm. (translated from German by J. Kościuk)

However, our observation should be treated with great caution. First, to date, there are no indications in the Inca metrology system of the existence of decimal multiplication of small measuring units, although such system is known from population organisation into tens, hundreds and thousands of individuals (Cobo, book II, chapter 25). Second, Müller does not disclose the mathematical apparatus behind these calculations. This problem might be the subject of further researches, but it is beyond the scope of this study. Keeping in mind all the presented above intricacies of metrological studies, we will move now to the metrological study of Llaqta Machupicchu.

9.2 Metrological Study on Llaqta Machupicchu Architecture and Some Related Sites

This research started in 2015 as doctoral thesis of A. Kubicka supervised by J. Kościuk and M. Ziółkowski (Kubicka 2019). The primary data for metrological analysis resulted from terrestrial laser scanning (TLS) of Llaqta Machupicchu carried out between 2010 and 2017 by the Archaeological Machu Picchu Park in collaboration with CEAC and LabScan3D. The TLS survey covered most of the Llaqta, excluding the southwest zone, where conservation works were carried out in those years (Fig. 9.5).

The TLS data collected on the field were registered into the common 3D coordinate systems at the LabScan3D, where also the main part of metrological studies, particularly statistical analysis, has been done.

9.2.1 Methodology and Methods

As already mentioned in the introductory chapter, the accuracy of input data for the metrological study plays an important role. Although contemporary TLS is recognised as one of the most accurate surveying technics for building archaeology (Kościuk 2012) it delivers data-reach 3D point clouds; thus, it is crucial to choose the right 3D points during measuring of particular building elements, which is usually done in the back-office phase of work. It is inextricably linked to the danger of introducing a human error—the error of the operator selecting for the measurement is not always adequate and the same points.

Fig. 9.5 The Llaqta Machupicchu. The red-hatched area indicates the part covered by TLS survey. Drawn by A. Kubicka

In order to estimate the accuracy and repeatability of data collected from the 3D point cloud, distances between randomly selected pairs of 3D points were measured. For each pair, measurements were repeated five times, and standard deviations and confidence intervals were calculated. Then, for the same pairs of points identifying the dimensions of specific building elements, verifying measurements were made directly in the field.

It turned out that the results of measurements from the 3D point cloud fall within the confidence interval of ± 1 cm at the significance level $\alpha = 0.01$. When assessing this result, it should be remembered that although TLS allows us to obtain millimetre accuracy of measurements, the specificity of Inca stonework (convex faces of stone blocks and usually rounded corners) does not permit us to determine the corners of the measured elements precisely. Later on, our experience in using the cosine quantogram method has also shown that even in the case of measurements with an accuracy of ± 1 mm, rounding the readings to full centimetres does not significantly affect the estimation of the cosine quantogram function value.

Introduced by Kendall (1974), cosine quantogram method has been already further developed and successfully used in a search for ancient quanta in several metrological studies (Pakkanen 2002, 2004; Hewson 1980). It allows detecting the smallest basic unit of measure (quantum) in a series of measurements of any architectural elements—ashlar blocks, members of architectural orders, openings as niches, windows or doors and finally, the whole plans of buildings and towns. The method particularly fits the case of Inca architecture, where no written historical records exist clearly and precisely defining the length of ancient units of measure. Therefore, the cosine quantogram method has been chosen as the main tool in the studies on Llaqta Machupicchu metrology.

The cosine quantogram analysis is presented in the form of a graph of quantum estimation, where the highest peak of the cosine quantogram function represents the strongest candidate for the basic unit of measure existing in the given set of measurements. Additionally, one should check whether the value of quantum falls into a narrow bootstrap confidence interval.

Bearing in mind Farrington's remarks on the difficulty of finding the quantum based on the measurements of the preserved relics of Inca architecture, particularly when we do not know the original level on which the outline of the building was possibly delineated, and additionally, when all the walls are battered, it was necessary to check how such conditions could affect the obtained results. For this purpose, several simulations were run for factious buildings planned according to the predetermined quantum and delineated in one of three possible scenarios:

- on the levelled ground (Fig. 9.6a),
- on the sloping ground (5, 10 and 15 degrees) with dimensions marked out parallel to the ground surface (Fig. 9.6b),
- on the sloping ground (5, 10 and 15 degrees) but with dimensions laid out horizontally and projected onto the ground surface with a plumb-like instrument (Fig. 9.6c).

For each scenario, the dimensions of the building outline were calculated at the height of 0.5, 1.0, 1.5 and 2.0 m above the theoretical stakeout level. It turned out that for buildings delineated on the levelled ground, the theoretically assumed quantum was still detectable, with an error within 1 cm, when measuring the building outliner even at the height of 2.0 m above the stakeout level. For the sloping ground with dimensions marked out parallel to the sloping ground surface, the limit of reliable results was the slope of the terrain up to 10 degrees and the measurement of the building outline at the level not higher than 1.0 m above the stakeout level. The results obtained for the third scenario were similar to the previous case.

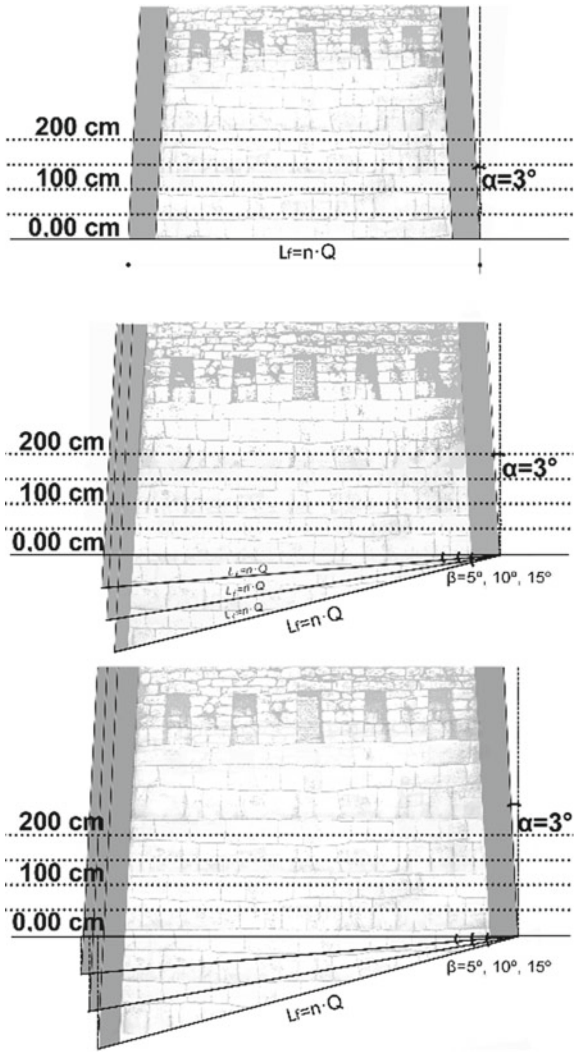

Fig. 9.6 Three possible scenarios of building plan delineation on the ground; **a**. on the levelled ground, **b**. on a sloping ground with measurements according to the ground surface, **c**. on a sloping ground with horizontal measurements projected onto the ground surface. Drawing by A. Kubicka

Metrological analysis using the cosine quantogram method covered all LLaqta Machupicchu buildings for which data from TLS survey were available (Fig. 9.5). Each building sector was analysed separately, hoping that the results may differ depending on the function or possible chronological phase.

9.2.2 Comparative Studies

Aside from the mentioned in the introduction data related to the Coricancha Temple, additional comparative material resulted from the simultaneous research carried out on the Chachabamba archaeological site near Llaqta Machupicchu (Bastante Abuhabda et al. 2020; Sieczkowska and Bastante Abuhabda 2021), and in the course of another project on el Fuerte de Samaipata in Bolivia (Kościuk et al. 2020). In Chachabamba, buildings' outlines, as well as niches, were measured. Only the original walls and niches were taken into account, ignoring all reconstructions from the 1980s. The dimensions of the niches in the so-called baths and that of the central buildings were collected separately (Fig. 9.7). The number of measurements in the samples ranged between 15 and 20.

In the case of el Fuerte de Samaipata where research was limited only to the sculptured rock constituting the site's core, only three samples of niches dimensions were collected. There, the number of measurements in each sample did not exceed a dozen. The first analysed group of niches belongs to the apparently Inca origin wall, set across the top of the rock in Sector W09 (Kościuk et al. 2020, 84). Although the wall is a modern reconstruction, several engraved lines still visible on the rock surface attest to its original shape and dimensions (Fig. 9.8).

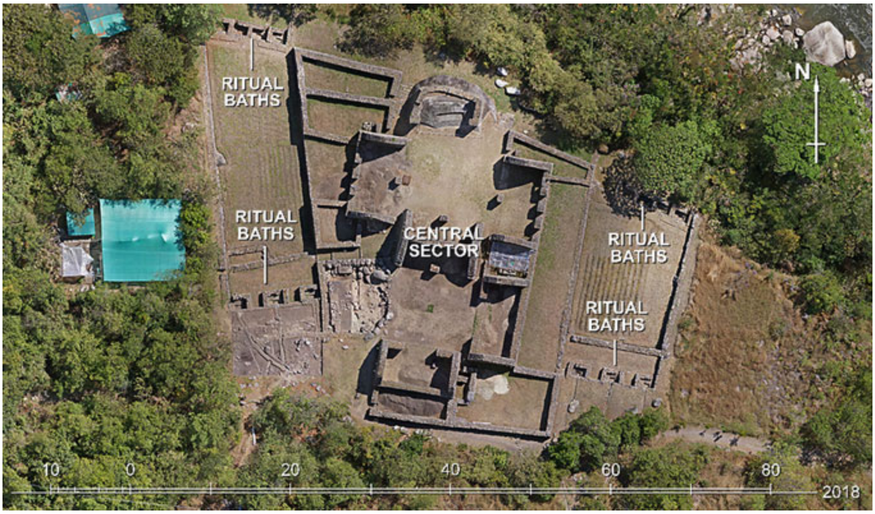

Fig. 9.7 Orthoimage of Chachabamba archaeological site. Elaborated by B. Ćmielewski

Fig. 9.8 El Fuerte de Samaipata. The transverse wall on the top of the rock. The red arrow indicates guidelines for the original wall position. Photo by J. Kościuk

Fig. 9.9 El Fuerte de Samaipata. The back wall of the Temple of Five Niches in Sector N08—orthoimage from 3D laser scan. Elaborated by J. Kościuk

The second analysed group belonged to the so-called Temple of Five Niches in Sector N08 (Kościuk et al. 2020, 91). There, neatly distributed niches also suggested that their dimensions and positions were well-planned (Fig. 9.9).

The last analysed group were unfinished niches, thus probably also of Inca origin, in a spacious room located in Sector S10 (Kościuk et al. 2020, 103). On the back wall of this room, several vertical grooves (6–7 cm wide) are extant in nearly equal intervals. A small bench (ca. 30 cm wide and ca. 40 cm high) runs alongside the base of this wall. On the vertical face of the bench, a sequence of small square niches has been carved—nearly perfectly in between the grooves above (Fig. 9.10). The distances between grooves marking the edges of future big niches and the distances between the centres of the small square niches below were analysed.

Fig. 9.10 El Fuerte de Samaipata. The back wall of a room in Sector S10—orthoimage from 3D laser scan. Elaborated by J. Kościuk

The authors are aware that comparative studies should be based on much broader material. The epidemic restrictions that began in 2020 made it impossible to collect the planned, further on-site studies. Thus, at the final date for submitting this chapter for publication, the authors were faced with two options: postponing the publication or publishing material currently available. Despite some doubts, as one can see, the latter option was chosen.

9.3 Results

9.3.1 Llaqta Machupicchu

Metrological analysis in Llaqta Machupicchu covered all the sectors for which 3D scanning data were available at that time (Fig. 9.11). For each sector, data were analysed separately.

In the first stage of the research, the outlines of the buildings plans were analysed. Surprisingly, attempts to estimate the quantum calculated from the outlines of buildings did not bring the clear results that could be expected (Fig. 9.12) when bearing in mind the effects of quantum search in Inka Calca (Farrington 2013, 67–70), Ollayantaytambo Qosqo Ayllu (Farrington 2013, 70–76) or some streets and buildings of Cusco (Farrington 2013, 117 ff). In some sectors, quantum was not detectable; in some others, estimation did not end with clearly unequivocal results.

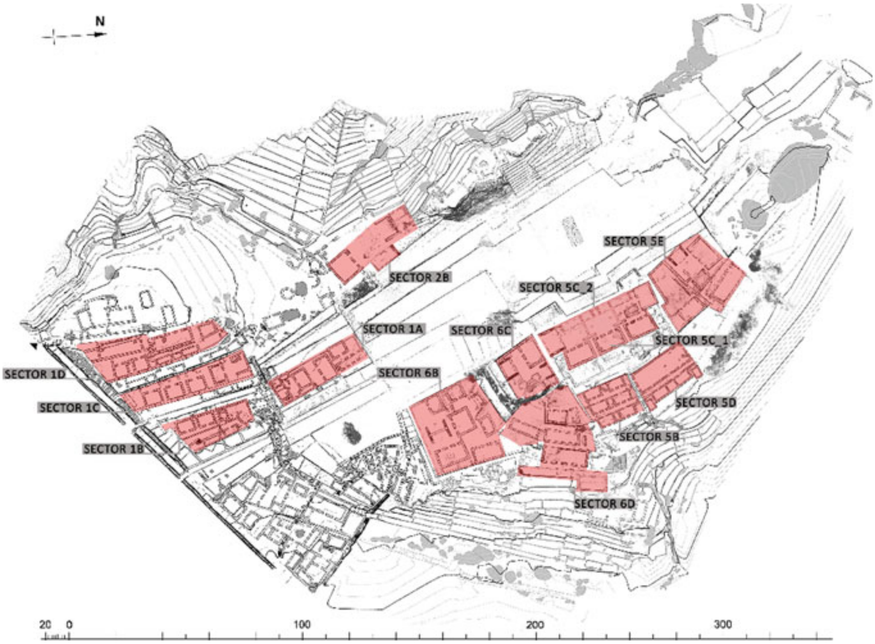

Fig. 9.11 Llaqta Machupicchu. Sectors analysed. Elaborated by A. Kubicka

Attempts to limit the scope of the analysis only to the fronts of buildings, possibly taking into account sections limited by successive entrance openings, also did not bring many sufficiently unequivocal results. However, they are examples of successful application of the cosine quantogram method based on smaller building elements, such as architectural details or even the dimensions of particular ashlar blocks (Pakkanen 2002, 2004). In Inca architecture, the typical architectural elements occurring nearly in every building, regardless of its function, are niches and windows openings located on the walls' inner faces. When reconstructing the method of walls erection, a clear alignment of stone layers at the level of the base of the niche can be seen (Fig. 9.13). Further on, in several places, at the threshold level of niches, traces are extant, indicating that the builders intended to set up niches in a precisely planned location—likely determined by some measurements (Fig. 9.14).

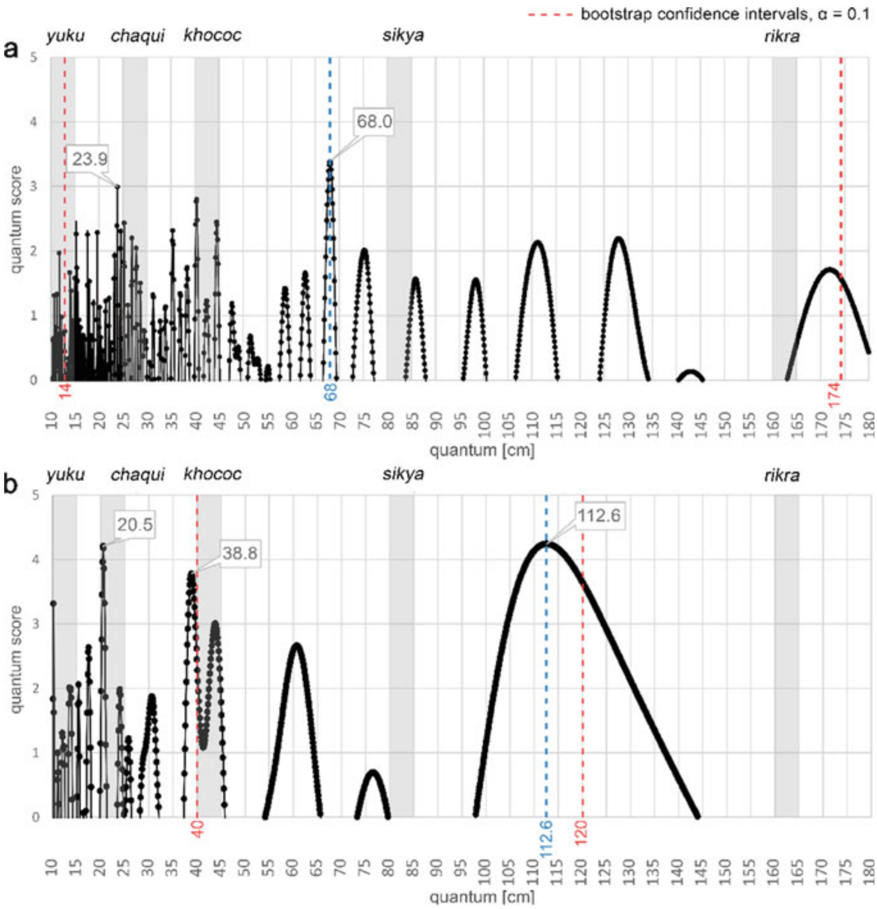

Fig. 9.12 Results of cosine quantogram analysis for building outlines in sector 6B for a sample of 20 dimensions. Known and expected Inca measuring units are marked in grey; **a**. buildings outlines, **b**. front walls and door openings. Elaborated by A. Kubicka

Further studies concentrated then on niches and windows' widths and distances between them. Measurements were gathered from 13 building sectors. Each group varied in terms of the number of measurements collected. The smallest sample consisted of not less than 40 measurements, while the most abundant one reached over 240. Since the niches are the smallest elements of Incas stones masonry, the search value range was set between 5 and 80 cm.

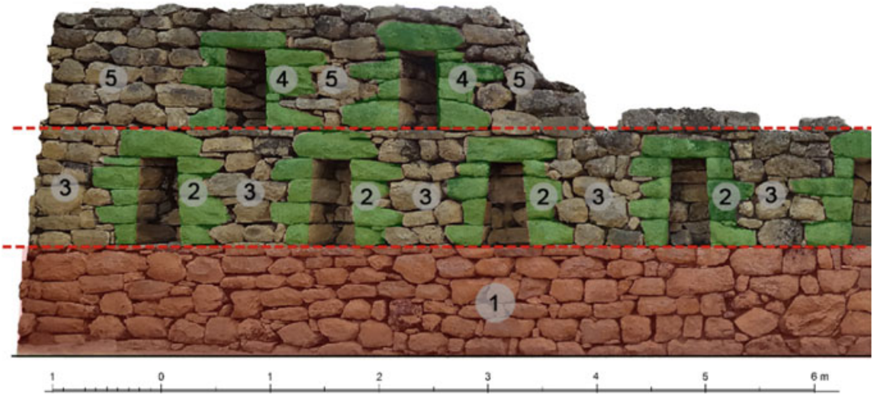

Fig. 9.13 The wall of the Great Kallanka in Sector 5D. Numbers correspond with subsequent technological phases of the wall erection process. Drawing by A. Kubicka

Fig. 9.14 The corner of a niche threshold in Sector 6B. Photo by A. Kubicka

The discovered quanta varied in each sector (Kubicka 2019; Kubicka and Kasiński 2020). Generally, two types of quanta are present. The first group fits well-known Inca measuring units suggested by other authors, as summarised in Table 9.1. A good example is the results of niches? analysis in Sector 1C (Fig. 9.15). The second cluster of detected basic unit is less compact and does not represent known and expected Inca measuring units, as in Sector 5C_1 (Fig. 9.16).

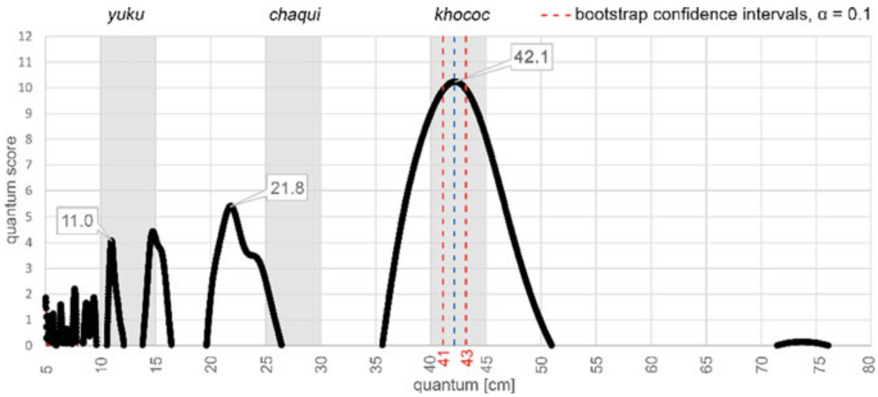

Fig. 9.15 Llaqta Machupicchu. Quantum detected for niches in sector 1C. Known and expected Inca measuring units are marked in grey. Elaborated by A. Kubicka

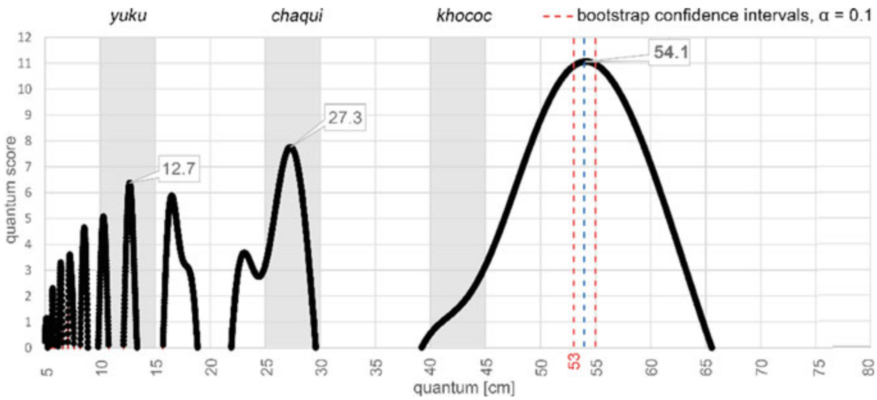

Fig. 9.16 Llaqta Machupicchu. Quantum detected for niches in sector 5C-1. Known and expected Inca measuring units are marked in grey. Elaborated by A. Kubicka

A similar analysis of the smallest architectural elements was carried out for the length of ashlars in the so-called Principal Temple. In this case, 137 measurements were collected, and their analysis indicated 54 and 108 cm as the most probable quanta (Fig. 9.17).

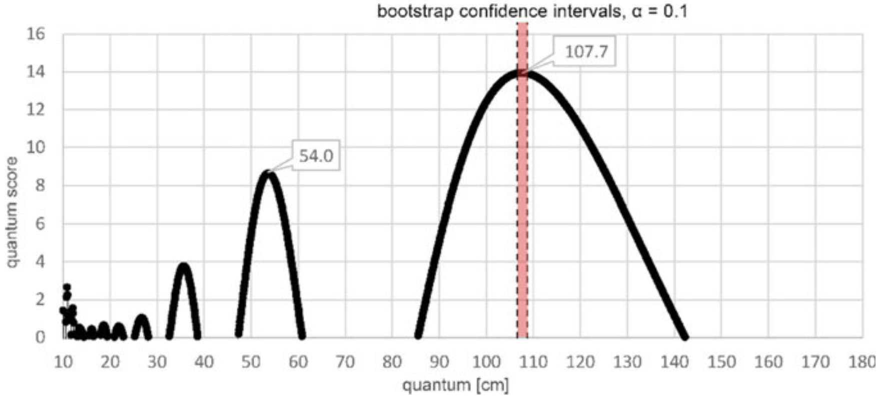

Fig. 9.17 Quantum estimation for a series of 137 stone block length measurements at the Teplo Principal. Elaborated by A. Kubicka

9.3.2 Chachabamba

As opposed to the Llaqta Machupicchu site, analysis of buildings' outlines from the Chachabamba central sector brought more precise results. For a small sample of 20 measurements, a quantum of 107 cm has been identified (Fig. 9.18). However, the cosine quantogram analysis of 39 niches from buildings of the central sector yielded different results. There, quanta of 13, 21 and 42 cm were detected (Fig. 9.19).

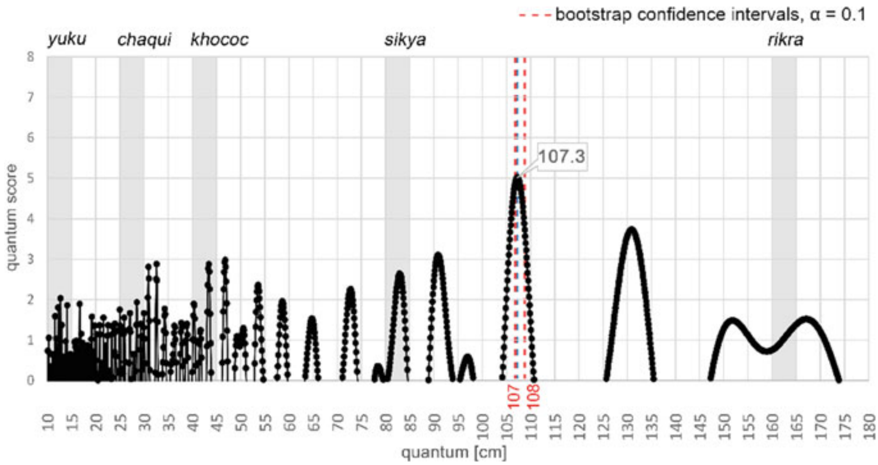

Fig. 9.18 Chachabamba, central sector. Quantum detected for building outlines. Known and expected Inca measuring units are marked in grey. Elaborated by A. Kubicka

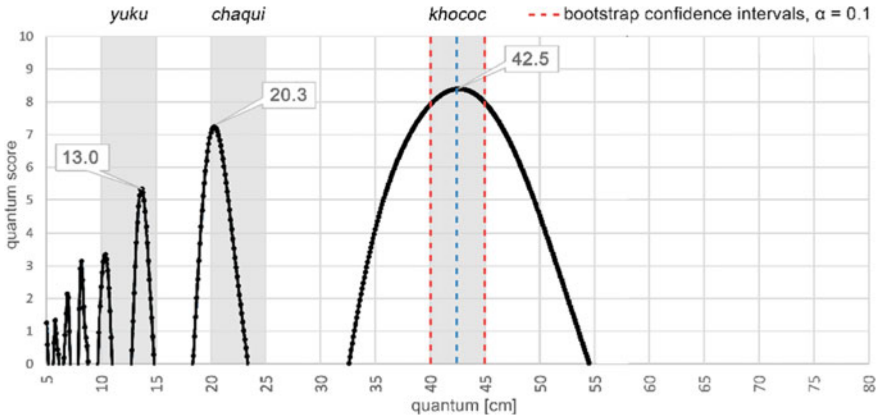

Fig. 9.19 Chachabamba, Central Sector. Quantum detected for niches. Known and expected Inca measuring units are marked in grey. Elaborated by A. Kubicka

Surprisingly, the analysis of the dimensions of the niches in the four ritual bath complexes (31 niches measured) showed a still different quantum of 26 cm (Fig. 9.20).

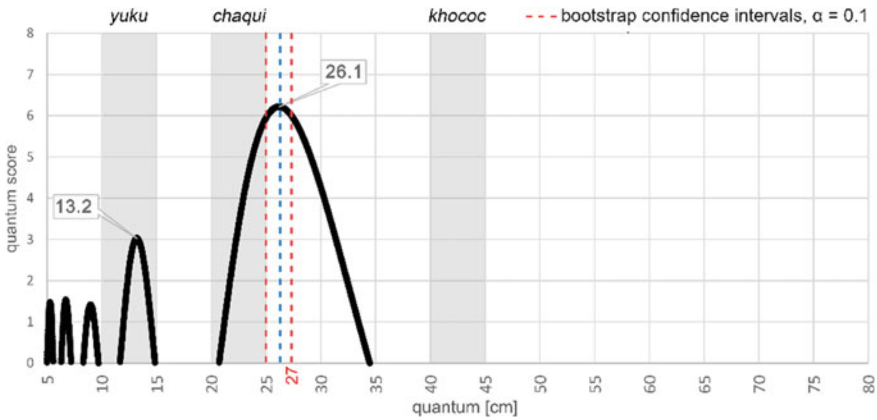

Fig. 9.20 Chachabamba, ritual bath. Quantum detected for niches. Known and expected Inca measuring units are marked in grey. Elaborated by A. Kubicka

9.3.3 El Fuerte De Samaipata

In El Fuerte de Samaipata, when comparing the dimensions of all the recesses in the wall in Sector W09, the results are inconclusive. However, if we limit our investigation only to the small inner recesses, the resulting quantogram matches measurement units typical for Group 50. The two nearly equal scores of cosine quantogram function were discovered for units of 51.8 cm and 103.3 cm (Fig. 9.21).

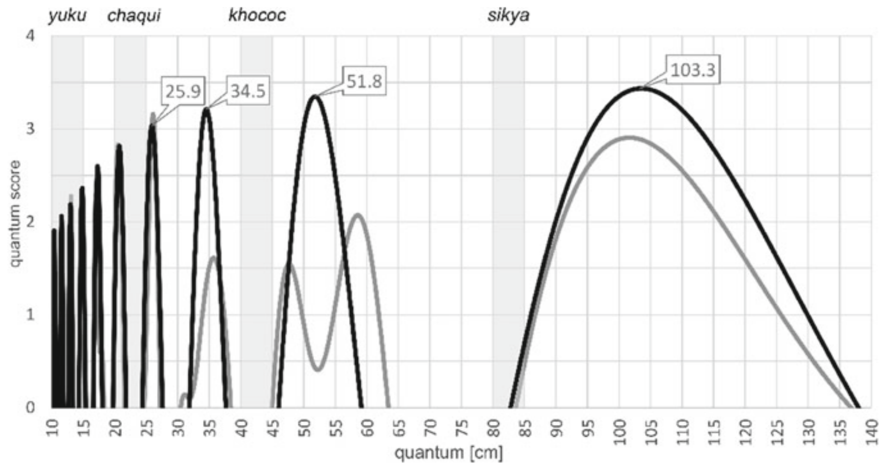

Fig. 9.21 El Fuerte de Samaypata, Sector S10. Quanta detected for wall recesses. Known and expected Inca measuring units are marked in grey. Elaborated by J. Kościuk

Metrological analysis of the width of the niches and the distances between them in the so-called Temple of Five Niches (Sector N08) indicate that in the process of their planning, a basic unit of measurement was used whose metric value corresponds to 54.5 cm.

In Sector S10, when applying the cosine quantogram method for analysing distances between grooves marking the edges of future big niches and the distances between the centres of the small square niches below, we find a standard unit of measurement of 50.4 cm, which might have been used to layout their plan (Fig. 9.22).

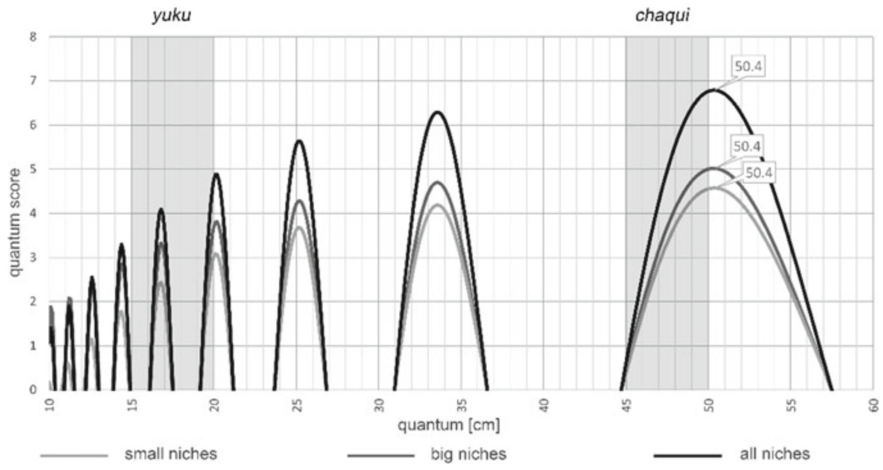

Fig. 9.22 El Fuerte de Samaypata, Sector S10. Quanta detected for niches planned niches. Known and expected Inca measuring units are marked in grey. Elaborated by J. Kościuk

9.3.4 Coricancha Temple

Three different quanta estimations were made for the Coricancha Temple: for the main perimeter walls of the entire temple, R2 and R3 building outlines, and niches of the so-called Enclosure of Stars (R3 building). The discovered quanta were, respectively, 164.9 cm (Ziółkowski and Kościuk 2018, 28, table 3), 164.5 cm (see the introduction to this chapter) and 10.5 cm (Fig. 9.23).

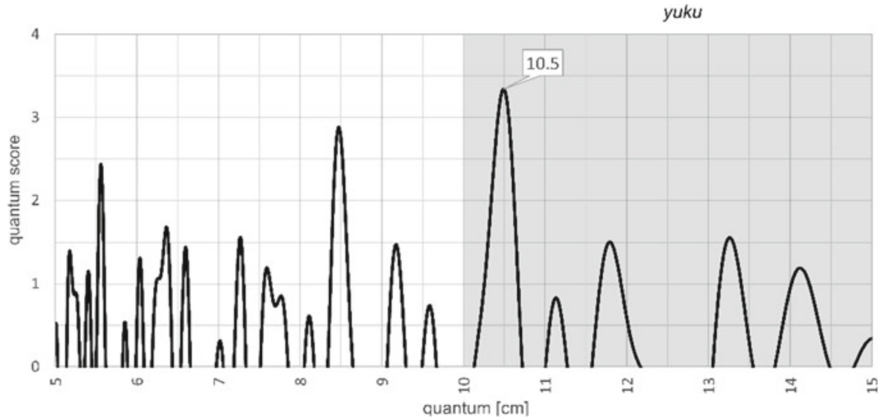

Fig. 9.23 Quantum estimation for the niche with the window of Coricancha R3 building. Known and expected Inca measuring units are marked in grey. Elaborated by J. Kościuk

9.3.5 Summary of results

The summarised results of quanta estimations give a complicated picture (Table 9.6). Across all the sampled buildings, no clearly visible common measuring unit shows up. Instead, the results represent a mixture of already known measuring units and others not fitting to any known Inca metrological system. Especially striking is that in some Llaqta Machupicchu sectors, it was impossible to detect any common measuring units for building outlines or at least their front walls. However, they clearly show up in Chachabamba central sector buildings and the Coricancha Temple. For single walls from El Fuerte de Samaipata, building outlines analysis could not have been done due to the insufficient sample size—the cosine quantogram method.requires a minimum sample of a dozen or so elements.

Table 9.6 Summarised results of quanta estimation

Site		Detected quanta [cm]	
		Buildings' outlines and fronts	Niches or recesses
Llaqta Machupicchu	Sector 1A	42.7 146.5	47.0
	Sector 1B_1	Undetectable	13.7
	Sector 1B_2	Undetectable	43.0
	Sector 1B_3	45.7 52.0	26.9
	Sector 1C	55.3 157.7	42.0
	Sector 1D	81.0	41.6 81.0
	Sector 5B	104.0 156.3	Undetectable
	Sector 5C_1	42. 3 55.7	54.0
	Sector 5C_2	180.4	39.9
	Sector 5D	58.4 157.5	41.0
	Sector 5E	80.9	44.1
	Sector 6B	113.0	49.8
	Sector 6C	Undetectable	50.3
	Sector 6D	52.2 116.6	44.5
Coricancha Temple	Buildings R2 and R3	164.5 164.9	10.5
Chachabamba	Central Sector	107.0	42.0
	Ritual Baths	not analysed	26.0
El Fuerte de Samaipata	Wall in Sector W09	not applicable	51.8
	Temple of Five Niches	not applicable	54.5
	Wall in Sector S10	not applicable	50.4

9.4 Discussion

Preliminary evaluation of quanta estimation for Llaqta Machupicchu buildings (Kubicka 2019, 164–175) suggested that we deal with two groups of values of measures that ancient builders could have used. In the first one, the quantum value is in the range of 40–45 cm, and in the second, 50–55 cm. For the sake of simplicity, in the following description, we will call them Group 40 and Group 50, respectively.

In order to verify the hypothesis that there are indeed two different quanta groups, a separate analysis has been done. Data from individual sectors were assigned to each hypothetical group, and a separate cosine quantogram analysis was performed for each group. The quantum search range was set to 10–100 cm with a sampling density of 0.1 cm. The bootstrap confidence interval was calculated for each of the estimates at the 95% confidence level, with a thousand-fold sampling. The obtained results confirm the hypothesis that there are indeed two separate quanta groups (Fig. 9.24).

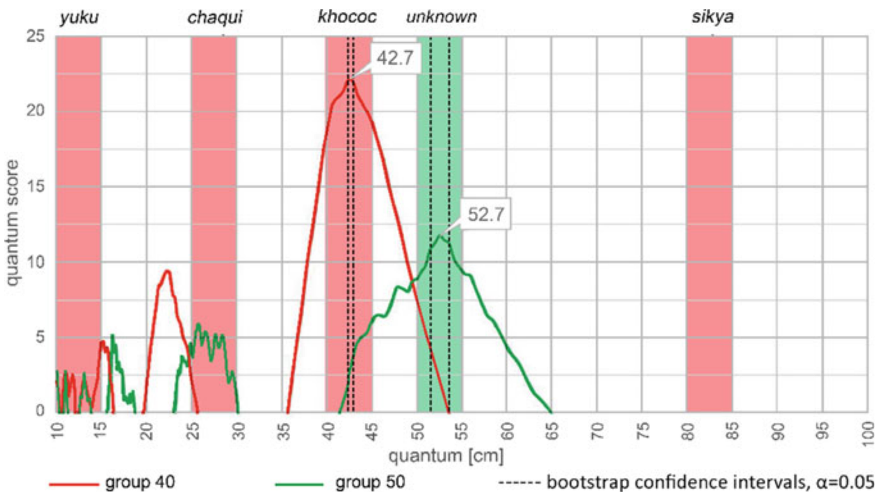

Fig. 9.24 Cosine quantogram estimation for combined quanta attributed separately to Groups 40 and 50. Elaborated by A. Kubicka

Group 40 includes dimensions derived from the basic unit whose metric equivalent is around 42 cm—according to many authors (Table 9.1) this value corresponds to the Inca measure of *khococ* (cubit), and the whole system is based on the multiplication or division of the basic unit by factor 2. As Marcia and Robert Aschers' (1997) studies on *quipus* suggest that the idea of multiplication and division operations, also by fractional parts, was no stranger to Inca mathematics—at least to Inca accountants (*quipucamayoc*).

For Group 50, we suggest the length of the basic unit as 54 cm—a value which differs from *khococ* and is not mentioned so far in the Inca metrological studies. However, if we apply to this unit, the principle of multiplying and dividing by factor 2, the resulting series of dimensions will contain a value of 27 cm known as the Inca *chaqui* unit (Table 9.1). There also dimensions as 13.5, 108 and 216 cm will be present, all until now not mentioned in previous studies on Inca metrology, but corresponding with the results cosine quantogram analysis of Llaqta Machupicchu sectors (Table 9.6). In this context, it seems reasonable to say that we are dealing with two separate systems of Inca measures (Fig. 9.25).

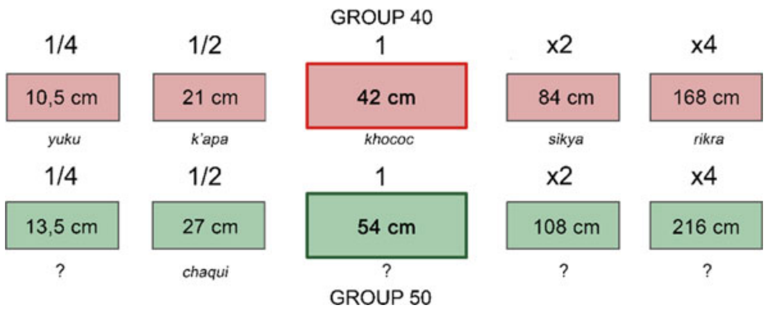

Fig. 9.25 Two proposed systems of Inca length measures. Elaborated by A. Kubicka

We must also emphasise that the results of the basic unit's estimations derived for particular sectors of Llaqta Machupicchu differ. This strongly suggests that a measure based on a common, physical standard was not used here. Instead, each time an individual builder set the measuring unit according to the proportions of his body. Both systems seem to be based on two cubit standards—the longer (Group 50) which corresponds to the length of the forearm with the outstretched palm and the shorter (Group 40) which may correspond to the length of the forearm with the clenched fist.

At this point, an association with the ancient Egyptian measurement system may come to mind. There were also in use two-length measurement systems based on two different cubit standards—the *short* (or small) *cubit* corresponding to ca. 45 cm (Clagett 1999), and the so-called *royal cubit* with metric equivalent of between 52.3 and 52.9 cm (Rossi 2007).

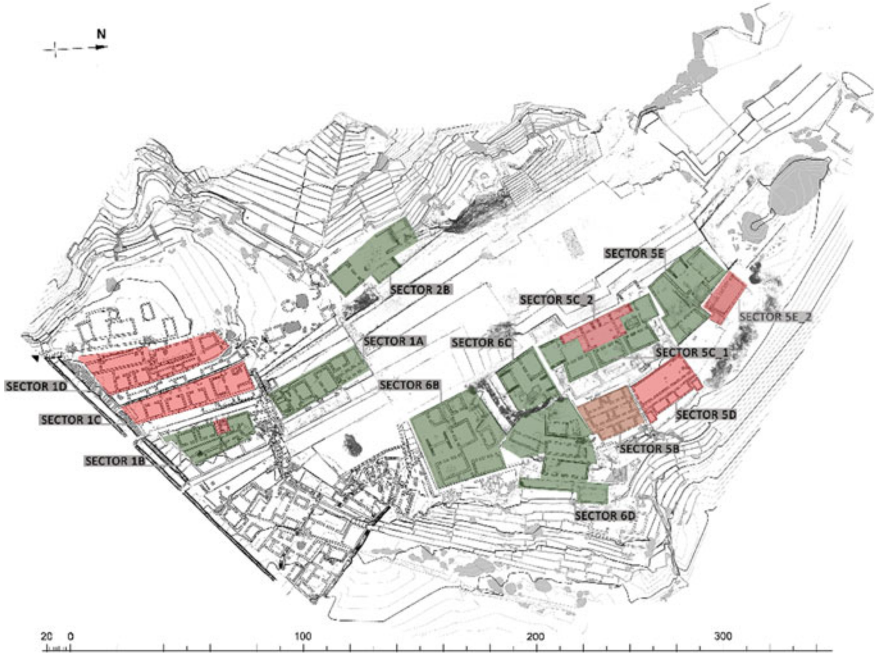

Fig. 9.26 Two quanta groups identified in specific Llaqta Machupicchu sectors. In red—Group 40; in green—Group 50; in brown—quanta undetectable on niches. Elaborated by A. Kubicka

Another interesting question relates to possible relations between the adopted standard and the function, type of stonework or the location of the analysed sectors of Llaqta Machupicchu. As Anna Kubicka proves in her doctoral dissertation (Kubicka 2019, 175, Table 18), such a relationship is clearly visible (Fig. 9.26). Quanta belonging to Group 50 were detected in higher prestige buildings (intended for the Inca elite or serving for ritual purposes) with a polygonal, layered or pseudo-layered (with a variable height of layers) stonework. In turn, Group 40 of quanta is present in buildings of lower prestige (buildings intended for craftsmen, servants and warehouses) with significantly inferior quality of stonework (less processed or rough stone blocks with mortar visible in the joints).

However, such a coherent picture is disturbed by the data from Chachabamba. While the outlines of the four most important Central Sector buildings indicate the use of Group 50 measures, the niches in these buildings were designed according to quanta belonging to Group 40 (Table 9.7). The situation is further complicated because in the case of niches in four ritual bath complexes, Group 50 measures have been used.

Table 9.7 Summarised results of quanta estimation from different sites

Site		Detected quanta [cm]	
		Buildings outlines	Niches or recesses
Llaqta Machupicchu	Buildings of a higher prestige	Group 50 if detectable	Group 50
	Less important buildings	Group 40 if detectable	Group 40
Chachabamba	Central Sector buildings	Group 50	Group 40
	Ritual Baths	not analysed	Group 50
Coricancha Temple	Perimeter walls and buildings R2 and R3	Group 50 (?)	Group 40
El Fuerte de Samaipata	Wall in Sector W09	not applicable	Group 50
	Temple of Five Niches	not applicable	Group 50
	Wall in Sector S10	not applicable	Group 50

The metrological analysis of the Coricancha Temple yields similar results. Quanta discovered in perimeter walls of the temple, and the outlines of buildings R2 and R3 are statistically closer to Group 50 (164.5 and 164.9 cm, respectively), while analysis of niches shows evident correlation with Group 40 (10.5 cm). In turn, the three examples analysed on El Fuerte de Samaipata consistently indicate the use of measures belonging to Group 50.

Comparative analyses, although still insufficient, obscure the coherent, as it would seem, picture that emerged from Llaqta Machupicchu metrology studies. Although in the case of prestigious buildings outlines, cosine quantogram analysis still indicate the use of measures belonging to Group 50, the analysis of niches in such buildings gives us contradictory results. As in the case of Llaqta Machupicchu, quanta from Group 50 are present there, but at the same time, measures indicating that the niches were planned based on Group 40 units show up.

It is also difficult to answer why no consistent quanta were found for some sectors of the Llaqta Machupicchu, while in the case of Coricancha Temple and Chachabamba, the analysis of the outlines of the buildings gave very unambiguous results. Perhaps the reasons are in a different topographic situation. Both the Coricancha Temple and the buildings of Chachabamba Central Sector were erected on almost flat terrain, while in the case of the Llaqta Machupicchu, builders often had at their disposal only narrow terraces on a steep slope. So, perhaps they did not mark out the plan of the erected building with the use of some or the other measures but utilised all the available space.

9.5 Conclusions and Future Works

To conclude, we must state that indeed two different metrological systems based on two different anthropometric measures are present in Inca architecture. However, many specific issues require further studies. First of all, comparative studies should cover a much larger number of archaeological sites. Only this way gives a chance to explain the critical problems that are only indicated here. The most important are the answers to the following questions:

- Is it possible to trace back the origin of both measurement systems? For example—preliminary analysis of publicly available Kalasasaya 3D laser scanning data (CAST 2005) indicates a high probability that quanta from Group 50 are present there.
- Can the presence of any of the systems (separately or both together) be related to the dating of the examined buildings?
- Does either of the measurement systems show any regional or ethnic correlations?
- Is the correlation between quanta of Group 50 and buildings of greater prestige (and better stonework) found on Llaqta Machupicchu can also be confirmed in other archaeological sites?
- Could the suggestion of a relationship between the topography of the site and the use (or not) of standard measures be confirmed by a broader study of buildings' outlines on steep slopes and narrow terraces?

In light of the questions posed above, the study presented here should be seen not as final conclusions but rather as an indication of areas for further research and appropriate methodology.

9.6 Epilogue

Let us return at the end to the Inca Yupanque cord as described in the introduction to this chapter in the quoted passage of Juan de Betánzos chronicle. If we accept that such a cord existed, was it actually a measuring instrument and not only a simple device to set out the straight lines on the ground? If it's the first, what were the principles of its "construction"?

In light of the results presented in this study, and especially the principle of multiplying or dividing consecutive units by factor 2, subsequent folding of the cord in half could determine partial measuring units. They might have been marked, for example, by fringes of coloured wool. This procedure could be repeated several times.

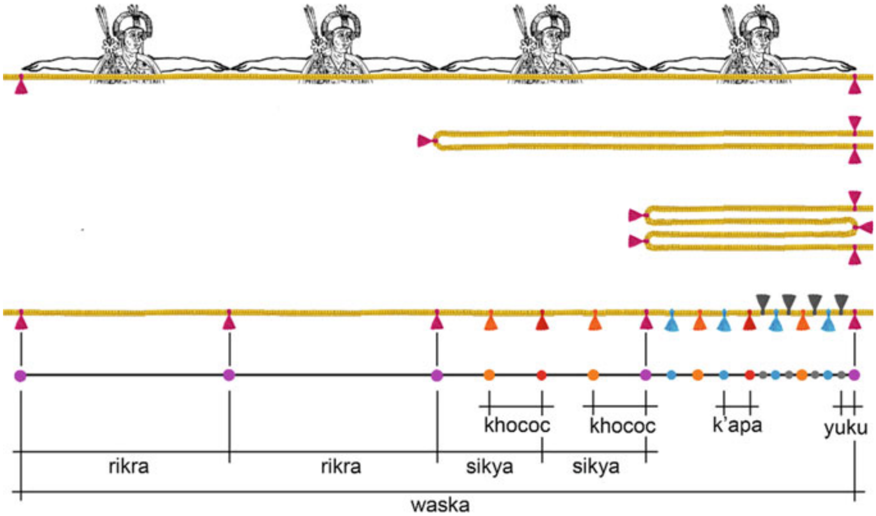

Fig. 9.27 Hypothetical reconstruction of the measuring cord principle. The cord and fringes are not shown in scale. Elaborated by J. Kościuk

Let us take, for example, a cord of a length equal to four times outstretched arms, that is, of one *waska* (around 672 cm). By folding it twice in half, we get the equivalent of a length unit known as *rikra* (168 cm). By folding again in half, we will get successive smaller and smaller units: *khococ* (42 cm), *k'apa* (21 cm) and finally *yuku* (10.5 cm). The *ñañu waska* (de González Holguín 1608, 206), an instrument constructed in such a way allows measuring distances consisting of any combination of all six basic units of measure known to us from historical sources (Fig. 9.27). However, such a measuring cord would be impractical for measuring the smallest units (*k'apa* or *yuku*). A rod or stick of a certain length, perhaps copied from our measuring cord, would be much handier.

When assessing the practical side of the use of such measuring instruments, it is worth referring again to ancient Egypt. Shorter dimensions were measured with rods, numerous examples of which have survived to this day and are exhibited in many museums (Fig. 9.1). For longer distances knotted cords of rope were used, similar to the *ñañu waska* proposed here. Although no such measuring ropes have survived in Egypt, their existence and use are well confirmed in iconography. For example, on the scenes from the tomb of Menna in Thebes, as well as in the tombs of Amenhotep-Sesi, Khaemhat or Djeserkareseneb, and also on the statues of New Kingdom officials such as Senenmut, Amenemhet-Surer or Penanhor (Rossi 2007). Of course, this is not a proof that such measuring ropes were actually used in the Inca Empire, at best it is an evidence of their practical usefulness.

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References

Agurto Calvo S (1987) Estudios aserca de la construcction arquitectura y planeamiento incas. Lima

Ascher M, Ascher R (1997) Mathematics of the Incas: Code of the quipu. Dover, New York

Bastante Abuhabda JM, Sieczkowska D, Deza A (2020) Investigaciones En El Monumento Arqueológico Chachabamba. In: Bastante Abuhabda JM, Astete Victoria F (eds) Machupicchu Investigaciones Interdisciplinarias, vol. II, Lima, pp 289–304

Baudin L (2003) Daily life of the Incas. Dover Publications, Mineola, New York

Bennet WC (1949) Numbers, measures, weights and calendar. In: Steward JH (ed.) Handbook of South Americans Indians, vol. 5, Washington, pp 601–619

Betanzos Juan de, Hamilton R, Buchman D (1996) Narrative of the Incas. University of Texas Press, Austin

CAST (2005) Internet source: https://core.tdar.org/sensory-data/391584/survey-of-the-kalasasaya-monument-tiwanaku-bolivia-using-the-optech-ilris-3d. Accessed: 20 Jan 2021

Clagett M (1999) Ancient Egyptian science: a source book. Vol. III: Ancient Egyptian Mathematics, Memoirs of the APS, vol. 232. American Philosophical Society, Philadelphia

Cobo B ([1980] 2005) History of the Inca Empire. Hamilton R (trans. and ed.). Austin.

Farrington I (1984) Medidas de tierra en el Valle de Yucay. Cusco, Gaceta Arqueológica Andina 11:10–11

Farrington I (2013) Cusco: urbanism and archaeology in the Inka world. Gainesville.
de González Holguín D (1608)Vocabulario de la lengua general de todo el Peru. Lima. Internet source: https://archive.org/details/vocabulariodelal01gonz/page/n3. Accessed 8 Nov 2017
Hewson AD (1980) The Ashanti weights - a statistical evaluation. J Archaeol Sci 7(4):363–370
Kendall DG (1974) Hunting quanta. Phil Trans R Soc Lond, A, Math Phys Sci 276(1257):231–266
Kubicka A (2017) The metrological research of the Machu Picchu site. Application of a cosine quantogram method for 3D laser data, ACTA IMEKO 6(3):52–56
Kubicka A (2019) Zastosowanie metody cosine quantogram do analizy metrologicznej kompleksu Machu Picchu/Application of a cosine quantogram method in the metrological analysis of the Machu Picchu settlement. PhD Thesis. Faculty of Architecture, Wrocław University of Science and Technology, Wrocław.
Kubicka A, Kasiński M (2020) The metrological research of Machu Picchu settlement: application of a Cosine Quantogram Method for 3D Laser Data, Proceedings of the 2017 Computer Applications and Quantitative Methods in Archaeology Conference (CAA 2017), pp 87–97
Kościuk J (2012) Modern scanning in modelling, documentation and conservation of architectural heritage, keynote lecture, In: Jasieńko J (ed), Structural analysis of historical constructions. Wrocław, pp 64–76
Kościuk J, Orefici G, Ziółkowski M, Kubicka A, Muñóz Risolazo R (2020) Description and analysis of El Fuerte de Samaipata in the light of new research, and a proposal of the relative chronology of its main elements. Architectus 2(62), https://doi.org/10.37190/arc2
Lee V (1996) Design by numbers. Architectural order among Incas. Wilson.
Müller R (1929) Die Intiwatana (Sonnenwarten) im alten Peru mit 8 Abbildungen und 6 Figuren. Baessler-Archiv. Beitäge zur Völkerkunde, Band XIII, Maass A (ed.), Berlin 1929, pp 178–187. Internet source: https://www.digi-hub.de/viewer/fullscreen/1500547264653/492/
Müller R (1972) Sonne, Mond und Sterne über dem Reich der Inka. Springer-Verlag Berlin – Heidelberg
Pakkanen J (2001) Deriving ancient foot units from building dimensions: a statistical approach employing cosine quantogram analysis. In: Burenhult G, Arvidsson J (eds.), Archaeological informatics: pushing the envelope, Proceedings of the 29th CAA conference 2001, pp 501–506
Pakkanen J (2002) The temple of Athena Alea at Tegea: revisiting design-unit derivation from building measurements. In: Ostby E (ed) Third international seminar on ancient arcadia, Held at the Norwegian Institute at Athens, Athens, pp 167–183
Pakkanen J (2004) The temple of Zeus at Stratos: new observations on the building design, Acta Philologica Fennica, vol. 38, Helsinki, pp 95–121
Rossi C (2007) Architecture and mathematics in Ancient Egypt. Cambridge University Press
Rostworowski de Diez Canseco M (1960) Pesos y medidas en el Peru Pre-Hispanico. Lima.
Rowe JH (1946) Inca culture at the time of the Spanish conquest. In: Steward JH (ed.) Handbook of South American Indians, vol 2. Washington, pp 183–330
Sieczkowska D, Bastante Abuhabda JM (2021) Las Phaqchas de Chachabamba (Parque Arqueológico Nacional de Machupicchu, Perú). Arqueologia Iberoamericana 47:91–101
s.n. (2015) Inca metronomy – an intersection of cultural elements. Internet source: http://www.electrummagazine.com/2015/03/inca-metronomy-an-intersection-of-cultural-elements/. Accessed: 12 May 2016.
Ziółkowski M, Kościuk J (2018) Astronomical observations in the Inca Temple of Coricancha (Cusco)? A critical review of the hypothesis. Teka Komisji Architektury, Urbanistyki i Studiów Krajobrazowych, Lublin 14(1):7–33

Chapter 10
Research at the Chachabamba Archaeological Monument

José M. Bastante, Dominika Sieczkowska, and Alexander Deza

Abstract The Chachabamba archaeological monument is located in the Historic Sanctuary—National Archaeological Park of Machupicchu (SHM-PANM). Excavations during the 2016 and 2017 seasons in the ceremonial sector defined constructive stages and changes in their functions. The objective of this work is to present the results of the two excavation seasons at the site. The comparative analysis of photos from the Paul Fejos expedition of 1941 and the actual condition show recent changes to the site has undergone through time.

Keywords Chachabamba · Inka · Ceremonial · Inka architecture · Apu

10.1 Introduction

The Chachabamba archaeological monument is a unique and extraordinary site due to its location and the unique example of *Inka* architectural and engineering knowhow. This *Inka* site is located at kilometer 104 of the Cusco-Hidroeléctrica railroad, on an alluvial terrace on the left bank of the river Vilcanota, between UTM coordinates E:769,857.294 and N:8,540,895.682, at an average altitude of 2172 masl according to the geodesic plate No. 50. This area corresponds to the eco zone Very Humid Low Subtropical Mountain Forest (bmh-MBS). Chachabamba is defined to the north by Vilcanota River, to the east with Inkaqhawarina hill, to the south with the archaeological monument Condorpata I and towards the west with the micro-basin of

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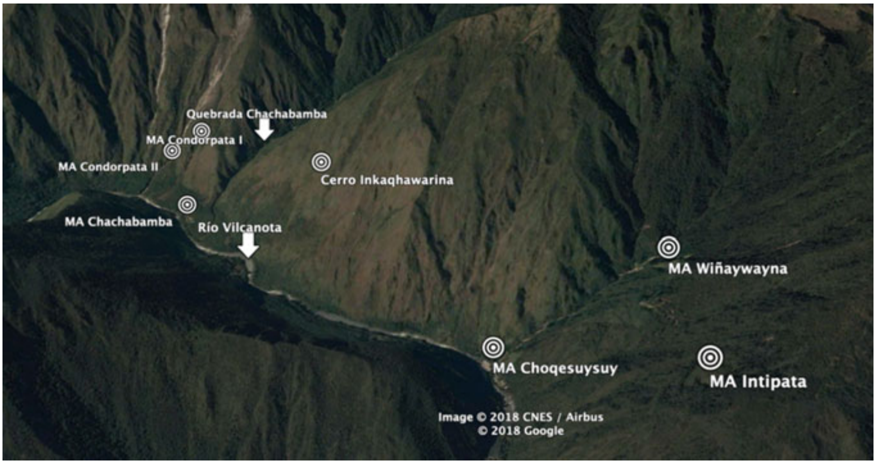

Fig. 10.1 Google Earth image with the location of the Chachabamba archaeological monument in relation to the Condorpata I and II, Choqesuysuy, Wiñaywayna, Intipata, the Chachabamba ravine, the Vilcanota river and the Inkaqhawarina hill

Chachabamba. Its strategic location is related to the sacred characteristics of the surroundings, highlighting the confluence between the Chachabamba stream and the Vilcanota River (Fig. 10.1).

Since 2016, Chachabamba has been researched by the Archaeological and Interdisciplinary Research Program in the Historic Sanctuary of Machupicchu (PIAISHM) with the support of the Center for Andean Studies of the University of Warsaw in Cusco (CEAC). During the *Inka* era, this monument was interconnected with other sites present in the SHM-PANM through the Inka trail on the left bank pf the Vilcanota River (which has collapsed partially) and by the right bank road through a bridge at km 104 (that the constant flooding of the Vilcanota River has significantly affected). The site has a direct relation with the Choqesuysuy archaeological monument, through a pre-Hispanic road, which presents a length of 2135 m and runs parallel to the river; with the Wiñay-wayna archaeological monument through a section of 4308 m in length; and with the Condorpata I archaeological monument, by a section of 440 m long.

10.2 Sectorization

The Chachabamba archaeological monument is divided into four sectors that overs an area of 27 861.29 m^2 (Fig. 10.2). Sector I or Ceremonial covers an area of 3501.16 m^2, and presents a central plaza associated with three *wayrana*, which form a *kancha* on which north side there is a *waka* composed of a partically carved boulder shrine of granitic rock with a series of steps and two carvings in the shape of altars

Fig. 10.2 Sectorization of the Chachabamba archaeological monument and excavations of the PIAISHM in 2016 and 2017 seasons

(Fig. 10.3), presenting also fine and rustic masonry on three of its sides. In addition to those structures, there was originally a gnomon thought not in its original position (Fig. 10.4). For its part, the open side of the *waka* face towards the plaza in the south and is visually related to the Salkantay snow peak (Fig. 10.5), one of the most powerful deities in the region. The relationship between the carved altar and the peak of Salkantay can be seen in a macro-regional context (Gose 1993). This means that the location, and later the functional adaptation, of the ceremonial altar was intentionally oriented towards the most important regional deity. Thus, the builders responsible for the planification of the site decided to use a natural boulder and transform it into an altar, like in numerous other Inka sites. The effect of the Inka planification can be observed via the intentional orientation of the altar in the direction of Salkantay through the pass behind which the snow peak is located. The direction of the opening of the altar towards this deity also marks the first axis of the complex construction. The other buildings were erected around two plazas and placed in line forming the traditional kancha complex. The described axis corresponds to an approximate north to south orientation (the arrow in Fig. 10.2 indicates the orientation of the *waka* towards Salkantay).

Fig. 10.3 The main *waka* of the Ceremonial Sector. Photograph by José Bastante

Towards the south of the central *kancha*, an additional *kancha* exists and it is composed by buildings that include niches and wide doorways, while on the east and west sides of both *kancha* there are fourteen water baths (Figs. 10.6 and 10.8), seven on each side, associated with sunken plazas (*plazas hundidas*) that flanks the sector. This sector has a connotation of sacredness, which is reflected in the planification, orientation, and density of certain structures compared to other sites in the area. The water system surrounding the main ceremonial complex highlights both the ceremonial and political role of the site. However, ideologically it also emphasizes the control of water (Gose 1993), which in this case is unique because it flows from the Salkantay snow peak.

The *wayrana* between the two *kanchas* share a dividing wall (Fig. 10.6) and reflects the most important axis according to the orientation of the site from east to west. Looking to the west from this location, one can observe the Intipata archaeological monument (Fig. 10.7). It is possible that this area corresponds to the beginning of the site construction, because the density of early materials is greater than in other intervened areas. The theory is also reinforced by the presence of artifacts and the number of distinguished archaeological levels during excavations which are supported by radiocarbon dating (Ziółkowski et al. 2020).

Sector II covers an area of 7277.06 m^2 and is located to the southeast of the monument and to the south of sector I. It is made up of a sequence of retaining walls and platforms.

There are circular, semi-circular structures and square (Fig. 10.2) while some of them are still covered by vegetation.

Fig. 10.4 The *waka* with the gnomon on the back and in its possible original position Photograph from 1941 by Paul Fejos

Sector III corresponds to the space between the path that leads to the Choqesuysuy site, to the north, and the road that leads to Wiñaywayna, towards the east. It covers an area of 10 085.66 m^2, and includes platforms and structures covered by vegetation.

Finally, sector IV occupies 6997.41 m^2 and is located in the northwest part of the site. This sector is made up of a sequence of platforms and retaining walls which ascend from the bank of the Vilcanota River to the road that leads to the Wiñaywayna archaeological monument. In this sector, there is architectural evidence of fine masonry corresponding to the channeling of the Chachabamba stream (Figs. 10.8 and 10.9).

10.3 Background

Before the research at the Chachabamba monument, the PIAISHM team conducted a search for reports and publications concerning the site. The first reference to Chachabamba has been found in a document from 1568 published by John Rowe. In this colonial administrative document the existence of the site is indicated, among

Fig. 10.5 Orientation of the open side of the *waka* towards the direction of the Salkantay. Photograph was taken from *waka* to south direction by José Bastante

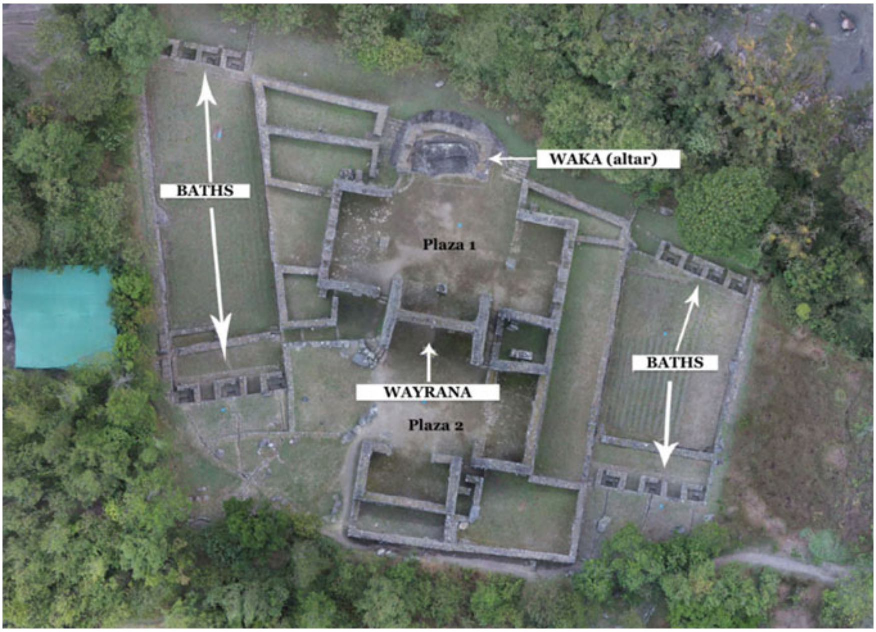

Fig. 10.6 Ceremonial (I) sector. Ortophoto by Cesar Medina, PIAISHM archives

Fig. 10.7 The Intipata archaeological monument, the only site visible from Chachabamba. Photograph by José Bastante

Fig. 10.8 Baths from the bottom of sector I (UE 01-2016). Photograph by Emerson Pereyra, PIAISHM archives

Fig. 10.9 Chachabamba stream channelling wall. Photograph by Dominika Sieczkowska

others, as “Chuchobanba” or “Chuchobamba”, on the left bank of the Vilcanota river. These areas would have been conquered by Inka Pachakuti and where part of his property (Rowe 1990: 152, 154). However, as we have highlighted in other publications, the interests of the informants may have biased their answers (Bastante 2016).

