Socio-economic responses to Late Holocene climate variability and environmental change in the Peruvian Andes

PhD

Department of Archaeology, School of Archaeology, Geography and Environmental Science

Josephine Handley

March 2022

Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Josephine Handley

Abstract

This thesis provides new palaeoenvironmental data from the Peruvian Andes and develops our understanding of socio-economic responses to environmental and climatic changes within the Late Holocene. The three study areas of the Callejón de Huaylas (Ancash Region); Chillón Valley (Lima Region); Chicha-Soras Valley (Apurímac Region), provide a transect across the Andes to better understand regional differences in social responses to, and variations in, environmental change. The analysis of wetland records located within the key agricultural belt of the Peruvian Andes (3000-4000m a.s.l.), provide valuable records of past human land-use. By analysing palaeoecological (pollen, non-pollen palynomorphs, phytoliths and micro-charcoal) and geochemical (micro-XRF core scanning) signatures within these records, we can ascertain how past societies responded to known periods of major climate change, such as the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA). The results of this research have demonstrated that pre-Hispanic societies were able to cope with changes in climate by adapting agricultural practices, including the construction of reservoirs, agricultural terraces, and the use of wet pasture meadows (*bofedales*), and in doing so were able to deal with variability within natural resources, such as water availability. They also ensured the stability of their agricultural systems with continuity within the land-use records occurring over hundreds of years. It has also demonstrated considerable potential for high-resolution analysis of environmental change and the detection of both longer-scale regional climate change (MCA and LIA) and short-term climatic fluctuations (El Niño). Understanding how pre-Hispanic societies mitigated the risk posed by climate variability is important for future land-use, water, and soil conservation practices. The future preservation of the wetlands within the study is highly important for both climate change regulation and for conserving a valuable archive of human-environment interactions.

Acknowledgements

First and foremost, I would like to thank my supervisors, Professor Nick Branch and Professor José Iriarte, for their continual support and guidance over the last four and a half years. This research project was funded by the South, West and Wales Doctoral Training Programme (SWWDTP), as part of the Arts and Humanities Research Council (AHRC) and my thanks goes to them for allowing me to carry out this research.

Dr Alex Herrera (Universidad de los Andes, Bogotá, Colombia) and Dr Carlos Farfán (Universidad Nacional Federico Villarreal, Lima, Peru) aided the identification of suitable fieldwork sites and their local knowledge of not only wetland sites but also the surrounding archaeology has been invaluable. Special thanks go to Dr Frank Meddens, Professor Andrew Wade, Dr Stuart Black, Dan Teeling (all University of Reading), Douglas Walsh (Cusichaca S.A.C, Cusco Peru) and Dr Chris Vane (British Geological Survey) for their assistance in the field and being good company in the freezing cold high Andes.

Radiocarbon dating in this project was supported by NEIF Radiocarbon NRCF010001 (allocation numbers 2339.0221 and 2196.1019), with thanks to Dr Richard Staff (SUERC) for his assistance with the age depth modelling for Antaycocha. The micro-XRF results were obtained from the ITRAX scanner at British Ocean Sediment Core Research Facility, National Oceanography Centre, Southampton (BOSCORF) and thanks is given to Dr Suzanne MacLachlan, Dr Millie Watts and Dr Miros Charidemou for their assistance with collecting and processing the data.

I would like to thank Kevin Williams, Dr Dan Young and Dr Heather Plumpton for their assistance in the labs over the years and for providing training in the key analytical methodologies. Thanks, is also given to Dr Sarah Elliot for her training in phytolith analysis at the University of Exeter and to Dr Mike Simmonds for help with all things figure and map-making. Thanks is extended to the Department of Archaeology as a whole for being such a welcoming and nurturing place, which fosters a vibrant research environment. Special thanks are given to Dr Wendy Matthews and Professor Dominik Fleitmann (University of Basel) for being supportive and inspiring panel chairs.

Finally, I would like to thank all my friends and family that have stood by me over the last four and a half years; to Mum, Dad and Jenna for your continual support through my academic career to date, to Ellen for always believing in me and to Roweena, Ayla, Becky and Dan for the many coffee chats which helped to keep me going whilst I finished this thesis.

Table of Contents

List of Figures

List of Tables

Data Availability Statement

The primary data collected for the production of this thesis is available at: https://doi.org/10.17864/1947.000438

Glossary

EH - Early Horizon

EIP - Early Intermediate Period

ENSO - El Niño Southern Oscillation

GSSCP - Grass Silica-Short Cell Phytoliths

ITCZ - Inter Tropical Convergence Zone

LH - Late Horizon

LIA - Little Ice Age

LIP - Late Intermediate Period

LPAZ - Local Pollen Assemblage Zones

MCA - Medieval Climate Anomaly

MH - Middle Horizon

NPP - Non-Pollen Palynomorphs

SASM - South American Summer Monsoon

SST - Sea Surface Temperature

WCF- Water Catchment Features

Chapter 1 - Introduction

1.1 Introduction

This body of research provides new palaeoenvironmental information for the past 2500 years from three regions in the Peruvian Andes and sheds new light on socio-economic responses to environmental and climatic changes within the Late Holocene. For the Peruvian Andes climate uncertainty has always been a concern, in the past farmers have used local knowledge of ecology and intricate production systems to cope, adapt and if necessary, reorganise over time. The cultural history of highland Peru suggests once large empires, from the Early Intermediate Period through to the Late Horizon (2150-418 cal yrs BP/ 200 BC-AD 1532), supported their populations through highly innovative agricultural systems, including the use of terraces, canals, reservoirs and raised fields. The archaeological record indicates that these agricultural systems were remarkably resilient as evidenced by the apparent persistence of human occupation in many highland areas. However, the relationship between increased climate variability and the resilience of pre-Hispanic societies is still poorly understood.

Despite the growing number of high-resolution records for past climate change in Peru from lakes, caves (speleothems) and ice, as well as marine records (see Rein *et al*., 2005; Bird *et al*., 2011; Vuille *et al*., 2012; Kanner *et al.,* 2013; Apaéstegui *et al*., 2014; Bustamante *et al*., 2015; Stansell *et al.,* 2017; Thompson *et al*., 2017), there remains a paucity of palaeoenvironmental data documenting changing land-use patterns and vegetation succession, especially from small lakes and wetlands proximal to zones of intensive human activity. Wetlands, in particular, are highly important resources in terms of preserving long-term histories of human-environmental interactions. Paleoenvironmental information recorded within these wetland archives provides a valuable insight into the sensitivity of the surrounding landscape and human environment to past climate change. These records of past human-environmental interactions can act as an analogue for the possible impact of current and projected future climate change within highly sensitive environmental settings. Therefore, this research project aims to use a multiproxy approach (geochemistry, palynology, phytolith, micro-charcoal and sediment lithology) to provide new high temporal resolution records (multi-decadal to decadal scale) of environmental and land-use change from three wetlands across the Peruvian Andes. By providing records analysed at a sub-centennial scale it is possible to analyse the environmental and climatic changes and their impacts on societal structures over relatively small timescale, this is especially important when cultures such as the Inca were only around for ~ 90 years.

At present day, Peru is home to 70% of the world tropical glaciers, 30% of the total ice mass of these has retreated in the last 30 years which has consequently led to water stress in many areas of both the Peruvian Andes and on the coast (Perez *et al*., 2010). Glaciers most at risk are situated in the lower-altitudes and may disappear completely within the next decade if trends persist. These glaciers make important contributions to the water resources available for people and agriculture within an Andean setting (Perez *et al*., 2010). Over the medium term, this reduction in glaciers could deny water supplies to major cities located above 2,500m a.s.l., which are already dealing with more variable climate regimes and unreliable summer rains, putting urban populations and food supplies at risk (Perez *et al.,* 2010; Drenkhan *et al*., 2015). As well as issues with water supplies, changing climatic conditions are also leading to a shift in the altitudinal limits of agricultural. With temperatures rising, the area of crops and animals adapted to the coolest, highest climatic zones is shrinking. Both herding and arable agriculture have risen approximately 300m, in the last 50 years within Southern Peru (Perez *et al*., 2010). Climate change may also affect farmer's ability to control pests, as well as effecting the stability of soils for crop growth. Therefore, there is a need for adaptive, water conservation strategies that can deal with any unpredictable changes that may occur (Fedoroff *et al*., 2010).

Modern day activities, such as the planting of *Eucalyptus*, have been seen to have a negative impact on the environment, increasing the vulnerability to drought, as they deplete underground water resources and increase risk of fire (Dawson *et al*., 2011). More appropriate agroforestry adaptations include the encouragement of indigenous tree species, such as *Polylepis*, which help to conserve water and act as a buffer for aridification effects (Dawson *et al.,* 2011; O'Donnell *et al*., 2016). Other responses that may aid with unpredictable climate regimes include planting different varieties of potatoes with a greater range in maturation dates and tolerance to drought in order to provide stable yields (Costanza *et al*., 2007). This is where it is beneficial to study pre-Columbian traditional non-intensive farming practices, as analysis of these systems provides us with an excellent opportunity to investigate and challenge concepts of sustainability and resilience in relation to prehistoric societies. Indeed, there is strength in studying long-term changes in environment and societies as it allows for the analysis of multiple completed cycles of the rise, spread and eventual decline of civilisations not examinable at shorter time scales (Costanza *et al*., 2007).

The last 2500 years was therefore chosen for this study as it encompasses the major societal developments and changes within complex state-scale societies, such as the Wari (1450-950 cal yrs BP/ AD 500-1000) and the Inca (512-418 cal yrs BP/ AD 1438-1532), as well as the intervening intermediate periods where a more localised, family (*Ayllu*) organisational system prevailed. This is set against variable climatic conditions including major events such as the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA), allowing for the study of socio-economic responses to climate change over a range of different regimes of social organisation, and in turn potential resilience capacities.

1.2 Structure of the thesis

The thesis is compiled of six main chapters, this chapter introduces the rationale for the project, geographical, archaeological, and climatic background to the Peruvian Andes and the specific research aims and questions this project hopes to address. **Chapter 2** outlines the methods used within this study. **Chapter 3, Chapter 4** and **Chapter 5** focus on the three study regions investigated and are presented in the style of a publication including individual introductions, site specific methodologies, results, and discussion sections. **Chapter 6** discusses the cross-cutting themes from the three study regions, while **Chapter 7** concludes the main findings and recommends further work.

1.3 Geographical context of study areas

The Peruvian Andes were formed by the movement of the Nazca plate under the South American Plate to create a subduction zone, resulting in vertical uplift creating the Andes Mountain range (Lau, 2016). The steep nature of the Andes leads to vertically stacked environmental zones (Fig. 1.1, Table 1.1), which you can travel between over relatively short distances by moving up or down in elevation. They extend horizontally over many kilometres, however. Altitudinal location is vital in the Andes in determining resource availability and potential. Below 3000m a.s.l., temperatures rarely drop below freezing, whilst above 4000m a.s.l. night frosts can occur up to 25 days per month during the winter (Quilter, 2014); precipitation and temperature also vary with altitude. The varied Andean environments has also led to vertically arrangement of settlements, production regimes and political organisation within the different environmental zones.

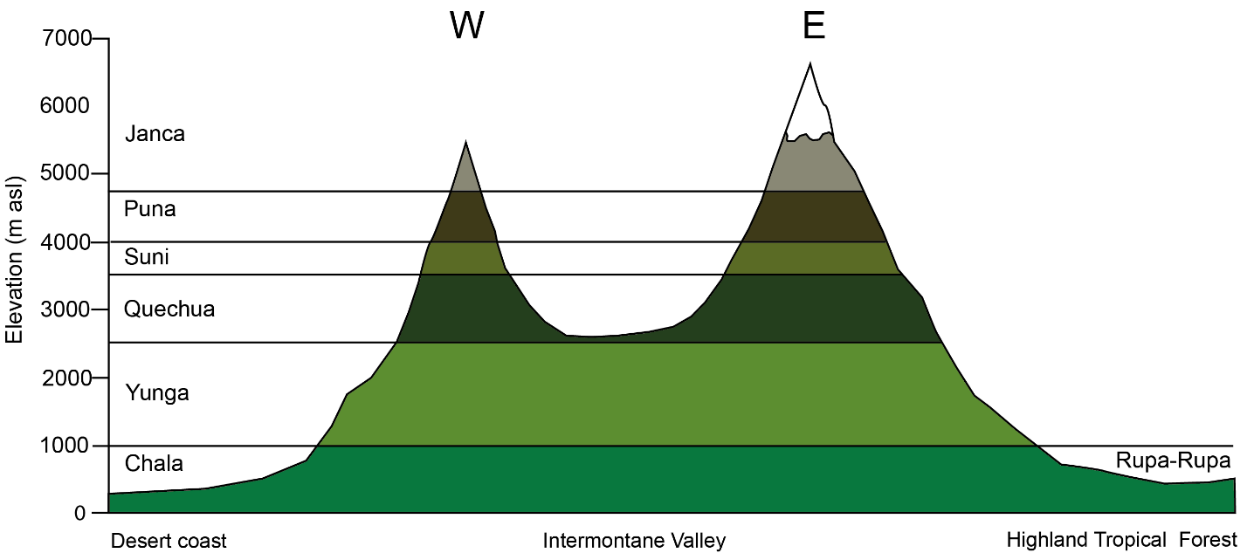


Figure 1.1: Cross section of the Andes, modelled on the Callejón de Huaylas, showing the environmental zones of Peru. Naming of zone follows Pulgar Vidal's (1987) original classification.

The environmental zones of Peru were first characterised by Peruvian geographer Javier Puglar Vidal using native Quechuan nomenclature (Pulgar Vidal, 1987). The most productive environmental zones agriculturally on the western flanks of the Andes are the *Yunga, Quechua* and *Suni* zones. The *Yunga* largely consists of the lower river valleys between 1000-3000m a.s.l. which receive regular and abundant precipitation, which can exceed 6000mm yr^{-1}, and are generally warm (between 6-22^{o}C), providing the right growing conditions for tropical crops (Moseley, 1992; Quilter, 2014). The *Quechua* zone at 2500-3500m a.s.l. is generally mild (average temperatures between 11-16 ^{o}C, with a maximum of 29^{o}C$^{)}$ and frost free making it suitable for a range of agricultural crops such as maize, squashes and other fruit and vegetables. The *Suni* zone is the highest arable agricultural zone at 3500-4000m a.s.l., this is sometimes also referred to as the tuber belt due to the growth of potatoes, oca and other tubers. This zone is generally cold (average 7-10^{o}C, with temperatures as low as -16^{o}C) and damp and receives the most rain out of any of the zones due to its higher altitude (Moseley, 1992; Quilter, 2014).

The sites within this body of research (see Section **1.8** for details), sit within the *Quechua* (Huarca and Ayapampa) and the *Suni* environmental zones (Antaycocha) (Fig. 1.3), meaning they are well placed to analyse past agricultural practices, as well as their responses to past environmental and climate change.

Table 1.1: Description of environmental zones within the Andes. (Produced using Moseley; 1992; Sandweiss and Richardson, 2008; Kuentz et al., 2011 and Quilter, 2014).

Elevation (m a.s.l.)	**Environmental zone**	**Characteristics**	**Agriculture**
400-1000	*Rupa-rupa*	Warm humid eastern slopes of the Andes. High tropical forest that differs in composition to the lowland Amazon below.	Peanuts, chilli pepper, manioc, gourd, lima beans.
1000-3000 *(N.B. this is a maximum range, in most cases upper altitude is between 2000-2500m)*	*Yunga*	Warm forested slopes and riverine areas of the lower valleys, both on the western and eastern flank. Agriculture is possible in fertile river valleys but the principle limiting factor to cultivation is the steepness of slope and threat of erosion.	Chilli peppers, coca, avocado, common beans and fruit.
2500-3500	*Quechua*	Mild zone located on the slopes of low mountain valleys; its frost-free nature makes it the most agriculturally productive zone. Primary subsistence crops native to the area are acclimatised to altitudes of 2000-4000 m a.s.l.	Maize, squashes, cotton, papaya, passionfruit and other vegetables.
3500-4000	*Suni*	Cold damp steep slopes of valleys which receive the most rain of any zone. This is the highest arable agricultural belt.	Tubers (potatoes, oca, *ullucu*), hardy cereals including introduced grains of wheat and barley, chenopodiums (quinoa, *kañiwa*).
3800-4800	*Puna*	Generally dry grasslands on high plateaus and inter-mountain drainage basins. Dominated by low temperatures, especially extreme diurnal temperatures and variable precipitation. Main vegetation type of grassland making it natural habitat for wild camelids (vicuña and guanaco).	Key zone for pastoralism above the limit of cultivation.
4800-6768	*Janca*	Uninhabited high mountain peaks.	

Figure 1.2 Four examples of the environmental zones of the Peruvian Andes. TL: Chala TR: Yunga BL: Puna BR: Janca (Photos taken by author during fieldwork in Peru)

Figure 1.3 The Suni (TL) and Quechua environmental zones (TR-BR), the key agricultural belt from which the three sites that will be studied in this body of research are situated. Photos taken by author during fieldwork in 2018 and 2019.

1.4 Past Environmental Context

Palaeoenvironmental, and in particular palaeoecological, records can provide us with an wealth of information on how the environment has change in the past and help illuminate the controls and factors affecting these changes (Hansen, 1994; Hansen and Rodbell, 1993; Chepstow-Lusty *et al*., 1996, 1998, 2003, 2004, 2007, 2009; Chepstow-Lusty and Winfield, 2000; Weng *et al*., 2004, 2006; Branch *et al*., 2007; Schittek *et al*., 2015, 2017; Bush *et al.,* 2015). Over the past 20-30 years several important palaeoenvironmental records have been published from Peru from a range of geological archives including lakes and mire deposits, as well as archaeological archives (Hansen, 1994; Hansen and Rodbell, 1993; Chepstow-Lusty *et al.,* 2007, 2009; Chepstow-Lusty and Winfield, 2000; Weng *et al*., 2004, 2006; Branch *et al*., 2007; Beresford-Jones et al., 2009; Beresford-Jones, 2011; Winsborough *et al*., 2012; Haas *et al.,* 2013; Roucoux *et al*., 2013; Schittek *et al*., 2015, 2017; Bush *et al.,* 2015; Kelly *et al*., 2017; Caramanica et al., 2018). These cover a range of temporal scales including the last 2000 years (Chepstow-Lusty *et al.,* 2003, 2004, 2007, 2009; Winsborough *et al*., 2012; Roucoux *et al*., 2013; Schittek *et al.*, 2017), full Holocene sequences (Hansen *et al.,* 1994; Kuentz *et al*., 2011) and Late Glacial records (Weng *et al.,* 2004, 2006; Bush *et al*., 2005, Urrego *et al*., 2011).

As Peru is home to a wide range of environmental conditions, as highlighted in Section **1.3** above, it is not surprising, therefore, that these records also come from varying ecological settings. For example, from the very arid deserts of the coast, to the moisture-rich cloud forests found in the North and the East and the highland environments of the Peruvian Andes. As well as focusing on overall vegetation dynamics and changes to plant community structure and compositions, many of these records also highlight the timing of the introduction of agriculture to regions across Peru and its development over time. However, our understanding is far from complete because of spatial clustering of research sites within certain parts of both the highlands and the coast, as well as the lack of use of a diverse range of proxy methods for reconstructing environmental change. The published records currently available for Peru will be reviewed here; first through a review of the types of records found in Peru, with analysis of their methods and modes of interpretation, and their strengths and weaknesses evaluated. The discussion of the type of records will be divided into five sub themes, in order to fully critique the range of sites and record types that have been published. This is followed by an overview of the content of the records and the palaeoenvironmental information they provide about past environmental change and the development of farming in the Peruvian Andes. This review will enable identification of key research contributions, but also thematic areas that require further or new investigation, which this research hoped to address.

A review of the palaeoecological records published for Peru was carried out and a summary of these can be seen in Table 1.2. This review was greatly helped by the work of Flantua *et al.,* (2015), with the creation and updating of the Latin American Pollen Database (LAPD). The LAPD is a comprehensive inventory of publications in both peer-review journals, books and grey-literature covering the whole of South and Central America. The scope here, however, is slightly broader than just pollen records and has been expanded to include other important palaeoecological proxies, such as plant macrofossils, Non-Pollen Palynomorphs (NPPs), phytoliths and diatoms. It was also extended to include some key archaeological excavations, that have revealed vegetation, land-use and subsistence histories. This was especially the case for sites on the coast of Peru in the hyper-arid desert regions, where no lake records were available. Some of the publications included in the LAPD were unattainable due to being in grey-literature, but every effort has been made to include as many of these as possible, to get a comprehensive overview of the Peruvian palaeoecological records.

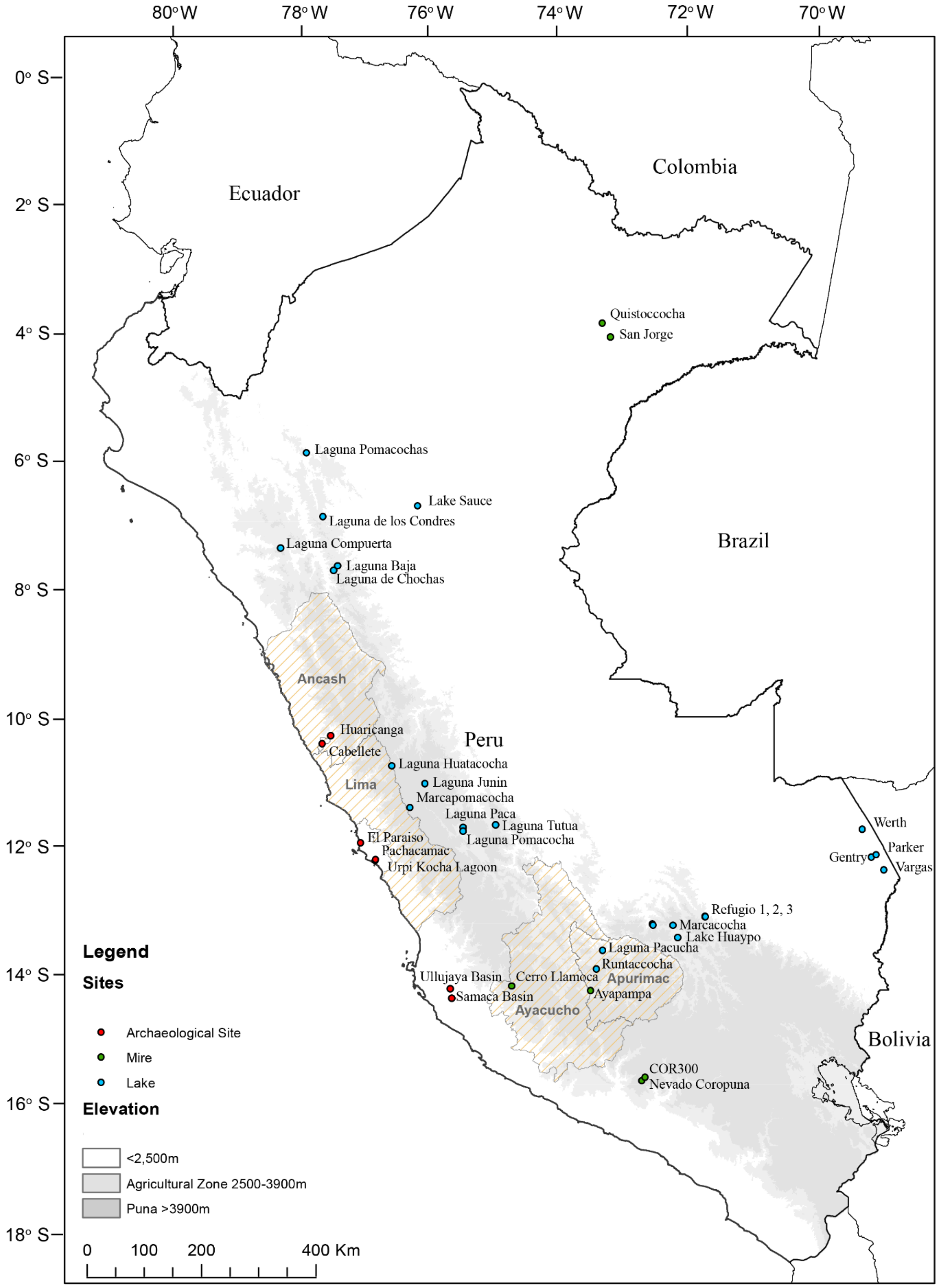


Figure 1.4: Location of palaeoenvironmental records referred to in text and Table 1. The areas shaded in yellow are regions of proposed work for this research.

Table 1.2: List of sites, papers and proxies used included in the review of palaeoecological data from Peru.

Region	**Site Name**	**Palaeoenvironmental Proxy**	**Reference**
North Peru	Quistococha	Pollen	Roucoux *et al*., 2013
North Peru	San Jorge	Pollen	Kelly *et al*., 2017
North Peru	Lake Sauce	Pollen and Charcoal	Correa-Metrio *et al*., 2010
North Peru	Lake Compuerta	Pollen and Charcoal	Weng *et al*., 2006
North Peru	Laguna de Cochas	Pollen and Charcoal	Bush *et al*., 2005
North Peru	Lake Pomacochas	Pollen and Charcoal	Bush *et al*., 2015
North Peru	Laguna de los Condores	Diatoms	Matthews-Bird *et al*., 2017
North Peru	Laguna de los Condores	Pollen and Charcoal	Åkesson *et al*., 2020
North Peru	Laguna Baja	Pollen and Charcoal	Hansen and Rodbell, 1995
North/ Central Peru	Yaguacocha, Chorreras, Cayambe, Surucucho (Ecuador) Compuerta, Baja, Huatacocha and Junín (Peru)	Pollen	Weng *et al*., 2004
Central Peru	Urpi Kocha Lagoon, Pachacamac, Cajamarquilla	Pollen and Diatoms	Winsborough *et al*., 2012
Central Peru	El Parasio	Pollen, Phytoliths	Caramancia *et al*., 2018
Central Peru	Cabellete and Huaricanga	Pollen, Starch Grains, Phytoliths and Coprolites	Haas *et al*., 2013
Central Peru	Laguna Tuctua, Laguna Paca, Laguna Junín, Laguna Pomacocha	Pollen	Hansen *et al*., 1994
South Peru	Cerro Llamoca	Pollen	Schittek *et al*., 2015
South Peru	Cerro Llamoca	Pollen, NPP, Plant Macrofossils and Charcoal	Schittek *et al*., 2017
South Peru	Samaca Basin	Pollen, Plant Macrofossils	Beresford-Jones *et al*., 2009
South Peru	Samaca and Ullyaya Basins	Pollen, Plant Macrofossils and Molluscs	Beresford-Jones, 2011
South Peru	Nevado Coropuna (6380m a.s.l.) (Peat bog core COR300 taken at 4400 m a.s.l)	Pollen	Kuentz *et al*., 2011
South Peru	Lake Pacucha	Diatoms	Hillyer *et al*., 2009

South Peru	Lake Pacucha	Pollen	Valencia *et al*., 2010
South Peru	Lake Huaypo	Pollen and Charcoal	Sublette-Mosblech *et al*., 2012
South Peru	Refugio, Refugio 2, Refugio 3	Pollen and Charcoal	Urrego *et al*., 2011
South Peru	Marcacocha	Pollen	Chepstow-Lusty *et al*., 1996
South Peru	Marcacocha	Pollen	Chepstow-Lusty *et al*., 1998
South Peru	Marcacocha	Pollen	Chepstow-Lusty and Winfield, 2000
South Peru	Marcacocha	Pollen	Chepstow-Lusty, 2003
South Peru	Marcacocha	Pollen	Chepstow-Lusty *et al*., 2004
South Peru	Marcacocha	Oribatid Mites	Chepstow-Lusty *et al*., 2007
South Peru	Marcacocha	Pollen, Charcoal and Plant Macrofossils	Chepstow-Lusty *et al*., 2009
South Peru	Marcacocha	Pollen, Oribatid Mites	Chepstow-Lusty, 2011
South Peru	Marcacocha	Sporormiella, Oribatid Mites	Chepstow-Lusty *et al., 2019*
South Peru	Marcacocha	Diatoms	Sterken *et al*., 2006
South Peru	Ayapampa	Pollen, Micromorphology	Branch *et al*., 2007
South Peru	Parker, Gentry, Vargas, Werth (Peru) Geral, Santa Mari, Saracuri (Brazil)	Pollen and Charcoal	Bush *et al*., 2007a
South Peru	Parker, Gentry, Vargas, Werth	Pollen and Charcoal	Bush *et al*., 2007b

1.4.1 Types of Records

Of the thirty-six references listed in Table 1.2, 22 of the records presented are from lake sediment sequences, five are from peat sequences and five come from archaeological excavations and their contexts. As lake sequences usually provide excellent preservation conditions for sub-fossil biological remains, especially pollen, it is not surprising this makes up the majority of the sites. However, it could be argued that same is true for peat sequences from mires, peat hummocks and peatlands (Branch *et al*., 2007; Kelly *et al.*, 2017; Kuentz, 2012; Roucoux *et al.*, 2013; Schittek *et al.*, 2015, 2017). This may therefore present an understudied resource within the Peruvian Andes, especially in areas for may be devoid of lakes but may still have wetland areas that contain undisturbed peat sequences. Peat deposits are also highly sensitive to climate change as they often receive most of their moisture from precipitation. As a result, the environmental histories recorded in these peat deposits may provide an important insight into past climate change (Kelly *et al.,* 2017).

Site Location

As well as preference in the literature to certain site types, there also appears to be a preference to site locations. From Figure 1.4, a clustering of sites in various locations across Peru can be seen. In the North of Peru, Weng *et al.*, (2004, 2006) and Bush *et al.,* (2005, 2015), as well as an earlier study by Hansen and Rodbell, (1995), have focused on records situated within the Peruvian Cloud Forests of the north. This is primarily due to cloud forests being one of the most threatened habitats to projected climate change. Data obtained from these long vegetation records can therefore provide information on past responses to climate change, which are important when developing appropriate future conservation strategies (Hillyer *et al.,* 2009; Valencia *et al.*, 2010). Studies published on the peatlands of North East Peru are also within modern day forests, however these are the forests of the Amazonian lowlands at the Eastern foothills of the Andes (Roucoux *et al.*, 2013; Kelly *et al.*, 2017).

Further south in the Central and Southern Andes these forest landscapes give way to the grasslands or *Puna* landscapes of the high Andes with many of the sites within this review being situated close to or above 3000m a.s.l. In Central Peru, these include Laguna Huatacocha, Laguna Juinín, Laguna, Tuctuna, Laguna Paca, and Laguna Pomacocha (Hansen, *et al*., 1994; Weng, *et al*., 2004). For the Southern Peruvian Andes this includes Laguna Pacucha, Marcacocha, Lake Huaypo, Refugio 1-3, Ayapampa, Cerro Llamaoca and the Nevado Corpuna peat core (COR300), (Branch *et al.*, 2007; Chepstow-Lusty *et al.*, 1996, 1998, 2003, 2004, 2007, 2009; Chepstow-Lusty and Winfield, 2000; Kuentz *et al*., 2011; Schittek *et al*., 2015,2017; Sublette-Mosblech *et al.*, 2012; Urrego *et a*l., 2011).

In the central and southern regions of Peru there are also a number of sites located along the coast within the hyper-arid desert regions, most of these are form archaeological contexts. In the south of Peru, two sites are located on the coast within the Ulluyaya and Samaca Basin (Beresford-Jones *et al.*, 2009, Beresford-Jones, 2011). For Central Peru this includes; El Parasio, Huaricanga, Cabellete, Upri Kocha Lagoon, Pachacamac and Cajamarquilla (Winsborough *et al.*, 2012; Haas *et al.*, 2013; Caramanica *et al.*, 2018). All of these are located close to the rivers that run from the high Andes down river valleys towards the coast, several of which provide the water supply for the modern-day city of Lima (Rímac, Chillón, and Lurín Valleys). This access to water most likely influenced the location of these sites, and provides a context for the preservation of palaeoecological proxies in an area where organic remains are relatively rare (Beresford-Jones *et al*., 2009). The records that do exist in riparian desert ecosystems are highly sensitive, with sharp boundaries existing in the surrounding landscape between the verdant riparian vegetation and the absolute desert. Therefore, the effects of past changes are often more easily discernible here than in the more climatically and ecologically diverse environments of the high Andes (Beresford-Jones, 2011). Figure 1.4 not only highlights a clustering of sites, but also where there are apparent regional gaps that have either not been studied or published on. For example, with exception of the recent studies in Amazonian Peru (see Kelly *et al*., 2017; Roucoux *et al.,* 2013), very few studies in North Peru have been undertaken outside of the higher elevation Andean cloud forests. However, this may be due to the visibility and accessibility of sites within the dense Amazonian forests of Northeast Peru and the deserts of Northwest Peru to the west of the Cajamarca district and Laguna Compuerta.

There is also an apparent absence of sites in the area below Laguna Baja and Laguna Chochos and above those in central Peru at El Pariso, Huaricanga and Cabellete. This falls mainly in the Department of Ancash, especially those areas in the highlands, as highlighted in Figure 1.4. Due to the paucity of sites in this region, this will form one of the three study areas for this research, enabling comparison between palaeoecological records and numerous archaeological studies that have taken place in the region (Herrera, 2005; Lane and Herrera, 2005; Lane, 2006, 2009, 2017; Lau, 2004, 2011; Szpak *et al*, 2016). It is also worth noting that of the 15 sites situated in the highlands of the Peruvian Andes, seven of these are situated above the limit for *Zea mays* (maize) growth, where only pastoral and some tuber farming takes place today. This project therefore aims to increase the number of records situated within a key agricultural belt within the highlands, both in the Ancash region, but also in the regions of Lima and Apurímac to enhance previous work in these regions (Branch *et al.,* 2007, Kemp *et al*., 2006, Valencia *et al*., 2010).

Scale

Many of the records presented in Table 1.2, present data that is obtained from a source area on a local scale (approximately two thirds). The archaeological records provide a local scale either of plant usage on site or of the vegetation in the surrounding landscape (Beresford-Jones *et al.,* 2009, 2011; Haas *et al*., 2013; Caramanica *et al.,* 2018). The mire records are also of a relatively local scale, either representing the vegetation growing on the mire surface itself or those within the immediate surrounding environment (Branch *et al*., 2007; Kuentz *et al*., 2012; Roucoux *et al*., 2013; Schittek *et al*., 2015, 2017; Kelly *et al*., 2017). Some of the lakes represent a local scale, not just because of their size but also due to the proxies that have been employed. For example, those studies including diatoms (Sterken *et al*., 2006; Hillyer *et al*., 2009; Winsborough *et al*., 2012; Matthews-Bird *et al.,* 2017). Diatoms provide a very local *in-situ* signal of environmental changes within the lakes themselves, but interpretations of these changes can provide a broader indication of the climatic conditions and human activity within the lake catchment area (Hillyer *et al.,* 2009; Matthews-Bird *et al.,* 2017; Sterken *et al*., 2006).

Some publications have overcome the issue of only being able to represent the local scale by grouping sites together within 50km or so of each other. For example, the four lakes in the Amazonia region of Southeast Peru (Perth, Gentry, Vargas and Werth), Bush (2007 a,b), and the three lakes within the highlands near Cuzco (Refugio, Refugio 2 and Refugio 3) in Urrego *et al*., (2011). Elsewhere sites are more dispersed but within the same environmental setting for example Hansen *et al.,* (1994), compared the records from Laguna Junin, Laguna Pomacocha, Laguna Tuctua and Laguna Paca, to build a regional picture across the central Peruvian Andes for the whole of the Holocene (last 11,400 years). Similarly, Sublette-Mosblech *et al.,* (2012), compared several sites within the Sacred Valley to obtain a valley wide reconstruction of environmental change since the mid-Holocene, this included Lake Huaypo, Marcacocha and Laguna Pacucha. This use of lakes in close proximity to each other allows for a landscape-scale analysis of human activity and disturbance as well as environmental change in areas that may be devoid of large lakes capable of capturing regional scale information (Bush *et al.,* 2007a, 2007b; Hansen *et al.,* 1994; Sublette-Mosblech, 2012; Urrego *et al.*, 2011).

Proxies

Within in these palaeoecological datasets, pollen is the most commonly employed proxy record of environmental change. This is often supported by charcoal analysis as well as non-palaeoecological lines of analysis such as organic matter content, magnetic susceptibility, carbonate content and stable isotopes. Out of the 36 papers only three focus on diatoms (Hillyer *et al*., 2009, Matthews-Bird *et al.,* 2017; Sterken *et al.,* 2006), and only two mention the use of phytoliths, these being archaeological deposit records and not lake or mire sequences (Caramancia *et al.,* 2018; Haas *et al.,* 2013). Phytoliths have been used elsewhere in Peruvian literature within archaeological studies in the context of discussing diet and human ecology, something that was considered out of the scope of this review. These phytolith reconstructions have primarily focused on the timing of the introduction and consumption of maize and other crops important in pre-Columbian diet and have ignored the potential archaeobotanical benefits of the phytoliths for vegetation reconstruction, especially when carried out in conjunction with pollen analysis (Perry *et al.*, 2006; Grobman *et al.*, 2012; Ikehara *et al.*, 2013). It is for this reason that phytoliths formed one of the main methods used in this research, as they can provide a wealth of information, not only on crop history, but also in helping to reconstruct past vegetation communities and environmental change.

Many of the datasets also only employed one or two proxies at a time. Pollen analysis was the most common, supported by charcoal, with only a few studies also including plant macrofossils, NPPs and Oribatid Mites as independent lines of evidence (Beresford-Jones 2011; Chepstow-Lusty *et al*, 2009, 2011; Schittek *et al*, 2017). This is especially true for archaeological contents which are often artefacts of human activity, resulting in anthropogenically altered assemblages that do not reflect a complete record of past environments; multiproxy approaches can help untangle this mixed signature (Beresford-Jones, 2011). The addition of phytoliths to studies, as well as plant macrofossils and NPPs, as a more common practice will provide more robust reconstructions from multiple line of independent evidence, representing a range of spatial scales, which allows for greater understanding of the complex network of interactions that occur within the natural environment (Birks and Birks, 2006). For example, the use of diatoms can provide some information of lake levels, as they are very sensitive to changes in water salinity, temperature and pH, and have narrow specific-species niche boundaries (Hillyer *et al*., 2009; Sterken *et al*., 2006; Winsborough *et al.*, 2010). However, pollen can also be used to help support this, for example at Lake Sauce, Correa-Metrio *et al.,* (2010), used Cyperaceae pollen levels to indicate relative changes in lake levels. During low lake stands the proportion of Cyperaceae increased as open water reduced and the marshes fringing the lake increased in area, consequently high percentages of Cyperaceae pollen were used to suggest dry climatic conditions (Correa-Metrio *et al*., 2010).

Data Resolution

Data resolution is a key factor in addressing how thorough and robust a record is. For the pollen records taken from stratified lake sequences, such as Marcacocha, Lake Huaypo and Lake Pomacocha, the data resolution is on a decadal to centennial scale, with a sample being taken on average every 50-80 years (Bush *et al.,* 2015; Chepstow-Lusty *et al*., 1996, 1998, 2003, 2009, 2011; Sublette-Mosblech *et al*., 2012). This scale of resolution is important in order to pick up short-term changes in climate regimes and even individual disturbance events, as well as the overall longer-term trends. Another strength of some of these studies is the adoption of sampling resolution based on sedimentation rates and lithologies of the deposits themselves. Hansen and Rodbell's (1995), serves as a good example, pollen was taken at 5cm intervals for the upper 380cm and 2cm interval for the basal 40cm based on the sedimentation rates (Hansen and Rodbell, 1995). Within archaeological data the chronological sequence is often not as well defined and sample resolution can be a lot coarser than the resolution achievable from geological sequences (Caramancia e*t al.,* 2018). However, they can provide a window into human-plant dynamics within a specific time scale, especially if the sites are well surveyed taking all context into account as is the case in Beresford-Jones, (2011) Caramancia *et al*., (2018), and Haas *et al*., (2013).

Dating

Precise and high-resolution dating is vital in order to reconstruct accurate vegetation histories that may then be comparable to equally well-dated climate records or cultural sequences. As highlighted by Blaauw *et al.,* (2018), many late Quaternary records have only a few radiocarbon dates, on average one date every 1,500 years, sometime less that one date per millennium (dpm). Blaauw *et al.,* (2018), suggested that a doubling of dates, to at least two per millennium, would significantly improve chronologies and increase the sequences value for reconstructing and interpreting past environmental changes on at least a centennial scale. Examples of sites with a high resolution of dates within the Peruvian records include Upri Kocha Lagoon, with 3 dpm, Quitococha, 2 or more dpm, Lake Huaypo, 2 or more dpm and Ayapampa for the top 250cm of the core with 4 dates covering the last 1000 years, allowing for more precise reconstructions of chronology (Branch *et al.,* 2007; Roucoux *et al*., 2013; Sublette-Mosblech *et al*., 2012; Winsborough *et al.,* 2012).

It is also important to consider the error margins on the dates included within the publications to ascertain how precise the dating regimes are. Modern dating techniques are relatively precise, especially if dating is carried out via accelerated mass spectrometry, with many of the publication being published in the last 10-15 years having error margins of no greater than ±60 years on their dates, proving dating of sequence from the Peru to be relatively precise (see Chepstow-Lusty *et al*., 2004, 2009, 2011; Urrego *et al.,* 2011; Roucoux *et al*., 2013; Bush *et al*., 2015; Schittek *et al.,* 2015, 2017; Kelly *et al*., 2017; Matthews-Bird *et al*., 2017). Some of the older publications have greater error margins, although this is to be expected due to advancements in AMS dating, both in their accuracy and precision. For example, Laguna Baja has error margins up to as much as ±690 years, and the sites within Hansen *et al.,* (1994) have error margins of up to 130 years, the resulting interpretations from these are likely to not be as robust, therefore (Hansen *et al*., 1994; Hansen and Rodbell, 1995).

As seen above the palaeoecological literature currently available from Peru covers a wide range of environmental setting, temporal and spatial scales and uses a range of proxies. There are, however, a paucity of records in some areas, for example the central-northern Highlands in Ancash, whilst other would benefit from multiple records in within a single region, for example Cerro Llamacocha is the only record situated in the Ayacucho Region. Gaining additional palaeoecological records, especially in the highland areas, is key in order to understand system sensitivity and environmental responses to climate change. Due to the very nature of the Andes, there are strong environmental gradients over a relatively short distances, all of which are very sensitive to climate change, allowing you to assess how several different ecosystems will respond, sometimes within the same study area. The use of multiple lake or peat records over this gradient may be extremely useful to obtain a regional view of past environmental histories over a range of ecosystems. It is also important that future studies in this region use as many lines of independent evidence as possible to help corroborate their results and use additional palaeoecological proxies, opposed to just pollen and charcoal, as well as potentially combining this with geochemical and standard geoarchaeological approaches. This analysis also needs to be carried out at high resolution and be matched by high resolution chronological sequences to make environmental reconstructions as temporally accurate as possible.

1.4.2 Environmental Change and the Development of Farming

Favourable conditions for the development of agriculture followed the mid-Holocene arid event (5000 cal yrs BP), with the transition to moister conditions, allowing agriculture to flourish across many parts of Peru. An increase in frequency of El Niño from 3000 cal yrs BP, and corresponding increases in moisture availability in the highlands, helped with this development in farming (Sandweiss *et al*., 2007). Quinoa (Chenopodiaceae/Amaranthaceae) is amongst the first cultivated crops to appear within palaeoenvironmental records at around 5,600-5,500 cal yrs BP (3650-3550 BC) (Weng *et al*., 2006). A gradual introduction of maize later accompanied this across the Andes from 3500-2400 cal yrs BP (1550-45 BC), with maize occurring in the Marcacocha record at ~2650 cal yrs BP (700 BC), and at Laguna La Compuerta at 2,600 cal yrs BP (650 BC) (Chepstow-Lusty *et al*., 2003; Weng *et al*., 2006). The introduction of domesticates is often recorded with a reduction in forest taxa, such as *Alnus* and *Polylepis*, an opening of the landscape and increase abundance of *Ambrosia*, a herbaceous weed used to stabilise soil conditions (Hansen and Rodbell, 1995; Chepstow-lusty *et al*., 2003; Weng *et al*., 2004, 2006; Valencia *et al.,* 2010). In some cases, this opening of the landscape was also concurrent with an increase in fire frequency, as recorded in charcoal records from many sedimentary sequences across Peru (see Chepstow-Lusty *et al*., 2004; Bush *et al*., 2007b; Sublette-Mosblech *et al.*, 2007; Urrego et al., 2010). As well as arable farming practices, camelid herding was often combined in an agro-pastoral mixed agricultural regime, as evidenced by a rise in Oribatid Mite abundances from 2650 cal yrs BP (700 BC) (Chepstow-Lusty *et al*., 2011).

Following the introduction of a full suite of cultivars to both the highlands and the coast of Peru agricultural activity intensified during certain periods of the last 2000 years. Often in relation to the development of complex societies, who were seemingly able to maintain high levels of agricultural productivity for many decades. On the coast south of Lima, intensification started with the development of the Nasca Culture (2150-1150 cal yrs BP/ 100 BC-AD 800), with maize reaching maximum abundance during the Early Intermediate Period (EIP). The high abundance of maize pollen associated with the Samaca archaeological site during this time suggests it was being grown within the immediate vicinity of the site, as maize pollen grains are large and are not transported very far from source (Silverman and Proulx, 2008; Beresford-Jones, 2011). The start of the Early Intermediate Period also saw agricultural activity increase in the region of Coropuna in the southern Peruvian Andes. An increase in abundance of *Ambrosia* coincided with increases in Solanaceae and Chenopodiaceae/Amaranthaceae, which, along with the archaeological record in the area suggests a high human presence and intensification in agricultural productivity (Kuentz *et al*., 2012).

In some areas of the highlands, intensification occurred later. At Marcacocha (Cusco Region), the beginning of the first century AD marked a shift in agricultural productivity, with a decline in evidence for sustained agriculture within the pollen record. This is concurrent with evidence for supressed cool temperatures within the pollen data, which may have led to low organic productivity (Chepstow-Lusty *et al.,* 2009). Following 1850 cal yrs BP (AD 100), Chenopodiaceae/Amaranthaceae disappears from the pollen record and does not recover above minor background levels, despite minor resurgences in agricultural activity at the end of the Early Intermediate Period/ beginning of the Middle Horizon ~1550 cal yrs BP (AD 500) (Chepstow-Lusty *et al.,* 2003, 2011). This corresponds with the Wari initiating a period of long occupation in the Lucre Basin and the construction of an administrative centre at Pikillacta, 30km south-east of Cuzco (Chepstow-Lusty *et al.,* 2004, 2011). Similarly, increases in agricultural activity occurred in the Chicha-Soras Valley, Apurímac. Ayapampa mire recorded evidence for maize cultivation and an increase in mineral matter entering the basin, likely reflecting activities such as construction of irrigated terraces, and increased cultivation by the Wari between 1350-950 cal. yrs. BP (AD 600-1000) (Branch *et al*., 2007). A later peak in agricultural activity at Marcacocha during the Middle Horizon (MH) was centred around 1050 cal yrs BP (AD 900), with minor increases in populations of Chenopodiaceae/Amaranthaceae, maize and Oribatid Mites, suggesting an increase of pastoralism as well as arable agriculture during the final stages of the Wari imperial expansion (Chepstow-Lusty *et al*., 2003; 2011).