Between July 20th and the 30th of October of 1941, work was conducted in the area of Chachabamba under the direction of Paul Fejos through the Wenner Viking Fund Expedition. The study was limited to “… clearing and to the excavation of the baths and terraces, the latter being done in a search for water channels supplying the baths. In the time available, it was possible to clear only a part of the site, and its full extend is not known…” (Fejos 1944: 37). Although, the work of this expedition was limited to the clearing and documentation of the Inka Trail sites, in the specific case of Chachabamba, it is not clear if excavations were executed and what was their extension (Fejos 1944: 37). After Fejos, Margaret Greenup MacLean was the next person to visit the site, however, her observations did not include new archaeological research. She employed the results of the studies conducted by Fejos and Rowe, and supported her work with observations from field prospecting in the region (MacLean 1987).

In 1995, the maintenance and conservation team of the PANM carried out cleaning and rehabilitation of the pre-hispanic road section from Chachabamba to Wiñay-wayna, including restitution work in the sections where there was still evidence of the original path. Moreover, during the following year, restoration works were conducted in the section on the *Inka* Trail from Piskakucho to Chachabamba, and were directed by Oscar Chara and Miguel Chávez (1996). Between September and December 1996, the National Institute of Culture also carried out restoration work, which included consolidation, restitution and protection of the walls of the central *wayrana* and of building N° 01; removal and clearing of vegetation in general; and covering of the clandestine excavations located in the ceremonial sector. Furthermore, nine excavation units (UE) were conducted for restoration purposes (Quirita 1996).

The recovered material was limited to one hundred fragments of Inka pottery, mostly from domestic objects, although there is no detailed report on this evidence. Quirita concluded that there is only evidence of an Inka occupation and that Chachabamba monument served as an articulation point for the transport of food. Also, she noticed the presence of traces of plaster in certain walls, determined the inclination of walls, and defined the foundation levels in relation to the original floors that were presented in almost all UE (Quirita 1996). Between January and May 1997, Quirita continued with the archaeological excavations for the purpose of restoration and enhancement of the site. Finally, the rehabilitation work of the Chachabamba-Wiñaywayna road was concluded (Cabrera 2006). This road is currently available for tourists for the one-day version of the Traditional *Inka* Trail.

10.4 Archaeological Research in the Seasons 2016 and 2017

During 2016, seven UE, that covered a total area of 322.81 m^2, were excavated. In 2017 six UE were excavated covering a total area of 382.03 m^2 (Fig. 10.2). Due to the proximity to the Vilcanota River, and the existence of a road on the right bank (which served as a mule track and on which the railway was built) treasure hunters had permanent access to the site. These activities affected the site until the middle of the 20th century. The excavations of the PIAISHM during both seasons and the characteristic architectural features of Chachabamba have allowed us to obtain valuable information regarding the use and function of the Ceremonial sector.

According to the results for each UE (with the exception of the EU06-2017), the architecture of the monument corresponds to a system characterized by two stages with continuous sequences of construction for each architectural space. The first stage corresponds to the original architectural design and the second corresponds to a modification of the first stage and to the raising of the floor level as part of a process of changes in the functionality.

Though while there is no perimeter wall surrounding the structures (Hyslop 1992: 151) and these are accessible from different sides, the morphology of the two spaces is classified as *kancha* (Hyslop 1990; Protzen 2005).

Excavation units UE01-2016 and UE03-2016 revealed that the two groups of baths located at the end of the main *waka* present a subterranean drainage system with similar characteristics (Figs. 10.10 and 10.11). The peculiar architectural typology, individual access and privacy of these structures, demonstrate their importance for ceremonial use in ablution rituals. The data obtained in the excavation areas corroborates the sophisticated level of *Inka* engineering for management and transport of water during the Late Horizon. At the same time, it represents an ideology according to which water control was the highest possible form of political power (Gose 1993).

Fig. 10.10 Orthoimage of UE01-2016. Elaborated by Dominika Sieczkowska

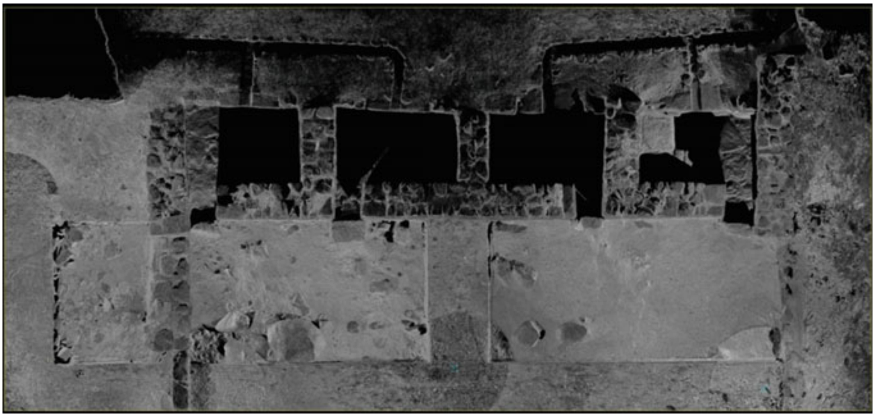

Fig. 10.11 Results of 3D laser scanning of the UE01–2016 carried out by the Laboratory of 3D Scanning and Modelling at Wroclaw University of Science and Technology in collaboration with CEAC UV. Elaborated by Bartłomiej Ćmielewski

During the 2017 research season, remote sensing was carried out at the site under the direction of Nicola Masini et al. (2018). The use of GPR equipment made it possible to establish that in the space between the western fountains, in the area of the so-called *plazas hundidas*, there were probably baths that are currently underground. Remote sensing results have determined that in the area between the upper and lower baths there was a hydraulic system built in an earlier construction phase of the site. These hypotheses were partially confirmed by archaeological excavations made in the same year in the upper baths (Sieczkowska and Bastante 2021).

During the excavation at UE05-2017, traces of channels were found, suggesting that the original design of the channels was modified. Moreover, the underground wall evidenced during the excavation of UE07-2016 does not correspond to the existing structures, but instead to forms of primitive *Inka* structures (Fig. 10.12). The evidence suggests that there was not a permanent occupation, however, on one of the original floor levels, clear signs of use were documented and associated with pottery fragments of the Late Horizon. Furthermore, chemical analysis by X-ray fluorescence of a the *tupu* found on this EU revealed that was composed of a copper-silver alloy and created using casting and hammering technique (Fig. 10.13).

Fig. 10.12 Underground wall corresponding to the initial stage of construction of the monument. Photograph by Emerson Pereyra, PIAISHM archives

It is likely that the initial constructions in Chachabamba were basic, while monumental structures were included during the second construction phase. This would have involved a redesign through the leveling of spaces followed by the construction of the present-day visible structures, and enclosing the *waka* with fine masonry walls on three of its sides.

This construction sequence shows how modifications altered the original design and/or the reuse of previous structures occurred, as has been reported in settlements on the right bank of the Vilcanota river basin.

In the case of the channels, the water supply origin is located in the Chachabamba stream, which, through the partially documented main line, the water is transported to the terraces and baths. Evidence of channeling of the Chachabamba stream was also found towards the west of the monument, close to the encounter with the Vilcanota river (Dominika et al. 2022). The *kancha* of the second plaza is related to the platform and, the latter articulates with the channels and the baths. This connection defines that no space worked independently. The architectural characteristics of the building, open spaces, and the water system suggest that the functions of the place were related to textile production, preparation of food, and ceremonial activities.

As in other monuments in the area, due to the environmental conditions and the acidity of the soil, the conservation of organic remains is deficient. However, between the second plaza (UE01-2017) and the platform (UE03-2017) pottery spindle whorls (*fusayolas*) were found, some with incised decoration (Fig. 10.14) and others made from reused fragments.

Fig. 10.13 The *Tupu* recovered in the EU07-2016. Photograph by Emerson Pereira, PIAISHM archives

These findings, and the architectural characteristics, support the theory that textile production took place at Chachabamba. According to Vásquez's analysis (2017), the carbonized remains found in UE03 and UE05 correspond to *Zea mays* (corn) and species of trees and plants that would have been used for wood and medicinal properties, such as *Polylepis sp.*, *Juglans sp.*, *Cedrella sp.*, *Alnus sp.* and *Schinus molle*; the latter two species also are used for the dyeing of textile fibers (Mostacero et al. 2009: 81, 85, 292, 464).

The analysis of the recovered pottery fragments from the monument allowed the identification of a varied typology, mainly corresponding to closed vessels. A decontextualized bronze knife was also recovered from UE02-2016, suggesting that this space would have accommodated ritual activities around the waka and that the sector I was also used for the preparation of food and drinks (Fig. 10.15) (Alconini 2013: 282). The same type of fragments was found in association with fragments of the Altiplano Pacaje or Inka-Pacaje style, similar to samples found by the Peru Yale Expedition (EPY) of 1912 in the llaqta of Machupicchu (Salazar 2004: 45; 2007: 173). This suggests the presence of *mitma* from Collasuyu in the area.

Fig. 10.14 *Fusayola* or spinning wheel. Photograph by Emerson Pereira, PIAISHM archives

Fig. 10.15 Location of the UE02-2016 in relation to the main *waka*. Photograph by Emerson Pereyra, PIAISHM archives

The excavations conducted in sector I also uncovered an obsidian slab (UE03-2017) and lithic hammers of different sizes (UE01, UE02, UE03, UE07-2016; UE01, UE02, UE03, UE04, UE05-2017). Based on the traces of use in such, it was possible to determine that some were used for stonework, while others were related to the preparation of food. Also, abundant preforms and a zoomorphic schists pendant were found (UE01, UE03, UE06-2017), which evidences the production of objects in this material, as in other monuments in the area.

The research conducted during 2016 and 2017 seasons, also allowed for establishing the presence of plaster, that is still visible in some niches, windows and walls that were not intervened with restorative work. A photograph of Fejos (1944) shows the plastering on the east wall of building 8, although due to natural phenomena and anthropogenic influence is hardly noticeable (Figs. 10.16, left and right). These findings suggest that a large part of the enclosures—mainly in their internal walls—were plastered in red and/or yellow colors, as in the case of the llaqta of Machupicchu. Conversely, in ceramic fragments recovered from the excavations, Vásquez (2017) identified starches from *Zea mays* (corn), *Manihot esculenta* (cassava), *Solanum tuberosum* (potato) and a phytolith of *Cucurbita sp.* (pumpkin), indicating the type of diet of the inhabitants of Chachabamba, which was most likely based primarily on corn, as was the case for the inhabitants of the llaqta of Machupicchu (Burger, Lee-Thorp and Van der Merwe 2003: 125–137; Burger 2004: 89–90) and the Choqesuysuy archaeological monument. These findings suggest that the population of Chachabamba had access to resources from various ecological floors and, it is likely that most of the production of the agricultural areas of the site corresponded to corn used for consumption and offerings.

Fig. 10.16 Comparative analysis of the plaster in the niche of the structure 08 (plaza 1). Left: 1941 photograph by Paul Fejos; Right: 2017 photograph by Dominika Sieczkowska

Fig. 10.17 The *wayrana* in sector I with the enclosed windows taken in 1941 by Paul Fejos

Finally, an extensive analysis of the photographs taken during Fejos' expedition during 1941, has made it possible to determine that, the windows and doors in sector I of Chachabamba, were intentionally filled and closed with rocks (Fig. 10.17). This process most likely occurred due to the abandonment of the region around the second half of the 16th century. A similar situation may have occurred in the llaqta of Machupicchu, as suggested in the study of 19th-century references, specifically to the following statement of Augusto Berns: "[...] While looking about one day I came upon the old city where the Inca gold and silver smiths lived. The building of stone are there all complete but their entrances have been all blocked up by stones built carefully into the wall" (1881).

10.5 Conclusion

The archaeological research conducted at Chachabamba has allowed us to form initial hypotheses concerning its function. Although the assumption that the site only functions as a stopover has been rejected, it is still unclear the complexity of the ritual activities that occurred in the ceremonial sector. The presence of artifacts related to textile production and architectural structures without an open wall indicates that textiles were made at the site. Moreover, the focal point of the entire site is the *waka*, i.e. the altar directed towards *Apu* Salkantay. This relationship, between the waka and the *Apu*, is considered to be the main axis of the entire complex. The high density of ritual baths around the central sector indicates that, in addition to rituals related to the *waka*, purification ceremonies, i.e. ablutions occurred. The results of this study clarify certain issues concerning the sacrality of the site, allowing us to consider Chachabamba as one of the most important satellite sites of the *llaqta* of Machupicchu.

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Photos from the expedition of Viking Fund (now Wenner-Gren Fundation) led by Paul Fejos (1940–1941) were obtained as part of the research grant Preludium 19 no. 2015/19/N/ HS3/03626 "Armakuna: ritual functions of the inca 'baths' in the Chachabamba ceremonial complex (Historic Sanctuary of Machu Picchu, Peru)" of the Polish National Science Center; such photos correspond to Figs. 10.4, 10.10, 10.16 and 10.17 of this article. We would like to thank the Metropolitan Museum of Art in New York City, the Department of The Michael C. Rockefeller Wing for permission to use archival photographs from the Viking Fund expedition led by Paul Fejos in 1940–1941. Within the framework of the Preludium project, photograph documentation of water system elements and a short-range photogrammetry of water structures during the process of excavation was made.

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Bibliography

Alconini S (2013) El territorio Kallawaya y el taller alfarero de Milliraya. Evaluación de la producción, distribución e intercambio interregional de la cerámica inka provincial. Chungara 45(2):277–292

Bastante J (2016) Investigaciones Interdisciplinarias En La Llaqta de Machupicchu. Arqueología y Sociedad 32:267–276

Berns A (1881) Carta sin destinario, Biblioteca Nacional del Peru

Burger R (2004) Scientific insights into daily life at Machu Picchu. In: Burger RL, Salazar LC (eds) Machu Picchu unveiling the Mystery of the Incas. Yale University, New Haven, pp 85–106

Burger R, Lee-Thorp J, Van Der Merwe N (2003) Rite and crop revisited: an isotopic perspective from Machu Picchu and beyond. In: Burger RL, Salazar LC (eds) The 1912 Yale Peruvian Scientific Expedition Collections from Machu Picchu: human and animal remains. Yale University, New Haven, pp 119–137

Cabrera D (2006) Rehabilitación del camino sagrado Chachabamba Wiñaywayna. INC, Cusco

Chara O (1996) Obra: camino sagrado del inca. Proyecto 502004. INC, Cusco

Dominika S, Bartłomiej Ć, Krzysztof W, Dąbek PB, Bastante JM, Izabela W (2022) Inca water channel flow analysis based on 3D models from terrestrial and UAV laser scanning at the Chachabamba archaeological site (Machu Picchu National Archaeological Park Peru). J Archaeol Sci 137:105–515. https://doi.org/10.1016/j.jas.2021.105515

Fejos P (1944) Archaeological Explorations in the Cordillera Vilcabamba Southeastern Perú. Viking Fund, New York

Google Earth (2018) [Monumento arqueológico de Chachabamba] [image]. Google Earth.

Gose P (1993) Segmentary state formation and the ritual control of water under the Incas. Comp Stud Soc Hist 35(3):480–514

Hancco S (1996) Investigación del conjunto arqueológico Chachabamba. Proyecto: 502004 Monumentos Arqueológicos. INC, Cusco

Hyslop J (1990) Inka Settlement Planning. University of Texas Press

Hyslop J (1992/1984) Qhapaq Ñan, el Sistema Vial Inkaico. Lima: Instituto Andino de Estudios Arqueológicos y Petróleos del Perú

Maclean, MG (1987) Sacred land, sacred water: inca landscape planning in the Cuzco Area. Berkeley

Masini N, Capozzoli L, Romano G, Sieczkowska D, Sileo M, Bastante J, Astete Victoria F, Ziółkowski M, Lasaponara R (2018) Archaeogeophysical-based approach for inca archaeology: overview and one operational application. Surv Geophys 39(6). https://doi.org/10.1007/s10712-018-9502-2

Mostacero J, Mejia F, Gamarra O (2009) Fanerógamas del Perú: taxonomía, utilidad y fitogeografía. Concytec, Lima

Protzen J-P (2005) Arquitectura y Construcción Incas En Ollantaytambo. Fondo Editorial de la Pontifica Universidad Católica del Perú

Quirita A (1996) Conjunto arqueológico de Chachabamba. Informe final de obra. INC, Cusco

Quirita A (1997) Conjunto arqueológico de Chachabamba. Informe final de obra. INC, Cusco

Rowe J (1990) Machupicchu a la luz de los documentos del siglo XVI. Revista Histórica XIV(1):139–154

Salazar L (2004) Machu Picchu: mysterious royal estate in the cloud forest. In: Burger RL, Salazar LC (eds) Machu Picchu. Unveiling the Mystery of the Incas. Yale University, New Haven, pp 21–48

Salazar L (2007) Machu Picchu's silent majority. A consideration of the inka cemeteries. In: Burger RL, Morris C, Matos Mendieta R (eds) Variations in the expression of inka power. Dumbarton Oaks, Washington, pp 167–185.

Sieczkowska D, Bastante J (2021) Las *phaqchas* de Chachabamba (Parque Arqueológico Nacional de Machupicchu, Perú). Arqueología Iberoamérica 47:91–101. https://doi.org/10.5281/zenodo.4572882

Vasquez V (2017) Informe: análisis arqueobotanico de materiales procedentes de las intervenciones del PIAISHM en los monumentos arqueológicos Choqesuysuy, Salapunku y Chachabamba [report]. SHM-PANM, Cusco

Ziółkowski M, Bastante Abuhadba J, Hogg A, Sieczkowska D, Rakowski A, Pawlyta J, Manning SW (2020) When did the Incas build Machu Picchu and its satellite sites? New approches based on radiocarbon dating. Radiocarbon. Cambridge University Press, pp 1–15

Part III
New Results from Archaeological and Historical Investigations

Chapter 11
Machu Picchu: Interdisciplinary Research

José M. Bastante, Alicia Fernández, and Fernando Astete

Abstract This article is the product of the work of the Archaeological and Interdisciplinary Research Program in the Historic Sanctuary of Machupicchu (PIAISHM) and shows the new sectorization of the *llaqta* of Machupicchu. In addition, the following is presented: the results of the archaeological excavations of the 2017 season both in the *llaqta* and in the Mandor archaeological monument; considerations regarding the inhabitants of the *llaqta*; the products that were consumed in the *llaqta* based on the archaeological botanical studies; the list of Inka bridges over the Vilcanota River in the area of the present Historic Sanctuary-National Archaeological Park of Machupicchu (SHM-PANM); the *llaqta* of Machupicchu.

Keywords Machupicchu · Inka · Roads · Bridges · Monuments · Diet · Construction History

The *llaqta* of Machupicchu is located on a rugged esplanade, or ridge-line at an altitude of 2435 m above sea level.[1] Its boundary to the north is with the Waynapicchu mountain, to the south with the Machupicchu mountain, to the east with the Putukusi mountain, and to the west with the Wiskachani or San Miguel mountain (Fig. 11.1). The material used for the construction of the *llaqta* of Machupicchu and a large part of the archaeological monuments of the SHM-PANM is primarily grayish-white

[1] Corrected height of geodesic plate No. 150 /located in the Main Square of the *llaqta* of Machupicchu.

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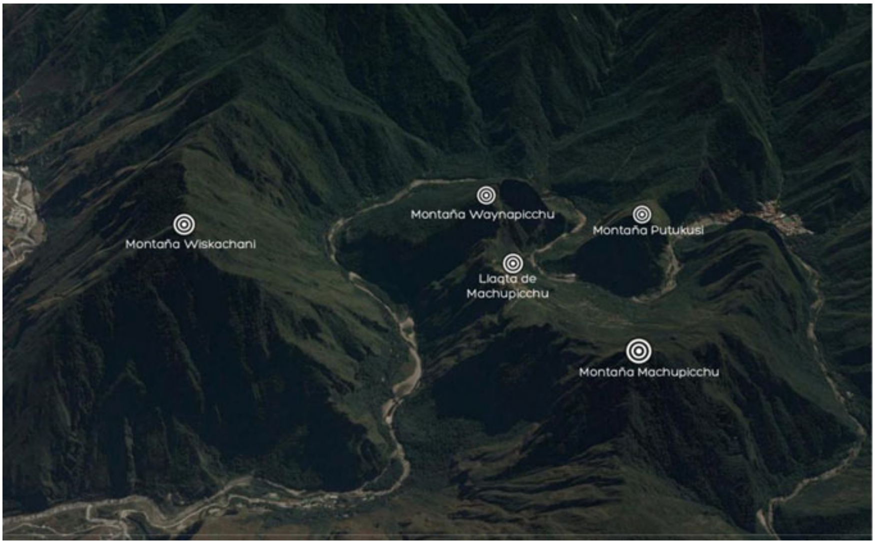

Fig. 11.1 Location of the *llaqta* of Machupicchu in relation to the tops of the surrounding mountains (*Source* Google Earth 2018)

granite, and, to a lesser extent, granodiorite and shale. Granite, with its respective variants, has been used for buildings, such as enclosures, platforms, and *phaqcha* (water fountains), among other constructions, which for the most part, constitute irregular, rustic buildings with stones edged and joined with clay mortar. Up to twenty types of masonry have been registered in the *llaqta*, with a percentage of structures made of fine construction—where the granite used was specially chosen in certain quarries—as in the case of the House of the Inka and a number of temples, including: the Principal, Three Windows, and the Sun Temple. The latter is one of the finest examples of advanced Inka stone construction and architecture, comparable to the Qorikancha ("Temple of Gold/Sun"), in Cusco.

11.1 Present Sectorization

The sectorization of the site used by the PIAISHM is based on that presented in the Master Plan of the Historic Sanctuary of Machu Picchu (2005–2010), although some modifications of a technical nature have been made. According to this, the nuclear area of the *llaqta* of Machupicchu occupies approximately ten hectares and includes some 193 enclosures (Bastante 2016: 268). This area is divided transversely—through the Dry Moat[2]—into the Agricultural and Urban zones, while

[2] It is drawn in a northeastsouthwest direction, it is formed along a geological fault and has the function of runoff drainage.

the dual (moiety) division of the nuclear area, known as *hanan* ("upper") and *hurin* ("lower"), whose division is the Main Plaza (Fig. 11.2), divide the site longitudinally. Adding in the annexed zones (III-Eastern Andenes; IV-Manuel Chávez Ballón Site Museum [MSMCB]; V-Machupicchu Mountain; and VI-Waynapicchu Mountain), the total area of the *llaqta* is approximately 711 hectares (Fig. 11.3).

11.1.1 Zone I (Agricultural)

Located to the south, it covers an area of approximately 43,572 m^2 and is divided into three sectors that include: terrace systems, ceremonial platforms, the water supply channel, several *waka* ("sacred places"), the major *kallanka* (long, rectangular ceremonial structure), and some *qolqas* (storage buildings), among other precincts (Table 11.1).

11.1.2 Zone II (Urban)

Located to the north and composed of housing and ceremonial enclosures, platforms, canals, square plazas, *phaqcha* and *waka*, among other elements. Its six sectors cover an approximate area of 5.4 ha (Table 11.2).

11.1.3 Zone III (Eastern Andenes-*Terraces)*

Zone III is located northeast of the *llaqta* of Machupicchu. This zone covers an approximate area of 23.5 ha and is made up of six sectors. From sector I to V, a perimeter retaining wall is projected as a platform around terraces, which had a double function: as a zone for cultivation and for site containment. This platform system was built following the topography of the land and the sectors are articulated along a main road and alternate roads that descend from the *llaqta* until they reach the lower part of sector VI, where there was a bridge that connected the main road with the road on the right bank of the Vilcanota river. The six sectors are as follows:

– Sector I. Made up of a series of seventeen platforms, associated with a phaqcha located in the lower part, as well as platforms, access openings and a series of stairways associated with water collectors.
– Sector II. Made up of a series of ten platforms of a greater height and width compared to those in sector I; these are articulated with entrances, water collectors and stairways with *sarunas* (flying steps).
– Sector III. Made up of a set of nineteen platforms, where—as in the previous sectors—there are road platforms and water dispersers to drain internal seeps,

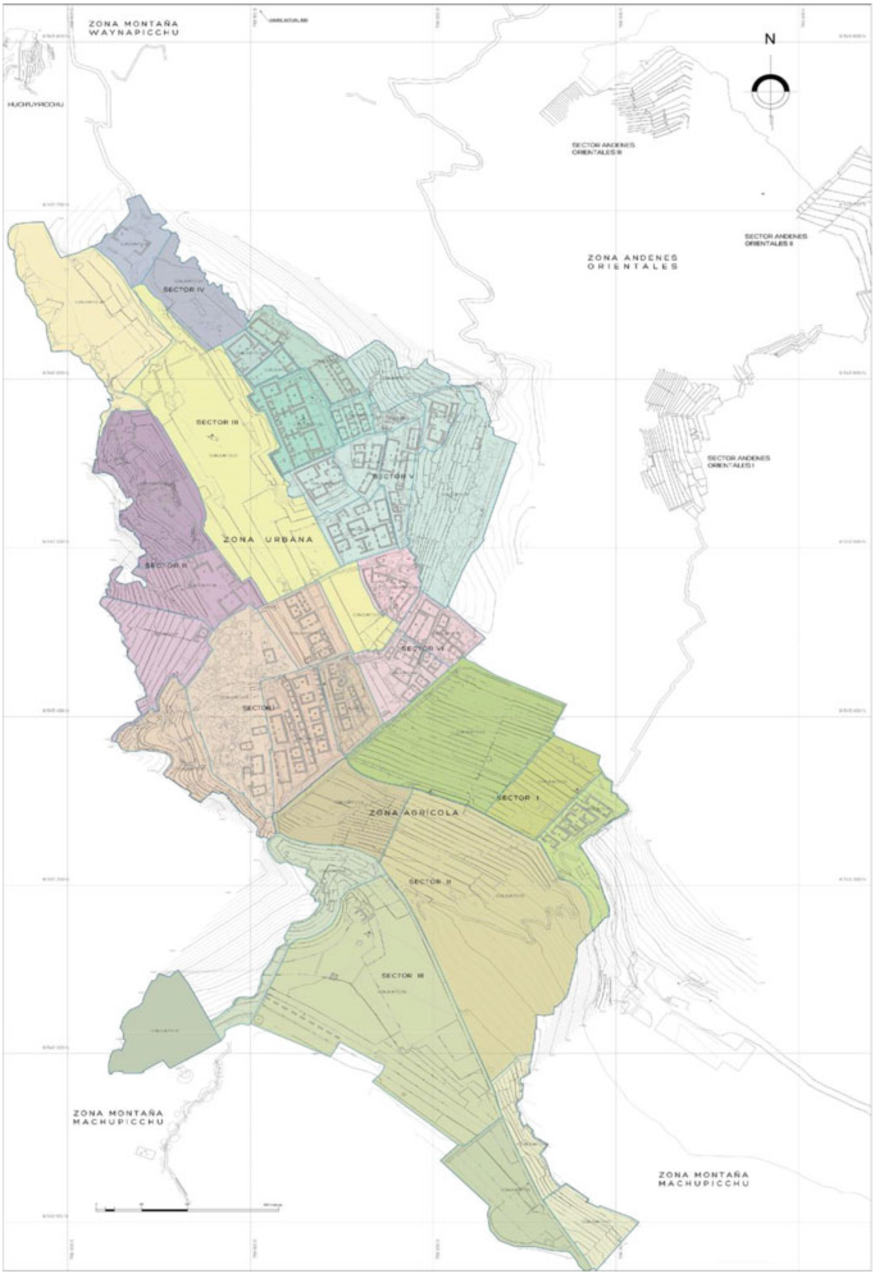

Fig. 11.2 Plan of sectorization of the core area of the *llaqta* of Machupicchu (*Source* PIAISHM)

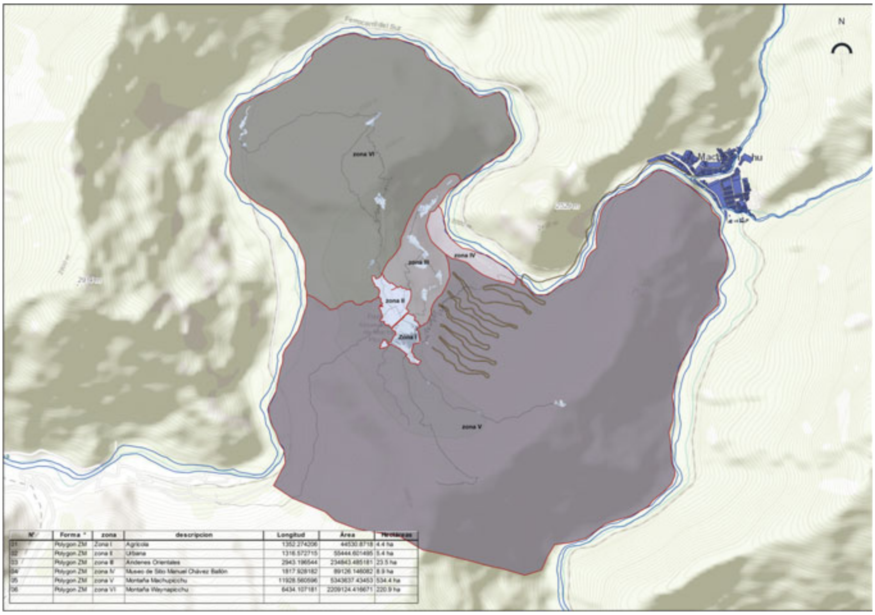

Fig. 11.3 Plan of the annexed sectors of the *llaqta* of Machupicchu (*Source* PIAISHM)

Table 11.1 Sectors of Zone I (Agricultural)

Sector	Aproximate Area (in m^2)	Number of Architectonic Ensembles
I	9857	3
II	16,153	4
III	17,562	4
Total	43,572	11

Table 11.2 Sectors of Zone II (Urban)

Sector	Aproximate Area (in m^2)	Number of Architectonic Ensembles
I	11,698	5
II	7912	3
III	14,331	3
IV	2963	2
V	14,907	13
VI	3598	3
Total	55,275	29

which follow in the direction of the geological fault and on down into the Vilcanota River. In the upper part of this sector, there are enclosures in the manner of a *wayrana*, and there is a *phaqcha* located in the lowerintermediate part.

– Sector IV. This sector covers an area greater than the previous ones. It is made up of a set of four platforms on the south end, while on the north end there is a set of sixteen platforms. These structures are articulated with a series of stairways, path platforms, channels, rainwater collectors and two *phaqcha*, distributed as follows: section C records two *phaqcha*, section E records a series, or set of four *phaqcha*.
– Sector V. Made up of sixteen platforms, it includes stairways, accesses and path platforms, as well as a dry moat (under construction). In the upper intermediate part, there is a fine masonry structure suitable as a rock shelter and another one towards the southern end of the sector, which, unlike the previous one, is composed of rustic masonry.
– Sector VI. Located in the lower part of the zone. It is made up of a large number of platforms covered by vegetation. The original line of the path that articulates sectors V and VI is projected along the slope of the Waynapicchu mountain. This path later articulates with a fine masonry structure associated with a path platform in whose lower part there is a total of fifteen steps carved on the surface of the rocky outcrop. A fine masonry wall was also built on the latter surface, approximately 20 m from the bed of the Vilcanota River.

11.1.4 Zone IV (Manuel Chávez Ballón Site Museum, MSMCB)

This zone is located on the left bank of the Vilcanota River, at km 112 of the Cusco-Hidroeléctrica railway. During 1996, archaeological excavations were carried out—under the direction of Julio Masa—in order to identify or disconfirm the existence of archaeological evidence relating to a plan for the expansion of the MSMCB. In 2014, the PIAISHM carried out archaeological investigations, defining three Inka platforms with an approximate width of 13 m and a dry moat that crosses them in a southwest-northeast direction. The area has been affected due to constant intervention, including land removal and the extraction of construction materials (e.g., sand and gravel). Within its limits, there is the MSMCB building and the botanical garden. This zone covers an area of approximately 8.9 ha.

11.1.5 Zone V (Machupicchu Mountain)

This zone covers an area of approximately 534 ha. It comprises the entire Machupicchu mountain and the sectors associated to it. It is made up of numerous structures, including platforms, rectangular and semicircular enclosures, as well as viewing sites located along the path that projects from the top of the agricultural area of the *llaqta* of Machupicchu. During the last prospecting work undertaken by the PIAISHM, two roads were identified, one that articulates the archaeological monument of Wayraqtambo with the top of Machupicchu mountain, and one that runs along the east side of the mountain with the Tambo sector of zone V. This zone comprises the following sectors:

- Sector I (Intipunku). Located to the northeast of the *llaqta* of Machupicchu, it includes a platform on which were built rectangular-shaped enclosures of rustic masonry construction and with irregular joins on trapezoidal spans and niches. There are also two groups of semicircular platforms located on each side of the road, which projects towards the *llaqta* of Machupicchu.
- Sector II (Tambo). This sector corresponds to a grouping of structures in which a *kancha* and two rectangular-shaped enclosures located on both sides of the road stand out. One of the enclosures has a front wall and a waka composed of alveoli and other carvings shown as altars. The second enclosure is a *wayrana* that probably had the function of controlling entrance to the *llaqta* of Machupicchu. There are also stairways which are connected to the path that is projected on the eastern slope of the Machupicchu mountain.
- Sector III (Pachamama). This sector is located 400 m from the Tambo sector and corresponds to a waka—located towards the left side of the road—represented by an outcrop shaped as a *wanka*, or rocky eaves. The access is traced through the intermediate part of the terrace platforms and the walls are of rustic construction. In this sector, the access road was carved on the rock surface, including stairways that are projected in the direction of the *llaqta*. Additionally, a series of quilcas (stone markings, or petroglyphs) relating to ritual activities have been registered.
- Sector IV (Inka Bridge). Located on the line of the road that is projected from the south side of the *llaqta*. This sector is made up of the route of the road associated with numerous platforms and an area of clustered constructions along the right side of the road. Another of its characteristics is a lateral wall along the precipice side of the road, constituting a protective ledge that, in some segments, exhibits windows located a few centimeters from the level of the road.
- Sector V (Wayraqtambo). Corresponds to the archaeological monument Wayraqtambo I, located in the southern part of the Machupicchu mountain. In this sector there is evidence of pre-Hispanic constructions within a space that articulates the various roads.
- Sector VI (Machupicchu). This sector corresponds to the roads that ascend to the top of the Machupicchu mountain associated with such sites as a shale quarry, enclosures and viewpoints.

11.1.6 Zone VI (Waynapicchu Mountain)

This zone covers an area of approximately 220 ha. It comprises the entire Waynapicchu mountain up to the entrance to sector IV of the Urban zone. In its upper part, there are enclosures, a complex system of terraces, carved caves and the path that projects towards the top of the mountain made up of numerous stairways. From the top, the path is projected to the western flank in the direction of the Great Cavern sector. Part of the structure of this path is a complex succession of stairways, some of whose sections display steps carved into the surface of the outcrop. This area is attributed an astronomical, ceremonial and control function due to its strategic location, the nature of the enclosures and the type of architecture found here. Zone VI has five sectors:

– Sector I (Huch'uypicchu). It includes several architectural features, including: platforms, double jamb doorway, a tomb and an overlook. There is also a mountain known as Uñapicchu, which is composed mainly of terraces.
– Sector II (Waynapicchu). It is composed of the architectural features on the south face of Waynapicchu mountain and those found on top of the mountain.
– Sector III (Great Cavern). It is made up of a system of terraces, a *phaqcha*, and roads; it is mainly characterized by rustic enclosures adapted to the rocky shelters and others associated with these that exhibit fine masonry, conferring a ceremonial function to the area.
– Sector IV (Inkaraqay). Is located approximately 600 m in a straight-line northwest from the *Gran Caverna* sector. It is made up of several rectangular and semicircular enclosures that exhibit rustic architecture, stairways, platforms, canals and a *phaqcha*.
– Sector V (Mirador). Sector V includes the structure known as the *Mirador de Inkaraqay*, as well as the enclosures and caves found on the road from this sector to its intersection with the road projected from the Great Cavern Sector.

11.2 Research in the 2017 Season

Interdisciplinary research has made it possible to determine that the *llaqta* of Machupicchu was an administrative, political and religious center of signal importance during the Late Horizon Period (Bastante and Fernández 2018: 37). It also represented an integrating core for the spaces of Vilcabamba and Picchu (Bastante 2016: 274; Bastante and Fernández 2018: 38). The decision of the Inka State to build the *llaqta* of Machupicchu responded to the fact that the site fully complied with the political-religious requirements of the elite in relation to the most important geographical features of the region, in addition to the presence of sources of water, abundant materials for construction, availability of land in relation to other places in the area, accessibility, availability of a workforce and the need to maintain control over the Vilcabamba region. For its part, the massive transformation of the natural landscape of the current SHM-PANM and Vilcabamba was carried out within the framework of a state policy of expansion and control of spaces (Bastante and Fernández 2018: 34), in which geography would have played a determinant role (Reinhard 2002 [1991]: 55).

The interdisciplinary research of the PIAISHM in the *llaqta* of Machupicchu has been carried out in an uninterrupted way since 2014, when investigations began with

4 excavation units (EU) in the lower part of the modern entrance, in addition to 28 excavation units (EU) in the MSMCB zone. During 2015, 31 EU were executed, while in 2016 excavations continued with 25 units. Finally, during 2017, 14 units were excavated in sector V of the Urban zone in the *llaqta* area (Fig. 11.4). In addition, the PIAISHM team carried out excavations in various sectors of the archaeological monuments of Salapunku, Choqesuysuy, Chachabamba (Seasons 2016 and 2017), and Mandor (Season 2017).

Based on the results of these interventions and a spatial analysis of the area, it is proposed that all archaeological monuments in the immediate area of influence of the *llaqta* of Machupicchu functioned as a unified settlement system. We refer to the allied sites of Chachabamba, Choqesuysuy, Wiskachani (San Miguel), Mandor, Wiñaywayna, Intipata, Wayraqtambo, Ch'askapata, Killapata and Intiwatana (km 121). The constructions registered in the Vilcanota river bed, such as canalization walls and terrace systems with dual functions (protection and agriculture), which in many sectors have disappeared due to the cyclical floods of the river, are evidence of the macro planning of the *llaqta* of Machupicchu area. The *llaqta* of Machupicchu was integrated with the monuments in its immediate area of influence by means of terrace systems based on the possibilities offered by the topography of the terrain.

11.2.1 Excavations in the llaqta *of Machupicchu*

During the 2017 research season, the excavations allowed us to verify that restorations of the bases of the walls were carried out during previous limited excavations. In some cases, modern drains were created without realizing the existence of original drains, as exposed in EU02, EU03 and EU05, where the projections of the drains were identified. It was determined that the open spaces presenting these features had the function of evacuating rainwater. The alteration due to clandestine or restorative excavations—for which no reports are available—created a void in terms of the possibility of interpreting the function of spaces, which in some cases were determined exclusively on the basis of their architecture and context.

- EU01-2017 (Fig. 11.5): This excavation unit pertained to the passage at the back of the *Espejos de Agua* enclosure, where two floors of Inka occupation were identified. The most recent one occurred along the entire passage, which showed a slight inclination towards the north and south profiles in order to articulate with two water evacuation channels. The first floor of occupation corresponds to a paving stone, which was evidenced only inside the *wayrana*, where a burning event associated with ceramic fragments was also found. Likewise, it was determined that the *wayrana* was built in a second phase of the construction process, due to which its roof altered the possible astronomical functions of the *Espejos de Agua enclosure.*
- EU02-2017 (Fig. 11.6): In this excavation, it was determined that, at the foundation level, the platform walls and the adjacent enclosures are in good condition

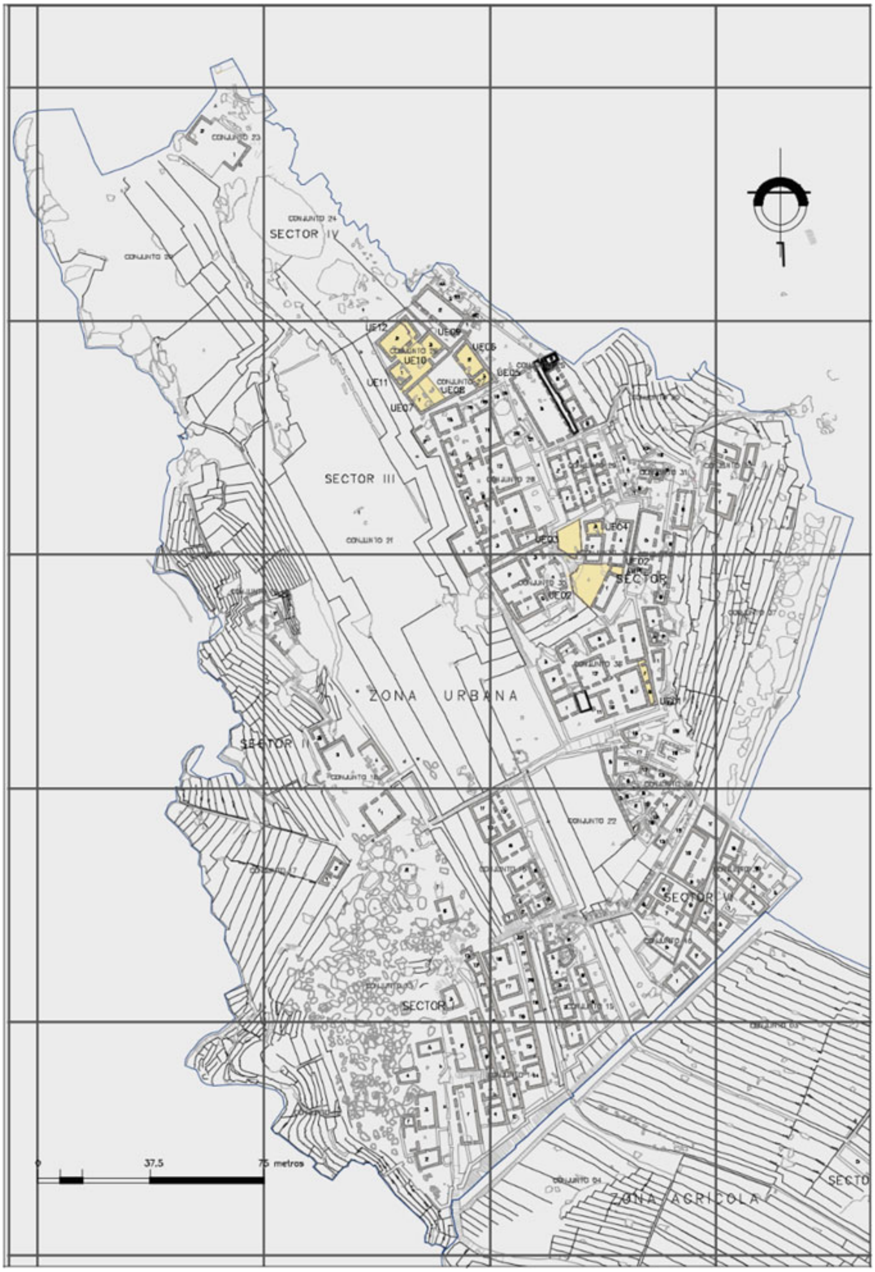

Fig. 11.4 *Llaqta* of Machupicchu, zone II (Urban). PIAISHM season 2017 excavation units (EU) in yellow.

Fig. 11.5 EU01, passage in the back part of the Water Mirrors enclosure. Note the cobblestones delimited by the circumference, the original upper floor, and the irregular outline of a previous EU for restorative purposes (Photo Rolando Rodrigo)

Fig. 11.6 Area of the EU02 where disturbed spaces are evident (Photo Marilú Espinoza) (Photo Marilú Espinoza)

mainly due to the large stones used in their construction and the restorations that were carried out before the intervention of the PIAISHM. To this circumstance there was the additional treatment carried out in certain segments of the platform (patio), which prevented the structures from settling. The largest amount of cultural material found in this EU corresponds to pottery fragments, shales (lids of vessels), hammers, a fragment of a tupu (shawl pin) and two needles, all found in association with contemporary material (i.e., layers II and III), which pertained to the filling that was carried out in leveling the ground for the contemporary floor treatment. Also, the projection of the drain for the evacuation of rainwater from the platform was identified. In the southern extreme of the EU, a wall of irregular masonry joined with mud mortar served as a bond that was attached to the foundation, the purpose of which was to give greater stability to the north wall of enclosure 2. Regarding the function of this space, the small amount of cultural material found in layer III (the Inka occupation level) and its evident disturbance by the previous restoration work limited the interpretation. However, in addition to corresponding to a rainwater evacuation zone, it is presumed, based on its dimensions and its location at the convergence of two roads, to be the only point of entry to the upper complex—where there is a *waka* that probably represents the Putukusi mountain' (Fig. 11.7). This latter space could have served for gathering a considerable number of participants during events for which they were not allowed to enter the upper complex.

– EU03-2017: It was determined from this excavation that the walls located at the northern, southern and eastern ends of the EU are in good condition, although some lithic elements at head-level have collapsed and that degradation is evidenced in the mortar between the joints. The highest percentage of recovered pottery fragments with decoration have geometric motifs and correspond to rims, bowls, small *p'uyñu (aríbalos)*, plates and a bowl rim with a fine finish and blackish coloring without decoration. Other vessel fragments correspond to containers for preparing corn mash-based drink, chicha; these include vessels such as *urpu* and *raki*. Among the plastic applications found, ornithomorphic representations predominate, having registered a feline representation in blackish paste that would correspond to a bowl. The possible function of this platform as part of the context of the waka, located in the upper part of the rocky outcrop, and the large amount of cultural material found at the eastern end of the EU where the layers are well defined and the alteration was minimal, was related to ceremonial activities that were carried out in the complex.

Fig. 11.7 Rocky outcrop in the upper part of which is the waka by which one ascends through the stairs on the right side of Fig. 11.5 (Photo Marilú Espinoza)

- EU04-2017: It was determined that the foundations of the north and south walls are in good condition and maintain their originality up to a height of 0.40 m. The rocky outcrop located in the central part of the EU has considerable dimensions (in relation to the size of the enclosure) and is projected towards the southeast vertex, to which the foundation of the north wall of enclosure 3 and part of the foundation of enclosure 4 were laid. The large amount of cultural material recovered from layer III corresponds to ceramic fragments, among which it was possible to identify *urpu* bases, *p'uyñu* rims and bodies, pots with evidence of soot, plates and bowls, besides other domestic objects. This suggests a constant activity in the enclosure, such as the preparation of drinks, food and offerings that would have been served in the adjacent open space (EU03).
- EU05-2017: The first layer was totally disturbed, while the second was partially disturbed. This corresponds to the Inka floor, where some ceramic fragments were recovered, as well as a *fusayola*, a scraper, a shale cap, and a lithic hammer. This open space functioned as a water runoff evacuation area. The archaeological materials found were out of context due to water flow.
- EU06-2017: The walls of enclosure 1 are in a good condition as they were restored before the intervention of the PIAISHM. The second course of the foundation wall has a 3 cm protruding flange that indicates the starting point of the restoration. The holes registered in the floor are traces left by cooking fires. The largest amount of cultural material found in this EU corresponds to ceramic fragments without decoration, including rims and bodies of pots, *p'uyñu* handles and a *tunaw* (grinding tool), which were used for domestic activities.
- EU07-2017 (Fig. 11.8, left): It was determined that layers I and II were disturbed during previous restorative interventions. The finding of the buried wall at the southern end and the accumulations of loose silty soil in segments of the EU suggest modifications to the original planning that occurred during the construction process. A minimal percentage of cultural material was recovered, corresponding to disjointed ceramic fragments, among which bodies and rims of domestic vessels stand out. The opening of coves 1, 2, and 3 allowed recognition that the foundations of the walls at the north and south ends as well as the central column of enclosure 2 are in good condition for having undergone restorative processes at the foundation level.
- EU08-2017: It was determined that—at foundation level—the walls of enclosure 2 are in a good condition due to having been previously restored, with the exception of the first course, which remains original with an average height of 0.27 m. The east-west projection of the wall found under the Inka floor treatment in EU07 confirms the modifications to the original planning during the construction process. The finding of a small number of ceramics suggests little activity in this area, while the finding of hammers associated with the rocky outcrop suggests that this kancha was not completed when the construction work was brought to an end ((Fig. 11.8, right).
- EU09-2017: It was determined that the walls of enclosure 1 are in good condition due both to the considerable dimensions of the lithic material used for the foundations and to the fact that the walls were subjected to restoration in previous

Fig. 11.8 (left) EU07 area. Note the buried wall in the lower left part of the image and the rocky block with evidence of carving towards the upper central part (Photo José Luis Sinchiroca); (right) EU08 area. Note the segment of the original wall delimited by the red circle (Photo José Luis Sinchiroca)

seasons. The scarce pottery recovered in the EU, the discovery of hammers associated with the stone block in the west end—which was possibly intended to be a central pillar to support the roof—suggest that the enclosure was still under construction. Because of these circumstances, it was not possible to define its use and/or function. The accumulation of scattered, worked lithics in the southeast angle is probably due to the collapse of the south wall.

- EU10-2017: At foundation level, the walls of the adjacent enclosures are in good condition because they were restored prior to the PIAISHM interventions. In addition, special treatment was carried out in certain segments of the platform (patio), where layer III was compacted prior to the settling of enclosures. The minimal amount of cultural material—corresponding to fragments of domestic pottery—recovered in this EU, as well as inside enclosures 1, 2 and 3 (EU11, EU09 and EU12, respectively) of this kancha, suggest little domestic activity in the area, apparently due to the fact that this space was still under construction (Fig. 11.9).
- EU11-2017: It was determined that the walls of enclosure 1 are in fair condition due to previously having undergone restoration. The scarce cultural material recovered suggests infrequent activities in this space, apparently because the *kancha* was still under construction at the time of abandonment. This hypothesis is reinforced by the discovery of lithic fragments at the southern end of the rocky outcrop and evidence of a sizeable stone block at the eastern end of the EU that was to be used as a central pillar to hold the enclosure's roof.

Fig. 11.9 Area of the EU10-2017, with a lithic block in the process of carving, one of the pieces of evidence that establishes that this kancha was not finished (Photo Marilú Espinoza)

– EU12-2017: It was determined that the walls of precinct 3 were in good condition because they were previously restored. Restoration was undertaken from the third course, although the restoration did not use all the original elements of the collapsed walls found in layer II. The recovered ceramic cultural material corresponds to domestic vessels, while the discovery of a large number of strikers and chipped stone, from the carving process (as in EU09-2017 and EU11-2017), allows us to infer that complex 7 was in the process of construction (Fig. 11.10).

In order to define or rule out possible structural problems at the Inkaraqay astronomical observatory, located on the western flank of the Waynapicchu mountain, a 1.00 m^2 test pit was made on the external face of its eastern wall, (Figs. 11.10 and 11.11, left). It was determined that the foundation level is –0.30 m below the surface of the platform, the latter of which shows fine finishing of large stone blocks that constitute a solid support for the wall that makes up a part of the platform. No cultural material was found. Thus, it was determined that the area was disturbed by clandestine excavations.

11.2.2 Excavations at the Mandor Archaeological Monument

To the northeast of the *llaqta* of Machupicchu and on the right bank of the Vilcanota River, there is an architectural element of vital importance called Mandor Wall, which is a raised path with an average height of 2 m, an average width of 2.6 m and a present length of 835 m (Figs. 11.11, right and 11.12). Archaeological excavations were carried out during the 2017 season in this structure and in adjacent areas—where

Fig. 11.10 General view of the EU12-2017. Note the presence of scattered lithic elements as a result of the collapse of the upper part of the walls (Photo José Luis Sinchiroca)

Fig. 11.11 (left) Detail of the architectural structure of the *Mirador de Inkaraqay* (Photo Alicia Fernández). (right) Excavation at the foot of the fine wall of the *Mirador*. Notice the treatment of the platform where the structure was settled (Photo Marilú Espinoza)

enclosures and platforms were registered—have allowed a better understanding of the functions of this structure. Based on the architectural characteristics, associated cultural material, as well as the context in which it is located, it is suggested that the Mandor Wall was built during the Inka occupation of the area. Considering its location and the large workforce that would have been used for its construction, its function could have been related to ritual activity linked to the Yanantin mountain. On the other hand, archaeological excavations defined the existence of an attached secondary road at a lower level, which follows the same projection as the main

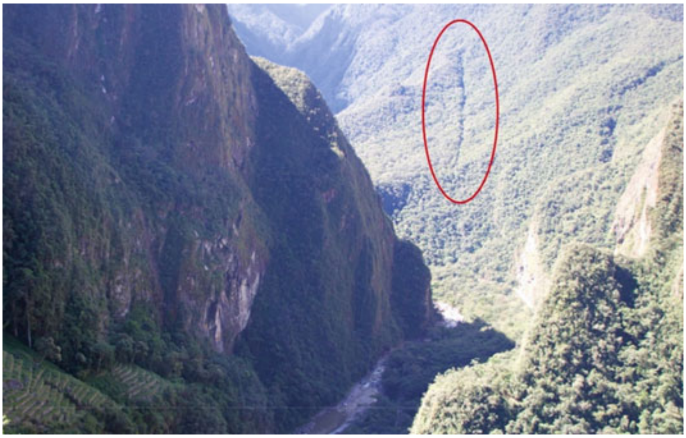

Fig. 11.12 General view of the Mandor archaeological monument taken from the lower part of the *qolqa* of the agricultural zone of the *llaqta* of Machupicchu. The outline of the ritual path delimited by the ellipse (Photo Alicia Fernández)

Fig. 11.13 Structure of the Mandor ritual path in relation to the *llaqta* of Machupicchu (indicated by the arrow) (Photo Balbino Rodríguez)

structure. In EU08 and EU09, it was determined that this secondary road is paved and has a width that varies between 2.0 and 2.5 m (Figs. 11.13 and 11.14).

Due to its location, the Mandor zone was closely related to the *llaqta* of Machupicchu. It might be that the construction of the mule road towards the end of the 19th century affected the initial part of the main structure (EU01, Fig. 11.14) and that the section connecting with the pre-hispanic bridge followed the same route

Fig. 11.14 Detail of the secondary road that is attached to and at a lower level than the main structure. The width is 2.50 (Photo Dennis Quispe)

as the actual railway line. This bridge articulated the right bank of the river to the path that is projected to the *llaqta* on the eastern flank.

The segment of the road between Mandor and the *llaqta* of Machupicchu would have been used repeatedly by the *mitma* (state tribute laborers) who inhabited the area. That there were such laborers quartered at the site is evident from the archaeological excavations, since the rectangular and semicircular structures (Figs. 11.15 and 11.16) in Mandor—which are scattered and without any apparent distributional order—were living spaces associated with a terraced field system (partially destroyed by the tea plantations). In this regard, a large percentage of domestic ceramic frag—ments were found in EU05, EU06, EU07 and EU12. Among this material were fragments corresponding to the pre—Inka, Late Intermediate Period (Killke), which suggests that the buildings were reoccupied or remained in use during the Inka period. This situation is similar to that found by Kendall in the Kusichaka area (1996: 124–125) as well as in our surveys in the area of SHM-PANM, where we identified small settlements with this type of structures on mountain slopes, mainly on the right bank of the Vilcanota River. The hypothesis gains greater strength based on the numerous surveys carried out in the province of La Convencion, farther down the Vilcanota/Urubamba River, where settlements composed of circular and ovoid structures corresponding to the Late Intermediate period have been identified (Ramos 1983; Silva 2003; Saintenoy 2008; Kaupp and Fernández 2010; Delgado y Araoz 2016) (Fig. 11.17).

Fig. 11.15 Side view of the initial section of the ritual path, which was probably affected by the construction of the modern road and the subsequent laying of the railroad tracks that are projected through the lower part of the valley floor (Photo Óscar Canales)

Fig. 11.16 Rectangular buildings registered toward the right end of the ritual path (Photo Dennis Quispe)

11.2.3 The Inhabitants of Machupicchu

Since the beginning of the 20th century, various authors have put forward hypotheses regarding the number of inhabitants in the *llaqta* of Machupicchu. The proposed numbers vary enormously from one scholar to the next. The latest calculations, based

Fig. 11.17 Semicircular structure located towards the upper left part of the ritual path (Photo Manuel Sarmiento)

on (among others factors) the number of existing housing spaces, have allowed us to estimate a population of 400 inhabitants that the *llaqta* could house permanently (Bastante 2016: 270), a population that would have been mostly composed of elite personages—including priests/astronomers—and servants. This number could have tripled at certain times of the year due to ritual activities. As we have already noted, individuals whose lives were dedicated to maintenance activities and agricultural labor lived in precarious structures elsewhere, such as Mandor, and not within the nuclear area of the *llaqta*.

The skeletal remains from the *llaqta* of Machupicchu recovered by the EPY in 1912 were analyzed by Eaton, who concluded—based on the cranial modifications of some individuals—that the population had been made up of people of multiethnic origins (Eaton 1916: 65; Guillén 1990: introduction). This was confirmed by craniometric analysis by Verano (2003: 88–97), strontium isotope analysis by Turner et al. (2009: 330) and by the study of the contexts of the tombs exhumed by EPY itself (Salazar 2007: 176–179). The individuals exhumed in the *llaqta*, mostly adults (Verano 2003: 85), would correspond mainly to *mitma* (tribute laborers) or *yana* (servants of inherited status) of different origins (Salazar 2007: 169, 171, 179), but with a predominance of individuals from the coast and the altiplano region (Verano 2003; Salazar 2007; Turner et al. 2009). This population make-up suggests that the *llaqta* was a center controlled by the *Inka* State.

Although Eaton defined the ratio between men and women as 1: 4 (Eaton 1990 [1916]: 65), toward the end of the 20th century, Guillén (1990: introduction) questioned the analyses that had led Eaton to suggest such a high ratio of women making up the population. The reanalysis carried out by Verano determined that the remains corresponded not to 164 individuals—as Eaton (1916: 65) has concluded, but rather to a total of 177, the sex of only 99 of which could be determined with total precision (Verano 2003: 82–83).[3] From this figure, it was found that were 60 females and 39 males; therefore, the ratio between men and women was revised to 1: 1.54 (Verano 2003: 83–84). Furthermore, if we consider the exhumations carried out by Elva Torres between 1994 and 1998—where 21 individuals were identified: 7 males, 1 female and 13 undetermined—the sex ration gap of males to females is reduced to 1: 1.33.

However, in all cases, the undetermined sex individuals (including the “possible” defined by Verano: 12 female and 2 male) are numerous. This information has made it possible to categorically rule out the hypothesis that the *llaqta* of Machupicchu was a place dedicated to the Virgins of the Sun and defines the population of the *llaqta* within normal parameters regarding the proportion between male and female individuals (Verano 2003). However, considering the *llaqta* of Machupicchu as a religious center, the presence of a relatively greater number of women can be understood in relation to the work of preparing beverages and manufacturing textiles. The evidence of both of these activities in the *llaqta* is quite pronounced.

Finally, the individuals exhumed in the *llaqta* of Machupicchu during the interventions of the EPY of 1912 and those found in subsequent researches in the monument do not present cranial trepanations (Torres 1994, 1996, 1998; Mormontoy 2003) which were often performed on cranial injuries following violent conflicts. This suggests that activities at the *llaqta* were not related notably to the defense of the site (Verano 2003: 114).

11.2.4 Archeobotanic Investigations

The analysis of ceramic fragments, soil samples and carbonized material carried out within the framework of the PIAISHM by Vásquez (2015, 2016, 2017) has allowed us to define the type of products that were used and consumed in the *llaqta.* From the samples obtained by mechanical flotation and others recovered directly in the excavations, charcoal fragments from five species of Polylepis sp trees have been identified (qeuña), Cedrella odorata (cedro colorado), *Tecoma* sp., Alnus sp. (alder) and Sambucus peruviana (sauco). The latter were of nutritional value, while the first four may have been used as wood for roof structures, as fuel, or for medicinal purposes. With respect to the qeuña, in addition to being an excellent fuel, it is a hard wood which is used in the manufacture of tools and in the construction of houses; furthermore, its branches and leaves have a high tannin content (Yacovleff and Herrera 1934: 35–37). For its part, *Tecoma* sp. and the red cedar are also cultivated for ornamental purposes (Mostacero et al. 2009: 436). A very common grass plant was also identified in the area: *Chusquea sp. (kurkur*); some herbaceous plants and charred seeds of cultivated plants of nutritional value, such as *Chenopodium quinoa*

[3] Among adults, adolescents, children and infants.

(quinoa), *Zea mays* (maize), and *Amaranthus sp.* (possible *kiwicha*). Two mother-of-pearl fragments (*Pteridae*), that correspond to a bivalve used for the manufacture of ornaments were also identified.

In ceramic fragments and in a lithic tool, ancient starches corresponding primarily to corn with polyhedral, spherical, and square morphologies were identified, which shows us that at least three races of corn were consumed in the *llaqta*. Likewise, two starches from *Solanum tuberosum* (potato) and one from *Manihot esculenta* (yucca; manioc) were reported. In the former case, there are already palynological reports that show its cultivation in the Eastern Andenes area of the *llaqta* and it is likely that the latter was cultivated in nearby areas at lower altitudes.

11.2.5 Inka Bridges Over the Vilcanota River in the SHM-PANM

The PIAISHM has identified and systematized the results of investigations of Inka bridges over the Vilcanota River between the Salapunku archaeological monument—the gateway to the Picchu ravine—and the confluence of the Vilcanota and Ahobamba rivers. A common denominator of these bridges is that the Inka took advantage of the narrower parts of the river for their construction. The evidence found has been affected by the cyclical floods of the Vilcanota River. In some cases, the bridges may have been hanging ones; in others, the structure must have been quite basic, with the use of logs and ropes. Between the limits of the present SHM-PANM and on the Vilcanota River, we have defined the existence of nine possible pre-hispanic bridges that fluidly connected the spaces on both banks of the river; they are described below, starting with the most distant in the far north (Figs. 11.18, 11.19, 11.20, 11.21, and 11.22).

The first bridge was near the present—day San Miguel bridge, at km 118.8 of the railway line (Fig. 11.23). This bridge articulated the Inka road on the right bank of the valley floor with the Intiwatana archaeological monument, near km 121 of the railway. A second bridge must have been located near the Inkaraqay sector, by km 116 of the railway (Figs. 11.23 and 11.24, left). Although there is no extend evidence—such as abutments—there is a road segment that descends from this sector to the left bank of the Vilcanota River (Fig. 11.25).

The third bridge was located at km 113.2 of the railway line, through which the *llaqta* was accessed along the Eastern Andenes area road. The abutment of this bridge on the left bank, which made it possible to connect the *llaqta* with the Inca trail on the right bank of the Vilcanota—and therefore with the Mandor zone—has been affected by the cyclical floods of the Vilcanota River.

The abutment and ramp of a fourth bridge appear at km 111.5, about 1200 m downstream from Aguas Calientes (the modern Machupicchu Town, in the river valley). This bridge was articulated to the pre-hispanic road that crossed and was

Fig. 11.18 Precinct 6—indicated by the arrow—from where the samples for radiocarbon analysis were extracted in 1983 (Photo César Medina)

Fig. 11.19 Location of the Aguas Calientes I and II, Andenes Orientales, Inkaraqay, and San Miguel bridges in relation to the *llaqta* de Machupicchu (Google Earth 2018)

affected by the construction of the Hiram Bingham highway (Fig. 11.26), which enters the *llaqta* through a doorway of the Eastern Andenes I sector (Fig. 11.27).

The abutment of a probable fifth bridge is evidenced 800 m up the river from the previous one (400 m from Aguas Calientes), entering an isolated area where archaeological prospects have failed to identify any type of pre-hispanic architecture (Fig. 11.28).

Fig. 11.20 Location of the Chachabamba bridge in relation to the archaeological monument of the same name (Google Earth 2018)

Fig. 11.21 Location of the Qoriwayrachina I and II bridges in relation to the archaeological monument of the same name (Google Earth 2018)

Fig. 11.22 Location of the Salapunku bridge in relation to the archaeological monument of the same name (Google Earth 2018)

A sixth bridge—from which there is no longer any evidence—probably existed at km 104 of the railway and would have connected the Inka road on the right bank with the Chachabamba archaeological monument. It is possible that the present bridge was built in the same place where the Inca bridge was located (Fig. 11.29).

A seventh bridge, called Qoriwayrachina I, which happens to be the best built in the SHM-PANM area, was located at km 88 of the railway line and connected the Qoriwayrachina and Machuq'ente monuments. The present evidence is the abutments, which have been used for the construction of a contemporary bridge (Fig. 11.30).

The eighth bridge (Qoriwayrachina II) was located at km 87, about 1000 m up the river from the seventh (Fig. 11.31). Based on an abutment on the left bank and a

Fig. 11.23 Abutment of the Inka bridge in San Miguel (Photo José M. Bastante)

Fig. 11.24 (left) Access span registered toward the lower part of the Inkaraqay sector; the Vilcanota river is located towards the right side of the image, where undoubtedly there was another bridge that articulated to the right bank (Photo Alicia Fernández). (right) General view of the Inkaraqay sector taken from the right bank with the location of the access opening (Photo Alicia Fernández)

low wall on the right bank, a ninth bridge (Salapunku) over the Vilcanota river would have been located at km 84 of the railway line (Fig. 11.32).

11.2.6 Roads That Articulate with the llaqta *of Machupicchu*

Hitherto, ten roads which interconnect the *llaqta* with the other archaeological monuments in the area have been registered (Fig. 11.33). According to Cobo (1964 [1653]), the maintenance of the roads and bridges was in charge of the people who inhabited each area, which, considering the high number of roads that converge in the *llaqta*, contradicts the idea of this location as an isolated place.

Fig. 11.25 Abutment on the left bank of the Vilcanota river corresponding to the Eastern Andenes bridge (Photo Alicia Fernández)

Fig. 11.26 Carved lithic block where the Aguas Calientes I bridge was located (Photo Alicia Fernández)

The first and probably the most important road—depending on the quality of its construction and dimensions—is the one that enters the *llaqta* through the Intipunku sector. The second one corresponds to that of the so-called Inka Bridge, which articulated the *llaqta* with the Ahobamba river basin and the Llaqtapata archaeological monument. A third one, called San Miguel, which is partially collapsed, appears at one end of the Chaos Granitico complex in the *llaqta* and heads toward the Intiwatana archaeological monument at km 121.

Fig. 11.27 Entrance to the *llaqta* of Machupicchu around the Eastern Andenes I sector (Photo Marilú Espinoza)

Fig. 11.28 Carved stone where the possible Aguas Calientes II bridge was located (Photo José M. Bastante)

A fourth road is the one that enters the llaqta through the Eastern Andenes VI sector; in this regard, it is highly probable that this was the path used by Augusto Berns to enter the *llaqta* of Machupicchu in the nineteenth century, as it can be deduced from his vivid description in a letter from 1881 (see Figs. 11.33, 11.34, and 11.35). It is important to note that Berns installed a sawmill in Aguas Calientes (modern Machupicchu Town) in the 1870s and created a company to loot archaeological monuments in the area.

Fig. 11.29 Present entrance bridge to the Chachabamba archaeological monument (Photo José M. Bastante)

Fig. 11.30 Abutments of the Qoriwayrachina I bridge (Photo José M. Bastante)

[…] While walking around one day, I came across the old city where the Inca gold and silver goldsmiths lived. The stone constructions are complete there, but all their entrances have been sealed by stones carefully built into the wall. The road to this city consisted of steps worked in the rock, but they have been disabled. Some of these steps are at the foot of the mountain. At the foot of the same mountain in which this city is located there are many large fountains carved in the rock of the most beautiful workmanship. The channels that reach them have also been carved

Fig. 11.31 Abutment and central part of the Qoriwayrachina II bridge (Photo José M. Bastante)

Fig. 11.32 Possible abutment of the Salapunku bridge (Photo José M. Bastante)

into the rock, they are perfect and lead the water to the sources that are never empty as before (Berns 1881).[4]

A fifth road enters the *llaqta* through the Eastern Andenes I sector from Aguas Calientes I bridge. A sixth enters through the Inkaraqay sector of the Waynapicchu area. The seventh, eighth, and ninth roads are those that, from the archaeological monument Wayraqtambo, enter the llaqta through the top, the west slope, and the east

[4] Letter without addressee (courtesy of the Biblioteca Nacional de Peru).

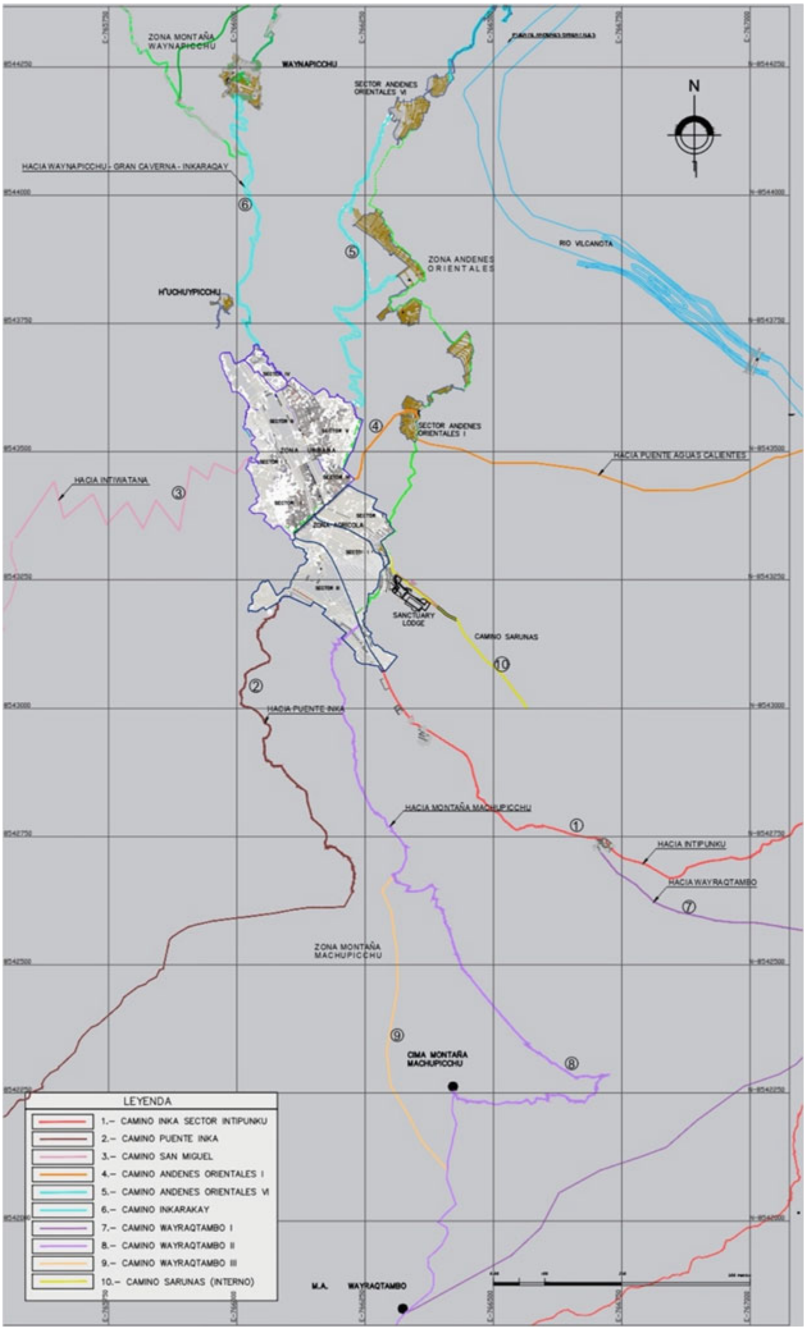

Fig. 11.33 Map with the roads that interconnect the *llaqta* of Machupicchu with the other archaeological monuments in the area

Fig. 11.34 Examples of *phaqcha* associated to the road in the Eastern Andenes zone (Photo Jose M. Bastante)

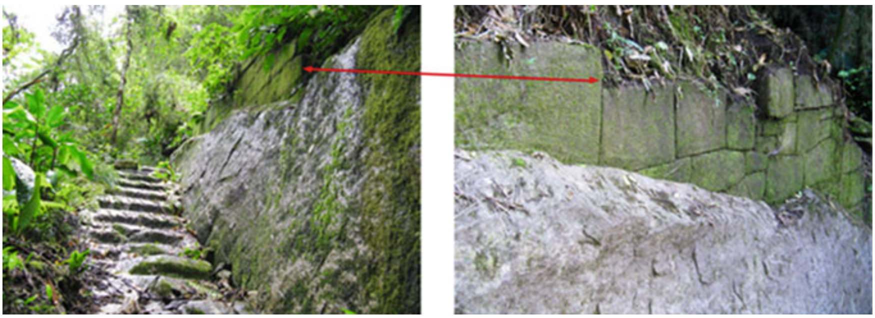

Fig. 11.35 (left) Steps worked on the bedrock at the beginning of the path, a few meters from the river bed (Photo Alicia Fernández). (right) Detail of the fine architecture seated on the rocky outcrop (Photo Alicia Fernández)

Fig. 11.36 Internal path of the *sarunas* (bottom right) that enters the nuclear part of the *llaqta* through the *qolqa* of the southeast flank (Photo Edward Ingris, 1961; courtesy of the Zlin Museum)

slope of the mountain, respectively. A tenth path—which is internal—corresponds to the *saruna* (Fig. 11.36), which connected the *llaqta* with the space where the Sanctuary Lodge hotel is located at present. Pre-hispanic structures (Ravines 2012 [1975]: 132) and Inca terraces existed toward the south of the hotel.

11.3 Conclusions

The llaqta of Machupicchu is not—nor was it in Inka times—an isolated settlement. On the contrary, it is part of the complex Inka state development in the region. In the area of SHM-PANM, more than 60 interconnected archaeological monuments have been registered through an intricate network of roads that exceeds 300 km. Due to the weather conditions and the accelerated growth of vegetation in the area, the human effort deployed during the Late Horizon for the construction and permanent maintenance of these evidences was immense.

At present, the personnel in charge of the conservation and maintenance of the *llaqta* amounts to 50 people, a quantity that can be used as a reference for the much greater number of individuals who would have been dedicated to the maintenance of roads, roofs and structures and agricultural work across the site during Inka time. According to the calculations made by the PIAISHM, without due maintenance, both the *llaqta* and the other monuments in their immediate area of influence would be totally covered by vegetation in less than two years. This situation was initially noticed by Bingham when he returned to Machupicchu after an absence of three years in 1915.

It should be noted that the research carried out in the *llaqta* have confirmed the presence of scattered charcoal remains and charcoal fragments from arboreal species at the original floor level of enclosures, which in some sectors of the *llaqta* were subjected to burning, as happened in the archaeological monuments Choqesuysuy and Chachabamba.

Considering the results obtained through the archaeobotanical analysis of the PIAISHM and the palynological analysis carried out in the *llaqta* since the 1990*s*, we can affirm that the diet of the inhabitants of Machupicchu was composed of a large number of products, including potatoes, quinoa, *kiwicha*, *virraca*, sweet potato, *achira*, chili pepper, *tarwi*, beans, avocado, elderberry, lucuma, *awaymantu,* and granadilla. Likewise, based on the analysis of the animal bones recovered during the EPY of 1912, it is deduced that the diet of these individuals must have been supplemented with the consumption of animal protein, mainly camelid (llama and alpaca) meat and to a lesser extent deer and guinea pig, among others (Miller 2003: 8). However, it is considered that the diet was based mainly on the consumption of corn, since the highest percentage of remains recovered or identified correspond to Zea mays, which is supported by the studies of Burger, Lee-Thorp and Van der Merwe (2003: 125–137) and Burger (2004: 89–90). These, by means of isotopic analysis of bone remains from 59 individuals exhumed in the *llaqta* by the 1912 EPY, determined that an average of 65% of their diet would have been made up of corn in its solid form or as *chicha* (corn beer) (Burger 2004: 89).

Regarding the function of the *llaqta*, many theories have been proposed since its scientific discovery in 1911. For his part, Salazar has indicated the reasons why she thinks the *llaqta* of Machupicchu would not have functioned as a political-administrative center, stating reasons that include aspects related to its extension, location, and architecture, among others (Salazar 2004: 25, 26). Rather, she argued, it should be understood as a retreat, the royal estate, of the *Inca* Pachakuti (Rowe 1990 [1987]; Salazar 2004; Niles 2004). This contrasts with what is proposed by Kaupp and Fernández, who have concluded that the *llaqta* of Machupicchu presents evidence of functions and characteristics similar to other administrative centers of Tawantinsuyu. Thus, they argue, it must be redefined in the context of its position as a regional capital (2010: 15–16; see also Valcárcel 2009 [1964]: 47).

The hypothesis that the *llaqta* of Machupicchu was a private property of Pachakuti is questionable if the following factors are taken into account: the massive works carried out in the area responded to a project that required a large concentration of workers led by skilled architects, engineers and planners (Valcárcel 2009 [1964]: 45); a constructive undertaking of such magnitude would not have been possible for the particular purposes of a certain group at the beginning of the period of rule of Inka Pachakuti because the privileges of his newly established *panaka* (kin group) would not have been automatic, nor sufficient in size; ethnohistorical evidence highlights the importance of the entire Vilcabamba region for the Inka State and the architectural and spatial differences between *llaqta* of Machupicchu and sites considered royal estates, such as in the cases of Urubamba and Chinchero, are notorious (Villanueva Urteaga 1971; Niles 1999, 2004); likewise, although the surroundings of the *llaqta* are conducive to activities such as hunting, the site is not in a place with a very favorable climate for resting, particularly if we compare the more favorable climate of other known royal retreats of the Vilcanota basin. To these considerations, finally, we note the evidence of a strong religious component, which could turn out to be one of its primary functions (Valcárcel 2009 [1964]: 29; Maclean 1986; Rowe 1987 [1990]; Hyslop 1990; Reinhard 2002 [1991]; Kauffmann 2005).

The systematization of the evidence produced by the archaeological excavations and the spatial analysis of the *llaqta* and its relationship and articulation with the other archaeological monuments in the area through an intricate network of roads, allows us—from a comprehensive, integral perspective—to propose that the function of the site was likely based on religion and was directly linked to an expansive policy of the deployment of Inka state power and control towards the Antisuyu, the tropical forest quadrant of the *Tawantinsuyu* or Inka Empire.

Bibliography

Ajie H, Kaplan I, Hauschka P, Kirner D, Slota P, Taylor RE (1992) Radiocarbon dating of bone osteocalcin: isolating and characterizing a non-collagen protein. Radiocarbon 34(3):296–305

Bastante JM (2016) Investigaciones interdisciplinarias en la *llaqta* de Machu Picchu. Arqueología y Sociedad 32:267–276

Bastante JM, Fernández A (2018) Avances de las investigaciones interdisciplinarias en Machu Picchu. Revista Haucaypata 13:34–59

Bauer B (1992) The development of the Inca state. University of Texas Press, Austin

Burger R (2004) Scientific insights into daily life at Machu Picchu. In: Burger R, Salazar LC (eds) Machu Picchu unveiling the mystery of the Incas. Yale University, New Haven, pp 85–106

Burger R, Lee-Thorp J, Van Der Merwe N (2003) Rite and crop revisited: an isotopic perspective from Machu Picchu and beyond. In: Burger R, Salazar LC (eds) The 1912 Yale Peruvian scientific expedition collections from Machu Picchu: human and animal remains. Yale University Publications in Anthropology 85, New Haven, pp 119–137

Chávez Ballón M (1971) Cuzco y Machu Picchu. Wayka, Revista Del Departamento De Antropología De La Universidad Del Cuzco 4–5:1–4

Cobo B (1964/1653) Historia del Nuevo Mundo. Biblioteca de Autores Españoles, Madrid

D'Altroy T, Williams V, Lorandi AM (2007) The Inkas in the Southlands. In: Burger R, Morris C, Matos R (eds) Variations in the expression of Inka power. Dumbarton Oaks, Washington, pp 85–133

Delgado C, Araoz M (2016) El Impacto Inca en los Sitios del Periodo Intermedio Tardío entre la Cuenca de los Ríos Urubamba. Salkantay y Saqsara. Cusco. Inka Llaqta 4(4):99–122

Eaton G (1916) The collection of archaeological material from Machu Picchu. memoirs of the Connecticut academy of arts and sciences 5. Yale University Press, New Haven

Eaton G (1990/1916) La colección del material osteológico de Machu Picchu (translation and foreword: Sonia Guillén). Rumi Maqui Editores, Lima.

Glave LM, Remy MI (1983) Estructura agraria y vida rural en una región andina. Ollantaytambo entre los siglos XVI y XIX. Centro de Estudios Bartolomé de las Casas, Cusco

Hyslop J (1990) Inca settlement planning. University of Texas Press, Austin

Kauffmann F (2005) Machu Picchu: tesoro inca. ICPNA, Lima

Kaupp R, Fernández O (2010) Vilcabamba desconocida. Instituto Nacional de Cultura, Cusco

Kendall A (1996) An archaeological perspective for late intermediate period Inca development in the Cuzco Region. J Steward Anthropol Soc 24(1–2):121–156

Maclean M (1986) Sacred land, sacred water: Inca landscape planning in the Cuzco area. PhD Thesis, Universidad de California, Berkeley.
Miller G (2003) Food for the dead, tools for the afterlife. zooarchaeology at Machu Picchu. In: Burger R, Salazar LC (eds) The 1912 Yale Peruvian scientific expedition collections from Machu Picchu: human and animal remains. Yale University Publications in Anthropology 85, New Haven, pp 1–63
Mormontoy A (2003) Informe final de conservación preventiva de varios sectores de la ciudad inka de Machu Picchu. Sector Agrícola I, II. INC, Cusco
Mostacero J, Mejía F, Gamarra O (2009) Fanerógamas del Perú: taxonomía, utilidad y fitogeografía. Concytec, Lima
Niles S (1999) The shape of Inca history: narrative and architecture in an Andean Empire. University of Iowa Press, Iowa City
Niles S (2004) The nature of Inca royal estates. In: Burger R, Salazar LC (eds) Machu Picchu unveiling the mystery of the Incas. Yale University, New Haven, pp 49–68
Ramos F (1983) Quintuna. Ocupación aldeana pre-inca en Vilcabamba. Arqueología Andina. INC, Cusco, pp 23–28
Ravines R (2012/1975) Machu Picchu, monumento arqueológico. Boletín De Lima 34(167):79–204
Reinhard J (2002/1991) Machu Picchu. El centro sagrado. Instituto Machu Picchu y Editora Automás, Cusco
Rowe J (1990/1987) Machu Picchu: A la luz de documentos del siglo XVI. Histórica XIV 1:139–154
Saintenoy T (2008) Choqek'iraw y el valle del Apurímac: hábitat y paisajes prehispánicos tardíos. Una investigación en curso. Boletín del Instituto Francés de Estudios Andinos 37(3):553–556.
Salazar L (2004) Machu Picchu: mysterious royal estate in the cloud forest. In: Burger R, Salazar LC (eds) Machu Picchu unveiling the mystery of the Incas. Yale University, New Haven, pp 21–47
Salazar L (2007) Machu Picchu's silent majority: A consideration of the Inka cementeries. In: Burger R, Morris C, Matos R (eds) Variations in the expression of Inka power. Dumbarton Oaks, Washington, pp 165–183
Silva J (2003) lnforme anual de identificación y registro arqueológico. Proyecto Qhapaq Ñan. Instituto Nacional de Cultura, Cusco
Torres E (1994) Exhumaciones de cuevas funerarias en el Santuario Histórico de Machu Picchu. Informe final. INC, Cusco
Torres E (1996) Investigaciones arqueológicas del Sector Agrícola. Informe final. INC, Cusco
Torres E (1998) Investigaciones arqueológicas en el Conjunto Arqueológico de Machu Picchu. Informe final. INC, Cusco
Turner B, Kamenov G, Kingston J, Armelagos G (2009) Insights into immigration and social class at Machu Picchu, Peru, based on oxygen, strontium, and lead isotopic analysis. J Archaeol Sci 36:317–332
Valcárcel LE (2009/1964) Machu Picchu. El más famoso monumento arqueológico del Perú. Fondo de Cultura Económica, Lima
Valencia A, Gibaja A (1992) Machu Picchu: la investigación y conservación del monumento arqueológico después de Hiram Bingham. Editorial Mercantil y Municipalidad del Qosqo, Cusco
Vásquez V (2015) Informe. Análisis arqueobotánico de materiales procedentes de las intervenciones del PIAISHM en la *llaqta* de Machu Picchu. Trujillo.
Vásquez V (2016) Informe. Análisis arqueobotánico de materiales procedentes de las intervenciones del PIAISHM en la *llaqta* de Machu Picchu y en los monumentos arqueológicos Choqesuysuy y Salapunku. Trujillo.
Vásquez V (2017) Informe. Análisis arqueobotánico de materiales procedentes de las intervenciones del PIAISHM en los monumentos arqueológicos Choqesuysuy, Salapunku y Chachabamba. Trujillo.
Verano J (2003) Human skeletal remains from Machu Picchu: a reexamination of the Peabody Museum's collections from the Peruvian expedition of 1912. In: Burger R, Salazar LC (eds)

The 1912 Yale Peruvian scientific expedition collections from Machu Picchu: human and animal remains. Yale University Publications in Anthropology 85, New Haven, pp 65–117
Villanueva Urteaga H (1971) Documentos sobre Yucay en el siglo XVI. Revista Del Archivo Histórico Del Cuzco 13:1–148
Yacovleff E, Herrera F (1934–1935) El mundo vegetal de los antiguos peruanos. Revista del Museo Nacional, vol III, pp 241–322; vol. IV, pp 29–102

Chapter 12
The Phaqcha from Chachabamba

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Abstract The planning and orientation of the Chachabamba archaeological monument provide us with information regarding its role among various sites in the area that directly influence the *llaqta* of Machu Picchu. An improved understanding of the function of architectural solutions and modifications discovered via archaeological interventions has been reached. Based on a study of the monument's hydraulic system, which is unique in the Inca world, it has been possible to reach conclusions regarding its function and role in Chachabamba and other monuments in the Historic Sanctuary—National Archaeological Park of Machu Picchu.

Keywords Archaeology · Inca · Water worship · *phaqcha* · Fountains · *armakuna* · Chachabamba · Machu Picchu

12.1 Introduction

The Chachabamba archaeological monument presents an interesting design that generates numerous questions. Although its architecture is of the imperial Inca type, an in-depth analysis by Bastante et al. (2020) revealed that the monument shows a great number of particularities that highlight its extraordinary design. The study focused on the orientation and distribution of the monument and has allowed us to obtain an understanding of its functions.

The following article is an English translation of a Spanish article published by Arqueología Iberoamericana (Sieczkowska and Bastante 2021). In the English-language version, some information has been supplemented.

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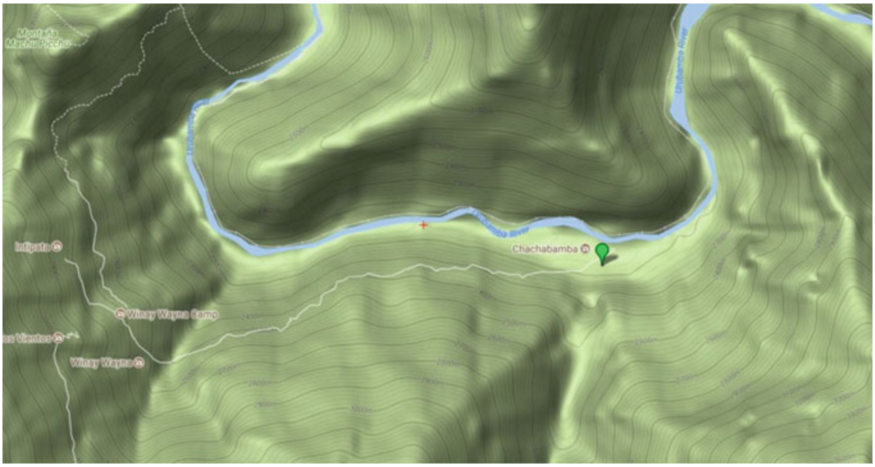

Fig. 12.1 A map of Machu Picchu National Archaeological Park in the section between Chachabamba and Machu Picchu. Note that Chachabamba is currently connected to the *llaqta*[1] of Machu Picchu through the Wiñaywayna site at a distance of approximately seven kilometers (CEAC archives)

Chachabamba is located on the left bank of the Vilcanota River, at kilometer 104 of the Cusco–Hidroeléctrica railroad and is bordered on the west by the stream of the same name, which originates in the glaciers of the snow-capped Salkantay mountain (Fig. 12.1). The monument was built in a mostly flat area at an average altitude of 2170 m above sea level. This allowed the Incas to avoid building on various slopes like those found in most of the archaeological monuments in the Historic Sanctuary—National Archaeological Park of Machu Picchu (SHM-PANM).

During the Viking Fund (now Wenner-Gren) expedition led by Paul Fejos in the region of SHM-PANM, other archaeological monuments were located and studied in addition to Chachabamba. Since the first scientific works conducted in Chachabamba between July 20 and October 30, 1941 (Fejos 1944: 37), the monument has been described as a location with ceremonial aspects. Currently, scientific research supports the supposition that the monument was a place of worship due to evidence of water management, possibly related to ritual ablutions.

Fejos' work focused on the clearing of sector A (referred to as ceremonial) of the monument, which included superficial excavations in the fountains (baths) and terraces (Fejos 1944: 37) as well as drawings and plans of the sector. A point of great interest to Fejos was the baths and the channels that delivered water to them (Fejos 1944, plates 43–44).

In this article, we use the term "fountain" to refer to the type of architectural structure known as *phaqcha* in the Quechua language. This term is also used for

[1] The term "*llaqta* de (of) Machupicchu" is the official term used by the Headquarters of the National Archaeological Park of Machupicchu—Machupicchu Historic Sanctuary in relation to the archaeological monument where "Machupicchu" is written together (Bastante 2016).

certain types of ceramics (Carrión Cachot 2005: 89–99). A detailed definition of the term was developed in the case of the *llaqta* of Machu Picchu by Fernández Flórez (2020). Conversely, the term "bath" used by many authors (Fejos 1944; Hyslop 1990; MacLean 1987) should be considered as a concept of ritual use. The objective of this rite was the act of ablution or ritual purification. In Quechua, the term applied to the baths is *armakuna*. In summary, the difference between the terms is that one corresponds to the utilitarian aspect and its architectural appearance while the other concerns the ceremonial aspect. A similar differentiation between the terms "water fountain" and "bath" has been provided in the Spanish-Quechua dictionaries (Domingo de Santo Tomas 1560; Gonzales Holguin 1608; Ricardo 1586). Thus, concerning the Quechua term for ritual baths, according to Holguin (1608: 26), its equivalent would be *armakuna*, while the term *armakuni* meant "to wash the entire body" (ibidem). The contemporary meaning of these terms is similar since, according to the dictionary published by the Academia Mayor de la Lengua Quechua, *armakani* is the place where there are pools to take baths, while *armakuna* means "bathing pool".[2] Thus, the distinction we propose in this context is to use the term "fountain" as an architectural object because of its building characteristics. In contrast, the term "baths" is applied in a strictly ceremonial context. In summary, a fountain as an architectural object may be considered a bath because of its ritual function.

In addition to the bath system, Fejos described a large granite outcrop in the form of an altar, or *huaca*,[3] associated with the central plaza of sector A (ceremonial) (Fejos 1944: 38). However, no information was provided regarding artifacts that were recovered during surface excavations.

In the 1990s, the system was investigated in the framework of an enhancement project, which included restricted excavations and restorations under the direction of Alicia Quirita (Quirita Huaracha 1997). As part of these works, the bath system, and the channels that supply it, were operational until destroyed by a landslide at the beginning of the twenty-first century.

Based on the scientific research conducted by the Archaeological and Interdisciplinary Research Program in the Historic Sanctuary of Machu Picchu (PIAISHM 2014–2017), a greater understanding of the functions of the monument and its role as having a direct influence on the *llaqta* of Machu Picchu has been achieved. This research has been systematically supported by specialists associated with the Center for Andean Studies at the University of Warsaw (Bastante et al. 2020; Masini et al. 2018; Ziółkowski et al. 2020).

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[2] (ACADEMIA MAYOR DE LA LENGUA QUECHUA 2005).

[3] The "*huaca*" in this context is a rocky outcrop in the form of an altar with multiple carved elements. For additional information on *huacas*, please consult the following publications: Bauer 2000; Bray 2013; Farrington 1992; Glowacki and Malpass 2003; MacLean 1987; Sotil Monteverde 2007.

12.2 Planning and Orientation

A discussion regarding the functions of the monument can be based on certain features such as its design. The monument is currently divided into four sectors (A, B, C and D), where sector A (ceremonial) corresponds to the central space of the monument in which PIAISHM has conducted research since 2016; sector B corresponds to a space containing probable domestic enclosures; sector C has not been defined due to being covered by dense vegetation and sector D contains a system of terraces not yet investigated.

Concerning the planning of sector A, the objective of the previous research seasons (2016 and 2017) was to verify or exclude whether its primary function was ceremonial (Glowacki and Malpass 2003; Gose 1993). Considering that the *huaca* is the central point of sector A, it is evident that the associated attachments underline its importance (Bastante et al. 2020). The open side of the *huaca* is associated with the central plaza and, together with the other enclosures around the plaza, a *kancha*[4] is configured, as defined by Protzen (1993: 64).

Toward the southern end of the central plaza, there is a double *wayrana*[5] with four windows similar to the *wayrana* in the Espejos de Agua complex in the *llaqta* of Machu Picchu. The open sides of this *wayrana* are associated with the central plaza and the south plaza, although the level of the south plaza (2) differs by approximately 1 m with respect to the central plaza (1) (Fig. 12.2).

Conversely, the east and west sides of the *kanchas* have sunken plazas associated with fountain systems. Remote sensing analysis on the sunken part of the plazas has demonstrated the existence of channeling or drainage elements related to the previous construction (Masini et al. 2018). The fountain systems are similar and each one is confirmed by three fountains in the upper part and four fountains in the lower part. Thus, the sunken plazas with the fountain systems flank the *kanchas*. The planning of the monument, at least after the last modifications that were made during the Inca period, shows an architectural design related to the duality and morphology of the terrain.

The complex of the two *kanchas* generates a type of axis, which could simply be related to the *huaca*. However, since the open side of the *huaca* is oriented toward the south (toward the snow-capped Salkantay mountain), it can be inferred that there is a relationship between the *huaca* and the snow-capped mountain. Although the latter is not visible from the monument, the line between the *huaca*, the plazas (central and south), and the mountain is diagonal, which suggests that the Incas defined the location of the site and planned it according to the mountain (Fig. 12.3).

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[4] The "*kancha*" is the basic unit of Inca architecture in the form of a rectangular building commonly composed of three walls; it is also a set of enclosures with three or more rectangular structures around the courtyard (Hyslop 1990: 17).

[5] The "*wayrana*" is a structure composed of two *kanchas* that share a wall.

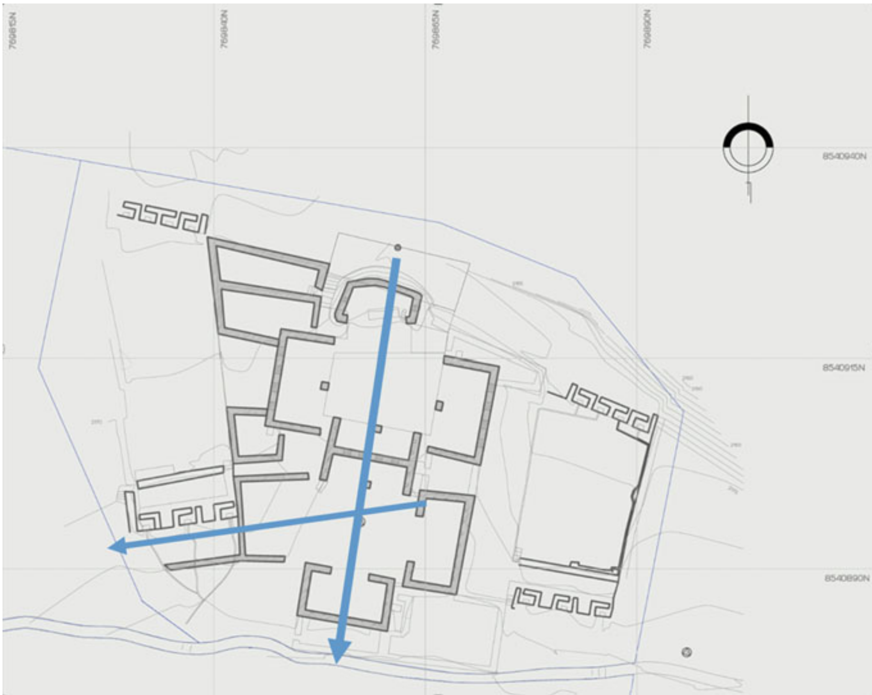

Fig. 12.2 Plan of sector A of the Chachabamba archaeological monument. The main axes are marked in blue (*Source* PIAISHM)

Fig. 12.3 View from the open side of the *huaca* to the south, in the direction of the Apu Salkantay (Photo D. Sieczkowska)

Fig. 12.4 The main *huaca* of sector A, surrounded by fine masonry walls in its first courses (Photo D. Sieczkowska)

The relationship between the *huaca* and the Apu Salkantay[6] is a relatively common arrangement among the sacred landscapes in the Andes (Dean 2011; Glowacki and Malpass 2003; Gose 1993; Sherbondy 1992, 1995).

Similarly, there is a second axis, perpendicular to the above-mentioned axis, that crosses the southern *kancha* and is oriented toward the Intipata archaeological monument, which is the only site visible from Chachabamba. Considering these two axes, it is possible that sector A was also planned considering the east-west axis, but perhaps on a smaller scale.

It is well known that the Incas built their settlements in relation to the sacred geography of the surroundings, and the presence of building materials and water resources (Reinhard 1991; Bastante 2016). In the case of Chachabamba, all these factors are present (Bastante et al. 2020).

This research considered the requirement of a space that complied with the notions of Inca sacredness, including the transformation of a large rocky outcrop into an altar that was encapsulated with thin walls on three of its sides (Fig. 12.4). Other factors such as the abundance of lithic material for the construction of the monument and its proximity to the Chachabamba stream and Vilcanota River were also considered.

At least two construction phases have been defined in sector A of the monument. The first relates to the *huaca* and the two *kanchas* and the second to the construction of the water systems and sunken plazas to the east and west of the *kanchas*. With respect to the other sectors, it is unclear what the construction process was or if there was meticulous planning as in the case of sector A. These sectors have not yet been investigated and only their approximate extension is known, for example, the

[6] The "Apu" Salkantay is the highest Nevado (Snowpeak) in the Cordillera Vilcabamba and was considered to be one of the principal deities in the pre-Hispanic cultures of the central highlands region (Bastante 2016; Farrington 1992; Reinhard 2007). It was believed that Apus existed to watch over the surrounding regions and command a hierarchy of the lower hills (Steele and Allen 2004: 213–216).

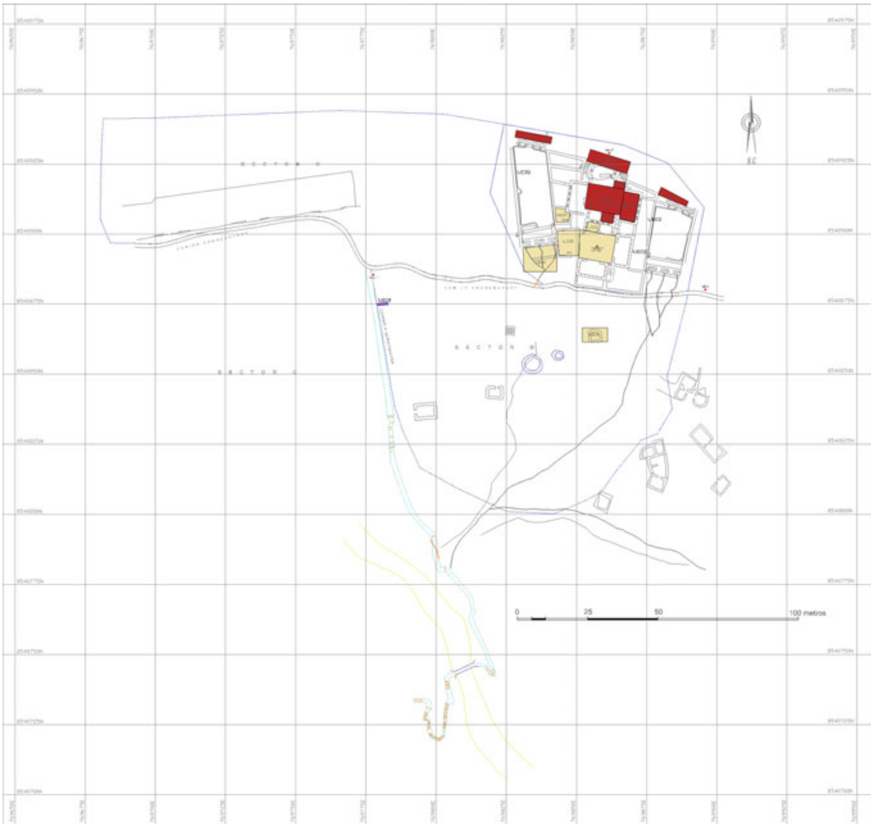

Fig. 12.5 Plan of the four sectors that constitute the Chachabamba archaeological monument. The excavations were conducted in the 2016 (red) and 2017 (yellow) seasons (*Source* PIAISHM)

presence of several structures (sectors B and C) in addition to a system of terraces in sector D and the channels that cross-sector B and connect with the fountains in sector A (Fig. 12.5).

12.3 Archaeological Investigations of the Water System

The previous three seasons of investigations at the site, which began in 2016, were concentrated in sector A. In relation to the sources, three units were excavated, which are briefly described below (Bastante 2018).

Unit UE01-2016 was located in front of the fountains in the lower part of the west side of sector A (Fig. 12.6). Research conducted in the unit revealed that each of the four fountains contains a drainage channel, which is split in two, with each double-channel possibly connected to a larger channel that would direct the flow

Fig. 12.6 Orthoimage of the final layer of UE01-2016 with visible drainage channels (Credit Dominika Sieczkowska)

into the Vilcanota River. No movable archaeological materials were found, possibly because restoration work had been conducted in the space in previous years (Bastante 2018; Fejos 1944; Quirita Huaracha 1997).

Unit UE03-2016 was traced at the foot of the fountain on the lower part of the east side of sector A, where it was possible to define the drainage channels with the same distribution as in UE01-2016. In this case, it was also discovered that restoration work had been performed on the fountains.

Unit UE05-2017 was located in the upper west part of sector A. The works were conducted on two levels. In the lower level, the area of the unit was crossed by three channels that were parallel to the fountains. The liquid element arrived at the upper level (Fig. 12.7). In this unit, five cultural layers were defined and excavated

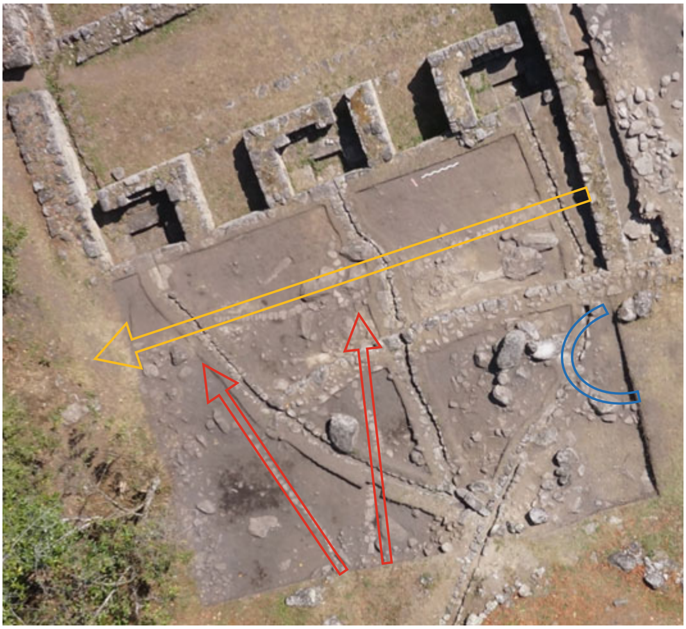

Fig. 12.7 Unit UE05-2017. The arrows indicate the directions of the uncovered channels and the semicircular wall (Photo B. Ćmielewski, analysis: D.Sieczkowska)

above the sterile level was reached. Two clearly marked construction phases were established. The first important feature discovered was a channel that crossed the unit in an east-west direction. Two additional drainage channels were discovered that were constructed below the visible channels on the west side of the unit. In both cases, the slabs that covered the channels or served as a base were evidenced if the hidden channels were constructed in the same way as those currently visible (Bastante 2018).

Based on this evidence, it was possible to determine that the builders changed the original orientation of the channels. The evidence indicated that the currently visible fountains and their channels were built during the last constructive phase of the monument and were adjacent to the two *kanchas* in sector A. It was also evident that the channels were built not only at the last phase (as they are currently visible) but also before this modification when the water flowed through the area of UE03-2017 (adjacent to and to the east of UE05-2017).

On the south-east side of unit UE05-2017, the projection of a semicircular wall with two faces built with partially worked granitic blocks was discovered. The excavation was deepened to the foundation of the wall from which charcoal remains were recovered for dating analysis. This wall is likely related to the first construction phase of the monument (Ziółkowski et al. 2020).

Thus, Chachabamba is a site of greater complexity than previously thought. The planning of sector A shows that the system of fountains and channels was built to frame the two courts. Moreover, based on the results of the excavations, it is highly plausible that this was the final phase of modifications.

12.4 The Function of the Site via an Analysis of the Water System

The presence of a system of fourteen fountains in sector A may indicate the function or functions of the Chachabamba archaeological monument. Only the two *kanchas* present in sector A are associated with the *huaca*, and the archaeological investigations conducted on the north side of the *huaca* unearthed the remains of ceremonial ceramics and a bronze knife (Bastante et al. 2020). This suggests that in this space, ceremonies were conducted in relation to the direction of the Apu Salkantay. However, when the system of fountains surrounding the *kanchas* is considered, the situation becomes more complicated.

The system of fountains is complex and covers the upper and lower parts of sector A, sacralizing the central area where the *kancha* and *huaca* are located. From a broader perspective, the *huaca*, oriented to the Apu Salkantay, is in the center of a hydraulic system. Through the complex water system present in Chachabamba, the Incas were able to control the water, turning it into a political issue (Gose 1993: 482). It is significant that the Inca cosmovision considered water as an element that surrounded the entire earth and flowed through channels, springs, lakes, and wells to finally end up in the sea (Carrión Cachot 2005: 115; Sherbondy 1992: 57). In summary, in the past, the flow of the water at Chachabamba represented “an almost obsessive concern for the ritual control of water” (Gose 1993: 482) but also fulfilled the role of the symbol of a natural process (Dean 2011: 23).

A comparison of the hydraulic system at the Chachabamba monument and that of the closest sites, such as Wiñaywayna, Choqesuysuy, or the *llaqta* of Machu Picchu, shows very few similarities. This is because the hydraulic systems at the three latter sites served a ceremonial and domestic purpose (for Machu Picchu see Wright and Valencia 2000: 31–33) whereas the hydraulic system in Chachabamba appears to have had an exclusively ceremonial function.

Planning for the correct functioning of the hydraulic system at Chachabamba was more complex than at the other sites (see Fig. 12.2 for the plan of the sector). In the upper part of the sector, there are three fountains in the east and three to the west of the *kanchas* which are connected via independent channels that lead through the ends of the sunken plazas, with the four sources on each side of the central *kancha* (Fig. 12.8). In all known cases where there are hydraulic systems with fountains, the objective is to supply water to a specific space. However, the Chachabamba hydraulic system does not connect with any building in sector A and the water flows into the Vilcanota River without entering the *kanchas*. Based on this, the *kanchas* and the *huaca* did not have direct supply of water.

Although the construction pattern of the fountains is homogeneous and analogous with those that are recent in most of the SHM-PANM monuments, the correlation between the function and quality of the construction is relative. It can be argued that the most important characteristic that demonstrates whether a given fountain has a ceremonial function is its architecture. However, in Chachabamba, the water system is located in a carefully planned central space with a more important orientation, although its architecture is rustic.

Fig. 12.8 The four fountains in the lower part of the west side of sector A (Photo D. Sieczkowska)

Besides the similarity in construction, there are few other similarities between the water system at Chachabamba and the water systems at the three above-mentioned sites. Particular attention should be paid to the arrangement of the fountains. As stated previously, in most of the cases from the park area, the fountains were placed in a continuous line, for example, in Machu Picchu, Wiñaywayna, Phuyupatamarca, and Choqesuysuy. Conversely, at Chachabamba, the arrangement of the fountains is relatively parallel, i.e., they are positioned in relation to the central north-south axis and located in the four corners of the ceremonial part of the site, enclosing it to an extent and forming a complex. Moreover, in Chachabamba six of the fountains are located in the upper part of the ceremonial sector (three to the east and three to the west) (Fig. 12.9) and eight are in the lower part (four to the east and four to the west) (Fig. 12.10). Nevertheless, the water structures were placed in a dual formation with

Fig. 12.9 Three upper baths on the west side of the central *kancha* and the *huaca* (generated by B. Ćmielewski from a 3D scan of the ceremonial sector)

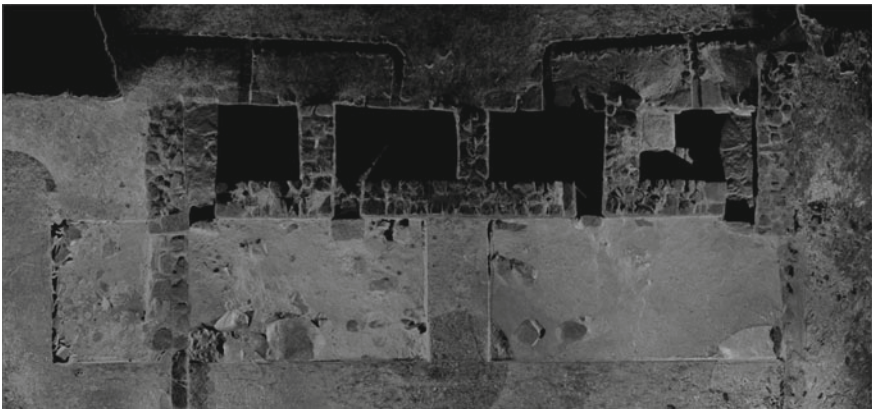

Fig. 12.10 Four baths on the west side of the central *kancha* and the *huaca* (generated by B. Ćmielewski from a 3D scan of the ceremonial sector)

half of them on the left side of the central sector and half of them on the right side of the central sector, emphasizing the sacred character of the site.

12.5 Discussion

The archaeological evidence from the excavations suggests that since the construction of the Chachabamba monument, there was a system that transported water to sector A. This reinforces the supposition that the water system corresponds to a ceremonial space around the *huaca*. During the second construction phase, although there were architectural changes, the function of this space was not altered. The high number of fountains (fourteen in a small space), their location on the sides of the *kanchas*, their relationship with the *huaca*, and the fact that Chachabamba controlled access to the *llaqta* of Machu Picchu, suggests that these fountains had a specific function related to the ablution ritual. This is in contrast to the hydraulic systems in other monuments of the SHM-PANM. The ablution ritual may have been performed during events of the Andean calendar. The evidence presented herein demonstrates that the water system at Chachabamba served a ritual purpose, for example, bathing and purifying oneself before accessing certain ceremonies. Evidence of ritual baths was also described during an encounter in Cajamarca (Estete 1535: 5; de Xerez 1534). Certain ceremonies may have been performed in Chachabamba next to the *huaca* dedicated to the Apu Salkantay. Nevertheless, it is also feasible that the site fulfilled the role of an obligatory stop prior to entering the *llaqta* of Machu Picchu. Under these circumstances, the pilgrims arriving at Chachabamba may have undergone ablutions before reaching the end of their pilgrimage. Under this assumption, Chachabamba would have maintained a strictly political-administrative dimension, as a mandatory stop before arriving at *llaqta* of Machu Picchu.

It is unclear what type of rituals occurred at Chachabamba. During the archaeological excavations, several tools for the production of textiles were discovered (Bastante et al. 2020). These findings could support the hypothesis that the site was a transitory location for ablutions, where the pilgrims received new clothing that was manufactured at the site. Unfortunately, few pieces of archaeological evidence exist to defend this theory with complete certainty.

12.6 Conclusions

The present study is part of ongoing research on the function of the hydraulic system at Chachabamba. The results obtained during the previous seasons of excavations have contributed to an understanding of the activities that occurred in the monument during the Inca period. The results of the investigations around the *huaca* revealed that it was a place primary ritual importance. Conversely, the investigation in part of the hydraulic system demonstrated that the fourteen water management structures had the sole function of being used for ritual purification baths associated with the ceremonial aspect of the site.

The evidence obtained to date suggests that the sole function of the Sector I or A was ceremonial, where the *huaca* and baths fulfilled a key role in the sacred landscape of the region dedicated to the Apu Salkantay and/or the llaqta of Machu Picchu. Undoubtedly, the interdisciplinary research to date has established that Chachabamba was the most important satellite site with ceremonies associated with the Apu Salkanaty and pilgrimage to the *llaqta* of Machu Picchu. The function of the other sectors at Chachabamba remains unclear. As interdisciplinary research continues, an improved understanding of the daily lives of the inhabitants of Chachabamba will be achieved.

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References

Bastante J (2016) Investigaciones interdisciplinarias en la Llaqta de Machupicchu. Arqueología Soc 32:267–276

Bastante J (2018) Informe Final. Programa de Investigaciones Arqueológicas e Interdisciplinarias en el Santuario Histórico de Machupicchu 2014–2017, Dirección Desconcentrada de Cultura-Cusco, Cusco

Bastante J, Sieczkowska D, Deza A (2020) Investigaciones En El Monumento Arqueológico Chachabamba. In: Bastante JM, Astete F (eds) Machupicchu Investigaciones Interdisciplinarias, vol. II. Ministerio de Cultura del Perú, Perú, pp 289–304

Bauer B (2000) El Espacio Sagrado de Los Incas: el sistema de Ceques del Cuzco. Centro de Estudios Regionales Andinos Bartolomé de las Casas, Cusco

Bray T (2013) Water, ritual, and power in the Inca Empire. Lat Am Antiq 24(2):164–190

Carrión Cachot R (2005) El Culto al Agua En El Antiguo Perú. Segunda edición. Instituto Nacional de Cultura del Perú, Perú
de Xerez F (1534) Verdadera Relación de La Conquista Del Peru. 2003rd ed. Biblioteca Virtual Universal
Dean C (2011) Inka water management and the symbolic dimensions of display fountains. RES: Anthropol Aesthetics 59(1):22–38
Diccionario Quechua - Español – Quechua (2005) Academia Mayor De La Lengua Quechua, Gobierno Regional del Cusco, Cusco
Domingo de Santo Tomas (1560) Lexicón, o Vocabulario de La Lengua General Del Perú
Estete, Miguel de (1535) Noticia Del Perú. 1918th ed. Boletín de la Sociedad Ecuatoriana de Estudios Históricos Americanos, Quito
Farrington I (1992) Ritual geography, settlement patterns and the characterization of the provinces of the Inka Heartland. World Archaeol 23(3):368–385
Fejos P (1944) Archaeological explorations in the Cordillera Vilcabamba Southeastern Perú. Viking Fund, New York
Fernández Flórez A (2020) Materialización del culto al agua a través de la arquitectura hidráulica en la Llaqta de Machupicchu. In Machupicchu Investigaciones Interdisciplinarias, Cusco
Glowacki M, Malpass M (2003) Water, huacas, and ancestor worship: traces of a sacred Wari landscape. Lat Am Antiq 14(4):431–448
Gonzales Holguin D (1608) Vocabulario Dela Lengua General de Todo El Peru Llamada Lengua Qquichua, o Del Inca. Impresso en la Ciudad de los Reyes: Por Francisco del Canto, Lima
Gose P (1993) Segmentary state formation and the ritual control of water under the Incas. Comp Stud Soc Hist 35(3):480–514
Hyslop J (1990) Inka settlement planning. University of Texas Press, Austin
MacLean MG (1987) Sacred land, sacred water: Inca landscape planning in the Cuzco area. PhD Thesis, Berkeley
Masini N, Capozzoli L, Romano G, Sieczkowska D, Sileo M, Bastante J, Astete Victoria F, Ziółkowski M, Lasaponara R (2018) Archaeogeophysical-based approach for Inca archaeology: overview and one operational application. Surv Geophys 39(6). DOI: https://doi.org/10.1007/s10712-018-9502-2
Protzen J-P (1993) Inca architecture and construction at Ollantaytambo. Oxford University Press, Oxford
Qurita A (1996) Conjunto Arqueológico de Chachabamba. Informe Final de Obra, INC, Cusco
Qurita A (1997) Conjunto Arqueológico de Chachabamba. Informe Final de Obra, INC, Cusco
Reinhard J (2002 [1991]) Machu Picchu, El Centro Sagrado. Instituto Machu Picchu, Cusco, Ed Automás S.A.
Reinhard J (2007) Machu Picchu: the sacred center. Cotsen Institute of Archaeology, University of California, UCLA
Ricardo A (1586) Arte y Vocabulario de La Lengua General Del Perú, Llamada Quechua, y de La Lengua Española, Lima
Sherbondy JE (1992) Water ideology in Inca ethnogenesis. In: Robert V, Dover H, Seibold KE, McDowell JH (eds) Andean cosmologies through time: persistence and emergence, Indiana University Press, Bloomington, IN, pp 46–66
Sherbondy JE (1995) El Agua: Ideología y Poder de Los Incas. In: González JA, Cuello AM (eds) El agua: mitos, ritos, y realidades. Centro de Investigaciones Etnológicas, Granada, pp 87–102
Sieczkowska D, Bastante JM (2021) Las Phaqchas de Chachabamba (Parque Arqueológico Nacional de Machupicchu, Perú). In: Arqueologia Iberoamericana
Sotil Monteverde, RL (2007) Los Ushnus y El Culto a Dioses Con Atributos Sobre El Agua En Beneficio de La Producción Agrícola Dentro de La Administración Estatal Inca. Rev De Arque Am 25:247–276
Steele PR, Allen CJ (2004) Handbook of Inca mythology. ABC-Clio Inc., Santa Barbara, CA
Wright KR, Valencia Zegarra A (2000) Machu Picchu Maravilla de la ingeniería civil. American Society of Civil Engineers, Virginia

Ziółkowski M, Bastante Abuhadba J, Hogg A, Sieczkowska D, Rakowski A, Pawlyta J, Manning SW (2020) When did the Incas build Machu Picchu and its satellite sites? New approches based on radiocarbon dating. Radiocarbon, pp 1–15. DOI: https://doi.org/10.1017/RDC.2020.79

Chapter 13
High Mountain Underwater Archaeology: Research in the Lakes at the Foot of Salkantay Mountain

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Abstract Salkantay, like other snow-capped mountains, had in Inca times the status of a sacred mountain, an object of imperial worship. The ritual activities associated with the latter also included various ceremonies dedicated to the lakes located at the foot of the mountains.

Within the framework of the Machu Picchu satellite sites research project, five lakes have been selected for terrestrial and underwater surveys in order to find traces of such ceremonial activities.

In the case of three lakes located near an Inca trail, traces of different pre-Hispanic ceremonial activities have been demonstrated. The remaining two lakes were found to be of relatively recent origin, but it is noteworthy that in the vicinity of all five lakes were traces of contemporary ritual activities related to traditional Andean beliefs.

Keywords High mountain underwater archaeology · Machu Picchu · Salkantay · Huaca · Sacred lakes

13.1 Introduction

During three seasons (2016–2017, 2019) archaeologists from the Center for Andean Studies of the University of Warsaw (CEAC), in collaboration with the Regional Delegation of the Peruvian Ministry of Culture in Cusco and the Research Team of

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Fig. 13.1 Salkantay summit. View from the approach from Soray Pampa (phot. M. Sobczyk)

Machu Picchu National Park, inaugurated a pioneering non-invasive survey of the lakes located in the foothills of the Salkantay mountain.[1]

But before describing the results obtained during these fieldwork campaigns, it seems necessary to explain why these highland lakes and their surroundings have been chosen as research targets? (Fig. 13.1).

13.2 Salkantay in Ethnohistoric Sources

In early colonial sources, among the main "huacas", objects of worship on a pan-Andean scale, some lakes are mentioned, but in particular several mountains, especially those snow-capped.[2] Although this cult had its pre-Inca antecedents, in Inca times the sacred mountains were incorporated into the network of imperial sanctuaries, and enjoyed important donations from the state:

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[1] This was part of a larger international project "The function of satellite sites in the Machu Picchu region: Inkaraqay and Chachabamba sites and the high mountain lakes of Nevado Salkantay (Peru)", coordinated by the CEAC. Some more detailed information is presented in the Acknowledgements at the end of this chapter.

[2] There is an abundant literature on this subject, the main contemporary works of reference being, among others, those of Pierre Duviols (1976), Antonio Beorchia N. (1985), Juan Schobinger (1986, 1999), Constanza Ceruti (2004), Johan Reinhard and Constanza Ceruti (2005), Johan Reinhard (2007), Thomas Besom (2009, 2010), Peter Gose (2016).

> There are many of these *guacas pacariscas* that the Inga rebuilt, giving them many *mitimas* [colonists, settlers – the Authors] for service, and for this purpose he moved them [the mitimas] from one province to another. He (the Inga) gave them (*guacas*) many cattle and vessels of gold and silver, and so it was in all the Cordillera that faces the sea, in all [the lands] that he conquered, especially in the snow capped mountains and volcanoes that face the sea, from which [the mountains] come out the rivers that irrigate many lands (…).[3]

This same author, in his list of main Inca places of worship, mentions Salkantay, in the province of Quichua: "Salcantay is a very high, snowy and highly revered mountain" (Albornoz 1967 [1584?]: 28). This information is confirmed by an indigenous chronicler, Don Joan de Santa Cruz Pachacuti Yamqui Salcamayhua, who attributes to Salkantay a very important role in the Inca imperial cosmovision and ritual. It would be, together with other mountains, the place of banishment and punishment of the huacas, considered by the Incas to be inept and liars:

> "all the *curacas* and their historians of the *orejones* told the same thing, that *ttonapa* had banished all the *guacas* and idols, to the mountains of *aosan ca ta* and *quiy an cata* and *sallcantay*, and to *pitosiray*".[4]

It is significant that Salkantay appears here as one of the four protective mountains of the Cusco region, together with Ausangate, Quiyancata (Callangate) and Pitusiray.

In this same source Salkantay appears again in a very particular context—as the place where Huascar Inca had been captured after being defeated and taken prisoner by Atahuallpa's generals:

> "and thus [they] capture and win the Person of *guascarynga inti cussiguallppa* taking him prisoner to sallcantay".[5]

This information is somewhat enigmatic, because it is not explained neither for what purpose, nor to what precise place Huascar was taken. It could be that this act had a symbolic meaning, associated with the first function of Salkantay mentioned by the chronicler.[6]

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[3] "Hay entre estas guacas pacariscas muy muchas que reedificaron los ingas, dándoles muchos mitimas servicios que para este fin los mudava de unas provincias a otras. Dioles (el inga) muchos ganados y basos de oro y plata como fue en toda la Cordillera que mira al mar, en todo lo que conquistó, en especial a cerros de nieve y bolcanes que miran a el mar y que salen de los ríos que riegan muchas tierras (…)" (Albornoz 1967 [1584?]: 20).

[4] "todos los y sus historiadores de los orejones los dixieron lo mismo q[ue] abian desterrado ese mismo ttonapa a todos los guacas y ydolos, a los serros de aosan ca ta y quiy an cata y sallcantay, y a pito siray" (Pachacuti Yamqui [1615] 1993, fol. 15v).

[5] " y assi los prende y gana al Cuerpo del guascar ynga inti cussi guallppa lleuando les, presso a sallcantay" (Pachacuti Yamqui [1615] 1993, fol. 42r).

[6] A question arises: what was the reason for taking the Inca prisoner Huascar first to "Salcantay", and not directly to Cusco? The explanation, tentative of course, could be the following: precisely because, according to this same chronicler, Salkantay was a place of exile for the huacas, considered to be defeated. Let us remember that a Sapay Inca (Huascar) in his capacity as "Son of the Sun and the Moon" was a "huaca". To take him to this particular place would be something like the confirmation of the loss of his status of "sacred being" and of the powers associated with that position. It is therefore not by chance then that in the following lines of his chronicle, Don Joan

The qualification of Salkantay as an important entity within the Andean cosmovision is confirmed, throughout the Colonial period, in a somewhat indirect, but very explicit way: through the name "Apu Salcantay" under which it appears in the documents related to the delimitation of the lands. In his detailed study of the distribution of properties in the Machu Picchu region, Donato Amado cites several documents in which the name of the mountain appears in this form (Amado, this volume). The title of "Apu" (literally "lord" in Quechua) is, to this day, attributed to the snow-capped mountains considered to be the divine protectors of a region, in this case—Cusco.[7]

In the texts analysed by Amado, we observe then that the Salkantay range and its division of watersheds is frequently mentioned in the layout of the administrative boundaries and private properties. As Catherine Julien has shown, the arrangement of Colonial administrative divisions in a determinate area is probably, to some extent, a reflection of the situation in pre-Hispanic times as well (Julien 1991). As in the delimitation of properties corresponding to the sixteenth and seventeenth centuries, the Llaqta of Machu Picchu and the northern part of the Apu Salkantay range integrate a single territorial entity (Amado, this volume—see Fig. 2). We can therefore assume that this was also the situation in pre-Hispanic times. As part of the same socio-political entity, also on a ritual level the Llaqta and the Apu Salkantay may have been symbolically and ritually linked through ceremonial sites, located along an Inca trail to those located at the very foot of the mountain. We have been able to archeologically document such a situation in the case of Nevado Coropuna: each of the three main Inca administrative-religious sites, located on three sides of this Apu, had its satellite site located in the high parts of the slopes, near the edge of the perpetual snow and the glacier of Coropuna (Sobczyk 2016, Ziółkowski 2014).

In the descriptions of chroniclers such as Guaman Poma de Ayala (1993 [1583–1615]), Cristobal de Molina (1989 [1575]) and Cieza de León (1977 [1550]), and in part of the Huarochirí manuscript (Arguedas 1966; Taylor 1987), there are repeated references to the lakes as places of particular important indigenous rituals. The main part of this corpus of data concerns Lake Titicaca, an object of pan-Andean worship already in pre-Inca times. There is a wealth of data about the role of Titicaca in the Andean cosmovision, about the rituals and offerings made in its honour and about the various ceremonial structures erected on its shores, on the islands or even at its

describes in great detail all the humiliations and affronts to which Huascar was exposed in public, already in Cusco, by the commanders of Atahuallpa, Quisquis and Chalcuchima (Pachacuti Yamqui [1615] 1993, fol. 42r–42v). This was very probably a way of demonstrating to the followers of the defeated Inca that he had definitively lost his quality of "sacred being". If this was the reason for taking Huascar "to Salcantay", it would remain to establish which site of ceremonial characteristics, supposedly located on the slopes of the snow-capped mountain, could it be? But this is a subject for a separate study.

[7] "Apu. s. mit. Espíritu tutelar de un pueblo que habita en las cimas de los cerros, en los nevados, en la peñolería o en una waka importante. EJEM: Apu Salqantay, Apu Pachatusan, Apu Awsanqati, dioses tutelares de la ciudad del Qosqo. || Ec: Jefe, mandatario, superior". (Avendaño 1955:). Compare note 2.

very bottom—much of this evidence has been confirmed by archaeological surveys, which will be discussed below[8] (Fig. 13.2).

However, other smaller lakes were also objects of worship in Inca times, at a more regional level. Some of these were considered to be *pacarinas*, i.e. places of origin of ethnic groups:

> Some [of the peoples] came from caves, others from mountains, others from springs, and others from lakes. (Molina 1989 (1575): 35–36)

Albornoz, on the basis of his long-term research of the huacas, names some lakes that enjoyed a particular cult:

> Choclocacha, a large lake in the puna of Guaytara, of great veneration, [because] rivers flow from it, and many sacrifices were made to it.
>
> (…) Chinchaycocha, the main guaca of the local Indians, is a lake. It was very revered and served by the Ingas.
>
> (…) Auquivilca, guaca of the Chinchaycocha Indians, is a lake next to the town of Llaca. The Caxamalca Indians say that they descend from this lake.[9]

The high mountain lakes in particular were considered to be the places of origin of llamas and alpacas. For the area of Recuay we have various testimonies of Rodrigo Hernandez Principe:

> These Indians pretended that the origin of their llamas was the Viccvicocha lake, which is why they whorshipped it.[10]

It is interesting to note the persistence of this belief that high mountain lakes are places of origin of domestic animals: at present such origin is attributed also to cattle (Gow et al., 1982: 64).