On the coast, in the Nasca region, the beginning of the Middle Horizon was most abundant archaeologically. Between 1450-1350 cal yrs BP (AD 500-600), a complete suite of south coast plant domesticated were being grown including gourds, maize, beans, peanuts, guava and chillies (Beresford-Jones, 2011). However, towards the end of the Middle Horizon 1150-950 cal yrs BP (AD 800-1000) the evidence for cultivated plants becomes more limited following the decline of the Nasca culture and associated decline in population, as seen in the abandonment of settlements at Pachacamac and Cajamarquilla (Segura and Shimada, 2010; Beresford-Jones, 2011; Winsborough *et al*., 2012).

A notable change occurred in pollen records from the highlands during the following Late Intermediate Period around 950-850 cal yrs BP (AD 1000-1100), for example at Marcacocha, Laguna Tuctuna, Laguna Paca, Laguna Pomacocha, Refugio 1-3, Lake Compuerta, Baja, Huatacocha and Junín. The reoccurrence of *Alnus* in these records may have reflected an upslope migration in response to elevated temperatures at higher altitudes, due to the Medieval Climate Anomaly (MCA) (Hansen and Rodbell, 1993; Hansen, 1994; Chepstow-Lusty *et al*., 2003, 2009, 2011; Weng *et al*., 2004, 2006; Urrego *et al*., 2010; Sublette-Mosblech, 2012). This MCA signal is recorded in the Poaceae pollen record from Cerro Llamoca, a sudden reduction in Poaceae correlates with a decrease in lowland populations and focus on settlements shifting to the middle and upper valley slopes, to counteract the impacts of reduced river runoff down slope (Schittek *et al.,* 2016).

In Refugio (1-3) records for the MCA signal also corresponded with the highest charcoal peak in the record around 950 cal yrs BP (AD 1000), an upslope migration of Andean forest taxa would also have led to an increase in fuel availability which consequently presents itself as a peak in burning activity (Urrego *et al*., 2010). However, *Alnus* populations remained relatively constant during the Late Intermediate Period (LIP), despite rapidly growing human populations and increased woodland exploitation, suggesting controlled agroforestry practices may have been employed (Chepstow-Lusty and Winfield, 2000). The rise of *Alnus* continued into the Late Horizon, where it reaches its peak concentrations in the pollen record from Marcacocha. This may reflect accelerated agroforestry activities around the basin as this species of tree represented one of the most important trees, both economically and symbolically, for the Incas (Chepstow-Lusty *et al*., 2009).

An increase in temperature during the LIP also led to a key zone within the Andean highlands becoming increasingly more important for agricultural activity (2800-3600m a.s.l.). As a result, a period of terrace expansion and reconstruction was also recorded in the Ayapampa record, Apurímac Region, with increased erosion in the landscape around the basin reflecting the construction, or reconstruction of Middle Horizon terraces, during the LIP. This period of landscape erosion also coincides with a temporary phase of maize cultivation (Branch *et al.*, 2007). At Marcacocha, an increased preference for crops such as maize overrode the importance of camelid herding, as camelids were moved to higher pastures, away from the key agricultural zones, to decrease competition for land and resources (Chepstow-Lusty *et al*., 2009).

At the end of the Late Horizon (LH), with the transition to the Colonial Period, and the occurrence of the Spanish conquest, a further shift in agricultural activity occurred. At Parker, Gentry, Vargas, and Werth in the southern Amazonian region of Peru, this resulted in a reduction in charcoal and an absence in crop indicators in the pollen record (Bush *et al*., 2007b). The sites around these lakes were likely abandoned following conquest, as supported by the palaeoecological record. The last millennium of the record represents a period of highest sustained lake levels for the whole of the Holocene, with the last 800 years being the wettest in the record, as a result the charcoal concentrations remain very low throughout the Colonial Period to present day (Bush *et al*., 2007a, 2007b). An increase in moisture is also recorded in the San Jorge peat accumulation record in the northern Peruvian Amazon, here peat accumulation rate increased after 400 cal yrs BP (AD 1550), with the site receiving its water primarily from rainfall at this time, indicating an increase in precipitation/rainfall (Kelly *et al*., 2017; Swindles *et al*., 2018). At Marcacocha, site abandonment and population reduction were also seen, with the Oribatid Mites indicating a rapid reduction in camelid livestock immediately following the Spanish Conquest (Chepstow-Lusty *et al*., 2007). Following 350 cal yrs BP (AD 1600), the record reflects a re-establishment of rural communities and a gradual return to agricultural areas, this time however accompanied by Old-World herbivores such as sheep, goats, horses and cattle opposed to camelids (Chepstow-Lusty *et al*., 2007). Lake Pacucha to the west of Marcacocha also recorded a rapid decline in crop and *Alnus* abundance following the conquest, with a reduction in fire frequency reflecting the much less intensive use of the landscape and the associated decrease in populations (Valencia *et al*., 2010).

1.5 Modern and Past Climatic Drivers and Environmental Responses in Peru

A number of global systems, including the El Niño Southern Oscillation (ENSO) and the Inter-tropical convergence zone (ITCZ) and local systems, such as the South American Summer Monsoon (SASM), control the climate of Peru. The Inter-tropical convergence zone is the zone near the equator where the northeast trade winds and the southeast trade converge to create an area of convective rain showers and thunderstorms. The ITCZ is not stationary throughout the year; however, it migrates towards the warmest surface areas. In the winter (austral summer), this is the Southern Hemisphere where solar radiation is strongest (Maasch, 2008). This causes a southward displacement of the ITCZ, at the same time South America experiences the South American Summer Monsoon, this in turn brings increased precipitation to the Southern Hemisphere. The further southwards the ITCZ is positioned, the more intense the SASM appears to be (Vuille *et al*., 2012). In summer (austral winter), the opposite is true, and the ITCZ moves to the north, reaching its most northerly position by June (Maasch, 2008).

During the austral winter, conditions in Peru are generally dry. This system is largely responsible for the seasonality in South America, with the switching of the ITCZ from winter to summer considered to be monsoon like due to the resulting extremes in weather (Garreaud *et al*., 2009). The SASM is responsible for more than 70% of the annual precipitation falling over tropical South American annually, this system carries with it water vapour which originates over the tropical Atlantic Ocean. As this moisture is transported across lowland South America there is a very small temperature gradient, this makes the application of $^{\partial}$18O suitable for palaeoprecipitation reconstructions, as opposed to being an indicator for past temperature regimes (Campos *et al*., 2019; Vuille *et al*., 2012). Despite the wide geographical dispersion of the paleoclimate records across Peru (see Fig. 1.6), these records tend to present a common signal throughout the Late Holocene which is likely due to their commonality of upstream rainout over the amazon basin (Vuille *et al*., 2012; Campos *et al*., 2019; Hurley *et al*., 2019; Orrison *et al*., 2022) and consequently these records have proven to be a good indicator of past changes to intensity of the SASM (Vuille *et al*., 2012; Campos *et al*., 2010; Orrison *et al*., 2022). It is also likely therefore that past precipitation regimes at the three sites within this thesis reflect those happening elsewhere in the Andes. Huarca and Antaycocha are particularly well placed with relatively local palaeoclimatic records (Fig. 1.6), although signatures recorded in the other more distant records are likely to be highly relevant to the three wetland study sites also due to the connectivity across records for the Late Holocene.

The other main system at play for Peru is the ENSO cycle, made up of El Niño and La Niña events. El Niño years usually result from an increase in sea surface temperatures (SST), which disrupts the Peruvian current bringing cold water to the surface off the pacific coast (Quilter, 2014). Under ‘normal’ conditions, this cold current interacts with the moist sea air at the pacific coast and rises to create rain in the Highlands. During El Niño, the different in temperature between the sea and the land is less and results in increased rainfall at the coast, which can lead to severe flooding (Garreaud *et al*., 2003; Maasch, 2008; Quilter, 2014). Conversely, La Niña can see very dry conditions on the coast and much wetter conditions in the highlands. La Niña results from abnormally cold SST in the eastern Pacific (Garreaud *et al*., 2003; Maasch, 2008; Quilter, 2014). Modern El Niño conditions were established by 3800-3200 cal yrs BP; however, no two ENSO events are the same and they can occur on different timescales depending on how severe the conditions are to be counted as a true El Niño event (Sandweiss, *et al.,* 2001; Quilter, 2014; Fehren-Schmitz *et al*., 2014). Large-scale teleconnections across South America mean dynamics of SASM are also affected by ENSO variability, however the nature of these interactions over decadal to centennial timescales is still not fully understood (Henke *et al*., 2017: Kock *et al*., 2020). It is possibly that Antaycocha, in the Chillón Valley, on the western flank of the Andes, may have experienced more influence by ENSO in the past than the other two sites, due to its proximity to the Pacific Coast. In a recent study it was identified that precipitation on the flank of the western central Andes was primarily sourced from the Pacific Ocean, which may also be true for periods in the past (Aron, 2021), this is worth considering in the interpretation of environmental change at Antaycocha.

In terms of past-climate change, a growing body of palaeoclimate research has been published from the Peruvian Andes (e.g., Rein *et al*., 2005; Bird *et al*., 2011; Vuille *et al*., 2012; Kanner *et al.* 2013; Apaéstegui *et al*., 2014; Bustamante *et al*., 2015; Stansell *et al,* 2017; Thompson *et al*., 2017) (Fig. 1.5 and 1.6), presenting records from a range of archives including lakes, peat bogs, ice cores, caves (speleothems) and marine sediments, and proxies, such as $^{\partial}$18O and in the case of the Lima marine core, % concentration of lithics. These records have provided evidence for Southern American expressions of global climatic events including the Medieval Climate Anomaly (MCA; 1050-700 cal yrs BP/ AD 900-1250), Little Ice Age (LIA; 550-100 cal yrs BP/ AD 1400-1850), and the Common Warm Period (CWP; AD 1850- present) as well as ENSO events. They also reveal the impact of the position of the ITCZ and its influence on the strength and weakness of the SASM in the past. Here the changing climatic regimes of the past 2000 years will be summarised with consideration of the impact this may have had on pre-Hispanic societies.

The emergence of highland dominance and regional states in the Central Andes began after AD 200 during a period of El Niño activity and variable precipitation, with the swings of climate change seemingly having influence over the development and collapse of complex societies (Kendall, 2013). Early Intermediate Period development of settlements at higher altitude such as the Recuay culture in the Callejón de Huaylas, may have been aided by more amenable climatic conditions from 1650-1450 cal yrs BP (AD 300-500), as seen in the more positive $^{\delta}$18O values of Huascarán ice core data, and in the Huagapo cave record (Fig. 1.5) (Thompson *et al.,* 2000; Kanner *et al*., 2013). From 1450 cal yrs BP (AD 500) climatic records from the Peruvian Andes indicate an increase in precipitation and the beginning of a pluvial period with the transition to the MH. (Bird, *et al*., 2011; Apaéstegui *et al*., 2014; Bustamante, *et al*., 2015). Palestina cave record shows an increase in precipitation from 1370-1230 cal yrs BP (AD 580-720) (Fig. 1.5), while Shatuca cave record shows a wet excursion in $^{\delta}$18O at 1500 years before 2000 (Apaéstegui *et al.,* 2014, Bustamante *et al*., 2015). This may have aided higher agricultural productivity during at a time when societies such as the Wari were developing their agricultural systems.

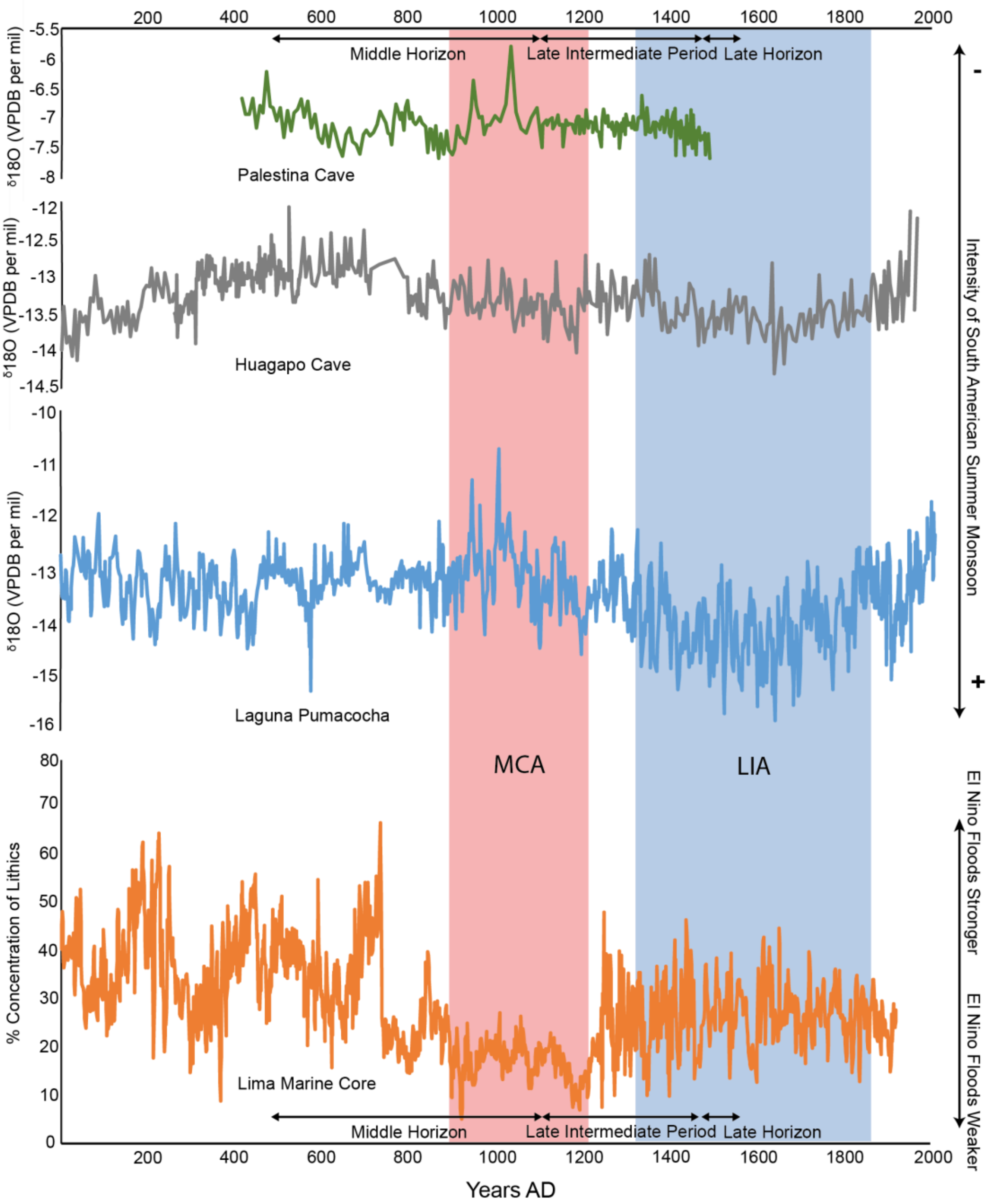


Figure 1.5: Palaeoclimatic data from Palestina Cave (Apaéstegui et al., 2014), Huagapo Cave (Kanner et al., 2013), Laguna Pumacocha (Bird et al., 2011) and Lima Marine Core (Rein et al., 2005). Dates presented in AD for comparison with archaeological chronology.

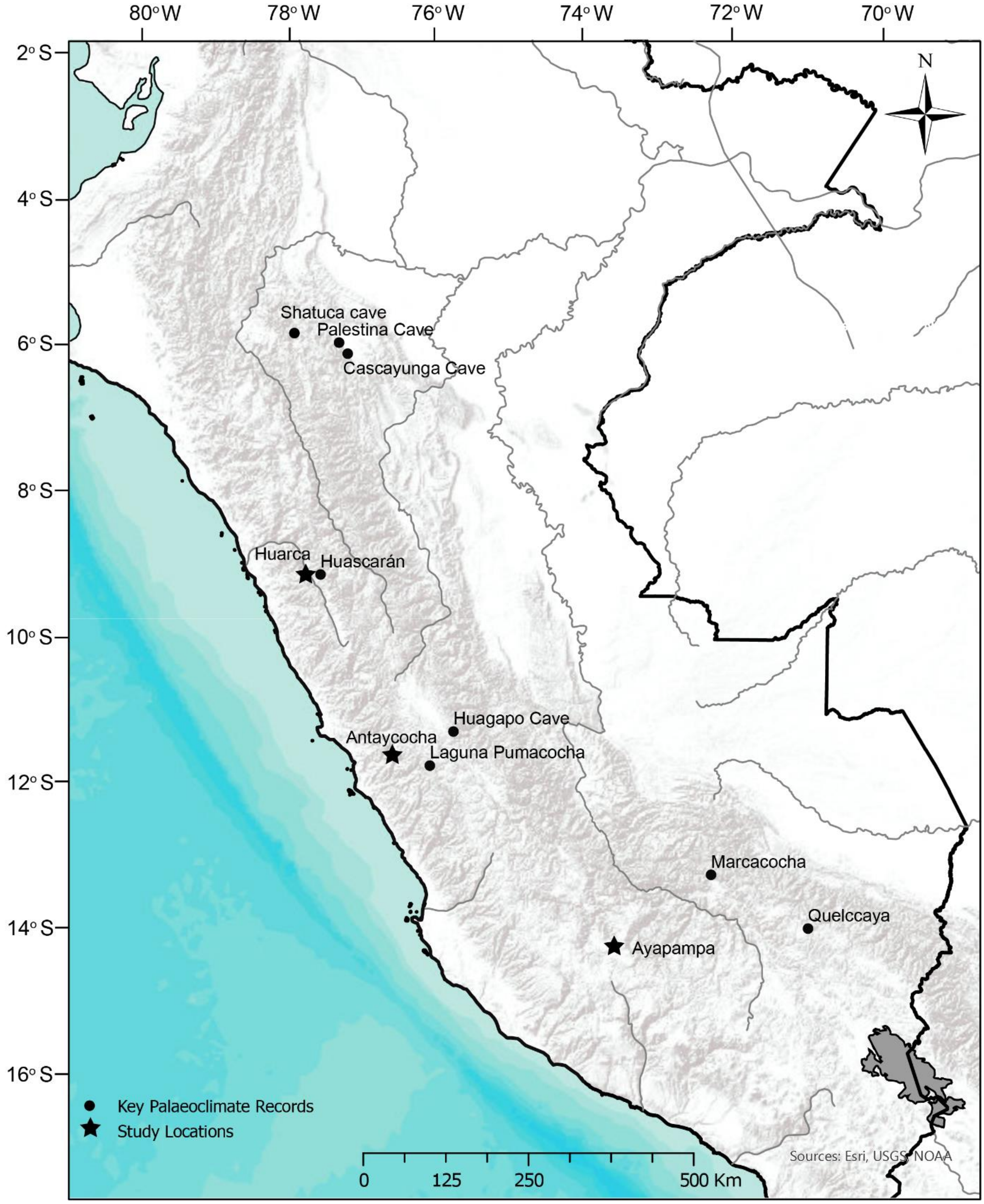


Figure 1.6 Palaeoclimate records mentioned in text alongside the locations of the three study sites within this body of research.

Towards the end of the MH however, there is a shift to more positive $^{\delta}18O$ values within the Laguna Pumacocha and Palestina Cave records (Fig. 1.5) with a prolonged period of marked aridity occurring from 1050-850 cal yrs BP (AD 900-1100) (Bird *et al*., 2011; Apaéstegui *et al.,* 2014). This also coincides with dust event signals in the Huascarán and Quelccaya ice core records, and a reduction in lake levels at Marcacocha (Thompson *et al*., 2013, 2017; Chepstow-Lusty et al., 2003). This dry signal has been accredited to the Southern Hemisphere (SH) expression of the MCA, and a weakening of the SASM, as well as a more northly position of the ITCZ (Haug *et al*., 2010; Bird *et al*., 2011; Vuille *et al*., 2012; Kanner *et al*., 2013; Apaéstegui *et al*., 2014). The Quelccaya ice core record has been cited to present an ENSO signature (Thompson *et al*.,2013), influenced by the pacific to the west, as well as a SASM signal (Hurley *et al*., 2019), despite its position relatively inland (Fig. 1.6). This makes untangling the influence on the $^{\partial}$18O values recovered from the Quelccaya ice cap rather complicated, however recent analysis of the proxy system model (Hurley *et al*., 2019), show that two-thirds of the $^{\partial}$18O signal is attributed to varying SASM intensity (Hurley *et al*., 2019; Sandweiss *et al*., 2020), and so can be used here to support the theory behind the main forcing factors in the SH expression of the MCA.

A reduction in precipitation from around 1150 cal yrs BP (AD 800) and prolonged aridity from 1050-850 cal yrs BP (AD 900-1100), including a distinctive “double peak” at ~1016 cal yrs. BP (AD 934) and ~911 cal yrs BP (AD 1039), has been attributed by many to be the cause for the collapse of MH agricultural societies, most notably those of the Wari and Tiwanaku civilisations. Agriculture may have become unsustainable at this time due to drought, and consequently led to failed crop yields, food shortages, and agricultural terrace abandonment (Ortloff and Kolata, 1993; Binford *et al*., 1997; Branch *et al*., 2007). However, it is difficult to distinguish climate change as a sole factor for collapse when many other factors were likely at play (e.g., warfare, intra-polity conflict, and shifting ideological beliefs) (Middleton, 2017), it is likely that climatic changes in conjunction with societal pressures resulted in the downfall of the large empires of the Middle Horizon. Although the MCA appears to be very arid from the speleothem records, it was not as dry as the mid-Holocene aridity period between 5000 -7000 cal yrs BP (Kanner *et al*., 2013).

In the following LIP increased precipitation and available moisture, as illustrated by the Laguna Pumacocha record (Fig. 1.3), led to a key altitudinal zone becoming increasingly more important for agricultural activity: 2300-3500m. From ~600 cal yrs BP (AD 1350), there is an increase in El Niño frequency recorded in a Peruvian marine record, from an apparent centennial to decadal ENSO flood events (Rein *et al*, 2005). This coincides with the onset of the LIA in Peru which varies considerably between archives but collectively they indicate a range from ~625-70 cal yrs BP (AD 1325-1880). The onset of the LIA was evidenced by minimum values of $^{\delta}$18O being observed in the Palestina and Huagapo speleothem records as well as the Laguna Pumacocha record, between 470-350 cal yrs BP (AD 1480-1600) (Bird *et al*., 2011; Kanner *et al.*, 2013; Apáestegui *et al.,* 2014). At Quelccaya, changes in geochemistry and a reduction in $^{\delta}$18O values indicate a period of higher precipitation between

430-70 cal yrs BP (AD 1520-1880) (Thompson *et al*., 2013; 2017). This corresponded to a substantial increase in SASM activity from 625-100 cal yrs BP (AD 1325-1850) and is synchronous with the cold event in the Northern Hemisphere during the LIA that led to a forcing of ITCZ to its most southerly position (Haug *et al*., 2001; Bird *et al*., 2011; Vuille *et al.,* 2012; Orrison *et al*., 2022). Following the LIA, lake, cave and ice core records in the Andes (Pumacocha, Huagapo, Huascarán and Quelccaya) show a strong upward trend in $^{\delta}$18O values with a return to drier conditions towards present day and the Common Warm Period (Bird *et al*., 2011; Kanner *et al*., 2013; Thompson *et al.*, 2013; 2017).

At present day, the SASM is relatively week in intensity with a reduction in rainfall, as well as reduced predictability of the timing of the wet season, being experienced in many parts of Peru. Therefore, assessing the effect of periods of decreased rainfall in the past, such as during the Middle Horizon, on agricultural systems may provide valuable information for how these systems may respond in the future if current climatic conditions persist.

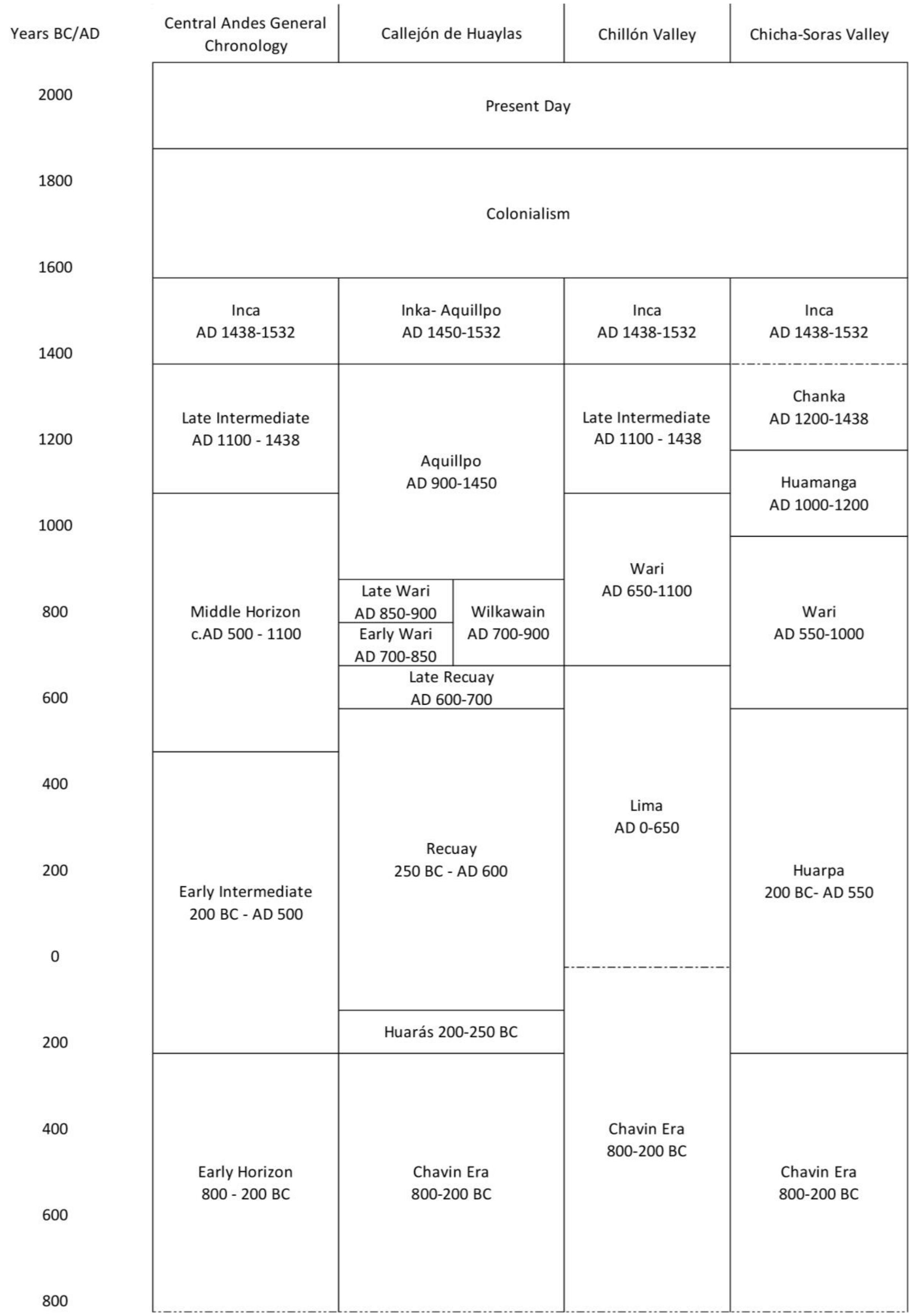
1.6 Archaeology of Peru

The master chronological sequence for Peru is well developed and has remained largely unchanged over the past two decades. Although domesticated crops and animal have been present in Peru since the mid-Holocene, the primarily focus of this study is on the last 2500 years, since the Early Intermediate Period (from 2100 cal yrs BP/ 200 BC) up to present day. This timeframe encompasses the main developments in agricultural techniques and changes in the state-scale cultures. The MH, for example, was the first time that large areas of the central-Andes were connected by inter-regional exchange, shared cultural influence and migration and the first time that agricultural was centrally controlled (Jennings and Yépez Alvarez, 2015). Table 1.3 outlines the main chronological framework for the Central Peruvian Andes, alongside that for the three study regions: the Callejón de Huaylas, Chillón Valley and Chicha-Soras Valley. The chronology differs on a regional scale as different cultures were often present within the same horizons or periods. For example, the Wari and Tiwanaku cultures both sit within the MH, with the Wari being present in the central highlands and the Tiwanaku around Lake Titicaca (Isbell, 2008). These also overlapped with the Nazca culture on the coast. The exact timing of the transitions between periods and horizons also differs with geographical location, for example in the Callejón de Huaylas, the MH starts later and ends earlier than the general chronology (Lau, 2016). The LH also starts later in the Northern Highlands, due to the time taken for the spread of the Inca Empire to reach the north from the Cuzco region (Isbell, 2008; Lau, 2016). For more detail on the archaeology and chronology of the Callejón de Huaylas, the Chillón Valley and the Chicha-Soras valley see Sections **3.1.1**, **4.1.1**, and **5.1.1**.

Very different social regimes existed within the different phases with an alternating pattern of horizons and intermediate periods. In the Central Andes pre-Middle Horizon urban centres were organised around different ceremonial centres, however, during the MH under Wari influence, this practice of small and rural proved to be less viable as larger settlements emerged (Valdez and Valdez, 2017, 2013). Activities within these larger scale centres became integrated and organised into different zones with areas dedicated to craft production, merchants, military, religious personals, and bureaucrats (Kendall, 2013). This was followed by the LIP, which witnessed a decentralization of these key policies with large-scale changes taking place in the structure of societies and in practices associated with agricultural and economic production (Tung, 2008). In the years leading up to the Inca conquest, further social reorganisation took place that aided the development of the Inca Empire. During the LH the food security provided by increasingly sophisticated terrace systems supported the development of elaborate administrative centres (Moseley, 1992; Kendall, 2013). Inca practices continued until the Spanish conquest, at the start of the Colonial Period, around 418 cal yrs BP (AD 1532) (Covey, 2008). The Spanish conquest brought drastic social changes leading to the destabilization of the cultural and knowledge system sustaining previous agricultural success (Kendall, 2013). In the immediate term the Spanish could utilize the decade’s worth of food stored in Incan storehouses, due to the agricultural system being so productive it created ample surplus (Kendall, 2013).

Differences within levels of control and co-operation in a society is likely to affect the resilience of traditional agricultural systems, as well as the resilience of the communities farming them, and is important to consider when assessing the stability of traditional agriculture systems to changes in human activity and environmental conditions. Of particular importance to this study when considering the archaeological record, is the socio-economic factors that may influence the stability of agricultural systems, these will be explored further when evaluating the results.

Table 1.3: Cultural Chronology of Central Peru in comparison to the three study regions: Callejón de Huaylas, Chillón Valley and Chicha-Soras Valley (Adapted from Meddens and Branch 2010; Finucane et al., 2007; Kemp et al., 2006; Lau, 2011, 2016).



Years BC/AD	Central Andes General Chronology	Callejón de Huaylas		Chillón Valley	Chicha-Soras Valley
2000	Present Day				
1800	Colonialism				
1600	Inca AD 1438-1532	Inka- Aquillpo AD 1450-1532		Inca AD 1438-1532	Inca AD 1438-1532
1400	Late Intermediate AD 1100 - 1438	Aquillpo AD 900-1450		Late Intermediate AD 1100 - 1438	Chanka AD 1200-1438
1200					Huamanga AD 1000-1200
1000	Middle Horizon c.AD 500 - 1100			Wari AD 650-1100	Wari AD 550-1000
800		Late Wari AD 850-900	Wilkawain AD 700-900		
		Early Wari AD 700-850			
600		Late Recuay AD 600-700		Lima AD 0-650	
400	Early Intermediate 200 BC - AD 500	Recuay 250 BC - AD 600			Huarpa 200 BC- AD 550
200					
0				Chavin Era 800-200 BC	
200		Huarás 200-250 BC			
400	Early Horizon 800 - 200 BC	Chavin Era 800-200 BC			Chavin Era 800-200 BC
600					
800					

1.7 Aims, Objectives and Research Questions

The aim of this research is to use a combined palaeoecological, paleoenvironmental, and archaeological approach to characterise the socio-economic responses to climate and environmental change in three regions in Peru: Ancash, Lima, and Apurímac. In order to meet this aim, the following objectives were undertaken:

1. Conduct field-based investigations to collect palaeoenvironmental samples from the chosen study sites,
2. Ascertain the age of the sediments though radiometric dating,
3. Conduct laboratory investigations to reconstruct vegetation histories, past environmental regimes, and land use changes,
4. Correlate palaeoenvironmental records with published palaeoecological, paleoclimate and archaeological data,
5. Evaluate the impact of climate and environmental change on traditional agriculture and the surrounding landscape.

Considering the previous research (See Sections **1.4, 1.5, 1.6**), key socio-environmental events have been identified within the archaeological and paleoclimate records, each of these will be considered below, before key research questions are posed for consideration when interpreting and discussing the results of this study.

During the late, Early Intermediate Period more amenable climatic conditions from ~1450-1650 cal yrs BP (AD 300-500), as seen in the more positive $^{\delta}18O$ *values of Huascarán ice core data, and in the Huagapo cave record, may have aided the establishment of high-Andean agricultural, with warmer temperatures at higher altitudes. At the transition to the MH, an onset of wetter conditions prevailed from 1150-1350 cal yrs BP (AD 580 – 800), with more negative isotope values recorded within several paleoclimate proxies. This climatic change may have influenced the development of irrigated agricultural systems and construction of agricultural terraces as a cultural response to the changing environmental conditions. These adaptations led to a highly productive agricultural system during the MH.*

- Is there evidence for increased agricultural activity in the palaeoecological and geochemical records during this pluvial period of the MH?
- Is there evidence for increased landscape erosion related to construction of agricultural systems?
- Is there any evidence for fire use as an agricultural management tool?

During the second half of the MH and in the transition into the LIP (~850-1150 cal yrs BP/ AD 800-1100) a shift to arid conditions, with a reduction in precipitation, recorded in the speleothem and lake records from Peru. This coincides with a reduction in cultural and agricultural activities, as Wari influence across the highlands comes to an end. These arid conditions prevailed throughout the LIP until ~600 cal yrs BP (AD 1350).

- What impact did the societal and climate changes between 850-1150 cal yrs BP (AD 800-1100) have on agricultural systems in surrounding landscapes?
- Are the drier conditions from 1150 cal yrs BP (AD 800) visible within the palaeoenvironmental records and is there any evidence for major hydrological changes within the wetlands?
- Is there a signature within the palaeoecological and geochemical records from the three sites for a reduction in agricultural activity during the transition from the MH to the LIP?

Towards the end of the LIP (~650 cal yrs BP/ AD 1300 onwards), there was a period of intense agricultural activity with renewed construction, as well as redevelopment of pre-existing agricultural systems. This late, Late Intermediate Period re-expansion of agricultural may have been a cultural response to increased frequency and variability of ENSO events from ~650 cal yrs BP (AD 1300), as well as an increase in population.

- In relation to the known changes in cultural activity during the late-Late Intermediate Period, is there any evidence for changes in human land use across the three study areas?
- Do we see an intensification of agricultural activity during the late, Late Intermediate Period within the pollen and phytolith records?
- In relation to increased agricultural activity, and reconstruction of agricultural systems, is there evidence for greater landscape erosion within the ITRAX records at this time?

Increased agricultural activity continued into the LH under Inca supervision, during a period of relatively stable climatic conditions. Increased temperatures at higher elevation also led to a recolonisation of Alder at higher altitudes from the late, Late Intermediate Period into the Late Horizon. The prevalence of Alder within palaeoecological records, despite evidence for increased agricultural activity, has led some scholars to suggest LH societies practiced agroforestry. This hypothesis is supported by a reduction in Alder population following the Spanish conquest.

- Due to the significance of *Zea mays* as an Incan food staple, can we identify maize growth from the pollen and phytolith records during this time?

- Do we see an increase in Andean forest taxa during this time that may be linked to agroforestry practices?

Towards the end of the LH and post-Conquest climatic conditions deteriorated, with a noticeable increase in precipitation recorded in paleoclimatic records, during a Southern Hemisphere expression of the LIA around 350 cal yrs BP (AD 1600). Post-conquest there was a reduction in the presence of cultivars and agricultural indicates with palaeoecological records across Peru, as well as a reduction in fire and camelid herding practices. This reduction in agricultural activity was most probably influenced by the wetter conditions and a reduction in population.

- During this prolonged pluvial period, is there evidence for changes in hydrological conditions of the basins?
- With the reduction in human and agricultural activity, is there a signature for reduced activity within the palaeoecological and geochemical records? For example, a reduction in landscape erosion within the µXRF records and/or a reduction in cultivars within the palaeoecological records.

1.8 Study Areas

In order to meet the aims and objectives outlined above three study regions were chosen, Ancash, Lima, and Apurímac (Fig 1.7), these three regions represent a north-south transect down the Peruvian Andes and allow for the study of socio-economic responses to Late Holocene climate change in three varied environments. Ancash, home to the tallest peaks and some of the largest glaciers in Peru relies heavily on glacier meltwater for water for irrigation and domestic consumption. Lima and Apurímac are without any major glaciers and present the opportunity to study a post-glacial melt system where water largely is sourced from seasonal rainfall and underground aquifers. Within each region, one valley was selected that was known to be agriculturally productive both at present, and in the past and which had suitable sites for the recovery of sediment cores for palaeoenvironmental analysis. For the Ancash Region, The Santa Valley or Callejón de Huaylas, for the Lima Region, the Chillón Valley, and for Apurímac the Chichas-Soras Valley. Within each of the valley's a wetland was selected to analyse its palaeoenvironmental history. Wetland sites were chosen as they are good archives for past environmental histories as they provide excellent preservation conditions for both micro and macro fossils (see **Chapter 2** for more details), they can also be highly sensitive to changes within the surrounding basins and the catchment more broadly, these include changes in human land use and environmental changes resulting from changes in climatic conditions.

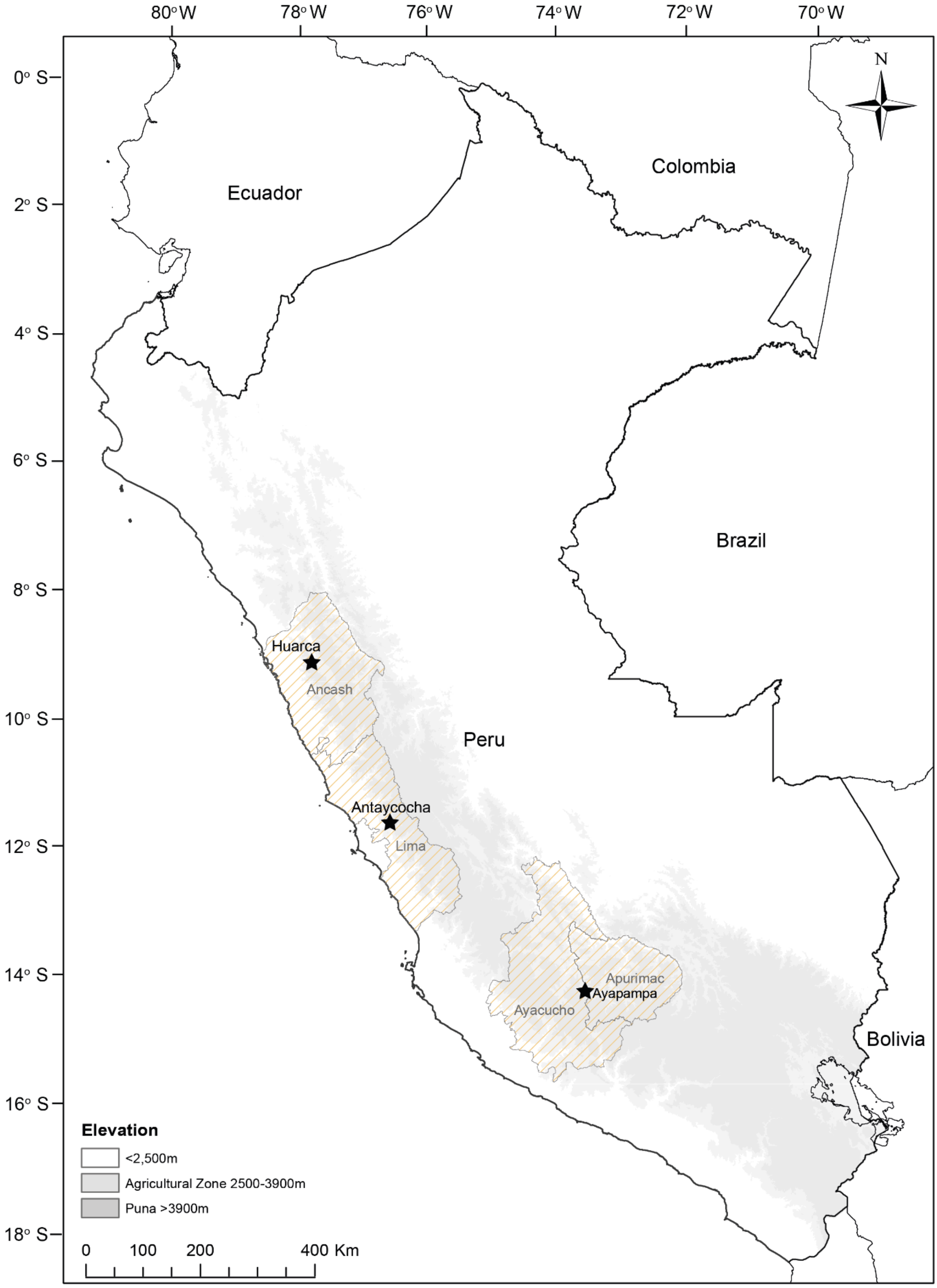


Figure 1.7 Location of the three study regions, and the main site from each of these regions.

In the Ancash Region, the intermontane valley between the Cordillera Negra and the Cordillera Blanca, referred to as the Santa Valley, as it is home to the Santa River, or as it is more locally referred to, as the Callejón de Huaylas was selected. This valley is the second largest on Peruvian's Pacific Coast and served as a major route through the highlands of Peru in pre-Hispanic times with connection to the Pacific, either to the north, where the Santa River drains to the Pacific Ocean, or by crossing the Cordillera Negra to the west and via one of the valleys connected to the coast (Bury *et al*., 2013). Within the Callejón de Huaylas the site of Huarca basin, within the Yungay province, was chosen for its proximity to a muti-period occupancy site of Keushu, as well as agricultural features such as relic terraces. Within the Callejón de Huaylas there is a paucity in environmental and land-use history records, therefore, Huarca is well placed to help answer questions raised within the archaeological record for the region. In addition to the infilled basin site at Huarca, six *bofedales*, and one terrace system, excavated at Awkismarka near the village of Pueblo Viejo de Huandoy, Caraz, were also included in this body of work in order to test the suitability of phytolith analysis for the study of human modified landscapes, including terraces and water meadows (or *Bofedales*). The site of Awkismarka is associated with a large ridge-top ceremonial centre with the remains of over 200 mortuary structures (*chullpas*) still visible today. The closeness of these *bofedales* to a large archaeological site provides an excellent opportunity to investigate agricultural and land-use practices of the people associated with the ceremonial centre, this is especially significant as the site has the largest concentration of *chullpas* in the region (Herrera *et al*., 2009).

The Callejón de Huaylas is a temperate valley with dry autumn and winters. Temperatures range from a minimum of 3-7^{o}C to a maximum of 19-23^{o}C. Annual rainfall within the mid-altitude agricultural lands of the valley ranges from ~700-1500mm yr^{-1} (SENAMHI, 2020) The Cordillera Blanca is home to 16 glaciated peaks above 6000m a.s.l., the highest of which, Nevado Huascarán (6786m a.s.l.), is situated near the study site of Huarca. Glacial meltwater is an important buffer to seasonal rainfall, making up 10-20% of total annual discharge in the Santa River (Bury *et al.,* 2013). Within the dry season glacial meltwater accounts for 40% of total available water, creating an important buffer for irrigation. Glacier recession initially will increase the amount of stream discharge, however once this resource is gone the amount of water available is heavily reduced. It is believed that the Cordillera Blanca has now transitioned into decreasing levels of annual and dry season discharge (Bury *et al.,* 2013) with a 30% reduction in the mass balance of the glaciers in the Cordillera Blanca from AD 1930 to the 20th Century (Schauwecker *et al.,* 2014). The Callejón de Huaylas receives 70-80% of its total annual rainfall within the pronounced wet season (austral summer), this mainly comes from the easterly winds carrying moisture from the Amazon Basin (Gerreaud *et al*., 2003). In the dry season most of the rainfall occurs at higher elevation in the Cordillera Blanca, with the valley bottom receiving very little (Schauwecker et al., 2014). The Callejón de Huaylas is therefore well placed to study the effects of past climate variability on traditional irrigated agriculture. In particular, Huarca basin may have been sensitive to past fluctuations in the Huascarán glacier and the amounts of glacial melt water, likely as an important resource for pre-Hispanic agriculture as it is today.

The geology of the Callejón de Huaylas is primarily volcanic, although no active volcanoes can currently be found within Ancash, and glacial in origin. The sites from this region are situated on the Yungay formation composed of dacitic tuffs which date to the Pliocene as well as glacial and alluvial deposits laid down in the Holocene (Fig. 1.8) (INGEMMET, 2022). Huarca basin is thought to have formed within an inter-morainic basin, with some areas of the peatland overlying erosional material, potentially alluvial in origin.