These beliefs and practices had their important ritual components carried out under the guise of Christian festivities:

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[8] The main source describing these aspects of Titicaca's position in the imperial Inca (and also pre-Inca) cult is the chronicle of Father Alonso Ramos Gavilan published in 1621 (Ramos Gavilan 1976 [1621]). A synthesis of ethno-historical and archeological data on the Sanctuaries of Lake Titicaca has been published by Brian Bauer and Charles Stanish (2003), see also the parts dedicated to Titicaca in the works of Johan Reinhard and Constanza Ceruti (2010). An interesting study on the continuity of the cult of the lake and associated divinities, in colonial times, mainly in the form of the cult in the sanctuary of the Virgen de la Candelaria in Copacabana, has been presented by Sabine MacCormack (1984). The calendar aspect of this continuity, in relation to the dates of the Inca festivities, has been analysed by Mariusz Ziółkowski (1994).

[9] "Y así, diçen que los unos salieron de qüebas, los otros de çerros, y otros de fuentes, y otros de lagunas, (...)" (Molina 1989 [1575]: 35–36).

"Choclo Cacha, laguna grande en la puna de Guaytara, de grande beneración, que nascen della ríos, y le hazían muchos sacrificios (...) Chinchaycocha, guaca principal de los indios chinchacochas, es una laguna. Fue muy reverenciada y servida de los ingas. Auquivilca, guaca de los indios chinchay cochas, es una laguna junto al pueblo de Llaca. Dizen los indios caxamalcas descender desta laguna". (Albornoz 1967 [1584]: 29–30). Compare the next note.

[10] "Fingen estos indios ser el origen de sus llamas la laguna de Vicvicocha, por lo cual la adoraban". According to Hernandez Principe this was also the case of other two lakes: Cónoc y Querococha (Hernandez Principe 1923 [1622]: 28, 37).

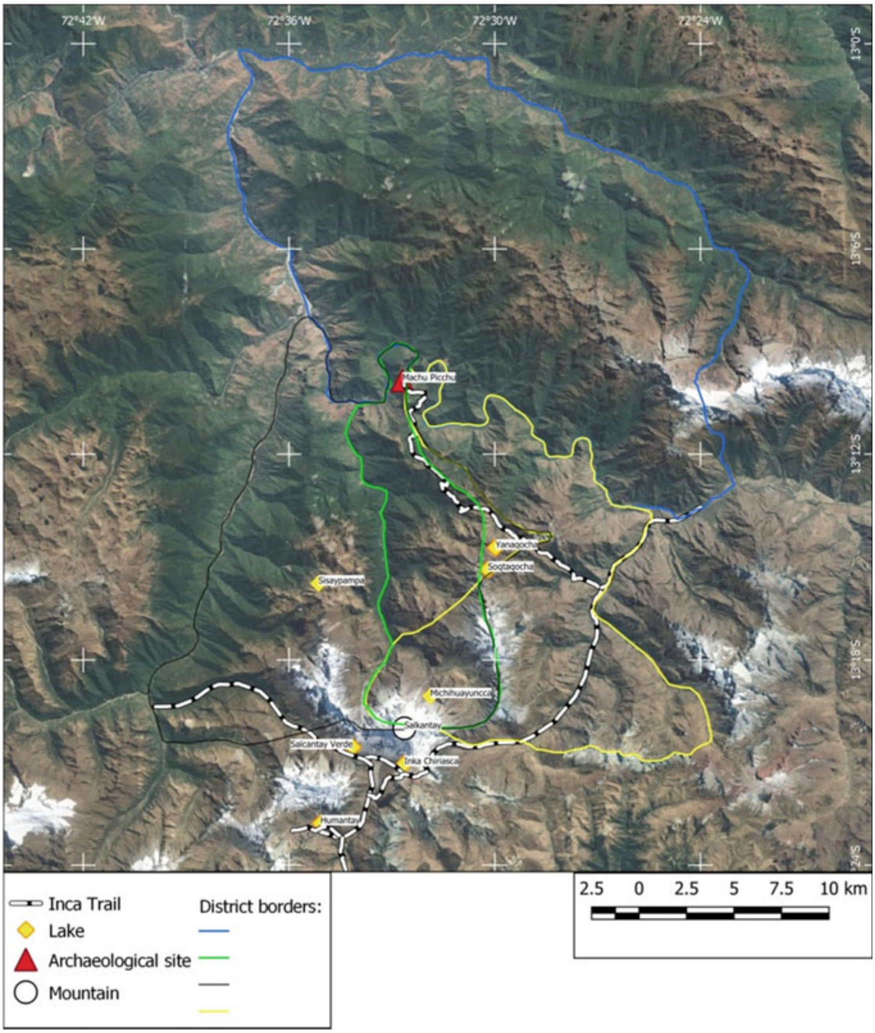

Fig. 13.2 Changes in local boundaries during colonial times according to Amado (in this volume). The course of the pre-Columbian roads, indicating the location of archaeological sites and lakes subject to the project (M. Popek, M. Sobczyk)

> And in the province of Chinchacocha, when it was visited [by the Fathers], it was found that they [the Indians] carried in the Corpus Christi procession two indigenous lambs [literally 'from this Earth' i.e. young llamas – the Authors], alive, each one on its *andas* [palanquin – the Authors], by way of feast and dance, and it was learned that they were in fact offerings and sacrifices, dedicated to two lakes, Urcococha and Choclococha, from where it is said that the llamas came from and had their origin.[11]

[11] "Y en la provincia de Chinchacocha, cuando se visitó, se averiguó que llevaban en la procesión del Corpus dos corderos de la tierra, vivos, cada uno en sus andas, por vía de fiesta y de danza, y

Another reason for the cult of the lakes was related to agriculture and, more precisely, to the supply of water to the fields, mainly for irrigation, but also to provide rainfalls. For the latter purpose, water was carried in containers from the lakes to the fields. This was one of the aspects of the traditional cult to which the priest Arriaga special attention in his warnings to the *visitadores de idolatrías*, recommending them to ask the Indians about:

> Tenth, what puquios, or lagoons do they [the Indians] worship (…) Sixteenth (…)_ from which lakes do they bring pitchers of water, to sprinkle the *chácara* [fields], and ask for rain, to which lake do they throw stones, so that [the fields] does not dry up, and rain comes [(2010, 139; 66)].

Offerings to the lagoons were made on their banks:

> And they also worship two *cochas* [lakes] that are in the puna, called mancococha and cochapuquio, so that they do not dry up and give them water, and [the Indians] offer them live guinea pigs and burn on the banks tallow, coca and mais.[12]

But the lakes could also be places within which *huacas* were located, as the aforementioned Father Pablo Jose de Arriaga testified:

> On his journey, the Father found on the road a lake, and in the middle of it a figure of thin stone, about two rods high, placed by hand. It did not seem right to him, and he spoke of it to the Indians, who told him that it was a *huaca*, and that it was called Quepacocha, and that it served to keep the lake from drying up, because with its water they watered their farms in time.[13]

As we shall see below, these testimonies are important for the archaeological identification of possible sites of offerings on the shores of the Salkantay lakes.

Titicaca, but at least one other lake Yahuarcocha in Ecuador, also benefited from the very prestigious human offering of *capacocha* (Hernandez Principe 1923 [1622]: 28, 41). What is interesting in this context is that of the list of people who had been sent from the ayllus of the Recuay region as *capacochas*, only one was explicitly dedicated to a mountain while six to the aforementioned lakes. Thomas Besom supposes that possibly the lakes might have been even more frequently the beneficiaries of such offerings than the mountains.[14]

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se supo, que realmente eran ofrendas, y sacrificios, ofrecidas a dos lagunas, que son Urcococha y Choclococha, de donde dizen que salieron, y tuvieron origen las Llamas" (Arriaga 1621: 76; 2010: 40).

[12] "Y que dos cochas que estan en la puna que son vnas lagunas llamadas mancococha y cochapuquio tanbien las adoran para que no se sequen y les dan agua y les ofrecen cuyes vibos y queman a las orillas sebo coca y mais (…)" ("Denuncia que hace Juan Tocas (…) San Pedro de Hacas, 1656–1658" in: Duviols 1986: 194).

[13] "Yendo el Padre este viaje halló en el camino vna laguna, y en medio de ella vna figura de piedra delgada, y demás de dos varas de alto puesta a mano. No le pareció bien, y habló de suerte a los Indios, que le vinieron a dizir que era huaca, y se llamaba Quepacocha, y servía para que la laguna no se secase, porque con su agua regavan a tiempo sus chácaras". (Arriaga 1621: 186; 2010: 86).

[14] The fact that, contrary to the view we have on the basis of archaeological findings, snow-capped peaks were not the main and priority places of deposition of *capacocha* offerings is also confirmed by the analysis of the huacas of the Cusco ceque system associated with such offerings (Besom 2010: 403–404).

Returning to Salkantay, although we do not have direct information from Prehispanic or Colonial period about the cult of the lakes, four of the latter do appear in colonial documents as reference points for the boundaries of the territorial divisions. Two (including one named Ancascocha) are also mentioned as being associated with *apachetas* or other types of markers supposedly of pre-Hispanic origin (Amado, this volume).

The next sources of information about Salkantay come from the nineteenth century, they are short records of Count Eugène de Sartiges and Antonio Raimondi. The first of those travellers had walked in 1834 at the foot of Salkantay through the trail leading from Mollepata towards Santa Ana, crossing the Abra Salkantay Pass, noting the difficult conditions on the pass: high altitude, snow, and strong wind but also the picturesque snow-covered peaks around (Sartiges 1851: 1020–1021, 1041). The second traveller (Antonio Raimondi) crossed in 1855 the same pass in the opposite direction from Santa Ana to Mollepata. The record of the journey is quite laconic but contains two important pieces of information. The first of these nevertheless adds slightly to the information about the Salkantay cult. Describing his passage through the pass, Raimondi notes that on the left he passes a peak called simply Salkantay and on the right a lower peak called Chino Salkantay or female Salkantay (today this lower peak is called Humantay). This supposes the existence of myths, similar to those known from other regions of the Andes, about marital relations between mountains (Valderrama and Escalante 1997: 82).[15] The second piece of information from Raimondi concerns the extensive snow cover and the extent of the glacier whose front descends well below the pass towards Soray Pampa (1874: 217).[16]

On the north-eastern side of the Salkantay massif the situation is more complicated due to the terrain. On the east and north side there are a number of deep valleys, high peaks and passes. It crosses them passing the closest Inca trail leading to Machu Picchu. The earliest information depicting the route and its characteristic elements comes from the 1930s and 1940s.

In his archaeological diaries, Julio C. Tello (1942) mentions lakes for the first time, two small reservoirs located close to the road in the area of Palcaymay and the Runkuracay site, the first lake being in the vicinity of the said site, the second after crossing the Runkuracay pass. Both lakes, in the period described and in the present day, are characterized by a seasonal, almost complete disappearance of the water. In the description of the survey, there is also information about the lake which is supposed to be located above. The description of the road and the lake itself is slightly ambiguous, but it can be connected with one of the currently explored reservoirs, it is Yanaqocha Lake, in the logs the same name appears, which in itself

[15] "Dentro de la cosmovisión andina la cumbre del Salqantay es un Apu, por lo tanto existe un China Salqantay (Salqantay hembbra) y Orq'o Salqantay (Salqantay macho)" (Avendaño: 1995: 767–768).

[16] The description of the pass and the extent of the glacier is confirmed by the illustration in the publication "Inca Land" by Hiram Bingham. As we know, he did not explore the pass.

described by the nineteenth century explorers, but he included an illustration showing the very front of the glacier descending towards Soray Pampa (Bingham, 1922).

is not any evidence because it is a common name for many lakes, e.g. one of the seasonal lakes near Runkuracay is also called so.

Let us conclude these introductory remarks with some data taken from anthropological research, mainly related to the contemporary cult of the mountain Apus and lakes. Undoubtedly, the most important corpus of information on this subject comes from the area of Ausangate, which, according to the aforementioned chronicler Don Joan de Santa Cruz Pachauti Yamqui Salcamayhua, was ritually and symbolically associated with Salkantay. In relation to the subject of our study, of particular importance are the rituals performed, up to the present day, at the edge (and underwater) of the lakes, in association with the initiation of the *altomisayuq*.[17] An essential stage of the initiation is the ritual bath, in the course of which the candidate, entering a glacial lake at night (generally located in the vicinity of an *apu* considered to be important), listens to the *wayra* (*huayra*), the voice of the *apu*, speaking to him and confirming his vocation. In the region of Ausangate, these ritual baths take place most frequently in one of the numerous lakes located on both sides of the Qhampa and Iskay Phaqcha Abras (Lanata 2008: 156). There is also some information, although not as detailed, about similar practices in the Salkantay area.[18]

It is noteworthy that in the invocations of the *altumisayuq* associated with the Apu Ausangate, there are also references to other apus of the Cusco region, including Salkantay, which testifies to the continued presence of the pre-Hispanic "sacred space" in the current Andean cosmovision:

> Now, now, señor Laramani Vilcanota, waman Hururu, Francisca, together, now, apuSalkantay, apuChinchina, Ausangate, Ocongate, Lima San Cristobal, and you, Misti volcano, PichuPichu, Salkantay, Machu Picchu, now you have your offering, your gift, I cannot do more, with flowers, that is what I offer you, here is my libation.[19]

The lakes are also places of contact with the *apus* themselves, as well as the origin of the *inqaychu*, or small animals that come out of the lakes at dawn: if one manages to catch one, it turns into a stone, which becomes a powerful amulet (Lanata, 2008: 287 and seq.).

In conclusion: ethnohistorical and ethnographic data testify to the importance of different ritual activities carried out from pre-Hispanic times to the present day, in the surroundings of high mountain lakes. The search for archaeological evidence of such activities in the Salkantay region may refer to sacrificial sites or other ceremonial structures at the border of the lakes, and in their surroundings, but also to the persistence of possible traces of offerings and cult objects inside the lakes themselves.

[17] *Altumisayuq, altomisayoc-* high-ranking priest in the Andean religious hierarchy. Compare Juan Victor Nuñez del Prado B. and Lidia Julia Murillo V. (1991).

[18] "In the Cusco region many ritual contemporary specialists (*paqos* and *altomisayoqs*) consider themselves under the protection, blessing, empowerment of either Salcantay or Ausangate, depending on the place where they resided when they learned their trade. In order to be "presented" to these mountains, the student and his teacher should journey to their slopes. Ritual specialists from Quillabamba in the tropical lowlands are also said to go to Salcantay for spiritual empowerment" (Reinhard 2007: 23).

[19] *Altumisayuq* Leonardo Chullo quoted by Ricardo Lanata (2008: 197–198—translated by the Authors).

The problem to be solved is which of these lakes existed more than 500 years ago, in Inca times? We will try to answer this question in the following paragraph.

13.3 Fluctuation of Glaciers

The study of the lakes around the Salkantay massif had primarily an archaeological aspect, but also a geological one. Climate change and the melting of glaciers have had a significant impact on changing the surrounding environment. In the case of the alleged "lakes of offerings", it was also necessary to take into account the reconstruction of the environment for pre-Columbian times; the existence of extremely picturesque lakes today does not mean that they existed in the period we are interested in. The behaviour of glaciers (melting or growth) is a reflection of the accumulation of climatic changes such as temperature, precipitation, and the associated changes in atmospheric fronts, winds, humidity, etc., all of which are very closely linked to the accumulation of the ice. All these factors are very closely linked to changes in the perception of the geomorphology of the land. The landscape, which today seems to us extremely attractive for the celebration of religious ceremonies may have changed over the centuries. The climatic changes associated with the slow warming of the climate are also reflected in the Andes massif. The increase in the temperature amplitude between the dry summer and rainy winter seasons and, on a "micro" scale, the increase in the temperature amplitude between day and night has a huge impact on changing the microclimate of the Andean valleys and, of course, on a macro scale, the whole Andean massif. Many high mountain lakes located at the foot of mountain ranges on the boundary of descending glacial tongues are the result of these climate changes, the accumulation of water from melting glaciers in the valleys at the foot of the mountains. There is increasing evidence that the general glacier retreat observed as a result of global warming has a strong direct impact on the climate of the Andes mountain range, having accelerated considerably in recent decades. The retreat of the Andean glaciers was not uniform throughout the twentieth century. Glacier mass balance, which is an estimate of the difference between snow and ice accumulation and their ablation (by melting and sublimation) appears to be strongly controlled by climate variability on decadal time scales, driven by the ENSO (El Niño) mechanism. The causes of tropical glacier retreat are the subject of intense international debate (Courdan at al. 2006, Fig. 1).

As a result of underwater studies carried out in high mountain lakes in the foothills of the Salkantay Massif, the documentation was supplemented by field observations and measurements. It was complemented by satellite observations inserted in the summary of the results. Geological processes associated with climate warming are also recorded in archaeological observations and studies. Unfortunately for archaeologists, some of the lakes researched as potential objects of prehispanic rituals could not play this role, because they were probably already formed in post-Columbian times, even possibly in the twentieth century, as a result of systematic climate warming.

In recent years, a number of studies have been conducted to determine the extent of glacial preservation in different regions based on analyses of retrieved cores. Determining the spatial variability of climatic conditions through the analysis of temperature and precipitation anomalies over the last millennium is a basis for understanding the mechanisms of glacial fluctuations, possible on a regional scale (Jomelli et al. 2009: 269). The study included, among others, glacier cores

recordings in the Cordillera Blanca and Vilcanota which are neighbours to the Salkantay massif. The study also used the analysis of moraines, which specifically show the previous positions reached by the glacier. Climatic conditions can be estimated from glacier length and other glaciological parameters, such as equilibrium line altitude (ELA) or mass balance, which can then be used to reconstruct the climate. The temporal resolution is lower than that obtained from ice core records and depends on the number of preserved moraines in the glacier foreland. The error in the dating obtained can range from one to five decades (Jomelli et al. 2009: 270).

Understanding glacier-atmosphere interactions is particularly complex in the tropics because accumulation and ablation processes are synchronous and must be separated for interpretation (Hastenrath and Ames, 1995; Kaser, 2001). Due to the unavailability or insufficient data, calibration between glacier masses and climatological parameters over the long term for the tropical Andes is more difficult in contrast to mid-latitude glaciers.

Essentially, three analogous phases of fluctuations of Andean glaciers have been identified: an early one ending around 1350, then between the seventeenth and eighteenth centuries, and a glacier retreat interrupted only by minor phases of glaciation. Between the fourteenth and seventeenth centuries there is limited evidence for glaciation proceedings. In several cordillera in Peru and Bolivia, the maximum glaciation of the last millennium—defined as the extent of the furthest valley recorded synchronously by most glaciers (32 glaciers)—occurred in the seventeenth century. In the Cordillera Blanca (Peru), moraines corresponding to this glaciation were dated to ca. 1630 ± 27 using the GEV method (Jomelli et al., 2008, 2009). The eighteenth and nineteenth centuries saw repeatedly recorded glacial fluctuations revealing advances visible in the moraines. Unfortunately, for the thirteenth and fourteenth centuries, climatic conditions for Peru and Bolivia cannot be estimated from moraine studies. Between the seventeenth and early nineteenth centuries, climatic conditions estimated from glacier fluctuations indicate a cooler and wetter period than the present (Jomelli et al. 2009; Figs. 4–6).

In conclusion, the results of the glacial studies carried out to reconstruct the climate in the last millennium (Jomelli et al. 2009; Engel et al. 2014) and therefore the mapping of glacial masses do not allow the interpretation and reconstruction of the landscape for small regions in pre-Columbian times such as the Salkantay mountain massif. Therefore, the studies of the lakes around the Salcantay massif involved verifying not only the function but also the possible existence of water reservoirs in pre-Columbian times.

13.4 The Lakes of the Salkantay Massif

The research included at first seven lakes, but after a ground survey around two of these, namely Michihuayuncca Lagoon and Sisaypampa Lagoon, they have been removed from the list due to the lack of any anthropic trace in their surroundings and the absence of access roads, which could have connected them to Machu Picchu or other Inca settlements.

The remaining five lakes were the subject of initial search including the aforementioned historical sources, analysis of satellite images, documentation of the Park which concerned information on the course of recorded pre-Hispanic routes and the location of archaeological sites in the vicinity.

The selected lakes belong to three different watersheds and in relatively close proximity to them. They are located near remains of pre-Hispanic routes and archaeological sites.

The southern watershed is fed from the Salkantay and Humantay glaciers which consequently feeds the Apurimac River through Soraypampa and Mollepata. Investigations in this area have included two lakes. The first is Lake Humantay located at 4270 m above sea level, coordinates 18L 761576, 8519609 (Fig. 13.3).

This lake is picturesquely located at the foot of the Humantay glacier (5473 m), above Soraypampa from where a trail of pre-Columbian origin leads to the pastoral areas.

The second lake, Inka Chiriasca, is located at the foot of the steep slopes of Salkantay, at an altitude of 4735 m, coordinates 18L 766065, 8522770. Below is Pampa Japonesa through which passes a trail with preserved elements of pre-Columbian roads (Fig. 13.13).

This trail leads from Soraypampa, bypasses the Inka Chiriasca Lake from the south, transverses through a pass named like the lake before descending to Wayabamba and the Urubamba valley. The choice of Lake Inka Chiriasca was based on its proximity to the pre-Hispanic road.

The western watershed is fed by water from the Salkantay glacier which flows west from the Abra Salkantay pass and from the northern slopes of the Humantay glacier.

This watershed feeds the Urubamba River valley below Machu Picchu. The largest reservoir of the western watershed is the Salkantay Verde lagoon, located at 4460 m above sea level, coordinates 18L 763300, 8523690 (Fig. 13.3), west of the Abra Salkantay Pass, through which the road from Soraypampa leading to Collcapampa passes. In addition to preserved fragments of the pre-Hispanic road, a large *apacheta* stands near the pass, which may be a mark of the remains of pre-Hispanic activity in the area.

The north-western Salkantay watershed covers the area enclosed by the west-facing arms of the Salkantay massif. This is the area between the Warmihuañusca and Abra de Runcuracay passes. The water is flowing down through Pacaymayu to Urubamba feeding two lakes - Yanaqocha Lagoon located at 4130 m above sea level, coordinates 18L 771,034, 8,534,317 (Fig. 13.3), which is fed primarily by water

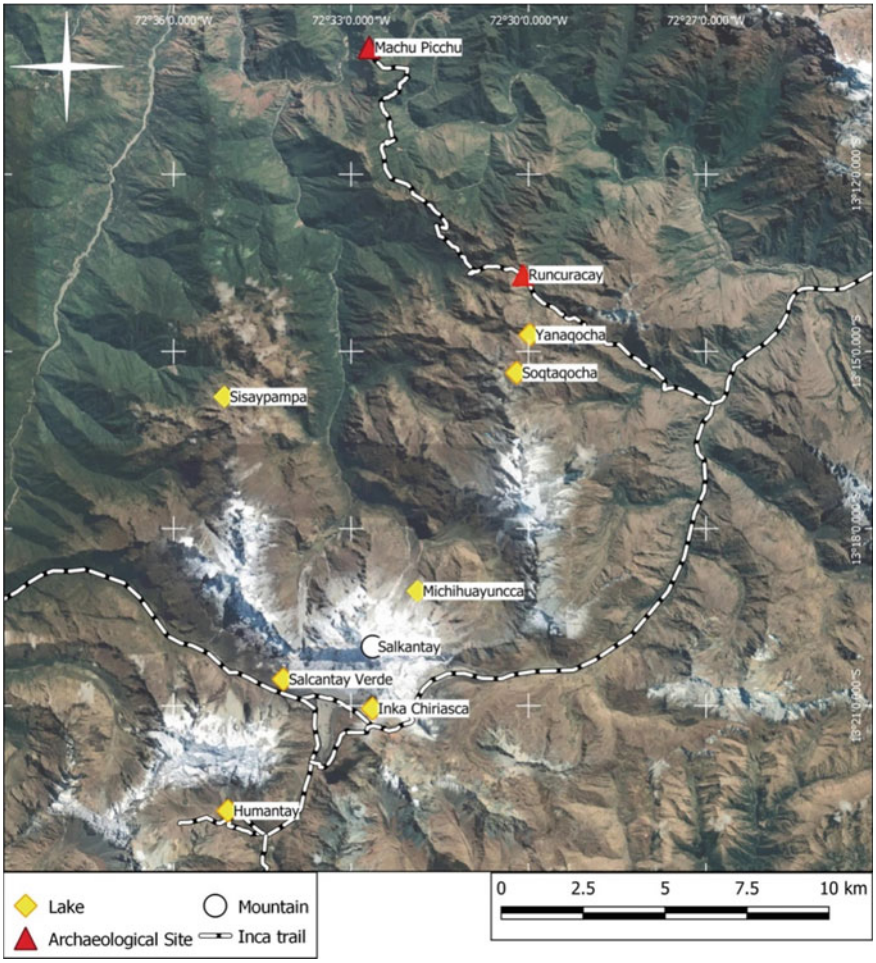

Fig. 13.3 Location of the researched reservoirs (M. Popek, M. Sobczyk)

flow from the Soqtaqocha lagoon, located at 4531 m above sea level, coordinates 18L 755,552 8,533,293 (Fig. 13.3). At a distance of about 1 km from the lower lake is Pacaymayu through which passes the tourist Inka Trail, and the Runcuracay site (see the next sections).

13.5 Research Methodology

On the basis of the data collected during the queries, a standard terrestrial survey was conducted, covering the roads leading to the lakes and surrounding areas. The obtained data were verified by analysis of satellite images, while the search was supplemented by information obtained from the local population, and the members of Machu Picchu Archaeological Park staff. A separate issue was the development of an underwater survey methodology.

13.6 Underwater Exploration in the Andes: History, Achievements and Challenges

In 1897, professional diving equipment was first used in the Andes. A Peruvian diver, Ignacio Galiano Loayza, was exploring in the Urcos and Lucre lakes in the costume of a classical diver, as evidenced by his diving helmet produced by the well-known French company Rouquayrol-Denayrouze (Marciniak 2012), which is kept to this day in one of the restaurants in Urcos run by a descendant of Loayza. However, it is only since the second half of the twentieth century that we can speak of regular underwater research, carried out mainly in Lake Titicaca. Among the underwater research described and published in the literature, it is necessary to mention William Mardoff, mentioned by Simone Waisbard (1975: 94–100), who carried out exploration in 1956. Ramón Avellaneda (1966) and consequently in 1968 Jacques Cousteau (1973) carried out exploration together with Avellaneda (after Reinhard 1992a, 1992b).

An important figure in the underwater archaeological research of lakes in the Andes is Johan Reinhard, who carried out explorations in many lakes, including the crater lake Licancabur in 1981–82, 1984 (the highest dive in the world at 5882 m) last with Carles F. Brush (1984), (Bronchia Nigris, 1985) and the lake at 5822 m on Paniri volcano in 1983 (Bronchia Nigris, 1985) in 1988–1991, he also continued research in Lake Titicaca (Reinhard 1992a, 1992b).

In 1987, 2002 and 2004 Reinhard carried out a series of underwater surveys in Lakes Urcos, Huacarpay and Piuray. In the 2002 and 2004 seasons he applied hydroacoustic equipment—sonar, to penetrate the bottom of the reservoirs (Reinhard 2002; Austermühle 2004).

In 2011, an interesting interdisciplinary underwater study was carried out in Lake Sibinacocha in the Cordillera Vilcanota at the foot of Mount Quelccaya (Michelutti et al. 2019).

How much underwater research results can be influenced by working methodology and modern technology is shown by the research conducted in Lake Titicaca by Christophe Delaere since 2012 (2017, 2019). It is noteworthy that these investigations produced very rich evidence of offerings deposited at the bottom of the lake (see Fig. 13.4).

Within each of these projects, the teams had to deal with individual logistical and methodological challenges, as well as safety issues. This allowed them to produce effective tools for conducting underwater archaeological work in high mountainous

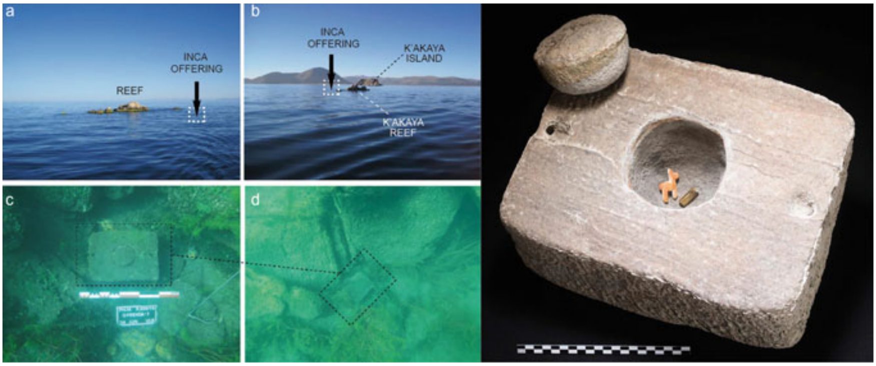

Fig. 13.4 Research from Titicaca show types of finds can be expected in the lakes off Salkantay. (Left) View of the K'akaya reef and position of the offering (A) and location with respect to K'akaya (Right) The stone box, its cap and contents, comprising a camelid figurine made of shell and a rolled gold foil (scale in centimetres; photograph by T. Seguin, Université Libre de Bruxelles) (Christophe Delaere, José M. Capril, 2020)

terrain, but adapting to local conditions each time. Investigations of our predecessors helped us to develop our own work plan.

In developing the research methodology for the project to be held in the Salkantay area, the challenges and problems posed by the aquatic and high altitude environment were divided into 3 categories: logistics, safety, methodology. Each of the activities leading to a specific objective was considered under each of these aspects. As a result, effective and safe methods were developed to achieve the objectives. Three types of underwater surveys were planned: (1) using hydroacoustic equipment, (2) underwater exploration by diver-archaeologists, (3) and verification of bottom anomalies or potential archaeological sites by sounding trenches. Each of these activities has been designed to have maximum effect.

Bottom prospecting with hydroacoustic devices such as echo sounders and side scan sonar is one of the primary research tools used for non-invasive identification of the bottom of water bodies and is extremely useful in underwater archaeology. "Bottom scanning" allows not only to record all bottom anomalies, imaged by photos and mosaics of sonar images, but it is also a method used in creating bathymetric maps of water bodies. Obtaining isobaths plans of the high mountain lakes was a secondary objective but extremely important for completing the maps and information on the geomorphology of the region.

The specific nature of the lakes' accessibility and their location at altitudes above 4,000 m above sea level presented major logistical constraints in transporting both hydroacoustic and diving survey equipment. The underwater survey equipment consisted of four components: the vessel, the propulsion unit, the sonar and the sonar attachment system to the vessel. Each of these components was tailored and adapted to the transport capabilities of the expedition. Above all, the scanning device had to be small in size. Therefore, the Lawrence probe model HDS 12 Gen3 was chosen,

Fig. 13.5 Assembled kit for acoustic measurements (phot. P. Trześniowski)

whose specification (resolution) was satisfactory for this kind of research (Sobczyk et al. 2016, 2017).

A small-sized Intex Seahawk pontoon was used as a vessel. It allowed to mount the engine on the transom and attach the installation with transducers for the sonar and side-scan sonar. The raft was propelled by a light electric motor, which was approved by the Machu Picchu National Park (Fig. 13.5).

The use of hydroacoustic equipment configured in this way allowed for the creation of lake profiles, which were used to build a bathymetric map. In the coastal zone of the lakes and in the area of "atypical" bottom anomalies the profiles were thickened in order to document the detail. The bottom registrations of water reservoirs were made safely, the helmsman was equipped with individual rescue equipment and due to avalanche hazard, the bottom mapping was limited in the zone of direct avalanche descent. Processing of bathymetric data was carried out in Reef Master software and was based on a 1 m grid. In the next stage, data were exported to the appropriate raster format in ASCII format (x, y, z). Ready maps with coordinates and isobaths were made in the Qgis programme.

After a thorough analysis of side-scan sonar images, it was possible to select the recorded bottom structures, which seem to be atypical for the natural environment of the lake geomorphology. Individual images were exported in *.kml format and the whole mosaic in *. mbtiles format was entered into Qgis software. In this environment, benthic anomaly maps were produced and measurements were taken. The outcome was presented on a composite map with the sonar mosaic and as images of individual objects with descriptions.

13.7 Underwater Prospecting

The underwater prospecting carried out by a team of three underwater archaeologists was limited both by logistical possibilities and the safety of diving at altitudes above 4,000 m.

The main logistical problem was the transport of a large amount of diving equipment to an altitude of about 4,500 m. This meant that the equipment for the divers had to be selected very carefully and kept to a minimum, while at the same time the priority was to ensure the safety of the divers underwater.

Additional items such as an air compressor were not taken, but more cylinders were secured, which were easier to attach to the pack animals. Moreover, the so-called additional equipment such as torches and redundant elements of the basic equipment was abandoned. Instead, an indispensable element was a set of spools and buoys, which allowed for precise depth measurement as dive computers at this altitude might not work properly (Trześniowski 2019: 100–102, 110).

The choice of search method during underwater prospecting is a very important factor. It affects the accuracy and effectiveness of the search. A number of underwater search methods have been described in the literature, such as circle search or field-based systems requiring the construction of survey grids (Green 2003: 50–57; Bowens 2009: 96–102,). The specificity of research in high mountain lakes, the observance of all safety measures and limited time spent underwater "forced" the searchers to conduct research "after isobaths", i.e. at strictly defined depths, e.g. 5 m.[20]

Based on these assumptions, areas of the lakes where archaeological artefacts could potentially be located were systematically and thoroughly searched.

The final stage in the archaeological investigation of the high altitude lakes of the Salkantay massif was the excavation of sounding trenches and the exploration of bottom sediments at locations identified by sonar data analysis and bottom prospecting by archaeological divers. For this purpose, it was decided to construct a water ejector (which could be made of lightweight PVC materials and the motorized pump were that was easier to transport in high altitudes (Bevan 2010).

By using the ejector it was possible to clean and verify the surface of stone structures that were potentially anthropogenic in nature. (Fig. 13.11). The lightweight design of the suction pump allowed for the rapid but gentle removal of silty layers and the preparation of structures for drawing and photographic documentation. The exploratory works carried out were aimed only at verification of the finds in situ. (Bass 1970; 1982; Bowens 2009: 141–147; Green 2003: 247–260).

The system prepared for exploration was sufficient and safe to be used in extreme diving conditions.

[20] These technical aspects are discussed in the aforementioned text by Trześniowski (2019).

13.8 Summary of Research Results

The work carried out and the results obtained consist of several complementary elements. Documentation and survey results of the lakes and a compilation of archaeological data on the surroundings of the lakes.

The area associated with the southern and western watershed.

Southern watershed:
Humantay Lagoon is an elongated reservoir of the area of approximately 6 ha, oriented north–south. It is divided in 2/5 of its length to the north by a small island connected to a peninsula on the eastern shore and a corresponding peninsula on the western shore (Fig. 13.6).

The maximum depth to the north of the constriction is 10 m and 20 m to the south; maximum visibility in the lagoon is up to 8 m. The bottom of the basin is covered with stones and boulders of different sizes (Fig. 13.7). The rock material is continuously delivered by regular avalanches descending into the lake, some observed during the survey.

These recent avalanches may influence the results of archaeological prospecting as potential objects of anthropogenic origin may be located under an undefined layer of rock rubble. In the central, i.e. the deepest part of the lake, the sonar survey found no rock material. The average water temperature was 8°C. Several dives were carried out over different seasons in this reservoir.

The dives were based on potentially interesting objects recorded in the images from the first season of work. Therefore, the last dives were completed with test works using an ejector. These dives did not yield positive results.

Surface surveys around the lake were more promising. On the plateau to the west of the lake (500 to 800 m) the remains of several enclosures and a long wall were found. There is no diagnostic material on the surface, but due to the type of construction of the walls they are probably pre-Hispanic.

At a distance of 500 m from the homesteads, there is a rocky outcrop partially covered with eroded rock engravings, *quilcas*; at least one representation of a quadruped and two human figures (Fig. 13.10).

According to the eminent expert on Andean rock art, Dr. Giuseppe Orefici, from a stylistic point of view these representations may belong to the Early Intermediate period (ca 0–600 AD).[21]

In the immediate vicinity of the rock in question, a set of artificial stacks of *apacheta*-type stones was located. Considering the very thick and unchanged layer of lichens and mosses that cover these structures, it seems obvious that their erection took place at least several centuries ago (Jomelli et al. 2009).

At a distance of 450 m east of the lake, fragments of a pre-Hispanic road leading from Soraypampa towards the lake are preserved, there are also remains of terraces and a small tambo.

[21] Giuseppe Orefici, Informe, 2018—Manuscript, in the archives of Centre of Andean Studies of the University of Warsaw.

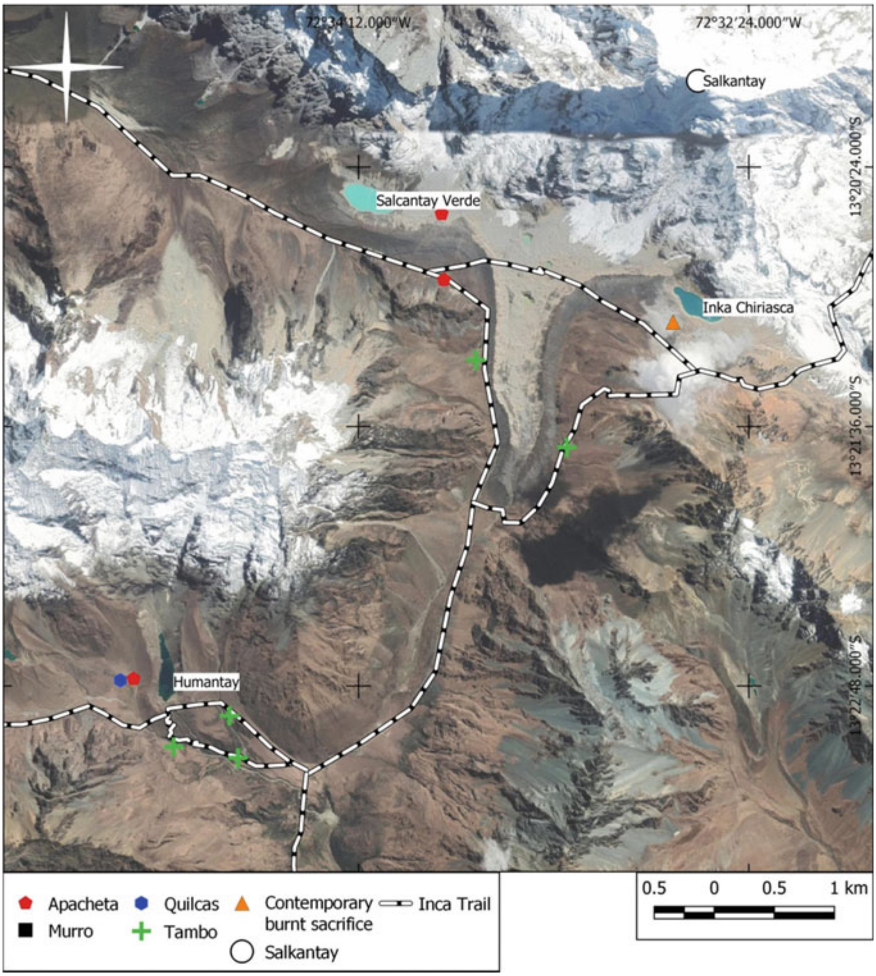

Fig. 13.6 Lakes of the Southern and Western watershed. (M. Popek, M. Sobczyk)

The layout of the ruins and the paths connecting them suggest that there were two symmetrical roads, perhaps used according to the season (Fig. 13.8).

The Inka Chiriasca Lagoon is a glacial lake of approximately 6.5 hectares. The lake is characterized by steeply sloping hillsides. Its maximum depth is 29 m. Visibility in the water reaches 3 m, due to a large amount of sediment.

The average water temperature is 6 °C. No traces of human activity have been recorded in the lake (Figs. 13.9, Fig. 13.10, Fig. 13.11).

But in its vicinity, there is a site that is currently used for burning offerings and a platform oriented towards it (25° towards the northeast).

Fig. 13.7 Lake Humantay. Sites selected for verification after analysis of underwater documentation from sonar work and first dives (phot. P. Trześniowski)

There are sections of Inca roads 600 m from the lagoon. At one of them, the remains of a prehispanic tambo located on the road to Pampa Japonesa leading from Soraypampa have been confirmed (Fig. 13.12).

Western watershed:

Salkantay Verde Lagoon. This is a reservoir of glacial origin with an area of approximately 8 ha (Fig. 13.13).

The lagoon has a geological conical shape and the lake bottom is flattened. The slopes of the lake are steep and the deepest parts are in the middle, averaging between 22.5 and 25 m.

The work in the lake included side-scan sonar and echo sonar surveys. A large number of rock blocks of natural origin were recorded on the bottom. The maximum visibility reached only 1.5 m, as a large amount of suspended sediment caused a loss of visibility (Fig. 13.14).

The average water temperature was 7°C. No signs of human activity have been recorded in the lake. At a distance of 500 m, there are well-preserved sections of Incan roads and the great *apacheta* already mentioned in the pass.

The three water reservoirs, although belonging to two separate watersheds, are connected by a common network of communication routes that leave from Soraypampa. In addition, surface investigations carried out between the Abra Salkantay and Abra Inca Chirisasca passes indicate that between them, in the vicinity of the lakes of the same names, a pre-Hispanic road crossed the glacier tongue, of which today only the last fragments of dead ice and negative glacial landforms remain. Elements of pre-Hispanic roads remain on both sides of the ice-dead zones.

Fig. 13.8 Orthophotomap of sites in the vicinity of Humantay Lake (M. Popek)

Fig. 13.9 Pastoral structures located in the vicinity of Humantay lake (phot. M. Ziółkowski)

Fig. 13.10 A pastoral corral with a built-up rock covered with rock engravings (phot. M. Ziółkowski)

Fig. 13.11 *Apachetas*, contemporary and probably pre-Hispanic located in the vicinity of Lake Humantay (phot. M. Ziółkowski)

Fig. 13.12 Lake Inca Chiriasca, site that is currently used for burning offerings and a platform (phot. M. Sobczyk, M. Ziółkowski)

Fig. 13.13 Lake Salkantay Verde and the *apacheta*, which is a trace of contemporary rituals (phot. M. Sobczyk)

Fig. 13.14 *Apacheta* on the Salkantay Pass and the road that passes through it (phot. M. Sobczyk)

Northeastern watershed:
Soqtaqocha lagoon. Its surface area is 2.8 hectares. The water level varies between 18 ± 2 maccording to the season (Fig. 13.18). Profiles were made around the basin, across it, and where protruding compacted objects were noted during the survey. This created a fairly accurate mapping of the shape of the lake basin. The bottom topography is varied with distinct peninsula-shaped shallows. The average water temperature is 7°C.

Side-scan sonar and echo sounder surveys were carried out in the lake. The bottom of Soqtaqocha is rocky with limited vegetation. The rocky material varies in size. On the western slope of the lake basin, which is very steep, there are boulders up to several meters in diameter. On the eastern side of the lake, the rock material is much smaller. On the north-eastern shore, there is a platform within which there is a large stone block. The main part of the platform, located on the very shore of the lake, has dimensions of 2.5×3 m. Archaeological work has been carried out within it and no cultural material has been recovered. There are three steps under the water, which apparently relate to the platform. Apart from a line of stones marking the side of the platform adjacent to the lakeshore, the other two steps are not paved with stones. They take the form of small faults in the ground, probably of natural origin. Of course, this does not eliminate them as elements used when descending from the platform into the water at high water levels in the lake (Fig. 13.15).

When the water level is low, it is an area above the water level, on which you can reach the vicinity of the large boulder mentioned above, which is then just below the water level. Several series of dives were made to verify the sonar data. An oval stone with a diameter of 5–7 cm (possibly a sling bullet) was located (Figs. 13.16–13.17).

Fig. 13.15 Lakes of the north-eastern watershed with context (M. Popek, M. Sobczyk)

Analysis of the bathymetric map confirms the existence of an irregular dike of stones in the southern part of the lagoon, which is exposed at low water level. Underwater work carried out within it cannot confirm for the moment whether it is an anthropic structure.

However, underwater structures known from studies in Lakes Titicaca (Reinhard 1992a, 1992b, Delaere 2017, Delaere et al. 2019, 2020) and Sibinacocha (Michelutti et al. 2019) allow us to suggest that the dike in question was used by humans visiting the lakes, especially since it periodically appears on the surface Yanaqocha Lagoon. This is a reservoir of an area of approximately 4 ha.

The depth of the lake does not exceed 5 m. The average water temperature is 8°C. Yanaqocha is fed from the south by a branching stream that flows from Soqtaqocha. This causes the overgrowth of the southern part and the formation of underwater

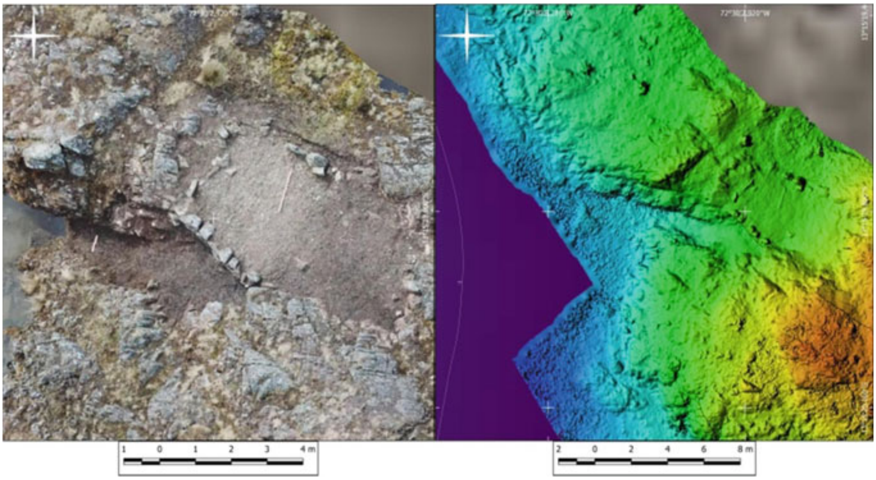

Fig. 13.16 Ceremonial platform on the shores of Lake Soqtacocha (M. Popek)

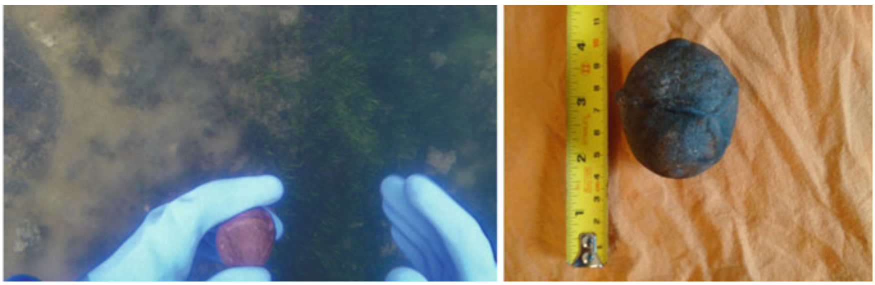

Fig. 13.17 Object found in Lake Soqtacocha. Probably a projectile for throwing from a slingshot. Such stone projectiles usually weigh in at around 65–70 grams at these sizes. The presented one weighs about 100 grams. It may be a meteorite used ritually (phot. M. Popek, M. Sobczyk)

Fig. 13.18 Underwater rampart of Soqtaqocha Lake with divers at work. At low water levels during the months of August-September, this feature can be above the water surface. (phot. K. Pilaszek)

caves, which completely changed the bottom and shores of the lake since pre-Columbian times. The northern shore of Yanaqocha is characterized by a thick layer of silt more than one meter thick. Above this shore, a platform rises on a peninsula jutting into the lake about 8 m from the shoreline, about 5 m above the water level (Fig. 13.18).

The main structural elements of the platform visible on the surface are 4 $\times$ 5 m. The structure consists of three levels and its profile was obtained using a preserved earlier excavation.

The grid-segment system of the stone elements of the structure indicates with a high degree of probability that it is a local pre-Inca construction. This excavation may be a trace of the exploration carried out by the team sent for prospecting by Julio Tello, if the description in his diary is about this lake. The logbook actually describes two reservoirs side by side (Tello 1942). But this is what lends credence to this description because the lake surveyed is clearly the result of the merging of two reservoirs. Side-scan sonar and echo sounder surveys was carried out in the lake, and several samples were taken from the bottom during the dives by drilling in different places. Selected sections of the bottom near the shoreline associated with the platform were subjected to additional fieldwork but did not yield additional archaeological data.

The form of construction of the platform, the construction technique and the processing of the stone material indicate that we are perhaps dealing with a pre-Inca construction. Of course, when analysing the functioning of the lakes and the structures preserved by them, one has to consider the context of the accompanying elements. Firstly, there is an Inca road one kilometer as the crow flies from the lake.

This is the road leading to Machu Picchu, now a tourist Inca road. At a distance of two kilometers along this road, there is a ceremonial site Runkuracay (Figs. 13.19, 13.20, and 13.21).

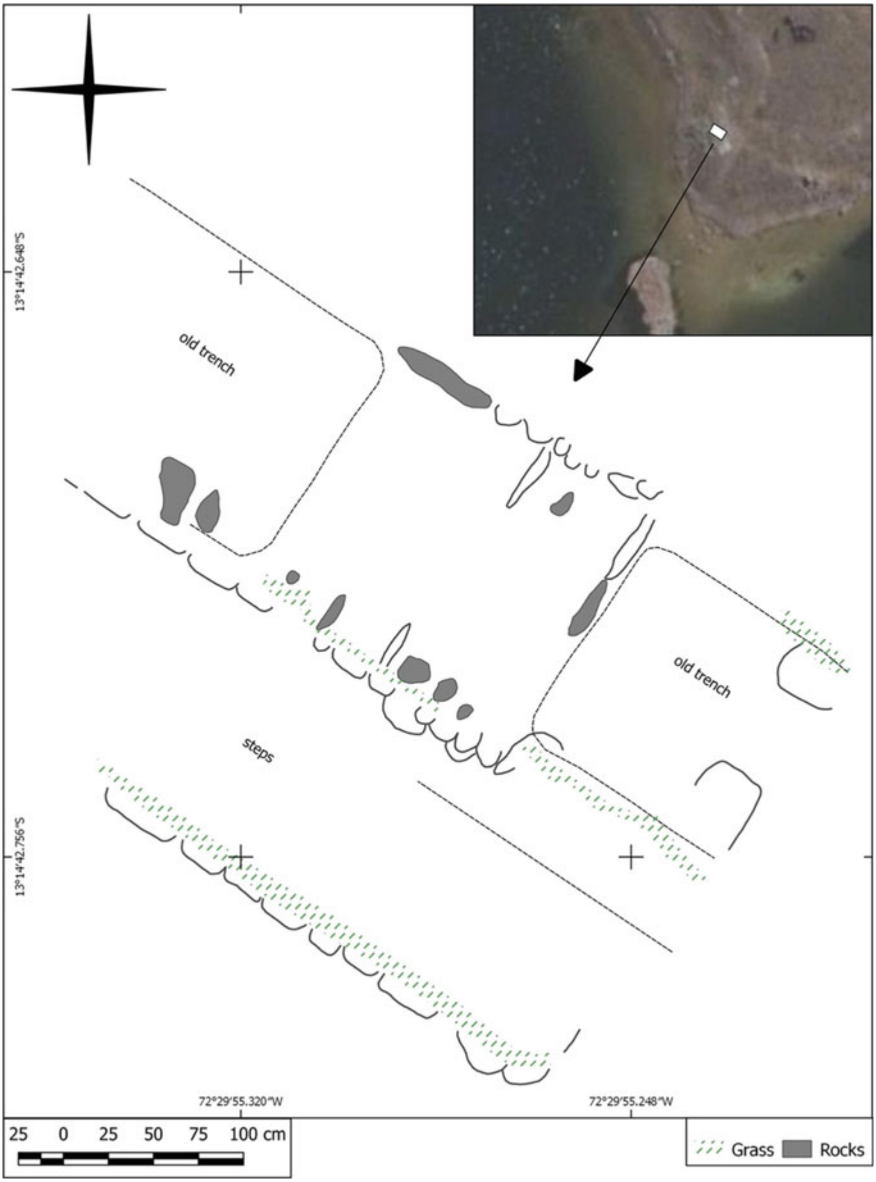

Fig. 13.19 Ceremonial platform on the shores of Lake Soqtacocha (M. Popek, draw. D. Sieczkowska, J. Kłaput)

Fig. 13.20 Runkuraqay plan and general view (phot. J. Bastante, draw. archive DDDC MC)

Fig. 13.21 Inca road next to Runuracay. A waterfall flowing from Lake Yanaqocha, next to this is the most obvious approach to the lake from the road (phot. M. Sobczyk)

Of course, the access from the road and from Runkuracay to Yanaqocha and the platform is not easy; there is a great difference in altitude and quite a difficult passage without the facilities typical of the Inca roads. However, we have in support of our hypothesis of the ritual function of the lagoons and the water flowing from them, an interesting contemporary fact, reported by Johan Reinhard: "(…), during the severe drought of 1988 men climbed up to the lake above the waterfall near Runcu Raccay and threw rocks into it to wake up the mythological being residing therein order for it to cause rain. This was a practice at other sacred lakes during the Inca period" (Reinhard 2007: 106).

13.9 Preliminary Conclusions

The results of studies that included data from archaeological prospection (terrestrial and underwater), dynamic geology and climatological studies, allow us to formulate the following conclusions.

Of the five lakes investigated, two (Salkantay Verde, Inka Chiriaska) and probably a third one (Humantay) did not exist in Inca times. At that time its present location was covered by glaciers. Therefore, the currently observed lakes are glacial relicts filling depressions in moraines. We do not have sufficient data whether during the previous periods of glacial recession in this area there may have been human activity in relation to the lakes in similar locations. What is interesting is that we have found traces of contemporaneous human activities, such as the presence of *apachetas*, a place for offerings and quadrangular stone structures, possibly for ritual use, similar to those documented in the region of Nevado Ausangate (Lanata, 2008; Sobczyk et all, 2020).

The case of the Humantay lake is somewhat particular, in comparison with the Inka Chiriaska and Salkantay Verde lakes. Although, like the latter, Humantay also occupies a depression enclosed by an ancient moraine, in the part immediately to the west of it, traces of pre-Hispanic (and probably pre-Inca) ritual activities (rock engravings) have been found, as well as, in the immediate vicinity of these, some corrals, a long dividing wall and a series of piles of stones (*apachetas*?) also most probably of pre-Hispanic origins (Sobczyk et al. 2017).

In the case of Soqtaqocha and Yanaqocha the situation is clearer, as ceremonial structures of pre-Hispanic or even pre-Inca origin (judging by the construction techniques and stone working characteristics) are found on their shores. Although the analysis of the first sediment samples from the bottom did not bring positive results, the underwater dike at Soqtacocha is very promising and requires further study. Analogies with other known underwater structures encourage further detailed work inside the structure. Even if its form is the result of natural processes, this does not exclude the possibility of its ceremonial use within the framework of traditional rituals, described in both historical and anthropological sources cited at the beginning of this study.

Adding to this evidence the proximity of an Inca road and, at a relatively short distance, from the Inca ceremonial complex of Runkuraqay, we can formulate the hypothesis that these two lakes could have been the terminal point of a ceremonial route, which linked them to the main Inca administrative-religious centres, among them—Machu Picchu.

Finally, it should be noted that in the vicinity of all five lakes there is clear evidence of contemporary ritual activities, possibly similar to those recorded in the region of the Nevado Apu Ausangate.

These are the hypotheses, and at the same time paths for future studies, which we intend to analyse in prospective fieldwork campaigns.

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Appendix

A selection of bathymetric maps and lake scan paths developed during the survey. And maps with walkways with measuring points in the lakes (Figs. 13.22, 13.23, 13.24, 13.25, 13.26, 13.27, 13.28 and 13.29).