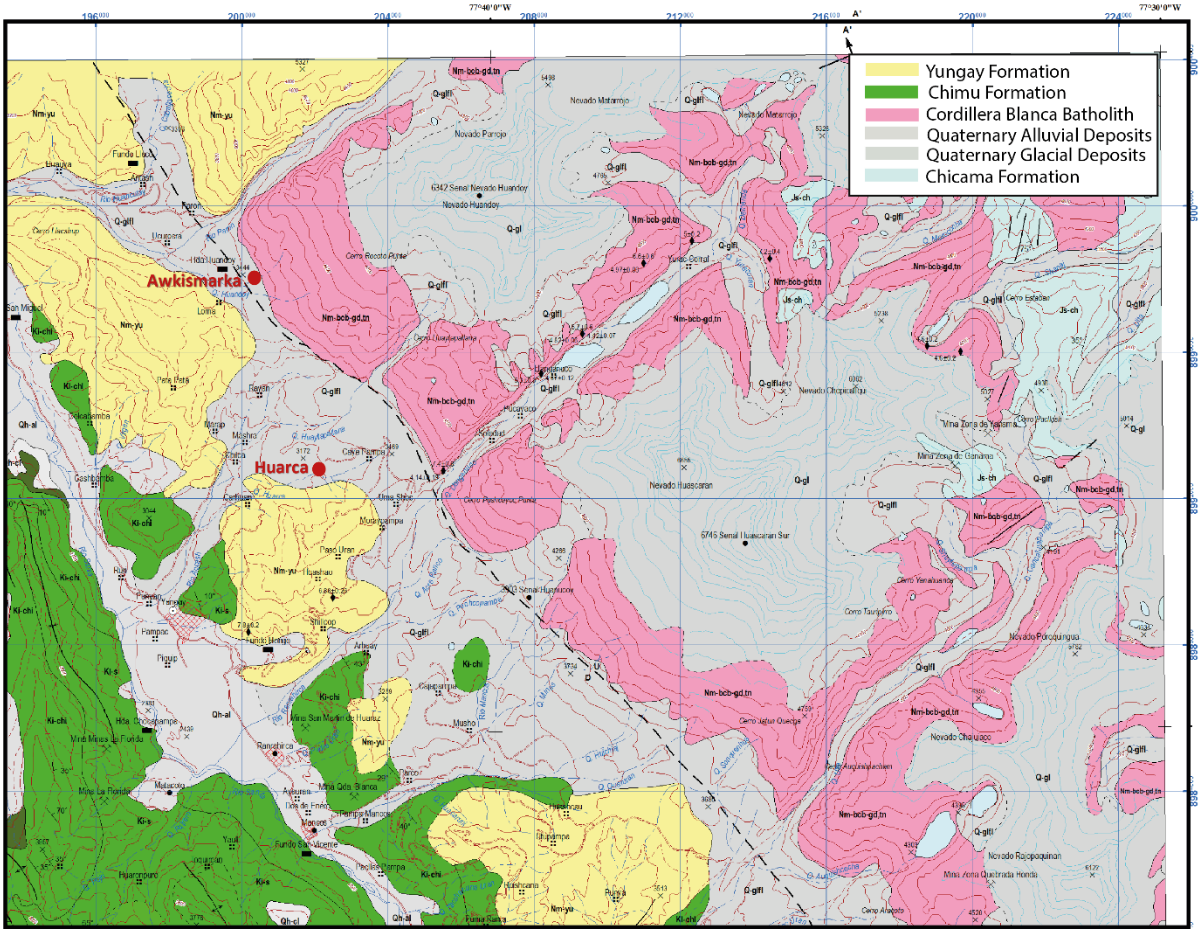


Figure 1.8 Geological map for the Yungay province of the Callejón de Huaylas showing the geological units surrounding Huarca basin and Awkismarka site. (Basemap sourced from INGEMMET, 2022)

Within the Lima Region, the Chillón Valley was selected which is home to one of the three rivers that feed into Lima and provides it with most of its water resources today. This valley goes from the coastline north of Lima into the high Andes and crosses onto the altiplano in the Junín Region and was likely used as a transhumance route in the past to allow trading between the high altitude altiplano and the coast. The mid-upper valley where the study site for this region, Antaycocha, is situated is semi-dry and cold at present day with relatively dry winters (200-700mm yr^{-1} precipitation). Temperatures range from a minimum of -7-5°C and a maximum of 13-17°C (SENAMHI, 2020). The valley is rich in agricultural land both at lower elevations where avocado, coca and fruits have been grown since pre-Hispanic times, and in high elevation where crops, such as potatoes, oca and quinoa were grown on an abundance of agricultural terraces on the steep mountain slopes. Therefore, this study region provides an excellent opportunity to access the resilience of once highly productive agricultural systems to environmental and climatic variability. The high peaks of the Chillón valley are unglaciated at present day and so the valley also provides an opportunity to study an environment without the input of glacial meltwater in the recent past, meaning it is likely highly sensitive to changes in precipitation regimes.

The study site of Antaycocha basin is situated near the village of Canta at 3601m a.s.l. proximal to the boundary of the *Quechua and Suni* environmental zones. An archaeological site of Cantamarca, is present on the hill above the basin which consists of multi-period occupation structures ranging from the Early Intermediate Period to the Late Horizon. The Antaycocha basin sits within a natural hollow on the slopes above Canta, created by the Rantao stream (see Section **4.1.2**). Holocene alluvial deposits, consisting of well-classified rounded clasts in a coarse sand mix, underlie the site. The hill on which the archaeological site of Cantamarca is situated is made up of the Colqui formation consisting of crystalline tuff and volcanic breccia limestone dating to the Eocene (Fig. 1.9) (INGEMMET, 2022). Higher up the mountain side above Antaycocha the geology is primarily volcanic in origin, belonging to the Pistamachay volcanic centre composed of andesitic dacite and lenticular lavas dating to the Miocene (INGEMMET, 2022).

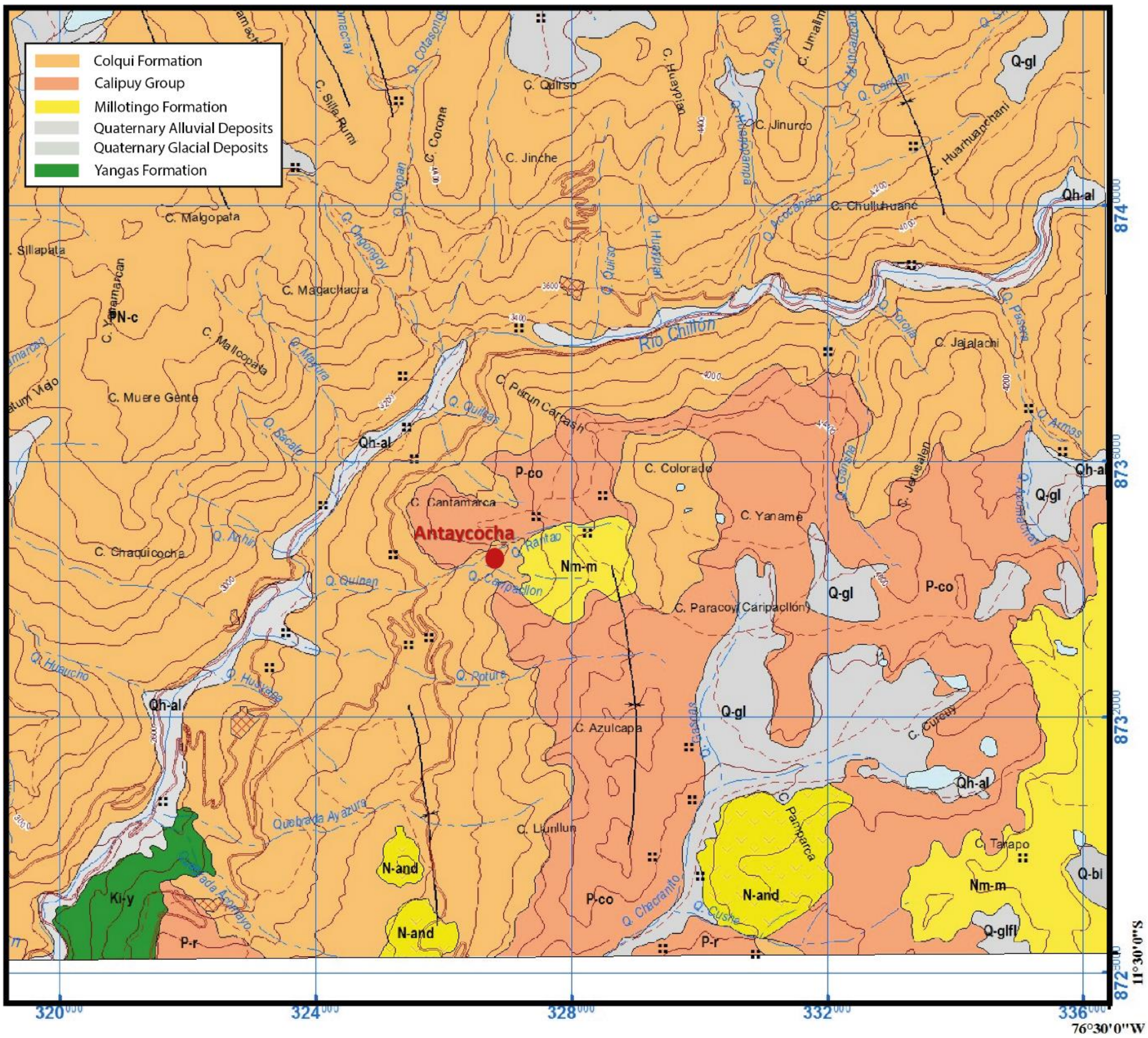


Figure 1.9 Geological map for the Canta province of the Chillón Valley showing the main geological units present within the landscape surrounding Antaycocha. (Basemap source: INGEMMET, 2022)

The Chicha-Soras Valley, which straddles the Ayacucho-Apurímac border, was chosen due to its rich cultural history associated with the Wari culture and its abundance of agricultural terraces. Within the valley, Ayapampa mire, situated near the village of Pampachiri in the Chicha-Soras Valley, sits at 3360m a.s.l., placing it in the *Quechua* environmental zone. The site is surrounded by relic terraces, there is no planted agriculture currently practiced on these terraces but they were likely a highly productive agricultural system in the past, with evidence for a network of irrigation canals associated with the terraces.

The valley experiences cold and dry autumn and winters with minimum temperatures of -1- -3^{o}C and maximum temperatures of 15-19^{O}C with average annual rainfull being between ~700-900mm yr^{-1} (SENAMHI, 2020). The Chicha-Soras is situated within a deep Andean valley system, which contains the Soras River, this has frequently exploit faults and incisions in this tectonically active region to create a deep cut valley and an environment that naturally lends itself to the construction of terraces (Silva, 2005). The Chicha-Soras Valley contains rocks of volcanic origin and consist mainly of basalt and tuff layers. Weathering of these volcanic deposits leads to the formation of especially fertile soils, and no doubt is a contributing factor in the agricultural success of the valley in pre-Hispanic times (Meddens and Schreiber, 2010). The Andamarca formation underlies the study site of Ayapampa, composed of ignimbrite and dacitic tuffs dating to the Miocene, these are overlaid by Quaternary alluvial deposits as shown in Figure 1.10. The highland plateaus of the valley are part of the Yacotungo volcanic sequence made up of pycroclastic tuff deposits which are rich in crystals, plagioclase, quartz, and biotite (Fig. 1.10) (INGEMMET, 2022). There is also evidence for Quaternary glacial deposits within the valley consisting of pebbles, gravel, and sands, with some morainic features visible in the local topography (Silva, 2005; INGEMMET, 2022).

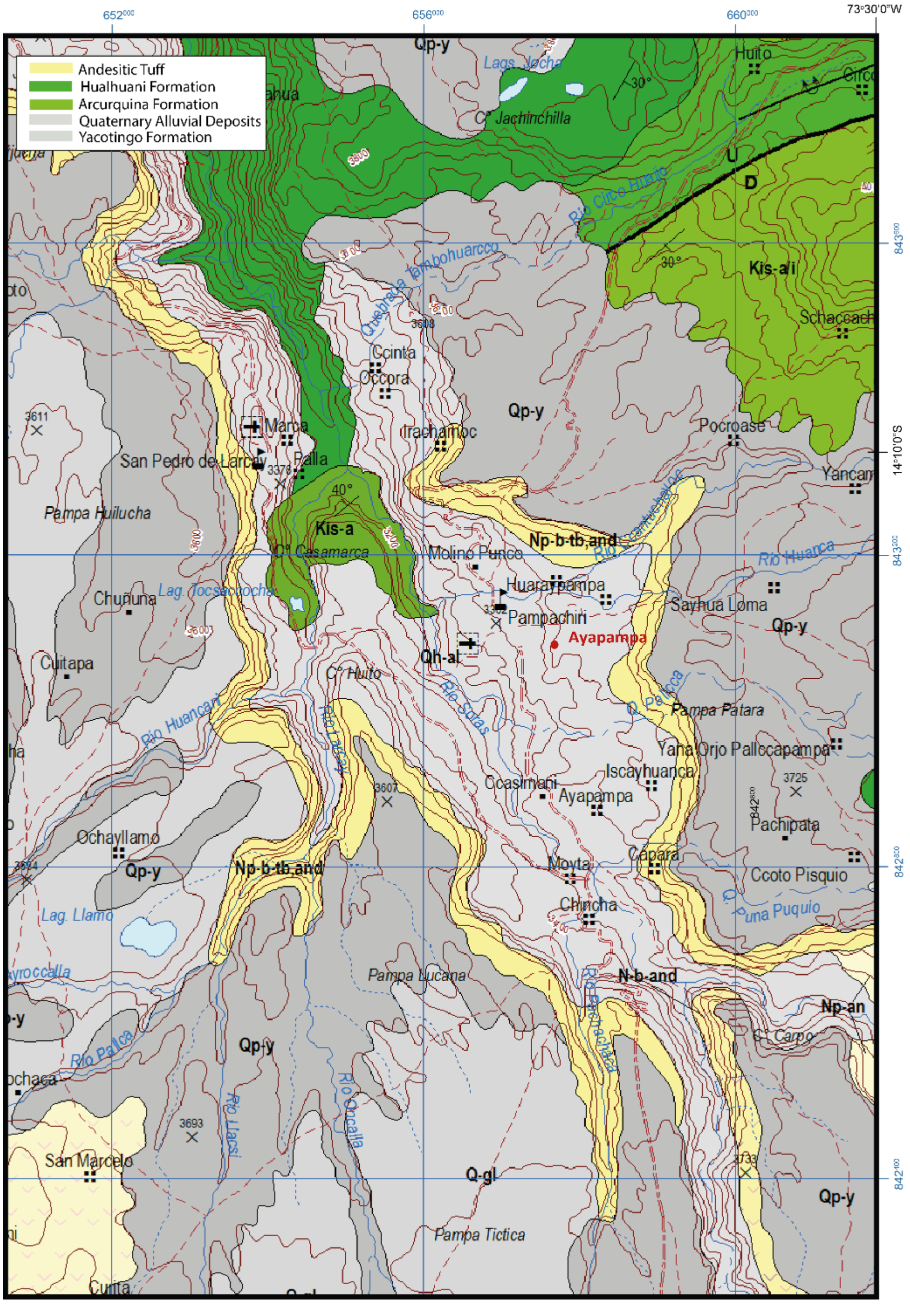


Figure 1.10 Geological map for the Pampachiri Province of the Chica-Soras Valley showing the main geological units around Ayapampa basin. Basemap Source: INGEMMET, 2022

Chapter 2 – Methodology

This chapter will detail the main methodologies used within this thesis. The theoretical framework and the rationale behind choosing each method is explained before the analytical methodologies employed on each of the three study areas are described.

2.1 Field Methodology and Sediment Descriptions

The following field methodology pertains to the cores recovered from the Ancash and Lima regions only. The core from Ayapampa, Apurímac had previously been collected by Professor Nicholas Branch and Dr Barbara Silva in 2001/2002 and stored at the University of Reading in cold storage (5^{o}C) (Silva, 2005; Branch *et al*., 2007). Site selection for the Ancash and Lima Regions was based on the following criteria: (1) the sequence was likely to be relatively long (4-5m of sediment) thus providing a high age to depth resolution and (2) the sites were located near known areas of agricultural activity in the past (either arable or pastoral, or a mixture of both). Sites in Ancash were selected with the help of Dr Alex Herrera (University of Los Andes, Bogotá, Colombia). Sites in the Chillón Valley were selected with the help of Dr Carlos Farfan (Federico Villarreal National University, Lima, Peru). Site descriptions, sampling locations (grid coordinates) and photographs were recorded in detailed field notes.

Figure 2.1: Left: Wrapped cores in the field. Right: 50cm core section in the Russian corer sampling chamber. Cores are collected into rigid plastic piping and wrapped in polythene sheeting to prevent the core drying out.

Cores were recovered using a Russian peat sampler (semi-circular, 5cm diameter), in 50cm sections (Jowsey, 1966). Two coring holes, no more than 30cm apart (A & B), were used to allow for 10cm overlaps between core sections because of potential disturbance to the sediment by the nose of the Russian sampler. Core sections were labelled appropriately: 0-50cm (hole A), 40-90cm (hole B), 80-130cm (hole A), and so on. Duplicate sequences were taken using two fresh holes to provide 'sister cores' in case analytical work required additional material. The cores were wrapped and sealed in the field (Figure 2.1) and transported back to the University of Reading, where they were placed in cold storage (5^{o}C). Upon return to the laboratory, the lithostratigraphy of the cores was described using the Troels-Smith method (1955), following Birks and Birks (1980).

Figure 2.2: Core section unwrapped in the laboratory. The core was described and divided into stratigraphic units, for each a Troels-Smith classification, colour and depths were recorded.

Troels-Smith classification allows for the analysis of three main sedimentological properties: composition, physical characteristics and the degree of humification. The physical properties include the colour of the sediments, which was described using a Munsell Colour Chart (Munsell, 1994), and the nature of the boundary between each stratigraphic unit. The composition was described using abbreviated terms of the Troels-Smith classification (Table 2.1), each stratigraphic unit was assigned a description based on proportionality, with each individual lithological component having a value of 1-4 (1=25%, 2=50%, 3=75% and 4=100%), and where the total components =4. It is also possible to have trace components (+) where a small inclusion of a specific composition as found but it did not add up to ¼ of the total unit composition. For the main component types encountered in this study see Table 2.1. The third sedimentological property that makes up the unit descriptions in Table 3.3 and 4.3, is the level of humification. This is primarily used for peat and lake sediments to provide extra description on how decomposed, or humified, the plant material is within the peat and lake sediment. This is recorded on a scale of 0-4, where 0 is unhumified and 4 is highly humified, or decomposed. The composition and the humification allows for a detailed shorthand description for each unit, for example Th2 Tb2 Ag+ Humo=2 which translates as a mixed herbaceous and moss peat with a trace of silt that is not very humified. The resulting lithostratigraphic logs can be seen in Tables 3.3 and 4.3 in the Sections **3.3.1** and **4.3.1**.

Table 2.1 Key components from the Troels-Smith classification encountered in this study, modified from Birks and Birks (1980)

Symbol	Name	Description
Tb	*Turfa byrophytica*	Mosses, +/- humous substance
Th	*Turfa herbacea*	Herbaceous plants, roots, rhizomes, stems or leaves etc connected with these. +/- humous substance. (Grass, sedge and fern peat)
Tl	*Turfa lignosa*	Ligneous plants, stumps, roots, stems, branches etc connected with these. +/- humous substance. (Wood peat)
Dl	*Detritus lignosus*	Fragments of ligneous plants >2mm (wood remains)
Dh	*Detritus herbosus*	Fragments of herbaceous plants >2mm (grass and sedge remains)
Dg	*Detritus granosus*	Frament of ligneous and herbaceous plants <2mm (small wood and herbaceous fragments)
Ld	*Limus detrituosus*	Organic Lake sediments
As	*Argilla steatodes*	Clay, mineral particles <0.002mm
Ag	*Argilla granosa*	Silt, mineral particles 0.002-0.06mm
Ga	*Grana arenosa*	Fine sand, mineral particles 0.06-0.6mm
Gs	*Grana glareosa*	Coarse Sand, mineral particles 0.6-2mm
Sh	*Substantia humosa*	Completely disintegrated organic matter and precipitated humic acids

Organic matter estimations were calculated for both sites. For Huarca, the resolution was every 4cm over the top 2.5m to match the pollen sampling resolution, and every 16cm for the bottom 2.0m to provide a 'skeleton' diagram from 3000 cal yrs BP to the base of the core at ~*11,470* cal yrs BP. The sampling resolution for Antaycocha was 8cm for the full 5.97cm sequence, which also matches the pollen resolution. The organic matter estimates were calculated using the loss-on-ignition method (Bengtsson and Enell, 1986); this involved drying 1cm of sediment overnight at 105°C in an oven, before cooling to room temperature in a dessicator to ensure no moisture remained in the samples before weighing. The weight of the crucibles and the combined weight of the crucibles and sample was recorded before placing the samples to a muffle furnace set at 550°C, in order to oxidise the organic matter to carbon dioxide and ash. To avoid overheating, the samples were placed in the furnace only when it had reached its constant and maximum temperature (Heiri *et al*., 2001). Samples were left in the furnace for 2 hours, before being removed and re-placed in the desiccator to cool. The crucible and the ashed samples were then weighed. The amount of organic matter lost was calculated using the following formula:

$$\% \text{ Organic Matter} = ((\text{Dry-Ash})/\text{Dry}) \text{ x100}$$

The results were presented as an Organic Matter (%) curve as seen in Figure 3.8 (Section **3.3.1**).

2.2 Micro-XRF Geochemistry

2.2.1 Theoretical Framework and Rationale

XRF core scanning provides rapid, non-destructive, semi-quantitative elemental data at sub-millimeter resolution and can provide information on geomorphological, climatological, and anthropogenic contaminant history of basin sequences (Löwemark *et al*., 2011, 2019; Davies *et al.,* 2015). Micro-X-ray fluorescence (µXRF) data is obtained using an ITRAX instrument (Fig 2.14) to scan core sections (Thomson *et al*., 2006). Widely used elements detected within ITRAX micro-XRF core scanning include Potassium (K), Titanium (Ti), Calcium (Ca), Iron (Fe), Manganese (Mn) Barium (Ba), Bromine (Br), Rubidium (Rb), Silica (Si), Lead (Pb), Zinc (Zn) and Strontium (Sr). Certain elements are commonly used to indicate variations in input of terrigenous material (K, Ti, Ca, and Fe) and therefore may indicate periods of erosion; although Fe is widely used it is redox-sensitive and redox-insensitive Ti is often a better choice for measuring terrigenous sediment fluxes (Rothwell and Croudace, 2015a). Ba, Br and high Br/Ti and Ba/Ti ratios are often used as a proxy for productivity and increase in organic matter, although these should be interpreted alongside organic carbon or organic matter concentration data (Rothwell and Croudace, 2015a). Other elements such as Cu, Pb, Zn, Phosphorous (P) and Sulphur (S) can be used as pollution indictors. Of particular significance to the Andean setting of this research is Cu, Pb, and Zn, three common elements in Peruvian polymetallic deposits which have been exploited since pre-Hispanic times and is the foundation for one of the world's largest mining industries. Lead was of particular importance to the Incan Empire as it was used in the form of galena to produce silver (Cooke *et al*., 2007; 2009; Eichler *et al*, 2015).

In addition to these elements, other scanning parameters can give important information on sediment properties, for example the incoherent/coherent (inc/coh) scattering ratio is commonly used among the lacustrine community as a proxy for organic matter content (Brunschön *et al.,* 2010; Rothwell and Croudace, 2015b; Davies *et al.,* 2015; Longman *et al.,* 2019). Mo inc and Mo coh represent the Compton (incoherent) and Raleigh (coherent) scattering data obtained during the XRF core scanning and relate to the average atomic number of the sample (Croudace *et al*., 2006). Organic rich sediments and peat have low average atomic mass and as a result generate high Compton (incoherent) and low Raleigh (coherent) scattering, resulting in a higher inc/coh scattering ratio than in-organic mineral rich sediments (Croudace *et al*. 2006; Chagué-Goff, 2016). Higher (more positive) inc/coh values are therefore interpreted to be representative of higher organic matter content and often match trends seen in organic matter content (via LOI) and total organic carbon (TOC) (Thomson *et al.,* 2006; Rothwell and Croudace, 2015a).

Figure 2.3: ITRAX core scanner at BOSCORF, NOC, University of Southampton (Left) and the core ready to be scanned and placed on the track within the scanner (right).

The high-resolution scanning provided by µXRF-core scanning can be particularly useful on peat and lake sequences with low accumulation rates in order to better constrain palaeoenvironmental changes that occur over very short intervals of time. However, lake and peat sequences tend to have greater variability down-core than marine cores, due to changes in water content and organic matter. In cores where there are large changes in organic matter, for example with a swing of 50% or more, variations seen in elements will largely mirror the changes in organic matter, as opposed to actual variations in elemental counts, known as the 'closed-sum effect' (Löwemark *et al*., 2011; Davies *et al.,* 2015; Longman *et al.*, 2019). This is also true for a core rich in carbonates, the elemental signal will reflect the changes in carbonate content as opposed to providing a true environmental signal. As µXRF scanning requires a clean and even surface for scanning, it is not possible to carry out loss on ignition on the cores to determine the organic matter or carbonate content prior to scanning. To combat this unknown, the normalisation of data from the cores is paramount; this is done by dividing elements by stable or conservative elements such as Ti, K or Ca and produces elemental ratios e.g., Fe/Ca or Si/Ti or counts per second (e.g., Ti/cps) (Löwemark *et al.,* 2011; Rothwell and Croudace, 2015b). Raw elemental µXRF data is presented in counts per second (cps) however the robustness of the interpretation of micro-XRF data can be further aided by the use of log-ratios (e.g., LnK/Ti), which provide easily interpretable signals of relative changes in chemical composition (Weltje and Tjallingii, 2008).

The age of the x-ray tube used in the scanning can have an effect on the counts measures; to combat this, cores should be scanned with the same x-ray tube in succession or within as close as possible time interval between scans (Löwemark *et al.,* 2011). Due to the high-resolution scanning (normally 500µm – 1mm) any defects in the core, such as cracks or gaps in the sample surface either caused by the collection process or due to the drying out of cores in storage, can also greatly affect the data quality. These defects can be identified through the core radiographs and sharp spikes or dips in the resulting data (Löwemark *et al.,* 2011), and data points removed accordingly.

Finally, it is important to note that the interpretation of XRF core data should be aided by knowledge of the geology of the catchment area and local catchment characteristics as well as comparing the data to other lines of evidence, such a palynology and measured isotopic data, in a multi-proxy approach.

2.2.2 Analytical methods

Full core sequences from Huarca and Antaycocha were scanned using an ITRAX core scanner at BOSCORF, Southampton (Fig 2.11). The core was first scanned to ascertain whether a constant working distance is attainable for the X-ray detector (Croudace *et al.,* 2006; Thomson *et al.,* 2006). This uses a laser distance finder to map the topography of a core section. Whilst this is happening, a digital line camera captures a photographic image of the whole core surface (Thomson *et al.,* 2006). After this is complete the core is reset to the zero position before the XRF scan begins. For the cores in this study a scanning resolution of between 500µm and 1mm was used to pick up very fine changes in geochemistry within the sediment sequence. A scanning frequency of up to 100µm can be achieved if desired (Thomson *et al.,* 2006). The XRF exposure time for each core was 15 seconds per sampling point with the X-ray beam being generated using a Mo tube and run at a voltage of 30KV and a current of 30mA. At each sampling position a 2cm wide high-resolution radiograph is also recorded. ITRAX produces semi-quantitative element count rates, although these elemental peaks are roughly proportional to the concentration of major and trace elements within the sediment.

The data produced from the core scanning was split into 50cm sections, which was then cleaned and spliced together to make one complete sequence for the core. This means removing some data points from where there is a 10cm overlap between core sections. A starting point to data cleaning is to look for sections with a validity of zero, where µXRF scanning was unsuccessful; for example, where scanning has continued across gaps across the tape in between core sections. The elemental data was recorded against a scanning position, which then needs to the converted into an actual depth (cm), before the core sections can be spliced together.

Once the data set was cleaned, in order to create more meaningful plots, the data needs to be normalised; this is usually done either against counts per second (cps), or it can be plotted as a ratio, for example Fe/Ti. Although Aluminium is usually used as the element for aluminosilicate normalisation, Aluminium is not detected efficiently enough by the ITRAX scanner to be used. Possible alternatives include Titanium, Potassium, and Rubidium (Thomson *et al.,* 2006). Titanium, in particular, is a stable and highly resistant element, and therefore makes it suitable as a conservative metal from which other relative enrichments and depletions of more mobile elements can be compared against (Brunschön *et al.,* 2010). The selection of the most appropriate element to use can be aided by the use of multivariate analysis, such as Principal Component Analysis (PCA), as this helps to identify which elements are covariant (plot on alternate sides of the PCA) and which relate closely to the scattering parameter (inc/coh) and those with lithogenic elements (e.g., Ti, Fe, Rb, K etc.) (Davies et al., 2015). Elements that plot opposite to each other on a PCA are most suitable for use as ratios. Once the ratios were plotted, they were presented graphically alongside the lithostratigraphy and organic matter content curve to allow comparison with the core structure. The resulting diagrams (see sections **3.3.2** and **4.3.2**) were then zoned via visual assessment of changes in the lithostratigraphy and the major changes within the elemental ratios themselves. The timing of these zones can then be compared to the chronological framework placed on the sequence by the age-depth model created for each sequence (**Section 2.5**).

2.3 Palynology

2.3.1 Theoretical Framework and Rationale

Palynology involves the study of pollen and spores in order to reconstruct past vegetation dynamics and environmental change. Pollen and spores are highly resistant to post-depositional processes and well preserved under anaerobic and acidic conditions (Branch *et al.*, 2005; Bell and Walker, 2005; Lowe and Walker, 2015). Pollen grains and spores have a very strong outer layer, or exine, made up of sporopollenin, which leads them to be found in deposits where other types of fossils would be destroyed by diagenesis (Faegri and Iversen, 1989). Pollen grains are produced by flowering plants, angiosperms, conifers and gymnosperms, while spores come from vascular plants such as ferns, mosses and fungi. Pollen grains and spores vary in shape, size and surface patterning, all of which make it possible to identify pollen grains to the taxon in which they originate (Bennet and Willis, 2001; Branch *et al*., 2005). Identification is aided by comparison to modern reference collections from identified plants as well as identification guides noting key features such as size, shape, aperture, furrows, and surface sculpturing (Bennet and Willis, 2001; Branch *et al*., 2005). Pollen counts normally include land pollen (tree, shrubs, and herbs) totalling 300 grains; aquatics and spores are not included in this count as they represent the very localised vegetation present on/within the sampling site and often are overrepresented (Branch *et al.*, 2005). This is especially true for bogs where mosses and ferns commonly grow on the surface. These surface plants can also trap airborne pollen and weaken this signal within the fossilised record (Bunting, 2008).

Pollen is transported by two main mechanisms, and consequently deposited in the fossil record: by insects (entomophilous) and by wind (anemophilous) (Faegei and Iversen, 1989; Bennet and Willis, 2001; Branch *et al*., 2005). Plants pollinated by animals and insects have a low probability of entering the fossil record because pollen is produced in smaller numbers by entomophilous plants, and secondly unless the carrier of the pollen perishes in a lake or bog or a whole flower drops into the water it is unlikely to reach the lake or bog. Conversely, wind pollinated plants produce large amounts of pollen and surplus pollen enters the environment. This eventually washes in or falls to ground and accumulates in the sediments of lakes and bogs, which often leads to high levels of wind pollinated taxa within the pollen record (Bennet and Willis, 2001; Roberts, 2014). High-level wind dispersal will lead to a mixing of pollen rain, with pollen from some taxa being carried over long distances, in particular pollen grains which have sacs to keep them airborne like *Pinus* and *Podocarpus*. This variation in pollen production and dispersal affects the final pollen assemblage recovered from sediments, which differs from the ‘life assemblage’ of the vegetation communities surrounding lakes and bogs (Fig. 2.3). This assemblage is further altered by differential preservation of spores and pollen with some grains being more prone to being crumpled and folded or broken completely beyond recognition (Branch *et al.,* 2005; Roberts, 2014). Ideal preservation conditions are those which are acidic, with low microbial activity, and anaerobic, free from oxygen. Anaerobic conditions occur wherever there is permanent waterlogging; there are two main types of anaerobic deposits in which fossil pollen records are recovered: allochthonous and autochthonous deposits. Allochthonous deposits consist of material originating elsewhere which are then deposited or redeposited in the place from which they are recovered, this is most common in lake sediments., where material is washed into them from the surrounding catchment. Autochthonous deposits consist of remains of vegetation that once lived in the place where the samples are recovered, for example vegetation growing on the surface of peat bogs and on the floors of lakes (Faegri and Iversen, 1989; Bennet and Willis, 2001). If optimal conditions for preservation do not exist, however, for example peat bogs can dry out due to changes in climatic conditions or human activity (e.g., drainage), differential preservation will occur. It is important to consider these factors when interpreting a pollen diagram.

A common aim of palynological research is to identify signals for past human activity; this, however, comes with a number of challenges. Pollen grains from crops such as maize, wheat and barley are poorly dispersed due to their large grain size, which often leads them to be underrepresented in pollen assemblages (Roberts, 2014). More common indicators of past agricultural activity come from taxon indicative of landscape disturbance such as *Ambrosia, Artemisia, Rumex* and *Plantago lanceolata*, within an Andean setting. However, these plants take advantage of disturbed ground no matter the cause and so do not solely indicate anthropogenic disturbance (Roberts, 2014). Furthermore, pollen from non-grass crops, such as *Solanum tuberosum* (potatoes)*, Chenopodium quinoa* (quinoa)*, Phaseolus lunatus* (beans) *and Capsicum sp.* (peppers). come from taxon that cannot be readily identified to a species level and often are not possible to identify below the family level e.g., Chenopodiaceae/Amaranthaceae, Solanaceae, Fabaceae etc. This leaves some ambiguity in interpreting an anthropogenic signature. A combination of evidence is therefore usually employed, including the use of Non-Pollen Palynomorphs (NPPs), micro-charcoal and changes in overall vegetation composition and structure.

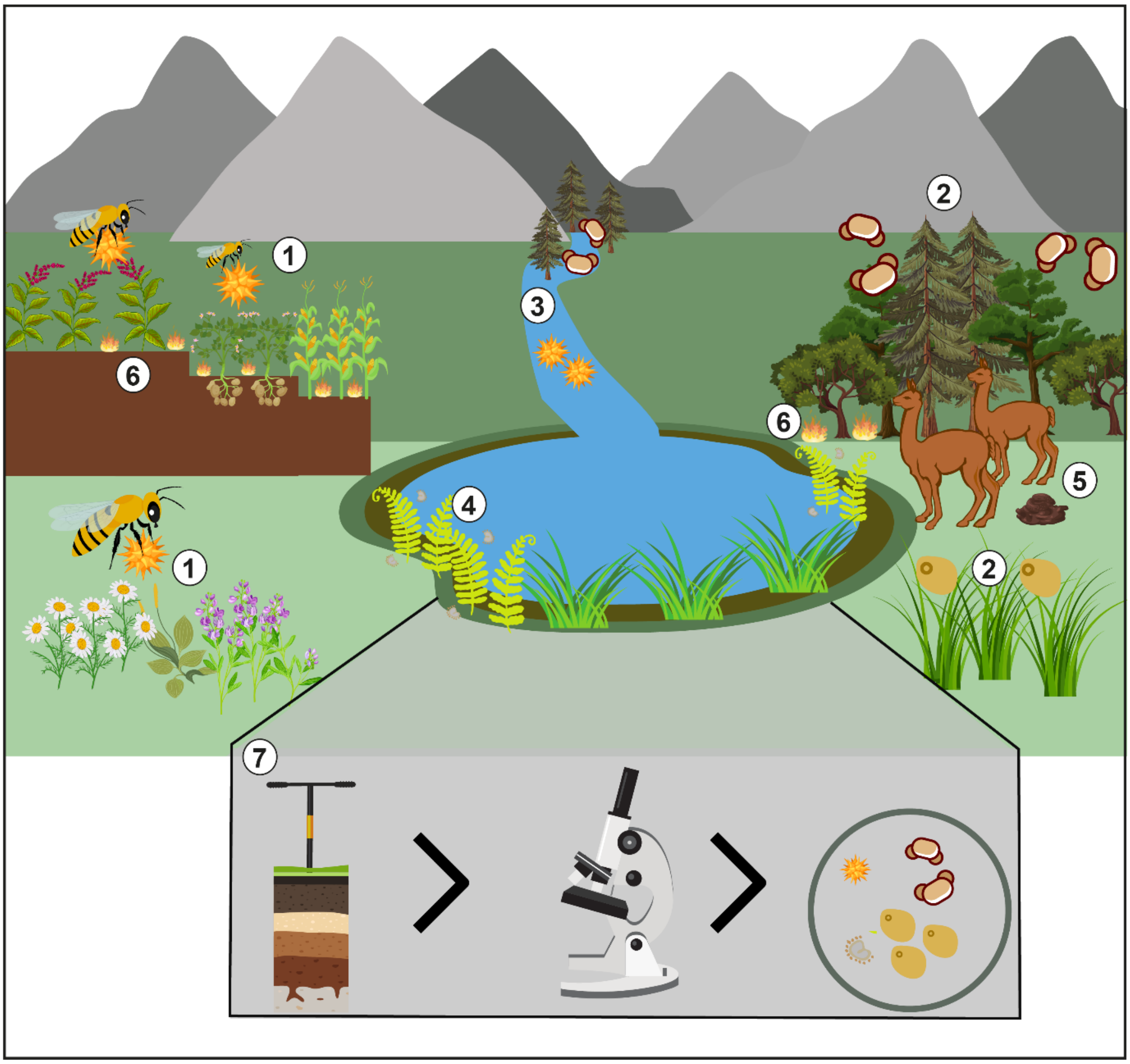


Figure 2.4: Pollen transport processes into lakes or mire sequences within the Andes. 1) Transport of pollen via insects, normally produced in low numbers and relies on animals directly entering the lake/mire to deposit the pollen. Typical of Quinoa (Chenopodium quinoa) and Potatoes (Solanum tuberosum). 2) Production of wind pollinated pollen in large amounts that is blown into the basin, e.g., from Alnus acuminata and Poaceae. 3) Long distance transport of pollen from plants at different altitudes on mountain slopes, either via wind or aided by transport in streams and rivers. 4) Dispersal of spores from ferns and vascular plants on the lake edge or mire surface. 5) Production of fungal spores within dung. 6) Production of micro-charcoal from burning events, fire is a common agricultural management tool in the Peruvian Andes, as well as in clearing of land for agriculture and in agroforestry practices. 7) These methods of pollen deposition make up the fossil pollen record which is recovered from lake and mire sequences via coring. Pollen assemblages are extracted from core sequences and analysed under a microscope.

Non-Pollen Palynomorphs (NPPs) include not only spores from ferns and mosses but also algae remains, cyanobacteria, and remains of invertebrates. Several hundred different types of NPPs have been recorded and described, and in a lot of cases there is little to no ecological or taxonomic knowledge to accompany them. However, this has improved in recent years with the collaboration with researchers in zoology, phycology, mycology and plant anatomy. Fossil fungal spores are more commonly recovered from peat deposits than from lake sediments, which is due to the localised nature of fungal spore dispersion, with fungal spores often becoming fossilised at or near the place they were produced (van Geel, 2001). It is also only relatively big thick-walled fungal spores that preserve; despite thin-walled smaller spores dispersing better, these are more likely to break-down before being fossilised (van Geel, 2001). NPPs can provide some data on human activity, in particular, on animal husbandry practices, through the presence of coprolitic fungal spores such as *Sporormiella* (Fig. 2.4). *Sporormiella* has a very localised dispersal and the presence of it within the fossil record normally equates to a source close-by to the site of deposition (Chepstow-Lusty *et al*., 2019).

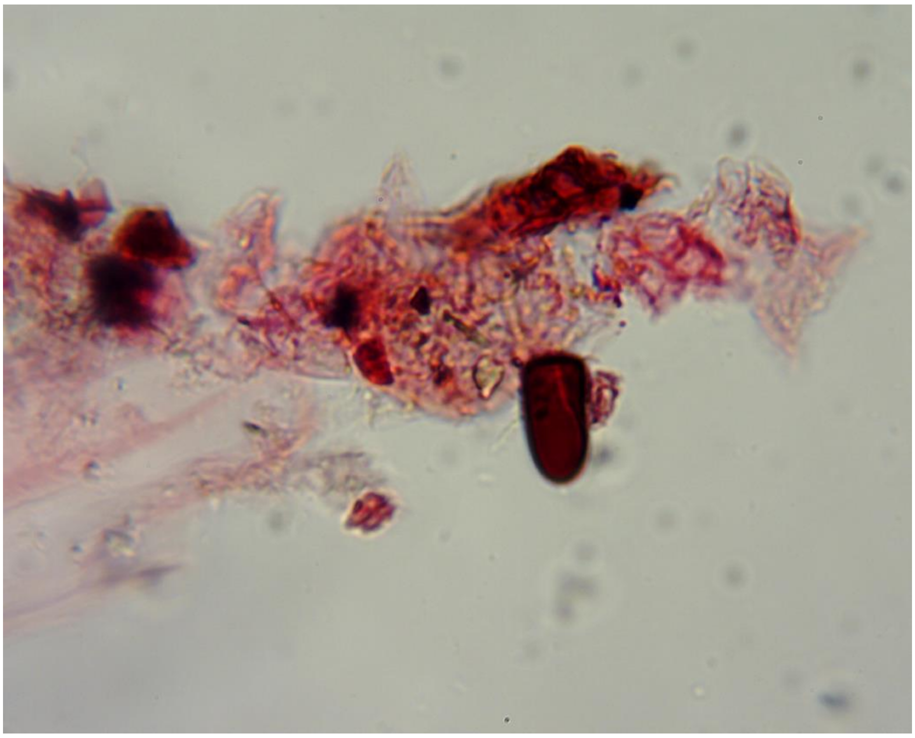


Figure 2.5: Sporormiella recovered from Huarca basin, photo taken at 400x magnification.

Finally, micro-charcoal can provide information on past fire-regimes. Micro-charcoal particles are usually jet-black with angular, straight edges, have a blue hue and are opaque (Fig. 2.5), identification will follow guidance of Turner *et al*., (2008). Several particles may be present in sediments that look very similar to charcoal, including pyrite, dark plant fragments and insect remains. One other complicating factor is that partial combustion can result in varying degrees of 'burntness' with some particles only being partially burnt. Therefore, only particles that include a combination of the key characteristics are commonly included in micro-charcoal counts (Turner *et al*., 2008). Micro-charcoal can become fragmented through the pollen extraction process due to its fragility and the mechanical and physical severity of the extraction procedure; this may lead to a higher micro-charcoal count if very small fragments are included in the count (Turner *et al.,* 2008). Therefore, only particles greater than 10µm were included in the microcharcoal counts.

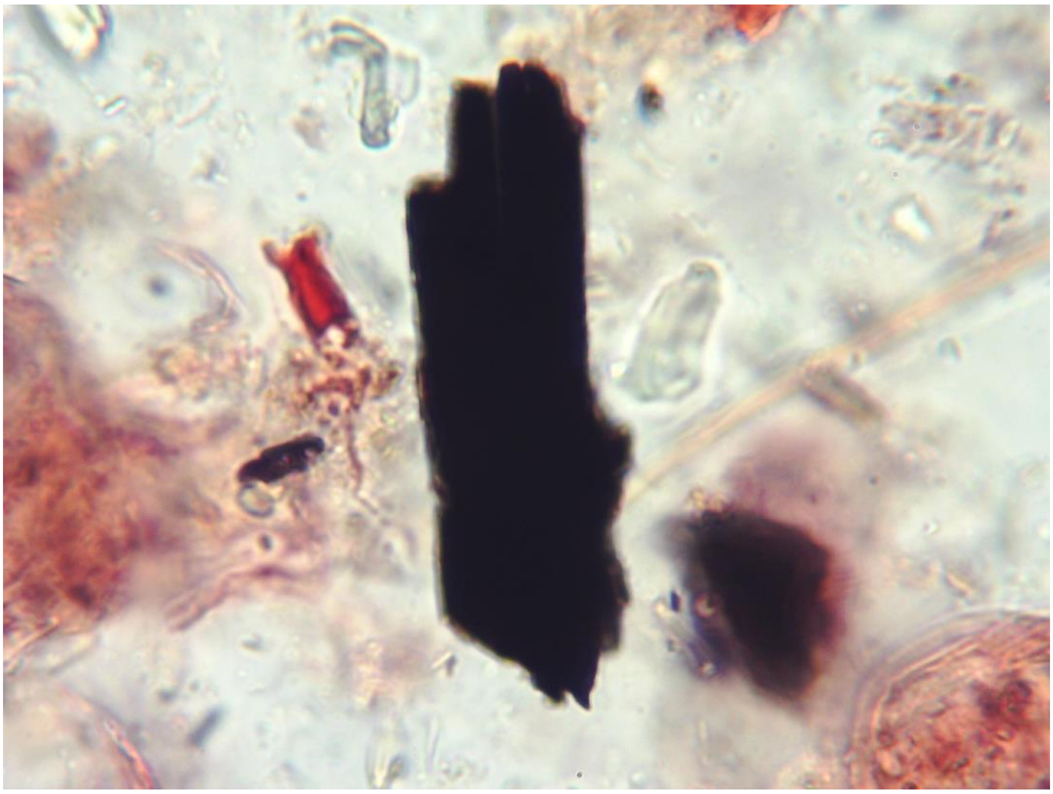


Figure 2.6: Micro-charcoal fragment within analysed samples. Photo taken at 400x magnification.

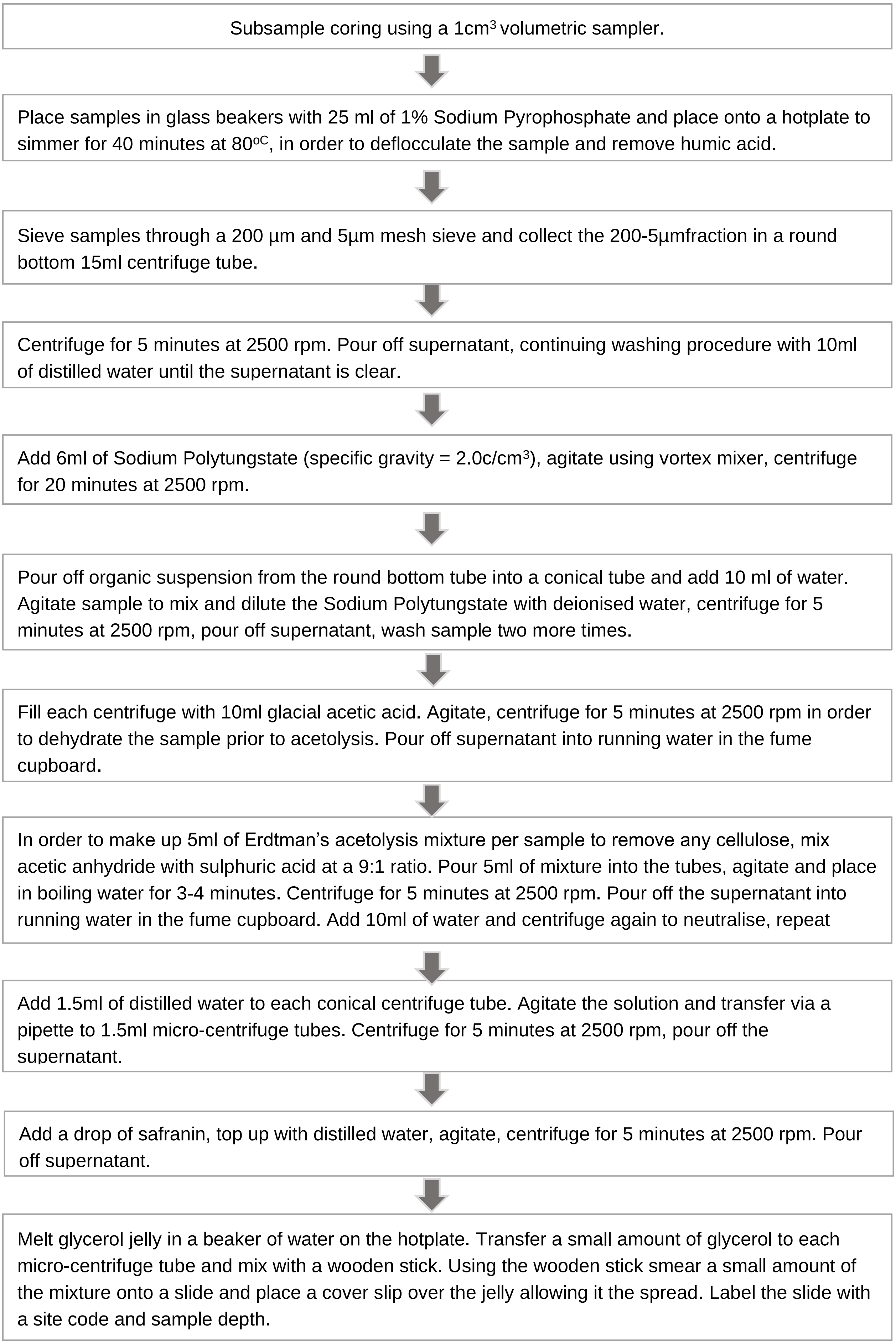
2.3.2 Analytical methods

Sub-samples for pollen analysis were taken from Huarca and Antaycocha basins, these samples also allow for the analysis of Non-Pollen Palynomorphs and micro-charcoal, which are also captured on pollen slides. For both sites, samples were initially taken at 16cm to provide a skeletal pollen diagram and assess the cores for pollen preservation. For Huarca, this resolution was increased to every 4cm over the top 2.5m of the core. It was initially estimated that this depth would cover at least the last 2000 years, this was later confirmed by the radiocarbon dating programme. The radiocarbon analysis of Huarca revealed the top 2.5m to actually cover approximately the past 2550 years (*~2548 cal yr BP*) (see Section 3.3.4), giving a sampling resolution of approximately one sample every 40 years. For Antaycocha, the resolution was increased to one sample every 8cm, as it was assumed a large proportion of the sequence (~3m) equated to the last 500-550 years, due to the 3m high dam wall at the site having been constructed in the late, Late Intermediate Period or early Late Horizon (*Farfan, pers.comms.).* Radiocarbon dating revealed that 5.5m of the sequence actually spanned the last 500 years giving a sampling resolution of approximately one sample every decade for the top 5.5m of the sequence, assuming a constant sedimentation rate.

The extraction of pollen followed the below flowchart methodology (Fig 2.6) based on Faegri and Iversen (1989) and Moore, Webb and Collinson (1991). A 200µm top mesh was used in to remove unwanted organic and mineral matter greater than 200µm; a bottom 5µm mesh was used to remove fine organic and mineral matter and the material between 5-200µm captures smaller grains, NPPs, as well as large tropical grains and larger *Zea mays* pollen grains. *Lycopodium* was added as an exotic maker to help calculate the concentration of pollen grains per cm^3 and pollen influx, the number of pollen grains per cm^3 per year, following Stockmarr (1971). Heavy liquid separation using Sodium Polytungstate was carried out to separate the pollen from non-pollen matter (see Campbell *et al*., 2016). The methodology (Fig. 2.6) also reduces the chance of fragile pollen grains and spores becoming damaged or destroyed in the extraction process.

Identification of pollen was aided by identification guides (Moore and Webb, 1978; Moore, Webb and Collinson, 1991) and online pollen databases: Global Pollen Project (Martin and Harvey, 2017), Australian Pollen and Spore Atlas (APSA, 2007), PalDat (PalDat V 3.4, 2022) and the Neotropical Pollen Database (Bush and Weng, 2006). The online databases were particularly useful in the identification of unknown pollen, especially those which allowed for a search to be made based on key metrices, such as number of pores and surface patterning (e.g., Bush and Weng, 2006). The identification of Non-Pollen Palynomorphs was aided by the Non-Pollen Palynomorphs Database (Shumilovskikh *et al*., 2021) and published work (e.g., van Geel, 1978; van Geel *et al*., 2011).

Pollen data are presented in three formats within Sections 3.3.3 and 4.3.3., firstly as a percentage pollen diagram, with percentages derived from the total of all land (trees, shrubs herbs) pollen. Secondly pollen accumulation diagrams are presented, which calculates the sediment accumulation rates, based on the age depth model for the sequence, to work out the length of deposition time, these are presented as grains cm^{-2} year^{-1}. Pollen accumulation, or influx, diagrams are not dependent on relationships between species and any changes represent independent changes in the grains deposited per year. The third type of pollen diagram is pollen concentration in grains per cm^2. Which requires the addition of an exotic marker, as previously mentioned for this study this was *Lycopodium*, to calculate the ratio of fossil pollen to exotic pollen. Both the concentration and accumulation diagrams have the ability to pick up trends in data not identifiable in the pollen percentage diagram, and when used in conjunction with each other provides a reliable method for understanding vegetation changes through time.



Subsample coring using a 1cm^3 volumetric sampler.

Place samples in glass beakers with 25 ml of 1% Sodium Pyrophosphate and place onto a hotplate to simmer for 40 minutes at 80^{oC}, in order to deflocculate the sample and remove humic acid.

Sieve samples through a 200 µm and 5µm mesh sieve and collect the 200-5µmfraction in a round bottom 15ml centrifuge tube.

Centrifuge for 5 minutes at 2500 rpm. Pour off supernatant, continuing washing procedure with 10ml of distilled water until the supernatant is clear.

Add 6ml of Sodium Polytungstate (specific gravity = 2.0c/cm^3), agitate using vortex mixer, centrifuge for 20 minutes at 2500 rpm.

Pour off organic suspension from the round bottom tube into a conical tube and add 10 ml of water. Agitate sample to mix and dilute the Sodium Polytungstate with deionised water, centrifuge for 5 minutes at 2500 rpm, pour off supernatant, wash sample two more times.

Fill each centrifuge with 10ml glacial acetic acid. Agitate, centrifuge for 5 minutes at 2500 rpm in order to dehydrate the sample prior to acetolysis. Pour off supernatant into running water in the fume cupboard.

In order to make up 5ml of Erdtman's acetolysis mixture per sample to remove any cellulose, mix acetic anhydride with sulphuric acid at a 9:1 ratio. Pour 5ml of mixture into the tubes, agitate and place in boiling water for 3-4 minutes. Centrifuge for 5 minutes at 2500 rpm. Pour off the supernatant into running water in the fume cupboard. Add 10ml of water and centrifuge again to neutralise, repeat

Add 1.5ml of distilled water to each conical centrifuge tube. Agitate the solution and transfer via a pipette to 1.5ml micro-centrifuge tubes. Centrifuge for 5 minutes at 2500 rpm, pour off the supernatant.

Add a drop of safranin, top up with distilled water, agitate, centrifuge for 5 minutes at 2500 rpm. Pour off supernatant.

Melt glycerol jelly in a beaker of water on the hotplate. Transfer a small amount of glycerol to each micro-centrifuge tube and mix with a wooden stick. Using the wooden stick smear a small amount of the mixture onto a slide and place a cover slip over the jelly allowing it the spread. Label the slide with a site code and sample depth.

Figure 2.7: Flowchart of pollen extraction methodology, following Faegri and Irersen (1989) and Moore, Web and Collinson (1991)

2.4 Phytoliths

2.3.1 Theoretical Framework and Rationale

Phytoliths are commonly used for the study of past human and environment interactions, vegetation reconstructions and diet studies with applications in archaeology, palaeoecology, archaeobotany and palaeoethnology (e.g., Chandler-Ezell *et al*., 2006; Grobman *et al*., 2012; Watling *et al*., 2015; Dickau *et al*., 2016; Hillbert *et al*., 2017; Astudillo, 2018; Maezumi *et al*., 2018; Contreras and Zucol, 2019; Plumpton *et al*., 2019; Plumpton *et al*., 2020; Crifò and Strömberg, 2020; Iriarte *et al*., 2020; Lombardo *et al*., 2020; McNichael *et al*., 2021; Zucol *et al*., 2022). In comparison to other micro-fossils, such as pollen, the transportation of phytoliths does not occur as readily, as they are not usually liberated into the air on the same scale as pollen. Therefore, a large proportion of phytoliths are *in-situ* deposits providing a good indicator of on-site plant usage within archaeological contexts, especially in a terrace setting, and provide a local-scale vegetation history within lake and mire records (i.e., those plants living proximal to the basin edge) (Piperno, 1988; Plumpton *et al.,* 2019). Phytoliths are opaline silica bodies created when hydrated silica is dissolved in groundwater and absorbed through the roots of plants. It is then carried through the plants vascular system and the soluble form of silica is deposited into intercellular spaces, cell walls and lumina of plant organs (Fig. 2.5) (Piperno, 2001; Shillito, 2013). The silica accumulates in aerial structures of the plant, including the leaves, fruits, seeds, reproductive systems, and roots (Piperno, 2001, 2006; Watling and Iriarte, 2013). The initial process of phytolith deposition from a plant is called necrolysis and involves the decomposition and degradation of the plant at time of death (Fig. 2.5 (b)) (Cabanes, 2020). The composition of phytoliths within a soil profile or sediment sequence primarily originates from those plants that have decayed and released phytoliths into the soil *in-situ*. However, it is worth noting that additional phytoliths maybe added to the assemblage via pre- and post-depositional taphonomic processes (e.g., bioturbation, translocation, and seismic activity) (Madella and Lancelotti, 2012; Zurro *et al*, 2016; Cabanes, 2020) as well as through slope wash processes, inflowing streams, human disturbance in the catchment (e.g., land clearance for agriculture) and through liberation into the air during fire events (Fig.2.7 (a)) (Piperno, 1988, 2001, 2006). Consideration of the environmental setting and potential modes of deposition within a sequence is therefore important during the analysis of phytolith assemblages. Recent studies have highlighted the potential of phytoliths to become translocated through soil profiles, leading to a greater number of phytoliths with a smaller surface/volume ratio (such as grass short cells) being transported to lower soil horizons (Liu *et al*., 2019; Liu *et al*., 2021). A greater number of these at lower soil depth may therefore suggested some form of translocation has occurred.

Environmental controls on a plant can affect the amount of silification, for example, increased evaporation in hot arid environments promotes the formation of phytoliths. Similarly, irrigation and farming in areas with poor drainage provides additional soluble silica for phytolith production (Branch *et al*., 2005; Piperno, 2006; Madella *et al.,* 2009). The amount of phytoliths produced can vary between different cell types within the same plant however, for example, some cells are devoted to the active accumulation of silica and are not controlled by specific hydrological conditions (Madella *et al*., 2009). These include the leaf epidermis and short cells which produce bilobates, saddles and cross-shaped phytoliths as well as the production of hair cells. Other cells such as epidermal elongate cells commonly produced in grasses are sensitive to hydrological conditions, with their mechanism for deposition being related to water flow and an excess of monosilicic acid in the plant, as provided in aforementioned environments (Madella *et al.,* 2009). Silica within plants has been thought to help re-enforce cell walls preventing them from collapsing during drought conditions (Strömberg *et al*., 2016). Phytolith assemblages can therefore provide evidence for a plant's growing environment and the water availability during phytolith formation (Madella *et al*., 2009; Jenkins *et al*., 2016). This consequently can provide information on the amount of irrigation during the plant's growth cycle (Madella *et al*., 2009).

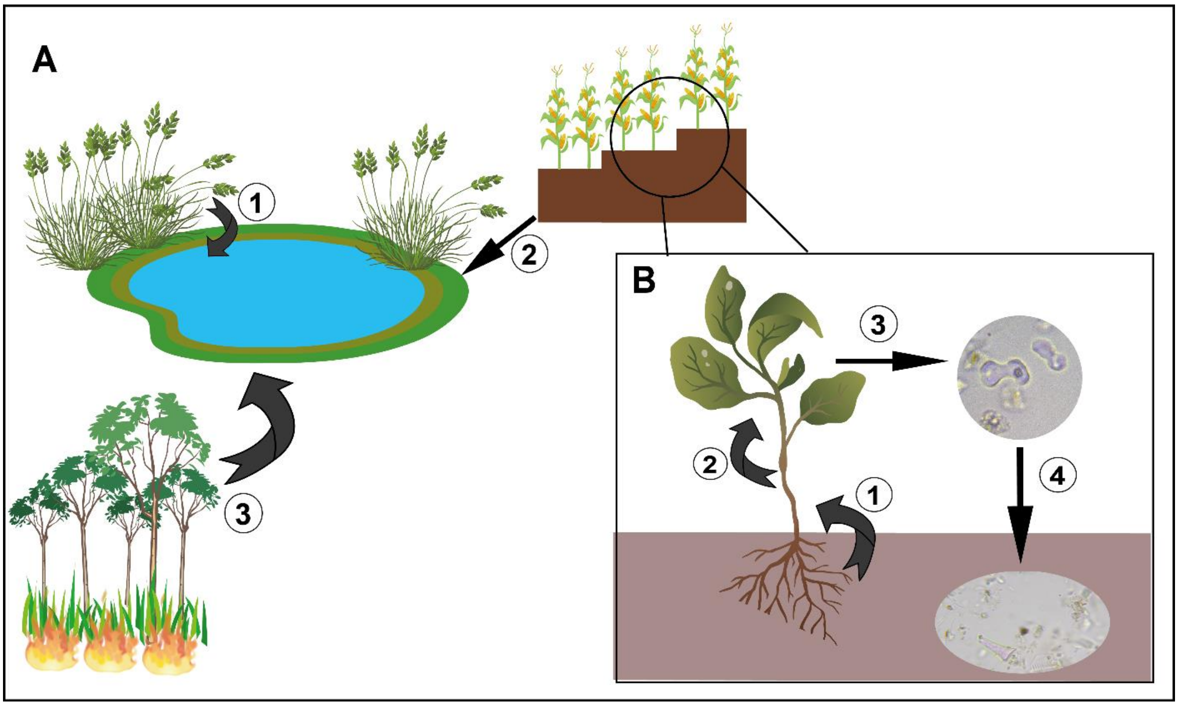


Figure 2.8: A: phytolith transport methods into lake or mire deposits. 1) Direct input from plants at water's edge or on the mire surface. 2) Landscape erosion and in washing of phytoliths from surrounding terraces and landscape. 3) Liberation of phytoliths from burning events. ***B****: Model for the production of phytoliths. 1) Absorption of soluble silica (H_4O_4Si) from groundwater through the roots and into transpiration stream. 2) Deposition of solid silicon dioxide (SiO_2) into cells and intercellular spaces within the plant. 3) Formation of opaline silica bodies*

(phytoliths), which are released into the soil when the plant dies. 4) Deposition of phytoliths into the soil where it forms the fossil assemblage.

Phytoliths are particularly useful for trying to identify cultivars present within the landscape due to the distinctive characteristics produced by some of the key domesticated taxa, for example maize, squash, wheat, and arrowroot (Piperno, 1988). Maize phytoliths are particularly distinguishable and can be identified by their leaf, stalk, seed, and chaff phytoliths, all of which have different morphotypes (Ball *et al*., 2016). In particular, wavy-topped rondels produced in the cobs and fruitcases of maize are diagnostic of cultivated maize (Piperno, 2006; Ball *et al.,* 2016). Similarly, *Cucurbita* or squash phytoliths are highly diagnostic, especially scalloped phytoliths produced in the fruit rinds of the plants. Domesticated *Cucurbita* phytoliths are often much larger than wild varieties and are well preserved over long time periods due to having thicker walls, which allows for their easy identification and can provide greater detail to the cultivar record if found within an assemblage (Watling *et al*., 2015; Ball *et al.*, 2016; Lombardo *et al*., 2020). Root phytoliths, such as arrowroot (Marantaceae) and manioc (Euphorbiaceae) are also highly diagnostic crop phytoliths that are fairly robust but are sometimes underrepresented in assemblages as they are not produced as abundantly as leaf phytoliths (Iriarte and Paz, 2009; Ball *et al.,* 2016). One disadvantage of using phytoliths to identify cultivars is that some cultivated families produce very few phytoliths, for example: Chenopodiaceae (chenopods including quinoa), Convolvulaceae (sweet potato), Solanaceae (potatoes, peppers and tomatoes) and Apiaceae (Carrots) (Piperno, 2006; McMichael *et al*., 2012). As a result, not all of the families likely to produce cultivated species will appear in a phytolith record. Therefore, the phytolith record was interpreted in conjunction with a pollen record to build up a more complete picture of past agricultural cropping regimes. This will also be the case for families of non-cultivated crops that commonly occur in an Andean setting but are not known to produce phytoliths, or where production is uncommon to rare, such as: Asteraceae, Cactaceae, Euphorbiaceae, Fabaceae, Myrtaceae, Polygonaceae, and Rosaceae (Iriarte and Paz, 2009; Strömberg *et al*., 2018; Piperno and McMichael, 2020).

One additional benefit of the use of phytoliths is the correlation between phytolith morphotypes and the C3 and C4 photosynthetic pathways in Poaceae, which not only represents different sub-families of Poaceae, but also provides some information on different environmental conditions (Barboni *et al*., 2007; Contreras and Zucol, 2019). The identification of Poaceae plants to sub-family level, something not currently possible from pollen analysis, is especially important (Strömberg *et al*., 2018: Plumpton *et al.,* 2019). For example, rondel phytoliths belong to the Pooideae sub-family, which represent the C3 pathway and therefore cooler and often higher altitude conditions (Twiss, 1992; Barboni *et al.,* 1999; Piperno, 2006; Lisztes-Szabo *et al.,* 2015). For the C4 pathway, saddles, belonging to the Chloridoideae sub-family and bilobates in the Panicoideae family are the most common distinguishable forms. These correlate to hot and dry, and hot and humid, environments respectively dominant in tropical-sub-tropical regions (Twiss, 1992; Branch *et al.,* 2014; Neumann *et al.,* 2017; Conteras and Zucol, 2019).

Phytolith preservation, although known to be good in contexts where other microfossils may not preserve (e.g., occupation layers), can be affected by post-depositional processes, such as diagenesis (Madella and Lancelotti, 2012; Rashid *et al*., 2019). This may be the individual or cumulative effects of physical, chemical, and biological processes that can result in the alteration of phytoliths, or even some being destroyed. These processes may include soil formation processes such as bioturbation, dissolution, erosion, and re-deposition (Madella and Lancelotti, 2012). The transportation of phytoliths before burial can also result in phytoliths becoming damaged or broken due to mechanical processes. For example, transportation can lead to breakages in the fine appendages and week points of phytoliths such as the narrow parts of a bilobate (Madella and Lancelotti, 2012). Chemical weathering can also occur in soils with a pH above 8, however not all phytoliths dissolve at the same rate. For example, phytoliths with a lower surface/volume ratio, which are more compact, dissolve less than those with a higher surface/volume ratio and with more complex decorations. Unfortunately, it is these morphotypes with greater surface decoration that tend to be most-diagnostic, often indicating the part of plant the phytolith originates from and the potential genus, or in some cases species (Cabanes, 2020). If these phytoliths lose this decoration, they may be misidentified or further analysis such as morphometries may not be possible.

2.3.2 Analytical methods

Samples from a series of *bofedales* and terraces in Ancash (see Section **3.4**) and from the Ayapampa wetland in Apurímac (Section **5.3.1**) were analysed for phytoliths. The samples from the *bofedales* and terraces were processed following the dry ashing method; described by Schelenberg (1908) and Netolitzky (1929) and cited in Piperno (1988; 2006:97) and Parr *et al.,* (2001) (Fig. 2.10). These samples were not highly organic, and any organic content would easily be removed during ashing in the muffle furnace. The temperature of the furnace did not exceed 500ºC to ensure no alteration to the physical or chemical characteristics occurred during the extraction process (see Parr *et al*., 2001). 5g of soil from each sample was sieved; due to the dry nature of these soils, they were dry sieved though a 500µm sieve before calcium carbonate removal. The samples were placed in 50ml centrifuge tubes and 10ml of Hydrochloric acid (HCl) was added to each sample. Samples from BOF 3 and BOF 9 reacted with the HCl and effervesced; a further 5-10ml of HCl was added to each sample to aid the reaction, after 15 minutes the samples were still reacting, and the samples were left overnight for the reaction to stop completely before being centrifuged and washed. Samples from BOF 1, BOF 6, BOF 10, BOF 13 and TER-1 had no reaction to the HCl. A sonication step was added (see Figs. 2.8 & 2.10) to help disaggregate the clays before samples were placed in 400ml beakers for clay separation by gravity sedimentation (Fig. 2.9). Samples in the 50ml tubes were placed in an ultrasonic bath for 5 minutes following Lombardo *et al*. (2016); carrying out this step before transferring the samples into beakers was found to speed up the process of clay removal via gravity sedimentation and resulted in less pour offs being required. Heavy liquid separation was performed on the samples using 6ml of Sodium Polytungstate (SPT), this heavy liquid was calibrated to a specific gravity of 2.3g/cm^3.

Samples were mounted in Entellan New^{TM}, which has a refractive index of 1.49-1.5; this is used because phytoliths have a refractive index of ~1.42 and therefore the phytoliths will have distinctively greater relief than the mounting medium (Piperno, 2006). Due to the acute toxicity of Entellan^{TM} New, mounting was carried our wearing full PPE (gloves, eye goggles, lab coat), in a fume cupboard and slides were left for 2-3 days to allow the mounting medium to cure and ensure no fumes are given off during microscopic analysis of the slides. Slides were analysed between 3-14 days of preparation to allow for the rotation of phytoliths within the Entellan to aid better identification of the phytolith morphotypes. After this window, the Entellan solidifies and the phytoliths cannot be rotated.

Samples from Ayapampa were taken every 8cm from *~692 cal yrs BP (AD 1258)* to present day (from the top of the hiatus in the sequence). A further eight samples were taken below the hiatus in the sequence, taking the phytolith record back to ~3000 cal yrs BP (see Section **5.3**). This resulted in eleven samples of Late Intermediate Period age, five samples of a Late Horizon age, and thirteen samples were from the Colonial Period through to modern day to complete the sequence up to the top (0cm). Initially it was hoped that these samples would be processed using the wet-ashing methodology (see Piperno 2006; 90) using Nitric Acid (HNO_3), however due to time limitations on completing the phytolith work, the dry-ashing method described above was employed. The use of Nitric Acid for organic matter removal is thought to be highly efficient at removing organics from highly organic peaty sediments, like those found in the Ayapampa sequence. However, the dry-ashing method has been seen to produce similar results and so was adopted here (Parr *et al*., 2001).

For Ayapampa, only 1cm^3 of material was extracted from the core; ideally, 3cm^3 would be collected to allow for the greatest possible representation of phytoliths within the final slides. However, the core had previously been used for pollen analysis and exploratory phytolith work and limited material was remaining. This pilot work found the phytoliths to be abundant within the core and so 1cm^3 was deemed to be an acceptable sample size. Due to the small sample size the samples from Ayapampa were not sieved, instead, the samples were placed directly in 50ml centrifuge tubes and 1/4 teaspoon of Sodium hetametaphosphate (SHMP) was added to each sample, and water topped up to 45ml. These were then placed in a sonicator for five minutes. After sonication the samples were centrifuged at 2500 rpm (this is higher than the previous samples due to the loose nature of the peat), for five minutes. The samples were not treated with HCL as they were organic peat rich and not known to contain any calcium carbonate. The samples were then transferred into crucibles and processed as detailed in Figure 2.10.

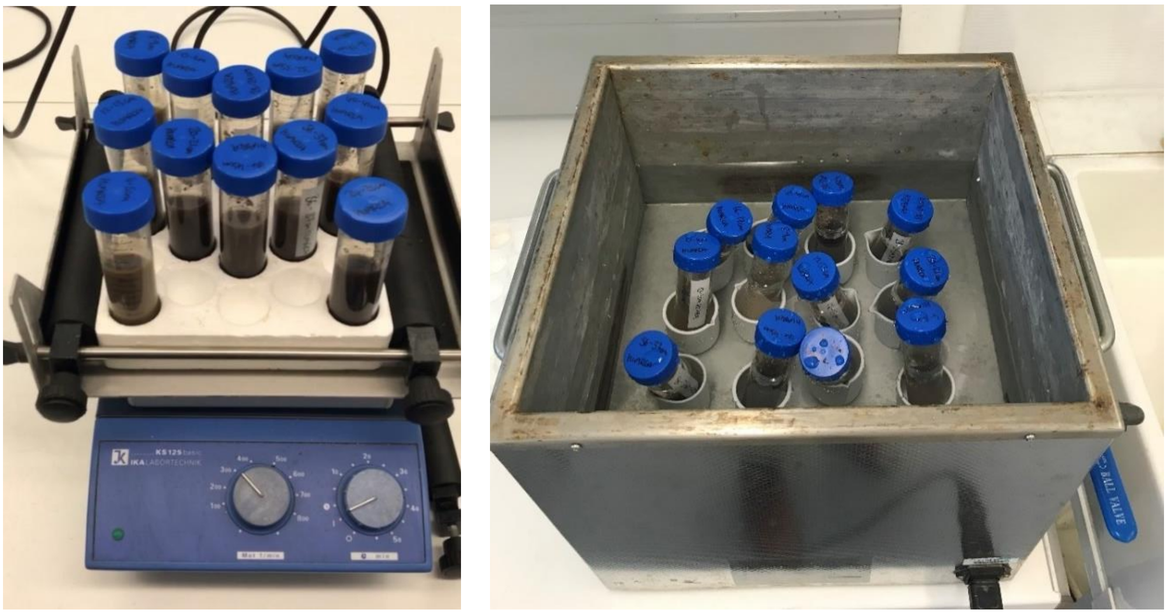


Figure 2.9: Left: Samples with SHMP on the shaker overnight Right: Samples in the ultrasonic bath.

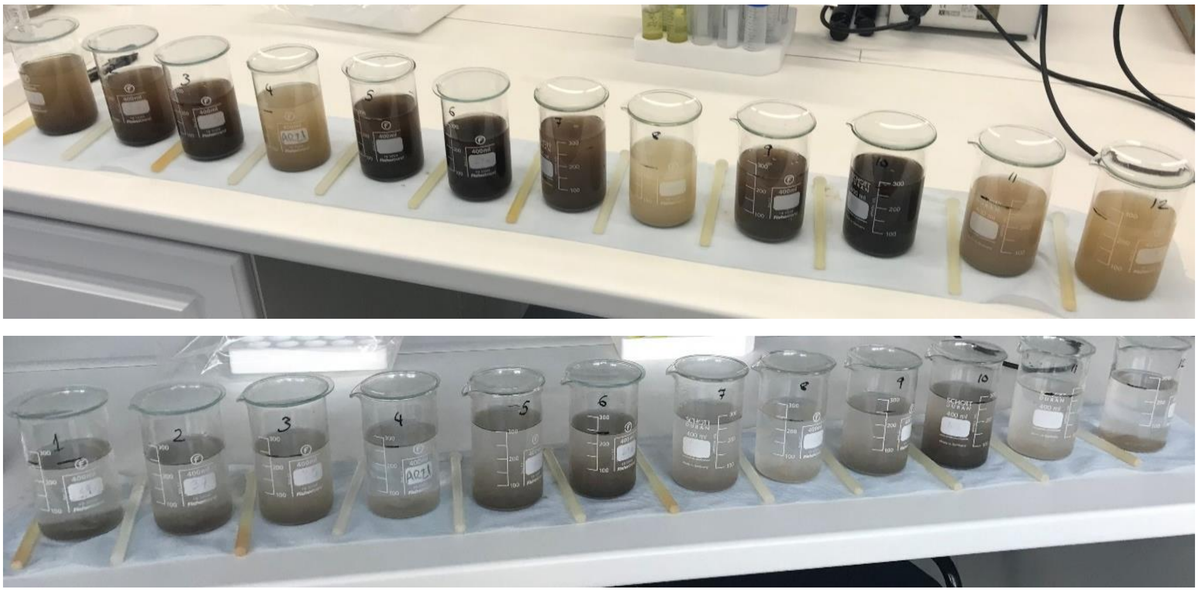


Figure 2.10: Top: Samples during clay-removal Bottom: Samples towards the end of the clay removal stage when the supernatant has cleared, some samples, e.g., 3, 5, 6, 9, 10 would still require further pour offs.

Sieve each sample through a 500µm mesh sieve on to shiny paper and transfer 5g of material to a 50ml centrifuge tube

Add 10ml of HCL to each sample, wait to see if there is a reaction, if so, wait until reaction has ceased and then fill up to 40ml with deionised water

Centrifuge for 5 minutes at 1200 rpm, once centrifuged pour off the supernatant and refill to 40ml with deionised water, then re-centrifuge (repeat wash 3 times).

Add 30ml of Sodium Hexametaphosphate to each sample and place on a shaker overnight

Transfer tubes into an ultrasonic bath for 5 minutes to disaggregate the clays.

Transfer sediment into 40ml beakers. Add 100 ml of Sodium Hexametaphosphate and fill up with deionised water. Leave to settle for 1 hour before pouring off the supernatant and refilling with deionised water. Repeat this process until the water is clear and the clay has been removed.

Transfer the remaining sediment to crucibles using a pipette. As little water as possible should be transferred across with the sample. Dry sample under a heat lamp for 2-3 hours until all the water is evaporated.

Transfer crucibles to a cold furnace. Heat furnace to 500ºC for 2.5 hours. Allow furnace to cool before removing samples. Once the samples have been ashed break up the samples in the crucible using a spatula, transfer into rounded 15ml centrifuge tubes.

Add 6ml with Sodium Polytungstate to carry out heavy liquid separation. Centrifuge at 1200 rpm for 10 minutes with the break off, after which the phytolith containing portion will be on top of the supernantant. Pour this (3-4ml) into a new-labelled 15ml conical centrifuge tubes. Re-centrifuge at 1200rpm for 5 minutes, brake on. Wash samples with water three times. Pouring supernatent into a beaker for recycling the SPT.

Add 1ml of ethanol to each sample and place into a fume cupboard to dry.

Transfer a small amount (equivalent to the size of a lentil) of material to a fresh centrifuge tube and add a couple of millilitres of Entellan New to the tube, stir well before transferring a few drops of the Entellan phytolith mixture across to a glass slide. Cover with a coverslip and leave to dry for 2-3 days.

Figure 2.11: Flowchart of the phytolith extraction methodology following the dry-ashing methodology.

2.3.3 Phytolith Identification

Phytolith identification was aided by published reference material (e.g., Piperno, 2006; Iriarte, 2010; Watling and Iriarte, 2013; Alves, 2017; ICPT, 2019), and by direct comparison with the modern reference collection housed at the University of Exeter. Naming of phytolith followed the International Code for Phytolith Nomenclature (ICPN) 2.0. where possible (ICPT, 2019). 300 phytoliths were counted per slide, and a scan of the slide was carried out to check for any missed morphotypes (see Zurro, 2018). Acute Bulbosus phytoliths were not included in this count as they are non-diagnostic and occur within a wide range of plants. Microphotographs of phytolith morphotypes encountered are shown in Figure 2.13.

A number of phytolith morphotypes are diagnostic of Poaceae, grass silica short-cell phytoliths (GSSCP) in particular are produced in grass epidermal cells. Phytoliths included in this group are trapezoid (Fig 2.13; i), saddle (Fig. 2.13; k), polylobate (Fig. 2.13; l), bilobate (Fig. 2.13; m), cross (Fig 2.12), crenate, and rondel (Fig 2.13: q). Rondel phytoliths can be split into tall and short types (Fig 2.11) and have been identified as such in the full phytolith diagrams (See Section **3.4.1**), however these are found within several Poaceae subfamilies and so are identified only to Poaceae in this analysis (Iriarte and Paz, 2009; Dickau *et al*., 2013). Bilobates are commonly found in Pooideae grasses in the tribe Stipeae, in comparison to published material the phytoliths within this study were identified to be thick bilobates from *Stipa* grass, as identified by Fredlund and Tieszen (1994) and Piperno and Persall (1998) and described in Iriarte and Paz (2009).

Bulliform flabellate phytoliths are also produced in Poaceae, as well as Cyperaceae, and a high number of these phytoliths are usually produced where water availability is high (Fisher *et al*., 2013). Elongate cells (Elongate entire (Fig. 2.13; o), dentate (Fig 2.13; s), sinuate (Fig. 2.13; u) and dendritic) are commonly produced in Poaceae in the epidermis of the leaves. Elongate dendritic phytoliths have been reported from domesticated cereals but are also common in wild grasses (Shillito *et al.,* 2011; Portillo *et al.,* 2012; Madella *et al.*, 2014; Novello and Barboni, 2015). Blocky phytoliths (Fig. 2.13; c) are common in the leaves Cyperaceae and Poaceae, but are also found in other monocots, dicots and conifers, due to this wide distribution block phytoliths have a low diagnostic value (ICPT, 2019). Phytoliths diagnostic of Cyperaceae include Cyperaceae conical phytoliths, or Cyperaceae cones, and Cyperaceae achene epidermal phytoliths (Piperno, 2006; Novello *et al*., 2012).

Arboreal plants produce a range of phytoliths, some of which are not diagnostic to plant part or family of tree, for example Figure 2.13 (d), this morphotype has been referred to herein as just Arboreal phytoliths. Sclereid phytoliths are most commonly produced by trees and shrubs and are used as an indicator for forest and other woodland vegetation and so have been included in the arboreal group on the phytolith diagrams (see Fig. 3.19 for an example) (Piperno, 2006; Dickau *et al*., 2013 Aleman *et al*., 2014). Tracheary phytoliths are also common of arboreal plants (Bozarth, 1992; Piperno, 2006; Dickau *et al*., 2013).

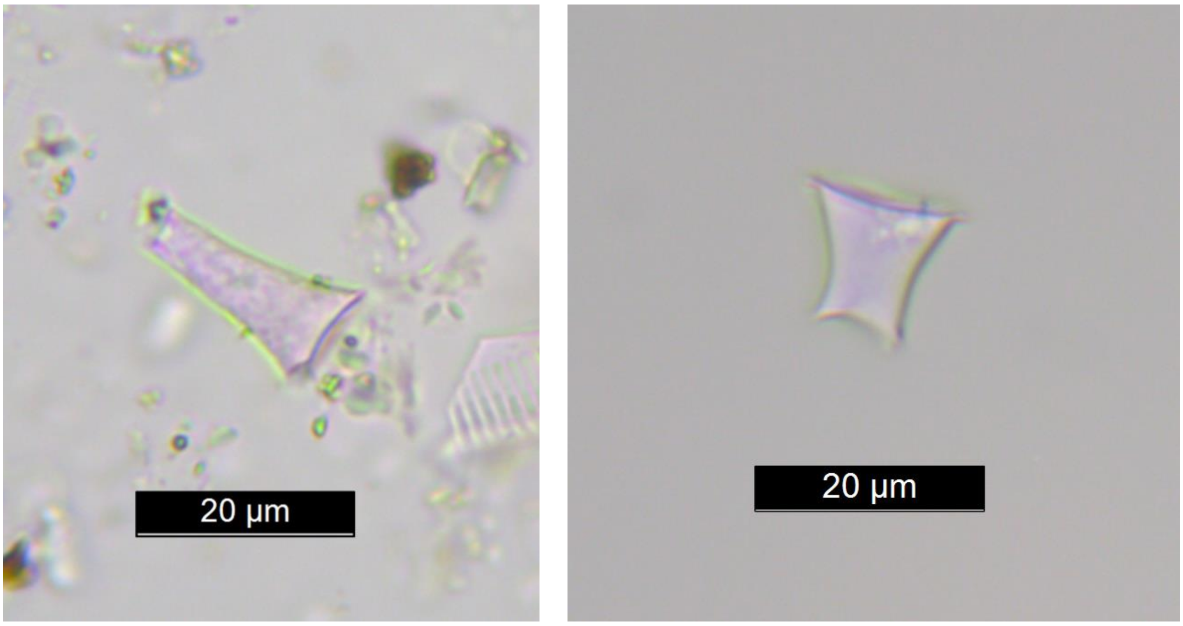


Figure 2.13: Microphotography of tall rondel (left) and short rondel (right).

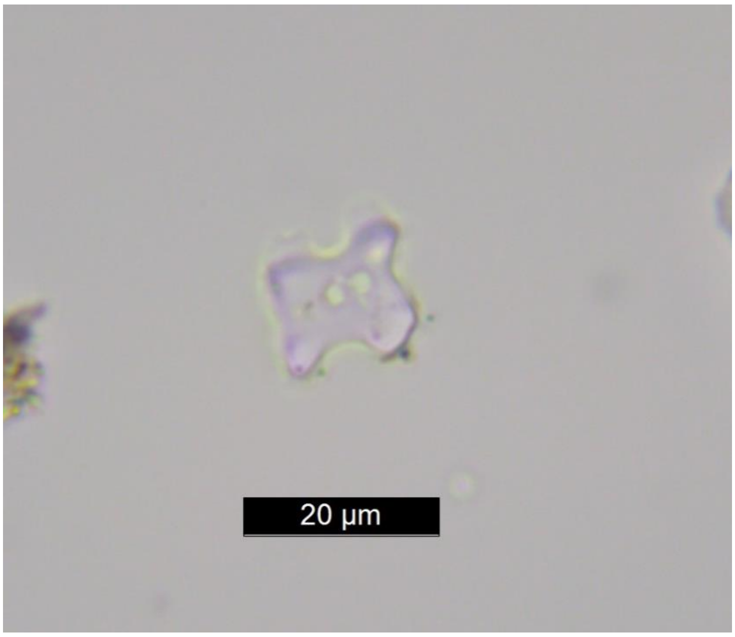


Figure 2.12: Microphotograph of cross phytolith from panicoid grass, potentially sourced from Zea mays.

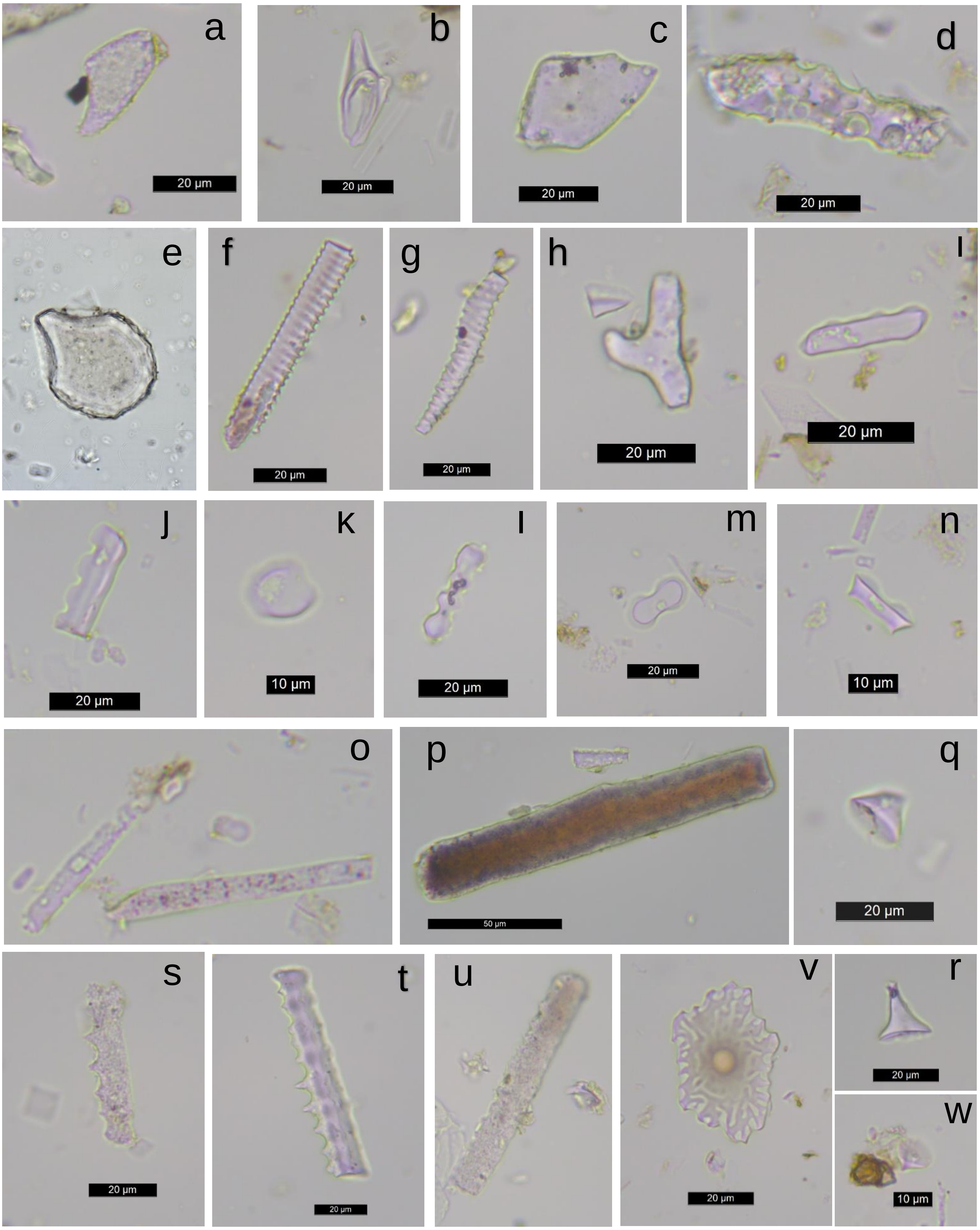


Figure 2.14: Phytolith plate a-b) Acute Bulbosus c) Blocky d) Arboreal e) Bulliform Flabellate f-g) Tracheary h) Sclereid i-j) Wavy Trapezoid k) Saddle l) Polylobate m-n) 'Thick' Bilobate o) Elongate Entire p) Elongate Entire with occluded carbon q-r) Rondel s-t) Elongate Dentate u) Elongate Sinuate v) Cyperaceae Achene w) Cyperaceae Cone.

2.5 Radiocarbon Dating

2.5.1 Theoretical Framework and Rationale

Radiocarbon ages are commonly calculated using accelerator mass spectrometry (AMS), which with recent developments allows for smaller sample sizes and quicker analysis time compared to more traditional methods such at radiometric dating (‘beta decay’) (Branch *et al*., 2005; Lowe and Walker, 2015). AMS dating determines the ratio of ^{14}C relative to that of stable isotopes of carbon (^{12}C and ^{13}C), the age is then calculated by comparing that ratio to standard known ^{14}C content (Lowe and Walker 2015). Error values are reported with the radiocarbon age (as ± X no. of years), which represent the statistical uncertainties in the measurement process (Lowe and Walker, 2015). Radiocarbon measurements are reported in years before present (BP), present being a fixed point of AD 1950, when the ^{14}C content of the atmosphere was approximately in equilibrium before the start of any nuclear bomb testing (Branch *et al*., 2005). Radiocarbon years do not directly correlate to calendar years and therefore a calibration curve is required to convert radiocarbon ages to calendar years. The current calibration curve is IntCal 20, which is based on tree ring records which extend back to 13, 910 cal yrs BP, for radiocarbon measurements older than this the curve uses lacustrine and marine sediments, speleothems and corals to extend the dataset back to ~53,970 cal yrs BP (Reimer *et al*., 2020). For samples which date to the period 1950-2019, a Post-Bomb curve is used, which is based on atmospheric CO_2 sampling and tree rings from clean-air sites; this allows for more accurate dating of recent (post-1950) terrestrial samples (Hua *et al*., 2021). The atmospheric bomb ^{14}C curve has five zones (Northern Hemisphere 1, 2 and 3 and Southern Hemisphere 1-2 and zone 3), based on the distance from the aboveground nuclear detonations between 1962-1964, which mainly took place in the Northern Hemisphere; for boundaries of the zonation’s see Hua *et al.* (2021). As radiocarbon dates are only usually obtained for certain depth intervals throughout cores (as opposed to every centimetre, as might be achievable via other dating methods such as ^{210}Pb analysis) an age-depth model needs to be constructed to provide approximate timings of events not directly dated through radiocarbon dating. Oxcal can be used to create a P-sequence depositional model in order to achieve this, using a P-sequence allows for the consideration of a variable rate of sedimentation, as is common within peat sequences. By including Variable K within the P-sequence model changes in the rate of deposition can be accounted for (Ramsey and Lee, 2013).

2.5.2 Analytical methods

The cores from Huarca and Antaycocha underwent a visual assessment for suitable dating material, in the form of large plant macrofossils, as well as assessing the organic matter content for organic rich units. Where no macrofossils were present, bulk organic sediment samples were extracted from the core as 1cm (core length) x 5cm (core width) diameter slices. In the case of Antaycocha, these were bulk organic lake sediments, where the organic matter content was greater than 30%. Sampling depths for radiocarbon dating were chosen based on the results of the palynological record and geochemistry, with several dates occurring at transitions in the ITRAX µXRF ratio plots and major changes within the palaeohydrology and vegetation history within the basins. Dating specific events allows for more precise correlation between the palaeoenvironmental records from the basins and published palaeoclimatic and archaeological records. Selected samples were carefully removed from the core to avoid cross-contamination, and gloves were worn, and equipment cleaned with distilled water in between taking each sample. Samples were places in aluminum foil envelopes and weighed before being wrapped and placed in labelled plastic sample bags. These were clearly labelled with the lab code (format: site, sample no, depth e.g., HURC-1-18), the material within the bag and the weight of the sample. These were then stored in a fridge until being packaged and sent for analysis. All radiocarbon samples (Nine from Huarca and five from Antaycocha) were submitted to the SUERC Radiocarbon Laboratory, East Kilbride for AMS ^{14}C dating. The samples were prepared to graphite at the NEIF Radiocarbon (Environment) Laboratory before being passed to SUERC AMS laboratory for ^{14}C Analysis.

The radiocarbon dates were calibrated using OxCal v4.4 (Bronk-Ramsey 2009) into calibrated years before present (cal yrs BP). These were then used to produce an age-depth model, to provide approximate dates for the depth intervals that were not directly dated using radiocarbon dating. OxCal v4.4 was used to create a P-Sequence model using the IntCal 20 atmospheric calibration curve (Reimer *et al*., 2020). An additional curve was used for Antaycocha to model the modern date received near the top of the sequence, for this a combination of the PostBomb curve (Bomb13SH12.14c) (Hua *et al*. 2013) and IntCal 20 atmospheric calibration curve (Reimer *et al*., 2020) was used. IntCal13 was originally used on both records, but IntCal20 was published during the lifespan of this project and so the dates were updated accordingly. Calibrated radiocarbon dates and the results of the age depth modelling are quoted at a 95% confidence interval. For more information on the results of the modelling see Sections **3.3.4** and **4.3.4**. Dates for Ayapampa had previously been obtained by Branch *et al.* (2007), Kemp *et al.* (2006) and Silva (2005); details of these can be found in Section **5.3.1**, however these have been remodelled here under the IntCal20 calibration curve to match the analysis carried out on Huarca and Antaycocha. Due to the core sequence from

Ayapampa containing a large sandy lithological unit, assumed to be because of catchment erosion, the model was run with a hiatus in the model spanning the depths of this unit, to try and better constrain the top part of the model that dates to the Late Intermediate Period to present day. It is unknown whether this erosional unit is one singular event or a phase of erosion; using a hiatus within the model, models the two halves of the p-sequence individually and does not attempt to model the dates across the sandy unit, the resulting age-depth model can be seen in Section **5.3.1**.