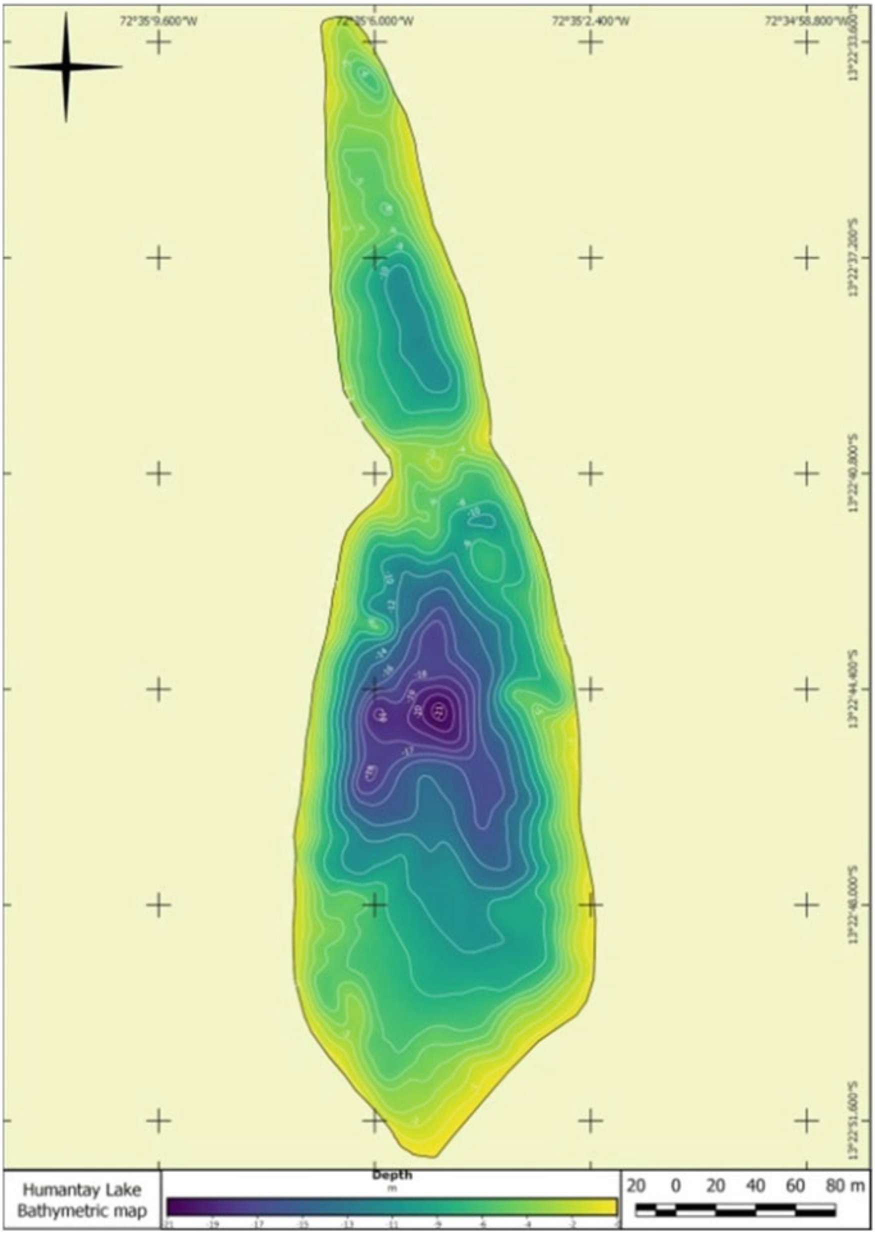

Fig. 13.22 Bathymetric map of Humantay Lake (M. Popek)

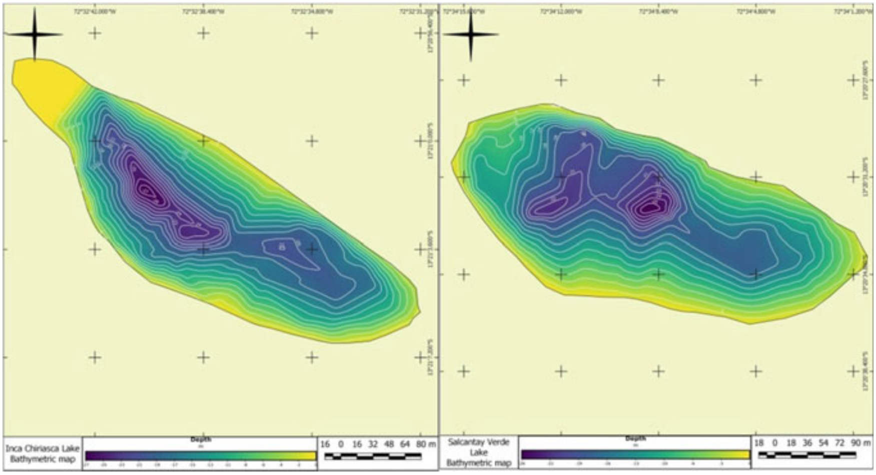

Fig. 13.23 Bathymetric maps of Inka Chiriaska Lake and Salkantay Verde Lake (M. Popek, M. Nowakowska)

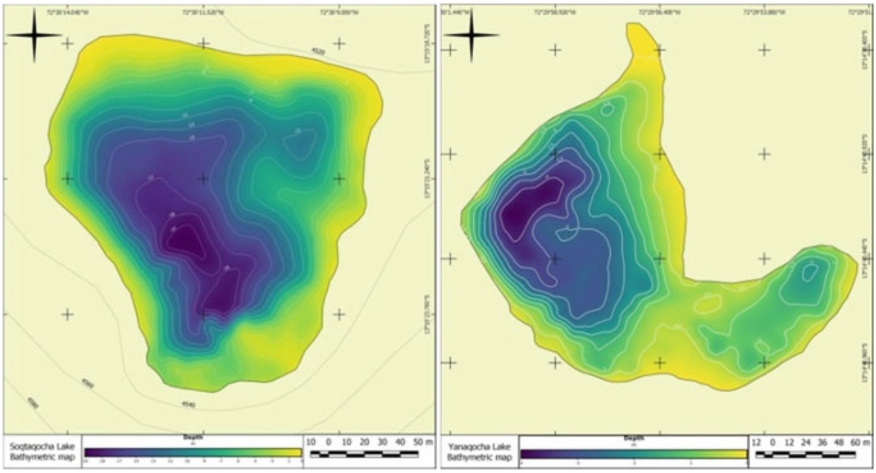

Fig. 13.24 Bathymetric maps of Soqtaqocha Lake y Yanaqocha Lake (M. Popek)

Fig. 13.25 Measurement points on Lake Humantay (M. Popek)

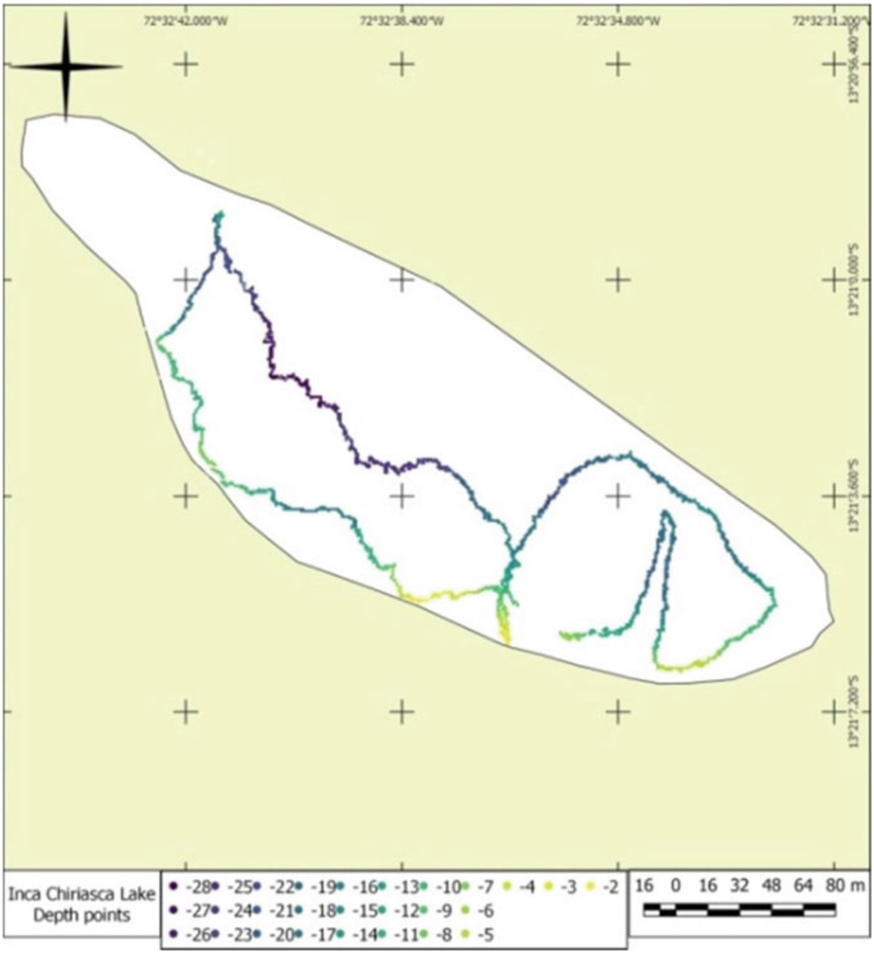

Fig. 13.26 Measurement points on Inka Chiriaska Lake (M. Popek, M. Nowakowska)

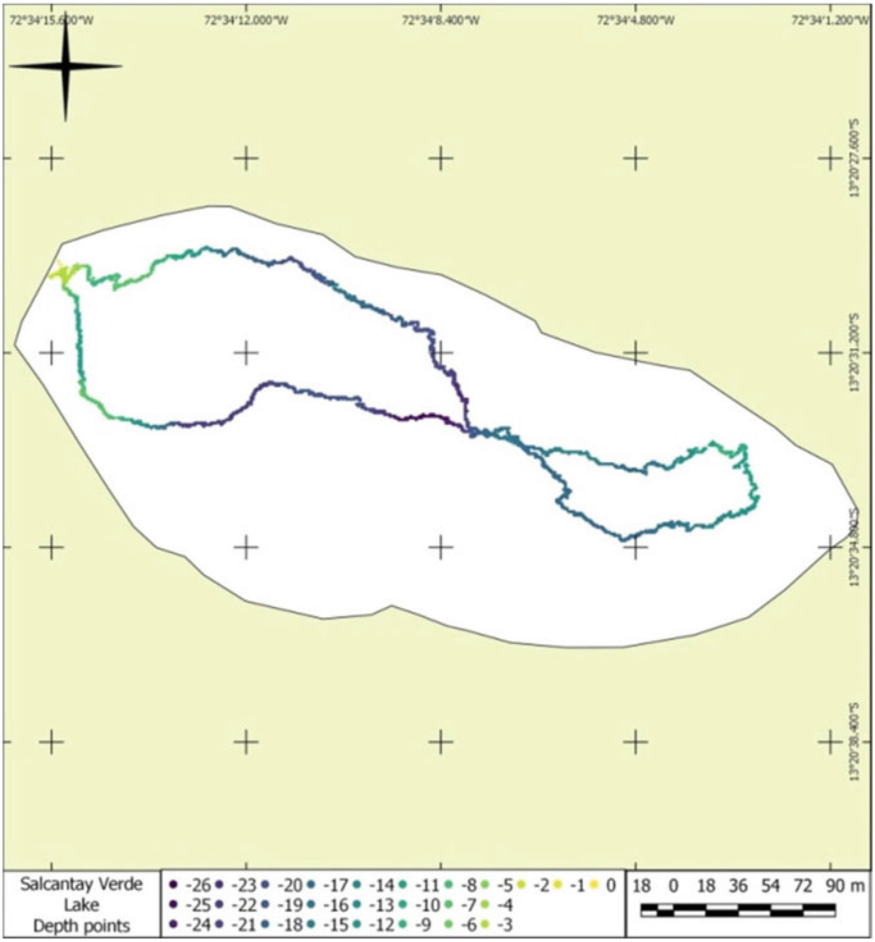

Fig. 13.27 Measurement points on Salkantay Verde Lake (M. Popek, M. Nowakowska)

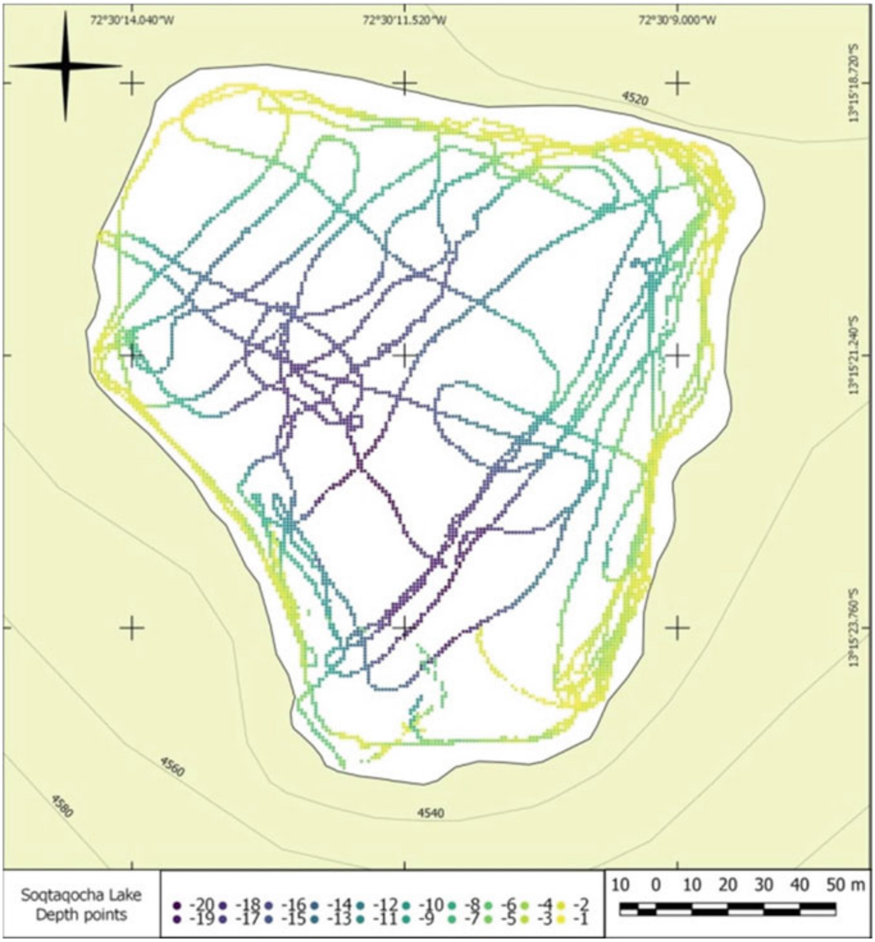

Fig. 13.28 Measurement points of Soqtaqocha Lake (M. Popek)

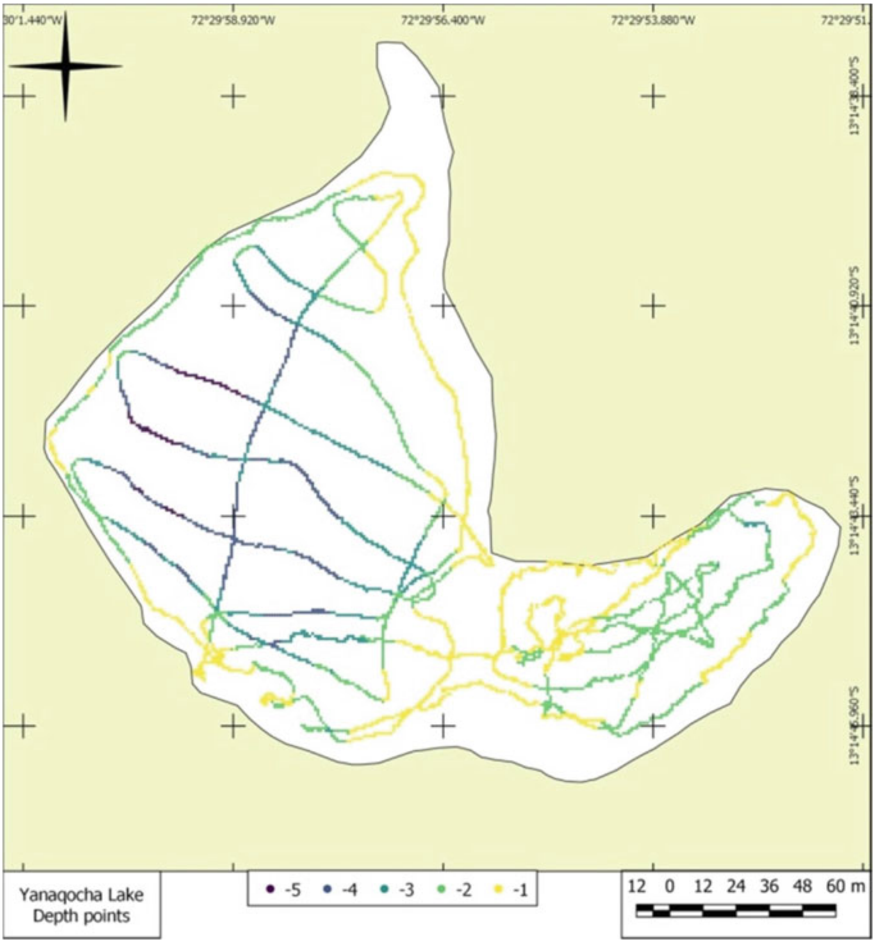

Fig. 13.29 Measurement points on Yanaqocha Lake (M. Popek)

References

Albornoz C (1967 [1584]) Instrucción para descubrir todas las guacas del Perú y sus camayos y haciendas. Ed. Pierre Duviols. En: Journal de la société des américanistes. 56–1, pp 7–39

Amado D Ethnohistorical documents of Machupicchu. In this volume

Arguedas, JM (1966) Dioses y Hombres de Huarochirí. Lima: IEP

Arriaga, P J (2010 [1621]) Extirpación de la idolatría del Perú Editorial del Cardo, Biblioteca Virtual Universal

Austermühle S (2004) Report: Underwater archeological survey of the lakes Urcos and Huacarpay near the City of Cusco, Peru. Manuscript

Avendaño A (1995) Diccionario enciclopédico del Qosqo, Municipalidad del Cusco

Avellaneda R (1966) Titicaca, viaje al fondo del enigma. Revista Clarin: Dic. 11(18):24

Bauer BS, Stanish Ch (2003) Las islas del Sol y de la Luna. Ritual y peregrinaje. En: Los Antiguos Andes Cusco: Centro Bartolomé de las Casas

Bass George F (1971) Archaeology under water

——— (1982) Nautical archaeology: An interdisciplinary field

Bronchia Nigris A (1985) El Enigma de Los Santuarios Indígenas de Alta Montaña. Centro de Investigaciones Arqueologicas de Alta Montaña, pp 410

Brush F. Ch. (1984) The Licancabur expedition , The Explorers Club Journal March/April/May

Besom T (2009) Of summits and sacrifice an Ethnohistoric study of Inka religious practices. Latin American Studies, pp 244

——— (2010) Inka sacrifice and The Mummy of Salinas Grandes Latin American antiquity, vol 21, No 4, pp 399–400

Bevan J (2010) The professional Diver's handbook

Bingham H (1922) Inca land: Explorations in the highlands of Peru

Bowens A (2009) Underwater archaeology: The NAS guide to principles and practice. Portsmouth

Ceruti, MC (2004) Toponimia y Folklore en torno a las montañas sagradas del valle del Cajón. El santuario incaico del Nevado de Chuscha (zona limítrofe Salta – Catamarca). Juan Schobinger compilador. Anales de Arqueología y Etnología Nº 56/8. Facultad de Filosofía y Letras de la Universidad de Cuyo. Mendoza

Cieza de Leon, Pedro (1977 [1550]) Crónica del Perú. El señorío de los Incas. Caracas: Biblioteca Ayacucho

Courdan A, Francou B, Kundzewicz Z (2006) Glacier Shrinkage in the Andes and consequences for water resources. Hidrological Sciences Journal 50(6)

Cousteau, JY (1973) Three Adventures: Galápagos, Titicaca, the Blue Holes. Nueva York: A Camp; W Visual Library

Delaere Ch (2017) The location of lake Titicaca's Coastal area during the Tiwanaku and Inca Periods: Methodology and strategies of underwater archaeology. J Marit Archaeol 12:223–238

Delaere Ch, Stanish Ch, Capriles JM (2019) Underwater ritual offerings in the Island of the Sun and the formation of the Tiwanaku state. Proc Natl Acad Sci 116(17):1–6

Delaere C, Capril JM (2020) The context and meaning of an intact Inca underwater offering from Lake Titicaca. Antiquity 94

Duviols P (1976) La Capacocha: Mecanismo y función del sacrificio humano, su proyección geométrica, su papel en la política integracionista y en la economía redistributiva del Tawantinsuyu. Allpanchis 8(9):11–57

——— (1986) Cultura andina y represión: procesos y visitas de idolatrías y hechicerías Cajatambo, siglo XVII Archivos de historia andina, T 5. Centro de Estudios Rurales Andinos "Bartolomé de las Casas", pp 570

Engel Z, Skrzypek G, Chuman T, Šefrna L, Mihaljevič M (2014) Climate in the West Cordillera of the Central Andes over the last 4300 years. Quatenary Science Reviews 99(2014):60–77

Gose P (2016) Mountains, Kurakas and Mummies: Transformations in Indigenous Andean Sovereignty. Población & Sociedad. 23:9–34

Gow R, Condori B, Urbano H (1982) Kay Pacha: tradición oral andina, Cusco: Centro de Estudios Rurales Andinos "Bartolomé de Las Casas"

Green J (2003) Maritime Archaeology. A technical handbook. San Diego

Guaman Poma de Ayala, F (1993 [1583–1615]) Nueva corónica y buen gobierno, editado por Franklin Pease G.Y., vocabulario y traducciones del quechua por Jan Szeminski. 3 tomos. Fondo de Cultura Económica, Lima

Hastenrath S, Ames A (1995) Recession of Yanamarey Glacier in Cordillera-Banc, Peru, during the 20th Century. J Glaciol 41:191–198

Hernandez Principe, R (1923 [1622]) Mitología andina

Jomelli V, Grancher D, Brunstein D, Solomina O (2008) Recalibration of the Rhizocarpon growth curve in Cordillera Blanca (Peru) and LIA chronology implication. Geomorphology 93:201–212

Jomelli V, Favier V, Rabatel A, Brustein D, Hoffmann G, Francou B (2009) Fluctation of glaciers in the tropical Andes over the last millennium and paleoclimatic implications: A review. Paleogeography, Paleoclimatology, Paleoecology 281(2009):269–282

Julien CJ (1991) Condesuyu: The political division of territory under Inca and Spanish Rule. BAS 19, Bonn

Kaser G (2001) Glacier-climate interaction at low latitudes. J Glaciol 47(157):195–204

Lanata XR (2008) Ladrones de sombra: El universo religioso de los pastores del Ausangate (Andes surperuanos) CBC IFEA Lima

MacCormack SG (1984) From the sun of the Incas to the Virgin of Copacabana. University of California Press

Marciniak M (2012) Historia badań podwodnych w Andach. Manuskrypt

Michelutti, N, Sowell, P, Tapia, PM. et al. (2019) A pre-Inca pot from underwater ruins discovered in an Andean lake provides a sedimentary record of marked hydrological change. Scientific Reports 9

Molina, C. (el Cuzqueño) (1989 [1575]) Relación de las fábulas y mitos de los Incas. Crónicas de América 48, Historia 16. Madrid

Orefici G (2018) Informe sobre arte rupestre- quilcas.—Manuscript, in the archives of Centre of Andean Studies of the University of Warsaw

Pachacuti Yamqui Salca Maygua, Don Joan de Santa Cruz (1615) Relacion de antigiiedades deste reyno del Peril, manuscrito NQ 3169, Madrid: Biblioteca Nacional

Raimondi A (1874) El Perú. vol. 1, Impr. del Estado, Lima

Ramos Gavilán, A. 1976 [1621] Historia del Célebre Santuario de Nuestra Señora de Copacabana, y sus Milagros, e Invención de la Cruz de Carabuco, La Paz, Cámaras Nacionales de Comercio e Industria y Academia Boliviana de Historia

Reinhard J (1992a) Investigaciones arqueológicas subacuáticas en el lago Titicaca. In: Carlos Ponce y otros (eds.). Exploraciones arqueológicas subacuáticas en el lago Titikaka. La Paz: La Palabra, pp 419–530

——— (1992b) Underwater Archaeological Research in Lake Titicaca, Bolivia [w:] Sunderes N. (red.), Ancient America: Contributions to New World Archaeology, Oxford, pp 117–143

——— (2002) A Report on a Sonar Survey of Sacred Lakes near Cuzco, Peru

——— [Report submitted to the Instituto Nacional de Cultura, Cuzco in 2003]

——— (2007) Machu Picchu: Exploring an Ancient Sacred Center. Cotsen Institute of Archaeology, University of California , Los Angeles, pp 188

Reinhard J, Cerutti C (2005) Sacred Mountains, Ceremonial Sites, and Human Sacrifice Among the Incas. Archaeoastronomy 19:1–43

——— (2010) Inca Rituals and Sacred Mountains: A Study of the World's Highest Archaeological Sites. The Cotsen Institute of Archaeology Press, pp 280

Sartiges E (1851) de. Voyage dans les républiques de l'Amérique du Sud. Les Antis,les ruines de Choquiquirao, le Bas-Pérou, Lima, Revue des deux mondes, juin 1851c, pp. 1019–1059.

Schobinger J (1986) La red de Santuarios de Alta Montaña en el Cuntisuyu y el Collasuyu: evaluación general, problemas interpretativos. Comechingonia. El Imperio Inka 1:295–317. Universidad Nacional de Córdoba, Córdoba

——— (1999) los santuarios de altura incaicos y el Aconcagua: aspectos generales e interpretativos. Relaciones de la Sociedad Argentina de Antropología XXIV. Buenos Aires. pp 7–27

Sobczyk M (2016) Apu Coropuna: estructura y funcionamiento del oráculo Inca según las fuentes arqueológicas e históricas. PhD thesis, Warsaw University

Sobczyk M, Nowakowska M, Trześniowski PA, Ziółkowski M (2016) Informe preliminar de investigación en el área de Salkantay. Temporada 2016. Cusco: Centro de Estudios Andinos de la Universidad de Varsovia

Sobczyk Maciej, Trześniowski PA, Popek M, Sieczkowska D (2017) Informe preliminar de investigación en el área de Salcantay. Temporada 2017. Cusco: Centro de Estudios Andinos de la Universidad de Varsovia

Sobczyk M, Nowakowska M, Trześniowski PA., Popek M (2020) Lagunas sagradas de Salkantay. Investigaciones subacuáticas en el Santuario Histórico de Machu Picchu in: F. Astete, J. M. Bastante (red.), Machupicchu. Investigationes interdisciplinarias, tomo 1, Cusco, pp 393–407

Taylor G, Ritos y tradiciones de Huarochirí del siglo (1987) Estudio biográfico sobre Francisco de Avila de Antonio Acosta, Instituto de Estudios Peruanos-Instituto Francés de Estudios Andinos, Lima

Tello CJ (1942) Diarios

Trześniowski P A (2019) Do not mess with the Apus: Technical and safety aspects of the high mountain underwater archaeology. In: ŚWIATOWIT Supplement Series U: Underwater Archaeology, vol II, Institute of Archeology UW

Valderrama Fernandez R, Escalante Gutierrez C (1997) La doncella sacrificada: mitos del Valle del Colca. UNSA pp 268

Waisbard S (1975) Tiahuanaco. Diez mil años de enigmas incas Editorial Diana, Mexico

Ziółkowski M (1994) Punchao, Wanakawri y la Virgen de la Candelaria o de los dilemas de los Incas de Copacabana. Time and astronomy at the meeting of two Worlds

——— (2014) The Ushnus of Condesuyos. In: Katie Willis, Colin McEwan, Nicholas Branch (eds), Inca Sacred Space: Landscape, Site and Symbol in the Andes Frank Meddens, Archetype Publications, London, Chap. 22, pp 245–260

Chapter 14
Quillcas in the Historic Sanctuary-National Archaeological Park of Machu Picchu: A New Line of Evidence for the Earliest Occupancy of the Middle Vilcanota Basin

Gori-Tumi Echevarría López and José M. Bastante

Abstract The article examines a set of petroglyphs, which were identified in the Middle basin of the Vilcanota river in the area of the Historic Sanctuary-Machupicchu National Archaeological Park (SHM-PANM). It is argued that, due to their technomorphological characteristics, these quilcas make up a defined artifactual and diagnostic group of evidence for the SHM-PANM archaeology. Based on this consideration, the authors establish that these artifacts form part of the cultural assemblage of the earliest occupation of the area, related to the Marcavalle civilization.

Keywords Quilcas · Archaeological context · Marcavalle · Isla Chico · Machupicchu

14.1 Introduction

A series of archaeological findings, carried out since 2017 in the SHM-PANM, has provided a very particular group of quilcas or petroglyphs, which are concentrated in the middle basin of the Vilcanota river, towards the vicinity of the Mizkipukio and Chakimayo rivers, and to the interior of the Isla Chico archaeological site. These materials can be found exposed to the open air, but since—the excavations in Isla Chico in 2019, they were registered in stratigraphic correlation, as part of archaeological contexts associated with the oldest occupation of the site; which is related to Marcavalle-type pottery.

The quilcas of Isla Chico, found in an archaeological context, were contrasted with two groups of quilcas registered in the Marcavalle archaeological site during the excavations carried out at this site between the years 2014–2015, and 2018. The result of this analysis allowed defining that the quilcas from both sites make up the

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same particular type of evidence, whose artifactual characteristics included formal and technological variables. Having established the definition of the artifact, it is considered that these quilcas constitute an archaeological diagnostic material of the first complex occupation of the SHM-PANM.

Due to the context of the quilcas of Isla Chico, at the beginning of the recognized archaeological occupation of the site, it is proposed to include them within the sequence of quilcas of the SHM-PANM, which was made on the basis of pictograms. It is probable that the studied quilcas -t'oqos and beveled lines- do not constitute the oldest sample of quilcas of the SHM-PANM, but they are one of the earliest, inscribed within the general tradition of abstract-geometric representations registered in the area.

14.2 Background

Archaeological researches at the SHM-PANM are one of the priorities of the Decentralized Directorate of Culture of Cusco, which has allowed us to learn more about human occupancies in the area and their cultural complexity. These researches are carried out in the form of interdisciplinary studies, which since 2014 have been in charge of examining the Machupicchu Llaqta, and the other monuments or archaeological sites in the scope of the SHM-PANM such as Patallaqta, Machuq'ente, Qoriwayrachina, Isla Chico and Choqelluska (Bastante 2016). These researches, in conjunction with archaeological work carried out in other parts of the region, have provided important cultural data, and greatly expanded our historic reference framework to understand the historic-social processes in the area of the SHM-PANM.

In view of the need to specify the associations of this of archaeological evidence, since 2017 we carried out a prospection in order to determine the existence and variety of archaeological monuments with quilcas, based on which it was possible to document 43 sites of this type (Fig. 14.1, Table 14.1); where petroglyphs and pictograms from different archaeological periods are included, as well as colonial samples (Astete et al. 2016; Echevarría López and Bastante 2019; Bastante and Echevarría López 2019). These findings make up a considerable and new volume of information for the SHM-PANM, and in general for any archaeological area circumscribed in the Cusco Region.

The results of the prospecting were preliminarily analysed, using sites with complex graphical evidence as a basis, which allowed establishing a general sequence of 29 production phases, and at least nine graphical periods for the entire park (Table 14.2). This sequence, establishes a minimum and preliminary reference for this type of graphic production recognized in the SHM-PANM, but not for their duration or its full temporal spectrum.

In chronological terms, the sequence achieved is not very indicative yet, which is due to the lack of diagnostic elements for a safe temporary determination. In this

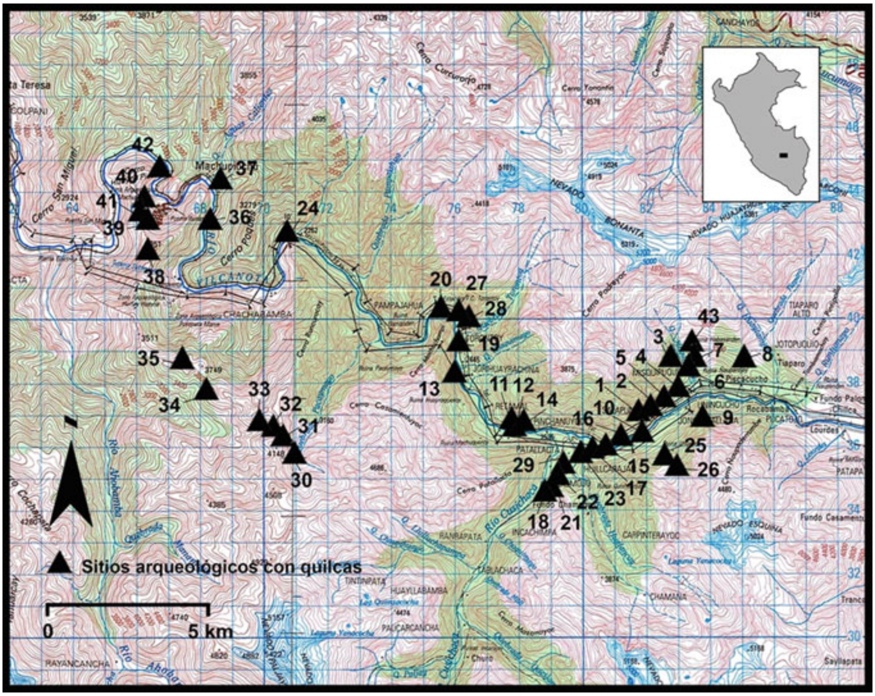

Fig. 14.1 Location map of the SHM-PANM quilcas sites. Based on the National Charter 27q and 27 r. Esc. 1: 100,000. According to the list of sites mentioned in Table 14.1

sense, the only time marker reached was obtained for period V, phase 18, of the sequence, which consisted of a pictorial scene from the Inka period (Figs. 14.2 and 14.3), (Echevarría López and Bastante 2019), the same one that is included in a complex graphic overlay context. As can be inferred, the chronological relationship of the sequence with the Inka pictorial phase marks an intermediate point in a long cumulative process, which still needs to be better understood in its temporality.

Due to the chronological limitations of the sequence and the lack of other time references, it is understood that there is much room for progress on these issues; especially in the chronological aspect, which is fundamental in order to establish the cultural context of the quilcas of the SHM-PANM. As will be seen later, new researches in archaeological monuments of Cusco and Machupicchu, can shed important light on the matter.

14.3 The Quilcas of Isla Chico in the SHM-PANM

The Isla Chico archaeological site is one of the most remarkable sites of the SHM-PANM (Fig. 14.4). It is located on the north hillside, right bank, of the Vilcanota

Table 14.1 List of archaeological sites with quilcas located in the SHM-PANM)

Site	Name	Characteristics	Chronology
S1	Salapunku	Pictograms and t'oqos	Precolonial
S2	Machay Salapunku	Pictograms	Precolonial
S3	Moqowasapoma	Petroglyphs	Precolonial
S4	Salapunku Terrace	Petroglyphs	Precolonial
S5	Salapunku Vano	T'oqos	Precolonial
S6	Miskipukio 1	Pictograms	Precolonial
S7	Miskipukio 2	Linear Petroglyphs and t'oqos	Precolonial
S8	Ayapata	Pictograms	Precolonial
S9	Yawarwaka	Pictograms	Precolonial
S10	Riel Salapunku	Pictograms	Modern?
S11	Qoriwayrachina 1	T'oqos	Precolonial
S12	Qoriwayrachina 2	Pictograms	Precolonial
S13	Pampaqhawa 1	Pictograms and t'oqos	Precolonial
S14	Qoriwayrachina 3/Cruces	Pictograms	Colonial
S15	Cruz Meskay	Pictograms	Colonial
S16	Qanamarka	Pictograms	Modern
S17	Wilkaraqay Tumba	Pictograms	Precolonial
S18	Tunasmoqo 1	Pictograms	Precolonial
S19	Ñam Torontoy	Petroglyphs	Precolonial
S20	Pampaqhawa 2	Pictograms	Precolonial
S21	Tunasmoqo 2	Pictograms	Precolonial
S22	Tunasmoqo 3	Pictograms	Precolonial
S23	Ñam Mizcay-Wilkaraqay	T'oqos	Precolonial
S24	Cedrobamba	Pictograms	Precolonial
S25	Qarpamayu 1	Pictograms	Precolonial
S26	Qarpamayu 2	Pictograms	Precolonial
S27	Pampaqhawa 3	Pictograms	Precolonial
S28	Pampaqhawa 4	Pictograms	Modern
S29	Tunasmoqo 4	Potholes	Natural
S30	Warmiwañusqa	Pictograms	Precolonial/colonial
S31	Runkuraqay 1	Pictograms	Precolonial
S32	Runkuraqay 2	Pictograms	Colonial
S33	Runkuraqay 3	Pictograms	Colonial
S34	Sayaqmarka	Pictograms	Modern?
S35	Ch'akiqocha	Pictograms	Colonial
S36	Parawachayoq	Pictograms	Precolonial

(continued)

Table 14.1 (continued)

Site	Name	Characteristics	Chronology
S37	Inkaterra	Pictograms	Precolonial
S38	Pachamama	Pictograms/Petroglyphs	Precolonial
S39	Roca de la Serpiente	T'oqos/Petroglyphs	Precolonial
S40	Roca del Sol	Petroglyphs	Precolonial
S41	Roca de los T'oqos	T'oqos/Petroglyphs	Precolonial
S41	Qollpani	Pictograms	Precolonial
S43	Miskipukio 3	T'oqos	Precolonial

River, at kilometer 81.7 of the Cusco–Machupicchu railway (Fig. 14.5). The site is a multicomponent deposit, with one of the longest occupation sequences in the park (Echevarría López and Bastante, Ms), which includes Marcavalle-type evidence at one end, while at the other, there is the testimony of Inka occupancy. The main characteristic of the site is the change and transformation in the use of space over time.

For our purposes, the earliest occupation is of enormous relevance, as it shows a complex set of cultural evidence, including architecture, burials, ceramics, lithic elements, quilcas, and middens. In several cases, this evidence is articulated in such a way that it is clear that these form domestic units; such as those found in excavation units 23 and 27 (Figs. 14.6 and 14.7), which were executed in 2019. The data obtained allow us to infer that the quilcas were part of the set of artifacts related to the first domestic occupation of the site.

The researches and works during the years 2019 and 2020, allowed discovery of six places with quilcas, at platforms 16a (IC1), 34 (IC2), 36 (IC3), 37 (IC4), 48 (IC5), and 54 (IC6) (see Fig. 14.4), which are added to the three sites registered by us in the prospecting works of 2017, which are the Moqowasapoma site on the right bank of the Cachimayu River (Fig. 14.8), and the Miskipukio 2 and Miskipukio 3 sites (Fig. 14.9) on the left bank of the Mizkipukio River; all adjacent to Isla Chico (see Fig. 14.1). The quilcas of platforms 34 and 36 (Figs. 14.10 and 14.11) were the only ones found in sealed -not altered- contexts, which provided the necessary contextual information to establish the cultural relationship of these artifacts.

The quilcas of Isla Chico, including the three sites of the 2017 prospect, are characterized by containing t'oqos and incised lines (Table 14.3). Three sites show lines exclusively, three show t'oqos and three show both features. All these marks are made on shale, a soft metamorphic rock, which allowed the characteristic manufacture of this evidence. The context of inclusion of the quilcas is varied, but this variation is due to the process of change in the settlement over the years. Apart from quilcas IC2 and IC3, the quilca with t'oqos of IC4 (platform 37) was found in a secondary context (Fig. 14.12), while those of the other spaces (IC1, IC5 and IC6) have been integrated into the late cultural landscape of the area, having been covered by sediments and lichens over the years (Fig. 14.13).

Table 14.2 Production sequence of quilcas (pictograms) for the SHM-PANM

Period[a]	Phase	Archaeological sites and formal groups[b]								General characteristic
		T2	S	P1	T1	Q3	I	Par	Pac	
IX[c]	29					X				Geometric abstract; Calvary Cross and Latin Cross with diagonal appendixes
VIII	28	19	3	8						Geometric abstract; motifs with painting in area
–	27	23			2/3		4?		1?	Geometric abstract; sinuous and thick lines Geometric abstract; concentric circles with linear appendixes
	26	21								Geometric abstract; straight, short and diagonal lines (with possible zoomorphic)
	25	24								Geometric abstract; outlined rectangles
VII	24	17		7						Geometric abstract; linear, straight, long and short paired lines
	23	18		7	1					Geometric abstract; dotted lines
	22	22								Geometric abstract, straight lines and dots
VI	21	20	2	5						Geometric abstract; continuous wavy lines of square corners
–	20			4						Geometric and seminaturalist abstract; simetric shapes, anthropomorphic lines and designs on bands
	19			3						Geometric abstract, linear and curved of thick stroke

(continued)

Table 14.2 (continued)

Period[a]	Phase	Archaeological sites and formal groups[b]								General characteristic
		T2	S	P1	T1	Q3	I	Par	Pac	
V	18	13								Geometric and seminaturalist abstract; anthropomorphic in red colour and representative shapes(frets)
IV	17	25								Geometric abstract; rectangular arc lines
	16	12								Geometric abstract; simple linear forming square spaces
	15	15								Geometric abstract; trapeze with painting on area and outlined shape
	14	7								Geometric abstract; linear, curves and triangular shapes
	13	6					3			Geometric abstract: pairs of opposite triangles Geometric abstract; triangle with rounded corners and rectangle, painting on area
	12						2			Geometric abstract, composite figures in closed geometric shapes, linear composite squares
	11						1			Geometric abstract, composite figures with straight and curved lines, open shapes
–	10	8								Geometric and seminaturalist abstract; anthropomorphic, linear and other motifs of irregular workmanship

(continued)

Table 14.2 (continued)

Period[a]	Phase	Archaeological sites and formal groups[b]								General characteristic
		T2	S	P1	T1	Q3	I	Par	Pac	
III	9	14	1							Seminaturalist;anthropomorphic with outstretched arms and fingers
II	8	3/11		1				1		Seminaturalist; big zoomorphic, trunk with painting on area
	7			6	5					Seminaturalist; zoomorfo grande, línea irregular
	6	2			4					Seminaturalista; zoomorphic with proportionate body oriented to the left, head with ears
	5	4								Seminaturalist; zoomorphic
	4	1								Seminaturalist; zoomorphic with wide elongated body, stylized
	3	5								Geometric abstract, seminaturalist;irregular zoomorphic and linear shape
I	2	10								Geometric abstract; thick, linear and irregular
	1	9								Geometric abstract; composite linear, thin stroke

Note. Taken from Bastante and Echevarría López (2019)
[a]Main cultural periods in the production of quilcas
[b]Abbreviations of the archaeological groups: T2 (Tunasmoqo 2); S (Salapunku); P1 (Pampaqhawa 1); T1 (Tunasmoqo 1); Q3 (Qoriwayrachina); I (Inkaterra); Par (Parawachayoq); Pac (Pachamama)
[c]Row fill colour:
– Dark grey: jumps in graphic trends in quilcas production
– Light grey: blocks or graphic trends in quilcas production
– White: particular moments in the production of quilcas

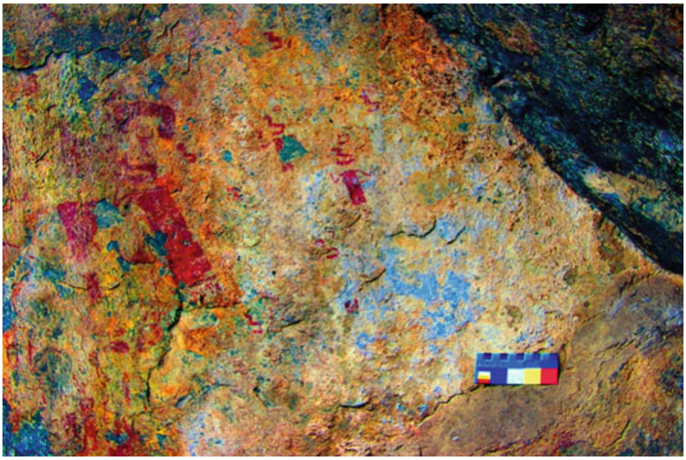

Fig. 14.2 Part of panel 4 with quilcas from Tunasmoqo 2 archaeological site showing a scene of the Inka period.
Photograph by Gori-Tumi 2020, processed with DStrech

The most characteristic detail of this evidence, in the case of the lines, is the type of sharp and beveled incision that has produced them, leaving a very characteristic V imprint. This line begins slightly at the ends and reaches its greatest depth towards the centre of its entire length, where it is noted that the greatest drag and cut force was produced. In all cases, this trait can be observed, especially in the IC2 and IC3 sites, which remained buried and free of lichens and erosion (Figs. 14.14 and 14.15). A microscopic view even reveals the production stretchmarks of the sharpened tool that was used to generate the quilcas. The t'oqos were produced by simple direct percussion (Fig. 14.16); and if we consider the stone from excavation unit 23 (IC2), these marks were made after the incised lines were produced at some of the sites (see Fig. 14.14).

Due to the location, stratigraphic, technical, and formal evidences, it is inferred that we are facing the same graphic phenomenon, which, because of a direct contextual relationship, corresponds to the oldest occupancy of Isla Chico, whose associated pottery is culturally linked to the Marcavalle civilization of Cusco.

14.4 The Quilcas of Marcavalle

Marcavalle is one of the most important archaeological sites in southern Peru, and constitutes the type monument for the first human occupancy with pottery of the Huatanay valley in Cusco (Fig. 14.17). Although its discovery and research began in the 1950s, it was only in 2013 that the monument received systematic archaeological attention from the DDC-Cusco (Monrroy 2019), which allowed a significant

Fig. 14.3 Detail of the central personage of the scene from the Inka period of Tunasmoqo 2 archaeological site.
Photograph by Gori-Tumi 2020, processed with DStrech

expansion for the comprehension of this civilization and its socio-cultural processes, which had been based almost exclusively on ceramographic analysis (Mohr 1977).

There were two findings at Marcavalle that, for our purposes, are extremely important. The first was made between 2014 and 2015, and consisted of two stones with t'oqos and incised lines that were part of a multiple funerary context (CF 138C), (Fig. 14.18); materials that were only analysed in 2016 (Echevarría López and Monrroy 2019). A second finding was made in 2018, it consisted of a stone with incised lines recovered in feature R7002 from unit 7 excavated that same year (Fig. 14.19). The entire set of materials represents a specialized type of artifact, which needs to be examined in more detail.

The quilcas of FC 138C consisted of two sandstone rocks, with rounded edges approximately 50 cm in diameter, which were found completely covered by t'oqos and natural holes (Fig. 14.20). The t'oqos, of different dimensions, were produced by simple percussion with an apparently random distribution. Due to the difference in patina on the faces, it is inferred that these artifacts were used by alternately exposing their surfaces, that is, when the piece changed position in its original context of use.

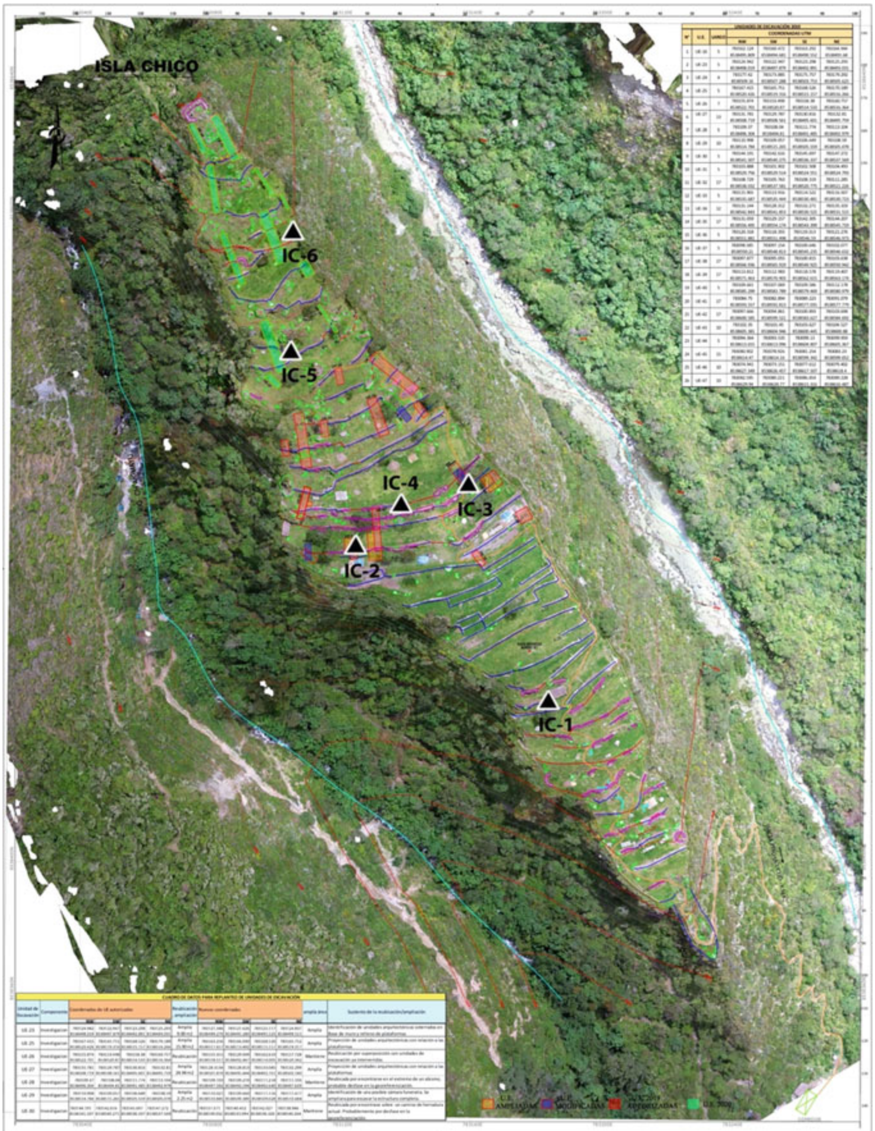

Fig. 14.4 Map of Isla Chico AS (PANM), based on drone image. The map includes the distribution of the quilcas sites

Only one of the rocks showed an area with beveled cutting incisions, which was overlapped by some t'oqos. These incisions had a general diameter of approximately 3 to 4 cm (Fig. 14.21) being arranged in a parallel and convergent manner. Due to their poor conservation, some of the lines have lost their beveled stroke, but this can be inferred through the marks that have better preserved this characteristic. In

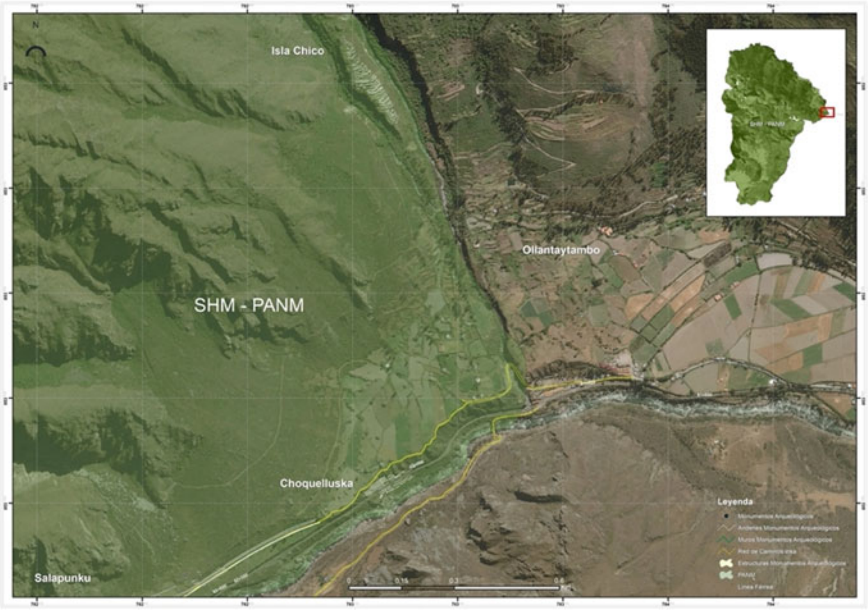

Fig. 14.5 Location map of Isla Chico AS (PANM)

Fig. 14.6 Excavation unit 23 of Isla Chico AS (PANM), showing a partial domestic unit from the Formative Period. The largest stone on the left in the centre of the image contains quilcas. Photograph by Gori-Tumi 2019

Fig. 14.7 Excavation unit 27 of Isla Chico AS (PANM), showing a complete domestic unit from the Formative Period where the conservation of the architecture of the time stands out. Photograph by Gori-Tumi 2019

this sample, the concentration and the formal parameter of the lines stand out, which seem to have been displaced by the massive production of t'oqos after their first uses; which is deduced by the superposition of marks. Thus, the lines were relegated to a marginal section of the rock.

In the case of the second sample, as mentioned above, it was recovered from excavation unit 7, where it was documented in association to an architectural context (Fig. 14.22). The artifact was found embedded in mortar, associated with other unmarked stones, apparently forming part of a wall-type structure. The lithic, also made of sandstone, showed a flat exposed surface of 19 cm in diameter, which was covered by 9 straight, parallel, and diagonal lines, most of which showed a technical manufacture of a V-shaped beveled incision. In this case, the technical detail is extremely clear, which can be noticed in the longest diagonal line, the bevel of which is inclined, highlighting the right wall of the canal; and on the major horizontal line, which intersects all the other straight and parallel lines (Fig. 14.23).

As in the case of the previous example, the technical feature is unmistakable. When this piece was removed, another incised line with the same characteristics was found on the opposite surface, which indicates that we are, as in the previous case, in front of a movable artifact, which has changed its position for use. This particular detail allows establishing a functional relationship with the quilcas found in the funerary context; one of which also contains beveled incised lines on one of its facets.

The archaeological context of correspondence of these artifacts is, without any discussion, that of the initial or formative settlement of Marcavalle (1100–700 BCE), which is linked to a very characteristic pottery (for a reference to the pottery complexity see Mohr 1977). For our purposes, it is important to consider that the

Fig. 14.8 Linear quilcas from Moqowasapoma archaeological site (PANM). Photograph by Gori-Tumi 2018

Marcavalle site presents a unique cultural occupation context, which, beyond the stratigraphic complexities (Echevarría López et al. 2019), has not been disturbed or altered; this means that the temporary correspondence of the quilcas is uniform and definite.

Fig. 14.9 Outcrop with t'oqos from Mizkipukio 3 archaeological site. Photo by Gori-Tumi 2020

Fig. 14.10 Rock with t'oqos and lines (IC2), exposed in excavation unit 23. Photo by Gori-Tumi 2019

14.5 The New Evidence and the Quilcas Sequence of the SHM-PANM

Before proposing a temporary situation for the quilcas that we are examining, we must establish that we are facing the same cultural phenomenon, which, from the anthropological point of view, represents a particular type of temporary related behaviour. This graphic object has a limited typological variation (lines and t'oqos) and a very

Fig. 14.11 Rock with lines (IC3), exposed in excavation unit 26. Photo by Gori-Tumi 2019

Table 14.3 List of sites with quilcas registered in Isla Chico SA (PANM) and their surroundings, including their characteristics and discovery context

Site	Quilcas		Context
	T'oqos	Lines	
Moqowasapoma		X	Free (outcrop)
Mizkipukio 2	X	X	Free (outcrop)
Mizkipukio 3	X		Free (outcrop)
IC1		X	Free (outcrop)
IC2	X	X	Stratigraphic
IC3		X	Stratigraphic
IC4	X		Secondary
IC5	X	X	Free (outcrop)
IC6	X		Free (outcrop)
Total	6	6	–

defined parameter of properties, especially of shape and manufacture. To these artifactual properties, we add the association and the archaeological context that, as we have seen for Isla Chico and Marcavalle, consists of undisturbed spaces assigned to the Formative Period.

The finding and recording of this evidence has allowed, in turn, to contextualize the quilcas that were registered exposed to the open air at Isla Chico and surrounding areas, and that for this reason have suffered physical-chemical and biological degradation; the latter characterized mainly by the growth of lichens. However, the technical and formal relationship between the quilcas of the entire

Fig. 14.12 Rock with t'oqos surrounding a natural concavity (IC4), placed as the top of a retaining wall, corresponding to enclosure 13 of Isla Chico. The rock is in a secondary context.
Photograph by Gori-Tumi 2019

Fig. 14.13 Rock with t'oqos and lines (IC5) on a rock outcrop, which was found covered with soil and sediment.
Photograph by Gori-Tumi 2020

Fig. 14.14 Detail of a grouping of lines and t'oqos on rock at IC2 site, found in excavation unit 23. Note the beveled character of the lines.
Photograph by Gori-Tumi 2019

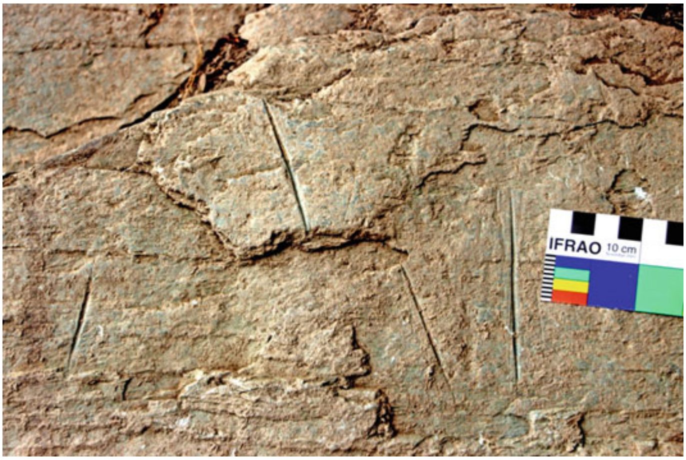

Fig. 14.15 Detail of a grouping of incised lines on rock, exposed at the IC3 site, found in excavation unit 27. Note the beveled character of the lines.
Photograph by Gori-Tumi 2019

sample is consistent, due to their features and peculiarities, which allows us to hypothetically recognize that these graphic evidences were produced under the same cultural parameters.

Archaeologically speaking, the quilcas of Isla Chico are the only evidence of their kind in the SHM-PANM that have been found in an undisturbed stratigraphic context, which places them so far as the oldest of the SHM-PANM. Although this

Fig. 14.16 Detail of a grouping of t'oqos produced by percussion on the rock at the IC5 site. Photograph by Gori-Tumi 2019

allows incorporating a new temporary reference to estimate longevity for the general production of quilcas in the area, its relationship with the sequence proposed for the SHM-PANM (Bastante and Echevarría López 2019) is still uncertain; mainly because this sequence was built entirely with pictograms. The exclusion of all the sites with t'oqos (see Table 14.1), was due to the fact that there was no archaeological evidence to allow us to establish a defined cultural or temporary correlation with the pictorial contexts that are shown in the sequence (see Table 14.2).

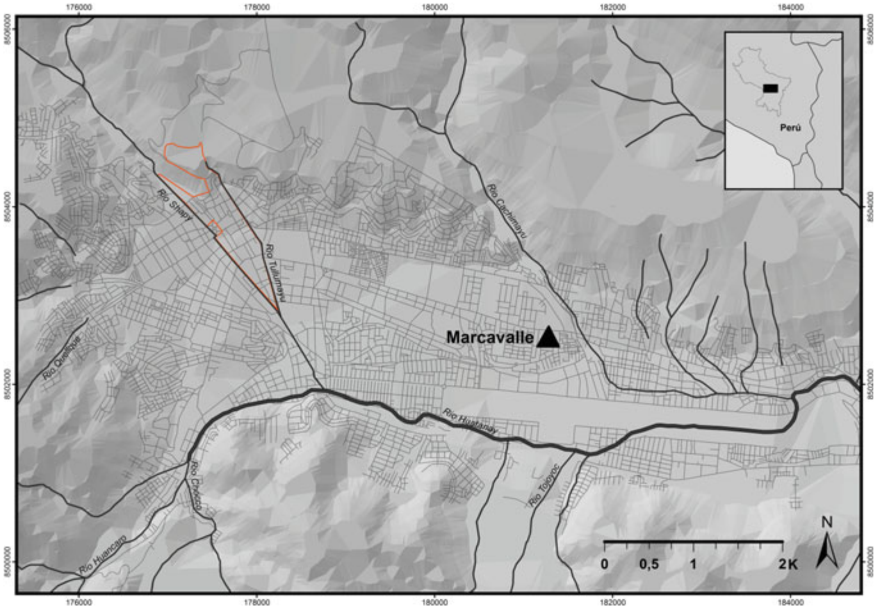

Fig. 14.17 Location map of the Marcavalle archaeological site. Marcavalle Project 2017

Fig. 14.18 Funerary context 138C, Marcavalle archaeological site. Note the rock with t'oqos associated with the skeletal remains.
Photography by Luz Marina Monrroy 2015

Fig. 14.19 Feature 7018, rock with incised linear quilcas. Marcavalle archaeological site. Photograph by Gori-Tumi 2018

Up to this point, however, it is clear that the Isla Chico findings allow the creation of a fairly regular corpus of graphical evidence, and the Ñam Mizcay-Wilkaraqay site could join this corpus, as its t'oqos are related to those of Isla Chico at the level of support and technical-formal features. From the representative point of view, we are facing a consistent assemblage of an abstract-geometric character.

In the sequence (Table 14.2) an alternation between stages of abstract-geometric and seminaturalist representation (zoomorphic and anthropomorphic) can be seen, with a historical trend of an abstract-geometric nature. If the quilcas of Isla Chico are

Fig. 14.20 Two rocks with t'oqos and incised lines excavated between the year 2014 and 2015 in the funerary context 138C, recovered in 2016 at Marcavalle archaeological site. Photograph by Gori-Tumi 2016

Fig. 14.21 Detail of the beveled incised lines of one of the rocks with quilcas recovered in FC 138C, Marcavalle archaeological site.
Photograph by Gori-Tumi 2018

Fig. 14.22 Structures discovered in excavation unit 7, Marcavalle archaeological site. In the central part of the image, right structure, the quilca was found embedded in the mortar. Photograph by Gori-Tumi 2018

part of this trend, then it can be considered that the t'oqos of this site correspond to the first phases of the sequence; at least from period 3, after phase 8. This latter phase linked to the representation of zoomorphic motifs with painting in area (Fig. 14.24). As it is understood, this is a preliminary assignment since it can be expected that some pictorial evidence could be much older than that of the quilcas of Isla Chico, which have been made in a soft stone such as shale. The t'oqos that we have examined in the SHM-PANM only imply an early stage of quilca production, the oldest from the

Fig. 14.23 Detail of the quilca, whose exposed surface was found covered with beveled incised lines (feature 7018), discovered during the excavations of unit 7 of the Marcavalle archaeological site. Photograph by Gori-Tumi 2018

Fig. 14.24 Quilca (pictogram) corresponding to phase 8, period II of the general sequence of quilcas of the SHM-PANM. Panel 1 of Pampacahua 1 archeological site.
Photograph by Gori-Tumi 2017, processed with DStrech

point of view of a particular archaeological excavation, but they are not necessarily the oldest graphic evidence of the area.

14.6 Discussion

The quilcas have been, for a few years, a novelty in the archaeological discussion of the SHM-PANM. This material, although known since 1912 (Bingham 1913), has never been a diagnostic cultural element for local archaeology, nor has it been used to make historical inferences. This is basically due to the lack of interest of archaeologists and researchers in endowing this artifact with the properties that allow its heuristic use. Since 2017, the works and findings made by PANM researchers have changed this reality, incorporating quilcas into the archaeological and historical discussion of Machupicchu, as well as promoting their academic value.

As we have already mentioned, the quilcas are not a novelty, but their contextual definition in the archaeology of the area is. The discovery of a particular type of quilcas, located between the Mizkipukio and Chakimayu basin, both in the open air and in sealed archaeological contexts, formed the first key corpus for the archaeological characterization of the evidence, the same that was contrasted with the findings made in the archaeological monument of Marcavalle in Cusco. This has made it possible to carry out an artifactual formalization of the material, and in turn, determine the context of cultural articulation of the artifact. In conjunction with Marcavalle, the technical definition allows considering these evidences as a diagnostic artifact of the earliest occupation of the SHM-PANM, with implications in the establishment of cultural and temporary relations at the regional level.

The situation of this type of quilcas, beveled incised lines and t'oqos, both in sealed contexts and outdoors, is linked to the long and voluminous process of transformation of the cultural landscape of the SHM-PANM, at least since the Early Formative Period (circa 1800–1000 BCE) in which the oldest assemblages of artifacts related to the Marcavalle culture are verified. As can be inferred from the excavations, these quilcas were covered by sediments from other times until the colonial era, and outside these contexts, they were kept exposed on isolated supports, away from the zones where the spatial changes happened by the successive human occupations of the area.

Although we are clear that these quilcas are from the Marcavalle epoch, that is, they correspond to the Formative Period of Cusco, their inclusion within the general sequence of quilcas of the SHM-PANM is complicated. This sequence has not taken petroglyphs into account due, as we have already mentioned, to the minimal formal and technological relationship between this type of quilcas and the pictograms, but mainly to the lack of a temporary parameter of relation between these materials. Now that we know that these quilcas are part of the cultural assemblage of the Marcavalle era in the PANM, it is considered possible to estimate a reference point for their inclusion in this series.

The sequence of quilcas of the SHM-PANM with 29 production phases is the longest in Cusco and, however, it does not have a diversified chronological tie. Nevertheless, this sequence can be considered of great antiquity, due to its complexity and the poor state of conservation of its earliest phases. Although it can be estimated that the t'oqos and beveled lines of the SHM-PANM are contemporary or are within one of the initial phases of pictogram production, due to its geometric abstract language, it cannot be asserted that we are facing the initial phase of quilcas in the area.

The "taphonomic threshold", that is, the moment when the rock art evidence begins to appear (Bednarik 2007: 163), is at the moment, for the t'oqos and beveled lines, in the Early Formative Period, but this does not have to be the same for the pictograms, whose conservation is not conditioned by the same physical and environmental aspects of the petroglyphs. The most famous examples of pictograms in the Andes are more than five thousand years old (Ravines 2015), so another chronology can be expected for the early phases of pictograms in the SHM-PANM, whose cultural assemblage probably didn't survive.

The fact that these assemblages of quilcas exist is something very relevant to the archaeological occupation of the SHM-PANM, and exposes cultural dynamics about which there was no previous knowledge, especially for such an early time in the cultural history of the area. As has been seen, petroglyphs are not excluded to the pictograms production, and we must understand these materials as a formal variation of a deeply rooted and defined cultural behaviour, which needs to be better investigated.

14.7 Conclusions

We consider that this work has shown that quilcas are a very important material for the archaeology of the SHM-PANM, being also culturally complex; especially due to the contextual variation in the archaeological association of this evidence for the Formative Period of Cusco. The petroglyphs are a socially standard artifact, so they form part of the cultural assemblage of the first human occupations of the SHM-PANM that are related to the Marcavalle civilization, whose known centre is in the Huatanay valley in Cusco.

Due to its formal and technological specialization, the quilcas of Isla Chico—t'oqos and beveled incised lines—make up a very particular and defined artifactual set, which allows considering this material as a diagnostic artifact, both chronologically and culturally. This is supported not only by its intrinsic properties but also by its stratigraphic situation, which has been clearly exposed during the excavation work at the Isla Chico and Marcavalle archaeological sites. This gives the material a very important status in the archaeology of Cusco, whose usefulness for making historical inferences must be better considered.

Due to the advances of the researches in the quilcas of the SHM-PANM, it is not possible to continue considering these artifacts as a disaggregated and insignificant element of the cultural landscape of Cusco and southern Peru, but as a promising material, and as a new line of evidence to gain a better understanding of our past.

References

Astete F, Bastante JM, Echevarría López GT (2016) Quilcas en el Santuario Histórico de Machupicchu-Parque Arqueológico Nacional de Machupicchu: análisis y perspectivas arqueológicas. Revista Haucaypata 11:62–86

Bastante JM (2016) Investigaciones interdisciplinarias en la *llaqta* de Machupicchu. Arqueología y Sociedad 32:267–276

Bastante JM, Echevarría López GT (2019) Las quilcas del Santuario Histórico-Parque Arqueológico Nacional de Machupicchu: evaluación y secuencia arqueológica preliminar. In: Bastante JM, Astete F (eds) Machupicchu, Investigaciones Interdisciplinarias, Dirección Desconcentrada de Cultura de Cusco, Cusco, pp 137–182

Bednarik R (2007) Rock art science, the scientific study of Palaeoart. Aryan Books International, New Delhi

Bingham H (1913) In the Wonderland of Peru. The work accomplished by the Peruvian expedition of 1912, under the Auspices of Yale University and the national geographic society. Nat Geogr Mag XXIV(4): 387–573

Echevarría López GT, Bastante JM (2019) Una escena pictórica de la época Inka en el Parque Arqueológico Nacional de Machupicchu. Qillqana. Revista arqueológica del Cusco 1(1):64–85. Cusco

Echevarría López GT, Bastante JM. Ms. Isla Chico, un sitio arqueológico de larga ocupación en el Parque Arqueológico de Machupicchu.

Echevarría López GT, Monrroy LM (2019) T'oqos o cúpulas del período Formativo en Cusco, Perú: un examen artefactual tecnológico – comparativo. In: Van Dalen P (ed) Recientes Investigaciones sobre Sitios con Quilcas o Arte Rupestre en el Perú, Lima: Juan Gutemberg Editores – Impresores, pp 9–24

Echevarría López GT, Vera C, Carbajal Y (2019) Análisis de la secuencia estratigráfica del sector central del sitio de Marcavalle (Cusco-Perú). Saqsaywaman 10:31–50

Mohr K (1977) Marcavalle: the ceramics from an Early Horizon site in the Valley of Cusco, Peru, and implications for South Highland socio-economic interaction. PhD Thesis. University of Pennsylvania, Pennsylvania.

Monrroy LM (2019) Repensando Marcavalle, Cusco, Perú. Nuevos enfoques e investigación arqueológica. Saqsaywaman 10: 13–29

Ravines R (2015) Toquepala arqueología. Boletín de Lima XXXVII(182).

Chapter 15
Ethnohistorical Documents of Machu Picchu National Archaeological Park

Donato Amado Gonzales

Abstract The article, based on sources from Cuzco, reconstructs the evolution of land tenure of the future Machu Picchu archaeological park since the conquest of the Incas until the Peruvian State extended state protection to the Ruins as National Heritage.

Keywords Machu Picchu · Vilcabamba · Encomienda · Tribute · Community of native people · National heritage · Huaqueros · Haciendas · Timber companies

15.1 Introduction

Based on ethnohistoric sources we intend to research the changes of names and toponymies of the Historical Shrine and National Archaeological Park of Machu Picchu. So we will explain how the present "Machu Picchu llaqta"—Inca city of Machu Picchu, since the sixteenth century, has had different denominations such as: "pueblo de Piccho", "encomienda de Piccho" and from the side of the native people of Vilcabamba (1587), "asiento de Vaynapiccho", in the seventeenth century, the "pueblo de Guaynapiccho" and at the beginning of the eighteenth century, the "pueblo antiguo del ynga nombrado Guaynapiccho", pointing out as landmarks: "Piccho, Machupiccho, Guaynapiccho y Apupiccho" and in 1905 "pueblo de Huaynapicchu". Only in 1911 Hiram Bingham called it Machu Picchu referring to the "ruinas de Machupicchu".

The evolution of land tenure, from the encomiendas granted by Francisco Pizarro, the taxes, and the land trials, which encompassed the lands of Machu Picchu Llaqta and the relationship between projects of huaqueros companies in La Convencion and Urubamba, and the influence of the building of roads and railways so that at

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the end of the nineteenth century the Peruvian State began to defend the national monuments.[1]

15.2 The Organization of Space in the Sixteenth to Nineteenth Centuries: Encomienda of Piccho, Town of Picchu, Asiento of Vaynapicchu, Guaynapicchu and Ancient Town of the Ynga Called Guaynapicchu

Friar Martin de Murúa (1611–1616), toward the end of the sixteenth century, made a first form of systematization of the "Historia de los Incas".[2] In his chronicle he indicates: "Despues fue Ynga Yupanqui a Yucay por el rio abaxo y llego hasta Viticos, junto a Vilcabamba, y todas aquellas provincias las conquisto y otros muchos pueblos vinieron a su obediencia sin ser conquistados, solo por el temor que concibieron de su valor y poder y de dos capitanes suyos Apomayta y Vicaquirao…" (Murúa (1611–1616), Capt. XIX). This information sustains that the Pachacutec Inca Yupanqui, conquered and integrated the Valley of Yucay and the province of Vilcabamba which then were integrated to the Tawantinsuyu State.

In the Amaybamba Valley, on March 22, 1568, at the order of licentiate Lope de Castro, President and Governor of these kingdoms and provinces in Peru, Diego Rodriguez de Figueroa, Corregidor and Major Judge of the province of Vilcabamba and Villa de Castro was in charge of the distribution of the unappropriated in "Piccho" and "Amaybamba". The Corregidor, ordered to declare "los Yngas mas principales y viejos: don Alonso Tito Atauche e a don Felipe Caritopa y a don Diego Cayo y a don Felipe Ynga y a don Gonzalo y a don Felipe Mayontopa" and the "cacique de Picho don Juan Nacora e don Gonzalo y don Felipe Caciques de Tambo", who indicated the lands on the right bank from Tancac, Rondobamba, Piscobamba, Torontoy, Pampacagua, Choquesuysuy to Pomachaca, which is next to the Amaybamba River and on the left from the Quentemarca River (Cusichaca River) to Condormarca which is next to the Vitcos or Vilcabamba River. The declarants indicate "Todos los pedazos de tierra que tienen dicho antiguamente lo que en ellos se coxia sirvió después de muerto el dicho Topa Ynga para los sacrificios e ritos del cuerpo muerto".[3] With these historical references it is clear that the lands of Vilcabamba were annexed by the Inca Yupanqui for the Tawantinsuyu State and the yield for the worship of Inca mummies.

[1] Grateful at Jan Szemiński for reading, for his comments and suggestion of the article we present. My gratitude to Rosita Canasa de Amado, for patiently reading my writings. Also to Mariana Mould de Pease and Alex Usca Baca.

[2] However, it is necessary to indicate that, almost 20 years before, Pedro Sarmiento de Sarmiento wrote his own and referred to Vilcabamba.