Chapter 3 - Huarca Wetland (Yungay, Callejón de Huaylas)

3.1 Introduction

Chapter 3 describes the results of the analysis on Huarca wetland, Callejón de Huaylas, Ancash Region. As a way of introducing the history of the region the first section focuses on the archaeological background within the Ancash Region, and specifically the Callejón de Huaylas. This is followed by a brief statement on the methodologies used (Section **3.2**); more details can be found within **Chapter 2**. A full description of the results from Huarca wetland (Lithostratigraphy and organic matter, µXRF, pollen, NPPs and micro-charcoal), is provided in Section **3.3**. These results are then interpreted (Section **3.3.5**). In addition to the data from Huarca wetland, a series of terrace and *bofedal* deposits from Awiskmarka were analysed for phytoliths, the results of this are present in Section **3.4**. Finally, the results of all analysis present in this chapter are discussed in Section **3.5**, with reference to published works.

3.1.1 Regional Archaeology

At the present day, settlement within the Callejón de Huaylas is largely focused on the *Suni* zone between 3,000 and 4000 m a.s.l. in order to take advantage of high-altitude agriculture and raising livestock for a combined economic subsistence strategy with a focus on agro-pastoral farming. The Ancash Sierra experiences marked seasonality with the wet season occurring between October and April; rains peak in January to March (Lau, 2011, 2016). This is important for the scheduling of agricultural activities and discrete fields are rotated with different crops, harvested at different times to make the most of the growing season (Lau, 2011). However, the consequences of recent climate change, such as glacier retreat and heavily modified grassland cover, has led to year-by-year assessments and adjustments to labour inputs, the size of herds, amount of land under cultivation, the types of cultigens and animals used, and where possible the location of fields and grazing areas (Lau, 2011).

The Callejón de Huaylas, which covers the intermontane drainage of the Rio Santa, formed a key route for exchange and interaction throughout prehistory (Lau, 2011, 2016). The area around the modern limits of Huaraz has been inhabited from at least the Chavin Era (2750 cal yrs BP/ 800 BC) with a seemingly continuous record of occupation and agricultural activity across the region. The following is a review of the key cultural phases within the Callejón de Huaylas from the Early Horizon until the Late Horizon. An overall chronology has been presented for the Callejón de Huaylas region and is compared to that of the general Central Andes chronology (Table 3.1). A large focus of archaeology in the Callejón de Huaylas has been on the Early Intermediate Period, given the large amount of material evidence from sites associated with Recuay-style ceramics. Less emphasis has been put on the Late Horizon Inca Period and even less still on the Late Intermediate Period (Aguilar, 2019).

Table 3.1: Archaeological framework for the Peruvian Andes and the Ancash Region over the last 4000 years. Modified from Branch, 2007 and Lau, 2016.

<table>
<tr><th>Central Andes General Chronology</th><th colspan="2">Callejón de Huaylas</th></tr>
<tr><td colspan="3">Colonial Period AD 1532-1826</td></tr>
<tr><td>Inca AD 1438-1532</td><td colspan="2">Inka- Aquillpo AD 1450-1532</td></tr>
<tr><td>Late Intermediate
AD 1100 - 1438</td><td colspan="2" rowspan="2">Aquillpo AD 900-1450</td></tr>
<tr><td rowspan="5">Middle Horizon
c.AD 500 - 1100</td></tr>
<tr><td>Late Wari
AD 850-900</td><td rowspan="2">Wilkawain AD 700-900</td></tr>
<tr><td>Early Wari
AD 700-850</td></tr>
<tr><td colspan="2">Late Recuay AD 600-700</td></tr>
<tr><td colspan="2" rowspan="2">Recuay 250 BC - AD 600</td></tr>
<tr><td rowspan="2">Early Intermediate
200 BC - AD 500</td></tr>
<tr><td colspan="2">Huarás 200-250 BC</td></tr>
<tr><td>Early Horizon 800 - 200 BC</td><td colspan="2">Chavin Era 800-200 BC</td></tr>
<tr><td>Initial Period 2000-800 BC</td><td colspan="2">Huaricoto 3000 -800 BC</td></tr>
</table>

Early Horizon – Chavin Era (2750-2150 cal yrs BP/ 800-200 BC)

The Early Horizon was a period of widespread adoption of ceramics and an increasing reliance on irrigation. Over this period there was a large investment in monumental construction and development of regional religious ideologies (Arkush and Tung, 2013). From 2750-2350 cal yrs BP (800-400 BC), during the EH, the Chavin cultural tradition flourished and at its peak was part of a wide network for interregional exchange of valuable goods. This all took place during a period of rather stable social conditions without any significant warfare or conflict. Fortified sites did not appear to develop in the region until after 2450 cal yrs BP (500 BC), indicating little intergroup conflict prior to this time (Arkush and Tung, 2013).

Towards the end of the Early Horizon, the cultural flexibility and diverse community built up by the Chavin gave way to social instability with a change in material culture and belief systems during the transition to the Recuay cultural period (Lau, 2016). This initially took the form of the Huarás culture from around 2150 cal yrs BP (200 BC). The Huarás culture constructed their settlements directly on top of that of the Chavin, reusing their once precious carved monoliths as common building materials (Lau, 2016). However, this may not have been done in direct disregard for Chavin cultural traditions, because from 2450 cal yrs BP (500 BC) construction activity at Chavin had mainly ceased and the site began to fall into ruin, with the temple of Chavin thought to have a *terminus ante quem* of 2350 cal yrs BP (400 BC) (Arkush and Tung, 2013; Lau, 2016).

Early Intermediate Period – Recuay (2150-1250 cal yrs BP/ 200 BC-AD 700)

Archaeological research has led to the sub-division of the Recuay cultural period into four phases spanning the terminal end of the Early Horizon and the beginning of the Middle Horizon (2150-1100 cal yrs BP/ 200 BC-AD 850). This includes the aforementioned Huarás Phase (2150-1700 cal yrs BP/ 200 BC-AD 250), the Recuay Phase (1700-1350 cal yrs BP/ AD 250-600), the Late Recuay Phase (1350-1250 cal yrs BP/ AD 600-700) and the Early Wari - Influence Phase (1250-1100 cal yrs BP/ AD 700-850). This last transitional phase overlaps with a period generally considered as the Wilkawain Phase for the Callejón de Huaylas (see Table 3.1) (Lau, 2002). By the first millennium AD, the Recuay culture had emerged as a key player in the north of Peru, and through the EIP there was a long period of relatively insular cultural development (Lau, 2002, 2006). This regional expression of the EIP was a time of major socio-economic innovation; rise in urban centres, and of development of regionally distinct technologies (Lau, 2004). Many urban centres occupied strategic locations along exchange and trade routes, as even though the Recuay developed their own culturally distinct traditions, they were also integral to long distance trade routes from the north to the south of the Highlands. Despite there being little evidence for a wide dispersal of Recuay goods, such as textiles and metalwork, outside of the Ancash region it is unlikely they were passive recipients of traded goods (Lau, 2006).

Smaller communities were established to exploit the high-altitude agricultural lands and zones of camelid pasture (Lau, 2004). This was a practice developed in the Huarás Phase and continued into the Recuay (Lau, 2016). Recuay villages were commonly located between 3500 and 4100m a.s.l. with a strong preference towards high-altitude S*uni-Puna* ecotones, allowing access to multiple agricultural zones. This high-altitude settlement may have been aided by milder and more amenable climatic conditions during 1650-1450 cal yrs BP (AD 300-500), coinciding with the expansion of the Recuay culture, as seen from Huascarán ice core data

(Thompson, 2001; Thompson *et al*., 2003; Lau, 2011). If this indeed the case a response in the paleoenvironmental record from Huarca may be visible, the hypothesis that Recuay culture expanded under more amenable climate will be investigate further within this chapter.

The high-altitude position of settlements may also be concurrent with the apparent increase in warfare broadly relating to the Huarás Period. The end of the EH and beginning of the EIP witnessed the development of forts within the Nepeña, Casma, and Santa Valley, some with elaborate designs of multiple concentric walls, parapets and bastions (Arkush and Tung, 2013). This warfare appeared to affect all levels of society and not just the elite. It is thought conflict developed for two primary reasons during the Recuay Phase. First, and the most common reason proposed, due to competition between elites during a time of uncertain authority following the fall of the Chavin which led to destabilisation and power struggles and warfare rose as a means of incorporating people into regional systems of social stratification (Arkush and Tung, 2013).The second, less common reason, was due to conflict over land and distribution of goods, especially land that had previously been owned by the Chavin state (Arkush and Tung, 2013). Throughout the Recuay culture there is evidence for heavy involvement in warfare with iconography depicting weapons and walled towns defended by armed fighters found on pottery and some structures (Arkush and Tung, 2013).

The colder conditions which prevailed in 1450 – 1350 cal yrs BP (AD 500-600) and 1350-1250 cal yrs BP (AD 600-700), as seen in the Huascarán $^{\delta}$18O record, may have caused a limitation to the available arable agricultural land, with an advancement of *Puna* like vegetation into the lower regions of the highlands due to the strong relationship between altitude and temperature (Thompson, 2001; Thompson *et al*., 2003; Lau, 2011). An analogue for this is seen during the LIA, historical accounts note how the villages in Huánuco, to the east of Ancash, could only grow potatoes at 3450m a.s.l., agricultural land above this elevation was avoided due to being frost-prone (Cardich, 1985). Today however a wide range of cultivars are grown at elevations much higher than 3450m a.s.l. This reduction in available land for food production, as a result of deteriorating climate, may have contributed to the demise of the Recuay culture in the eighth century (Thompson, 2001; Thompson *et al*., 2003; Lau, 2011). It is possible therefore that a reduction in human activity may be seen around Huarca wetland at the transition from the Recuay Period to the Middle Horizon. This will be explored further within this chapter.

By 1250 cal yrs BP (AD 700), with the transition to the early Wari phase of influence, nearly all distinctive techniques and imagery typical of the Recuay fineware style had been abandoned, signalling the end of the Recuay cultural tradition (Lau, 2004).

Middle Horizon – Wilkawain (1250-1050 cal yrs BP/ AD 700-900)

With the start of the Wari expansion into the region and dissolution of the Recuay culture by 1250 cal yrs BP (AD 700), the boundaries with surrounding areas became much more permeable with greater external cultural influences seen in the Callejón de Huaylas (Lau, 2002, 2004, 2006). A greater abundance of 'non-local' pottery has been recovered from archaeological sites, compared to the preceding Recuay. These are mainly of Wari style and are strongly associated with contexts for status display and funerary practices (Lau, 2002). The Wari presence in the Callejón de Huaylas is broadly referred to as the Wilkawain Period, named after one of the key sites for this period (see Table 3.1).

Most of the funerary contexts dating to the Middle Horizon are in the form of *chullpas*; above ground mortuary structures, the largest of which emerged as dominant structures in the landscape, often found in association with many smaller *chullpas* and residential sectors (Lau 2002, 2012; Tschauner, 2004). These *chullpas* often featured Wari imports or Wari inspired items and the majority of the *chullpas* in the Callejón de Huaylas are located in well-watered lands on the western flanks of the Cordillera Blanca, such as the *chullpas* at Keushu, and those at Honcopampa (Isbell, 1991; Lau, 2002, 2012). Keushu is directly associated with a major stream fed by meltwater from the Huandoy glacier and an ephemeral glacial lake. These were considered as *Apu's* or *Pacanna's*; places of origin of the ancestors and homes of the deities (Herrera, 2005). The distribution of these chullpas also suggests a close link between tomb emplacement and the assertion claims over water, acting as markers for scheduled rights over water for irrigation (Herrera, 2005).

The Wari presence in the Callejón de Huaylas appears to have been part of an expansion of the core Wari region and not in the form of a satellite administrative centre under direct Wari control (Lau, 2004, 2016). There is also variation between sites in the level of Wari interaction; for example, the settlement sites of Queyash Alto and Pashash do not show evidence of discernible Wari influence, while others show Wari interaction whilst maintaining local cultural traditions, (e.g., Honcopampa and Chichawas) (Lau, 2016).

During the Middle Horizon, most settlements were strategically located to exploit key trade routes of the intermontane valleys and coastal-to-highland valley routes. Communities near transportation routes (e.g., Wilkawain and Chinchawas) and valley bottlenecks (e.g., Honcopampa) grew increasingly important, and these were developed into well-located multipurpose settlements with cemeteries, public spaces and residential sectors (Lau, 2012). The positioning of Honcopampa, in a non-central valley location making it unsuitable for displays of imperial power, storage or the organisation of goods and labour, seems to have been determined by its location near to intakes of meltwater streams to control supply of water to irrigation systems (Lau, 2012). It is also situated near the Quebrada Honda, one of the main communication routes between the Callejón de Huaylas and neighbouring Callejón de Conchucos (Tschauner, 2004). However, Honcopampa is not considered a strictly Wari settlement, with architectural styles that point to a local traditions; the archaeological evidence instead suggests the residents of Honcopampa interacted with the Wari and adopted certain ideas but the site did not form part of its territorial domain (Lau, 2001; Tschauner, 2004).

A similar mixing of cultural influences is seen at Chinchawas during the Middle Horizon. Chinchawas is located in a strategic vantage point above an important costal-highlands trade route through the Casma Valley, and one of the lowest mountain passes across the Cordillera Negra (Lau, 2005). Chinchawas was occupied from the middle of the EIP and characterised as being an insular community with some connections with the Recuay culture. It was at 1150-1050 cal yrs BP (AD 800-900), however, that Chinchawas really flourished. This expansion took place within a wider network, associated with the Wari expansion, focused on exchange. In particular, exchange of camelid products, due to the site's location within an ecotone boundary between high altitude (*Suni* and *Puna*) cultivation and pastoral farming (at around 3900 m a.s.l.) (Lau, 2005). This is reflected by an increase in camelid bones, as well as spindle whorls for the processing of camelid hair into fibres, in the archaeological record within deposits dating to 1250-1050 cal yrs BP (AD 700-900) (Lau, 2007). The archaeological record also reflects the presence of interregional connections through the presence of exotic pottery, long distance-sourced obsidian, and marine shells from the coast, all of which occur in greater frequencies during this period (Lau, 2007).

In north Peru, the dynamic cultural interactions attributable to the Wari influence during the Middle Horizon slowed within the period's first few centuries and at Chichawas the decline of this influence has been recorded from around 1000-950 cal yrs BP (AD 950-1000), shown by a decline in access to foreign ceramics, obsidian, and an overall cultural elaboration (Lau, 2005).

Late Intermediate Period - Aquillpo (AD 900 - AD 1450)

In the Callejón de Huaylas, cultural development after Wari-influence is generally referred to as the Aquillpo. This has been recorded as a period of increased regional specialisation of material styles, indicating a greater diversity in cultural groups, as society became more disintegrated (Lau, 2016; Aguilar, 2019). This was also a period of conflict and increasing reliance on fortified hilltop settlements. The archaeological record shows increased frequency of combat related traumas in the highlands for this period. This combat is thought to have been between smaller polities and not by organised armies (Arkush and Tung, 2013; Aguilar, 2019). The *chullpas*, built during the Middle Horizon, also became increasingly abundant in the Aquillpo, however they contained very few grave goods, and settlements associated with them are thought to have had limited social stratification (Lau, 2016).

The LIP was a highly productive time in terms of herding in Ancash, due to the management of complex hydrological technology geared towards maximum herding potential, for example the construction of silt dams that provided camelids with a rich biota of plant life for grazing (Lane, 2009). This tendency towards pastoral activities was also likely influenced by the higher-altitude settlement patterns, with a large majority of settlements recorded from the LIP being situated in the *Suni* and *Puna* zones, above the current key agricultural belt (Herrera, 2003; Aguilar, 2019).

Late Horizon – Inka - Aquillpo (AD 1450-1532)

During the Inca period, Ancash belonged to one of the four sectors of the Incan Empire, Chinchasuyu. Settlements were developed on lower-lying flat lands (with a few exceptions e.g., Cajarumi) often near to state roads and incorporated facilities dedicated to state activities, such as provisioning and sheltering state functionaries, storage, and spaces for public ceremonies (Lau, 2016). An example of such settlements is that of Pueblo Viejo (also referred to as Choquerecuay or Sucorecuay), although the settlement was occupied from the EIP it has largely been focused on as an Incan administrative site, with reoccupation of former sites being a show of dominance and a change to the previous social and political structures (Tantaleán and Carmen, 2004; Bernabé, 2015; 2017; Aguilar, 2019). Pueblo Viejo is situated 5 km NE of current town of Recuay on the east bank of the Santa River close to an Inca road. It is well located in the *Suni* Zone (3000-4000 m a.s.l.) and in a favourable position for access to arable agriculture, for the growth of tubers such as potatoes, and a large area of productive *Puna* for livestock herding (Tantaleán and Carmen, 2004; Bernabé, 2015; 2017; Aguilar, 2019).

One of the main features of the site is its great square that would have likely served as a gathering place for the local populations. Large numbers of people would have been able to meet and participate in acts of secularisation, with ceremonies being organised by the Inca elites, in order to allow the redistribution of consumer goods (Tantaleán and Carmén, 2004). It appears that the site was under direct administrative control from the Inca even though the archaeology of the site dating to this period is not strictly of Inca design (Tantaleán and Carmén, 2004). This differentiation from Inca architecture is likely to be due to the integration and adoption of some parts of the material culture of preceding societies that were absorbed by the new state system. It is also known from elsewhere in Peru, that many structures were planned and designed by Inca architect's but were in fact built by local labour forces that may have had some role in the variation in structural design (Tantaleán and Carmen, 2004). The site is made up of *Colcas (storehouses), Kallankas (rectangular public buildings), Kanchas (complex of Kallankas)* and a potential *Ushnu* (stone stepped pyramid) platform. The *Colcas* or storehouses would have allowed for the collection of state provincial products such as surplus food, raw materials and artefacts produced by the local population and served as taxation storage structures (Bernabés, 2015, 2017). Associated with these are a series of terraces covering approximately 60 ha, most of which is under potato and maize cultivation today, as well as a series of canal-like structures and corral-like enclosures (Aguilar, 2019). The presence of *Kallankas*, which are thought to have been used for state officiaries as banqueting halls for ritual feasting, provides evidence for direct imperial control (Bernabé, 2015; Aguilar, 2019). This archaeological evidence suggests that Pueblo Vejo was some form of capital in charge of the managing of political-administrative affairs of the region towards the south of the Callejón de Huaylas.

Elsewhere in the Cordillera Negra, the high-altitude site of Cajarumi (3600 m a.s.l.) is situated at the headwaters of the Nepeña Valley, suitable for exploiting a region rich in water and land resources for high altitude farming and herding. The Inca presence at Cajarumi has been indicated by the presence of large cut stones and carved bedrock as seen at other Inca sites. It has been hypothesised that the location of Cajarumi was chosen to act as a boundary marker between valleys and as a sacred place in association with the circulation of water and fertility (Lau, 2016).

3.1.2 Study Area and Site Descriptions

Core samples were taken from a site near Huarca village, Yungay province within the Ancash Region. The site of Huarca (see Fig. 3.1) was chosen for its proximity to a muti-period occupancy site of Keushu, as well as agricultural features such as relic terraces. Within the Callejón de Huaylas there is a paucity in environmental and land-use history records, therefore, Huarca is well placed to help answer questions raised within the archaeological record for the region. Samples from terraces and *bofedales* at Awkismarka (Fig. 3.1) have also been obtained from Dr Alex Herrera, Universidad de los Andes, Bogotá, for the analysis of phytoliths to add to the palaeoenvironmental reconstructions from Huarca. These allow for on-site analysis of past land-use within the environment near to Huarca. Descriptions of sites from the Ancash study region are provided below (Sections **3.3** and **3.4**).

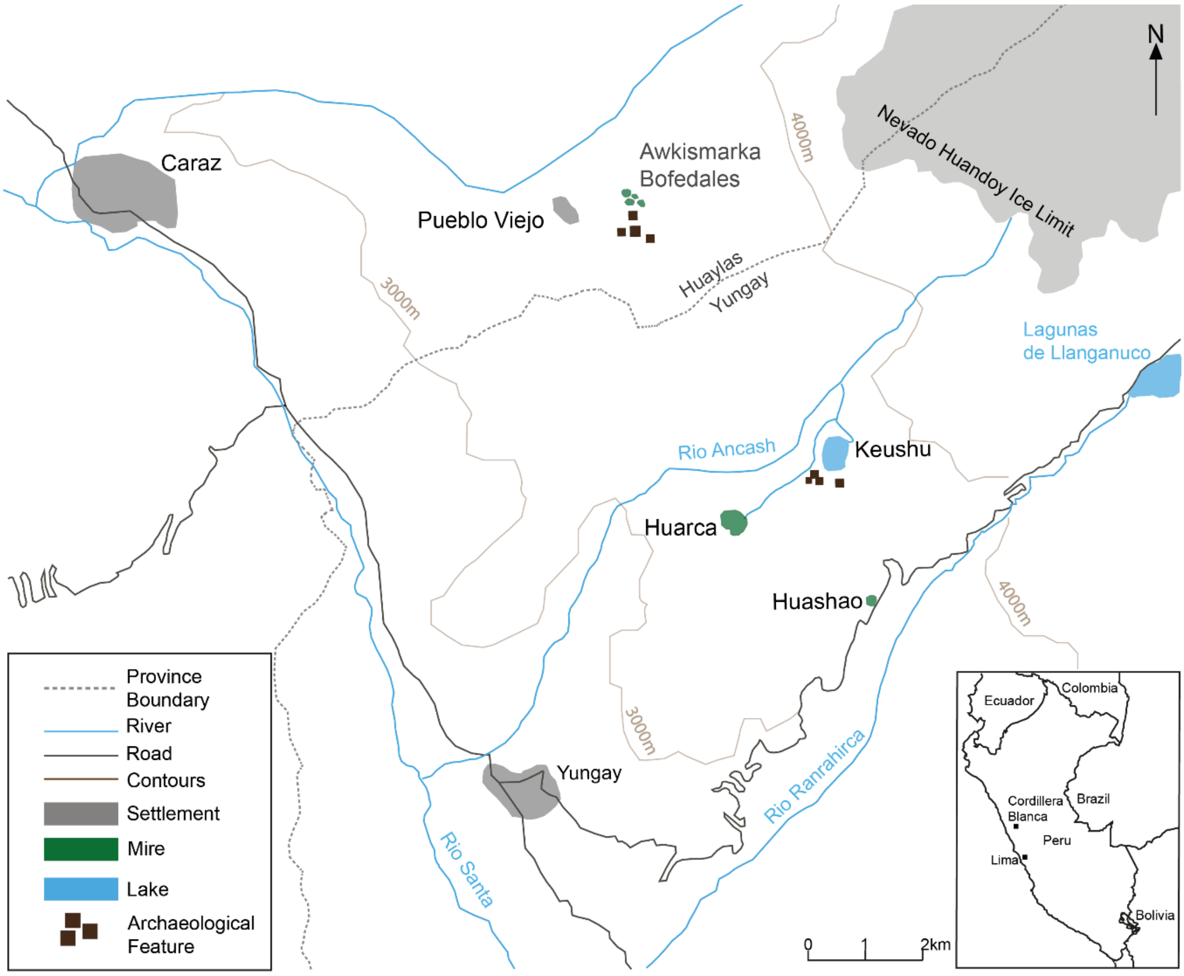


Figure 3.1: Location of sites in the Ancash Region situated within Cordillera Blanca.

3.1.1.1 Huarca Basin

The wetland next to Huarca Village (referred to herein as Huarca - Figs 3.2, 3.4, 3.5) is situated at 3190m a.s.l. (9º5’55” S 77º42’45” W). The large (325x385m), infilled basin is primarily covered in grassland at present day within the dry season, however the basin would most likely be a wetland area in the wet season as indicated by the presence of *Phragmites* reeds growing near the centre of the basin. These reeds rely on shallow water to grow. The basin is surrounded on three sides by terraces and field systems that are in cultivation today with potatoes, maize, and quinoa. There is also evidence for sheep, pig and cow farming. In pre-Hispanic times, the wetland is thought to have been used for camelid herding (*A. Herrera pers. comm.).* The site is in the shadow of Nevado Huandoy and Nevado Huascarán with the landscape surrounding the basin most likely being formed because of glacial processes. The basin itself is thought to be an inter-morainic basin, creating a relatively enclosed basin (Fig 3.3). A stream flows through the site from Lake Keushu (Fig. 3.1), which is fed by the meltwater of Nevado Huandoy. Artificial channels cut across the mire surface today (Fig 3.4), the age of which are unknown, but the village near the site is currently trying to drain water from the mire, in order to increase their available land for agriculture and expansion of the village (*A. Herrera pers. comm.)*. The sequence recovered from Huarca is 4.7m deep, this, however, was believed to be the limit for the coring equipment due to the impenetrable nature of the sediments as opposed to the true base of the sequence.

Figure 3.2: Huarca basin; taken from the edge of village looking northeast across the basin to the surrounding slopes and Nevado Huandoy in the background. Photo taken by author, 2019

Figure 3.3: Coring location looking southeast towards the village and a moraine surrounding the basin, as well as land currently used for sheep and cattle grazing. Photo taken by author, 2019.

Figure 3.4: Coring location, showing artificial channels cut into the Huarca basin Photo taken by author, 2019.

3.1.1.2 Awkismarka bofedales and terraces

In addition to Huarca basin, samples were obtained from a further six *bofedales*, and one terrace system, excavated at Awkismarka near the village of Pueblo Viejo de Huandoy, Caraz (Fig. 3.1). Locations of these *bofedales* can be seen in Figure 3.6. Table 3.2 provides further location data. Figure 3.6 shows the location of additional *bofedales* that have been excavated and surveyed, however samples for these were not provided for phytolith processing. *Bofedales* here denotes an area of naturally or artificially irrigated grassland favourable for agro-pastoral activities (following Herrera *et al.,* 2009 and Lane, 2009), and differs from the more generic definition of *bofedales* as high elevation wetlands commonly found in the *Puna*. The *bofedales* referred to here are not limited by elevation, whereas the more traditional definition places them only above 3800m a.s.l.; there is also a difference in vegetation type as high altitude *bofedales* within the *Puna* are primarily formed of cushion-forming plants, most commonly *Distichia* (Fonkén, 2014). The site of Awkismarka is associated with a large ridge-top ceremonial centre with the remains of over 200 mortuary structures (*chullpas*) still visible today. The closeness of these *bofedales* to a large archaeological site provides an excellent opportunity to investigate agricultural and land-use practices of the people associated with the ceremonial centre, this is especially significant as the site has the largest concentration of *chullpas* in the region (Herrera *et al*., 2009). The *chullpas* are thought to have been in use from the second century BC, with some structures at Awkismarka similar to those seen at Chavin de Huntar, particular the use of underground galleries in association with the tombs (*A.Herrera pers. comm*.).

Many of the *bofedales* identified in the field by Herrera *et al*. (2009) have been artificially modified in some way; for example, the building of retention walls and additional structures being added to improve the retention of the alluvium and enhance slope stability (Herrera *et al*., 2009). There is also evidence within the surrounding landscape for feeding systems providing water to the *bofedales*, including various hydraulic elements like canals, sluice gates and check-dam structures (Herrera *et al*., 2009). Two different types or ‘categories’ of *bofedales* were identified through excavations. The first is referred to as a *bofedal*-reservoir structure (Bof 1 & Bof 2). These contain finely grained soil with high porosity, which aids in the volume of water that can be retained within the *bofedales* structure (Herrera *et al*., 2009). The second, known as *bofedal*-pasture, has coarser soil with evidence of less sustained maintenance (Bof 3, Bof 6, Bof 9, Bof 10 & Bof 13). This second set of *bofedales* do not have as straight delimitation and the retention walls are often not as developed as in the bofedal-reservoir, or absent completely (Herrera *et al*., 2009). This second set of *bofedales* are found at higher elevation (3500-3800m a.s.l.) and were likely limited to domestic animal pasture.

Some of the terrace structures, found below the *bofedales* on the hill slope (see Fig. 3.5 & 3.6), were also excavated and analysed within the field as part of the survey work carried out by Herrera *et al.,* (2009). Terrace 1 soil profile contained finely grained soils in horizons 1 and 2, however, Horizon 3 comprised of large stones >200mmm, these were possibly placed here artificially in order to aid with drainage. The terraces at Awkismarka have not been formally dated due to lack of suitable material for radiocarbon dating, they appear to follow Kendall's Type 2 methods of construction for Andean terracing within the Patacancha Valley (Kendall, 1991; Kendall and Rodriguez, 2009; Kendal, 2013). Type 2 terraces, also known as platform terraces, are horizontal terraces built up with stonewalls and which often feature irrigation and water distribution features, such as canals, and thought to have been primarily constructed during the Middle Horizon (Kendall, 1991; Kendall and Rodriguez, 2009; Kendal, 2013). Although this typology has not been widely tested outside of the Sacred Valley, the terraces form and their association with the Chullpa's at Awkismarka which likely saw a fluorescence in the Middle Horizon (*A. Herrera pers. comms*.), suggests a Middle Horizon or later date for these terraces.

In addition to the *bofedales*, Herrera *et al*. (2009) also surveyed a number of Water Catchment Features (WCF) in the field. One of the WCF identified are check-dams that feed some of the *bofedales*. This is a system of 1-1.5m high walls built into a slope that permits the transport of water where a traditional canal would be inefficient due to the strong slope of the land. Check-dam systems reduce water velocity and provides greater slope stability (Herrera *et al.*, 2009). It is thought that water flowing through the check-dam system arrives at the *bofedales* and is then redistributed to terraces via underground drainage systems, providing the terraces with water for irrigation (Herrera *et al*., 2009). This connected water system was likely managed as a whole, with periods of construction and reconstruction in the past, the causes for this reconstruction may have been in response to climatic pressures and the need to manage water resources more closely, this is something that will be explored further in the discussion section of this chapter (Section **3.5**).

Figure 3.5: Terraces in Sector C of Awkismarka (source Herrera et al., 2009).

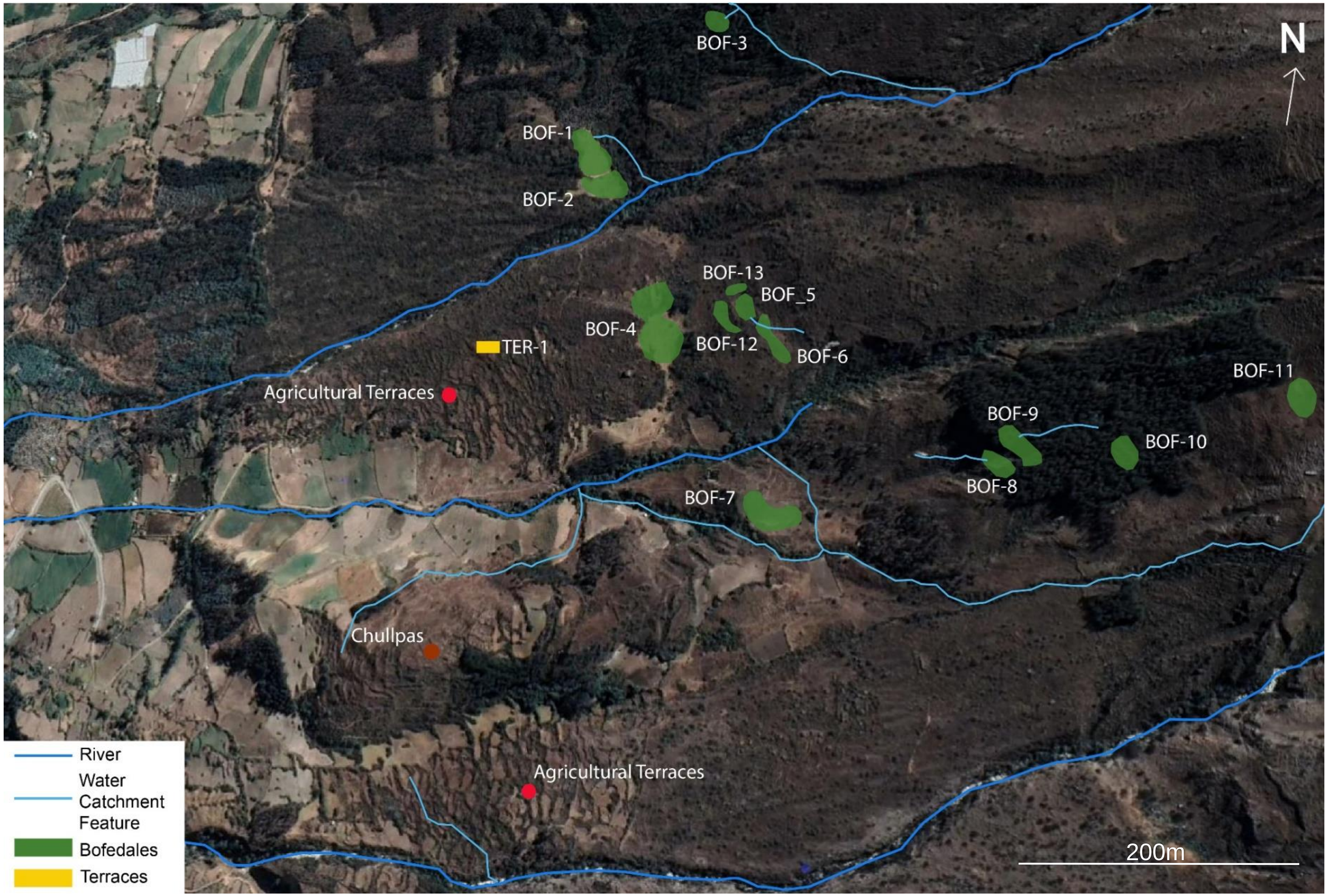


Figure 3.6: Awkismarka bofedales and terraces, and associated Water Catchment Features. Adapted from Herrera et al., 2009.

Table 3.2: Description of bofedales and terraces with associated samples for phytolith analysis. Area of the sites are given where known. (Adapted from Herrera et al., 2009).

Feature	**Location**	**Altitude (m)**	**Area (m^2)**	**Description**
YU-5/BOF-1	9º2’52” S 77º43’44” W	3455	1620	Uncultivated at present day, last known cultivation 1940-1950's. *Bofedal* has a retaining wall on the western side and is fed by a canal with three sluice gates to the north and east.
YU-5/BOF-3	9º2’47” S 77º43’40” W	3522	163	Appears to be a natural *bofedal*, fed by a check-dam system it has formed in a natural residue of a past mudslide.
YU-5/BOF-6	9º2’58” S 77º43’36” W	3520	483	*Bofedal* fed by check-dam system.
YU-5/BOF-9	9º3’01” S 77º43’23” W	3677	1719	No retention wall present, *bofedal* is fed by a check-dam systems that originates in Bof-10.
YU-5/BOF-10	9º3’01” S 77º43’19” W	3766	62	A small retaining wall is visible on the north side. Several walls are visible in the slope between Bof-9 and Bof-10. Maybe for a path or in order to stabilize the slope.
YU-5/BOF-13	9º2’59” S 77º43’35” W	3520	483	*Bofedal* slope follows slope of the hill, no retaining wall visible but potential check-damn structure built across the *bofedal*.
TER-1	9º3’01” S 77º43’46” W	3394	-	Artificial structure with a horizontal surface built up with retention walls. Past landslides may have destroyed part of the original terrace systems in the area.

3.2 Methodology

For the main methodological techniques employed on the Huarca core see the methodology chapter (**Chapter 2**), below is some site-specific methodologies for Huarca Basin.

3.2.1 Field Methodology

The sampling site for Huarca was chosen in 2018 for its central location within the basin, in the hope it would pick up the surrounding vegetation signal from all sides of the basin, including anthropogenic activity indicators. Upon returning to the site in 2019 further work was carried out and a deeper sequence was recovered from closer to the relic terraces on the northern edge of the basin (09º05’49” S 77º42’45.2” W). An 8.7m sequence was recovered from a wetter area of the basin with a long peat sequence (Teeling, in prep), this core does not have an erosional sandy unit within it unlike the Huarca 2018 core, used for this body of work (see Section **3.3.1**) and therefore is thought to be taken off the moraine fan deposit. Preliminary pollen work on this core (Giannitto, 2020), revealed the presence of *Zea Mays* and other human activity indicators, such as *Sporormiella*, indicating that a coring site closer to the edge of the basin may be more beneficial for recovering indicators of human activity.

3.2.2 Pollen Analysis

For the pollen analysis of Huarca basin the initial set of samples at 16cm resolution, taken to form the skeletal diagram and for an assessment of pollen preservation, were processed without *Lycopodium* tablets. This was due to a global shortage of *Lycopodium* tablets at the time. The samples processed at 8 and 4cm were able to have *Lycopodium* added to them, the *Lycopodium* counts for these were then used to interpolate the missing *Lycopodium* values by taking an average of the values either side, although this is not a true representation of the *Lycopodium* present it allows for a best estimate with the data available. All samples were processed in the same way apart from this following the methodology in Section **2.2.**

3.3 Huarca Basin

3.3.1 Results of the Laboratory Sedimentology and Organic Matter Content Analysis

The 470cm sequence from Huarca provided a detailed lithostratigraphic record comprising of 20 units (Table 3.3 and Fig. 3.7). The basal unit (Unit 1, 470-443cm) estimated to be *~11,470-10,808 cal yrs BP* was rich in sands, both fine and coarse and corresponded to very low organic matter percentages (2-3%). Units 2, 3, and 4 dating to *~10,808-4265 cal yrs BP* (443-283cm) were organic-rich peat, likely representing a gradual infilling of the basin overtime There is a sharp increase in organic matter content with the transition to an herbaceous peat unit at 443cm (Unit 2), here the highest value in the sequence occurs at 400cm (97%). Decreases in organic matter percentages which occur at 336cm and 320cm were not recorded in the sedimentary descriptions and indicate an increase in mineral content within the herbaceous peat. Organic matter content increases again after 320cm and remains high during units 2, 3 and 4. At 304cm, 89% organic matter corresponds to an herbaceous peat unit rich in plant macrofossils which is very dark in colour and has a high humification value of three (Unit 4). From *~4265-4066 cal yrs BP* (Unit 5, 283-281cm), the record indicates a transition to silty lake sediment representing a lake environment with open water. The basin infills again between *~4066-2653 cal yrs BP* during Units 6 and 7 (281-257cm), with the formation of herbaceous peat, organic matter remains high in Units 5, 6 and 7 (~90%).

During Units 8-12 (257-167cm), a large body of coarse and fine-grained sand and silt was deposited in the basin over a period of ~1070 years (*~2653-1213 cal yrs BP*). Organic matter levels decrease to very low values (below 7%). At 192cm, organic matter is particularly low at 0.93% during the coarsest sand unit in the sequence (Unit 10). Following this peat formation resumes in the basin from 167cm (*~1213 cal yrs BP*) to the top of the sequence at 0cm, apart from the presence of a sandy unit from 140-119cm (*~813-739 cal yrs BP*). At 160cm organic matter levels increase again to 57% as the sequence transitions to moss peat deposition with a high humification value of four. Maximum organic matter values within this unit (Unit 13) occur at 148cm (62%). Organic matter values decrease again from 144cm with a transition back to coarse sand (Unit 14). Organic matter levels during this unit are very low (0.93%).

From 108cm, organic matter levels remain relatively high during the top section of the sediment sequence (above 40% for Units 15, 16, 17 and 19), except for a decrease in values at 76cm down to 13.2% organic matter corresponding to the thin silty clay layer and a pause in moss peat formation (Unit 18). The second highest organic matter value of the sequence occurs at 56cm (96%), higher organic matter content during the top section of the core correlates with herbaceous and moss peat unit containing abundant plant macrofossils (Unit

19). At 65cm, there is a decrease in organic matter during the very top section of the core (13.7% at 4cm) within an herbaceous peat unit containing some silt material.

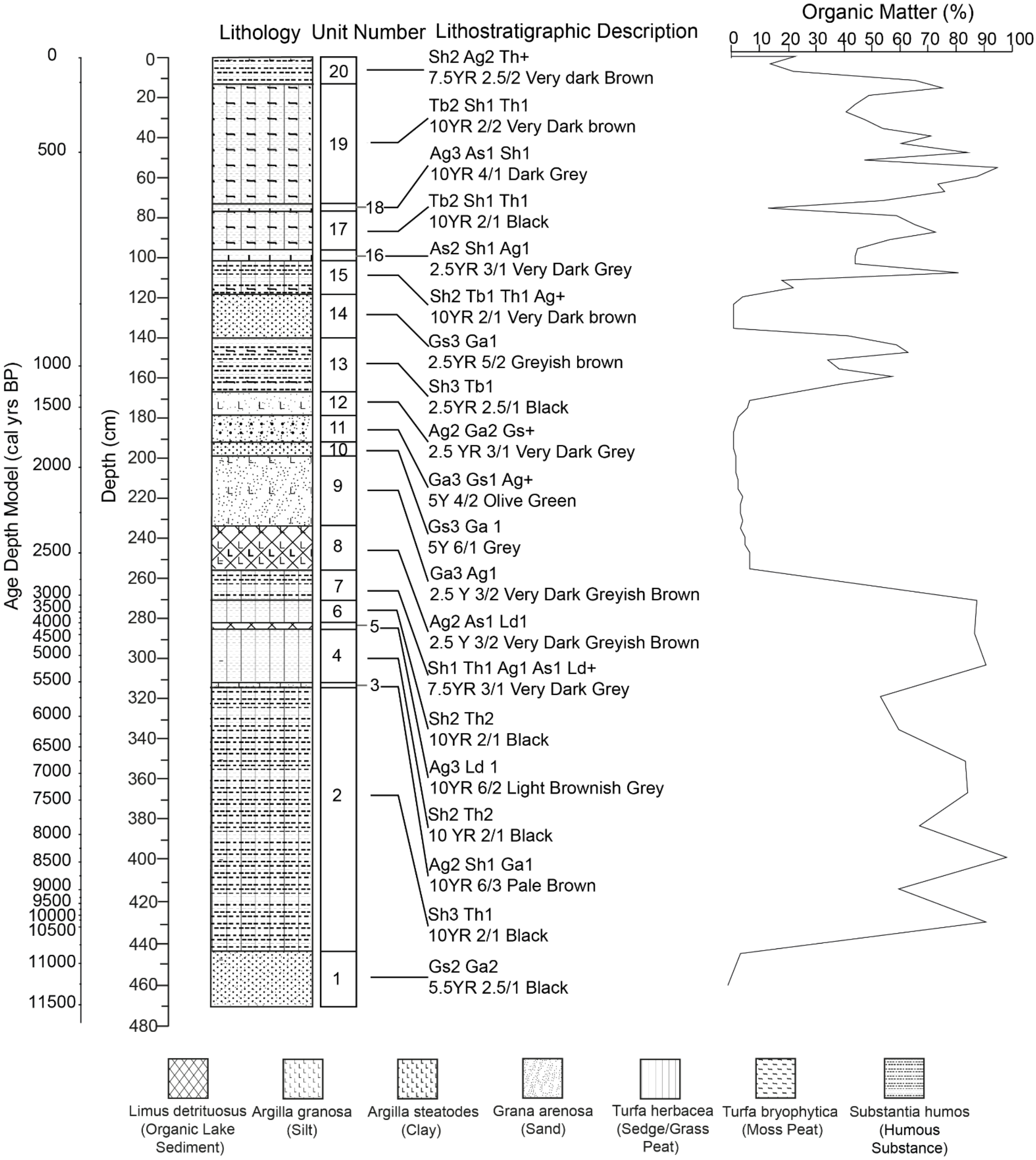


Figure 3.7: Lithostratigraphic diagram and organic matter curve for the full Huarca sequence.

Table 3.3: Lithostratigraphic descriptions of the core from Huarca Basin.

Depth (cm)	**Unit**	**Troels- Smith**	**Colour**
0-12	20	Sh2 Ag2 Th+ Humo = 3	Main colour = 7.5YR 2.5/2 Sections of Gley 1 6/10Y
12-74	19	Tb2 Sh1 Th1 Humo = 3	10 YR 2/2 V. dark brown
74-77	18	Ag3 As1 Sh1 Humo = 2	10 YR 4/1 Dark grey
77-98	17	Tb2 Sh1 Th1 Humo = 3	10 YR 2/1 Black
98 - 102	16	As2 Sh1 Ag1	2.5 YR 3/1 V. dark grey
102-119	15	Sh2 Tb1 Th1 Ag + Humo = 4	10 YR 2/1 V. dark brown
119 -140	14	Gs3 Ga1	2.5 YR 5/2 greyish brown
140 - 167	13	Sh3 Tb1 Humo = 4	2.5 YR 2.5/1 Black
167-179	12	Ag2 Ga2 Gs +	2.5 YR 3/1 V. dark grey
179-191	11	Ga3 Gs1 Ag +	5Y 4/2 Olive Green
191-199	10	Gs3 Ga1	5Y 6/1 Grey
199-233	9	Ga3 Ag1	2.5 Y 3/2 V. dark greyish brown
233-257	8	Ag2 As1 Ld1	2.5 Y 3/2 V. dark greyish brown
257-270	7	Sh1 Th1 Ag1 As1 Ld+	7.5 YR 3/1 V. dark grey
270-281	6	Sh2 Th2 Humo = 3	10 YR 2/1 Black
281-283	5	Ag3 Ld1	10 YR 6/2 Light brownish grey
283-311	4	Sh2 Th2 Humo = 3	10 YR 2/1 Black
311-314	3	Ag2 Sh1 Ga1 Humo 1	10 YR 6/3 Pale Brown
314-443	2	Sh3 Th1 Humo = 3	10 YR 2/1 Black
443-470	1	Gs2 Ga2	5.5 YR 2.5/1 Black

3.3.2 Results of the micro-XRF Geochemical Analysis

The Huarca core was scanned at a 500µm resolution for the full 4.7m sequence using an ITRAX scanner (see **Chapter 2**, Section **2.2** for methods). Log elemental ratios were calculated in Microsoft Excel, for some elements counts per second (cps) was used to normalise the data where trends in a single element are analysed. Resulting values are presented in Lncps, where each element has a raw count per second value which has then been converted into a log ratio. The µXRF diagram was zoned based on changes in the lithostratigraphy and the major changes within the elemental ratios themselves. This resulted in five zones and four sub-zones (Fig. 3.8 and Fig. 3.9).