[3] ARC. Educandas. Titulos de la Hacienda de Tancac. Leg. 2, 1568–1722, f. 14–15. Averiguación de tierras por parte del Señor Rodrigo de Figueroa Corregidor de la Provincia de Vilcabamba e de la Villa de Castro. Cusco 22 de marzo de 1568.

The lands on the left bank, from Quentemarca River, Pacaymayu, Machuchobamba, Carmenga, and others, according to the declarants, also were considered the "Ynga Yupanqui"'s lands, having been conquered for the State. Since the government of Tupac Inca Yupanqui, the lands of Intiguatana, were marked as "lands of the Sun"[4] and lands for the dead bodies of the Incas. The surrounding lands, i.e. the lands of Carmenga, Lucrepata (Huiñayhuayna), Machuchobamba, today called Chachabamba, Pacaymayo, and Quentemarca, (today called Patallaqta, Machoquente, Huaynaqente), were also lands and terraces of the Inca State, which were commonly called "The Inca's lands". This is how, in 1564, four years before the declaration of the chief and old Yngas (1564), the lands of Quentemarca were granted for sale by Gonzalo Cusirimachi, "cacique de tambo", clearly, as "tierras del Ynga en favor de Xuarez".[5]

According to the historical and legal documents of the sixteenth, seventeenth, eighteenth, and nineteenth centuries,[6] the following is proposed: 1. the present archaeological monument Machu Picchu, "Llaqta de Machupicchu" or Machu Pikchu Llaqta, was an Inca administrative, political, and religious center, from where, through an entire system of the Inca roads, control and management of the territorial space called Vilcabamba was developed, 2. The lands linked to the people were the lands destinated for the production of coca, from Intiguatana to the meeting of the Amaybamba, Vitcos or Vilcabamba River, and the Yucay River, 3. the Lands of Intiguatana, as lands of the sun, the lands on the right bank from Tancac to Pomachaca or Amaybamba River, were the lands of the Inca, whose yield served for the worship of the mummies, 4. the terraces of Quentemarca belonged to the Inca State, the lands of Lucrepata or Huiñayhuayna for the cultivation of chili, peanuts, yuca, sweet potato, all controlled and state-run, including the ceremonial centers such as Yuncapatamallauqasa, Yuncapata or Qantupata, Incarmana or Sayaqmarca, Salqantay, Yanatin, and other apus of the village of Machupíccho.

[4] ARC. Ciencias. Documentos Silque, 1635–1722. Part No.13. "Titulos y amparos de tierras debajo de Quente" made for Martin García de Licona, provision of 1579.

[5] ARC. Ciencias. Documentos Silque, 1635–1722. Part 4, f.17, pp. 95. Sale and borders of the lands of Luichubamba and Quentemarca. Cusco December 29, 1564.

[6] Land titles, land purchase and sale, land leasing, land visit, and land agreement between the Crown and the individual, among others. Documents located in the background "Colegio Ciencias, Documentos Sillque 1635–1722", Titles of the Hacienda of Tancac, in Educandas Num. 2, 1568–1722; from the Archivo Regional del Cusco. Documents on the encomienda of Piccho, in the Archivo General de Indias de Sevilla-España.

15.2.1 *Encomienda of Piccho and Amaybamba*

The Toledo Capitulation of 1529[7] authorized the Adelantado[8] Francisco Pizarro to grant encomiendas or repartimiento of Indians[9] to his fellow conquerors. The conqueror—receiving an encomienda of Indians, received from them personal services and tribute, but territorial jurisdiction corresponded to the Spanish Crown. The encomienda then did not assume any right over the "Indians" only the tribute they paid, nor did it give any rights over the lands. That means, legally, the encomendero did not have ownership of the encomienda nor the free disposal thereof to third parties nor through a will but was only a temporary beneficiary and limited by the Grace granted by the Crown.

Hernando Pizarro (1502–1578), one of the most important main characters in the conquest of Peru by the Spaniards, was native from Trujillo, Extremadura. He was Francisco Pizarro's brother, and actively participated in the conquest of Peru. In 1539, Francisco Pizarro, showing preferences for his brother Hernando, prepared a good plea, a sustained and long list of services rendered in favor of the Crown in the taking over of "Atabalipa" in Cajamarca. He was awarded encomiendas of several villages located in the four "suyus". Among the villages granted to him in the Chinchaysuyu was the village of Piccho:

> … y el caçique de Tanbo con todos sus yndios e principales a el subjetos y el pueblo de Chauca de que es caçique Tito y el valle de Amaybanba y el caçique Xuaxaca con todos los yndios e principales e mitimaes del dicho valle e a el subjetos y el valle de Pisco con los caçiques Guaxani e Hoyarama con lo a el subjetos y el pueblo de viticos con todos sus yndios y el valle de Bilcabamba con todos sus yndios.[10]

To understand encomienda it is interesting to observe the system of taxation of the indigenous people of Piccho and Amaybamba, in favor of their encomendero Hernando Pizarro between 1548 and 1560.

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[7] This Capitulation was a Royal Decree made by Francisco Pizarro with Isabel of Portugal, the consort Queen, by mandate of King Charles V in Toledo, July 26, 1529. The document has the Marco agreement of the advancements for the conquest and population of the South Sea Coast.

[8] An "adelantado" was a person who the Castilla Kingdom, during the low middle age, trusted on for the Command of a Maritime Expedition and granted him, in advance, Legal Competences and the government of the conquered lands.

[9] De la Puente Brunke, José. Encomienda y Encomenderos en el Perú. V Centenario del descubrimiento de América, Num. 14. Sevilla, 1992, p. 18.

[10] Archivo General de Indias, PATRONATO, 188, R.20-1-Imagen Num: 1/86. Lima de 1561. "Informacion de como el Repartimiento que en terminos del Cuzco hera de Hernando Pizarro e se encomendo a Arias Maldonado, no estaba en la Corona Real quando encomendó ni mando poner en ella" F. 19v. Catherine Julien has also published the document signaled as AGI. Justicia 406, Numero 6. El Comendador Hernando Pizarro detenido en la mota y Fortaleza de Medina del campo sobre el cumplimiento de una Real Cedula…1564. Titulo de encomienda de Francisco Pizarro a Hernando Pizarro, Cuzco 27 de Abril 1539, pieza 5, ff. 51–54. This documentation has been transcribed and checked by Catherine Julien, on our part we have also revised and summarized in the Archivo General de Indias - Sevilla, in 2000. One can access it through the PARES page, Patronato section, which is published in digital format.

Tasa de Amaybamba de la Encomienda de Hernando Pizarro (1550)

Don Juan Mayta Cacique Principal

Doscientos cestos de coca, del tamaño y pesos en cada mita (6 meses el día de San Juan y Navidad), puestas la mitad en la ciudad del Cuzco y la otra mitad en el asiento de Tambo del valle de Tambo

Veinte cuatro isangas de fruta, las hubiera en la tierra (fruta de la tierra), puestas en el Cuzco y dar cuando el encomendero este en su pueblo

Veinte jáquimas, con sus cabestros, cinchas, látigos de cordel y sueltas de cada una de estas, veinte cinco guascas para atar petacas o carneros a cinco barzas cada uno, seis sogas del mismo tamaño para lazos y sobrecargas, una arroba de cabuya por hilar, todos ellos puestos en Cuzco

Veinte ovillos de hilo de algodón de libra cada uno, veinte pares de ojotas, puestos en la ciudad del Cuzco

Sustentación para el Clérigo, que los caciques y principales deben dar cada mes

Cada mes una fanega de maíz, cada cuatro meses un puerco o en su lugar 12 gallinas y patos la mitad hembras. Y una carga de sal, un cesto de coca, cestillo de ají, cada semana dos gallinas y patos y mitad hembras y perdices, los días de pescado, cada día seis huevos, algún pescada si tuvieran, en tiempo de fruta, leña para quemar, yerba para sus cabalgaduras. El salario en dinero debía pagar el encomendero

Fuente: AGI, Patronato 90B, Num.1, ramo 43 (6), 3 folios. Tasa de Amaybamba. Los Reyes, 21 de octubre 1550. En Catherine Julien Andean Past, 6, 2000–2001: 229–275.

Tasa de Piccho de Hernando Pizarro

Hernando Macuri Cacique Principal

Cincuentas cestos de coca de tamaño y medida de las que se acostumbra a coger la coca, puesto la mitad en la ciudad del Cuzco y la otra mitad en el asiento de tambo, en el Valle de Tambo

Cada mita doce costales de ají, del tamaño que soléis dar, puestas en la ciudad del Cuzco

Cada mita diez jáquimas con sus cabestros y zinchas, con sus látigos de cordel, sueltas de cada cosa. Doce guascas, para atar petacas y carneros de a cinco brazas cada una, cuatro sogas del mismo tamaño para lazos y sobrecargas, media arroba de cabuya por hilar, puestos en la ciudad del Cuzco

Diez ovillos de hilo de algodón de a libra cada uno, diez pares de ojotas, todo puestos en Cuzco

Cada mita quince isangas de frutas de las hubiere en sus tierras del tamaño que soléis dar, puestas en Cuzco y dar cuando el encomendero este de visita

Sustentación para el Clérigo, que los caciques y principales deben dar cada mes

Cada mes, una fanega de maíz, cada cuatro meses un puerco o en su lugar doce aves, gallinas y patos, la mitad hembra, una carga de sal, un cesto de coca, zestillo de aji, cada semana dos gallinas, patos y perdices. Los días de pescado cada día seis huevos y algún pescado, el tiempo que hubiera alguna fruta, leña para quemar, yerba para sus cabalgaduras. El salario de dinero pagara el encomendero

Fuente: AGI. Patronato 90B, Num. 1, ramo 43 (7), 3 folios. Tasa de Piccho. Los Reyes, 21 de octubre 1550. En Catherine Julien Andean Past, 6, 2000–2001: 229–275.

The encomiendas of Piccho and Amaybamba, in economic terms, meant benefits for the encomendero Hernando Pizarro, since the higher income tax must have been the coca baskets that evidently ended up in the markets of Cuzco and in the mines of the Villa Imperial de Potosí. The rest of the taxes were complementary to the coca marketing process. The jaquimas, ropes, and cords were tools for loading products onto horses, mules, and rams of the land, that means llamas. The cabuya–Agave americana was the material to make ropes. All this material could be obtained in the area because it grows there.

The baskets of chili and fruit were products that from the time of the Incas were the most precious offerings received by the Inca. In the case of the encomienda of Piccho, the measure of the costalejos and "baskets" was used for the taxation of chili. The twelve costalillos of chili must have contained several baskets[11] and it was quite an amount. These were called fruits of the land and those that arrived with the Spaniards were considered as fruits of Castilla. The pacaes, lucmas, guayabas, and chirimoyas were highly appreciated. The measure to give this product was called "isangas", which at present are those that we could call canastones, in which several hundreds of fruits can fit in. An isanga or lucma canaston must have contained two or three hundred of this fruit.[12]

In 1559, Viceroy Marques de Cañete, through a Provision Real, notified the encomendero Hernando Pizarro that don Juan Cayo Topa, don Diego Laxa, and don Alonso Ruca, native chiefs from Amaybamba, complained that they were assessed and taxed two hundred baskets of coca each mita, which they could no longer pay because the tax population had declined since many of them had died and due to attending and producing the coca tax they had no more time to attend their own fields, which were the livelihood of their women and children and that they had gotten sick due to that work. For these reasons they had asked for an end to grievance, inconvenience, and hard work. The Viceroy, in response to this request, had a new appraisal of the tax made. The moderate rate was arranged as follows:

Tasa de Amaybamba 1559

Don Juan Cayo Topa, Principal del pueblo de Amaybamba

Cada mita, ciento sesenta cestos de coca, del peso y tamaño que habéis acostumbrado. Los sesenta puestos en la casa del encomendero y los cien en el Tambo del valle de Tambo

Sustentación para el Clérigo, que los caciques y principales deben dar cada mes

[11] A basket of coca or chili was the load of an indigenous loader, two baskets were the load of a llama.

[12] Then about 10–14 kg was the load of a loader and more than 20 in case of a llama.

Cada mes una fanega de maíz, cada cuatro meses un puerco o en su lugar 12 gallinas y patos la mitad hembras. Y una carga de sal, un cesto de coca, cestillo de ají, cada semana dos gallinas y patos y mitad hembras y perdices, los días de pescado, cada día seis huevos, algún pescado si tuvieran, en tiempo de fruta, leña para quemar, yerba para sus cabalgaduras. El salario en dinero debía pagar el encomendero

AGI, Justicia 449, Num. 1, pieza 3. María Contreras con el fiscal, ff. 140–141. Tasa de Amaybamba. Los Reyes, 25 de Septiembre 1559. En Catherine Julien Andean Past, 6, 2000–2001: 229–275

The same way, Viceroy Marques de Cañete had notified Hernando Pizarro, neighbor in the city of Cuzco, don Hernando Macori, main Cacique, the chiefs, Indians natives, and mitimaes of the town of Piccho that having seen and revised the last visit made by Damián de la Bandera, the rate established by the commission of President La Gasca, considering the acted background, was arranged in the following form: at the rate of 1550, the indigenous people of Piccho had to go with 50 baskets of coca to the encomendero and at the new rate of July 30, 1560 it was established as follows:

Tasa de Piccho 1560

Don Hernando Macori, Principal del pueblo de Piccho

Cada mita acostumbrada, treinta y cinco cestos de a 18 libras de pura coca cada una, puestos en el pueblo de Tambo

Sustentación para el Clérigo, que los caciques y principales deben dar cada mes

Cada un mes de que personalmente estuviera en vuestras tierras tres fanegadas de maíz e veinte dos aves, y cada día de pescado diez huevos, leña para quemar en su casa, yerba para una cabalgadura suya. El salario en dinero debía pagar el encomendero

AGI, Justicia 449, Num.1, pieza 3. María Contreras con el fiscal, ff. 134–135. Tasa de Piccho. Los Reyes, 20 de Julio 1560. En Catherine Julien Andean Past, 6, 2000–2001: 229–275

In 1572, Captain Diego Maldonado, the Rich, appears as encomendero of Piccho and Amaybamba. Observing the decrease of his tax people and the tax, he asked for a new appraisal of the tributaries, for which Pedro Alonso Carrasco and García de Melo were commissioned. They made the appraisal of the taxes of the Piccho people, it was valued at 35 baskets of coca worth 210 pesos. Failure to pay taxes and the tax people decline was justified in the statement of don Juan Yanque Yupangue, main cacique of Amaybamba and Piccho, who pointed out that after the war of the Inca began and when they killed Anaya, all the people, Spaniards and Indians who had come and returned from Vilcabamba, had passed through their town of Amaybamba. Despite being few taxpayers, they had provided the travelers with firewood, weed, food, as well as given Indians, for porters and chasquis, and other things.[13] That means, the

[13] ARC. Corregimiento Causas Ordinarias. Leg. 1, 1551–1585. C.11. fs. 57. Cuentas presentadas por Pedro Alonso Carrasco y Garcia de Melo.

people who passed back and forth had destroyed their chacras and houses, for that reason they had not paid the tribute they owed to their encomendero.

15.2.2 The Foundation of the City of San Francisco de Vitoria de Vilcabamba and Land Distribution

In 1561, Titu Cusi Yupanqui, who was crowned Inca, promoted an important contract or agreement with the Spaniards, including the extension of the government boundaries of the Vilcabamba Inkas, which encompassed the left bank of the Apurimac River and the right bank of the Vilcamayu River[14] with the authorization to make villages in the Amaybamba and Piccho valley, which were Captain Diego Maldonado's encomiendas until in 1571, he died and Tupac Amaru I took over the government. This clearly indicates that the people of Piccho (at present Machu Picchu) were under the jurisdiction and domain of the Incas of Vilcabamba.

Then, in 1572, viceroy don Francisco de Toledo, already being in the city of Cuzco and taking advantage of the death of Titu Cusi, decides to invade Vilcabamba. After hard resistance and battles in the places of Vitcos, Pampacona, Huaynapucara, and Machupucara Tupac Amaru I was captured and executed on September 21, 1572, and later buried in the temple of Santo Domingo.

To strengthen the conquest of Vilcabamba, don Francisco de Toledo commissioned and appointed don Martin Hurtado de Arbieto as governor of the area and ordered the recruitment and transfer of 52 indigenous people from the parishes of the city of Cuzco with the necessary supplies to found the city of "San Francisco de Vitoria" of Vilcabamba on October 4, 1572. The transferred population had the obligation of serving the Spanish conquerors in Vilcabamba as the Cañares in Cuzco did (Fig. 15.1).

For the livelihood of the transferred indigenous people, Francisco de Toledo ordered the distribution of land, from Vitcos, Choquetacarpo, and all the remaining lands at the foot of the Salcantay Apu. These lands were noted as: Uticmayu, Pitupuquio, Sedrobamba, Rucmabamba, Yntiguatanapampa, Uaynapiccho (Huaynapicchu), they were lands for corn, chili, peanuts, fruit trees, and other legumes. In 1574, Miguel Rimache Mayta, main cacique of Vilcabamba, representing the yanaconas who had been transferred from the city of Cuzco, requested a visita of these

[14] Here, it is interesting to note that on January 29, 1582, Viceroy Martin Enríquez dispatched a provision, addressed to Martin Hurtado de Arbieto, governor of Vilcabamba, ordering him not to distribute lands in the Maranura Valley. That is, Maranura was part of the jurisdiction of Cusco and not of the gobernacion of Vilcabamba. This sector was located on the right bank of the Vilcanota River. This reference makes out that the capitulation of Titu Cusi Yupanqui in which he asked for the extension of the jurisdiction of Vilcabamba, to the right bank of the Vilcanota River had not been attended and was not taken into account, it is also an indicator that after the death of Tupac Amaru, the agreements with the Spaniards had been left without effect (Maurtua 1906, TomoVII, p. 171).

lands, which they had received at the order of Viceroy Don Francisco deToledo, after the visita done by visitador don Antonio de Pereira.[15]

By memorial of 1588, several citizens of the area such as Miguel Yupa, Alonso Guaipa Condor, Juan de Malli Francisco Coro, Cristóbal Pariguna, Bernabe Gualpa Tito, Martin Parinango, Francisco Taquichin, Pedro Paco, Juan Palpa Juan Yauruchaco, Francisco Cicha, Francisco Coro and Juan Yaros, indicated that at the orders of Viceroy Conde del Villar, the yanacona indians transferred from the parishes of Cuzco to Vilcabamba were again evicted and forced to move to the site called "Vayna Piccho" (Huaynapiccho) to monitor the conquered Indians (Pilcozones, Iscaysengas), for which they were assigned surrounding lands.[16]

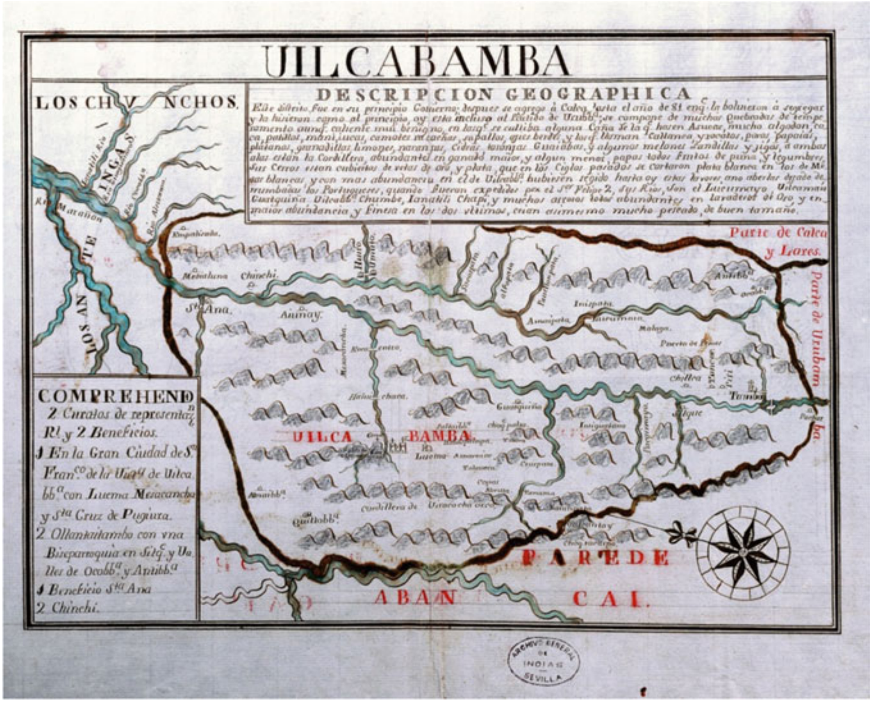

Fig. 15.1 MP-MAP of the Province of Vilcabamba. Agi. PERU_CHILE097

[15] ARC. Ciencias. Documentos Sillque, l1635-1722. Parte No. 1. Peticion presentada don Juan Concha y Juan Tomas Concha y Juan Quispe sus hijosy los demas descendientes de los cincuenta y dos yndios que visito don Antonio Pereira en 1574, f. 9v.

[16] Archivo Regional del Cusco. Ciencias, Documentos Sillque 1635–1772. Parte No.1. Peticiones y Memoriales de don Juan Concha, Tomas Concha, Juan Quispe y Juan Navi, fs. 1–11.

In 1635, don Juan Concha, Juan Tomas Concha, Juan Quispe, their children and the other descendants of the 52 native people transferred from Cuzco, strengthened their material and bodily possession over the assigned lands, appropriately demarked and landmarked in: Vayanaycasa, Rucmabamba, Pitupuquio and Cedrobamba, whose borders were:

> desde Guaynapiccho hasta el cerro llamado Mallaucasa y desde alli hasta Guaironcasa (Warmiwañusqa) y por el otro lado hasta Palcay de donde va un rio que llaman Uticmayo hasta el encuentro con el rio del Vilcamayo que corre todo para abajo y por la otra parte linda con las tierras de don Baltazar Yepes y en cada moxon[17] tiene sus cruçes puestas desde tiempo antiguo, la qual posesion les di de las dichas tierras juntamente con seis buhios que en ellas avia cubiertos de paxa.

In 1644, Don Juan Tomas Concha, "Principal and Mandón" of the yanacona Indians from the city of Vilcabamba of Peru, on behalf of the native population of Vilcabamba, of their ancestors and grandparents who were transferred from the parishes of the city of Cuzco to the said province, indicates that from the time of the Incas and due to the distribution viceroy don Francisco de Toledo carried out to his ancestors, they retained the possession of the lands called Guaynapicho, Mallaocasa, Guayroncasa, and Salcantay, which were protected by the corregidores of that province and by royal provisions of the government, with which they could get supported and paid their taxes.

15.2.3 Demarcation of the Land in Guaynapiccho, Pitupuquio

In 1658, before the visit and composition of lands[18] of redress, led by Friar Domingo Cabrera de Lartaun, the possession and management of these lands continued with María Cisa, Clara Vispa, Melchora Pata, and Lucia Pata (the latter married don Diego Sanabria Catcorrayo, of Cañare ancestry, principal from the city of San Francisco de Vitoria de Vilcabamba) who in 1662, got the demarcation and the setting of landmarks as follows (Fig. 15.2):

> ...Y de ai subimos por un zerro arriba ba a dar a Apu Salcantay que es un Zerro nebado que sirve de lindero de a donde viene un rrio llamado Utimaio ba a topar al rrio grande de Vilcamayo que sirve de lindero y buelve lindando con las tierras de Nicolas Juarez y las tierras de Don Andres Habanca y de ai buelve por una cuchilla ba a dar al asiento de Uairurcasa Puerto donde linda con las tierras de dho Nicolas Juares y de ay bajan a dar al

[17] Mojon or moxon, is a pile of stones as a milestone, on which crosses were set as a sign of land boundary.

[18] The Composition of Lands comprises sanitation of the domain through an ancient title, invoking possession of land, expansion of surrounding land, acquisition of unappropriated or abandoned lands, without prejudice to the rights of Indians or third parties.

assiento de RRunco Guasi y de ay ba a dar a Yancacalla donde estan dos lagunas que sirve de lindero linda con las tierras de Don Baltasar Yepes y de ai baja por una loma abajo ba a dar al assiento de Inca Armana que son cinco pesos de piedras que sirve de lindero (sic) y linda con las tierras /f.32/ de Don Baltasar Yepes y de ai baja por una loma abajo ba a dar al assiento de Inca Armana que son cinco pesos de piedras que sirve de lindero[19] y linda con las tierras de Don Baltasar Yepes ba a dar a Yunca Patamallaucasa RRucripata que son linderos y entra por Arco pongo a Guainapicho donde ai media fanegada de tierras y tres aposentos cubiertos de paja de que asi mesmo le di posecion y de ai baja y ba a dar a Pumapabanca linda con la de Don Baltasar Yepes que es la orilla del rrio grande que es llamado Utimayo y de ai ba dar a las tierras nombradas Yntiguatana donde ai quatro aposentos cubiertos de paja y le di posesión de las dhas tierras y casas y de ai ba a dar a rrucmaiopampa que ai una fanegada de tierras que asi le di posesión….[20]

Fig. 15.2 Demarcation of lands of Guaynapicchu-Pitupuquio

[19] The underline is to indicate it is repeated so we write (sic).

[20] ARC. Ciencias. Documentos Sillque, 1635–1722. Part 14”, f. 31.

From the textual quotation the original toponymies such as: Apu Salcantay which retains the same name until now, Utimayo-Ahobamba, Vairurcasa-Huarmihuañusqa, Runco Guasi-Runcoracay, Yancacalla-Runcuracaycasa, Inca Armana-Sayaqmarca, Yunca Patamallaucasa-Puyupatamarca, Rrucripata-Wiñaywayna, Intipata, Arcopongo-Intipunku, Guainapiccho-Inka City of Machu Picchu, Pumapavanca-Inca Racay, Intiguatana-Intihuatana, Rrucmaiopampa-Torrepata follow. As for the possession of these lands, the legislation of the time which was part of the Indian law, arranged and indicated:

> Porque tierras que poseia el d[ic]ho yndio no se pueden bender ni enagenar a españoles por ser contra las cedulas de su Magestad y de parte de su Magestad cuya parte exsorta y rrequiere a las justicias de la provincia de Vilcabamba Calca y otras partes.[21]

During the eighteenth century, even until the mid-nineteenth century, these lands remained in the possession of the natives. This is how in 1849, don Juan Uscamaita Valentín and his wife doña Francisca Cullo, neighbors of the town of Limatambo, Anta province, claimed to be legitimate successors of his dead father don Manuel Valentin Uscamaita, one part of the lands, that they indicate as haciendas called Suriray, Chillcapampa, Ahobamba, Patallacta, Qquente, the old town of Palcay, Huairuro Ccasa Major, Huairuro Ccasa Minor, Huaynapicho, Machupiccho, Ynteguatana, Machopilone, Huaynapillone, Atunpilloni, Uchuypilloni, Huiñay Poccoy, Unoyne Huayracpata, Huayracmachay, Salcantay, Umantay, and other names of lands located in boundaries of the valley and town of Mesacancha, remembering the favors and services that they have deserved and received from their wedding godfather don Mariano Santos, for having no child during the long time being married, until they got to a state of decrepitude, for which reason they can not handle themselves the mentioned farms, they granted a donation deed in favor of their godfather don Mariano Santos. This document shows us that from the distribution of lands at the time of the creation of the city of San Francisco de Vitoria de Vilcabamba (1572), until 1849, these lands remained in the hands of the native people who had inherited them.

15.2.4 Demarcation of Land of Hacienda De Sillque and Land of the Natives in Vilcabamba

To demonstrate the stealing of native lands in Vilcabamba, it is necessary to explain about the borders of the Silque hacienda, belonging to Isidro Juarez de Bera's heirs. For that, we proceed to point out the demarcation of land carried out in 1714 through the Fourth Visit and Composition of Lands presided over by Don Gonzalo Ramírez de Baquedano, who delegated and commissioned the visit of lands to Joseph de Los Reyes y Rocha as visitor judge, before whom Father Joseph de la Soledad of the

[21] ARC. Ciencias. Documentos Sillque, 1635–1722. Parte 14. F.27v. Auto de Amparo del Reverendo Padre Fray Domingo Cabrera de Lartaun. 29 de marzo de 1658.

Betlemit order, prefect of the convent of the Almudena in Cuzco, owner of the Sillque hacienda[22] and Mr. Isidro Juárez de Bera, owner of the lands of Huayllabamba, Quesca, Choropampa, Pampacahuana, Matara, and Guacoto, which were undivided among Antonio Ramírez de Guzmán's heirs, to negotiate the demarcation of lands. In compliance with this request, the borders were recognized as follows (Fig. 15.3):

> Por la parte de arriba la apacheta de la vista a la laguna nombrada Ancascocha, por un lado con tierras de la hacienda de Sillque y de ella corre hasta otra apacheta nombrada Acocasa y de ella por la cuchilla del cerro nevado va a la a otra nombrada Tanca Piray, de ella corre al cerro de Salcantay y de allí por el río de Palcay aguas abajo hasta dar a seis buhios antiguos del tiempo del Ynga y de ellos a otra apacheta nombrada Guaira Casa y de allí para el Pueblo Antiguo del Ynga Nombrado Guainapiccho y de él baja al río Grande de Vilcamayo y aguas arriba del hasta por donde entra a el río nombrado Guayllabamba que baja del paraje del mismo nombre y aguas arriba del hasta llegar a el Paraje nombrado Quesca que sube a la Apacheta de Ancascocha.[23]

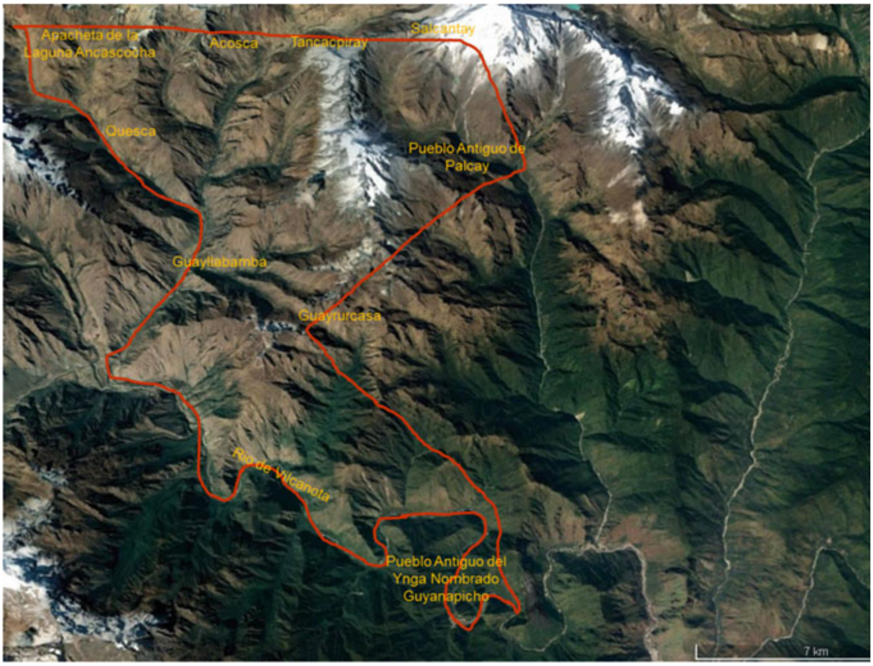

Fig. 15.3 Demarcation of lands between the Silque Hacienda and lands of the natives in Vilcabamba

[22] " El Dr. Juan Centeno Fernandez Heredia, cura, propio de la doctrina de Ollantaytambo, otorgo en donación la hacienda Silque a favor de la religión de los betlemitas y en su nombre al Rmo. De Rodrigo de la Cruz, el primero de diciembre de 1698. (ARC. Protocolo Notarial Pedro Lopez de la Cerda, Prot. 133, f. 832-839v).

[23] ARC. Ciencias, Documentos Sillque, 1635–1722. Part 11. "Este convento, e Isidro Juares de Vera se presentaron al Licenciado don Joseph de los Reyes y Rocha, Juez Visitador y componedor de tierras por delegacion de don Gonzalo Ramirez de Baquedano, y pidiendo amparo de las punas y tierras nombradas Guayllabamba, Quesca, Churo Pampacauna Mattara, Guayror, Guacoto,

Thus, it is clear that the boundaries of the Sillque hacienda and the lands of Isidro Juarez de Bera, are signaled in linear and imaginary way from:

> seis bohios antiguos del tiempo del ynga,

which at present is called Rayancancha, from where the lines are drawn up to Huayraccasa and from there to the

> Pueblo Antiguo del Ynga nombrado Guaynapiccho,

that is, that these boundaries, named tangentially and in a reference way, reached the wall of the Inca city that was the boundary of the

> Pueblo Antiguo del Ynga nombrado Guaynapiccho.

On the other hand, when it is noted that from this ancient village the border goes down to the Rio Grande Vilcanota, it runs upstream until it touches the Huayllabamba River and continues along this river to Quesca and the Apacheta de Ancascocha, including lands that were not theirs incurring land stealing.

Instead, don Diego Sanabria Catcorrayo, a representative of the community's land, took possession from the Salcantay mountain glaciers, making reference to his boundary neighbors don Nicolas Juarez, possessor of the lands of Pampacahuana estancia and don Andrés Abanca possessor of the Matara lands. On the area of Huarurcasa, his boundary neighbor was Nicolás Juarez, owner of the lands of Huayllabamba and Quentemarca (today Patallacta). From Inca Armana or Sayaqmarka, Yuncapatamallaucasa or Puyupatamarca, Lucrepata or Huyñayhuayna and Pumauanca or Incaracay, in all this jurisdiction the boundary neighbor was then by 1662 don Baltazar Yépez, who was designated as cañari Indian of the village of Yucay.

15.2.5 The Lands of the Right and Left Bank of the Valley Floor of the Vilcanota River

In 1772 doña Manuela Almirón, don Francisco Mendo's widow, daughter of Captain don Pedro de Almirón y Villegas and doña Ambrosia Ruiz Barba (Fig. 15.4). Doña Manuela, faced a lawsuit against the Betlemitas of the Convent of Almudena of the city of Cuzco. To defend her lands she arranged a whole titles file, which was composed of the reconfirmation of 1579 land grant by Francisco Toledo, given in favor of Don Martin García de Loyola. These lands were composed of fifty land fanegadas, which was a site for a mill, two blocks for the house and orchard called: Piccho viejo, Carmenga, Pacaymayo, that were located between a mountain that was called Yanacaca and the estancia of Quinte, which had belonged to late Xuares, the

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Salcantay, hasta Guaynapicho ofreciendo 100 pesos a S. M. por las demasias y en su virtud fueron amparados bajo los linderos que aqui se espresan en que entran desde Ancascocha por el Puerto de hasta el dicho Guaynapicho que esta mucho mas abajo de Quenti y obtuvieron despacho confirmatorio del Señor Baquedano año de 1715 en 13 de Febrero".

large river bank, three leagues from the village of Tambo, attentive to the fact that those lands had belonged to the

> yngas antiguos dedicados al sol y a las huacas y estan eriazas y monte aspero, como tal no se habian sembrado ni cultivado de mas de tiempo de quarenta años.[24]

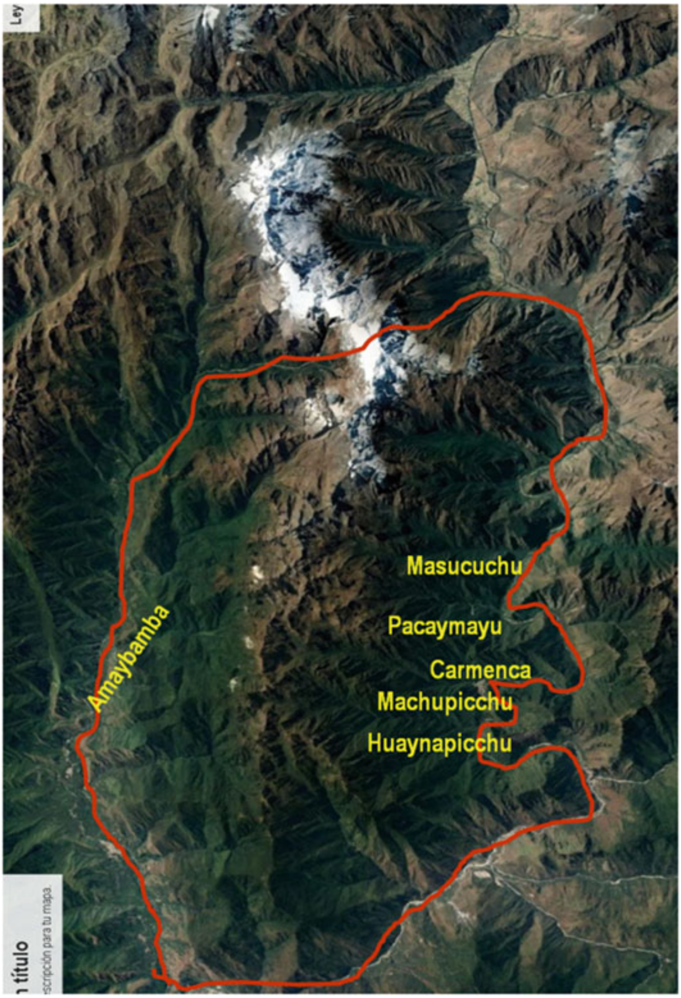

Fig. 15.4 Lands of the right bank of the Vilcabamba River

[24] ARC. Ciencias. Documentos Silque, 1635–1722. Parte No. 13. "Titulos y amparos de tierras debajo de Quente hechos a Martin Garcia de Licona año de 1579 sucediendole en ellas Mateo Velazques de Cobarrubias quien obtuvo repetidas posesiones contra unos indios yepez y en fuerza de ellas vendio a Pedro de Almirón las tierras nombradas Masocucho, pacaymayo, Carmenga, Masocaca, Piccho, macho Piccho, Guayna Piccho, Apupiccho y otros nombres exponiendo haberlas

Doña Manuela Almirón's arguments were supported by the document of 1568, which consisted of the declaration of the principal curacas of Piccho and Tambo[25] and an exaggeration in the expansion of the lands, all these made it suspicious that doña Manuela's request and maneuver were not correct but were altering the borders.

Attached to these documents were the documents produced by don Mateo Velázquez Covarrubias neighbor and hacienda owner of the town of Silque, around 1703, which granted for lease in favor of Andrés and Cristóbal Cusiguaman the lands of Pacaymayu, whose borders reached Champicasa, on the other side, to the Amaro Machay cave down the river, and up the river to Guayrurcasa, for two years, at 35 pesos each year. The lease was with the expressed condition of not cutting the cedar trees, but only the alders for timber and the rest of the trees to make firewood and charcoal. Until May 14, 1706, when don Mateo decided to sell in favor of Don Pedro Almirón, the lands Masocucho, Pacaymayu, Masocaca, Piccho, Machupiccho, Guaynapiccho, Apupiccho, up to the meeting of the rivers of Vilcamayu and Amaybamba, whose lands were composed with Fr. Domingo Cabrera de Lartaun. The sale was made at 400 pesos. On May 9, 1711, don Andrés Cusihualpa, ordinary mayor, granted possession in the name of Don Diego Esquivel and Xaraba, Corregidor of the province of Calca and Lares, in favor of don Pedro Almiron Villegas, of the lands named:

> Pacay Mayo, Guayruru casa, que esta pegado con el zerro de Salcantay, Yancacalla, Acupiti, La Apretana, el labadero de oro, la Laguna aunde esta una cruz por lindero viejo y Mallau Cassa y se baxa por la Cuchilla de Pitupuquio, hasta el rio que se encuentran con Vilcamayo y Carmenga y los Piccho abitación del Ynga. espresados en los ynstrumentos y don Gabriel Capcha quien me mostro todos los linderos y moxones y otros antiguos que vivin juntamente con el dicho Alcalde de Guayllabamba y de sembrar mays ajial y otras ligumbres.[26]

Here it is important to indicate that these lands point out the piccho as boundaries (Machu piccho, Hutuy picho, and Guayna picchu) and they are considered as Inca's dwellings, by the native people of Wayllabamba, who belonged to the jurisdiction of Tambo (Ollantaytambo). Diego Sanabria Catcorrayo, however, who was a chief from Vilcabamba, indicated the village of Waynapicchu. On the other hand, this is in the same perspective as in 1714 when the landowner of Sillque points out his borders "el pueblo antiguo del ynga nombrado Guaynapicchо".

Thus, on November 7, 1714, don Pedro de Almirón, asks for the composition of leftover land, at the sum of 20 pesos. So far the lands indicated by Mateo Velázquez Covarrubias and Pedro Almirón, went smoothly, although they were evident and exaggerated in wishing to extend the borders of their lands.

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comprado de S.M por composición con el reverendo Padre Fray Domingo Cabrera, y en dichas tierras sucedió Don Marcos Antonio de la Camara y hoy las poseen los Ochoa", f. 2-2v.

[25] It is the declaration of the most important elders they made on March 22, 1568, at the request of the Augustinians, in their attempt to search for wasteland to ask for through mercy.

[26] ARC. Ciencias. Documentos Sillque, 1635–1722. Parte No. 13. f. 15. Don Juan de Carbajal accompanied by don Andrés Cusigualpa Ordinary Mayor granted possession in favor of Don Pedro Almirón y Villegas, on May 9, 1711.

On August 28, 1773 it was observed that everything acted by sisters Manuela and Dominga Almirón Villegas contained in the file prepared to reclaim their stolen and usurped land, were fake claims.

The letter to the Viceroy of don Marcos Antonio de la Camara Escudero, Corregidor of Calca and Lares, was overwhelming in pointing out: first, attending the father Fr. Domingo Cabrera de Lartaun's decrees of composition, the corregidor decided to grant her possession. At that moment she intended to enter and spread into many leagues of land, more than the titles indicate, possessed by the regular religious orders: Augustinians, mercedaries, and Betlemites. During the act of possession, the religious administrators of the hacienda of "Umuto y Uiro" contradicted and did not allow doña Manuela possess, so doña Manuela went secretly before the ecclesiastical judge complaining against the administrators of the said haciendas, and obtained favorable providences. The Corregidor intercepted, halfway through, the documents carried by Antonio Ximenes, doña Manuela's representative, and don Pedro Mollinedo, priest of the Amaybamba valley, commissioned to grant possession of land, the corregidor indicated:

> …rreconosi que llevaba consigo un testimonio de los títulos, escrito todo de letra del dho Ximenes; y al pareser autorizado por Juan de Dios de Quintanilla escrivano y rubricas que estan al pie de las distintas plumas del mamotreto eran falsas y fingidas y demostravan su simulasion al primer golpe de vista, y que el ultimo pliego de a quartillo en que recae la autorizacion, era añadidos leylo y reconosi igualmente que estavan añadidas en dho testimonio, muchisima mas tierras de las que se contenían en el ynstrumento original que se me presento.[27]

With all these demonstrations, the sentence was pronounced on September 10, 1777, favorable for Friar Carlos del Rosario religious of the convent of Nuestra Señora de la Almudena, which commanded in the possession and property of Quente, Guacoto, Churo, and Guaillabamba, which had acquired through a will of transaction and sale, by don Gabriel Mariño's heirs. Instead, Manuela and Dominga Almiron had to be content with the lands: Masocucho, Pacaimayo, Carmenga, Piccho, Machupiccho, and Guaynapiccho, enumerated in the sale made by don Mateo Velázquez Covarrubias in favor of Pedro Almirón Villegas.

In 1778, doña Manuela de Almirón y Villegas, don Francisco Mendoza y Valdez's widow, neighbor of this city of Cuzco, Peru, don Pedro de Almirón y Villegas and doña Ambrocia Ruiz Barba's legitimate daughter, on behalf of her heirs and successors sold in favor of don Pablo and don Antonio Ochoa[28] (the latter absent from the city) brothers and their heirs and successors, lands (without tools, cattle or houses) named Masocucho, Pacaymayo, Carmenga, Masocaca, Piccho, Machupiccho, Guaynapiccho, and other names that are downstream, up to the encounters of the large rivers of Amaybamba and Vilcamayo, which are in terms of the parish of Ollantaytambo, province of Calca, Lares, and Vilcabamba. In 1782, Ambrosio Landivisnay,

[27] ARC. Ciencias Documentos Sillque, 1635–1722. Parte No. 13, f. 27. Report addressed to the Viceroy, by don Marcos Antonio de la Camara Escudero, August 28, 1773.

[28] Dr. Jorge Flores Ochoa, who has published several articles referring to Machupicchu, has an extensive knowledge of the descendants and oral tradition of this family.

on behalf of his nephews don Pablo and don Antonio Ochoa, brothers, sold to the Captain Commander of the artillery front of Cuzco don Marcos Antonio de la Cámara y Escudero, lands (without tools, cattle or houses) named Quenti, Masocucho, Pacasmayo, Carmenga, Yanacacca, Masocaca, Picchu, Machu Picchu, Guaynapicho, and other names, which are downstream up to the encounter of Amaybamba and Guayruro Ccasa of the large rivers of Amaybamba and Vilcamayo, that these lands are three leagues down the village of Ollantaytambo.

In 1849, don Pedro Antonio Ochoa, neighbor of the city of Cuzco, indicates that he had inherited from Antonio Ochoa, his father

> unas tierras nombradas Masocucho, Paccaymayo, Carmenga, Masoccacca, Piccho, Machopiccho, Guainapiccho y otros nombres que estan rio abajo hasta el encuentro de los rios grandes de Amaibamba y Vilcamayo, en la comprension de las doctrinas de Ollantaytambo, provincial de Urubamba, las cuales otorga en venta a favor de don Jacinto Alegria vecino de la doctrina de Ollantaytambo, en 300 pesos.

Don Jacinto Alegría, a natural of Huarocondo, neighbor of the town of Ollantaytambo, Urubamba province, truly sold to Santiago Angulo and his wife doña Rufina Guillen, a farm called Intihuatana, located in the village of Ollantaytambo, Urubamba province, at 450 pesos cash. The borders of these lands underwent a drastic modification noting that there was transformation of the borders and names of places that served as landmarks. These lands are described as follows:

> deslinda con la hacienda de Sillque, Cusichaca para abajo, por las alturas con Huacoto, Medio Cuchihuayllabamba, Llullucha, Huchuyhuairuro, Toccorumiyoc, Sedrocortado, Sallcantay, por el rio Intihuatana, Piccho, Hatunpiccho, Huchuypiccho, Carmenga, Pepeño, Chuchubamba, Durasnoocy, Champiccasa, Lluchayoc y Qquente.[29]

Don Santiago Angulo and his wife, doña Rufina Guillen, in less than two years, on February 25, 1862, sold to Colonel Ramón Nadal, the farm called Yntihuatana, under the same conditions, the same borders and price in which they had been bought from don Jacinto Alegría, in 1860, at 450 pesos.[30]

In the sale granted by don Jacinto Alegría in favor of Santiago Angulo, expressly and directed, the names of the lands are changed: Masocucho, Pacaymayo, Carmenga, Masocacca, Piccho, Machupiccho, Guaynapiccho, to the farm called Yntiguatana and the borders are apparently expanded appearing as borders of the "Intihuatana River". Then, suspiciously, don Santiago Angulo and his wife Rufina Guillen, in less than two years, transferred these lands in favor of Colonel Ramón Nadal, under the same conditions in which they had been bought, without mentioning the names of the lands or the borders, indicating only lands "colindantes de la hacienda Silque"

[29] ARC. Garate Carlos, Prot. 102. 1860–1862. F. 244v, "Venta que hace don Jacinto Alegría a favor de don Santiago Angulo y su esposa doña Rufina Guillen de una finca nominada Yntihuatana, situada en el pueblo de Ollantaytambo, provincia de Urubamba, en la cantidad de cuatrocientos y cincuenta pesos al contado ". Cusco, September 17, 1860.

[30] ARC. Garate Carlos, Prot. 102. 1860–1862. f. "Venta que hace don Santiago Angulo y su esposa doña Rufina Guillen a favor del Señor Coronel don Ramón Nadal de una finca denominada Yntihuatana cita en el pueblo de Ollantaytambo y provincia de Urubamba en la cantidad de cuatrocientos cincuenta pesos al de contado". Cusco, February 25, 1862.

having to point out that according to the sale of 1860 and 1862, the hacienda of Silque or the Intihuatana farm, they do not mention as its borders the Ahobamba River, because don Jacinto Alegría was aware that the lands of Ahobamba were within the jurisdiction of don Juan Uscamayta Valentin's lands.

15.3 Land Grabs Between 1849 and 1944: Machu Picchu National Heritage of the Peruvian State

See Fig. 15.5.

Fig. 15.5 Don Manuel Valentin Uscamayta's lands, 1849

15.3.1 Don Ramon Nadal, His Descendants, and the Sillque Hacienda

Don Ramón Nadal was a natural of the city of Salta in the Republic of Argentina, Mr. Juan Nadal y Guarda and Mrs. María Francisca Velarde's legitimate son. He was married to María Mercedes Picoaga and they had children: Alejandro, Julian, Adeodato, and Antonio.[31] Years later, on August 3, 1896, on the death of don Adeodato Nadal, don Ramón Nadal's son, the descendants of the Nadal family celebrated a deed of division and an extrajudicial partition of goods. Thus the Silque hacienda was divided as follows:

> Dona Genara Suarez, Nadal's widow, got the farms Camicancha, Ancascocha, Chancachuco, Chaquilhuairacalle, Cutija, Pampacahuana, Palcay, Churumayo.
>
> Don Ramón Nadal, received the farms and punas: Manchaybamba, Cachicata, Patapata Chico and Churo.
>
> Don Alejandro Nadal, received the haciendas of Mansanayoc, Huilque, Ccoyabamba and Intihuatana.
>
> Don Eduardo Nadal, received Chillipahua, Rocca Cocha, Turpay, Pacupata, Huacacancha, Chira, Pocpoc, Huamancancha, Capillapata, Anapahua and Jaccas.
>
> Enriqueta Nadal, received the haciendas of Sillque, Patapata Grande and the estancias of Quesca, Roccabamba, Carpamayo, Mescay, Huilcaraqui, Huaccoto, Huayllabamba and Chamana.

It was determined, in the transaction document, that the borders of the Silque hacienda were in the north the Vilcanota River, to the south, Pachar, the road to Limatambo, the Sondor hacienda and Mollepata and to the west Huadquiña, with an area of 2,884 hectares, valued at 60,000 soles.[32] According to this document, for the first time the borders of the Sillque hacienda, get to adjoin the Huadquiña hacienda, Ahobamba River was the border.

Then, in 1907, don Eduardo Nadal became the owner of the fraction called Intihuatana, which was an integral part of the hacienda Sillque. He bought it from don Alejandro Nadal at 2800 soles with an extension of 2000 has. Its borders were: to the north, the Urubamba River, to the east the lands of Machu Picchu or Chuchubamba, to the west the river Aguabamba or Ahobamba and to the south the Palcay ravine.[33] This reference confirms that the boundary of the Sillque hacienda reached the Ahobamba River, while the Intihuatana hacienda, on the east side, reached the "Machu Picchu or Chuchubamba lands".

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[31] ARC. Notario Jordan Clemente Prot. 146, 1865–1866. F. 420 testamentos de Don Ramón Nadal, natural de la ciudad de Salta de la República de Argentina.

[32] SUNARP. Escritura publica de division extrajudicial de los bienes fincados por fallecimiento de don Adeodato Nadal entre sus herederos. Asiento Numero 2.

[33] SUNARP. Hacienda Sillque en el distrito de Ollantayatmbo, de la provincia de Urubamba. Asiento Numero 31. Don Eduardo N. Nadal ha pasado ser dueñode la Fraccion llamada Intihuatana,parte integrante de la hacienda de Sillque.

So far it is necessary to observe the handling and change of place names. In 1849, don Juan Uscamayta Valentin, indicates that he owns among others the haciendas called: Pueblo Antiguo de Palcay (Rayancancha), Great Huayrurcasa (Abra Huarmihuanusqa), Minor Huayrurcasa (Abra Runcuracay), Huaynapiccho, Machupiccho, and Intihuatana, among others, which he leaves as a donation to Don Mariano Santos; on the other hand, also in 1849, don Pedro Antonio Ochoa neighbor of the city of Cuzco, indicates he has inherited from Antonio Ochoa, his father, among other lands, "Piccho, Machupiccho, Guaynapiccho". Both land possessions point out Machupiccho and Huaynapiccho. However, it is necessary to clear out that don Juan Uscamayta Valentin, according to his titles, has effective possession over the lands of Huaynapiccho, because in 1663, the visitor measured half a fanegada and found three lodgings covered with straw and in Intihuatana he found four lodgings.

Instead, those mentioned by Pedro Antonio Ochoa as: Picho, Machupiccho, and Huaynapicho, are designated as borders or boundaries. Don Pedro Antonio Ochoa sells the designated land to Jacinto Alegría. In 1860, in the sale Jacinto Alegria executed, in favor of Santiago Angulo and his wife Rufina Guillen, the names of the lands are indicated as: Piccho, Hatunpiccho, Huchuypiccho. Curiously, the names of Machupiccho and Huaynapiccho are mentioned in inverted form, the only one that remains is "Piccho". It is from 1860, that the names of Machupiccho and Huaynapiccho are not mentioned in land sales nor are they indicated in the demarcation and borders, but they are apparently included within the Intihuatana hacienda, so in 1907, Intihuatana, bordered to the east, with lands of Machupiccho and Chuchubamba, which are toponymic and linguistically different. Machu Picchu means cerro Viejo [?] and Chuchubamba, means hard or dry pampa.

For the years 1896–1976, it is interesting to show the results of historian Ivan Usca Baca's research. He indicates that the awards made to each of don Adeodato Nadal's heirs, generally corresponded to lands located both on valley floor, punas and farms for cattle, thus encompassing lands within the districts of Ollaytambo and Machu Picchu. It is worth emphasizing that during this period (1896–1910) the dominance of the Nadal family still remained, since land transfers took place between themselves under inheritance and buy-and-sell mechanisms.[34]

[34] In the Archivo de la SUNARP del Cusco there are properties that have been registered as a transfer of domain of estates. So in Partida No. 02016781. Tomo 28. Foja 219. Asiento No. 34. Año 1908. Don Eduardo Nadal buys from Doña Genara Suarez the fractions of Carpamayo, Misccay, Huillcaraqui, Chamana Huaccoto, Churumayo, Pampacahuana and Pallcay. And in Tomo 40. Foja 92. Asiento No. 48-48v. Año 1910, The fractions called Pocpo, Huamancancha, Anapahua, Jacas, and Intihuatana Roccobamba, Carpamayu, Mescay, Huillcaraqui, Chamana, Huacoto, Churumayu, Pampacahuana, Palcay, Camicancha, and Sayllapata valleys become transferred to doña Genara Suarez, for inheriting them from her son Eduardo Nadal.

15.3.2 *Don Mariano Ignacio Ferro and the Abril Vizcarra Family*

Since 1904, don Mariano Ignacio Ferro begins to acquire different property extensions from the descendants of the Nadal family, especially the area of Q'ente. Thus, the Ferro family managed to register their alleged property of the Silque hacienda on page 60 of Volume 1 of the Cuzco Estates Registry. Later on, Mrs. Lourdes Ferro de Abril's heirs carry out and register in Annotation 9 of the volume mentioned, the division of that estate into 4 lots, including the Santa Rita de Q'ente and Q'ente estates.[35] The Nadals began to decay, when some of their fractions or farms were transferred to third parties, such as to the conjugal society of don Mariano Ignacio Ferro and María Laureana Vizcarra, who acquired as a purchase the fractions called Cutija, Huayrancalla, and Huayllabamba, that belonged to the Sillque hacienda, the process of acquiring land by the Vizcarra-Ferro conjugal society, not only encompassed part of the Sillque estate, but extended their domains to La Convencion province, where they obtained the goods by way of purchasing the Huayopata Hacienda, with its fractions: Chalanqui and Chuyamayo. Thus in 1921, doña María Laureana Vizcarra, expresses in her will:

> Declaro, que dichos bienes son la mitad de la Hacienda Huayopata alta…la mitad de Huayopata Baja…compuesta de las fracciones Chalanqui y Chuyamayo; la mitad de la Hacienda Cutija…compuesta por las fracciones: Cutija, Manchaybamba, Kcamicancha, Santa Rita e Intihuatana….[36]

The goods acquired in the Ferro-Vizcarra conjugal society, were transferred to their children: Manuel Esteban, Felipa, María Salome, Saturnina, and Tomasa Ferro Vizcarra. The latter receives as a legitimate advance from Mariano Ignacio Ferro the Primavera hacienda, called Cutija before, which, later on, could manage to get consolidated with the Abrill-Ferro family as a unit that housed all the sectors or estates indicated above, remaining undivided until 1944, year in which Tomasa Ferro's heirs requested the division of these properties, which were divided equally among the indicated three heirs (José Luis, Carlos, and Julia Lourdes Abrill Ferro) and J. Emilio Abrill Vizcarra, Tomasa Ferro's husband; thus in the trial of partitioning of goods, it is precised:

> … se adjudica a Don José Luis Abrill Ferro, el lote Numero dos o de Primavera y punas de Pampacahuana… a Don Carlos Alejandro Abrill Ferro, el lote número tres o de Camicancha…al Dr. J. Emilio Abrill Vizcarra, se adjudica el lote número Cuatro o de Qquente…, con los linderos siguientes: Por el Norte con el rio Vilcanota, por el Este con la Hacienda Camicancha y Pampacahuana punas de la Hacienda Primavera. Por el Sur con la hacienda la Estrella, por el Oeste con la hacienda huadquiña, con un área de veintidós mil hectáreas….[37]

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[35] Resolucion No. 239–2007-SUNARP-TR-A del Tribunal Registral.

[36] ARC. Notario. José Alosilla. Folio. 886. No. 390. Año. 1921. Testimony of Mrs. María Laureana Vizcarra de Ferro's will Document provided by historian Alex Usca Baca.

[37] ASUNARP. Zona registral XI. Sede Cusco Partida No. 02016781. Tomo 121. Foja 220. Asiento No. 90-90v. Año 1944. Partition of the goods followed by Tomasa Ferro de Abril's heirs.

As a result of this division and partition of goods, the production unit of the Primavera or Cutija estate was split into four large estates: Chumumayu, Primavera, Camicancha, and Q'ente. The Q'ente fraction owned by J. Emilio Abrill Vizcarra, was transferred for purchase and sale on September 12, 1944, in favor of the conjugal society: Julio Zavaleta Flores and Rosa M. Zavaleta Alvarez; as recorded in the purchase-sale deed:

> El doctor J. Emilio Abrill Vizcarra es propietario de la hacienda denominada "Qqente"…-compuesta de las siguientes secciones, conocidas con nombres de Qqente, Santa Rita, Intihuatana, Cedrobamba, Matipata, con todas sus comprensiones, así como sus punas denominadas Huayruro, Matara, Mesada, Palcay…por el precio de sesenta y tres mil soles…expresamente se deja constancia de que no está comprendida en esta venta el pago de las indemnizaciones que se siguen ante el gobierno por la expropiación de las ciudades incaicas Machu Picchu, Huayna Picchu, Huiñayhuayna, Sayac Marca, Phuyupatamarca, actualmente poseídas por el Estado…[38]

Lot 4, the 22,000 hectare-Q'ente estate was awarded to Mr Emilio Abrill Vizcarra. Then, by means of Public Deed of September 12, 1944, don Emilio Abrill Vizcarra sold Julio Zavaleta Flores the 22 thousand hectares, establishing in the fifth clause of the contract, a sales reservation, which excluded from it, the compensation that was followed before the government for the expropriation of Machu Picchu, Huayna Picchu, Wiñay Wayña, Sayaq Marka, and Phuyupatamarca Inca citadels, compensations that were later given through expropriations followed by the Direccion Regional de Reforma Agraria, despite the fact that some names of the lands changed, such as: Incarmana to Sayaqmarka, Yuncamallaucasa to Phuyupatamarka, Rucrepata to Wiñaywayna. However, the names of Machu Picchu and Huaynapiccho are preserved until now.

15.4 Peruvian State Regulation, Integration of Spaces, Cultural Heritage Protection Between 1822 and 1929

Since 1830, the tax named Alcabala de Coca established in the Santa Ana Valley, was loaded a real for each arroba of coca. This contribution was destined for the opening of the "Camino Nuevo a los Valles de Santa". Its management and administration was in charge of a board constituted at that time by, Martín de Concha, Vicente Francisco Garmendia, Martín Julián Garmendia, and Esteban de Navia, who requested a detailed report of everything invested in the construction of the "camino nuevo".

On March 20, 1846 they presented their cost proposal for the opening of the "camino nuevo", to the Prefect and the Board of the Camino Nuevo to the Valleys of Santa Ana, in three continuous years, at a total cost of 25,000 thousand pesos,

[38] Testimony of public deed of purchase and sale of the Qquente property granted by J. Emilio Abrill Vizcarra in favor of Julio Zavaleta Flores and Doña Rosa M. Zavaleta Alvarez. Before the Public Notary Public Rosendo A. Fernández. 1944. Document photocopied in the Archivo General de la Nacion, by Mariana Mould de Pease.

paid this way: the 15,000 thousand pesos at the beginning and the remaining 10,000 pesos paid at the end of the work. The Board of Works of the Camino Nuevo, having made the evaluations of Mr. Arguelles and Mr. Tejada's proposal, decided to carry out the auction of the work in favor of José Manuel Montesinos.[39]

15.4.1 Construction of Camino Nuevo Piri-Santa Ana, by Engineer Herman Gohring

Herman Gohring's New Road. On November 5, 1869, the Chairman of the Board of Directors of the Coca Alcabala signed a contract with Eucher Henry; in this document it was stipulated so that in 30 months, the final work of the opening and repairing of the roads of the valleys of Santa Ana, Lares, and Ocobamba and Chahuillay Bridge would be delivered. Engineer Eucher could not fulfill or execute the transaction held, which was transferred in favor of engineer Herman Gohring, who accepted plainly, with all the recommendations of the work he was to carry out. The respective contract was signed on June 12, 1870, with it the first stipulation was ratified.[40] On November 12, 1872, Engineer Herman Gohring, Entrepreneur of the Opening and Repairing of the Roads of the Valleys of Santa Ana, Lares, and Ocobamba, through a letter makes it known and tells the Chairman of the Honourable Board of Directors of Alcabala de Coca, that the second section of the road from Piri to Chahuillay, which is the Media Naranja, is ready in a state of delivery, in accordance to the requirements of the contract (Fig. 15.6).[41]

Herman Gohring's letter was brought to the attention of a member of the commission Mariano Vargas Zárate, who, in turn, issued his opinion and opinion that the second section of such work should not be delivered yet, without the first section being expedited, which preferably had to be arranged according to the provisions of the contract. But the entrepreneur or contractor, in order to do it better, preferred to undertake the work in the "Second Section", which was believed to be the most difficult and dangerous. Therefore, the Board, having seen the contractor's letter

[39] ARC. Administracion del Tesoro. Legajo 88. Folios. 60. Asuntos Contenciosos. Proceedings on the opening of the new road to the Santa Ana Valley. f.21/ Report of Don José Manuel Montesinos to the Prefect of Cusco and to the Board of Directors of the road of Santa Ana.

[40] ARC. Registro Oficial del Departamento del Cusco. Tomo XXV. Cusco Enero 28, 1874. No. 2. p. 8. Chairman of the Board of Directors of the Coca Alcabala. Cusco. December 6, 1874. To Herman Gohring, Entrepreneur of the Roads of Santa Ana and Lares.

[41] BC-UNSAAC. Hemeroteca El Ferrocarril, Redactores y Escritores, J. Emilio Luna y Abel A. Luna. Año VI. Cuzco, Febrero 1, 1873. No. 144. Documents of the Administrative Board of the Coca Alcabala and Roads.

and having made the corresponding evaluation, believes that as soon as possible a commission of one or two persons is appointed, so that a neat inspection is carried out and their report about the condition of such "Second Section of the Road", and also about the rest of the works being executed is released to the Board. At the same time M. Vargas, member of the board, suggested that the commissioner be Mr. José T. Rozas, accompanied by some hacendado from the Santa Ana Valley, since they were the main interested ones in the execution of the work.[42] Mariano Vargas's opinion was approved in the session of December 2, 1872. On December 6, 1872, the commission headed by José Teodosio Rozas, member of the board, accompanied by the landowner D. Tomas Polo was appointed, they had the mission to inspect the work that Herman Gohring had been executing on the Route from Piri to Chahuillay and report about the present condition of the "Second Section" to the Board of the Coca Alcabala.[43]

Fig. 15.6 H. Gohring. NEW ROAD BUILDER

[42] BC-UNSAAC. Hemeroteca El Ferrocarril, Redactores y Editores, J. Emilio Luna y Abel A. Luna. Año VI. Cuzco, Febrero 1, 1873. No. 144. Documents of the Administrative Board of the Coca Alcabala y Caminos. Letter of Mr. Vocal Mariano Vargas Zárate addressed to the Board of Alcabala de Coca, Cusco, November 27, 1872.

[43] BC-UNSAAC. Hemeroteca El Ferrocarril. Redactores y Editores, J. Emilio Luna y Abel A. Luna. Año VI. Cuzco, Febrero 1, 1873. No. 144. Documents of the Administrative Board of the Coca Alcabala y Caminos. In the Session of the Board of the Coca Alcabala, on December 2, 1872. Vocal José Teodosio Rozas and the landowner Tomas Polo were comissioned.