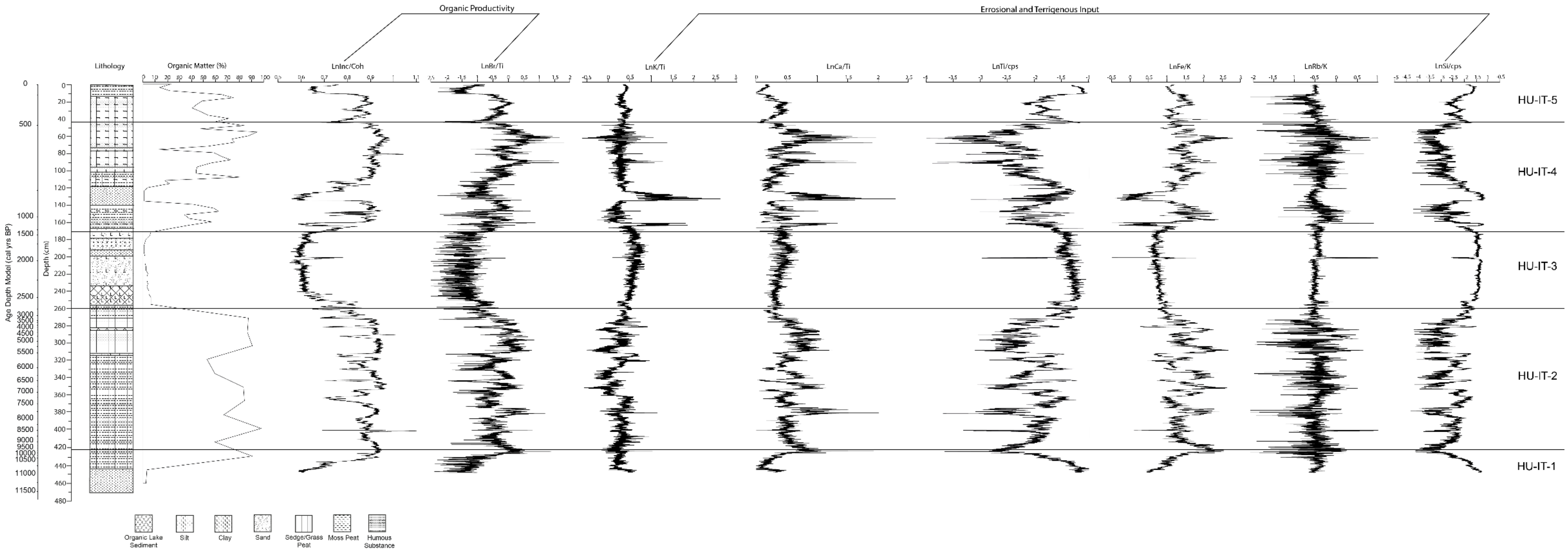


Figure 3.8: Micro-XRF geochemical data for the full Huarca sequence, elemental ratios presented as log values.

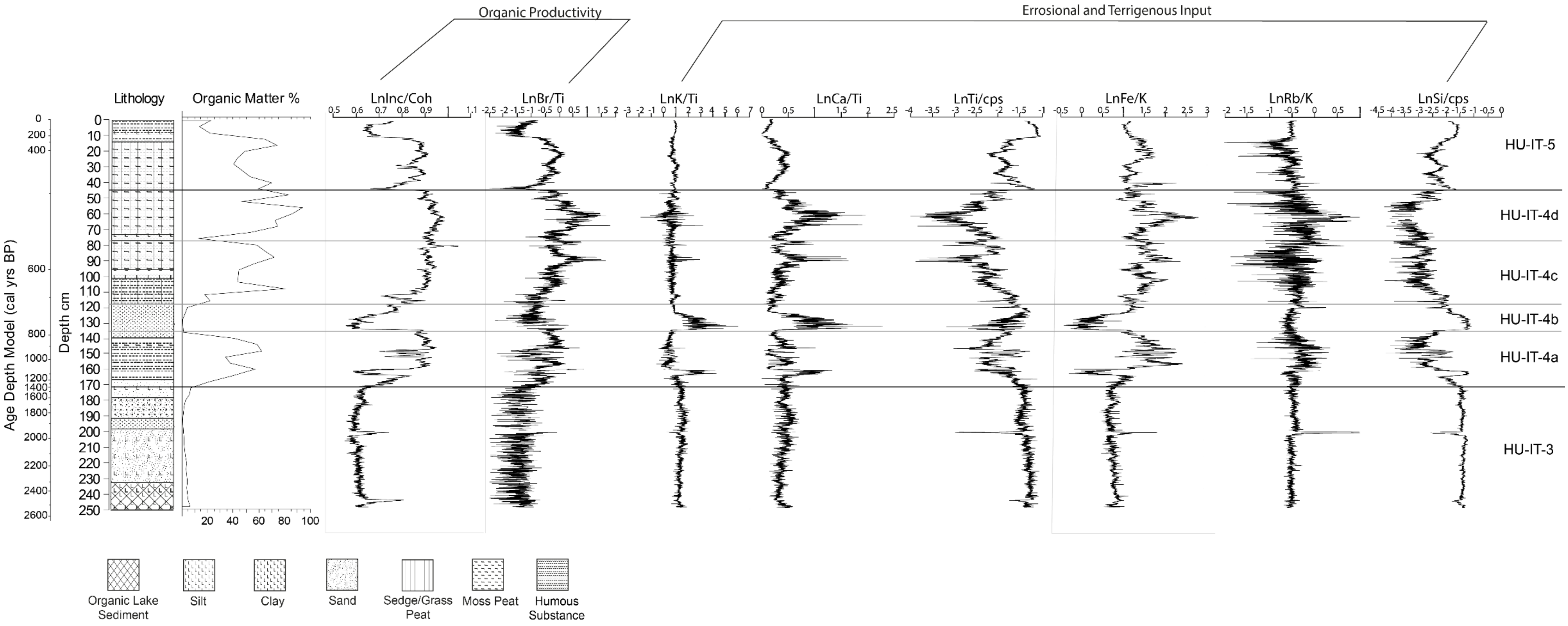


Figure 3.9: Micro-XRF geochemical data for the top 2.5m of Huarca sequence, elemental ratios presented as log values.

HU-IT-1 470-422cm *(~11,470-9417 cal yrs BP/ ~9520-7461 BC)*

This zone is characterised by increases in organic productivity indicators, LnInc/Coh and LnBr/Ti, associated with increases in organic matter content as sediment begins to accumulate in the Huarca basin from *~11,470* cal yrs BP*.* LnTi/cps decrease from -1 to -2.8 and LnSi/cps decreases from -1.3 to -4. LnFe/K (minimum 0.5, maximum 2.5,) and LnCa/Ti (minimum 0, maximum 1.1) ratios increase towards the top of this zone. LnRb/K as an indicator of grain size is relatively stable through the zone, (maximum 1.7, minimum -1.8).

HU-IT-2 422-260cm *(~9417 -2713 cal yrs BP/ ~7461-763 BC)*

Fluctuations occur in all ratios during this zone, amplitude of these fluctuations are high during a zone of elevated organic matter content and peat deposition over ~6,700 years. LnInc/Coh and LnBr/Ti values, as organic productivity indicators are also high. LnCa/Ti ratio values reach one of the highest values of the sequence in this zone (maximum 2). LnTi/cps fluctuates in antiphase with the LnCa/Ti and Ln Fe/K ratios reaching some of its lowest values for the sequence in this zone (minimum -3.7). This zone is also characterised by greater fluctuations in LnRb/K (maximum 1.4, minimum -2.1)

HU-IT-3 260-171cm *(~2713-1392 cal yrs BP/ ~763 BC-AD 548)*

This zone is characterised by reduced values of LnInc/Coh and LnBr/Ti during a zone of low organic matter values and a period of relatively stability across all ratios. LnInc/Coh values initially decreases from 0.86 to 0.58 before remaining low (minimum 0.55). At 200.5cm there is an inflection recorded in LnTi/cps, LnFe/K and LnSi/cps curves, with an uncharacteristic decrease in a period of relatively stable ratio signals. LnSi/cps values initially increase in this zone (from -2.2 to -1.5). Values reach some of the highest values in the sequence during this period of sand deposition from 233cm to 171cm, over ~920 years.

HU-IT-4 171-45cm *(~1392-468 cal yrs BP/~ AD 548-1483)*

This unit is characterised by greater variability in all ratio values than the zone above or below and encompasses the Middle Horizon and Late Intermediate Period. This zone has been divided into four sub zones (see Figure 3.10), based on changes in ratio values, sedimentology and organic matter content.

> HU-IT-4a 171-145cm *(~1392-905 cal yrs BP/~ AD 548-1047)*
>
> Zone 4a is characterised by an increase in LnFe/K values (maximum 2.4) and a reduction in LnSi/cps (minimum -4.19). LnInc/Coh increases (maximum 0.95) with increases in organic matter content and the transition between the Middle Horizon and Late Intermediate Period. LnK/Ti and LnCa/Ti values initially increase (maximum 1.86

and 1.33 respectively) before decreasing with the transition to the Late Intermediate Period (minimum of -0.17 and 0.13 respectively) and remaining relatively stable for the rest of the zone.

HU-IT-4b 145-118cm *(~905-728 cal yrs BP / ~AD 1047-1214)*

LnInc/Coh, LnBr/Ti and LnFe/K ratio values all decrease in this zone with a reduction in organic matter and a transition to a sandy unit within the lithostratigraphy. LnInc/Coh reaches similarly low values as in the preceding sandy unit in HU-IT-3 (minimum 0.56), LnFe/K values are lower in this zone than in HU-IT-3, with a minimum -0.41. LnK/Ti values increase (maximum 2.63) before decreasing to near baseline values (minimum 0.12). The LnCa/Ti ratio signature is very similar to LnK/Ti for this zone (maximum 2.28, minimum 0.1). LnSi/cps values are high during this sandy zone (maximum -1.14).

HU-IT-4c 118-78cm *(~728-586 cal yrs BP/ ~AD 1214-1365)*

LnTi/cps values decrease in this zone from -1.46 to a minimum of -3.89. LnSi/cps values also decrease (minimum of -4.23) during a period of moss and herbaceous peat deposition over a period of 160 years. LnFe/K values increase to a maximum of 2.4 at 90cm, with LnCa/Ti and LnBr/Ti also peaking around 90cm (maximum 1.64 for both ratios). LnInc/Coh values increase during this zone from 0.7 to a maximum of 1.

HU-IT-4d 78-45cm *(~586-468 cal yrs BP / ~AD 1365-1483)*

This zone is characterised by higher LnRb/K values, increasing to a maximum of 1.37, before decreasing again in the second half of the zone to a minimum of -1.9. LnFe/k values are also high reaching some of the highest values in the sequence (maximum 2.79). Organic productivity ratios are high, with elevated levels of organic matter, during a moss and herbaceous peat unit. LnInc/Coh values remain high from the preceding unit (HU-IT-4c) (maximum 0.98). LnBr/Ti values increase from -0.2 to 1.8 in the middle of the zone before decreasing to -1. LnCa/Ti and LnFe/K also peak in a similar way to the LnBr/Ti curve (maximum of 0.79 and 2.79 respectively) Ln Ti/cps values decrease in antiphase to LnCa/Ti to a minimum of -4 before increasing to -1.8 at the top of the zone.

HU-IT-5 45-0cm *(~468-0 cal yrs BP/ ~AD 1483-2006)*

This zone is characterised by elevated LnTi/cps values, initially decreasing from -1.2 to -2.1 before increasing to -1 during the Colonial Period and remaining high in the present day. LnInc/Coh and LnBr/Ti increase in this zone during the Late Horizon and Colonial Period, before decreasing with the transition to present day. Values of both ratios increase again within the top 5cm of the core. LnCa/Ti values follow a similar pattern to the organic productivity values, increasing from 0.07 to 0.58, before decreasing to -0.02 and increasing again to 0.19 at present day. LnK/Ti values are relatively stable during this zone (maximum 0.55, minimum 0.14). LnRb/K values decrease during the Late Horizon and Colonial Period to a minimum of -2.7, before increasing and remaining stable during the present day (average -0.5). Overall LnSi/cps increases to a maximum of 1.54 at the top of the zone.

3.3.1.1 Statistical analysis of the micro-XRF data for Huarca

Statistical analysis was carried out on the micro-XRF dataset from Huarca using Principal Components Analysis (PCA; Legendre and Legendre, 1998) in order to explore trends in the data and identify element groups and potential sources. PCA provides an overview of linear relationships between the different variables and in doing so helps to explain variability in the data. The largest possible variance is extracted in the first principal component, whilst the second principal component can explain the maximum portion of the remaining variance, and so on with each successive component accounting for less and less variance (Gebregiorgio *et al,* 2020). If a few principal components capture most (70-90%) of the variance in the data, the PCA has been very successful in representing the variability in the data. A KMO (Kaiser-Meyer-Olkin) and Bartlett’s test was first run on the data using SPSS (version 28.0.1.0) to check it was suitable for PCA. The KMO had a satisfactory score of 0.911, anything above 0.6 in general is considered suitable for PCA, and the significance of the Bartlett’s test was 0.00, which meant that the null hypothesis could be rejected, and no identity matrix exists (anything below 0.05 is acceptable).

A PCA was then carried out using Minitab (21.1.0), as this allows for more manipulation of the resulting score plots; first the PCA was run with no limits on the number of factors (or components) extracted to analyse how many components make up the variance in the data. Components 1 (61%), 2 (17.7%) and 3 (7.7%) had a cumulative eigenvalue of 86.5% and therefore explain ~87% of the variability in the data; a further PCA was then run to extract these three components. Only elements with cps of 300 or higher were selected for the PCA, as anything lower than this is not considered a reliable count and at the lower end of the detection limits; including these data may unnecessarily skew the PCA results. In this case the elements included were Si, K, Ca, Ti, Mn, Fe, Ni, Zn, Br, Rb, Sr, Ba, W, Pb, and Mo Inc and Mo coh.

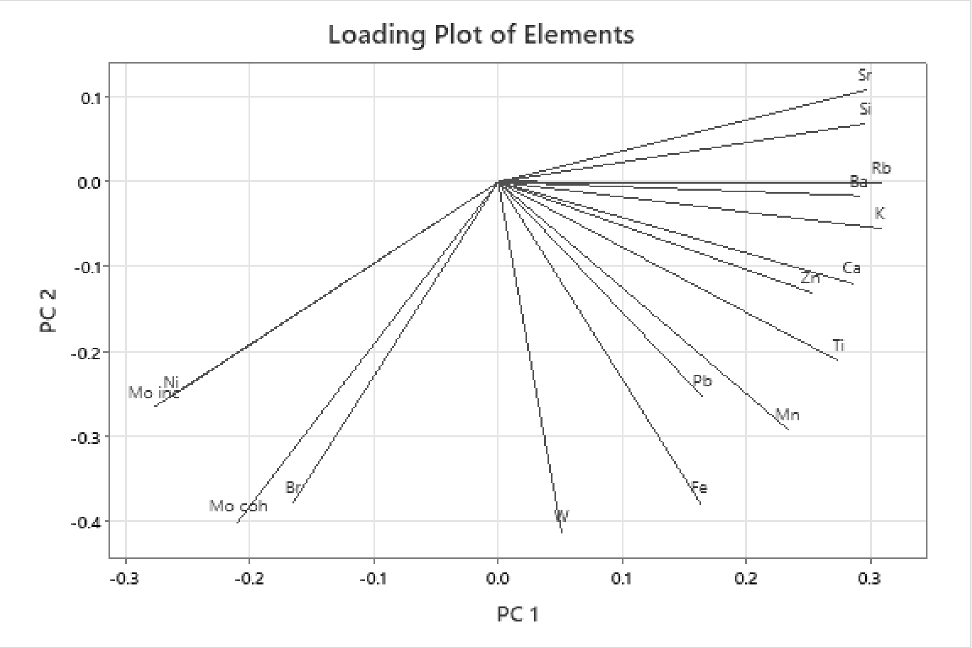


Figure 3.10: Loading plot of the elements used within the PCA (created using Minitab 21.1).

The results of the PCA revealed principal component 1 (PC1) to mainly be influenced by terrigenous elements found in the earth's crust, for example Ti, Sr, Rb, K, Ca and Si. Principal component 2 (PC2) was comprised of elements related to organic productivity, such as Mo inc, Mo coh and Br (Fig. 3.10). A third component (PC3) was highlighted in the analysis which contained, W, Fe, Mn and Pb; these elements pertain to pollution and redox signals. These elements were not included in the elemental ratio plots above as the counts for W and Pb were low and only just above the 300cps threshold, with Pb having a score of 0 for large sections of the core. Fe and Mn are often used to represent redox, however this signal is harder to interpret within peat as the elements are free moving within the peat and not as stable. Fe/K has been included as a ratio here as it can give information on variations in terrigenous sediment delivery (Rothwell and Croudace, 2015).

A biplot of the elements in the PCA was produced (Fig. 3.11) and colour coded according to core sections. The core was split into 50cm slices down core in order to get a sense of where certain depths of the core plot on the score plot. This allows for analysis of any correlation between core stratigraphy and weightings of the elemental ratios. For example, the data points from section 350-300cm and 400-350cm appear to plot closely to PC 2, containing the organic productivity indicators (Fig. 3.11); this section of core between 400 and 300cm has elevated organic matter content (Fig. 3.7). Data points from 150-100cm largely plot to towards the left-hand side of the diagram (Fig. 3.11) and are being pulled in a positive direction by PC 1; within this section of the core there is a sandy erosional unit and lower organic matter content (see Fig 3.7). The data points in red, reflecting the top 50cm of the core, are also being pulled in the positive direction by PC1, and likely reflect the disturbance of the sediments from modern day land practices with a silt cap being recorded at the very top of the Huarca core. The results of the PCA, in conjunction with the other lines of analysis (lithostratigraphy, organic matter content and to some extent the palynological analysis), can help to further define the nature of the sediments in Huarca basin and begin to identify periods of landscape disturbance and erosion, which may be reflected by a more positive PC1 value. This will be explored further in the interpretation of the sediment history from Huarca in section **3.3.5.1**.

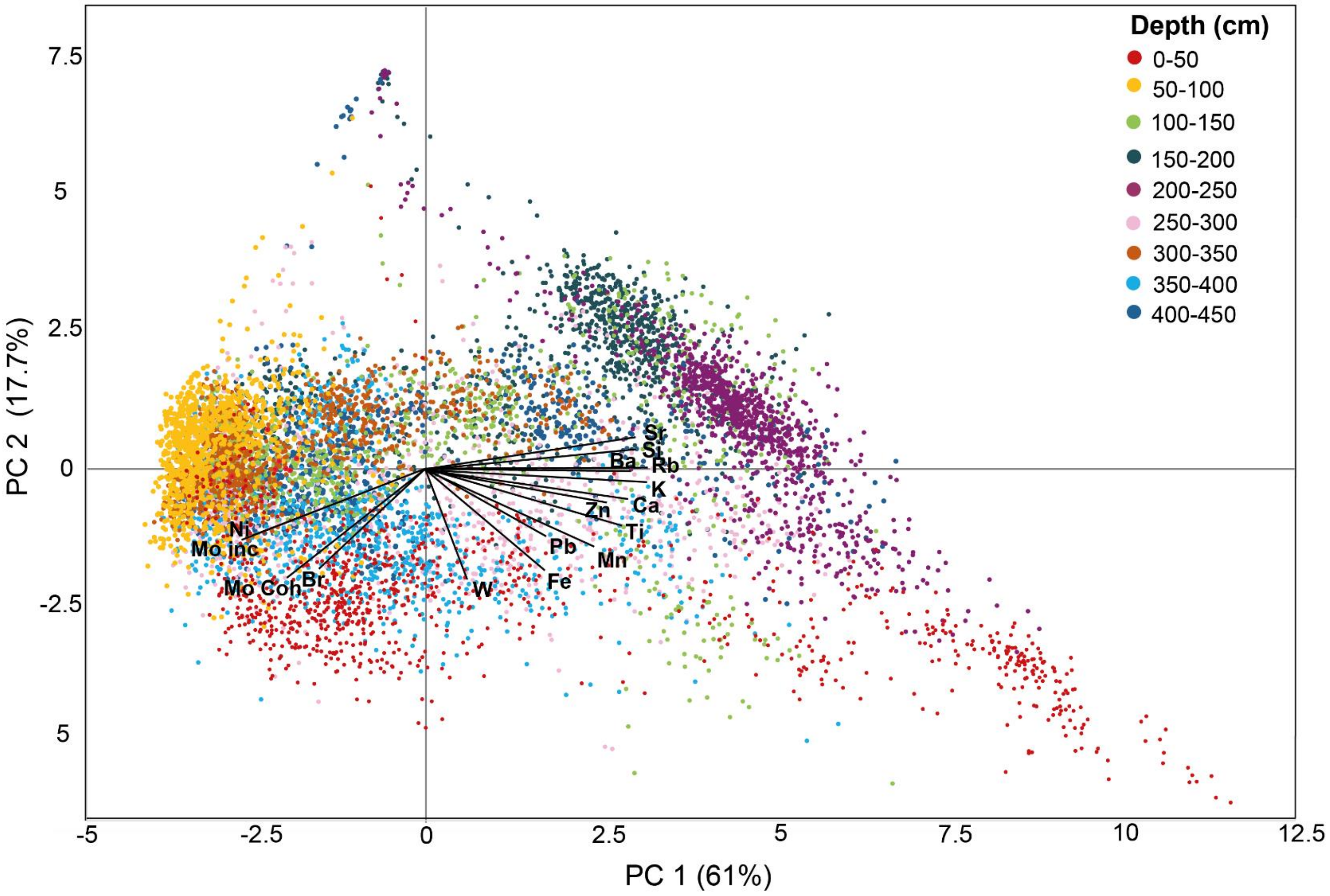


Figure 3.11: Biplot for Huarca showing the results of the loading plot over the elemental score data illustrating the PC1 and PC2 groupings. Core sections are colour coded according to depth (cm) (Created using Minitab 21.1 data, graph plotted in Microsoft Excel).

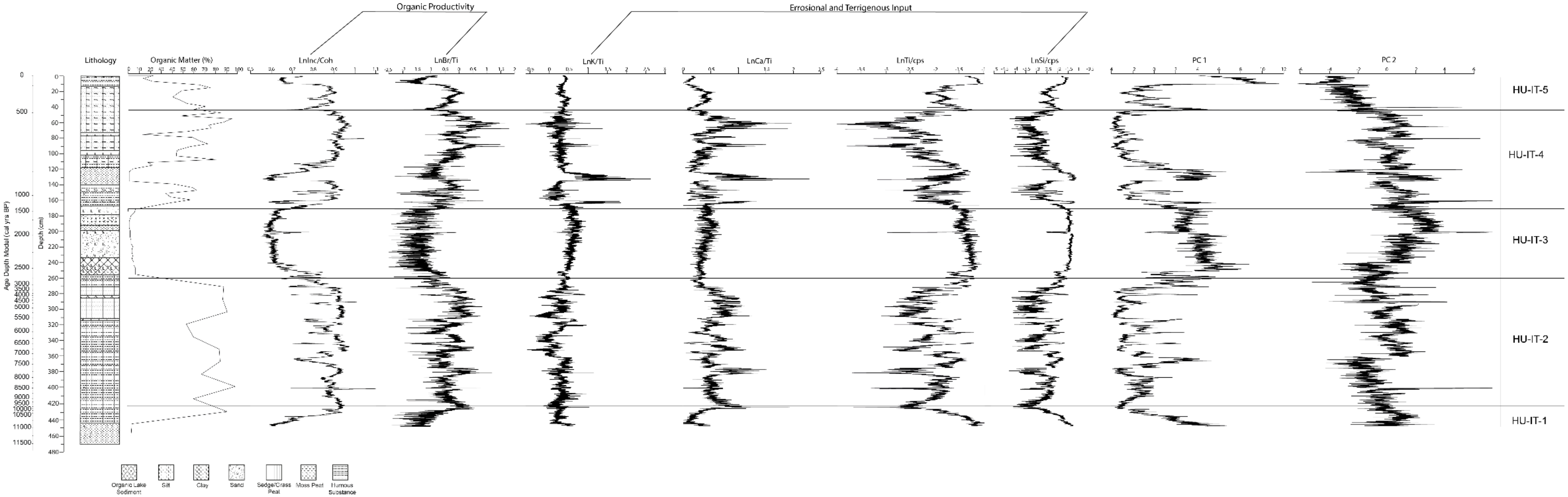


Figure 3.12: Micro-XRF elemental ratio plots for Huarca with PC1 and PC2 axes. PCA was carried out in Minitab (21.1), elemental ratios were calculated in Microsoft Excel.

3.3.3 Results of the Palaeoecological Analyses

Pollen samples were taken at 16cm resolution throughout the core to provide a skeletal analysis of the Huarca sequence and to assess pollen preservation throughout the core. This sampling resolution was then increased to 4cm for the top 2.5m of the core as this was assumed to cover the last 2000 years of the sequence and provide a high-resolution record for the period of interest; as the sediment accumulation was ~12yrs/cm, this provides one pollen sample every ~50 years. The results of the pollen counts were transformed into a percentage pollen diagram (Fig. 3.13), pollen accumulation diagram (Fig. 3.14) and a concentration diagram (Fig 3.15) using Tilia 2.6.1. (Grimm, 2019). The percentage pollen diagram was divided into five local pollen assemblage zones (LPAZ) based on visual assessment and stratigraphically constrained cluster analysis (CONISS).

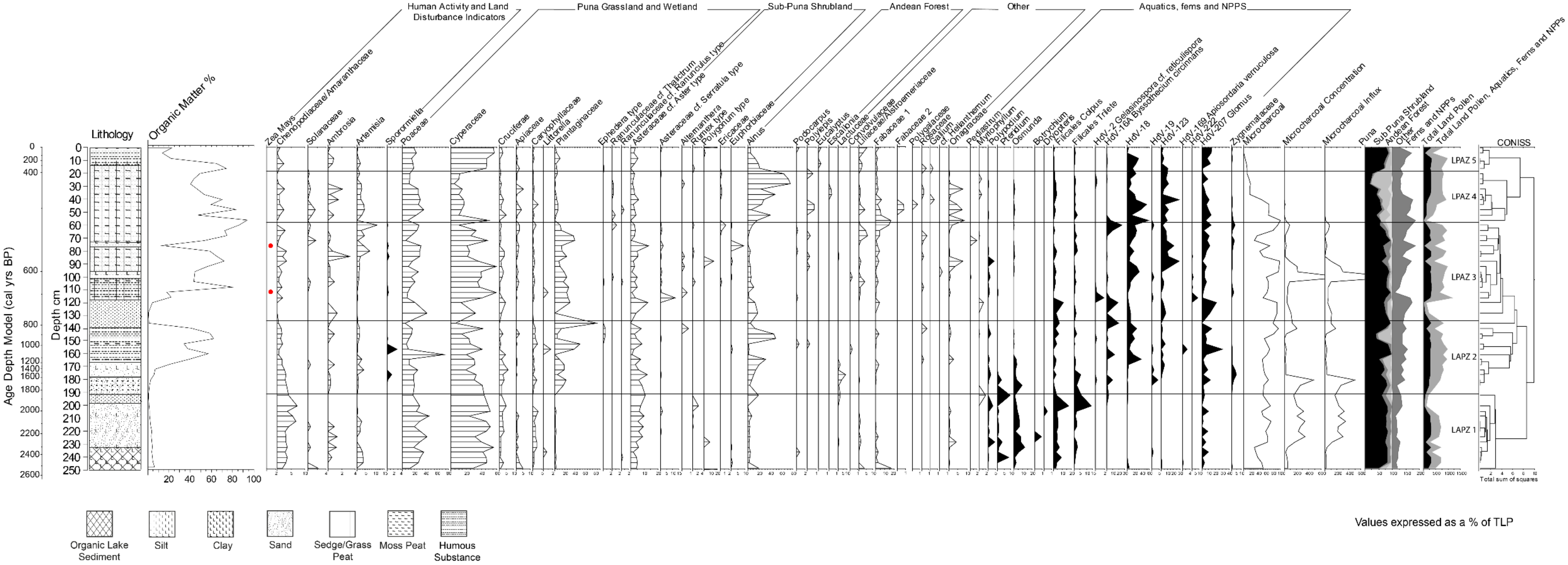


Figure 3.13: Huarca full taxa pollen diagram, pollen values are expressed in % of total land pollen produced in Tilia 2.6.1, microcharcoal concentration and influx values were calculated in Tilia. Cluster analysis (CONISS) was used to zone the diagram in Local Pollen Assemblage Zones. Zea mays is presented as presence or absence data due to a low number of Zea mays pollen grains being found per sample (n=2).

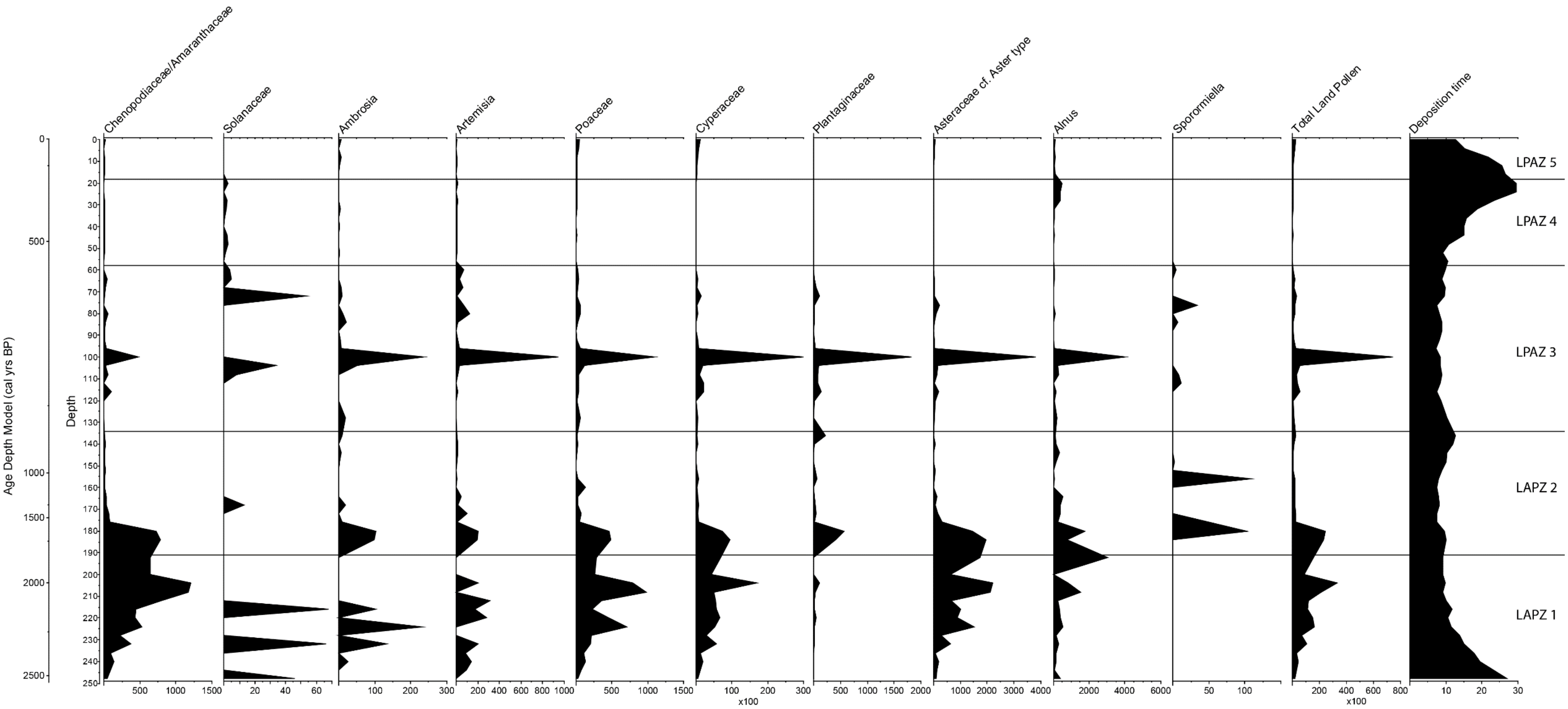


Figure 3.14: Pollen Accumulation Diagram for selected pollen taxa and Sporormiella from Huarca Basin presented as grains cm^{-2} year^{-1}, diagram produced in Tilia 2.6.1 (Grimm, 2019).

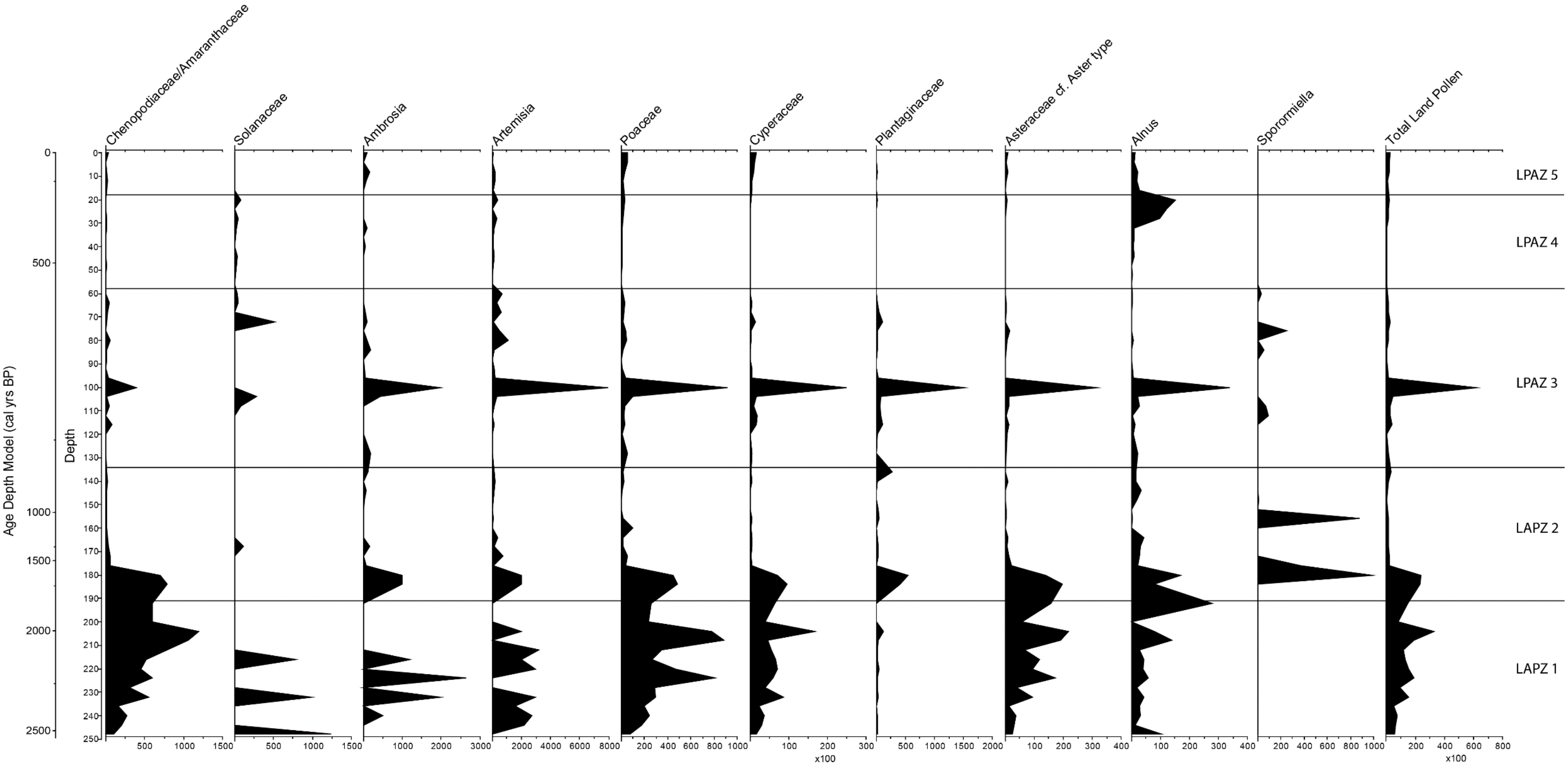


Figure 3.15: Pollen Concentration Diagram for selected pollen taxa and Sporormiella from Huarca Basin presented as grains per cm^3, diagram produced in Tilia 2.6.1 (Grimm, 2019).

LPAZ 1 (248-191cm) ***(~2522-1847 cal yrs BP/ 568 BC- AD 106)***

Cyperaceae – Poaceae - Chenopodiaceae/Amaranthaceae

Dominated by herbaceous taxa, Cyperaceae (57%), Poaceae (46%), Chenopodiaceae/Amaranthaceae increases to highest values in record (7%). Asteraceae cf. *Aster* type (11%), Cruciferae (5%) and Caryophyllaceae (3%) are present throughout. Apiaceae decreases from 5% to 0%. Andean forest taxa are represented by *Alnus* in low values (5%) and one occurrence of *Podocarpus* (<1%). Solanaceae is present towards the bottom of the zone (2%). Plantaginaceae values are low (4%). Fabaceae 1 decreases from 17% to 0% by the middle of the zone. *Pteridium* and *Osmunda* are present with highest values of both taxa occurring within this zone (9% and 12% respectively). Filicales Colpus and Filicales Trilete increase towards the top of this zone (Maximum 17% and 14% respectively). *Glomus* values fluctuate (maximum 10%, minimum 0%). All other NPPS are absent or only represented in small values (<5%). Micro-charcoal is present throughout (maximum 72%). Total Land Pollen concentrations are high during this zone (Maximum 329,593 grains per cm^3).

LPAZ 2 (191-134cm) (*~1847-786 cal yrs BP/ AD 106- AD 1166)*

Cyperaceae – Poaceae - Plantaginaceae

Plantaginaceae increases to the highest values in the sequence towards the top of this zone (from 18% to a maximum of 83%). Poaceae increases to a maximum of 73% in the middle of the zone, before decreasing again towards the top (5%). Cyperaceae levels remain high (maximum 40%). *Alnus* initially increases (to 32%) before decreasing and increasing again (maximum 49%). *Podocarpus* and *Polylepis* are also present in low values (2% and 1% respectively). Asteraceae cf. *Aster* type is present throughout (8%), Chenopodiaceae/Amaranthaceae decreases from 4% to 1%. Other herbaceous taxa include *Ambrosia* (1%), *Artemisia* (3%), and Cruciferae (maximum 6%). *Osmunda* values decline from 9% to 0%. *Glomus* (HdV-207) reaches maximum values (30%). *Sporormiella* (2%), HdV-169 (3%) and Zygnemataceae (5%) are present in the middle of this zone. Micro-charcoal values are relatively stable (maximum 94%). Pollen concentration and accumulation is initially high in this zone before decreasing to low values with Total Land Pollen (TLP) concentration decreasing from 233,296 to 34,195 grains per cm^3 and accumulation from 23,042 to 2,991 grains cm^{-2} $year^{-1}$.

LPAZ 3 (134-58cm) (*786-569 cal yrs BP/ AD 1166 – AD 1381*)

Cyperaceae – Poaceae - Plantaginaceae

Dominated by high levels of Cyperaceae (maximum 60%). After an initial decrease, Plantaginaceae increases (to 25%). The only presence of *Zea Mays* in the sequence occurs within this zone (<1%). Andean forest taxa are represented by low values, *Alnus* (5%), *Podocarpus* (<1%) and *Polylepis* (<1%). Herbaceous taxa present include Asteraceae cf. *Aster* type (maximum 13%), Cruciferae (3%) Chenopodiaceae/Amaranthaceae (3%) and *Ambrosia* (maximum 3%). *Artemisia* increases from 0% to 7%. Fabaceae 1 values initially remain stable (1-2%) before increase towards the top of the zone (14%). Aquatic taxa are represented by *Pediastrum* and *Myriophyllum* percentages in low values (1-2%). Filicales Colpus decreases from 11% to a minimum of <1%. HdV-18 and HdV-123 increase towards the top half of the zone. HdV-2 values reach their highest (2%), and there is the only occurrence of HdV-222 in this zone. Micro-charcoal values are high throughout fluctuating between a minimum of 29% and a maximum of 97%. In the middle of this zone there is a peak in concentration and accumulation of all pollen taxa (TLP maximum 623,447 grains per cm^2), as well as micro-charcoal (972,895 grains per cm^2). *Sporormiella* concentration increases twice during the zone independently of the land pollen taxa increase (Maximum 248 grains per cm^3).

LPAZ 4 (58-18cm) (*569-386 cal yrs BP/ AD 1381- AD 1564*)

Alnus - Poaceae

This zone is characterised by an increase in *Alnus* values to the highest values in the record (maximum 75%) and a reduction in Cyperaceae (from 50% to 4%). Onagraceae values increase fluctuating between 1% and 8%. Andean forest taxa include *Polylepis* and *Escallonia* (1% and <1% respectively). Asteraceae cf. *Aster* type (6%), Apiaceae (6%), and *Artemisia* (4%) are present throughout the zone. Solanaceae is characterised by an initial increase to 2% before a decline to <1%. *Myriophyllum* is present in low percentages (<1%). HdV-18 decreases through the zone (maximum 60%, minimum 6%), while *Glomus* (HdV-207) levels remain stable (13%). HdV-123 increases to 30% before decreasing again. Micro-charcoal values decrease from 99% to 8% by the end of the zone. Concentration of *Alnus* pollen increases in this zone from 28 grain per cm^3 to a maximum of 15,120 grains per cm^3, whilst other pollen concentrations remain low.

LPAZ 5 (18-0cm) (*386-0 cal yrs BP/ AD 1564- AD 2006*)

Cyperaceae – Poaceae - *Alnus*

Characterised by high herbaceous values, Cyperaceae (57%), Poaceae (24%), Plantaginaceae (maximum 11%), Asteraceae cf. *Aster* type (5%) and Liliaceae/Alstoemeriaceae (3%). Andean forest taxa a present throughout this zone, *Alnus* decreases from 21% to 5% and the only occurrence of *Eucalyptus* is found within this zone (<1%). *Artemisia* values are low varying between 2 and <1%. *Ambrosia* levels are also low throughout (between 0.9-0.3%). Fabaceae 1 is present at 3%. Aquatics are absent from this zone. NPPs are represented by HdV-18, HdV-123 and *Glomus* (HdV-207). Micro-charcoal is at its lowest values for the sequence decreasing from 8% to 0%. Pollen concentration and accumulation is low during this zone (Total Land Pollen maximum of 18,339 grains per cm^3 and 2,223 grains cm^{-2} year^{-1} respectively).

3.3.4 Results of the Radiocarbon Dating Programme

Nine samples for radiocarbon dating were taken from Huarca Basin (Table 3.4), based on high organic matter values and/or the presence of plant macrofossils. The purpose was to constrain the palaeoenvironmental events recorded in the Huarca sequence and to allow comparison with terrestrial, marine, and ice core palaeoclimatic records as well as correlation with nearby archaeological records. Where possible samples were submitted as picked sedge and grass material (five out of the nine samples), where there were not enough plant macrofossils present, bulk organic sediment samples were submitted for dating. One date (SUERC-99700) has been omitted from the age-depth model (see below, Fig 3.16) due to being younger than the date above it in sequence, resulting in an age reversal. This sample may have contained some younger plant material either due to the presence of rootlets in the sample, or the material may have been contaminated during the field sampling (coring).

The age-depth model, Fig. 3.7, was created using Oxcal v4.4 (Ramsey, 2021) and IntCal 20 atmospheric calibration curve (Reimer *et al*., 2020) and is presented in both cal yrs BP and AD/BC. The age-depth model offers a satisfactory ‘Amodel’ value of 99.9 (Table 3.5), suggesting the model is a good fit for the dates provided (anything higher than 60 is considered acceptable). The model shows sediment in the Huarca basin started accumulating *~11,470 cal yrs BP* probably following retreat of ice towards the end of the last glaciation. This age has been interpolated from the radiocarbon date at 433-432cm, and is therefore a modelled age, with the base of the sequence older than the basal date of 10,662-10,425 cal yrs BP (at 95% confidence). Sediment accumulation was continuous until present day, with the top of the sequence being modelled to a modern date (*AD 2006*).

Table 3.4: Results of the radiocarbon dating programme at Huarca Basin.

Lab No.	**Sample ID Code**	**Sample Depth (cm)**	**Radiocarbon Age BP**	**Calibrated date cal. BP (95% confidence)**	**d13C ‰**	**Material Dated**
SUERC-84607 (GU50157)	HURC-18-18	18-19	333±34	309-475	-25	Picked Sedge Material
SUERC-99698	HURC-1-42	42-43	408±37	320-522	-27.4	Picked Sedge Material
SUERC-99699	HURC-2-56	56-57	564±37	521-646	-24.9	Picked Sedge Material
SUERC-99700	HURC-3-88	88-89	359±37	314-495	-27.2	Picked Sedge Material
SUERC-99701	HURC-4-108	108-109	623±37	548-659	-27.6	Picked Sedge Material
SUERC-99702	HURC-5-144	144-145	1001±37	793-960	-26.5	Bulk Organic Sediment
SUERC-99703	HURC-6-165	165-166	1215±37	1008-1270	-24.5	Bulk Organic Sediment
SUERC-84608 (GU50158)	HURC-18-273	273-274	3011±34	3075-3337	-23.7	Bulk Organic Sediment
SUERC-84609 (GU50159)	HURC-18-432	432-433	9339±34	10425-10662	-20	Bulk Organic Sediment

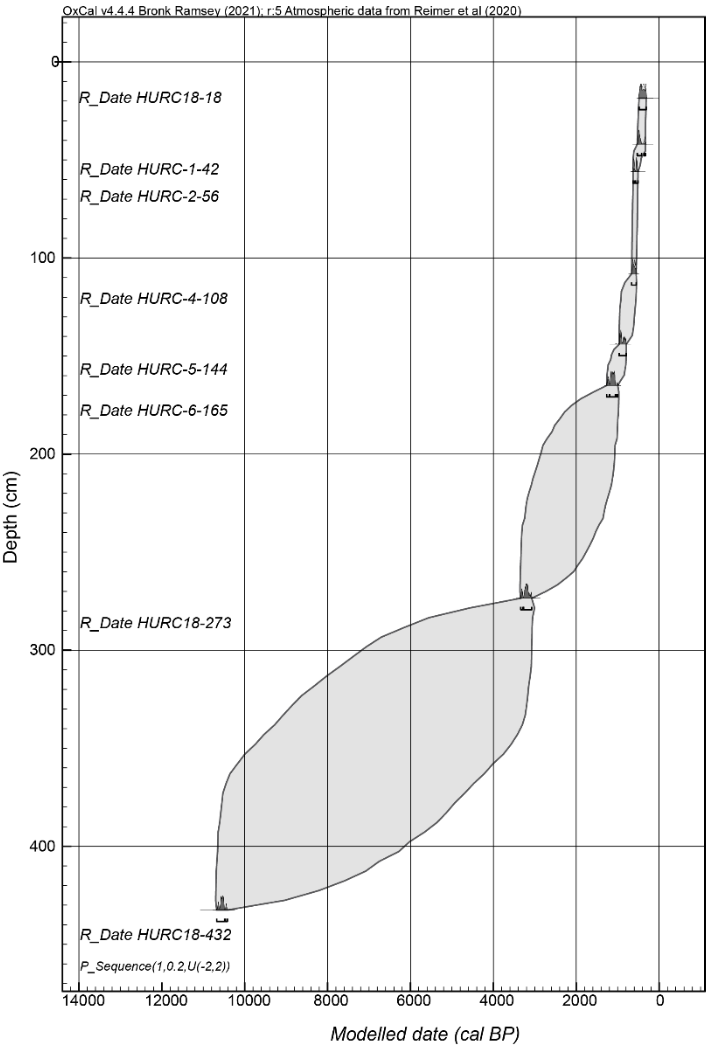


Figure 3.16: Age-Depth model for Huarca. For modelled cal BP dates and model agreement see Table 3.5 below.