Complying with the entrusted mission, Mr. José Teodosio Rozas, points out that on December 18, 1872, he undertakes the expedition, in Piri, going through the Tancac Estate, Runtumayu, Choquellusca, Corihuayrachina' crag, Torontoy hacienda, so far the road had been cleared. The next section was from Torontoy to the Pampa de Artilleroyoc and Cedrobamba[44] where they were impeded by a crag, the commission could not go by on horseback but by an ancient road (Camino del Inca), going along the hillside until they reached "Poquescasa".[45] From Poquescasa, the descent is more extensive and steeper than the ascent. From this part you can see the imposing "Peñon de Huaina Picho" in front of which is located the famous "Media Naranja". In Aguas Calientes (Village of Machu Picchu) there was Herman Gohring's campsite, from where the Media Naranja road (Putucusi) was near, they were filled with enthusiasm which became redoubled even more upon suddenly hearing the continuous detonation of six cannon shots out of 24 that dominated the impetuous loud crash of the river onto the hill of Huaina Piccho, then it would crash the Media Naranja.[46] José Teodosio Rozas's premonition was evident and eminent, when he says that "dia vendra en que en un lugar de la estrecha senda que ahora atraviesa la Media Naranja, se abra un tunel, para dar paso a la locomotora y unir con un eslabon de vapor y de granito el Nuevo Mundo con el Antiguo". From this spectacular vision of the future and the feeling come true, Entrepreneur Engineer Herman Gohring was presented as a hero who conceives the reason and exalts the future, fighting and overcoming the obstacles that nature presents to man's work.[47] It is important to take into account that in the description of the inspection of the new road in the section of Media Naranja (Putucusi) the "Cerro de Huayna Picchu" is highlighted.

José Teodosio Rozas announces that he will work on the part of the Media Naranja in the description of the new road very carefully. The Media Naranja deserved the following description:

> … es una roca de granito, de una inclinación casi perpendicular sobre el nivel del rio, cuya elevación calculo, a la simple vista en 150 a 180 varas y 360 varas de ancho en el lugar donde se ha abierto el camino, estención que ha aminorado en 320 varas con la ruptura de la peña. Su testero es unida, solida, pulimentada por la acción del río. Su color es blanquisco azulado, por el cuarzo y la única que dominan su composición. Tiene pocas resquebrajaduras y forma una pequeña curba en su conjunto. El Huayna Piccho que está al frente y a muy pequeña

[44] José Teodosio Rozas's explanation of the pampas is interesting and it is as follows: "Es preciso saber que lo que se entiende por pampa en aquellos lugares, son pequeños girones de terrenos angostos y llano las que a cada momento se ven entrecortadas por recodos de cerros y pañolerias" (Rozas 1873: 118, see footnote 43.).

[45] Ibid., 118.

[46] The detonations of the dynamites forced José Teodosio Rozas to have solemn reflections such as: "aquellas detonaciones salidas del seno del granite, reperentidas (repetidas) de roca en roca y desvanecidas en la cumbre de las montañas, silenciosas e inmovibles hasta entonces, fueron, una voz, una palabra solemne, un llamamiento de la civilizacion, congregando a los hombres al concurso del trabajo y a la creación de las riquezas. La dureza del granito ha cedido al cincel del hombre y ha franqueado su seno para sostener sus audaces plantas. Estos bosques salvajes, que solo alimentaban ponzoñosas viboras ahora han abierto sus tesoros a la industria del hombre laborioso"(Rozas 1873: 122).

[47] Ibid., 118.

> distancia, es de una elevación mas considerable y mide un ancho como de un cuarto de legua. Es la misma roca cortada y separada de la Media Naranja por la acción lenta, dilatada, pero seguro del río, en el transcurso de incalculables siglos (Rozas 1873: 118).

It is important to stand out that the new road, from Piri to the Santa Valley, which runs through Piri, Tancac, Chqouellusca, Corihuayrachina, Torontoy, Cedrobamba, Poquesccasa, Herman Gohring Camping Site, Media Naranja (Putucusi), is the one that leads the Yale expedition in 1911. On the other hand, it is important to highlight the name of Peñon de Huaynapiccho, Cerro de Huaynapiccho, and Huaynapiccho, which is perfectly located and marked. Now, let's take a look at the other case concerning Augusto Rodulfo Berns, German, and also engineer, whose first purpose was the searching for cedar wood.

The maintenance, repairing, and placement of metal bridges on the new Piri - Santa Ana Valley road were of interest to the Board of the Coca Alcabala of the Province of La Convencion. This is how Mariano Vargas treasurer of the Coca Alcabala of the province of La Convencion, on August 12, 1892, certifies that in the proceeding of the auction practiced for the construction and placement of the iron bridges in San Miguel Pavayoc and Chahiuillay, the auction was held under the chairmanship of Mayor of the Honorable Provincial Council don Manuel Tinajeros, Lieutenant Mayor don Antonio Rueda, First Instance Judge of the province Dr. Juan Rivera Hermosa, Trustee of First Nomination don José Jordán, Treasurer of the Coca Alcabala Funds doña María Vargas and the Municipal Treasurer José Rebollar. Thus, the auction of the three bridges over the Vilcanota River called Pabayoc, Chahuillay and San Miguel was executed. The proposal of the Braillard Brothers and Co., and Mr. Lacaveratz was approved for being the ones to provide security and advantages mostly and in terms of the conservation of the bridges with guards and paint for every year was accepted since it was the obligation of the council.[48] On the other hand, on June 8, 1892, the auction proceedings for the repairing of the roads of La Convencion was manifested, it was granted in favor of Fernando Palma, who would improve the previous proposal without demanding any remuneration for the repair and opening of the two fractions: from Pumachaca to Pacaymayo to the present bridge of Collpani. Thus, don Fernando Palma has carried out the auction of the opening of the "Nuevo Camino de Torontoy" under the three sections expressed, with bail for the sum of 6311 soles (six thousand three hundred and eleven soles) that "we force ourselves by mortgaging the second at 5000 soles which is the value of the Santutis estate".[49]

[48] ARC. Registro Oficial del Departamento. Tomo XLIII, Cusco August 31, 1892. No. 17, p. 4.

[49] ARC. Registro Oficial del Departamento, Tomo XLIII. Cuzco September 30, 1892. No. 19. p. 2.

15.4.2 Exploitation of Wood and the Huaca del Inca Company. Augusto Rodolfo Berns

By 1872, don Augusto Rodolfo Berns,[50] was already informed about the existence of a new road and timber between Torontoy and Media Naranja. The columnist of "Maderas Cuzqueñas" for the newspaper El Ferrocarril in 1874, identified with the pseudonym "Cuzco", indicates that so far no profit has been gotten "los magnificos e inmensos de las dos haciendas denominadas Cercado de San Antonio y Torontoy", which are rich in wood in the variety of kinds as in quality.

On October 4, 1872, a necessary contract for eight years was entered into, before the Judge of Urubamba, between don Santiago Angulo, a natural of the city of Cuzco and neighbor of Urubamba and don Augusto Rodolfo Berns, a natural member of the German Confederation or Germany and a neighbor of Cuzco. In this contract, the second one forced himself to cut the wood from the forest of the hacienda del "Cercado and Ccollpani", owned by the first one (Fig. 15.7). The contract was made with the following agreements.[51]

El Cercado hacienda, don Santiago Angulo's property, comprised from the point called Cedrobamba—located a league from Torontoy—to the Collpani hacienda. In this long and wide space of the mentioned hacienda, don Augusto Rudolfo Berns promises to cut the timber trees into boards and quarters and sell on his own. Don Santiago Angulo, promises not to sell wood of any kind from his estate El Cercado nor make another contract with any person, nor stop carrying trees or wood of any kind, but only to Augusto Rudolfo Berns. Augusto Rudolfo Berns, will pay Santiago Angulo, for all kinds of timber trees from the Hacienda del Cercado, four cents for each Castilian cubic foot either for wood cut into boards, in quarters or entire trees; to the same extent, he promises to grant 400 soles on account of the first items. Berns also promises to leave all kinds of machines that have been used to cut boards and trees after the fulfilling of the contract which is for eight years. These machines are two vertical wheels with their two wheel saws, those wagons were all ordinary, in good conditions so that Santiago Angulo can cut boards and quarters. Another commitment Berns acquires is to give 2000 soles on account of the four cents for each cubic foot of wood. This is after having taken the wood out of the farm and after the six months of signing the contract with the Enterprise of the Railway from Juliaca to Cuzco, the stipulation is about the construction of bridges from Cuzco to

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[50] According to the declaration of don Augusto Rodolfo Berns, in 1887 before the Peruvian government, he had a permanence and experience of fifteen years going along the Peruvian territory. As such, Berns would have arrived in Peru in 1872, his first contacts, happened in Lima and Arequipa with the exploring companies. Don Bautista Constantini, member of the Forga house and the Arequipa Company, would be a mechanism that energized don Augusto Rudolfo Berns's life to explore the province of Urubamba and La Convencion, in the search for tree gum, rubber (caucho), husk, and wood.

[51] ARC. Corte Superior de Justicia Judicial Civil. Leg. 212, 1880, con 24 expediente. Contract proceedings entered into between don Santiago Angulo and don Augusto Rudolfo Berns so that the second can cut the timber wood from the forest in the farm of the first, granted before the Judge of First Instance of the province of Urubamba, held on October 4, 1872.

the Romeccolcca ravine; in case of not signing such a contract he will give the 2000 soles once he has been established in the Hacienda del Cercado.[52]

Fig. 15.7 Augusto Rodolfo Berns. Wood and huaca del Inca exploiter

Augusto Rudolfo Berns, once the contract with Don Santiago Angulo, for the exploitation of wood in the estate of "El Cercado" is concluded, established a series of mechanisms to ensure the production of wood, ensure profitability and for this it was necessary to establish agreements with houses and companies that could provide capital for the best performance of wood production. Therefore, he immediately takes a round trip to Cuzco, Arequipa, and Lima, in which he establishes links. Thus, on December 19, 1872, he celebrated a public deed in the city of Lima, with don Bautista Constantini, member of the Forga House. This agreement between Berns and Constantini, entitled the Forga House to exploit the tree gum, rubber, and husk in the El Cercado hacienda. In return the Forga House, obliged themselves, to give Berns machines and tools, place them in Arequipa, at a price of 4,000 soles. Also, on January 21, 1873, Berns establishes a link with the Arequipa Company, to obtain more capital for the contract he had concluded in Cuzco. Augusto Rudolfo Berns had a whole prospect of establishing a Timber Industrial Company, for which he

[52] Ibid., f.137–142v.

obtained the necessary funds and capitals, amounting to a total of 5524 soles, which was remitted to New York, for the purchase of machinery to saw wood.[53]

Augusto Berns found it necessary to seek more capital and associated people, besides securing the good dividends, so he identified strategic partners, promoting with these principles, on September 11, 1873, the formation of a "Society", whose business name was "Alisedo, Berns, Balaguer and Campero". This entity was constituted by don Augusto Rudolfo Berns, single, from Germany; don José Balaguer, single, from Spain; don José Alisedo, married, from the republic of Argentina and don Juan Manuel Campero, single, from Cuzco. The goal of this "Society" was to exploit the timber trees from the hacienda, called "El Cercado", owned by Santiago Angulo with the capitals supplied by Forga House. The duration of the society was forced for the term of eight years. According to this society, the partners were free at their convenience besides taking care of the businesses of the society. The expenses made by the partners in El Cercado hacienda, such as supplies and forage, were on the account of the enterprise. If any member invested any amount for the good of the company, it would be paid from the profits of the other partners. The partners committed not to buy land for the exploitation of wood, nor associate with anyone else in this type of business, just keep in common in this society. They adopted a unanimous agreement: to take stock every three months and the profits would be made in four equal parts. At the end of the eight-year period, each member would be entitled to a quarter of the existence of ownership of the company.[54]

Two years after the wooden exploitation contract with Santiago Angulo and one year after the formation of the company "Alisedo Berns, Balaguer y Campero", the Timber Company, founded by Augusto Rudolfo Berns, showed the need to grow and expand the production center, so on November 20, 1874, a "Society Contract" was entered into, therefore they granted a society deed between don José Alisedo, don Augusto Rudolfo Berns, don José Balaguer, and don Manuel Campero, for a period of time of six forced years. This deed of society contract voided all previously made either collectively or individually concerning the exploitation of wood. This company was constituted with the business name "Alisedo y Compañía", being the only manager of the company, don José Alisedo. It had the purpose of the exploitation of wood in the haciendas of the Valley in El Cercado and Torontoy, which were purchased from Mr. Santiago Angulo and his daughter doña Manuela Angulo de Flores, by Mr. José Alisedo.[55]

The wood-exploiting company, formed the following capitals: don JoséAlisedo, contributed the amount of 12,438 pesos; don Manuel Campero contributed the

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[53] ARC. Protocolos Notariales.Garate Carlos. prot.110.1873. f. 926v. En la ciudad del Cusco, el 11 de setiembre de 1873, forman una sociedad: Don Augusto Rudolfo Berns, de estado soltero, natural de Alemania y vecino de la ciudad del Cusco, Don José Balaguer, soltero, natural de España y vecino del Cusco, Don José Alisedo, casado, natural de la Republica de Argentina y vecino de Cusco y Don Juan Manuel Campero, de estado soltero, natural y vecino de la ciudad del Cusco.

[54] Ibid., f. 927–928.

[55] ARC, Garate Carlo. Prot. 111. 1874–1875. f. 673, "Society contract granted by don José Alisedo, don Augusto Rudolfo Berns, don José Balaguer and don Manuel Campero, adults, neighbors of the city of Cusco. Cusco November 20, 1874.

amount of 7081 pesos, from which 6600 pesos was the value of a house sold in favor of Santiago Angulo and 581 pesos in cash, as part of payment of the Torontoy estate. Don Augusto Rudolfo Berns and José Balaguer, are committed to paying 4879 pesos, which is the quarter of the invested capital with the interest of 1% until the cancelation to don José Alisedo and don Juan Manuel Campero. Berns, Balaguer, and Campero recognize the 1% monthly interest from the 35,000 pesos which is the cost of the haciendas of the Valle del Cercado and Torontoy, which have been paid by Mr. José Alisedo. On the other hand, the members Campero, Berns, and Balaguer, promise to pay Mr. Alisedo a quarter of the value of the haciendas, which are 8750 pesos each one within three years, since the signing of that deed. As capital has to be invested in the support and improvement of the Collpani estate, which is in charge of José Alisedo, the partners will assume a quarter of the improvements of the estate. The four partners promise not to mortgage nor sell all or part of the stock to a stranger without the unanimous knowledge of the partners.[56]

The four partners will also make new outlays until the final installation of the sawing machine. They also recognize the credits contracted with the Forga House of Arequipa and with the Astete brothers. In addition, the company established some principles, as: only three united partners can ask for the separation of the other, obviously with a fair reason; any difference in the society will be vented only by Referee Judges, friendly and conciliators and never by courts nor judges of the country or foreigners. It was forcing to develop the economic balance every three months and have the result of the profits be divided into four equal parts. At the end of the period of the company contract which is six years, the partners will be entitled to one-quarter of the purchased existence of the company.[57]

By March 1874, the industrial timber company established by the dynamism of don Augusto Rudolfo Berns, managed to unify the ancient haciendas "El Cercado de San Antonio and Torontoy", in a single large hacienda called "La Concepción", which encloses a forest more than 10 leagues long by six wide, prodigiously endowed with valuable woods, which have been classified into more than 50 different species among which can point out: "boj, sumbayllo, caoba, nogal, jacaranda, laurel, el palo-santo, amarillo y colorado".

In addition, a complete shipment of trains had arrived with the machinery from the United States, for the estate of "La Concepción". This sawmill machinery, gathered all the perfections of the last advances of the time, which will allow on a large scale the exploitation of the rich woods, and that fact would contribute powerfully on the opening a new coming of wealth and would be useful for the well-being of the Departamento del Cuzco. The expert engineer Mr. Berns, was the author of all this feat which marched under his direction. On the other hand, the distance between the city of Cuzco and the hacienda "La Concepción", offered no obstacle, since there was

[56] Ibid., f. 673.

[57] Ibid., f. 674–675.

a good horseshoe road, which at very little cost can become a beaten road. Evidently, this road has just been delivered by Engineer Herman Gohring.[58]

On April 1, 1887, Augusto R. Berns, German engineer, submitted a request, to the Benemerito General don Andrés A. Cáceres, in which he pointed out that having resided for 20 years in Peru and gone along the territory in different trips and excursions, he has had the opportunity to discover the existence of several gentile huacas which are hidden. He emphasizes that: "Por las leyes vigentes, el Tesoro y toda cosa enterrada cuyo dueño no puede ser conocido, si se halla en terrenos publicos, o de ninguno, corresponden, al que los encontró, (Art. 522 del Codigo Civil) teniendo que dividirse por iguales partes entre el dueño del terreno y el inventor o descubridor, salvo convenios especiales, si el tesoro encontrado se halla en propiedad particular" (Art. 523, del Codigo Civil).[59]

In this perspective, Augusto R. Berns, wishing his discovery, if it was carried out, could:

> servir de algun alivio al Estado, y a fin de que quede debidamente expresado por vuestra excelencia las condiciones en que me encontrase al efectuarse mediante los costosos trabajos y penosas exploraciones ya hechas y que me propongo emprender, el hallazgo de los objetos….

So he goes to the President of the Republic, previously requesting the "respective permission" and at the same time the express protection of the authorities in case such discoveries became of importance. Because of the proposal, he offers to cede to the State:

> La decima parte del valor intrinseco de los objetos de plata o oro que llegasen a extraerse, es decir, que pesados dichos objetos abonare al contado al erario nacional el diez por ciento del valor en plata o oro, segun su ley de los mencionados objetos… en seguida despues de haber vendido los mencionados objetos que ponder en seguida vender aqui o exporter libremente al extranjero. Los objetos de madera, barro, cobre u otra materia de valor intrínseco no estarán afectos a pago ninguno.[60]

In the third article of the proposal, Berns points out that the Supreme Government, at the time of the discovery of articles made of or with precious metals:

> Podra nombrar un empleado o comision de su confianza, para intervenir en la operacion de pesar los objetos encontrados a fin de calcular el monto de diez por ciento sobre su peso bruto en plata o oro….[61]

He begs the President of the Republic, saying his request is urgent, since he wants to undertake the work by taking advantage of the dry season.

The Peruvian Government, attending and viewing engineer Augusto R. Berns's request and proposal, in which he expresses the purpose of doing: "excavaciones

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[58] BC. UNSAAC. El Ferrocarril: redactores y editores J. Emilio Luna y Abel A. Luna. Cusco, 17 de marzo de 1874. Las Maderas Cuzqueñas. Escrito bajo el seudonimo "Cuzco".

[59] AGN. Prot. 934. Notario Claudio José Suarez. f. 474-425v. Request for permission submitted by Augusto R. Berns, Engineer, to the Benemérito General, don Andrés de Cáceres. Note: That time the Civil Code of 1852 was in force.

[60] Ibid., f. 475–475v.

[61] Ibid., f. 476.

en huacas incasicas y en construcciones gentilicas", located in the provinces of La Convention and Urubamba of the department of Cuzco, accepts Berns's proposal, so it issues a Supreme Resolution, dated—Lima June 16, 1887, in whose sixth article, orders the prefect of Cuzco, to appoint a person to accompany Berns and witness the excavation work, give account of the circumstances and a detailed notice of what was discovered. The Government agrees to make the public force available to Berns. Finally, the Government indicates that any difficulty that arises in the fulfillment of this agreement, will be resolved by the Courts of the Republic.

It should be pointed out then that through this Supreme Resolution, the Peruvian Government showed that all the: "Huacas incasicas y construcciones gentilicas" are owned by the Peruvian State, so the request and proposal of Engineer Augusto R. Berns, is accepted with conditions and it immediately orders that the prefect of the city of Cuzco designate a person to accompany Berns and observe and give account of the possible discoveries.

15.4.3 The Decreto Supremo of April 27, 1893 Which Declared All the Ancient Buildings, Prior to the Conquest, National Monuments (Period of Cultural Management 1893–1929)

With all these considerations, the Peruvian government, in terms of pre-Hispanic properties, also banned exploration or excavation, in ancient huacas, fortresses, temples, and in places located on public lands for searching for archaeological objects: "Sin el permiso especial del Estado". In this perspective, the second article of the above-mentioned decree explicitly indicates:

> Declárense monumentos nacionales todas las antiguas construcciones anteriores a la conquista, que se encuentran dentro del territorio nacional, y objeto de interés público su conservación y vigilancia, quedando por consiguiente prohibida la destrucción o mutilación de las dichas construcciones.[62]

The license for exploration and excavation in pre-Hispanic properties had to be requested in the Capital of the Republic before the: "Junta Conservadora de las Antiguedades Nacionales" and in the departments before the branch boards. The "Junta Conservadora" consisted of the Minister of Public Instruction, who chaired it, the Prefect of the department, the Director of the Museum or the National Library and the Director of Public Instruction. In the departments, everything was ready to create Branch Boards, composed of the Prefect, the Prosecutor or the Prosecutor Agent, and the Department Treasurer. The license request had to express the site and the kind of work, the goal and the duration of time. The license concession was

[62] ARC. El Registro Oficial del Departamento. Tomo XLIV. Cuzco, Mayo 20, 1893. No. 16. Dirección de Instrucción. Remigio Morales Bermúdez, Presidente Constitucional de la Republica. Decreto Supremo, Lima, 27 de abril de 1893.

issued at the bottom of the document under the conditions which guarantee the rights of the State.

The work that could be undertaken had to have a fixed term and should be carried out before a person appointed on behalf of the government. All the objects found belonged to the one requesting the license, but the latter was required by right to give the State a duplicate of each of the objects that were discovered or photographic copy of those that did not have a similar, supported by a detailed description to have an accurate idea of the object in question.

The said Supreme Decree, almost as a way of conclusion, indicated in its Article 10:

> Las disposiciones de este decreto serán extensivas a los terrenos de propiedad particular, en la forma y términos que los determine el Poder Legislativo, el que presentara oportunamente con este fin el respectivo proyecto de Ley.[63]

In this perspective, the knowledge and protection, of the State, related to the discovered Inca cities were a priority. This is how, in 1909, the Department of Justice, Instruction and Worship, by an Oficio of March 20, 1909 had the Prefect of Cuzco know about the supreme agreement by which the decree was issued, considering that it was convenient for the Supreme Government to know: "De la manera mas fidedigna posible todo lo relativo al descubrimiento de la ciudad incaica de Choqquequirao, recientemente realizado en el Departamento del Cuzco", all this was necessary for the government to dictate rules of: "Conservacion indispensables para adoptar las que sean necesarias para el resguardo de los intereses del Estado".[64]

Therefore, it was decided to commission the Director of the National History Museum Dr. Max Uhle and Dr. Julio C. Tello so they established themselves in the place, in order to proceed with the study of the discovered ruins, being authorized to carry out the excavations that are considered indispensable and having the extracted objects sent to the Museum.[65] In the second part, it was arranged that Dr. Uhle submitted a report that should: "Estar acompañado de un plano o croquis del lugar, fotografiar las más numerosas que se puedan y de un inventario todo lo detallado posible" and he was forced to point out: "las medidas que a su juicio deben adoptarse en orden a la conservacion de las ruinas o a los trabajos que sean necesarios verificar para su intervencion completa, todo como lo dispone la clausulas 2da". Carlos A

[63] Ibid.

[64] ARC. Tomo XVIII. Cuzco, Mayo 20 de 1909. Num. 14. p.1. Ministerio de Justicia, Instruccion y Culto. Direccion General. Lima, 20 de Marzo de 1909. Señor Prefecto del Departamento del Cuzco. En acuerdo Supremo de la fecha se ha expedido por este despacho la siguiente Resolucion"siendo conveniente que Supremo Gobierno conozca de la manera mas fidedigna posible todo lo relativo al descubrimiento de la ciudad incaica de Choqquequirau, recientemente realizado en el Departamento del Cuzco, tanto para dictar las medidas de conservación indispensables cuanto para adoptar las que sean necesarias en resguardo de los intereses del Estado;se resuelve. 1. Comisionar al Director del Museo de Historia Nacional, Dr. Max Uhle y al Dr. Julio Cetello".

[65] Ibid.

Romero, one of the members of the Historical Institute, published the research results on the Ruins of Choquequirao on May 4, 1909.[66]

Hiram Bingham's letter, addressed from Yale University on February 28, 1911 to President Felipe Pardo, points out that on his plan of archaeological explorations, he had already commented with President A.B. Leguía, so he had requested archaeological exploration in the valleys of Apurímac and Urubamba for "Merecer la aprobacion de su Gobierno" and requests for the usual facilities granted to scientific expeditions. In response to this letter, President A. B. Leguía, considering that, in keeping with national interests, he amended the Supreme Decree of April 27, 1893 on permission for the extraction or study of Peruvian antiquities. Thus, Decree No. 1 was amended regarding article 6.11, as follows:

> Todos los objetos que se encuentren, pertenecen al Estado, quien puede conceder los duplicados a los que solicitan la licencia, siempre que se trate de corporaciones científicas de carácter oficial. De los objetos únicos, los solicitantes solo pueden tomar fotografías. El Modelado se permite únicamente en los casos en que no haya peligro de que se malogre los objetos de los que quiera tomarse copia.[67]

In the second article, it was provided that for license concessions for excavations and studies, an interventioner, representing the government, would be appointed to monitor the work. In the third part of the article, it was authorized for the objects to be sent by the prefects of the departments to the National History Museum of this capital. Finally, it refers that as long as Congress issues the Antiquities Conservation Act, its export is absolutely prohibited, whatever its class and condition.[68]

Hiram Bingham's letter dated February 12, 1912, addressed to the President of the Republic Augusto B. Leguía, explaining his way of working, argues that it will be similar to those developed by explorations in Egypt and Assyria. Regarding the fact that ancient monuments are the State's property, it indicates explicitly:

> El gobierno peruano, con la finalidad de proteger sus monumentos antiguos de la depredación, mayormente de los buscadores de tesoros locales, ha aprobado un ley que decreta que todas las ruinas y ciudades antiguas son propiedad del Gobierno Peruano, y no pueden ser excavadas por personas privadas. También se ha aprobado una ley prohibiendo la exportación del país de las antigüedades peruanas.[69]

Hiram Bingham thus set out to obtain a legal permit of at least fifteen to twenty years, to have the right to freely excavate and explore the remains of the ancient sites. He also raised the possibility of: "la deportación del Peru de cierta cantidad de material encontrado durante el trabajo de excavación".

The Supreme Resolution No. 17850 of October 31, 1912, made some observations on the explorations and excavations carried out to date by Dr. Hiram Bingham,

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[66] El Comercio del Cusco, Tuesday, May 4, 1909. Historical Institute and the Ruins of Choqquequirau by Carlos A Romero.

[67] Decreto Supremo, publicado en "El Peruano", Lima, Sabado 2 de Setiembre de 1911. Año 71, Tomo II, Semestre II, No. 50. En Mariana Mould de Pease, 2003: 141–142.

[68] Ibid.

[69] Hiram Bingham's letter addressed to the President of the Republic A. B. Leguía. Yale University New Haven, February 12th, 1912. In Mariana Mould de Pease, 2003: 141–145.

concluding they had not been strictly subject to what is required in Articles 5th and 6th of the Supreme Decree of April 27, 1893, however, in accordance to Article 1 of the Supreme Decree of August 19, 1911, the Supreme Government granted the duplicate objects extracted from the excavations to the official scientific corporations. Although it is true that Article 4 prohibited to take objects of archaeological value out of the country, however, the Peruvian Government was induced to agree, as an exception and for only once, to the petitioners' request in order to carry out scientific studies, called to be of positive utility for the history of Peru.

So the Peruvian Government determined by Supreme Resolution of January 27, 1916:

> Autorizar al Dr. Hiram Bingham, para que en representación de la Universidad de Yale y de la Sociedad Geográfica Nacional de los Estados Unidos de Norte América, continúe practicando las exploraciones y excavaciones que tiene iniciadas en terrenos sin dueño o fiscales del Departamento del Cusco, siempre que como consecuencia de ellas no sufran, se destruyan o mutilen, en lo más mínimo, los monumentos o construcciones de la época incaica o colonial que en dichos terrenos se encuentran y con arreglo de las condiciones siguientes:
>
> 1. Este permiso caducara el 1 de diciembre próximo y después de esta fecha queda prohibida toda exploración o excavación, debiendo vigilar las autoridades el cumplimiento de esta disposición.
>
> 2. Las exploraciones y excavaciones se verifican bajo la inspección del Comisionado del Supremo Gobierno Dr. Dn José Gabriel Cosio, quien formara en presencia del prefecto del Cusco y del Geólogo de la Comisión Científica exploradora, un inventario detallado de todos los objetos que para tal fin serán llevados a la ciudad del Cusco. Dicho inventario se remitirá a la Dirección General de Instrucción Pública.
>
> 3. Todos los objetos que los concesionarios extraigan en virtud de esta autorización o hayan extraído antes de esta fecha, puedan remitirse por la Aduana de Mollendo después de inventariados, conforme a lo dispuesto en el artículo anterior y solo con destino a la Universidad y Sociedad Geográfica referidas por los inventariados, también por el subprefecto administrador de la aduana de este puerto y el geólogo de la Comisión Científica exploradora quien cuidara de abrir los bultos y acondicionar dichos objetos.
>
> 4. El Gobierno del Perú se reserva el derecho de exigir de la Universidad de Yale y de la Sociedad Geográfica Nacional de los Estados Unidos de Norte América la devolución de los objetos únicos y de los duplicados que se extraigan y hayan extraído a lo que se refiere el Art 1 del Supremo Decreto del 19 de agosto de 1911, ya citado, así como copia de todos los estudios o informes relativos a las exploraciones que se hayan practicado en el territorio nacional para declararlo oficiales si lo proveerá así oportuno previo dictamen del Instituto Histórico del Perú.
>
> 5. Todos los gastos que originan las exploraciones y publicaciones correrán por cuenta de los concesionarios sin responsabilidad alguna para el gobierno así como para los funcionarios que de él dependen, los gastos del comisionado especial del gobierno serán de cuenta de este.

At the request made by Mr. Ellwood C. Erdis, sub Director of the North American Scientific Expedition, chaired by Dr. Hiram Bingham, the Supreme Government of Peru, through the Supreme Resolution also conceded the authorization to export:

> 74 cajones que contienen objetos arqueológicos extraídos del Departamento del Cuzco en los años 1914 y 1915, quedando obligados la Universidad de Yale y la Nacional Geographie

> Society a devolver en el plazo de diez y ocho meses contados desde la fecha, los objetos cuya exportación se permite debiendo remitirse también al Ministerio de Instrucción los estudios que respecto a ello se hubieren practicado así como las fotografías que con motivo de dichos estudios se tomaren.

On June 13, 1915, the Chairman of the Scientific Commission of Yale University, Mr. Hiram Bingham, sent a letter to the President of the Historical Institute of Cuzco Luis E. Valcárcel and to his committee composed of Mr. Vega Enríquez, Mr. Gibaja, and Mr. Saldivar (who were involved in the excavation that were being developed by Hiram Bingham in Patallacta, for this reason they were in Ollantaytambo) indicating that the scientific commission:

> Ha recibido todas las facilidades y recomendaciones del Supremo Gobierno para hacer todos los estudios que están comprendidos en su programa. Entre ellos, los de la arqueología se ocupan en explorar las ciudades antiguas que están situadas al interior del departamento del Cusco.

15.5 Conclusions

1. According to the ethnohistoric references and documents of the sixteenth to nineteenth centuries, the llaqta or Inca city of Machu Picchu was an administrative, political, religious, astronomical, and head center of Vilcabamba. The space of the Machu Picchu llaqta was a strategic site that allowed to integrate and articulate, through an entire road system called Qhapaqñan, the Amazon space—Antisuyu with the mountain range—Chinchaysuyu. The surroundings of the llaqta, consisted of lands of the Sun (Intihuatana), lands of the mortal remains of the Incas (lands of the dead), lands of the Inca, these later marked as “lands of Inka Yupanqui”. This was a strategic management made by the descendants of Inka Yupanqui, to avoid the Spanish authorities from granting them through the Crown’s will to the Spanish. The inhabitants of the village of Huaynapicchо or Machu Picchu, had control of the ecological or altitude floors, that is, they had access to different products, all this is confirmed by the taxation system of the Piccho encomienda and by the land tenure of the seventeenth century. The territorial area of the Historic Sanctuary and National Archaeological Park of Machu Picchu consisted of: coca lands, agricultural land: chili, peanuts (inchis), cassava, sweet potato, together with the fruit trees: lucma, pacay, chirimoya, guayaba (sawintu), and avocado, followed by the cornlands (Quentimarka and Pitupuquio), lands of tubers (potatoes, ocas, maswa, and lizas) and the lands of the “ganado del Inca” (Pampaqawana, Matara, where you can see camelid pens).) In the colonial time, the production of chili, cassava, and sweet potato lasted, alternating with the exploitation of cedar wood and Castilla fruit trees (oranges, lemons, citrons, etc.) were introduced.
2. In 1572, by disposal of Viceroy don Francisco de Toledo, the city of San Francisco de Vitoria de Vilcabamba was created. The viceroy condemned 52 native families of Cuzco to move to the Vilcabamba area and work as

> forced laborers in a Spanish settlement construction. In 1588 the 52 transferred native people were visited and received land between two major mountains Choquetacarpo and Salqantay, with their respective ravines that converge in the Vilcanota River and these spaces were called "yuncas and chaupiyuncas" producers of maize, coca, chili, peanuts, cassava, sweet potato, and native fruit trees (avocado, guayaba, chirimoya, pacay, lucma), and from Castilla (oranges, apple trees, peaches, etc.). The possession of these lands was confirmed and periodically protected in the visits and compositions of lands promoted by the Royal Crown of Spain. Thus, in 1662, don Diego Sanabria Catcorrayo, representing the native of the community of Vilcabamba, requests protection and possession of the lands of Uticmayu, Pitupuquio, Cedrobamba, Rucmabamba, Yntiguatanapampa, Uaynapiccho (Huaynapicchu). These lands were measured and the demarcation "inicia en rio Uticmayo, hoy llamado Ahobamba, que nace del nevado Salcantay", this river runs along up to the encounter with the Vilcanota River. The possession and demarcation of this space, although with some attempts of appropriation on the part of the Betlemitas of the Convent of Almudena in Cuzco, dona Manuela and Dominga Almirón, owners of the lands on the left and right bank of the floor of the Vilcanota river valley, those transferred from Cuzco managed to constitute a community that effectively defended their lands until 1849, which indicates that the mechanisms and internal organization of the community worked efficiently.

Don Juan Uscamayta Valentín and his wife doña Francisca Collo indicate they have inherited from don Juan Uscamayta's father, as demonstrated in the "documentos primordiales antiguos", which he keeps since his "great-great-grandparents". These lands, according to Juan Uscamayta and his wife since they are in a state of decrepitude and not being able to manage these lands, they leave them in "donation and transfer session" in favor of Mariano Santos. After signing this document they left and moved to the village of Limatambo, Anta province. According to the Recopilacion de las Leyes Indias, concerning the distribution of the natives' lands, these could not be sold nor given in a donation session to Spaniards or others,[70] since they belonged to the Indian community, and were lands passed from parents to children, from generation to generation and in the absence of them, the lands returned to their community or ayllu.[71] After 1849, the grabbing of indigenous lands took place, taking advantage of the division of Maras district, which provides

> Articulo unico, dividase el Segundo distrito de la provincial de Urubamba en dos, quedando la comprension de Maras hasta la quebrada de Pichingoto como Segundo distrito, y Ollantaytambo como tercer distrito bajo sus limites conocidos desde la dicha quebrada de Pichingoto

[70] "que a los indios se les dexen tierras… se reserven en primer lugar y por ningún caso no se les puedan bender, ni enajenar…" (Recopilación de las Leyes de Indias, Ley 18, Tit. 12, Lib. IV, dada el 16 de Marzo de 1642).

[71] In the books of distribution of native lands, it was indicated that "Hará que se ponga y asiente en un libro que ade estar en la casa de la comunidad donde este con distinción y claridad lo que a cada un yndio le queda señalado y se lo dará entender para que le sirva de título y como se les provee que no ande poder vender ni enagenar agora ni en ningún tiempo en manera alguna las dichas tierras".

> y el estrecho de Patashuaylla hasta los confines de las haciendas Huadquiña y Huiro que pertenecen a la provincia de La Convencion.[72]

From the creation of the Ollantaytambo district, its boundaries reach the limits of the Huadquiña hacienda, which at that time already reached the Ahobamba River. This law was used by don Ramón Nadal's descendants to extend their limits of the Sillque hacienda. Therefore, the document of division and extrajudicial partition of 1896, determined the borders of the Sillque Estate or hacienda, to the North the Vilcanota River, to the South Pachar, the road to Limatambo, the Sondor and Mollepata estate and to the west, Huadquiña. This means that the Sillque hacienda extended its borders to the limits with the Huadquiña hacienda, which must have been up to the Ahobamba River. This fact confirms that, in 1907, don Eduardo Nadal owned the fraction called Intihuatana, a part of the Sillque estate, for having acquired it from his brother Alejandro Nadal. The borders, on the west side reached the Ahobamba River. From then on the systematic change of the names of the borders of the lands such as Lucrepata into Wiñaywayna, Yuncapatamallauqasa into Phuyupatamarka, Incarmana into Sayaqmarka, erased the original place names. In this perspective, the question is important: Why was it important for the Nadal and Vizcarra Abril families to change the names of the places?

3. The Peruvian State, through the Coca Alcabala, established in the Santa Ana Valley and Paucartambo, promoted the construction of new roads in order to facilitate the communication system between the city of Cuzco and its valleys. The ancestral road which joined Cuzco and the Santa Valley via Ollantaytambo, the Malaga Abra and Amaybamba, was a difficult route so they decided to open the road from Piri-Ollantaytambo following the Vilcanota river basin on the right bank, passing through Choquelluska, Qoriwayrachina, Torontoy, Media Naranja (Putucusi), Mandor, Collpani, Challway and thus reach Santa Ana-Quillabamba. This project came true in 1869 by hiring the German civil engineer Herman Gohring, who between 1871 and 1873, managed to build the new road. In the execution of this work, the archaeological monument of Choqelluska was affected. For opening a new road for the transit of horses and mules, the pre-hispanic trace of all the archaeological monuments that were on the way, such as Choqelluska, the crag of Qoriwayrachina, Torontoy, Llamacancha, Pukisqasa

[72] ARC. Libro. 104. Registro Oficial del Departamento del Cuzco. 1875. Tomo. XXVI. Cuzco enero 1875. Num. 2. p. 1. Manuel Pardo ha dado la Ley siguiente el Congreso de la Republica. Que el segundo distrito de la provincia de Urubamba tiene una grande extensión territorial y una población considerable. Dado en la Sala del Congreso en Lima a 27 de octubre de 1874. In 1921 "Delimitación defectuosa Urubamba y Convención" is published, it is indicated there "Por la margen izquierda del Vilcanota, Urubamba tiene jurisdicción hasta el riachuelo de Aobamba, distante once leguas de Ollantaytambo distrito al que pertenece el fundo Cutija, mediante el riachuelo nombrado y la hacienda Huadquiña, que pertenece a la Convención, tan solo legua o legua y media…" (El Comercio del Cusco, jueves 7 de agosto de 1921). In 1924, the demarcation of La Convencion province is fixed "regresando a Sallcantay para definir el lindero del Este bajamos el riachuelo Aobamba hasta el Vilcanota". In other words, the Aobamba River is the limit between La Convención and Urubamba (El Comercio del Cusco, sábado 6 de setiembre de 1924. Redemarcación territorial i Vialidad de La Convención).

were affected, as well as the opening of a road in the living rock of Media Naranja did. The construction of this road was evaluated by a commission chaired by José Teodosio Rozas and Tomas Polo, who gave the approval of the functionality of the built road. In fact, the opening of this road energized the search for the treasures of the Inca. The description of the road highlights in a special way the hill of Huaynapicchu, so it must have been visited not only by Herman Gohring but by the workers.

Also, in the 70s of the nineteenth century, don Bautista Constantitni, member of the Forga House and the Company of Arequipa, commissioned the German civil engineer Augusto Rodolfo Berns, to develop explorations in the Vilcanota basin in the search for timber trees, husk, and rubber. Thus Berns for 1872 was already in the city of Cuzco and on October 4, 1872 he entered into a contract with don Santiago Angulo before the judge of Urubamba for eight years. Don Angulo was the owner of the lands on the right bank called Cercado de San Antonio and Torontoy. In the contract, the second one promised to cut the wood on his land or estate and sell it exclusively to Berns. Augusto Rodolfo Berns, after seeing the number of timber trees, intends to institute a Wood Industrial Company, for which he gets the money and acquires from the USA, a sawmill machine and places it in what is now Aguas Calientes or village of Machu Picchu. The business of wood seems to give him good dividends, so on September 11, 1873, he decides to found a "Society" whose name is "Alisedo, Berns, Balaguer y Campero", the entity was constituted by don Augusto Rudolfo Berns, single, from Germany; don José Balaguer, single, from Spain; don José Alisedo, married, from the republic of Argentina and don Juan Manuel Campero, single, from Cuzco, they signed for a period of time of 6 years. In this perspective, it is important to indicate that don Santiago Angulo also owned the lands of the left bank, whose borders reached the outskirts of Machupiccho, Huaynapiccho, so, he had full knowledge of the llaqta or Inca city of Machu Picchu. In the same way we can mention don Juan Manuel Campero, who inherited part of the lands of the right bank from don Marcos de la Camara. Therefore, we must assume that Augusto Rodolfo Berns did have full knowledge of the "ruins of Machu Picchu". Based on all this experience of Inca time sites, in 1887 he decided to formulate the "Proyecto Compañía Huaca del Inca" and managed to obtain permission from the Peruvian government through the Supreme Decree of June 16, 1887 "excavaciones en huacas incasicas y en construcciones gentilicas", located in the provinces of La Convencion and Urubamba of the department of Cuzco. The question is important: Where did the necessary capital for the companies of both German engineers come from? In both cases, does it seem the capital was from the Peruvian State and the profits were for foreign enterprises?

4. The Coca Alcabala of La Convencion province was periodically in charge of the maintenance and conservation of the "camino nuevo", the traffic on this route intensified, but during the rainy season it became impassable. So, on August 12, 1892 the auction file for the construction and placement of the iron bridges in San Miguel, Pavayoc, and Chahiuillay was certified. On the other hand, it is important to indicate, the transit of this new route intensified

the search for the treasures of the Incas and the presence of mainly foreign travelers in the jurisdiction of the Province of La Convencion of the department of Cuzco. Consequently, the extraction and purchase and sale of movable heritage were done indiscriminately, so private collectors of antiques emerged such as María Ana Centeno, José Miguel Medina, José Lucas Caparó Muñiz, Mariano Macedo, Vidal Olivera, Abel Montes, and others. The Peruvian State immediately assumed its responsibility to stop the unrestricted commercialization of antiquities and promote the conservation of antiquities, it issued the Supreme Decree of April 27, 1893, declaring "Monumentos Nacionales a todas las antiguas construcciones anteriores a la conquista", which are within the national territory and whose conservation and surveillance are of public interest, it prohibited its destruction and mutilation. The license for exploration and excavation in pre-hispanic properties was to be requested to the "Junta Conservadora de las Antiguedades Nacionales" and in the departments before the branch boards. The "Junta Conservadora" consisted of the Minister of Public Instruction, who chaired it, the Prefect of the department, the Director of the Museum or the National Library and the Director of Public Instruction. In the departments, everything was prepared to establish "branch boards" which were composed of the Prefect, the Prosecutor, and the Departmental Treasurer. The license request was to indicate the site, type of work, the goal, and the duration of time. Thus, the greed of companies organized by foreign and national entrepreneurs led to the creation of laws and institutions in order to defend the national heritage. Hiram Bingham, in a letter of February 28, 1911, asked the Peruvian State to give him the usual facilities which are conceded to the scientific expeditions, in order to develop the archeological exploration in the valleys of Apurimac and Urubamba. In response to this request, President A. B. Leguía, considered the national interests and so the Supreme Decree of 1893, was amended by Decree No.1, in article 6.11, which grants duplicates to those who requested a license, as long as they are scientific corporations of official character. Thus, the law was required.

During the years from the assassination of Tupa Amaru Inqa in 1572 to the eleven year period of President A. B. Leguía, and regarding the lands of the Historical Shrine and National Archaeological Park of Machu Picchu, every juncture provoked new conflicts and new economic opportunities among ranchers, Vilcabamba native people, ecclesiastical institutions, road-building companies, logging companies, looters, and looter companies, until finally causing intervention of the Peruvian State in defense of the national heritage.

References

Flores Ochoa J (2011) El "Descubrimiento" de Machupicchu: Tradición Oral y Etnohistoria. En "El ANTONIANO": Revista Científico Cultural 21(117). UNSAAC

Julien C (2000) Inca Estates and the Encomienda: Hernando Pizarro's Holdings in Cusco. Andean Past 6. 2000–2001: 229–275

Maurtua V (1906) Juicio de Límites entre Perú y Bolivia: Vilcabamba. Tomo VII, Barcelona

Mould De Pease M (2003) Machupicchu y el Código de Ética de la Sociedad de la Arqueología Americana, Concytec- PUCP 2003

Murúa M. de [1611–1616] (1962–1964) Historia General del Perú, origen y descendencia de los Incas. Introducción y notas de Manuel Ballesteros Galbrois. Colección Joyas Bibliográficas. Bibliotheca Americana Vetus 2(1–2). Madrid, Spain

Rozas JT (1867/2000) Perspectivas y Observaciones de los Valles de Santa Ana. Cusco Edición Manuel Jesús Aparicio Vega. Biblioteca I.A. Arte

Chapter 16
Proof of Concept: Chemical Studies of the Biodeterioration of Ancient Structures in Machu Picchu

Ewa Bulska and Julio Torres Eleguera

Abstract Machu Picchu National Archaelogical park is located on an environment which promotes the growth of organisms on the surfaces of rock's structures, being the reason for intensive biodeterioration due to being a natural reservoir of nutrients that can be used by microorganisms. In this work, we proposed the analytical approach enabling to identify the types of biodeteriogens and elemental composition. In order to achieve the goal, fit-for-purpose analytical scenario was proposed to collect complementary information. The microscopy and molecular methods (DNA barcoding) were applied for the morphotypes of lichens identification. The evaluation of elemental composition was performed with the use of X-ray fluorescence (XRF) as well as Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Keywords Lichen · Elemental analysis · Morphological analysis · Machu Picchu · Conservation

16.1 Introduction

The growth of lithobiontic communities on the cultural heritage stones relays on the interaction of the organism with the surrounding environment and the feature of the stone substrate. Local factors as chemical composition and morphology of stone surface, as well as environmental conditions, e.g. presence of air pollutants, light intensity, and temperature among others affect the suitability of given surface to be colonized. Organisms as lichens are biodeteriogens able to grow on several types of surfaces, and depending on the species the results on the impact of deterioration will show different proportions between the biogeophysical and biochemical damage process (Tonon et al. 2019).

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A lichen may be described as an association between a fungus, and one or more photosynthetic partners, generally green algae or cyanobacteria. The lichens occupy rocks as their substrates, the effects generally shown morphologically and compositionally, including modification of surface features, fragmentation of grains, separation of layers, depletion of structural cations, dissolution of ultrafine crystals, and precipitation of amorphous gels on mineral surfaces. Due to the alteration of rock-forming minerals, the parent rocks correspondingly suffer surface stain, disintegration, exfoliation, and breakdown, at various degrees (Chen et al. 2000).

Nowadays, molecular genetics, chemotaxonomy, and traditional morphological methods are equally important for the investigation of lichen species that is because there is a high complexity during lichen taxonomy (Konoreva et al. 2019). For to enrich the identification is also important to know how the lichens interact and affect their surroundings, this can be achieved by elemental analysis as X-ray fluorescence (XRF) or inductive coupled plasma–mass spectrometry (ICP-MS) techniques. XRF allows recording compositional data in a completely non-invasive and non-destructive way from the object under examination (Legrand et al. 2019). XRF has been used during studies of biodeteriogens present in biofilms growing in constructions causing esthetical and physical–geochemical problems (Gallego Cartagena et al. 2020). ICP-MS is widely used in the investigation of elemental content in lichens, mosses, and vascular plants in particular to establish baseline concentrations and identify anomalies of several elements including rare earth elements (Chiarenzelli et al. 2001).

Cusco is a highly explored region in Peru, in this region can be found several types of ecosystems which are ideal for the growth of several species of lichens. The archeological site of Machu Picchu has a cloud forest ecosystem the weather is humid and subtropical. In the area were found 67 species of macro-lichens, several families like *Hygrophoraceae*, *Parmeliaceae*, or *Physciaceae* were identified (Núñez-Zapata et al. 2015).

Due to the relevant historical heritage that represents Machu Picchu is important to find and identify what and how biodeteriogens, like lichens, affect and damage the structures in the archeological site, the understanding of those processes can lead to propose conservation methods which allow the proper removal, cleaning, and prevention of re-growing from such organisms.

16.2 Experimental

16.2.1 Samples

Samples were divided into three groups, the first group as controls samples were rocks with visible colonization of lichen and other microorganisms, with a high level of damage which can be observed as several thin layers of rock between layers of microorganism, the samples were taken from Agricultural sector (Fig. 16.1a). A

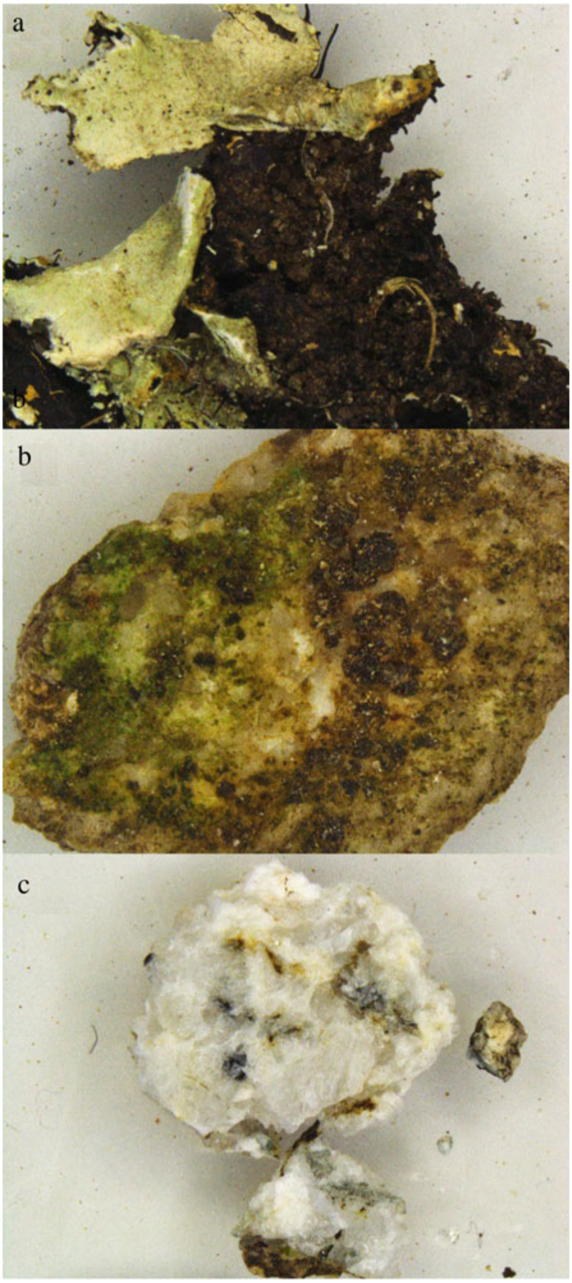

Fig. 16.1 Rock fragments with (**a**) high impact of lichen colonization, (**b**) low impact of colonization, and (**c**) after cleaning treatment with aqueous extract from *Heliocarpus americanus*

second set of samples were samples of rock fragments with visible colonization on the surface because of crustose lichens and other bio-organisms, with a low level of damage belonging to Three windows temple (Fig. 16.1b). The last group was rock samples with a low level of colonization because of a cleaning treatment by applying an aqueous extract of bark from *Heliocarpus americanus* tree also from Three windows temple (Fig. 16.1c).

16.2.2 Instrumentation

Microscopic observations of samples undertaken using a stereoscopic microscope (Nikon SZM 18) equipped with lenses enabling up to 13.5 × magnification.

Portable X-ray fluorescence spectrometer (XRF) was used during non-invasive qualitative analysis. Tracer III-SD spectrometer (Bruker) equipped with an Rh X-ray tube and a single drift detector (SDD) was used with a vacuum system (NASA, Bruker) coupled to the spectrometer. The vacuum system was applied to increase the sensitivity of measurements for lighter elements such as Mg, Al, and Si. Each XRF spectrum was acquired from the area of *ca.* 0.5 cm^2 and spectrometer operating parameters are Lamp voltage 40 kV, Current 23 μA, and the fluorescence spectra were always collected during the constant time of 30 s, with the use of the vacuum set-up.

For elemental analysis, approximately 100 mg of sample was digested using concentrated nitric acid, silicate rocks were decomposed using microwave-assisted digestion (Milestone UltraWAVE, Sorisole (BG), Italy). Next, the samples were diluted with deionized water and filtered through a 0.45-μm syringe filter directly before ICP-MS analysis. A model NexION 300D quadrupole ICP mass spectrometer was used (Perkin Elmer Sciex, Canada). It was equipped with glass Meinhard nebulizer and a cyclonic glass spray chamber. It was operated in a standard mode, using RF power 1200 W and signal acquisition by peak hopping with a dwell time of 50 ms, 5 sweeps, and 7 replicates. The following isotopes were monitored: ^{27}Al, ^{51}V, ^{52}Cr, ^{55}Mn, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{69}Ga, ^{75}As, ^{82}Se, ^{85}Rb, ^{88}Sr, ^{95}Mo, ^{111}Cd, ^{208}Pb, and ^{115}In as internal standard. The performance of the spectrometer was verified right before measurements accordingly to the manufacturer guidelines.

16.3 Results and Discussion

16.3.1 Lichen Identification

Lichens were identified both using morphological analysis (microscopy methods) and analysis based on the evaluation of phenetic features, such as, e.g., morphology of thallus, presence and type of vegetative diasporas, size and shape of spores or type of sacks, as well as using molecular methods on DNA barcoding using the ITS region. In DNA barcoding, the user compares an unknown sequence against a sequence database, such as International Sequence Database (in our case GenBank at the National Center for Biotechnology Information, GenBank, NCBI) and identifies species based on sequence similarity. After the extraction of total genomic deoxyribonucleic acid (DNA) was performed the amplification of some sections of DNA (Primers) by polymerase chain reaction protocols (PCR). The sequences edited, assemble, and establish the proper alignments were summated to sequence database (Hartvig et al. 2015). In the obtained material we identified four morphotypes of lichens, two mosses, and two biofilms with uncertain, fungal, or algal origin. Molecular identification was performed for all four morphotypes of lichens and for biofilms on samples belonging to Three windows temple; biofilms were identified as *Anarctomyces psychrotrophicus*, and lichen are presented in Fig. 16.2. Mosses were not identified. The methods used for identification on this project as the use of DNA metabarcoding for assessing lichen biodiversity complements morphology-based research, making it an efficient, objective, and reliable approach for characterizing lichen-forming fungal diversity (Wright et al. 2019).

Many lichens species produce characteristic secondary metabolites, which can perform various functions; however, in many cases, their role seems still insufficiently understood. In addition to the great importance of these metabolites for lichen themselves, they are also used in the taxonomy of this group of organisms, especially crustaceous species often forming only sterile stages, and therefore poor in morphological and anatomical features. In such cases, lichen substances often play a decisive role in identifying research material. Parrot et al. (2015), indicate that metabolic profiles represent specific chemical species and by comparing them between different lichen species and can be found compounds as organic acids and phenolic compounds among others. Cala et al. (2019), using HPLC-MS/MS for identifying lichens show promising results in finding specific features for each one of the three species of lichen used in their research by considering the distribution of 13 markers after applying chemometric data analysis.

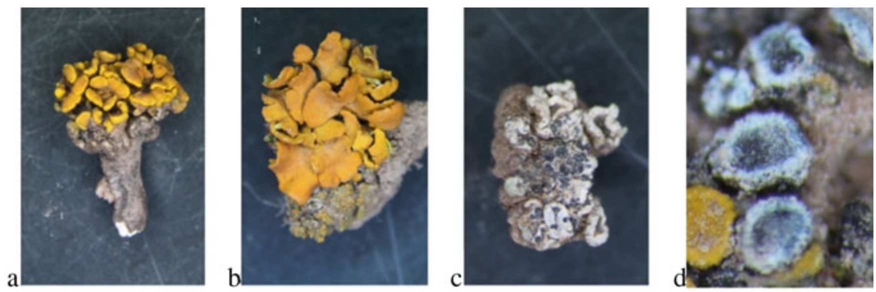

Fig. 16.2 Microscope pictures of micro-samples taken from Three windows temple identified by morphology and DNA barcoding as lichens (**a**) *Placomaronea sp.*, (**b**) *Xanthomendoza mendozae*, (**c**) *Diplotomma sp.*, and (**d**) *Lecanora sp.*

16.3.2 Elemental Content

XRF is a device which is capable to displace electrons from their atomic orbital by the emission x-rays on the sample; this process has a second stage where an outer shell electron will take the empty space to regain the stability of the atom, and during this process, there is a release of energy in the form of fluorescence that is characteristic of a specific element. This technique is non-destructive and is useful to determine the composition of the sample. The obtained spectra were collected to evaluate the elemental composition of the samples taking mainly alfa lines (Kα). On the spectra, elements like nickel, rhodium, palladium, and ruthenium cannot be taken into count because the signals belong to the materials from the machine. In Fig. 16.3 are showed all the results obtained from the analysis of high impact of damage (control samples) on where can be noticed an intense signal for iron compared to low colonization impact (Fig. 16.4) and low level of colonization after cleaning treated samples (Fig. 16.5), comparing the low level of colonization with and with treatment iron also appears to be an element correlated to the presence of lichen, because the complexity of the obtained data proposed the use of statistical tools like Principal component analysis (PCA).

The results obtained using principal component analysis (Fig. 16.6) indicate that profiling of mineral elements in rock samples from three types of colonization impact is a viable tool for their discrimination. The cleaning treatment can be observed as a lower intensity on the elements usually related to bio-organisms (e.g. Sulfur, Phosphorus). Hauck et al., indicate that for some types of lichen it is possible to correlate the iron content with sulfur content to mainly bond as sulfide but it is also suggested that secondary metabolites as anthraquinone parietin may form a complex

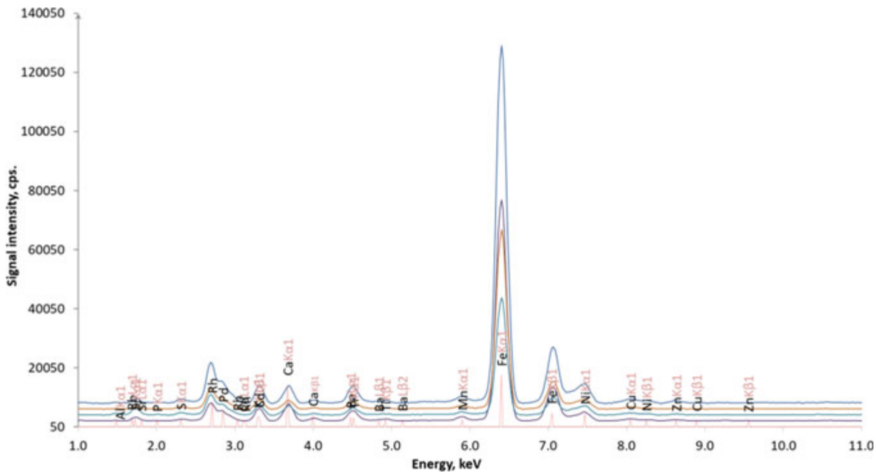

Fig. 16.3 Spectra of all XRF measurements collected from high-impact colonization of lichen in samples

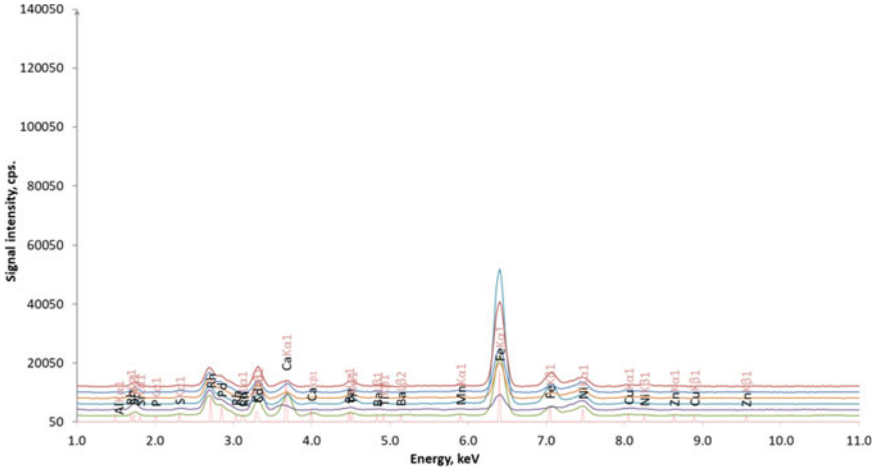

Fig. 16.4 Spectra of all XRF measurements collected from low-impact colonization of lichen in samples

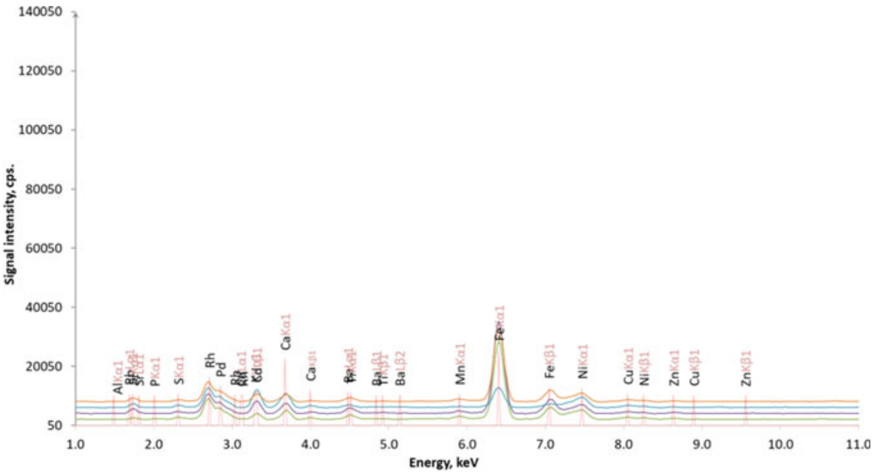

Fig. 16.5 Spectra of all XRF measurements collected from low-impact colonization of lichen in samples after cleaning treatment

with iron ion; this can explain the behavior of those elements on the PCA, all of them are on the right side of the X-loading plot (Fig. 16.6b) by comparing with Scores plot (Fig. 16.6a) on that side is taken by the low and high colonization impact of lichen; the principal component 2 on the X-loading plot separate sulfur and iron which be explained by the effect of another substance acting as a complex for this element (Hauck et al. 2007). Samples 3, 5, and 7 show similarities to non-treated samples indicating low effectiveness from cleaning procedure. Lichens have the capability

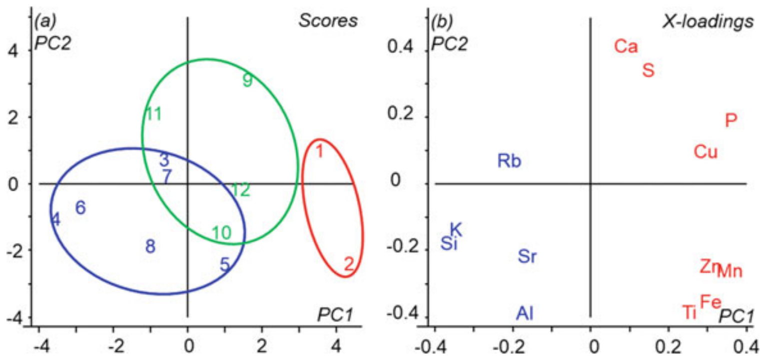

Fig. 16.6 Principal component analysis obtained for elemental intensities from XRF from three sample groups: (**a**) score plot showing the distribution of samples in accordance with the level of colonization and (**b**) X-loading plot showing distribution of elements, both in bidimensional space of the first two principal components that describe 30% and 30%, respectively

to work as biomonitors for assessing atmospheric pollution (Marié et al. 2018), this can explain the presence of titanium and zinc which are components of sunscreens (Barbosa et al. 2018), used by the people visiting the archeological site. Elements like Calcium, Manganese, and Copper can be found as oxalate crystals at the rock-lichen interface, indicating a biodeterioration of stoneworks (Adamo and Violante 2000). Elements aluminum and silicon can be found as the main components of rocks being correlated with the left side on both plots and can be used as parameters for the evaluation during the removal of lichens on the ancient buildings. The results obtained on this project have good accordance with the obtained by Morillas et al. (2019); they analyzed the Sacred Rock in Machu Picchu indicating that calcium usually is one of the elements used by bio-colonizers as a nutrient for their growth.