Table 3.5: Results from the Huarca age-depth model.

Name	**Unmodelled (BP)**			**Modelled (BP)**			**Midpoint (cal. BP)**	**Indices**	
								A_{model}=99.9	
								$A_{overall}$=100.4	
	from	**to**	**%**	**from**	**to**	**%**	**Rounded**	**A**	**C**
P_Sequence (1,0.2,U(-2,2))	-2	2	95.4	-1.7919	-1.4119	95.4		100	99.9
Boundary Bottom				10680	10418	95.4	10,550		99.9
R_Date HUARC18-432	10662	10425	95.4	10680	10418	95.4	10,550	97.2	99.9
R_Date HURC-18-273	3337	3075	95.4	3339	3075	95.4	3,200	99.8	99.9
R_Date HURC-6-165	1270	1008	95.4	1267	1000	95.4	1,130	99.5	99.9
R_Date HURC-5-144	960	793	95.4	962	793	95.4	880	100	100
R_Date HURC-4-108	659	548	95.4	662	555	95.4	610	100	100
R_Date HURC-2-56	646	521	95.4	628	510	95.4	570	96.8	100
R_Date HURC-1-42	522	320	95.4	529	332	95.4	430	111.8	100
R_Date HURC-18-18	475	309	95.4	484	312	95.4	400	96.7	99.9
Boundary Top				484	312	95.4	400		99.9

3.3.5 Interpretation of Palaeoenvironmental Data

To aid in the interpretation of the palaeoecological data the pollen taxa recorded have been divided into those indicative of plants formally growing within the basin and those in the surrounding dryland landscape (see Table 3.6 for more details). Those that grew within the basin, along with the lithostratigraphy and organic matter content, as well as some of the ITRAX ratios, help to develop an understanding of the sedimentary history of the basin. The micro-charcoal, remaining pollen taxa and ITRAX ratios enable discussion of the vegetation and land-use history of the surrounding landscape. Figure 3.17 shows a comparison of the cultural and radiocarbon dated chronology for Huarca with the lithostratigraphic sequence and the different zonation's for the µXRF and pollen diagrams to allow for better comparison between the data sets already presented within this chapter.

Table 3.6: Plant ecology of pollen taxon within the Huarca basin record, both in relation to where it was most likely growing, either on within the wetland itself or on the surrounding dryland, and it usual ecological habitat. Categorisation of ecology types based on Brako and Zarucchi (1993) and the Missouri Botanical Garden's Tropicos database (www.tropicos.org). Information about pollen taxon/type common on Bofedales from Polk et al., 2019.

Pollen taxon / type	**Plant Ecology**	**Palaeoecological Grouping**
Zea mays	Surrounding dryland. Agricultural land	Human Activity and Land Disturbance
Chenopodiaceae/ Amaranthaceae	Surrounding dryland. Agricultural land, grasslands	Human Activity and Land Disturbance
Solanaceae	Surrounding dryland. Agricultural land	Human Activity and Land Disturbance
Ambrosia	Surrounding dryland. Disturbed areas, pastures, agricultural land, waste ground, dry open ground	Human Activity and Land Disturbance
Artemisia	Surrounding dryland. Disturbed areas, *A.annua* occurs in Peru as cultivated material	Human Activity and Land Disturbance
Poaceae	Within the basin and surrounding dryland. Bog surface, grasslands, disturbed areas	Human Activity and Land Disturbance
Cyperaceae	Bog surface, And some surrounding grassland	Puna Grassland and Wetland
Cruciferae	Surrounding dryland. Disturbed areas	Puna Grassland and Wetland
Apiaceae	Surrounding dryland. Grasslands and rocky slopes. Some species grow in disturbed areas. Important family at high altitudes.	Puna Grassland and Wetland
Caryophyllaceae	Surrounding dryland. Grassland, some species grow on disturbed land. Important family at high altitude.	Puna Grassland and Wetland

Littorella	Surrounding dryland and within the basin. Bog surface, submerged, seasonally inundated areas	Puna Grassland and Wetland
Plantaginaceae	Surrounding dryland and within the basin. Bog surface, rocky slopes, disturbed areas	Puna Grassland and Wetland
Ephedra type	Surrounding dryland. Grassland, shrubland, rocky slopes	Puna Grassland and Wetland
Ranunculaceae cf. *Thalictrum*	Surrounding dryland. Grasslands, some species found in *bofedales*	Puna Grassland and Wetland
Ranunculaceae cf. *Ranunculus* type	Surrounding dryland. Grasslands, rocky slopes, some species are aquatic and grow on bog surfaces	Puna Grassland and Wetland
Asteraceae cf. *Aster* type	Surrounding dryland. Grassland and shrubland, some species grow in disturbed areas. *Werneria sp*. is common in *bofedales*	Puna Grassland and Wetland
Asteraceae cf. *Serratul*a type		Sub-Puna Shrubland
Alternanthera	Surrounding dryland. Grassland, disturbed areas, rocky slopes	Sub-Puna Shrubland
Rumex type	Surrounding dryland. Disturbed areas and rocky slopes	Sub-Puna Shrubland
Polygonum type	Within the basin and surrounding dryland Shrubland, disturbed areas, riversides some species live in seasonally inundated areas or fully submerged aquatic settings	Sub-Puna Shrubland
Ericaceae	Surrounding dryland. Shrubland	Sub-Puna Shrubland
Euphorbiaceae	Surrounding dryland. Grasslands, shrublands, rocky slopes, riversides	Sub-Puna Shrubland
Alnus	Surrounding dryland. Forests, riversides. *A. accuminata* grows in riverine woodlands	Sub-Puna Shrubland
Podocarpus	Surrounding dryland. Forests	Andean Forest
Polylepis	Surrounding dryland. Open woodland, shrubland	Andean Forest
Eucalyptus	Surrounding dryland. Forests and disturbed areas	Andean Forest
Escallonia	Surrounding dryland. Forests, riversides and disturbed areas	Andean Forest
Lactuceae	Surrounding dryland. Drylands	Andean Forest
Convolvulaceae	Surrounding dryland. Grassland, shrublands, possibly cultivated	Other
Liliaceae/ Alstroemeriaceae	Surrounding dryland. Shrubland, disturbed slopes, rocky areas	Other
Fabaceae 1	Surrounding dryland and within the basin. Grassland and shrubland, rocky slopes, possibly cultivated. *Trifolium* is common in *bofedales*	Other
Fabaceae 2		Other
Polygalaceae	Surrounding dryland. Grassland, shrubland, rocky slopes	Other
Rosaceae	Surrounding dryland. Shrubland, grassland	Other
Gallium	Surrounding dryland. Dryland, waste ground	Other
cf. Helianthemum	Surrounding dryland. Shrubland	Other

Onagraceae	Surrounding dryland. Grasslands, shrublands, riversides, some aquatic species.	Other
Pediastrum	Within the basin Submerged, aquatic	Other
Myriophyllum	Within the basin Submerged, aquatic	Aquatic

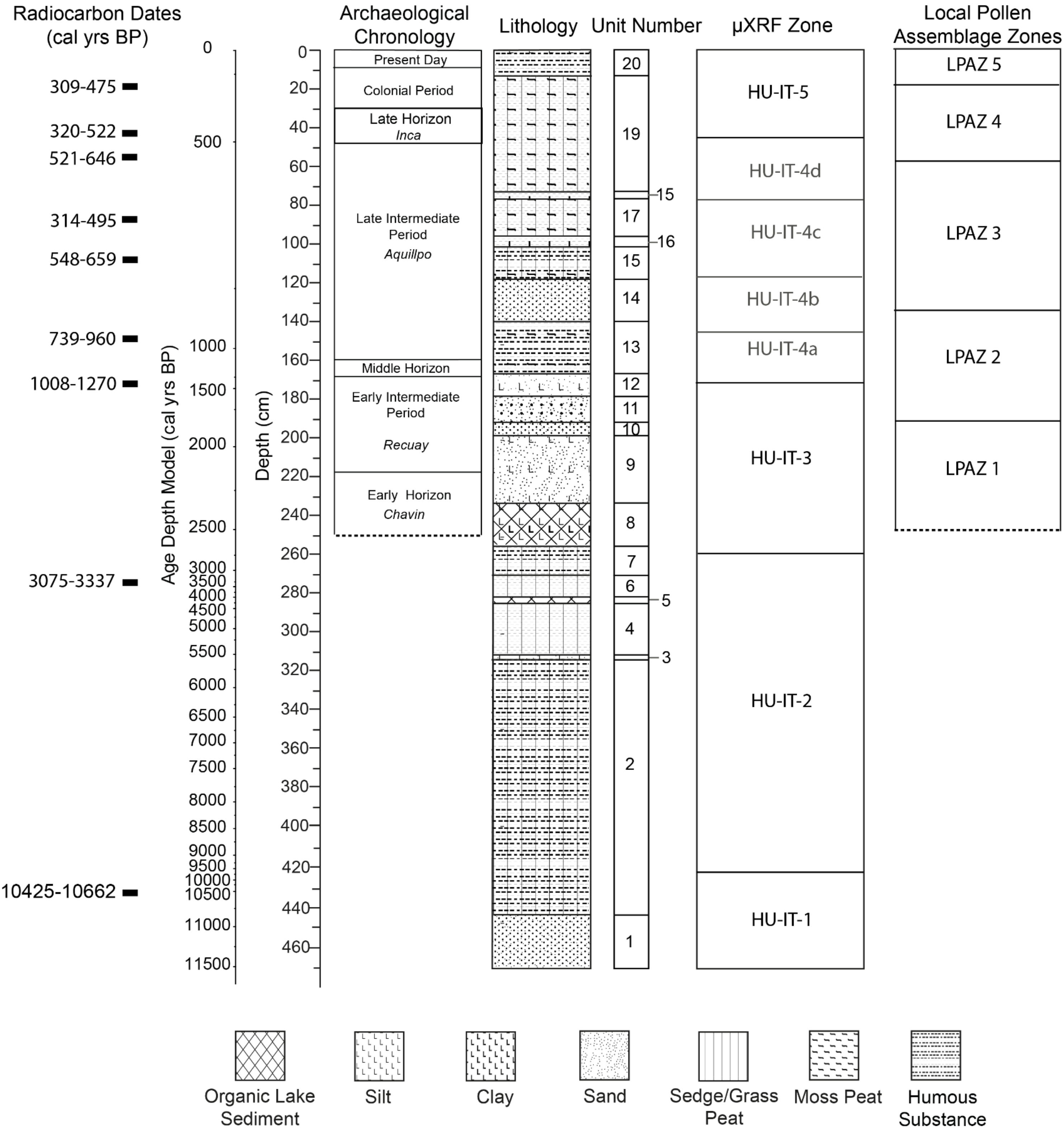


Figure 3.17 Comparison of chronology, lithostratigraphic units, µXRF zones, and local pollen assemblage zones for Huarca

3.3.5.1 Sedimentary History

The sedimentary sequence from Huarca basin began *~11,470 cal yrs BP* with the deposition of sand, both fine and coarse (Unit 1), probably after the retreat of ice following the last glaciation. During this first unit, PC 1 values are elevated indicating terrigenous sediment input into the basin (ITRAX Event 4; Fig. 3.18), because of increased meltwater discharge due to localised deglaciation resulting in greater surface runoff. Following this, organic-rich peat began to form, representing the formation of a freshwater wetland from *~10,808-4265 cal yrs BP* (Units 2-4) during a period of relatively stable conditions and minimal anthropogenic influence on the basin (see below). From *~4265-4066 cal yrs BP* (Unit 5), an open water, lake environment develops within the basin, possibly as a result of increased precipitation following the mid-Holocene South American arid period (Bird *et al*., 2011). The lake water level falls again between *~4066-2653 cal yrs BP* (Units 6-7) indicated by the formation of peat suggesting a return to more stable environmental conditions.

The sediments in Units 8, 9 & 10, during LPAZ 1, are sand and silt rich and low in organic matter, indicating a prolonged period of landscape erosion (~806 years; *~ 2623-1847 cal yrs BP*) within the catchment and in washing of large amounts of mineral matter. Unit 8 also contains lake sediment, which overlies a peat unit (Unit 7), suggesting the formation of an open water setting within the centre of the basin and a major hydrological change from *~2623 cal yrs BP (~673 BC*) at the transition of Unit 7 to Unit 8. This is supported by high percentages of Cyperaceae, which would have grown in the shallow waters on the lakeshore. Wetter conditions within the basin are supported by the presence of ferns, which grow in moist soils, including the only occurrence of *Botrychium* and *Dryopteris* in the record. A transition in the geochemical signature of the basin is also seen at this time, from *~2713 cal yrs BP (~763 BC),* PC1 values are elevated, with higher proportions of Si and Ti in the record, indicating greater influence on the basin by terrigenous input. This period of more positive PC1 values continues until *~1400 cal yrs BP (~AD 550)* into LPAZ 2 and has been highlighted (see Figure 3.18) as a major erosional event within the ITRAX record (ITRAX Event 3, corresponding with ITRAX zone HU-IT-3). This inferred period of wetter conditions at Huarca corresponds to a known period of increased precipitation within the Peruvian palaeoclimate records from ~2500-1500 years ago, which could have led to greater surface runoff and contributed to the formation of a lake within the basin (Rein *et al*., 2005; Bird *et al*., 2011; Kanner *et al*., 2013). It also broadly coincides with the EIP in the Callejón de Huaylas (2150-1250 cal yrs BP/ 200 BC-AD 700), when the Recuay Culture was thought to be prolific; this landscape erosion may therefore be as a result of wetter climate and increased human activity and will be explored further in Section **3.5**.

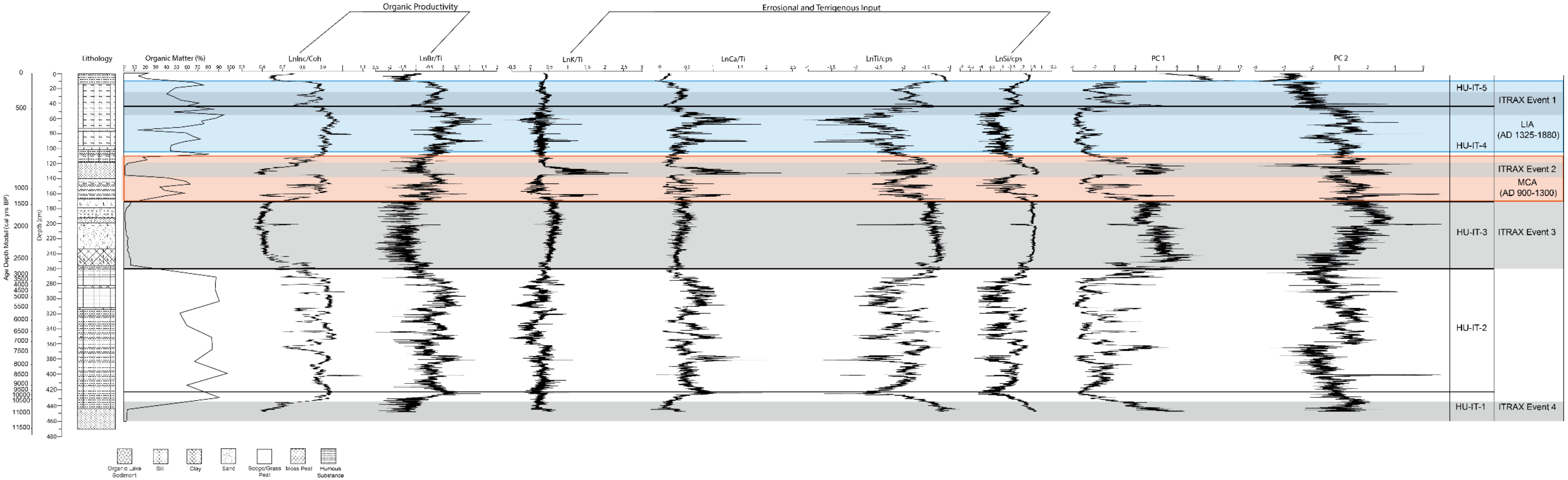


Figure 3.18: Summary ITRAX diagram for the full sequence from Huarca basin showing the timings of four main events within the ITRAX data, alongside major climatic events.

Landscape erosion continues into LPAZ 2 until *~1213 cal yrs BP (~AD 727*), with Units 11-12 being rich in sand and silts and some clay material. However, lake sediments are no longer present within the sedimentary record representing a reduction in water levels during this time. This is supported by the increase in Plantaginaceae and a decrease in Cyperaceae from *~1847 cal yrs BP (~AD 106).* It is highly likely Plantaginaceae here is represented by *Plantago tubulosa*, a species which commonly grows on the surface of *bofedales* alongside species of Cyperaceae (e.g., *Phylloscripus deserticola and Oreobolus obtusangulus*) and Asteraceae (*e.g., Werneria pygmaea*) as well as some species of Gentianaceae (*Gentiana sedifolia*) and Campanulaceae (*Lobelia reniformis*) (Fonkén, 2014; Polk *et al*., 2019).

Peat formation in the second half of LPAZ 2 from *~1213 cal yrs BP (~AD 727*) (Unit 13) led to an increase in organic matter, with Poaceae and Cyperaceae likely being the main peat forming plants, as populations of both families increase with this sedimentary transition from Unit 12 to Unit 13. The humification value at this time was also high (Humo=4, Unit 13), suggesting bog surface wetness was low, allowing for the colonisation of the wetland by Plantaginaceae. Lower surface wetness would also explain the reduction in abundance of ferns, with the decrease in *Osmunda* to negligible levels by *~1000 cal yrs BP (~AD 950)*. The timing of this decrease in surface water coincides with less negative, more enriched values of $^{\delta}$18O values recorded in the Palestina Cave speleothem record, indicative of an arid period with a weakening of the South American Summer Monsoon (SASM) 1230-1130 cal yrs BP (AD 720-820) (Apáestegui *et al*., 2014).

Plantaginaceae populations increase after *~1054 cal yrs BP (~AD 896),* with a peak in abundance at *~985 cal yrs BP (~AD 965)* and a later peak at *~791 cal yrs BP (~AD 1159)*, with the transition to LPAZ 3. The first of these increases coincides with a drier signal in the Palestina cave record between 1030-950 cal yrs BP (AD 920-1000), with a double peak in less negative, more enriched $^{\delta 18}$O values focused on 1015 cal yrs BP (AD 935) and 911 cal yrs BP (AD 1039) (Apáestegui *et al*., 2014). Drier conditions in the basin may have allowed Plantaginaceae populations to thrive on the bog surface, as previously suggested. This period of increased Plantaginaceae from *~1054 cal yrs BP (~AD 896)* to *~985 cal yrs BP (~AD 965)* coincides with a period of higher organic matter and lower values of PC1 within the µXRF record, suggesting less terrigenous input into the basin and reduced landscape erosion during a period of drier climatic conditions. The second of the two peaks within the Palestina cave record at 911 cal yrs BP (AD 1039) also coincides with a period of lower PC1 values and higher organic matter content, with elevated levels of the LnInc/Coh ratio and LnBr/Ti indicating higher organic productivity at this time. This indicates that the µXRF data from Huarca basin is a sensitive indicator to environmental changes; this will be explored further in the discussion section (Section **3.5**).

Sand is deposited in the basin once more from *~813 cal yrs BP (~AD 1135)* until *~739 cal yrs BP (~AD 1212)* (Unit 14) resulting in a decrease in organic matter. This is probably another period of landscape erosion during the LIP as the timing coincides with ITRAX Event 2 (Fig. 3.17) (*~800-735 cal yrs BP/ ~AD 1135-1214*), with elevated valued of PC1, and peaks in Si/cps, Ca/Ti, and K/Ti. LnInc/Coh is low during this time indicating lower organic productivity. From the palaeoecological record, *Glomus* (HdV-207) increases, an indicator for soil erosion (Van Geel *et al*., 2011). Unlike the previous ITRAX events this period of landscape erosion occurred within an arid event, with increased temperatures during the Southern Hemisphere expression of the MCA (1100-700 cal yrs BP/ AD 850-1250) (Bird *et al*., 2011; Kanner *et al*., 2013; Apáestegui *et al*., 2014; Bustamante *et al.,* 2016). The MCA was characterised by a regional reduction in precipitation and possibly an increase in temperature, both of which may have increased either aeolian or fluvial sediment transportation. Certainly, lower precipitation and higher temperatures would have caused a change in the net accumulation rate of ice and increased melting of the nearby Huandoy glacier causing greater meltwater discharge and suspended sediment deposition in the basin. An increase in meltwater and water availability in the streams feeding the site would be supported by the presence of *Myriophyllum* within the record at *~741 cal yrs BP (~AD 1209),* which is indicative of running water. The hypotheses put forward here will be discussed further in the vegetation history section in relation to landscape erosion (Section Error! Reference source not found.), and in the discussion section (Section **3.5**).

By *~739 cal yrs BP (~AD 1211)* peat formation resumed until *~569 cal yrs BP (~AD 1381)* (Units 15 -19). Plantaginaceae increased with the formation of peat from *~739 cal yrs BP (~AD 1211)*, indicating a recolonisation of the bog surface. This coincides with an increase in Asteraceae and Cyperaceae populations, some species of which, as previously mentioned, commonly grow alongside *Plantago tubulosa* on bog surfaces (Fonkén, 2014; Polk *et al*., 2019). An increase in these bog forming plants also leads to an increase in organic matter from ~ *683 cal yrs BP (~AD 1267)*, which remains elevated until *~587 cal yrs BP (~AD 1363)* in Unit 17. The resumed formation of peat may have been due to a reduction in water levels as a result of a decrease in meltwater discharge following the end of the MCA. This unit is situated within the transition between the MCA and LIA and may represent a temporary stabilisation of the depositional environment before an increase in precipitation during the LIA.

In Unit 18, a decrease in humification indicates greater bog surface wetness between *~585-583* cal yrs BP *(*~AD *1365-1367),* supported by the presence of the freshwater algae *Pediastrum*. Collectively these indicate a body of standing water on the wetland. There is also a decrease in organic matter at this time and an in washing of silt into the basin suggesting increased surface runoff. This increase in water availability may be related to greater precipitation, with more negative $^{\delta}$18O values seen in the Laguna Pumacocha and Palestina cave record at this time, indicative of the start of the Little Ice Age (625-130 cal yrs BP/ AD 1325–1820) (Bird *et al*., 2011; Apáestegui *et al*., 2014). The period of increased bog surface wetness is relatively short-lived within the Huarca record, with the humification increasing again from *~583 cal yrs BP (~AD 1367)* until *~569 cal yrs BP (~AD 1381)*, at the top of the LPAZ 3 (Unit 19, Humo = 3). Organic matter content increases, as silt is no longer washing into the basin, from *~583 cal yrs BP (~AD 1367)* and Plantaginaceae and Cyperaceae populations increase, contributing largely to bog formation and organic matter content at this time.

Alnus populations start to increase in LPAZ 3 at ~ *578 cal yrs BP (~AD 1372)* and continue to increase in LPAZ 4 until *~414 cal yrs BP (*~AD *1536)*. *Alnus* may have colonised the bog edges at this time, as it is known to thrive in wet environments (Russo, 1990). However, *Alnus* trees produce vast amounts of anemophilous pollen (Chepstow-Lusty and Winfield, 2000), and so pollen may have been transported from the surrounding slopes of the basin where Alder trees grow today, opposed to representing a 'closer' source of pollen, i.e., on the bog surface. This corresponds with a reduction in organic matter after *~547 cal yrs BP (~AD 1523)*; this reduction may be as a result of an increase in fine mineral sediment being washed into the basin at this time. Although the lithostratigraphy does not detect any sand or silt within the sediment, the µXRF data reveals increased PC1 values between *~583-408 cal yrs BP (~AD 1367-1542)* during ITRAX Event 1 (Fig. 3.18), indicating higher terrigenous input with elevated Ti and Si values. The lower Plantaginaceae levels may also be as a result of greater bog surface wetness with the presence of the aquatic taxon *Myriophyllum* from *~426* cal yrs BP *(~AD 1524)* until *~414* cal yrs BP *(~AD 1536)* indicating the presence of running water once again. This is also supported by the presence of Ranunculaceae cf. *Ranunculus* within LPAZ 3, several species of which grow under aquatic conditions within Peru (Brako and Zarucchi, 1993*;* Polk *et al*., 2019). This could be a resumed response to wetter LIA climatic conditions within the basin; this will be discussed further in Section **3.5**.

After *~569 cal yrs BP (AD 1381)* Plantaginaceae populations remain low until present day, suggesting a major change in bog surface vegetation and basin hydrology, with Poaceae and Cyperaceae becoming the more dominant bog surface vegetation from *~569 cal yrs BP (~AD 1381)*. This may also be supported by the reduction in Asteraceae populations within LPAZ 4 and 5, a family commonly found on cushion forming *bofedales* alongside Plantaginaceae (Polk *et al*, 2019). Cyperaceae percentages increase from *~400 cal yrs BP (~AD 1550)* to reflect modern day vegetation coverage in the Huarca basin with some Poaceae also growing on the bog surface. There are no aquatics or ferns present within the pollen record within LPAZ 5, reflecting the drier bog surface conditions seen at present day. There is an in-washing of silt from ~*336 cal yrs BP (~AD 1614)* until present day (Unit 20), resulting in a reduction in organic matter and elevated PC1 values, influenced by greater Ti and Si levels, within the µXRF data. This in-washing of silt may be related to more modern human activity around the basin, including the building of the village and development of modern agricultural soils around the basin leading to landscape erosion. The build-up of silt has caused a silt cap to form across the basin in some areas.

3.3.5.2 Vegetation History

Pollen data from Huarca basin allows for the reconstruction of the dryland vegetation community from *~2522 cal yrs BP (~568 BC)* during the Early Horizon (EH) through to present day. LPAZ 1 was dominated by grassland and shrubland taxa with forest taxa present in low numbers; there were also a number of indicators for human activity around the basin during the EH. Chenopodiaceae/Amaranthaceae populations increase from *~2522 cal yrs BP (~568 BC)*, reaching maximum abundance within the pollen record at *~1963 cal yrs BP (~13 BC)*. This may represent an increase in cultivation of *Chenopodium* or *Amaranthus* with a transition to the Recuay culture in the Early Intermediate Period from *~2150 cal yrs BP (~200 BC)*. Species from both the *Chenopodium* genus and the *Amaranthus* genus are currently, and have been historically, cultivated in Peru; this includes Quinoa (*Chenopodium quinoa*), *Kañiwa* (*Chenopodium pallidicaule*), and *Kiwicha* (*Amaranthus caudatus*) (National Research Council, 1984, 1989; Thapa and Blair, 2018). This may also represent an increase in wild Chenopodiaceae/Amaranthaceae with genera such as *Atriplex* (Chenopodiaceae) and *Guillerninea* (Amaranthaceae) also being known to grow in the Ancash highlands (Brako and Zarucchi, 1993). The presence of wild species of Chenopodiaceae/Amaranthaceae would also be indicative of human land disturbance as they are emblematic Andean agricultural weeds (Rindos, 1984). The presence of Solanaceae in the record could also indicate both wild growth and cultivated Solanaceae, potentially potatoes (genus *Solanum*), with two thirds of the species of Solanaceae pertaining to the Ancash region at present day belonging to *Solanum* (Tropicos, 2022) Several species of *Solanum* have originated from the Peruvian Andes including *Solanum andigenum* (*Andigena* in Quechua), this is thought to be the ancestral species for the common potato, *Solanum tuberosum*, as well as *Solanum stenotomum* (*Pitiquiña*), *Solanum goniocalyx* (*Limeña*), and *Solanum x chaucha* (*Chaucha*). The last species is a hybrid of *S. steriotomum* and *S. andigenum,* which originated in the central highlands and has now spread across almost the entire country (National Research Council, 1989; Brako and Zarucchi, 1993). However, it may also represent the growth of the wild genera of *Salpichora*, *Lycianthes* or *Cestrum,* all recorded to grow at the altitude of Huarca (3000-3500m a.s.l.) within the Ancash Region (Brako and Zarucchi, 1993).

The presence of herbaceous taxa within this zone suggests the landscape was open and heavily grazed at this time. Cruciferae, Apiaceae and Caryophyllaceae increase from around *~2284 cal yrs BP (~336 BC)*, whilst *Rumex* first appears in the record from *2126 cal yrs BP (~174 BC). Rumex* is probably represented here by *Rumex acetosella* or *Rumex peruanus*, both known to grow in Ancash at the present day. The latter is often found growing in bog habitats and therefore *Rumex* may also reflect changes in the basin's vegetation community (Brako and Zarucchi, 1993). The presence of *Ambrosia* and *Artemisia* (*Artemisia annua* and *Artemisia absinthium*) at this time also supports the presence of disturbed ground, with *Ambrosia arborescens*, the only species of *Ambrosia* recorded in Ancash, naturally favouring disturbed ground (Brako and Zarucchi, 1993, Chepstow-Lusty and Winfield, 2000). *Ambrosia arborescens* is also used for stabilising rudimentary terraces today in the Peruvian Andes, such as those that were almost certainly constructed around Huarca during these earlier periods (EH and EIP) (Kendall, 2009; Chepstow-Lusty and Winfield, 2000). The presence of *Ambrosia* in the pollen record has been linked to agricultural activity elsewhere in Peru at Marcacocha in the Patachanca Valley (Chepstow-Lusty and Winfield, 2000; Chepstow-Lusty, 2011) and in northern Peru at Laguna Compuerta (Weng *et al.,* 2004; 2006).

Interestingly, very few trees are present within the record during this zone; this may be a result of forest clearance to create space for the developing agriculture during the EH and EIP. Burning activity increases from *~2400 cal yrs BP (~450 BC)* as the basin changes from an open-water lake setting and sand and silt material starts to build up (Units 8-12). In Section **3.3.5.1**, it was hypothesised that this catchment erosion may be linked to a prolonged pluvial period from ~2500-1500 years ago, although the comparison with the cultural chronology here may also suggest this was due to an increase in agricultural activity.

There is a reduction in abundance of certain herbs (Apiaceae and Caryophyllaceae) and other landscape disturbance indicators (*Artemisia* and *Ambrosia*) around 210cm (*~2055 cal yrs BP/ ~105 BC*). This may represent a decrease in grazing pressure, or more likely, it is related to a lower total land pollen concentration, which is probably due to poor pollen preservation and physical degradation of the pollen grains as a result of the sandy lithology towards the top of LPAZ 1, (Fig. 3.13). Abundance of families such as Rosaceae and Fabaceae remain low, indicating that shrubland communities did not develop during this time perhaps due to intensifying grazing. Both families contain species of thorny shrubs (Rosaceae e.g., *Tetraglochin cristatum*, *Rubus bogotensis*; Fabaceae e.g., *Tara spinosa*), which are unpalatable to grazing animals, further providing evidence that the reduction of herbs is not linked to a decrease in grazing pressure (Brako and Zarucchi, 1993).

Chenopodiaceae/Amaranthaceae populations decrease within LPAZ 2 between *~1847 cal yrs BP (~AD 106)* and *~1054 cal yrs BP (~AD 896)* suggesting a potential change in agricultural practices, as opposed to a reduction in activity. This is because *Ambrosia* and *Artemisia* populations increase alongside the presence of *Sporormiella* during the latter half of the Recuay period at *~1562 cal yrs BP (~AD 388).* The intensification of human activity from *~1847 cal yrs BP (~AD 106)* is further evidenced by an increase in micro-charcoal accumulation. This was probably brought into the basin by catchment erosion, with the charcoal particles already being deposited within the surrounding dryland soil, especially as this coincides with a sandy unit within the basin (Unit 12). *Glomus* (HdV-207) also increases at this time indicating soil erosion into the catchment was high during the later Recuay period.

The age modelling for Huarca revealed only two pollen samples with a mid-range date within the MH, at 164cm (*~1117 cal yrs BP/ ~AD 833*) and 160cm (*~1054 cal yrs BP/ ~AD 896*). This is also partly to do with the Middle Horizon being shorter in the Ancash Region (*1250-1050 cal yrs BP/ ~AD 700-900*) than elsewhere in the Peruvian Andes. During the MH, there was an increase in *Alnus*, with a peak at *~1117 cal yrs BP (~AD 833)*. The Palestina cave record indicates a pluvial period between 1130-1030 cal yrs BP (AD 820-920) (Apáestegui *et al*., 2014), which may indicate that *Alnus* growth was encouraged by MH anthropogenic activities, as the treeline is known to be supressed in elevation during cooler and wetter periods (Weng *et al*., 2004). Due to the limited number of data points, there is little other evidence to support increased human activity in the MH, although HdV-16A and HdV-18 do increase which may indicating greater in washing of spores into the basin.

The Late Intermediate Period, known locally as the *Aquillpo*, starts earlier than in the central Andean chronology (see Table 3.1) at *~1050 cal yrs BP (~AD 900)*. This cultural transition was characterised by an increase in *Sporormiella,* a reduction in Chenopodiaceae/Amaranthaceae and an absence of *Ambrosia* and *Artemisia* in the record. This may reflect the notion that after the collapse of the Wari, and a reduction in Wari influence in the Callejón de Huaylas in the MH, populations in Ancash moved to a pastoral farming system alongside the migration of people to higher altitudes (Herrera, 2003; Aguilar, 2019; Ponte, 2014). There is also a reduction in *Alnus*, potentially due to it no longer being managed under agroforestry practices, while *Podocarpus* and *Polylepis* occurred at *~985 cal yrs BP (AD 965)*; these species may have become more dominant in the surrounding landscape in the absence of *Alnus*. If the LIP populations did move to higher elevation, it was not long lived, with an increase in *Ambrosia* and *Artemisia* from *~1011 cal yrs BP (~AD 939)* indicating an increase in land disturbance. This is supported by elevated PC 1 values in the µXRF record, with high Ti and Si values, indicating increased terrigenous input. Perhaps therefore, there was a change in farming regime with the reduction in Wari influence in the Callejón de Huaylas, as opposed to site abandonment or a move to higher elevation. This will be explored further in the discussion section of this chapter (Section **3.5**).

Within LPAZ 2 there is a second peak in *Alnus* populations centred around *~959 cal yrs BP (~AD 991).* This coincides with a drier, and most likely warmer, conditions during the MCA, with the Quelccaya ice core record showing enriched $^{\delta}$18O values at 960 cal yrs BP (AD 990)

(Thompson *et al*., 2013, 2017). These climatic conditions probably led to an increase in the tree line to higher altitudes, and increased *Alnus* populations during the MCA have been seen elsewhere in Peru at Laguna Compuerta (Weng *et al*., 2004), Marcacocha (Chepstow-Lusty *et al*., 2009) and Laguna Paca (Hansen *et al*., 1994). *Alnus* populations decrease again around 140cm *(~815 cal yrs BP/ ~AD 1135*), with the Palestina cave record indicating a return to more negative (less enriched) $^{\delta}$18O values from 850 cal yrs BP (AD 1100) (Apáestegui *et al*., 2014). The position of Huarca, at the modern upper altitudinal limit for *Alnus acuminata* (~3200m a.s.l.) (Brack Egg, 1999), places it in a potentially highly sensitive position to monitor *Alnus'* response to past changes into temperature and moisture availability. With the treeline moving above and below Huarca with changes in climatic regimes.

Within LPAZ 3 (*~786-569 cal yrs BP/ ~AD 1166–1381)* there are several indicators for an increase in human activity around the basin, possibly related to developments in LIP societies, as a prelude to the rise of the Late Horizon Inca Empire. The presence of increased herbs within this zone including Cruciferae, Caryophyllaceae, Apiaceae, *Rumex* and *Alternanthera* alongside *Sporormiella* suggests that the landscape around the basin was open and heavily grazed. As well as indicators for grazing there was an increase in Chenopodiaceae/Amaranthaceae from *~739 cal yrs BP (~AD 1211),* and *Zea mays* was present in the record at *~680 cal yrs BP (~AD 1270), and again at 583 cal yrs BP (~AD 1367)*, immediately after a peak in *Ambrosia*, indicating crop growth on the slopes and terraces around Huarca basin. The occurrence of *Zea mays* with *Ambrosia* may indicate deliberate conservation and stabilisation of terrace soils ready for maize cultivation. A large influx of charcoal at *~602 cal yrs BP (~AD 1348)* indicates that burning was undoubtedly used as part of these agricultural practices. This influx occurs during a relatively stable period in terms of landscape erosion, with no obvious indicators for large catchment erosion within the µXRF data. This suggests that burning of the surface of agricultural fields may have been a common practice to remove unwanted crop waste and enhance the nutrient status of the soil.

At the end of the LIP and into the LH (LPAZ 3 and 4) *Alnus* increases. At Laguna Compuerta and Marcacocha, there is also renewed *Alnus* populations during the LH (Weng *et al.*, 2004; Chepstow-Lusty *et al.,* 2009). *Alnus* is thought to be a very important tree species in Incan agroforestry, both economically and symbolically, and was likely used for timber, building materials and for fuel, as well as in rituals (Chepstow-Lusty *et al.,* 2009). The clear increase in *Alnus* within the landscape around Huarca suggests anthropogenic management during a period of higher precipitation during the LIA, when population may have been otherwise suppressed.

Late Horizon anthropogenic activity likely included agriculture as well as agroforestry. Chenopodiaceae/Amaranthaceae increased from *~512 cal yrs BP (~AD 1438),* either indicating an increase in crop growth or more agricultural activity due to an increase in agricultural weeds, with *Ambrosia* and *Artemisia* also indicating disturbed ground. Interestingly there is no *Zea mays* within the pollen record during the LH, which is likely due to the limited dispersal range of *Zea mays* pollen, as the Maize is a self-pollinating plant, and not an absence of maize growth; a crop widely acknowledged to have been important and emphasized by the Inca (Hastoff and Johannessen, 1993; Burger, 2003; Finucanne, 2007; Hastoff, 2017). The only occurrence of *Escallonia* within the record dates to the LH *(~428 cal yrs BP/ ~AD 1522*). *Escallonia resionosa* (*Chachacomo*) is a particularly important tree species to the Incas, as it is one of the most common materials used to make *Keros* (drinking cups), an item synonymous with Incan power and a key component of Incan religious festivals and feasts (Carreras and Escalera, 1998). *Chachacomo* was also used as an Incan building material, as it is a harder wood than *Alnus* (Kendall, 1996). Its occurrence here alongside *Polylepis,* another important tree species ethnographically, may indicate mixed agroforestry practices with *Alnus*.

Within LPAZ 4, there is an increased abundance of short shrubs and herbs, including *Escallonia,* Cruciferae Apiaceae, Onagraceae (e.g., genus *Epilobium*) and Ranunculaceae *cf. Thalictrum* indicating that parts of the landscape were not forested may have been open shrubland and grassland. There is no *Sporormiella* present within this zone, but Llama and Alpaca husbandry was a common practice during the Inca period.

The maximum abundance of *Alnus* occurs at *~414 cal yrs BP (~AD 1536)*, with populations staying high during the Colonial Period. This could be for one of two reasons: either the populations in this area of Ancash were not altered by the Spanish conquest and agroforestry remained, or perhaps more likely, the lack of human activity following the conquest in combination with an improving climate may have led to continued and uninterrupted growth within the Colonial Period, with the tree line likely sitting in a similar altitudinal limit today. This lack of human activity into LPAZ 5 is supported by a reduction in land disturbance indicators and marked reduction in micro-charcoal from *~420 cal yrs BP (~AD 1530)* onwards. There is a reduction in *Alnus* from *~360 cal yrs BP (~AD 1590),* which coincides with the first occurrence of *Eucalyptus* in the record; a tree introduced by the Spanish. At Marcacocha and Laguna Compuerta, the reduction in *Alnus* appears to occur slightly earlier than in Huarca (500 yrs ago); at these sites it was attributed to forest clearance with increased grazing and agricultural pressures (Weng *et al.,* 2004; Chepstow-Lusty 2009).

The pollen assemblage as a whole is less diverse in LPAZ 5, with a reduction in herbs, as well as human disturbance indicators such as *Artemisia* and Solanaceae. Potatoes and Quinoa were recorded growing in the fields on the slopes surrounding Huarca today, although there is not a strong signal for these within the pollen record. There is a slight increase in Liliaceae/ Alstroemeriaceae, which may represent the flowers that are grown on the basin edge for export to market. During fieldwork these were mainly observed to be *Alstroemeria* (Peruvian lily or lily of the Incas), the pollen of which (Alstroemeriaceae) may be represented within this part of the record.

3.4 Awkismarka Terraces and Bofedales

As part of the original excavations at Awkismarka, the nature and internal characteristics of the soils within the *bofedales* were recorded, the results of this assessment are summarized in Table 3.7 below. Description of the deposits followed the Archaeology Site Manual methodology (MOLAS, 1994) in order to describe the main soil horizons, colour and texture (Herrera *et al*., 2009). The new contribution of phytolith analysis from these excavated contexts is presented in Section **3.4.1.**

Table 3.7: Results of the soil assessment for Awkismarka terrace and bofedales, modified from Herrera et al., 2009.

		BOF 1		
Depth cm	**Layer**	**Colour**	**Texture**	
0-12	I	Light brown		
12-36	II	Light brown	Sandy clay	
36-55	III	Light greyish white	Fine sand	
55-95	IV	Dark brown	Clayey silt	
95-99	V	Light brown	Clayey silt	
99-105	VI	Light brownish grey	Coarse sand + gravel	
105-106	VII	Light brown	Clayey silt	
106-112	VIII	Light brownish grey	Coarse sand + gravel	
112-116	IX	Light brown	Clayey silt	
116-120	X	Light brownish grey	Coarse sand + gravel	
120-124	XI	Light brown	Clayey silt	
124-135	XII	Middle reddish grey	Clayey silt	
135-143	XIII	Dark reddish brown	Clayey silt	
143-161	XIV	Light reddish brown	Clayey silt	
161-222	XV-XXVI	12 alternating layers of light brown and light brownish grey soil	12 alternating layers of clayey silt and coarse sand and gravel	
		BOF 3		
0-36	I	Middle brown	Silt	1-5cm; 30% Very poorly sorted; Angular

36-49	II	Brownish grey	Coarse sand + gravel	1-15cm; 50% Very poorly sorted; Angular
49-80	III	Light brown	Sandy silt	1-20cm; 40% Very poorly sorted; Angular
80-119	IV	Middle brown	Silt	1-60cm; 80% Very poorly sorted; Sub-angular
119-140	V	Light yellow	Coarse sand	1-20cm; 80% Very poorly sorted; Very angular
		BOF 6 Hole 1		
0-54	VI	Light brown	Sandy silt	1mm-6cm; 40% Very poorly sorted; Sub-angular
54-134	V	Dark brown	Sandy silt	1mm-6cm; 20% Very poorly sorted; Sub-angular
134-205	VI	Light greyish brown	Medium sand	1-10cm; 50% Poorly sorted; Angular
205-220	VII	Light yellow	Fine sand	1-15cm; 75% Poorly sorted; Sub-rounded
		BOF 6 Hole 2		
0-95	I	Light brown	Sandy silt	1mm-6cm; 20% Very poorly sorted; Sub-angular
95-122	II	Middle brown	Silt	1mm-2cm; 10% Poorly sorted; Angular
122-152	III	Dark brown	Sandy silt	1mm-8cm; 40% Poorly sorted; Angular
152-188	IV	Middle brown	Sandy silt	1mm-6cm; 40% Poorly sorted; Angular
188-240	V	Middle greyish brown	Sandy silt	1mm-2cm; 20% Moderately sorted; Sub-rounded
		BOF 9		
0-38	I	Middle brown	Sandy silt	1mm-12cm; 20% Poorly sorted; Sub-rounded
38-88	II	Light yellowish brown	Fine sand + gravel	1mm-20cm; 80% Poorly sorted; Very angular
88-95	III	Middle brown	Clayey silt	1mm-10cm; 20% Very poorly sorted; Sub-rounded
95-185	IV	Black	Clayey silt	1mm-100cm; 90% Poorly sorted; Sub-rounded
185-200	V	Light yellow	Fine sand	1mm-10cm; Moderately sorted; Sub-rounded
		BOF 10		
38-88	II	Middle brown	Silt	1mm-8cm; 35% Moderately sorted; Angular
88-95	III	Dark yellow	Fine sand	1mm-10cm; 40% Moderately sorted; Very angular
95-185	IV	Middle brown	Clayey silt	1mm-10cm; 20% Very poorly sorted; Sub-rounded
		BOF 13		

0-54	I	Light brown	Sandy silt	1mm-6cm; 40% Very poorly sorted; Sub-angular
54-134	II	Dark brown	Sandy silt	1mm-6cm; 20% Very poorly sorted; Sub-angular
134-205	III	Light greyish brown	Medium sand	1-10cm; 50% Poorly sorted; Angular
205-220	IV	Light yellow	Fine sand	1-15cm; 75% Poorly sorted; Sub-rounded
		TER 1		
0-23	I	Light brown	Fine sand	3cm max; 2% Well sorted; Rounded
23-120	II	Light brownish yellow	Fine sand	2cm max; 2% Well sorted; Rounded
120-150	III	Light brownish yellow	Fine sand	20-60cm; 80% Well sorted; Sub-rounded

3.4.1 Results of the Phytolith Analysis

Phytoliths samples were taken from six *bofedales* sequences and one terrace sequence from the Awkismarka area. The results of the phytolith counts were transformed into percentage phytolith diagrams (Fig. 3.19) using Tilia 2.6.1 (Grimm, 2019). Due to samples being from various contexts the phytolith diagrams have not been zoned. The phytolith assemblages have first been presented as full morphotype diagrams (Fig. 3.19 & 3.20) to aid in the description of the phytolith profiles. Summary diagrams have also been produced in order to aid in the interpretation of the vegetation communities present at each site (Fig. 3.21 & Fig 3.22). A summary of the averaged percentage data of the main taxa in each context is presented in Table 3.8.