Inductively coupled plasma mass spectrometry (ICP-MS) is an elemental analytical technique capable of detecting most of the periodic table of elements at milligram to nanogram levels per liter. The Inductively Coupled Plasma (ICP) is an energy source that decomposes chemical molecules into its constituent elements induced the excitation of those elements, followed under special conditions by their transformation into ions. It is typically composed of argon gas, and energy is “coupled” to it using an induction coil to form the plasma (Bulska and Ruszczyńska 2017). The preliminary information provided by XRF was important to select elements that can provide better information on trace levels. After nitric digestion, an appropriated dilution samples of treated sample and high-impact colonization were introduced to the ICP-MS. The results are shown in Table 16.1; elements such as aluminum, manganesium, copper, zinc, rubidium, and strontium have the same tendency as observed in XRF analysis, and the main advantage is the capability to measure trace elements and the ones that are standard interferences in XRF as nickel. It is strongly suggested to perform chromatographic analysis hyphenated to ICP-MS to identify the presence of sulfide complex and organic complex from secondary metabolites.

Table 16.1 Elemental concentration (μg g^{-1}) in two types of samples collected in Machu Picchu, Peru

Element	After treatment	High colonization
Al	8735.62	7670.45
V	13.82	1.46
Mn	543.81	41.03
Co	2.74	0.86
Ni	1.55	N.D
Cu	6.39	10.18
Zn	120.19	245.09
Ga	14.04	8.54
As	1.33	1.44
Rb	435.34	144.10
Sr	33.69	6.90
Mo	0.15	0.05
Cd	0.21	0.47
Pb	17.58	15.93

16.4 Conclusions

In the obtained material were identified four morphotypes of lichens from Three windows temple using microscopic visualization and molecular biology techniques. Molecular mass spectrometry techniques will allow to identify metabolites involve during the alteration of rock caused by the actions of lichens which will support their identification. With respect to XRF elemental analysis, its combination with statistical data analysis were important tools to evaluate the effect of cleaning treatment for the removal of lichens. The total elemental content provided by ICP-MS analysis provides more accurate results compared to the ones provided by XRF, especially for trace elements. For a better understanding, the use of ICP-MS hyphenated to Laser Ablation and Liquid Chromatography will provide information concerning to distribution and speciation of key elements, respectively.

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References

Adamo P, Violante P (2000) Weathering of rock and neogenesis of minerals associated with lichen activity. Appl Clay Sci 16:229–256

Barbosa J, Neto DM, Freire RM, Rocha JS, Fechine LM, Denardin J, Valentini A, Araujo TG, Mazzetto S, Fechine P (2018) Ultrafast sonochemistry-based approach to coat TiO_2 commercial particles for sunscreen formulation. Ultrason Sonochem 48:340–348

Bulska E, Ruszczyńska A (2017) Analytical techniques for trace element determination. Phys Sci Rev 2(5). https://doi.org/10.1515/psr-2017-8002

Calà E, Benzi M, Gosetti F, Zanin A, Gulmini M, Idone A, Serafini I, Ciccola A, Curini R, Whitworth I, Aceto M (2019) Towards the identification of the lichen species in historical orchil dyes by HPLC-MS/MS. Microchem J 150: 104140

Chen J, Blume H-P, Beyer L (2000) Weathering of rocks induced by lichen colonization—a review. CATENA 39:121–146

Chiarenzelli J, Aspler L, Dunn C, Cousens B, Ozarko D, Powis K (2001) Multi-element and rare earth element composition of lichens, mosses, and vascular plants from the Central Barrenlands, Nunavut, Canada. Appl Geochem 16:245–270

Gallego Cartagena E, Morillas H, Maguregui M, Patiño K, Marcaida I, Morgado Gamero W, Silva L, Madariaga J (2020) A comprehensive study of biofilms growing on the built heritage of a Caribbean industrial city in correlation with construction materials. Int Biodeterior Biodegr 147: 104874

Hartvig I, Czako M, Kjær ED, Nielsen LR, Theilade I (2015) The use of DNA barcoding in identification and conservation of rosewood (Dalbergia spp.). PloS One 10(9)

Hauck M, Huneck S, Elix J, Paul A (2007) Does secondary chemistry enable lichens to grow on iron-rich substrates? Flora Morphol Distrib Funct Ecol 202:471–478. https://doi.org/10.1016/j.flora.2006.08.007

Konoreva L, Prokopiev I, Frolov I, Chesnokov S, Rozhina S, Poryadina L, Shavarda A (2019) Metabolite profiling of the Cladonia lichens using gas chromatography-mass spectrometry. Biochem Syst Ecol 85:3–12

Legrand S, Van Der Snickt G, Cagno S, Caen J, Janssens K (2019) MA-XRF imaging as a tool to characterize the 16th century heraldic stained- glass panels in Ghent Saint Bavo Cathedral. J Cult Herit 40:163–168

Marié DC, Chaparro MA, Lavornia JM, Sinito AM, Miranda AGC, Gargiulo JD, Böhnel HN (2018) Atmospheric pollution assessed by in situ measurement of magnetic susceptibility on lichens. Ecol Ind 95:831–840

Morillas H, Maguregui M, Gallego Cartagena E, Huallparimachi G, Marcaida I, Salcedo I, Silva L, Astete F (2019) Evaluation of the role of biocolonizations in the conservation state of Machu Picchu (Peru): The Sacred Rock. Sci Total Environ 654:1379–1388

Nuñez-Zapata J, Divakar P, Huallparimachi G, Holgado M, Vela Clavo Z, Pavlich M, Crespo A (2015) Nuevos registros de la liquenobiota del Santuario Histórico de Machu Picchu Perú. Rev Peru Biol 22(3):323–328

Parrot D, Peresse T, Hitti E, Carrie D, Grube M, Tomasi S (2015) Qualitative and spatial metabolite profiling of lichens by a LC-MS approach combined with optimised extraction. Phytochem Anal PCA 26(1):23–33

Tonon C, Favero-Longo S, Matteucci E, Piervittori R, Croveri P, Appolonia L, Meirano V, Serino M, Elia D (2019) Microenvironmental features drive the distribution of lichens in the House of the Ancient Hunt, Pompeii, Italy. Int Biodeterior Biodegr 136:71–81

Wright B, Clair LL, Leavitt SD (2019) Is targeted community DNA metabarcoding suitable for biodiversity inventories of lichen-forming fungi? Ecol Ind 98:812–820

Chapter 17
In a Search for Inca Construction Process Logistics. Case Studies of Four Structures from the Llaqta Machu Picchu

Jacek Kościuk and José M. Bastante

Abstract Against the background of general reflections on the Inca building art research, this chapter discusses four specific examples of constructions in the Machupicchu complex. Separate case studies concern the Intimachay astronomical observatory, the Mirador de Inkaraqay serving the same function, the enclosure wall separating agricultural terraces from the residential area, and the building known as the Sala de los Morteros. Particular emphasis was placed on the analysis of the technique and logistics of the construction process. Based on detailed observations of masonry threads and data from 3D laser scanning, an attempt was made to isolate individual technological construction phases and determine their mutual logistic connections. In the case of Sala de los Morteros, it made it possible to estimate the number of workers directly employed in the construction of this building and the time needed to erect it. The obtained results should be treated as an introduction to further research on the planning and logistics of constructing the Llaqta of Machupicchu as an important, complex and state-run political, administrative and religious centre.

Keywords Machu Picchu · Architecture · Stonemasonry · Construction process

17.1 Introduction

It is paradoxical and surprising that we know much more about ancient Egyptian monuments' construction methods and logistics from more than 4500 years ago than

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about Inca building methods from approximately 600 years ago. In some Egyptian monuments, we not only can estimate the duration of the construction process but even reconstruct the number of workers involved in particular operations (Arnold 2017, p. 394, Tab.1). Except for the Ollantaytambo site (Bengtsson 1998), nothing like that was done until now for other Inca monuments.

The reasons behind this matter are out of the scope of this study, but the main difference between both cultures and their history must be taken into consideration. Unlike the Egyptian, the Inca civilisation did not develop writing in the full sense of the word. Therefore, as Lisbet Bengtsson (1998, p. 11) states:

> Much of the information on the construction of fine masonry in the historical sources is based on oral tradition. In a few cases, data were kept on khipus, the knotted strings used as mnemonic devices. To my knowledge, no information was passed on to the chroniclers or to representatives of the colonial administration by people who had been directly involved in the stonework.

Despite their undeniable value, some of the information offered by post-invasion chronicles should be treated with caution. Critical analysis of sources shows the earlier chronicles, like Betanzos (1987 [1551]) and Cieza de León (1985 [1554], 1986 [1553]), are in many cases more reliable than the later ones (Wedin 1966).

Nevertheless, we can still extract from these sources a certain amount of helpful information related to our main problem from these sources. Betanzos, for example, describing the construction of the Saqsaywaman fortress above Cusco (Betanzos 1987, p. 170 [1551, Ch. 37]) writes that the layout of the fortifications by Inca engineers took two years altogether. This includes cutting rock blocks and their transport from a quarry of Guairanga located 28 km away (probably only the initial part necessary to lead out the foundations) and the excavations for foundations. Also, he mentions that further operations on the construction site involved up to 10,000 men and lasted for six years.

In turn, Cieza de León (1985, p. 147–149 [1554, Ch. 51]) doubles the number of workers. However, he offers more detailed numbers related to workforces involved in specific operations: 4,000 men were working in the quarries, 6,000 workers were engaged with blocks transportation and 10,000 were busy on the construction site. Similar numbers rounded to thousands or tens of thousands of workers, and a corresponding level of details concerning work organisation, are offered by both chroniclers regarding the construction of the Coricancha temple in Cusco and the imperial settlement and residence in Chinchero.

Regardless of the differences in numbers, the chronicles point to the fact that many workers were brought from different parts of the empire to carry out all the tasks related to imperial building activities. We do not know whether these numbers can be taken literally or whether thousands or tens of thousands represent a vast number of workers working in turns on a particular place, difficult to quantify precisely. However, some sources, still from the time of the ongoing conquest, namely documents written by Spanish inspectors transcribed directly from information recorded on the *khipus*, point to a significant proportion of the local population from different parts of Tawantinsuyu delegated to imperial construction works (after Bengtsson 1998, p. 15–16).

Nevertheless, none of the chronicles offers detailed information about building operations' technical details or its logistic. We only know that Inca inspectors supervised the construction process and that with such a large number of workers employed, there must have been some sort of work organisation system involved.

However, does this mean that we will never be able to approach the level of understanding about the Inca building art comparable to our knowledge about ancient Egypt? The answer to this question is neither obvious nor unequivocal. Thanks to previous research, to mention only the research of Gasparini and Margolies (1980), Agurto Calvo (1987), Protzen (1985, 1986), Protzen and Batson (1993), Protzen and Nair (1997, 2013), Bengtsson (1998), Astete Victoria (2008) many aspects related to the Inca construction technology have already been at least partially clarified. Some new research directions have also been outlined (Gavazzi 2020).

The publications mentioned above, as well as many others, which will be quoted below, focus on five general aspects related to the construction process: the choice from where to obtain construction materials, stone extraction and splitting techniques, tools used, different aspects of transportation and, finally, the labour organisation. The last often relied on historical sources (Gasparini and Margolies 1980, p. 306). When it comes to the details of work organisation, for example, where the different stages of the stonework were executed, particular authors differ in their opinions.

Velarde (1946, p. 54) reasonably argues that depending on the character of the masonry thread, regularly shaped blocks were already prepared outside the construction site, while the irregularly shaped stones (for example, for polygonal masonry) were prepared while placing particular blocks on the wall. Direct studies on stone extraction sites show that preparation of blocks might have been already done in the quarries, as in the case of Rumiqolqa. The detailed studies on stone flakes and stone powder from the rock-slides Kachiqhata quarries and from the Ollantaytambo temple show that rough preparation of stone blocks took place at the building material extraction site (Bengtsson 1998, p. 53) and in one case in the storage yard alongside the transportation route to the temple (Protzen 1985, p. 164; 1993, p. 147). The later fine preparation of the blocks has been done at the construction site (Bengtsson 1998, p. 54), but there are also a few examples of fine finished blocks at the stone extraction site (Bengtsson 1998, p. 86–90).

Based on the archaeological evidence, Bengtsson also comes to interesting conclusions regarding work logistics:

> Each phase of the stonework was thus organised separately. With this model, the extraction of material was organised apart from the actual construction. The different phases were not coordinated. … For example, one person … might have been in charge of the work in the quarries, another of the transportation, and a third of the construction. These leaders did not coordinate the efforts made in the different sectors. Instead, each sought to fulfil any

> demands made on them from higher levels in society. … One possible outcome of such a system is, of course, that there will be either a shortage of blocks ready to be transported or a surplus. The same could then easily occur at the construction site: the builders might have to wait around for the material to arrive at the spot or in other instances they might have the problem of having to move over and in between building material that had arrived too early. Such logistic problems would be even more apparent, if the workers did not move between different tasks and different sectors but were rather bound to one single task or were placed to work in one single sector (Bengtsson 1998, p. 128–129).

Further on, she also observed Protzen 1983 been working on different faces of the same stone block as attested by different marks left by different tools. However, our alternative interpretation suggests that these differences may also be caused by a different position of the processed plane (more horizontal or more vertical) or by a change of the tool (hammer-stone) resulting from its wear.

In the Kachiqhata quarries, there are also signs indicating that groups of workmen designated for one kind of task did not interfere with other teams' activities. Different groups extracted stones, and others brought the supply material to build transportation ramps, which in turn were constructed by still another task group (or rather several task groups in charge of different sections of a particular ramp). Finally, different teams transported the blocks to the construction site. (Bengtsson 1998, 129–131). Of course, the stonemasons responsible for installing the blocks on the walls had to be a separate group. When it comes to the number of workers involved in stone blocks transportation in Ollantaytambo, it is considered that about seven hundred men were working on the left bank of Vilcanota River (Bengtsson 1998, 134).

Last but not least to mention are the researches of Protzen and his collaborators on Inca stone quarrying and building technology (Protzen 1985, 1986; Protzen and Batson 1993; Protzen and Nair 1997, 2013). Particularly important are his experimental archaeology studies on stone processing techniques (Protzen 1985). They will be discussed in detail and used to support our estimations.

In the following paragraphs, we will present four case studies on Machupicchu architecture aimed to show how we can further approach the main problem of Inca building technology and logistics.

17.2 Case Studies

Particular cases studies included below present a different level of detail and a different level of reliability—in extreme cases, they will only set the direction for further research and propose analytical methods that will have to be further verified. They were all based on the achievements of previous researchers.

17.2.1 The Intimachay Cave

Among the many structures on Machupicchu which have functions related to astronomical observations, the cave of Intimachay is one of the leading examples. Dearborn et al. (1986) first recognised and described it, proofing its function as a December solstice observatory. Further studies (Ziółkowski et al. 2013, 2014) added to this also observations of June solstice, equinoxes and the Major Northern Lunistice.

The natural cavity adapted to serve as an astronomical observatory has been intentionally reshaped and extended by additional stone constructions. Thus, it can also be studied as an example of Inca builders' ability to solve problems related to such difficult circumstances where required precision of orientation regarding astronomical events met difficult local conditions. They resulted from the necessity to adapt to the complicated system of large rock blocks, which were literally piled one against the other at this particular place.

Thanks to 3D laser scanning (the entire structure), structured light scanning and digital photogrammetry (eastern observation tunnel), it was possible to trace the construction's technological phases and notice how the Inca builders solved technical problems they encountered.

In the first phase, a large rock boulder forming the lintel of the cave entrance (Fig. 17.1) has been secured by a massive pillar. When following the direction of the December solstice (green lines in Figs. 17.2 and 17.3), the northern corner of the observation tunnel's western end would be built upon a steep rock slope. This created a risk of the entire construction slipping under the heavy load of the architrave.

Therefore the tunnel direction had to be altered (red line in Figs. 17.2 and 17.3), and the southwest corner of the pillar was moved towards the south, behind the rock's ridge (red arrow in Fig. 17.3).

Fig. 17.1 The Intimachay cave entrance as seen from the northeast (photo by J. Kościuk)

Fig. 17.2 The Intimachay cave. Grey—natural rock; brown—stone masonry; green—the December solstice direction; red—the correction of the observation tunell direction enforced by inconvenient local conditions (elaborated by J. Kościuk)

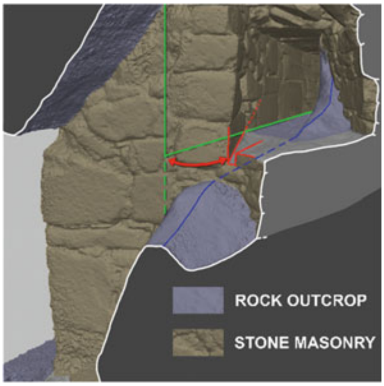


Fig. 17.3 The western end of the eastern observation tunnel (elaborated by J. Kościuk). Green—the December solstice direction; red—the correction of the observation tunell direction enforced by unconvenient local conditions; blue—the ridge of a rock boulder

As a result, the directions of the northern face of the eastern observation tunnel built in the first and second phases did not coincide with each other and intersected at an obtuse angle. The resulting gap was filled with less careful masonry in the third construction phase (Fig. 17.2).

In conclusion, we can state that the builders were aware of basic principles of structural stability, and they took particular care to master this "astronomical instrument" as precisely as possible despite many construction constraints.

17.2.2 El Mirador de Inkaraqay

Located on the northern slope of Huayna Picchu mountain, the relics of El Mirador de Inkaraqay belong to a small group of buildings that can be described as "real", precise astronomical instruments. The structure has already been the subject of previous archaeoastronomical research (Astete et al. 2016/2017). The study presented below will cover problems of Inca stonework and the logistics of the construction process on the example of the front wall of the observatory.

More than the 10-m-long front wall of the observatory (Fig. 17.4) is situated on a steep slope and preserved up to a height of ca. 4.0 m above the stone platform securing its foundations. It consists of 11 layers of well-fitted, slightly convex granite blocks of various sizes (from 20 × 30 cm to 60 × 120 cm) arranged in a wavy thread.

The state of preservation and the nature of the stonework allow for an attempt to reconstruct the logistics of the construction process. For this purpose, stonework units that could have been erected in separate technological phases were identified, and they received unique numbers (Fig. 17.4). The sequence and direction of individual stone blocks laying, including the use of wedge-stone, were also examined. The method of analysis was inspired by Protzen's research on the architecture of Saqsaywaman (Protzen 1985, p. 180–182). To check the logic of technological phases sequencing, all the assembled data were loaded to Imela Herzog's Stratify v.1.5 software utility that produced a corresponding Harris matrix (Fig. 17.5).

The first layers of blocks (01 ÷ 04) were placed against the sloping face of the rock outcrop. The work started from the north and followed towards the doorway to the south. The same block-stacking direction applies to layer 05 that started the northern corner of the wall. The subsequent layer (06) started from this corner and ended with two wedge-stones (07 and 08) when it met the 04 layer. In this way, an approximately horizontal base of the entire wall was obtained, raised about 2 m above the stone platform securing its foundations, which roughly corresponds to the floor level of the corridor on the other side of the wall.

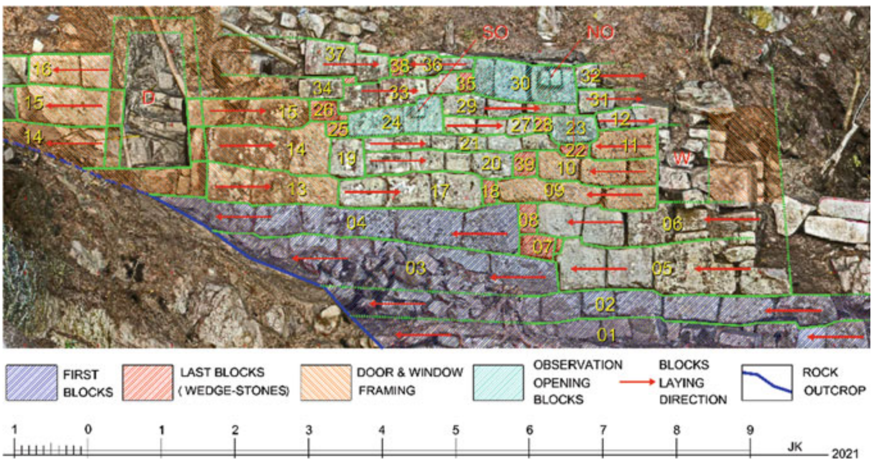
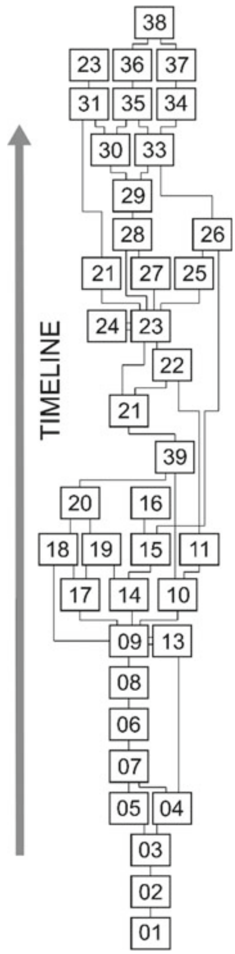


Fig. 17.4 Stratigraphy of the front wall of the astronomical observatory El Mirador de Inkaraqay (elaborated by J. Kościuk). NO—northern observation hole; SO—southern observation hole; D—door; W—window; yellow numbers correspond with that in Fig. 17.5

Fig. 17.5 Harris matrix for the front wall of El Mirador de Inkaraqay (elaborated by J. Kościuk)



Further work was carried out independently at the southern and northern ends of the wall. It is not excluded that two independent teams of stonemasons executed them. This may be indicated by differences in the size and slight differences in how the blocks were finished. It seems that one team worked at the south end of the structure, erecting a double recessed doorway (D in Fig. 17.4) and adjoining wall sections—layers 13 ÷ 16. A second team constructed the opposite northern corner of the building with a small window opening (W in Fig. 17.4)—layers 9 ÷ 11. The space between these two fragments was filled in the next phase (layers 17 ÷ 22 and 39). Again, the distinctive wedge-stones, smaller than the other blocks, indicate places where successive layers met existing ones (stones 18, 39 and 22). This phase of construction raises the wall for about 1 m.

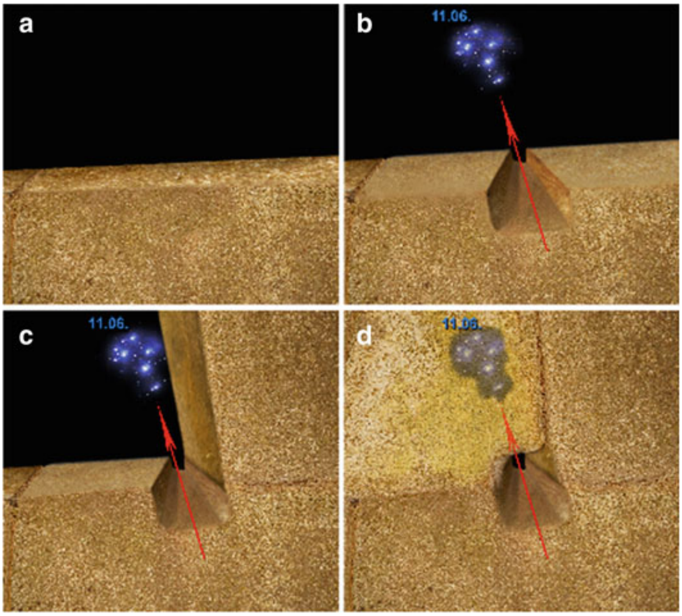


Fig. 17.6 The reconstruction of the southern observation hole construction sequence (reconstructed by Jacek Kościuk)

At this level, the work reached the height where the southern observation hole meant to follow the heliacal rise of the Pleiades (Astetee et al. 2016/2017, 21–22) had to be installed (SO in Fig. 17.4 and group of blocks 24).

The entire process started from the zenith orientation of the top horizontal plane of the block in which the observation channel was made, and then subsequent blocks completed the design (Fig. 17.6a–d).

On roughly the same level, there is interesting stone block 23 (Fig. 17.4). The place for it has been deeply cut into layers 11 and 21 as well into the wedge-stone 22. Interestingly, its width almost exactly corresponds to the total width of the two blocks (30) in which the northern observation hole (NO in Fig. 17.4) was cut in. It seems that the first intention of builders was to place the northern observation hole at this level. However, it has been noticed that due to ca. 55 cm lower position, the sun's ray entering the interior on the June solstice (Astete et al. 2016/2017, 19–21) would fall at the very base of the rear wall of the corridor behind, and therefore in a place very inconvenient for precise observation. The carefully prepared place has been thus abandoned, and both blocks for the northern observation hole were placed above the later added stone blocks layer 29.

The process of the northern observation hole construction was even more sophisticated than the former. First, a stone block with a slightly sloping north face was embedded (Fig. 17.7a). The orientation of its lateral face indicated approximately the direction of the Yanantin summit. In the next step, the direction was corrected so that its plane crossed the horizon line at the point of June solstice sunrise (Fig. 17.7b). Probably, directly following the June solstice observation, a shallow canal was carved in the already prepared lateral face of the block, indicating precisely the sunrise point over the summit (Fig. 17.7c). The final step was adding yet another block with an already carved, much deeper groove (Fig. 17.7d). Stone blocks 31–38 filled the remaining space between both observation holes. Also there, the presence of small wedge-stones indicates the direction of blocks laying.

However, it seems that the building has never been completed, as indicated by the absence of ruined stone blocks—particularly door and windows architraves. The place is too remote from any other building sites to assume that these big blocks might have been reused for other buildings.

The example of El Mirador de Inkaraqay, a basically small building, can therefore be a basis for studying the Inca stone technique, logistics of the entire construction process, and engineering solutions. The already mentioned platform securing the foot of the observatory front wall might be a good example. As the entire structure was situated on a steep slope (more than 40 degrees), the proper foundation and stability of the entire structure were one of the essential problems.

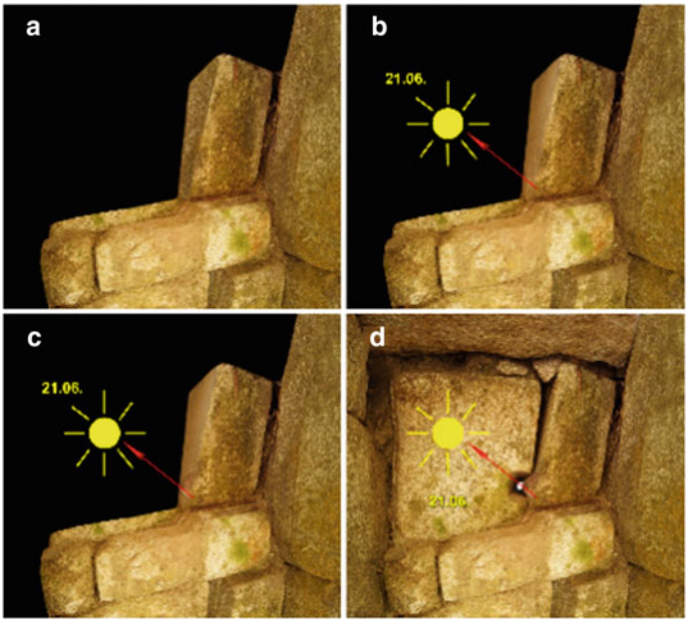


Fig. 17.7 The reconstruction of the northern observation hole construction sequence (elaborated by Jacek Kościuk)

A small archaeological sounding executed at the front wall's foot reveals the foundation method (Fig. 17.8d). A layer of stone blocks of an irregular shape and sharp edges was used as the foundation. They were arranged in a way that ensured the mutual wedging of individual blocks counteracting the strut forces that could stress the retaining wall surrounding the entire platform on which the front wall was built. In addition, the sharp edges of the blocks increased internal friction and prevented the possible sliding of the structure on the bedrock.

Another example of engineering solutions used in El Mirador de Inkaraqay may be a small fragment of the retaining wall in the northern part of the entire complex. The wall stabilises the slope, but at the same time there is a water culvert in its foot. So the water infiltrating down the slope has an outlet and does not press against the retaining wall. Such solutions are commonly found on Andean terraces. What may be surprising is the fact that the wall was built on a semi-circular plan—the radius is about 3.5 m. Again, such solutions are not alien to Inca architecture—the Torreón of Machupicchu and the Coricancha temple in Cusco might be the best-known examples. What is surprising in this case is the fact that this semi-circular wall is turned with its convex side towards the pressing water (Fig. 17.9d). It is a solution that uses a circular structural arch principle, commonly used in modern hydraulic engineering.

The structural circular arches are not known in Inca architecture, and at the same time, the Authors are not aware of any other example of Incaic semi-circular dams. Therefore, it is not easy to judge whether this shape results from an engineering common sense (even subconscious) or is the effect of adjusting to the local topography. Nevertheless, this example of Inca building art is worth noting.

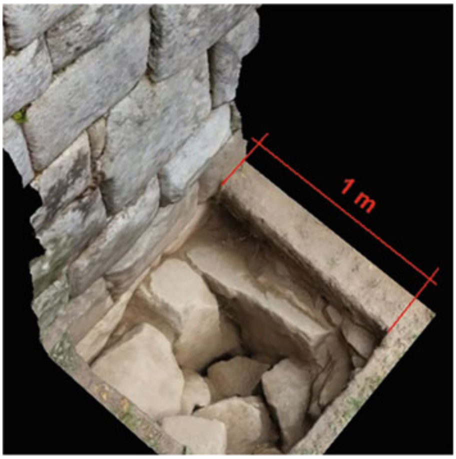


Fig. 17.8 3D model of the sounding at the foot of the front wall (photos by José Bastante Abuhadba, photogrammetry by Jacek Kościuk)

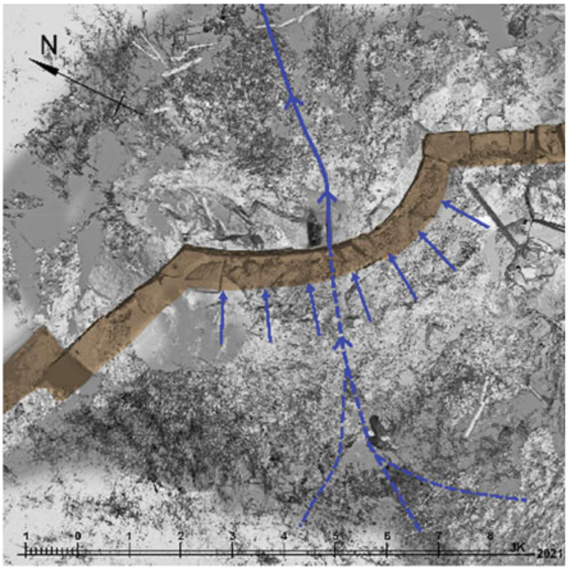


Fig. 17.9 Semi-circular retaining wall with a water culvert in the northern part of El Mirador de Inkaraqay (elaborated by Jacek Kościuk)

17.2.3 The Enclosure Wall Between Agricultural and Domestic Areas

The Llaqta of Machupicchu urban zone is separated from the agricultural terraces by a massive enclosure wall (Fig. 17.10). It is built with the use of various threads and different types (shapes and ways of surface processing) of various size stone blocks and megalithic boulders. The steeply descending southern part of the enclosure wall (level difference of about 20 m over a distance of 80 m) was selected as the subject of a study on the logistics of the Inca construction process. The wall section in question starts at the main gate leading to the residential area (Fig. 17.11) at the ca. 2455 masl and, after nearly 80 m, terminates at ca. 2438 masl (Fig. 17.14).

The input data for the following analyses was a photogrammetric study based on over 250 photos high-resolution photos. For publication reasons, the resulting image has been divided into four sections (from A to D), each approximately 20 m long (Figs. 17.11, 17.12, 17.13 and 17.14). As the individual wall fragments run at different angles, an average projection plane was selected—hence the scale in the horizontal direction is distorted differently for each fragment.

The orthoimage was used to delimit boundaries of technological stonework units (green lines in Figs. 17.11, 17.12, 17.13 and 17.14). The distinguishing feature here was the difference in the nature of the stone thread, the size of the stone blocks and clear joints between the individual units. In many cases, the latter manifested with much smaller stones wedging junctions between different technological phases. Often, they showed up on both—horizontal and vertical joints.

Fig. 17.10 Aerial photo of the central part of Llaqta Machupicchu. The studied part of the enclosure wall marked in red (*source* archives of the PANM-DDC-CUS/MC)

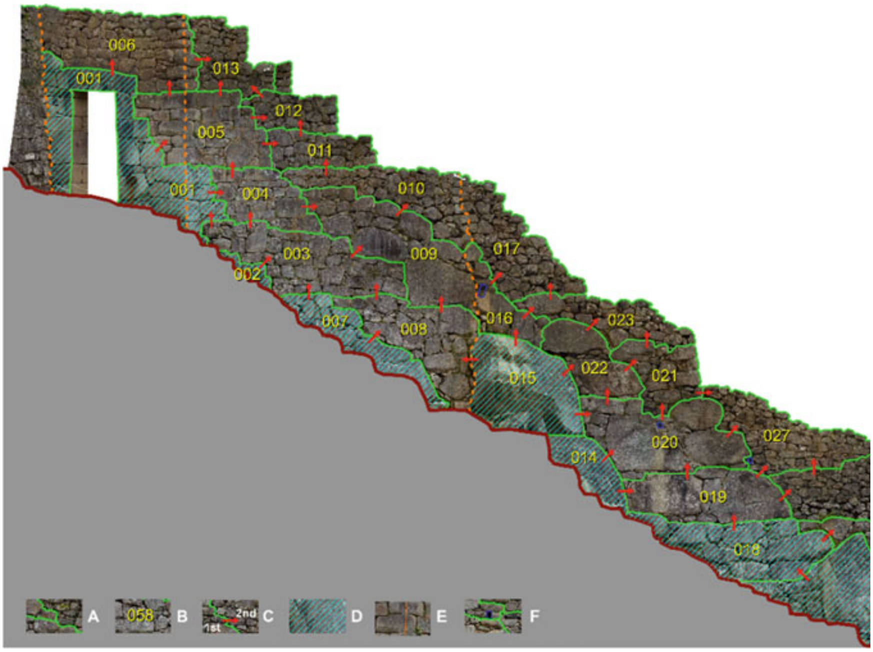


Fig. 17.11 Section A of the enclosure wall. A—boundaries of technological stonework units; B—stonework units numbers (in random order); C—phase sequence; D—foundation phase; E—corners of the enclosure wall; F—water culverts (photo José M. Bastante; elaborated by J. Kościuk)

Subsequently, each stonework unit was given a unique number in random order, and their mutual chronological relationships between particular pairs of stonework units were determined (red arrows in Figs. 17.11, 17.12, 17.13 and 17.14). Only a simple relationship was defined at this stage, like unit *x* was built earlier or later than unit *y*. As already mentioned, this analysis method was inspired by Protzen's study on the architecture of Saqsaywaman megalithic walls (Protzen 1985, p. 180–182).

Again, to check the logic of technological phases sequencing, all the assembled data were loaded to Imela Herzog's Stratify v.1.5 software utility which produced a corresponding Harris matrix, from which only the most critical stonework units were extracted (Fig. 17.15).

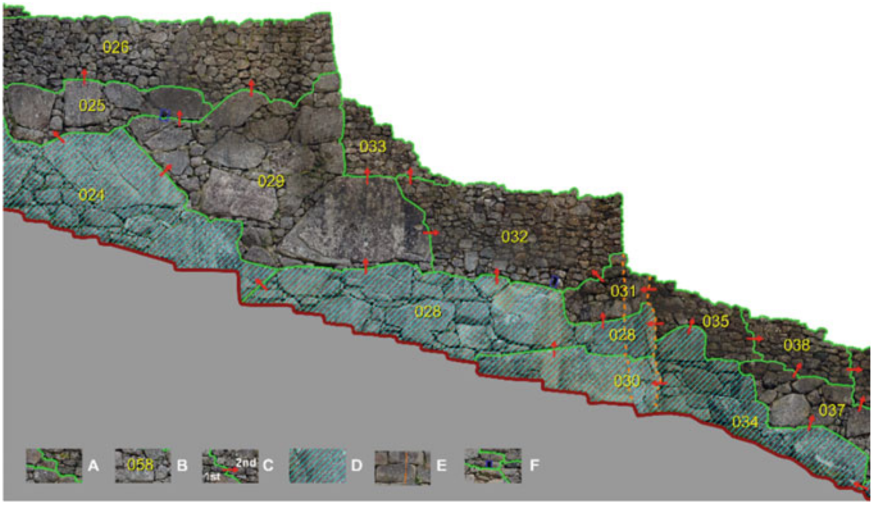


Fig. 17.12 Section B of the enclosure wall. A—boundaries of technological stonework units; B—stonework units numbers (in random order); C—phase sequence; D—foundation phase; E—corners of the enclosure wall; F—water culverts (photo José M. Bastante; elaborated by J. Kościuk)

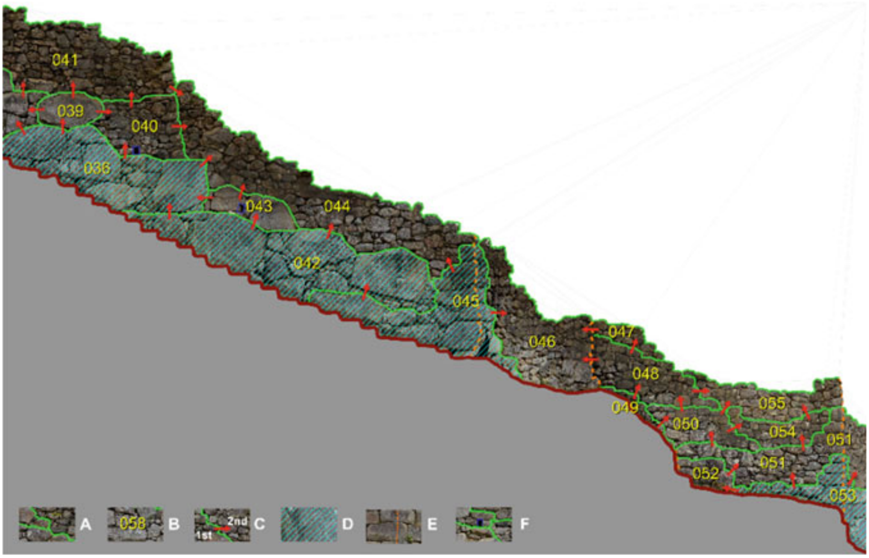


Fig. 17.13 Section C of the enclosure wall. A—boundaries of technological stonework units; B—stonework units numbers (in random order); C—phase sequence; D—foundation phase; E—corners of the enclosure wall; F—water culverts (photo José M. Bastante; elaborated by J. Kościuk)

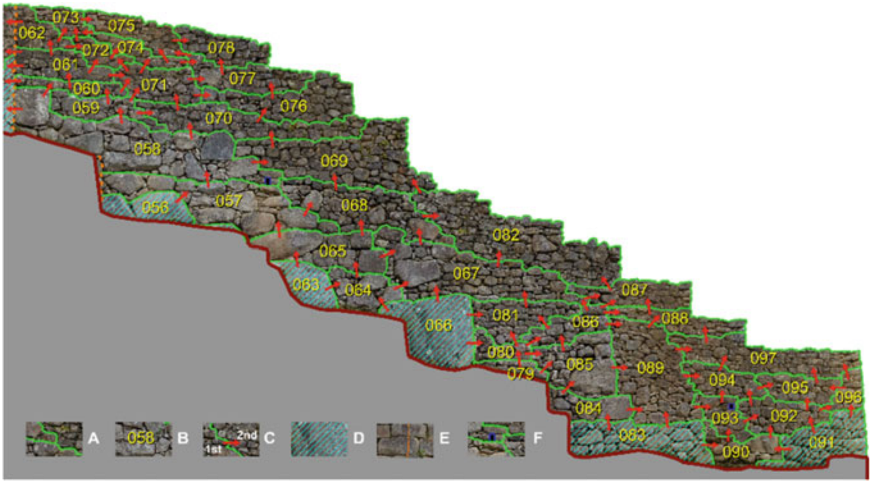


Fig. 17.14 Section D of the enclosure wall. A—boundaries of technological stonework units; B—stonework units numbers (in random order); C—phase sequence; D—foundation phase; E—corners of the enclosure wall; F—water culverts (photo José M. Bastante; elaborated by J. Kościuk)

The first, somewhat surprising result of these analyses was the statement that the erection of this wall proceeded from the foot of the slope to the top (Fig. 17.15). It should be noted at this point that we are talking only about the sequences of the enclosure wall construction and not about the order of the slope terracing—both did not necessarily follow the same logistic.

However, this simple preliminary picture got complicated when all stonework units with all their mutual chronological relations were analysed. Indeed, the general direction of progress in construction works has been confirmed. In the light of the available data, and it should be remembered here that the observations concern only the visually accessible parts of the walls—but not their foundations, the work proceeded from the foot of the slope to the top. However, the reconstructed path of work progress meanders from the bottom up and back down (Fig. 17.16).

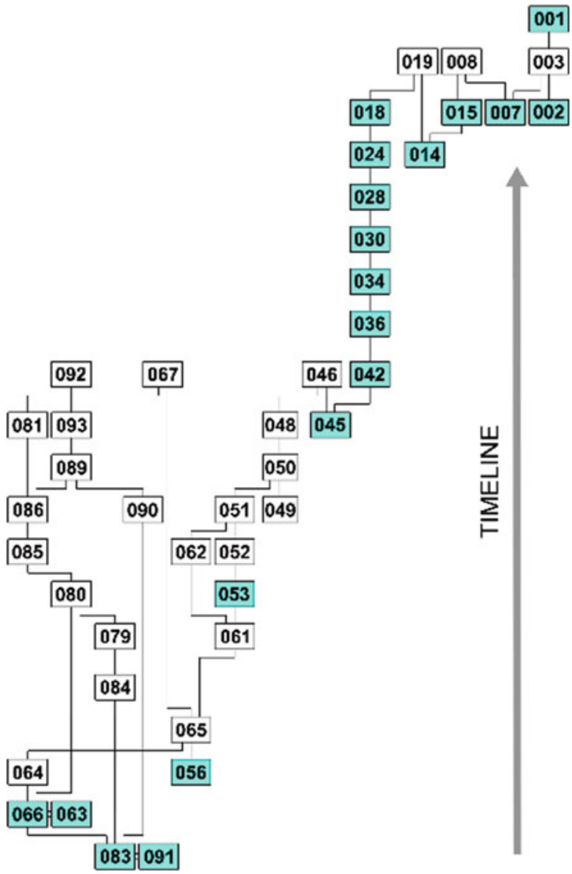


Fig. 17.15 Harris matrix for the enclosure wall. Only the most critical stonework units are included. In cyan—stonework units belonging to the foundation phase (elaborated by J. Kościuk)

The limitation of this case study is the lack of stratigraphic data concerning wall foundations and the fact that visual observations are limited to only the southern face of the wall. Further works should also include the northern face with particular attention to differences of the ground level on both sides of the wall.

Fig. 17.16 Section D of the enclosure wall. Hypothetical reconstruction of the first two phases of the perimeter wall erection. The boundary between the phases is marked in red (photo José M. Bastante; elaborated by J. Kościuk)

17.2.4 The Sala de los Morteros

The Sala de los Morteros is located within a bigger complex, the so-called Industrial District or the Cuarto de los Morteros in the eastern part of the Llaqta Machupicchu (Fig. 17.17). The building has been already thoughtfully researched but mainly from the point of view of its possible archaeoastronomical significance (Cabada Hildebrandt 2008, p. 33–63; Kościuk and Ziółkowski 2020).

Fig. 17.17 Aerial photo of the central part of Llaqta Machupicchu. The eastern wall of the Sala de los Morteros is marked in red (*source* archives of the PANM-DDC-CUS/MC)

The lower sections of the Sala de los Morteros outer walls were built with well-fitted, convex, roughly quadrilateral granite blocs arranged in four layers. The height of successive layers decreases, starting from 85 ÷ 115 cm in the first layer and ending at 58 ÷ 85 cm in the last layer. The length of the blocks also varies—the longest exceed 185 cm while the shortest are about 45 ÷ 50 cm, except for the frequently used wedge-stones. The length of the latter, with a few exceptions, varies between 12 and 35 cm.

This lower section of the Sala de los Morteros eastern wall was selected for further research on the Inca stonework and the logistics of the construction process. Thanks to the precise data from 3D laser scanning and the resulting virtual 3D model, both sides of the wall could have been examined simultaneously. Again, stonework units that might have been erected in a separate technological phase were identified, and they received unique numbers. Frequently used wedge-stones helped to reconstruct the sequence and direction of individual stone blocks installed on the wall. All these data were applied to the orthoimages of the wall on both faces (Fig. 17.18).

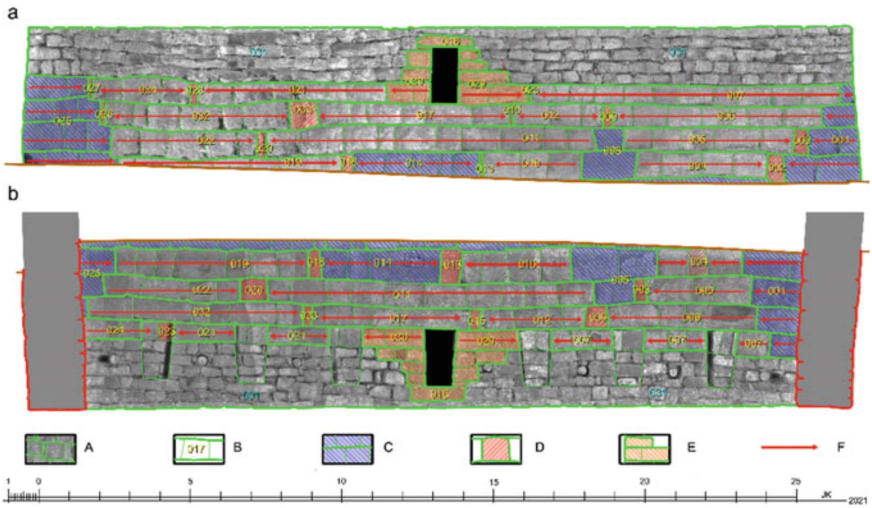


Fig. 17.18 Outer (a) and inner (b) face of the Sala de los Morteros eastern wall. A—boundaies of technological stonework units; B—stonework units numbers (in random order); C—stonework units erected during the 1st phase; D—wedge-stones; E—window framing; F—blocks installing direction (elaborated by J. Kościuk)

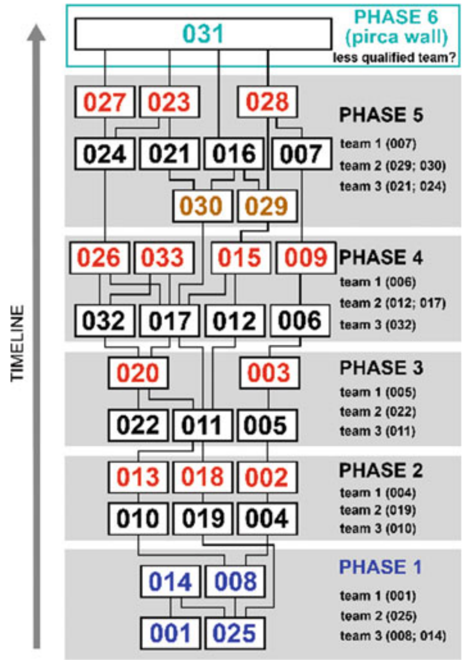


Fig. 17.19 Harris matrix for the eastern wall of the Sala de los Morteros (elaborated by Jacek Kościuk)

On this basis, it was easy to identify the sections of the wall that were erected as the first—not only, what obvious, the corners of the walls (01 and 025 in Fig. 17.18) but also two sections between them serving as guides marking both faces of the wall (08 and 014 in Fig. 17.18). The corner sections were probably built at once to their full height (four stone-courses), while the guide-sections received only one or two layers of stone blocks. For further analysis, we used again Stratify v.1.5 software. The resulting Harris matrix (Fig. 17.19) suggests that this wall construction was carried out in six phases.

The first were already mentioned corner "pillars" and guide-sections. The second phase until the fourth was to reach the level of the window and internal niches sills. In the fifth phase, the blocks framing the window (including its lintel) were installed, and at the same time, first guide blocks marking the niches on the inner wall face were set up. The last, sixth phase was executed as an inferior quality pirca-wall that reached the construction intended height.

It remains an open question how the work has been organised. While we already have a certain picture about the organisation of stone quarrying and subsequent transport, thanks to the works of, among others, Protzen (1985, 1993) and Bengtsson (1998), the reconstruction of the construction logistics itself is much more problematic.

How this work might have been then organised, and how long it took? In the lack of reliable data, the answer to this question can be based only on highly speculative reasoning only partially supported by the evidence from other research. An essential starting point for further considerations will be arbitrarily adopted assumptions. They are as follows:

- Only the lower part of the wall will be considered at first—the *pirca*-wall constituting the upper sections is excluded from detailed estimations. The foundation phase is also omitted.
- It is assumed that, according to Bengtsson's (1998, p. 128–129) observations, the process of extracting the building material, its transport and final preparation together with the installation on the wall was handled by independent groups of workers.
- The necessary amount of material and tools was always available on the construction site.
- Due to the physical properties of Machupicchu granites (see below), the stone blocks delivered to the construction site were already pre-treated before shipment and received the roughly cuboid form. The remaining processing steps took place on the construction site.
- The logistics of the construction process was aimed at minimising the time needed to erect the wall.

The direct consequence of these considerations and the previously identified construction phases is the statement that three teams of workers could have participated in the erection of this wall (Fig. 17.19). Taking into account the thickness of the wall (about 180 cm at the base) and the size of the stone blocks used (some of them weighed over 1,200 kg), we can assume that each team consisted of a minimum of six workers—half of them working on each side (outside and inside) of the wall. In this way, nine stonemasons worked simultaneously on each side of the wall—enough to manoeuvre most of the stone blocks. In the case of the largest ones, groups working on both sides of the wall would have to cooperate—that is, a total of 18 workers.

Another critical issue is the estimation of the time needed to process stone blocks. The already mentioned Protzen's experiments (Protzen 1985, p. 173–176) might be a helpful reference. In his experiments, Protzen uses a raw block of andesite, while the stone fabric of Machupicchu buildings is relatively fine-grained granitoid rock. Thus, we must consider the possible differences in the processing of both materials to see how far Protzen's data are applicable in our situation.

The general opinion among stonecutters is that granites, particularly fine-grained, are easier to work since they more readily split along rift and grain directions. When hammered, granite tends to split towards an edge. The closer to an edge one applies the blow, the more the crack runs outside rather than down through the stone. This property makes granites an ideal rock for processing with pounding and hammering by other stones. Additionally, some scholars (Menegat 2019; Hennings and Lynch 2020) point to the particular physical properties of Machupicchu granites resulting from the fact that the area lies at the intersection of three main geological faults causing an intensive rock fracturing along planes of weakness. This greatly reduces the amount of work to split the stones and to process them. Further on, these researches suggest that Incas had chosen deliberately such sites for their main building activities. In the case of Machupicchu, it is considered that the source of building stone material was the so-called "Granitic chaos" and the paleo-landslide discovered in recent years (Canuti et al. 2009, p. 256). However, it is important to notice that the whole llaqta of Machupicchu was a huge quarry, and the granite employed in fine masonry buildings was obtained from certain parts of the llaqta (Bastante 2016).

Thus, returning to the main topic, it can be assumed that Protzen's experiment results relating to the time necessary to process the andesite block are also reliable for granite processing. The work may have even progressed faster, but we will stick to the figures obtained by Protzen. Dressing one face (25 by 30 cm) of the rough andesite block by pounding with a hard stone hold between both hands took him only 20 min (Protzen 1985, p. 173). For drafting four sharp edges around this face (ca. 110 cm length in total), he spent another 30 min. How would these results convert into the processing time of a typical block from the eastern wall of Sala de los Morteros?

On average, the face of the stone blocks used to build this wall measures 75 by 95 cm. Comparing this to the Protzen data, we get about 190 min needed to process the face of such the block. Further on, before starting the work with the other faces, the stonemason must have been cutting four sharp edges around this face. This gives us another almost 90 min. To summarise, the face of a typical block took less than 5 h to be processed.

With a wall thickness of about 180 cm at the base and no large blocks reaching both sides of the wall, it can be assumed that the typical block depth did not exceed 60 cm. We can also assume that not more than one-third of both vertical side faces of the block was precisely worked out while the bottom surface must have been processed entirely. The same assumption applies to all side edges. Including the time needed to manoeuvre the block gives a total of about 4.3 h necessary to work out the two sides and the bottom surface together with their edges. This way, preparation of a typical block would take one stonemason between 11 and 12 h. As we assumed, six groups of three men each simultaneously processing the stones, one can expect up to 18 blocks prepared every one and quarter of a working day.

We suppose that stone block preparation has been executed just in front of the wall section erected. For example, four blocks for the stonework unit 004 (Fig. 17.18a) were placed alongside the eastern facade of the building, keeping distances between particular blocks suitable to turn them to the side to process blocks side faces. This assumption goes roughly in hand with Bengtsson opinion about the order in which different block-sides were prepared (Bengtsson 1998, p. 133). Free spaces between the blocks also facilitated the preparation of neighbouring blocks side faces. A simple method proposed by Vincent Lee (Fig. 17.20) might have been used. We estimate that preparing a good fit between two neighbouring blocks could take not more than two hours. Since the operation required moving blocks and turning them several times, probably three workers were involved in preparing each block.

There are 216 blocks altogether on the eastern and western faces of the wall in question. Some are bigger than the typical block we took for our estimations, and the others are smaller. The time for their processing changed adequately. The same can be said about the time necessary for installing the blocks on the wall. It was assumed that the average time did not exceed six hours per typical block. It included lifting the block to the top of the wall, preparing the horizontal surfaces (it often required cutting into the former layer of blocks or the bottoms of the new blocks—Fig. 17.21) and final adjusting horizontal and vertical joints. However, lifting blocks and manoeuvring them on the wall required a bigger team of nine workers minimum. Therefore, only two such teams (half of the whole 18-men crew) could work simultaneously for the bigger stones, so averagely, not more than three typical blocks could have been installed daily.

Erecting of the lower part of the eastern wall of the Sala de los Morteros took this way around 30 working days—13 days for stone blocks processing (18 stonemasons involved simultaneously), 5 days for vertical joints preparation (6 teems of 3 workers each working simultaneously) and around another 13 days for installing blocks on the wall (2 teams of 9 workers each working simultaneously). A similar time would be necessary for the western wall of the building where fewer stone blocks were to be prepared and installed, but multiple entrances and pillars between them imposed additional complications. For lateral, shorter northern and southern walls, 20 working days should be added. This makes a total of around 82 working days of an 18-men well-trained stonemasons team. However, there are some indications on the lateral walls that another 18-man team could have been working independently on the other western side of the building. If so, the time could be reduced by half.

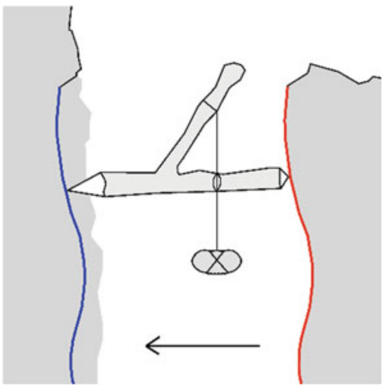


Fig. 17.20 A simple device proposed by Vincent Lee to copy blocks faces (redrawn from Lee V. (2013))

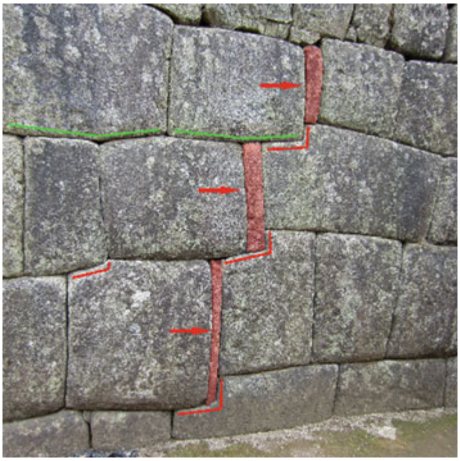


Fig. 17.21 Alternative ways to fit horizontal layers. Cuts into the top of lower layers (red lines). Cuts into the bottoms of blocks (green lines). Wedge-stones are indicated by red arrows and coulored in red (Photo: J. Kościuk)

Until now, we were trying to estimate the time needed to erect only a part of the walls projecting above the ground surface level, neglecting the upper sections executed in a *pirca* manner and the foundations. Unfortunately, there is no reliable data to estimate how long these two phases of construction lasted. We can only estimate that site preparation, trenches excavation and foundations construction could take the same amount of time. That is, assuming that indeed two 18-men teams worked here simultaneously, about 40 working days. Another 20 or so days might be added to complete *pirca* walls, but a less qualified team of stonemasons might have executed this phase. If, as we suppose, the *pirca* walls were clay-plastered, one would probably engage a different group of workers for a couple of weeks. The same applies to roofing construction and covering it with a thatch.

When trying to sum up all these numbers, it seems that a building the size of Sala de los Morteros could have been erected from scratch in less than six months. So within the period of optimal weather conditions on Machupicchu, which begins in mid-April and lasts until mid-October.

17.3 Conclusions and Future Works

The authors are fully aware that the above-proposed estimations are highly hypothetical and rather based on assumptions than on hard evidence. They should be seen only as a starting point for further discussion on Inca building art logistics. Other specialists should assess the results from the point of view of sources the authors omitted or interpreted differently. Further experimental archaeology tests could also help to validate the assumptions made by the authors.

On the other hand, if one is heading towards generalisation aimed at reconstructing the time needed to build the entire Llaqta of Machupicchu, the problem becomes even more complicated. Workers preparing building materials (such as stone blocks, wood, clay, cane and tools) and providing food or water should also be considered. Particularly, limited water resources in the immediate vicinity of the Llaqta of Machupicchu will be an important factor influencing the total number of workers employed at the same time. For the dry months, when the main building activities could have been successfully carried on, the local water resources were enough to meet the needs of a population estimated between 300 and 1,000 individuals (Wrigh et al. 1997).

Of course, the water shortages could have been replenished from the inexhaustible source of the Vilcanota River flowing in the valley. However, this would require additional workers transporting water daily over a distance of more than 800 m (in a straight line) with a level difference that exceeds 400 m. Even if they were stationed in the valley, they required additional food supplies and accommodation, which additionally tangled the entire project's already complicated logistics. So even if the water supply is not considered one of the critical constraints in the construction process of the Llaqta of Machupicchu, this factor cannot be ignored.

The architectural and engineering knowledge, planning and the complex logistics displayed by the Inca state allowed the construction of the Llaqta of Machupicchu and many other sites of the area, including roads and the canalisation of the Vilcanota River. Although all these imperial-driven activities considerably transformed the site (Bastante et al. 2020), they were executed with much respect and harmony to the local landscape considered sacredness by the Incas.

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References

Agurto Calvo S (1987) Estudios acerca de la construcción, arquitectura y planeamiento incas. Capeco, Lima

Arnold F (2017) Logistik einer Pyramidenbaustelle Markierungen am Baumaterial der Pyramidenanlagen des Königs Snofru in Dahschur. In: Kurapkat D, Wulf-Rheidt U (eds) Werkspuren: Materialverarbeitung und handwerkliches Wissen im antiken Bauwesen ; Internationales Kolloquium in Berlin vom 13–16. Mai 2015, Diskussionen zur archäologischen Bauforschung ; Bd. 12, Regensburg, pp 389–398

Astete Victoria JF (2008) Proceso constructivo de la ciudad Inka de Machupicchu, Revista Saqsaywaman N°8, Instituto Nacional de Cultura Peru

Astete Victoria JF, Ziółkowski M, Kościuk J (2016/2017), On Inca astro-nomical instruments: the observatory at Inkaraqay—El Mirador (National Archaeological Park of Machu Picchu, Peru), Estudios Latinoamericanos, 36/37, pp 9–25

Bastante JM (2016) Investigaciones interdisci-plinarias en la llaqta de Machupicchu, Arqueología y Sociedad, No. 32, pp 267–276

Bastante JM, Astete F, Fernandez A, Usca Alex I (2020) Estado de la Cuestión: Historia y Arqueología de la llaqta de Machupicchu. In: Fernando A, José B (eds) Machupicchu Investigaciones Interdis-ciplinarias, Dirección Desconcentrada de Cultura. Cusco, tomo I, pp 141–236

Bengtsson L (1998) Prehistoric stonework in the Peruvian Andes. A case study at Ollantaytambo, Etnologiska studier 44, Göteborg

Betanzos J de (1987[1551]) Suma y narración de los Incas. Tran-scription, notes and prologue by María del Carmen Martín Rubio, Atlas, Madrid

Cabada Hildebrandt E (2008) Calendario solar de Machupicchu y otras incognitas. Gráfica Retai S.A.C., Lima

Canuti P, Margottini C , Casagli N, Delmonaco G, Falconi Luca M, Ferretti A, Lollino G, Puglisi C, Spizzichino D, Tarchi D (2009) Monitoring, geomorphological evolution and slope stability of Inca citadel of Machu Picchu: results from Italian INTERFRASI project. In: Sassa K, Canut P (eds) Landslides—disaster risk reduction. Springer, Berlin, Heidelberg, pp 249–257

Cieza de León P (1985 [1554]) Crónica del Perú. Segunda parte. Edition, prologue and notes by Francesca Cantù' Pontificia Universidad Católica del Perú, Fondo Editorial, Lima; (1986 [1553]), Crónica del Perú. Primera Parte. 2nd rev edn. (1st ed. 1984). Introduction by Franklin Pease, Pontificia Universidad Católica del Perú, Fondo Editorial, Lima

Dearborn David SP, Schreiber Katherina J, White Raymond E (1987) Intimachay: a de-cember solstice observatory at Machu Picchu, Peru. Am Antiq 52(2): 346–352

Garcilaso de la Vega (1960 [1609]) Comentarios reales de los Incas. Primera parte. In: Carmelo Saenz de Santa María P, Biblioteca de Autores Españoles, t. 133, Madrid

Gasparini G, Margolies L (1980) Inca architecture. Indiana University Press, Bloomington

Gavazzi A (2020) Tecnomorfología de la llaqta inka de Machupicchu. Materiales, métodos y resulta-dos del levantamiento arquitectónico y paisajístico. In: Astete VJF, Bastante AJM (eds) Machupicchu. Investigaciones interdisciplinarias. Tomo 1, Lima, pp 353–381

Hennings J, Lynch H (2020) Finding faults with the Inca. Bureau of Economic Geology, The University of Texas at Austin, Fact Sheet: Episode ED 166 (source: https://www.earthdate.org/finding-faults-with-the-inca)

Kościuk J, Ziółkowski M (2020) Sala de los Morteros at Machu Picchu: another precise astronomical instrument of the Incas?. Es-tudios Latinoamericanos (in print)

Lee Vincent R (2013) Ancient moonshots: megalithic mysteries from before technology. Sixpac Manco Publications

Menegat R (2019) How incas used geological faults to build their settlements. paper delivered at GSA Annual Meeting in Phoenix, Arizona, USA, paper No. 148–9 (source: https://www.researchgate.net/publication/336250791_How_Incas_used_geological_faults_to_build_their_settlements)

Protzen J-P (1985) Inca quarrying and stonecutting, J Soc Archit Hist 44(2):161–182

Protzen J-P (1986) Inca stonemasonry, Sci Am 254(2):80–88

Protzen J-P, Batson R (1993) Inca architecture and construction at Ollantaytambo, Ox-ford University Press, New York

Protzen J-P, Nair S (1997) Who taught the Inca stonemasons their skills? a comparison of Tiahuanaco and Inca cut-stone Masonry, J Soc Archit Hist 56(2):146–167

Protzen J-P, Nair S (2013) The stones of Tiahuana-co: a study of architecture and construction. Mono-graph 75, Cotsen Institute of Archaeology Press University of California, Los Angeles

Velarde H (1946) Arquitectura peruana. Fondo de Cultura Económica, Mexico City

Wedin Å (1966) El concepto de lo incaico y las fuentes. Estudio crítico. Akademiförlaget, Uppsala

Wright Kenneth R, Kelly Jonathan M, Valencia Ze-garra A (1997) Machu Picchu: ancient hydraulic en-gineering. J Hydrau Eng 123(10):838–843

Ziółkowski M, Kościuk J, Astete VF (2013) Astronomical observa-tions at Intimachay (Machu Picchu): a new approach to an old prob-lem. In: ŠPRAJC, Ivan and Peter Pehani (eds) Ancient cosmologies and modern prophets: proceedings of the 20th conference of the Eu-ropean Society for Astronomy in Culture. Slovene Anthropological Society, Ljubljana, pp 391–404

Ziółkowski M, Kościuk J, Astete VF (2014) Inca Moon: some evidence of lunar observations in Ta-huantinsuyu. In: Ruggles CLN (ed) Handbook of ar-chaeoastronomy and ethnoastronomy. Springer, pp 897–912