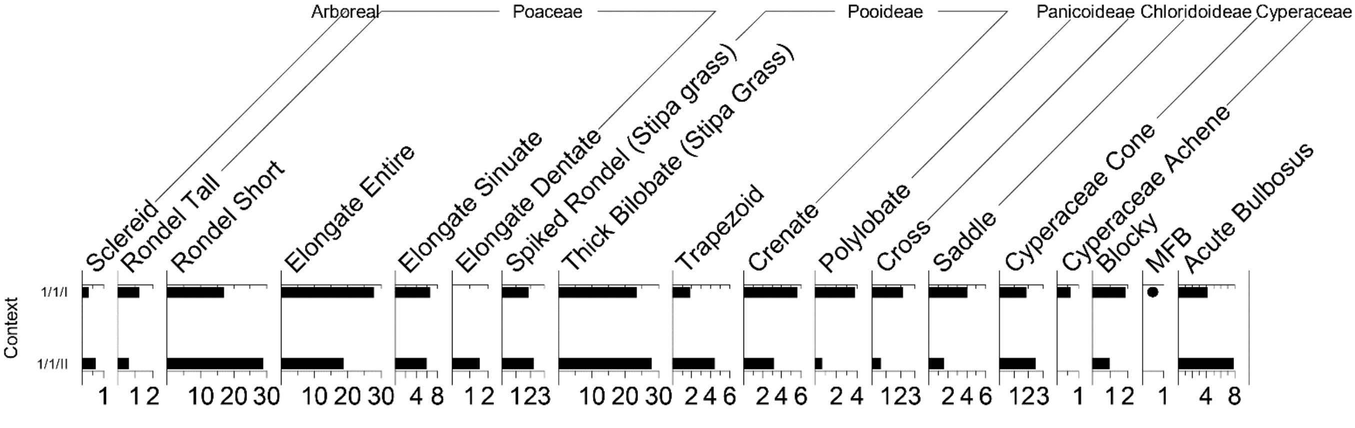
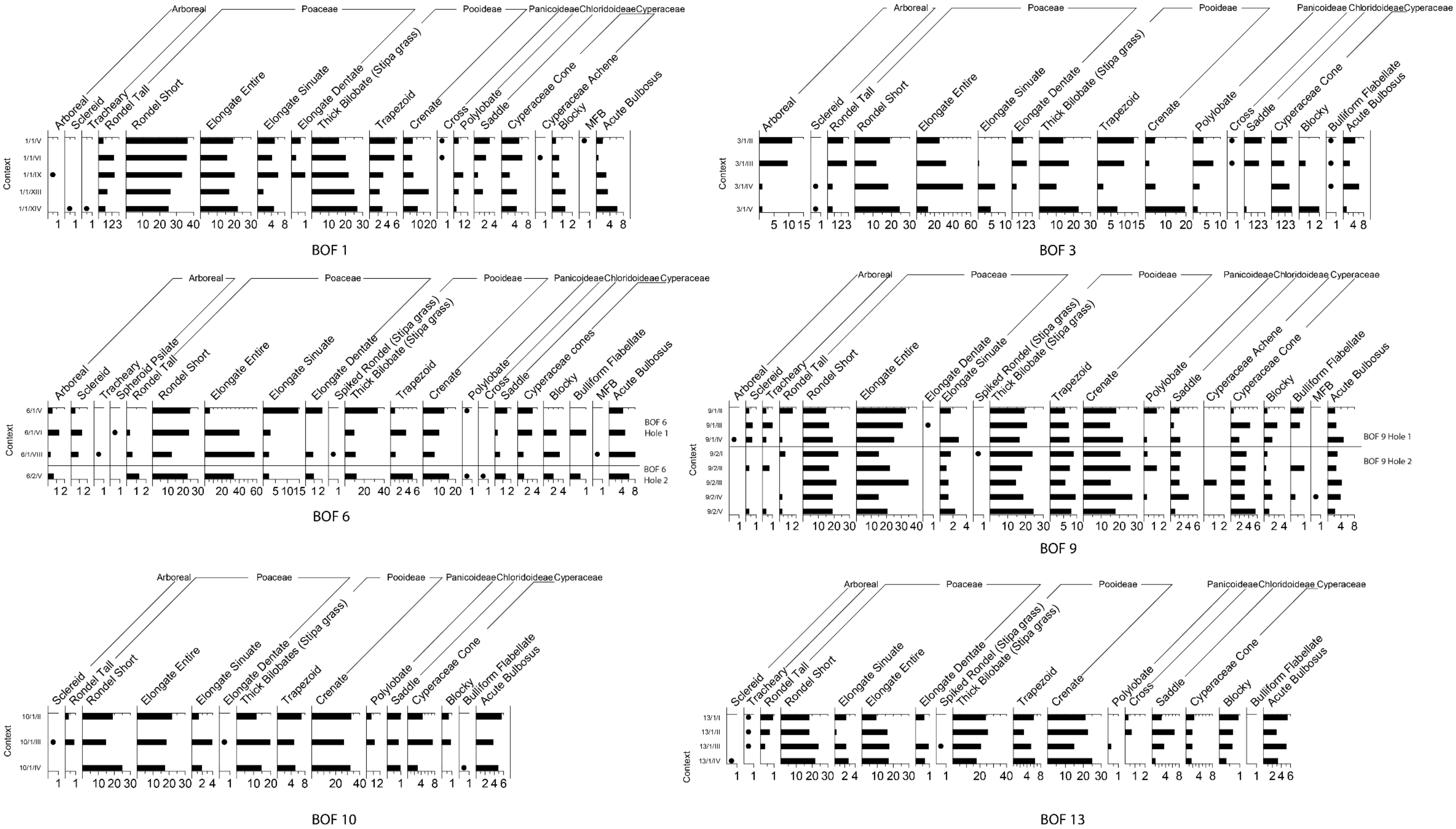


Figure 3.19: Detailed Phytolith profile from Terrace 1. Diagram produced using Tilia 2.6.1 (Grimm 2019). Values are expressed as a percentage of the total phytolith assemblage.



Values expressed as a percentage
of the total phytolith assemblage

Figure 3.20: Detailed phytolith diagrams from the six bofedales showing all morphotypes. Values expressed as a percentage of the total phytolith assemblage. Acute Bulbosus have not been included in this count, as they are non-diagnostic and found in most terrestrial plants. Diagrams produced using Tilia 2.6.1 (Grimm 2019).

Table 3.8: Phytolith assemblage descriptions for the bofedales and terrace at Awkismarka. Values rounded to the nearest whole percentage.

Layer	**Depth cm**	**Phytolith Assemblage**	**Summary of phytolith taxa**
TER1/1/I	0-23	Poaceae-Pooideae	Non-diagnostic Poaceae, 45%; Pooideae, 33%; Other, 10%; Panicoideae, 6%; Chloridoideae, 4%, Cyperaceae, 3%; Arboreal, <1%.
TER1/1/II	23-120	Poaceae-Pooideae	Non-diagnostic Poaceae, 54%; Pooideae, 38%; Other, 3%; Cyperaceae, 3%; Chloridoideae, 2%; Panicoideae, 1%; Arboreal, 1%.
BOF 1/1/V	95-99	Poaceae - Pooideae	Non-diagnostic Poaceae, 62%; Pooideae, 28%; Cyperaceae 5%; Chloridoideae, 3%; Panicoideae, 1%; Other, 1%.
1/1/VI	99-104	Poaceae - Pooideae	Non-diagonostic Poaceae, 58%; Pooideae, 32%; Cyperaceae, 6.4%; Chloridoideae, 2%; Other, 1%; Panicoideae, <1%.
1/1/IX	107-112	Poaceae - Pooideae	Non-diagnostic Poaceae, 63%; Pooideae, 32%; Cyperaceae, 2%; Panicoideae, 1%; Chloridoideae, 1%; Arboreal 1%; Other, 1%.
1/1/XIII	124-135	Pooideae -Poaceae	Pooideae, 46%; non-diagnostic Poaceae, 46%; Cyperaceae, 5%; Chloridoideae, 2%; Panicoideae, 1%; Other, 1%.
1/1/XIV	135-142	Poaceae-Pooideae	Non-diagnostic Poaceae, 53%; Pooideae, 40%; Cyperaceae, 4%; Aboreal 1. Panicoideae, <1%; Other 1%.
BOF 3/1/II	36-49	Poaceae -Pooideae	Non-diagnostic Poaceae, 48%; Pooideae, 32%; Arboreal, 11%; Panicoideae, 4%; Chloridoideae, 3%; Cyperaceae, 2%; Other, <1%.
3/1/III	49-80	Poaceae-Pooideae	Non-diagnostic Poaceae, 50%; Pooideae, 29%; Arboreal, 10%; Panicoideae, 8%; Chloridoideae, 2%, Cyperaceae, 2%; Other, 1%.
3/1/IV	90-119	Poaceae-Pooideae	Non-diagnostic Poaceae, 76%; Pooideae, 17%; Cyperaceae, 3%; Panicoideae 3%; Arboreal 1%; Other, 1%.
3/1/V	119-140	Pooideae-Poaceae	Pooideae, 50%; Non-diagnostic Poaceae, 43%; Cyperaceae, 3%; Panicoideae, 2%; Other 2%; Arboreal, 1%; Chloidoideae <1%.
BOF 6/1/V	54-134	Poaceae-Pooideae	Non-diagnostic Poaceae, 47%; Pooideae, 47%; Cyperaceae, 2%; Chloridoideae, 1%; Arboreal, 1%; Panicoideae, <1%.
6/1/VI	134-205	Poaceae-Pooideae	Non-diagnostic Poaceae, 66%; Pooideae, 23%; Other, 4%; Arboreal, 4%; Cyperaceae, 3%; Chloroideae, <1%.
6/1/VIII	205-220	Poaceae-Pooideae	Non-diagnostic Poaceae, 73%; Pooideae 20%; Other, 4%; Arboreal, 2%; Cyperaceae, 1%; Chloridoideae, 1%.

6/2/V	188-240	Poaceae-Pooideae	Non-diagnostic Poaceae, 61%; Pooideae, 33%; Other, 3%; Cyperaceae, 1%; Chloridoideae, 1%; Panicoideae, 1%; Arboreal, 1%.
BOF 9/1/II	31-46	Poaceae- Pooideae	Non-diagnostic Poaceae, 51%; Pooideae, 43%; Other, 2%; Chloridoideae, 2%; Panicoideae, 1%; Arboreal, 1%; Cyperacae, 1%.
9/1/III	46-51	Poaceae- Pooideae	Non-diagnostic Poaceae, 48%; Pooideae, 43%; Cyperaceae, 4%; Other, 3%; Arboreal, 2%; Chloridoideae, 1%.
9/1/IV	71-113	Poaceae- Pooideae	Non-diagnostic Poaceae, 47%; Pooideae, 46%; Other, 2%; Chloridoideae, 2%; Arboreal, 2%; Cyperaceae, 2%; Panicoideae, <1%.
9/2/I	0-27	Pooideae-Poaceae	Pooideae, 53%; Non-diagnostic Poaceae, 40%; Cyperaceae, 4%; Chloridoideae, 3%; Other, 1%; Panicoideae, <1%.
9/2/II	27-88	Pooideae-Poaceae	Pooideae, 52%; Non-diagnostic Poaceae, 40%; Cyperaceae, 3%; Chloridoideae, 2%; Other, 1%; Panicoideae, 1%; Arboreal, 1%.
9/2/III	88-104	Poaceae-Pooideae	Non-diagnostic Poaceae, 57%; Pooideae, 35%; Cyperaceae, 4%; Chloridoideae, 2%; Other, 1%.
9/2/IV	104-140	Pooideae-Poaceae	Pooideae, 55%; Non-diagnostic Poaceae, 35%; Chloridoideae, 4%; Cyperaceae, 3%; Other, 2%; Panicoideae, <1%.
9/2/V	140-200	Pooideae-Poaceae	Pooideae, 50%; Non-diagnostic Poaceae, 42%; Cyperaceae, 6%; Other, 1%; Chloridoideae, 1%; Arboreal, 1%.
BOF 10/1/II	38-88	Pooideae-Poaceae	Pooideae, 51%; Non-diagnostic Poaceae, 42%; Cyperaceae, 4%; Chloridoideae, 1%; Other, 1%; Panicoideae, 1%
10/1/III	88-95	Pooideae-Poaceae	Pooideae, 52%; Non-diagnostic Poaceae, 38%; Cyperaceae, 7%; Panicoideae, 1%; Other, 1%; Chloridoideae, 1%; Arboreal, 1%.
10/1/IV	95-185	Pooideae-Poaceae	Pooideae, 52%; Non-diagnostic Poaceae, 44%; Cyperaceae, 3%; Chloridoideae, 1%; Other, <1%.
BOF 13/1/I	0-54	Pooideae-Poaceae	Pooideae, 51%; Non-diagnostic Poaceae, 42%; Chloridoideae, 3%; Cyperaceae, 3%; Panicoideae, 1%; Other, 1%; Arboreal, 1%.
13/1/II	54-134	Pooideae-Poaceae	Pooideae, 51%; Non-diagnostic Poaceae, 39%; Chloridoideae, 7%; Cyperaceae, 2%; Panicoideae; 1%; Other, 1%; Arboreal, <1%.
13/1/III	134-205	Poaceae-Pooideae	Non-diagnostic Poaceae, 52%; Pooideae, 41%; Chloridoideae, 4%; Cyperaceae, 2%; Other, 1%; Panicoideae, <1%; Arboreal, <1%.
13/1/IV	205-220	Pooideae-Poaceae	Pooideae, 49%; Non-diagnostic Poaceae; 48%; Cyperaceae, 2%; Chloridoideae, 1%; Other, <1%; Arboreal, <1%.

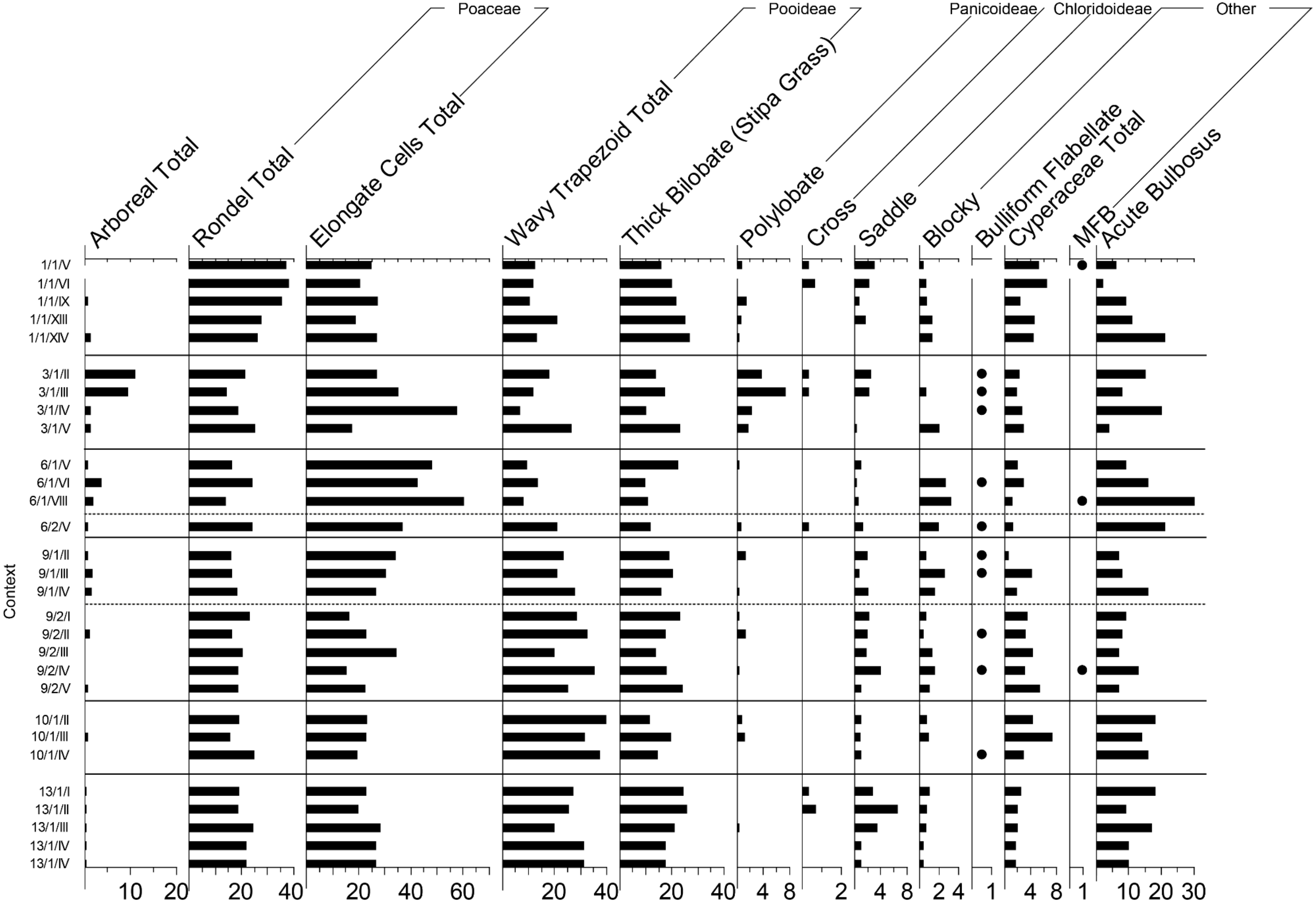


Figure 3.21: Summary diagram across all BOF sites, similar classes of phytoliths have been totalled (e.g., all elongate phytoliths). Diagram produced using Tilia 2.6.1 (Grimm 2019). Values are expressed as a percentage of the total phytolith assemblage.

TER 1 (120-0cm) Poaceae-Pooideae

The samples from terrace 1 are dominated by non-diagnostic Poaceae phytoliths (1/1/I, 45%; 1/1/II, 54%), with a high number of short rondels (~23%) and elongate entire (~23%). Elongate dentate phytoliths occurred in context 1/1/II only. Pooideae sub-family phytoliths are the second most commonly occurring (~35%), with all Pooideae morphotypes present in both samples. Panicoideae sub-family phytoliths occur in greater abundance in 1/1/I (~6%) than in 1/1/II (~1%). Chloridoideae saddle are also greater in 1/1/I (~4%) than in 1/1/II (~2%). Overall Cyperaceae percentages are the same in both samples (~3%), however Cyperaceae achene only occurred in 1/1/I. Arboreal phytoliths were only represented by sclereids in TER 1 in small numbers (<1%). Blocky phytoliths were greater in 1/1/I (~2%) than in 1/1/II (~1%), and multifaceted bodies (MFB) only occurred in the top sample (<1%).

BOF 1 (161-95cm) Poaceae-Pooideae

The sequence from BOF 1 is dominated by non-diagnostic Poaceae (~52%), short rondels increase up the soil profile (~25% in 1/1/XIV and ~36% in 1/1/V), while elongate entire fluctuates (minimum, 16%; maximum, 22%). Elongate dentate phytoliths are present in the top three samples 1/1/IX (~1%), 1/1/VI (<1%) and 1/1/V (~1%). Pooideae sub-family phytoliths are the second most abundant group of phytoliths, thick bilobates from *Stipa* grass decrease up the soil profile (from 27% to 16%), while trapezoids increase (3%-6%). Crenate phytoliths are generally present around ~7% apart from in context 1/1/XIII where they increase to ~19%. Panicoideae phytoliths occur in all samples (~1%), however cross shaped phytoliths only occur in the upper two samples 1/1/V and 1/1/VI (<1%). Chloridoideae saddles occur in all but 1/1/XIV and are in greatest abundance in the upper samples (~3%). Cyperaceae phytoliths are mainly represented by Cyperaceae cones (~5%), with one sample containing Cyperaceae achene bodies (1/1/VI, <1%). Arboreal phytoliths were only present in two contexts in trace amounts (1/1/IX, ~1%; 1/1/XIV, 1%). Blocky phytoliths decreased up the soil profile (from 1 to <1%). Multifaceted bodies were present in one sample (1/1/V, <1%).

BOF 3 (140-96cm) Poaceae-Pooideae

Non-diagnostic Poaceae is dominant in all but the last context for BOF 3 (3/1/V), for which Pooideae is the most dominant group of phytoliths (~50%). Non-diagnostic phytoliths are highest in 3/1/IV (~76%). Panicoideae phytoliths are most abundant in 3/1/III (~8%), with cross-shaped phytoliths only occurring in the two upper samples (3/1/II and 3/1/III). Chloridoideae saddles occur in all contexts except 3/1/IV and are greater in the upper samples (maximum ~3% in 3/1/II). Cyperaceae in BOF 3 is only represented by Cyperaceae cones, occurring in all samples (~3%). Arboreal phytoliths include non-diagnostic arboreal which is highest in context 3/1/II (~11%) and decreases down the soil profile (3/1/V, ~1%). Sclereids were present in trace amounts in the lower two samples (3/1/IV and 3/1/V). Blocky phytoliths are present in two samples (3/1/III, ~1%; 3/1/V, ~3%) and bulliform flabellates occur in trace amounts in the upper 3 samples (<1%).

BOF 6 Hole 1 (220-0CM) Poaceae-Pooideae

BOF 6 hole 1 is dominated by non-diagnostic Poaceae phytoliths (~62%), with the highest abundance in 6/1/VIII. The amount of elongate entires decrease (57-6%) up profile whilst short rondels increase up the soil profile (13-25%). Elongate dentates are present in two of the sample, 6/1/V and 6/1/VIII. Pooideae phytoliths (~25%), includes one occurrence of spiked rondels from *Stipa* grass in context 6/1/VIII (~1%). Thick bilobates and crenates both increase up profile (~11-34% and 7-13% respectively). There is one occurrence of Panicoideae polylobate phytoliths in the upper sample, 6/1/V (~1%), but no occurrences of cross-shaped phytoliths. Chloridoideae saddle’s increase up profile (~1%-2%) as do Cyperaceae cone’s (~1%-3%). Arboreal phytoliths are greatest in 6/1/VI (~4%), which contains non-diagnostic arboreal phytoliths (~1%), sclereids (~1%) and trace amounts of spheroid psilate phytoliths (1%). The only occurrence of tracheary phytoliths is in context 6/1/VIII (~1%). Bulliform flabellate phytoliths are present in 6/1/VI only (1%), and Multifaceted bodies are present in 6/1/VIII in trace amounts (<1%).

BOF 6 Hole 2 (240-188cm) Poaceae-Pooideae

Phytoliths for BOF 6 hole 2 only came from one sample, for this sample non-diagnostic phytoliths were the most abundant group (~47%), with a high proportion of short rondels (~23%) and elongate entire phytoliths (~34%). Pooideae phytoliths (~33%) were the second most abundant. Both phytoliths from the Panicoideae sub-family group, cross-shaped and polylobate, were present in trace amounts (>1% and 1% respectively). Chloridoideae saddles made up ~1% of the total assemblage. Arboreal phytoliths are represented by non-diagnostic phytoliths arboreal phytoliths (~1%) only in hole 2. Blocky (~2%) and bulliform flabellate (~1%) phytoliths are also present.

BOF 9 Hole 1 (200-38cm) Poaceae-Pooideae

This sequence is dominated by non-diagnostic Poaceae phytoliths (~50%), with elongate entire phytoliths increasing up the profile (~25%-34%). Short rondels decrease across the three samples, (~19%-15%). There are two occurrences of tall rondels (~2% and <1%) and elongate sinuate phytoliths (~2% and ~3%) in context 9/1/II and 9/1/IV and one of elongate dentate in 9/1/III (<1%). Pooideae phytoliths are highest in the lower context 9/1/IV (~46%), with a greater number of crenates (~22%) and trapezoids (~7%). There are no occurrences of spiked rondels from *Stipa* grasses in hole 1. Chloridoideae phytoliths (~2%) are in greater abundance than Panicoideae phytoliths (<1%) in BOF 9 hole 1, saddles being highest in the lower most sample (9/1/IV, 2%). No cross-shaped phytoliths were present in BOF 9, so the Panicoideae phytoliths are represented by polylobates only (maximum ~1%). Arboreal phytoliths are made up of sclereid (~1%) and tracheary (~1%) phytoliths and one occurrence of non-diagnostic arboreal phytoliths in 9/1/II (~1%). Cyperaceae is represented by Cyperaceae cone phytoliths only at a maximum of 4%. There are two occurrences of bulliform flabellate phytoliths in contexts 9/1/II and 9/1/III (~1% in both). Blocky phytoliths are also present (~2%).

BOF 9 Hole 2 (180-0 CM) Pooideae-Poaceae

The sequence from the second excavation hole in BOF 9 was predominately made up of Pooideae phytoliths, with a high abundance of crenate phytoliths in contexts 9/2/II (~26%) and 9/2/IV (~27%). There is one occurrence of spiked rondels from *Stipa* grass in context 9/2/1 (<1%). Non-diagnostic Poaceae phytoliths (~43%) are the second most abundant group, except for in context 9/2/III where they are greater (~57%) than Pooideae phytoliths (~35%), due to a high proportion of elongate entire phytoliths (~35%) and short rondels (~22%). Cyperaceae phytoliths make up ~3% of the total assemblage in hole 2. There is one occurrence of Cyperaceae achene phytoliths in context 9/2/II (~1%). Chloridoideae phytoliths are greatest in context 9/2/IV (4%) with an overall abundance of ~2%. Panicoideae phytoliths a present in lower abundance, ~1% of the total assemblage. Arboreal phytoliths are represented by sclereid (<1%) and tracheary phytoliths (<1%) only in two context. Bulliform flabellates occur in two contexts (9/2/II, 1%; 9/2/IV, <1%) and multifaceted bodies in one (9/2/IV, <1%).

BOF 10 (195-0cm) Pooideae-Poaceae

Pooideae phytoliths are the dominant group in BOF 10 (~52%), with non-diagnostic Poaceae being the second most dominant (~41%). Elongate dentate occurs in context 10/1/III only (~1%), and tall rondels in two contexts (10/1/II, <1%; 10/1/III, ~1%). Cyperaceae, represented by Cyperaceae cones only, is highest in context 10/1/III (7%) in the middle of the sequence. Chloridoideae phytoliths are present in all contexts (~1%), whilst Panicoideae phytoliths are present in two contexts, 10/1/II (~1%) and 10/1/III (~1%). Arboreal phytoliths, represented by sclereids only are present in one context, 10/1/III (~1%). Blocky phytoliths occur in two contexts (10/1/II, ~1%; 10/1/III, ~1%) and bulliform flabellates occur in the lowest context only (10/1/IV, <1%).

BOF 13 Hole 1 (220-0cm) Pooideae-Poaceae

BOF 13 hole 1 is dominated by Pooideae phytoliths (~48%). Thick bilobates increase up the soil profile (~18%-25%), while crenates decrease (maximum, ~25%, minimum, ~15%). There is one occurrence of spiked rondels from *Stipa* grass in context 13/1/III (<1%). Non-diagnostic Poaceae phytoliths are the second most dominant group (~45%) across the profile, with non-diagnostic Poaceae being more dominant than Pooideae phytoliths in context 13/1/III (~52%). Both short rondels (~22-18%) and elongate entire (~23-20%) phytoliths decrease up the soil profile. Chloridoideae saddles are greatest in context 13/1/II (7%) along with Panicoideae phytoliths, represented by cross-shaped phytoliths (~1%). Cyperaceae phytoliths increase up the soil profile and are highest in the top context 13/1/1 (~3%). Arboreal phytoliths are represented by tracheary phytoliths in trace amounts the upper three contexts (13/1/1, 13/1/II and 13/1/III, <1%) and sclereid phytoliths in the bottom context, 13/1/IV (<1%). Blocky phytoliths are present in all contexts, increasing up profile (<1%-1%).

3.4.2 Interpretation of Phytolith Assemblage

The phytolith assemblage from the *bofedales* and the terrace at Awkismarka can provide information on the vegetation communities present at each site. The dominating vegetation cover across all sites was grassland, this included Poaceae as the most dominant phytolith type recorded, and grasses identified to the Pooideae sub-family were second most common. The presence of Panicoideae and Chloridoideae grasses was recorded at all sites but it in smaller numbers. Cyperaceae was also present across the *bofedales* and terrace. Arboreal phytoliths were recorded in small values at all sites but were most prevalent in BOF 3. The high presence of grasses reflects the sub-*Puna* grasslands present within the altitudinal range for the sites (3394-3766m a.s.l.), at the boundary between the *Quechua* and *Suni* environmental zones. The *bofedales* and terraces are thought to have been in use from at least the MH, due to the architectural style of the associated funerary contexts and pottery remains found within these (Herrera *et al*., 2009 and in prep). However, due to there being no radiocarbon dates for these sites, the results cannot be discussed in relation to changes through time. Consequently, each *bofedales* is considered as a whole and discussed in relation to its proposed function and environmental setting.

Despite the overall low abundance of arboreal phytoliths, one site (BOF 3) had considerably more arboreal indicators. The two upper samples contained more arboreal phytoliths than the lower samples; this likely reflects the modern vegetation of shrubs and small trees on the slope above this *bofedal*. In comparison, BOF 1, situated on the hill slope below BOF 3 in a more open environment, contained much fewer arboreal phytoliths and a greater proportion of

Poaceae and Pooideae phytoliths. The high presence of Pooideae grasses, in particular in BOF 9 and 10, is likely a reflection of the higher altitude nearer the *Puna* zone. Pooideae grasses are abundant within this elevation and may represent genera including *Agrostis*, *Brachypodium, Calamagrostis*, *Nassella* and *Piptochaetium,* all recorded within Ancash today (Brako and Zarucchi, 1993). The presence of *Stipa* grass was recorded at all sites in the form of thick bilobates, and in some cases spiked rondels (Fig 3.19) (Fredlund and Tieszen, 1994).

BOF 3 contained the highest abundances of Panicoideae grasses, likely reflecting wild Panicoideae grasses within the *Paspalum* or *Pennisetum* genus, as recorded in Ancash at this altitude at present day (Brako and Zarucchi, 1993). The presence of cross-shaped phytoliths within the upper two samples of BOF 3 (3/1/2; 3/1/3), could represent the presence of cultivated grasses, i.e., *Zea mays*, however no discriminant function analysis (see Piperno, 2006: pp.49) was able to be carried out on the cross-shaped phytoliths to determine if they are from cultivated maize or other Panicoideae sub-family grasses. The presence of wild Panicoideae grasses is further supported by the fact BOF 3 pertains to the *bofedal*-pasture group of *bofedales* (see Section **3.4**), which contained coarser soil not suitable for cultivation and is believed to be a natural feature formed in a natural residue of a past mudslide with very little human modification (Herrera *et al*., 2009). The same goes for BOF 6, 9, 10 and 13, which also contained cross phytoliths. Chloridoideae grasses were also present in low numbers across each of the sites, this is likely represented by genera of *Chloris*, *Muhlembergia, Aegopogon* and *Sporobolus* (Brako and Zarucchi, 1993). The greatest abundance of Chloridoideae phytoliths were seen in BOF 13, this may suggest a slightly drier environment was present within the *bofedales,* this is supported by the absence of bulliform flabellates and lower values of Cyperaceae phytoliths*.*

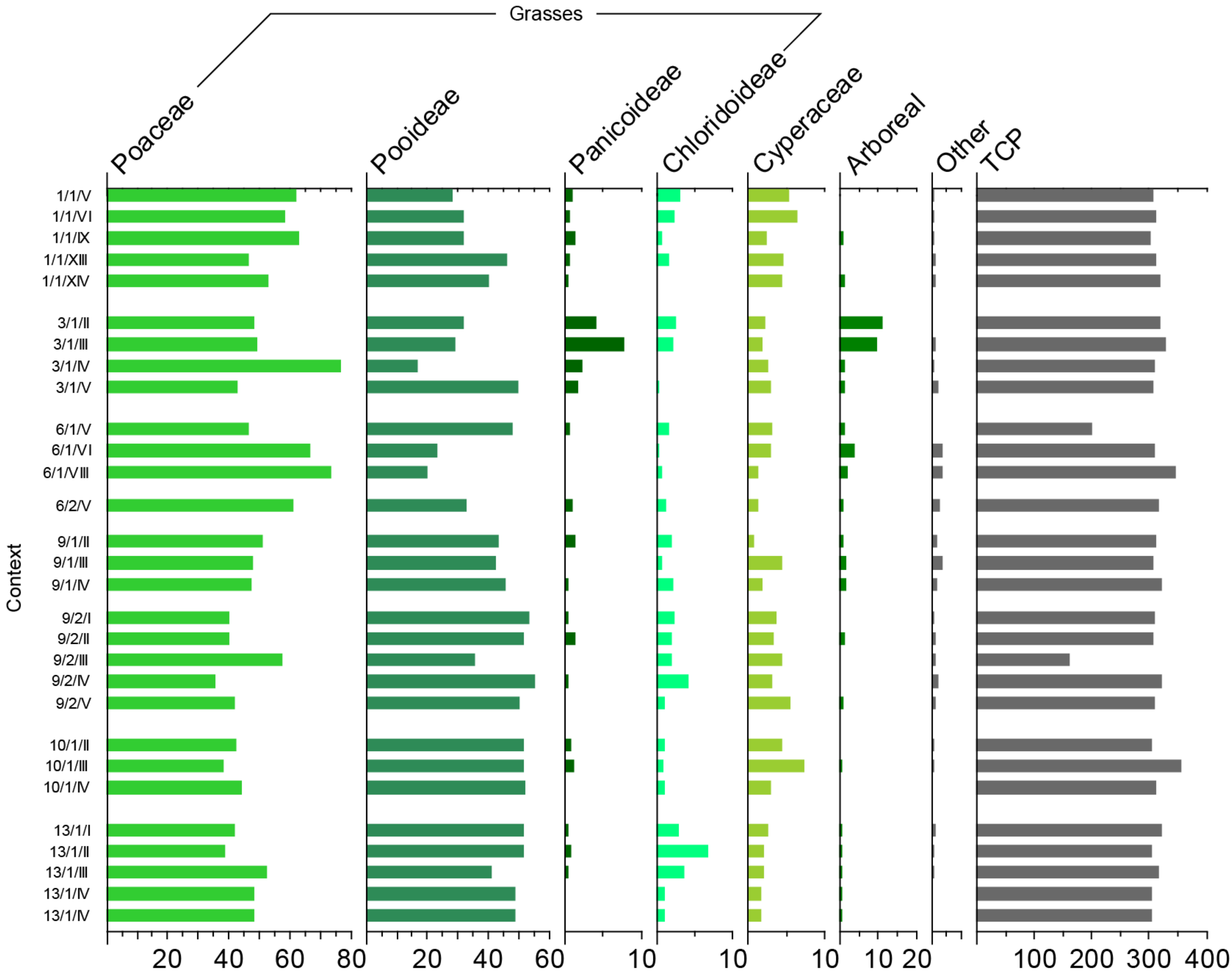


Figure 3.22: Summary diagram by family and sub-family of grasses where applicable. No lower-level classification of arboreal phytoliths was possible during this study. Diagram produced using Tilia 2.6.1 (Grimm, 2019). Values are expressed as a percentage of the total phytolith assemblage.

The high proportion of bulliform flabellates and Cyperaceae phytoliths within the *bofedal*-pasture contexts (BOF 3, 6, 9, 10 and 13), is concurrent with the theory these were used as wet-pasture meadows for camelid grazing (Dransart, 2002; Herrera *et al.,* 2009), as bulliform flabellates are produced under an excess of water within the growing conditions (Piperno, 2006, 35). Many of these *bofedales* (BOF 3, 6 and 9), were fed by Water Catchment Features (WCF), which provided a constant source of irrigation water and the *bofedales* were likely kept well-watered to increase potential as grazing pastures (Herrera *et al*., 2009 and in-prep; Lane, 2009).

BOF 1 belongs to the *bofedal*-reservoir group (Section **3.4**) and was thought to have been cultivated in the past; no wavy top rondels were found within these contexts to provide unequivocal evidence for maize cultivation, however. Cross-shaped phytoliths were present within the assemblage but as with the other *bofedales*, no discriminant function analysis could be carried out on these samples to determine if these were from cultivated maize. The number of cross-shaped phytoliths present within BOF 1 were similar to those found in TER 1, which was also thought to have been cultivated in the past, potentially with maize (*A. Herrera, pers. comm.).* As there is no definitive evidence for maize cultivation it is highly likely these terraces were used for the cultivation of a range of other Andean crops such as quinoa (*Chenopodium quinoa*), potatoes (*Solanum tuberosum*) or beans (*Phaselous vulgaris*), all of which have been recorded to be growing in the fields near Awiskmarka today. These crops produce little-no phytoliths and those which do are not diagnostic (Piperno, 2006), therefore identifying Andean crops other than maize within the phytolith record is problematic. The possible presence of other cultivars being grown in the region at the time these terraces were thought to have been in use (MH onwards), will be discussed in light of the data from Huarca in Section **3.5**.

3.5 Discussion

The main focus of this discussion will be on the period from *~2500 cal yrs BP* to present covered by the palynological record from Huarca, and which correlates to the main developments archaeological in the Peruvian Andes from the Early Horizon (2750 cal yrs BP/800 BC). A brief summary of pre-2500 cal yrs BP conditions within the basin will be discussed here based on the lithostratigraphy and µXRF data.

Sediment within Huarca basin started accumulating *~11,470 cal yrs BP*, following the rapid retreat of ice after the last glaciation, with glacial retreat reaching near modern limits in the Cordillera Blanca by 12,830-12749 cal yrs BP (Rodbell and Seltzer, 2000). The initial period of glacial retreat led to an increase in terrigenous sediment input into the basin with elevated PC 1 values, and the deposition of coarse and find sands, during a period of increased melt water (ITRAX Event 4, Fig. 3.18). From *~10,808 cal yrs BP*, after glacial retreat had ceased, the depositional environment within Huarca basin stabilised and organic-rich peat began to form. This continued to be deposited through to *~4265 cal yrs BP* during a period of relative warming compared to Late-Glacial/Early Holocene conditions (Thompson *et al*., 2017). From *~4265-4066 cal yrs BP*, conditions at Huarca got wetter with an open water, lake forming within the basin, as temperatures cooled and precipitation increased following the mid-Holocene South American arid period, centred on 4500 cal yrs BP (Bird *et al*., 2011; Thompson, 2000; Thompson *et al*., 2017). There is an apparent re-stabilisation of the depositional environment following *~4066 cal yrs BP* with a renewed formation of peat within the basin and a likely lowering of the water table at this time.

3.5.1 Early Horizon – *Chavin Era*

(2750-2150 cal yrs BP/ 800-200 BC)

The pollen record from Huarca (Fig. 3.13) shows that by the EH the landscape was already agriculturally productive, heavily grazed, and cleared of trees, with very few arboreal taxa present. This parallels records from elsewhere in Peru, which indicates agriculture was well established from the Initial Period; for example, Chenopodiaceae, alongside *Ambrosia*, was recorded at Marcacocha from *~4150 cal yrs BP* (Chepstow-Lusty *et al*., 2003). During the EH cultivation was most probably largely focused on psuedocereals *Chenopodium* and/or *Amaranthus* (e.g., *Chenopodium quinoa* and *Amaranthus caudatus*) as well as the growth of potatoes (e.g., *Solanum tuberosum, Solanum andigena*, and *Solanum stenotonum*), with *Ambrosia* present as an agricultural weed. There was no maize found within this early zone so it may be possible that quinoa and potatoes were the primary focus. However, as previously discussed, maize pollen may not have been captured within the sequence at Huarca due to the distance of the coring site away from the agricultural terraces at the edge of the basin. Elsewhere, at Pomacochas in northern Peru, maize was recorded from 3200 cal yrs BP and at Lake Compuerta, by a minimum of *~2600 cal yrs BP* (Weng *et al*., 2006; Bush *et al*., 2015), showing maize to be cultivated elsewhere in the highlands by this time.

The presence of herbaceous taxa including Cruciferae, Apiaceae, Caryophyllaceae and *Rumex* suggests the landscape was relatively open with very few trees present, likely as a result of landscape clearance in order to create more land for agriculture. Burning activity increased at Huarca from *~2400 cal yrs BP (450 BC),* this is concurrent with an increase in Chenopodiaceae/Amaranthaceae and an intensification in agricultural activity during the latter stages of the Chavin cultural tradition within the Callejón de Huaylas (Lau, 2016). *From ~2713 cal yrs BP (~762 BC*), with an increase in agricultural activity, elevated levels of terrigenous input are seen at Huarca. It is likely that at this time the terraces around Huarca were being constructed in order to support agriculture expansion, this increase in human presence would have led to more landscape erosion. The timing of this erosional event (ITRAX Event 3) also coincides with a period of increased precipitation inferred from the palaeoclimate records from ~2500-1500 years ago (Bird *et al*., 2011; Kanner *et al*., 2013). This would have led to increase surface run off and likely contributed to the formation of an open water lake within the Huarca basin from *~2623 cal yrs BP (~673 BC)*. This coupling of increased human activity and surface run off resulted in a period of major erosion and the deposition of a large unit of sand and silt within the basin, with a PC 1 signature paralleling the scale of erosion following glacial retreat (ITRAX Event 4, Fig. 3.18).

3.5.2 Early Intermediate Period – *Recuay*

(2150-1250 cal yrs BP/ 200 BC – AD 700)

A period of increased SASM activity and precipitation continued into the EIP, with the deposition of sand within Huarca basin continuing until *~1213 cal yrs BP (AD 727).* Although conditions were wet at the start of the EIP, $^{\delta}$18O values from Huascaran suggest temperatures were warm (Thompson, 2001), this would have aided Recuay agriculture expansion, an increase in Chenopodiaceae/Amaranthaceae is seen at the beginning of the Recuay cultural period which may support this theory. Agricultural expansion during the EIP is seen elsewhere in Peru at Coropuna in the south, where an increase in *Ambrosia* was recorded alongside an increase in Solanaceae and Chenopodiaceae/Amaranthaceae (Kuentz *et al*., 2012). The beginning of the Recuay phase (from 2150 cal yrs BP/ 200 BC) was obviously a time of major development within the Callejón de Huaylas, with the advent of what is believed to be continuous occupation at nearby sites of Pueblo Viejo de Huandoy and Keushu (Lau, 2002; Herrera *et al*., 2009). The increase in precipitation may have resulted in the movement of people to the headwaters of the rivers, in the case of Pueblo Viejo de Huandoy the Rio Llullán, and Keushu the Rio Ancash (Fig. 3.1), to capitalise on the surplus water. At Awiskmarka, near Pueblo Viejo de Huandoy, a series of sub-terranean tombs were created within the early-mid EIP, dated in accordance with architectural style and associated Recuay ceramics. These are associated with tributaries of the nearby river, showing a clear relationship between water features and ancestor veneration at this time (Herrera *et al*., 2009 and in prep).

Agriculture activity intensified around Huarca basin during the second half of the Recuay phase, although Chenopodiaceae/Amaranthaceae decreases *Ambrosia* and *Artemisia* populations increase alongside the presence of *Sporormiella* from *~1562 cal yrs BP (AD 388).* This potentially suggests there was a change in the agriculture practices, with micro-charcoal increasing from *~1847 cal yrs BP (~AD 106)*, indicating an increased fire use, potentially related to agricultural activities. Solanaceae is present, along with *Ambrosia*, in the latter Recuay phase (*~1252 cal yrs BP/ AD 678*) suggesting the focus may have shifted to alternative crops. A reduction in Chenopodiaceae/Amaranthaceae is also recorded at Marcacocha following 1850 cal yrs BP (AD 100) (Chepstow-Lusty *et al*., 2009, 2011), signalling a change in agricultural practices may have been synchronous across different cultures within the Peruvian Andes.

In the latter stages of the Recuay phase 1450-1250 cal yrs BP (AD 500-700), climatic records from the Peruvian Andes indicate an increase in precipitation (Bird, *et al*., 2011; Apaéstegui *et al*., 2014; Bustamante, *et al*., 2015), with the Palestina cave record showing more negative $^{\delta}$18O values from 1370-1230 cal yrs BP (AD 580-720). The Huascarán $^{\delta}$18O record also expresses more negative values at this time (Thompson, 2001; Thompson *et al*., 2003), this deterioration in climate may have led to the decline in agriculture yields and the eventual demise of the Recuay culture, as previously discussed in Section **3.3.5**. The timing of this pluvial period corresponds with the change in agricultural practices seen at Huarca (*~1252 cal yrs BP/ AD 678)*, which may suggest instead of a decline in agricultural activity the people around Huarca adapted their farming strategies to cope with the wetter and cooler conditions.

3.5.3 Middle Horizon – *Wilkawain*

(1250-1050 cal yrs BP/ AD 700-900)

The Middle Horizon within the Callejón de Huaylas witnessed a period of terrace development, for example those found at Awiskmarka, as well as the construction of irrigation canals and other Water Catchment features (WCF) (Herrera *et al*., 2009). This period of terrace construction was part of large-scale landscape modification (Herrera *et al.*, in prep), which included the construction *of chullpas* at Awiskmarka and elsewhere in Ancash including at Keushu (Herrera, 2005; Herrera *et al*., 2009 and in prep; Gerdau-Radonic and Herrera, 2010). The construction of water catchment features suggests there was a need to control water at this time, likely due to the decrease in precipitation from 1230 cal yrs BP (AD 720) as a result of a weakening of the SASM (Vuille *et al*., 2012; Apáestegui *et al*., 2014). During this interval the bog surface wetness was low at Huarca, allowing the colonisation of the wetland by Plantaginaceae and a corresponding reduction in the abundance of ferns.

There is very limited evidence from Huarca as to the nature of agricultural activity during this time, due to only a short section of the sequence dating to the Middle Horizon between 164-160cm. The reduction in water availability may have led to a reduction in sediment accumulation at this time, a problem encountered elsewhere at Ayapampa (**Chapter 5**, this volume). Low water levels are also recorded at Marcacocha and in Lake Titicaca during the MH (Abbott *et al*., 1997; Chepstow-Lusty *et al*., 2003). It is also not possible to comment on the nature of agriculture during the Middle Horizon Wilkawain phase from the terraces and *bofedales* at Awiskmarka due to lack of dating and no discernible evidence for cultivation. However, this period is known to have fostered the development of state-scale cultures such as the Wari when agricultural activity was undoubtedly high to sustain the increase in human activity. Wari influence in the Callejón de Huaylas seems to be variable, in most instances settlements experienced Wari interaction, as evidenced though the presence of Wari pottery, whilst maintaining local cultural traditions, such as at Honopampa and Chinchawas (Lau, 2012; 2016). One potential evidence for increased human activity during the MH at Huarca is the increase in *Alnus* populations within the Late Wilkawain Phase ~ *1117 cal yrs BP (AD*

833). This may indicate agroforestry practices within the local environment, as is suggested for the later *Alnus* peak during the LH (See **3.5.5**), although it has also been hypothesised this may be due to the more amenable climate during the MCA, where warmer conditions may have led to the treeline rising above Huarca, and its modern altitudinal limit of 3200m a.sl. (Brack Egg, 1990).

3.5.4 Late Intermediate Period - *Aquillpo*

(1050-500 cal yrs BP/ AD 900-1450)

The transition to the LIP revealed a short-lived reduction in Chenopodiaceae/Amaranthaceae and an absence in *Ambrosia* and *Artemisia* in the record suggesting a decrease in agricultural activity around Huarca with the reduction in Wari influence. This is accompanied by a reduction in *Alnus*, however this may have been due to a shift in climate opposed to a decrease in human management. As previously suggested Huarca is likely well placed to identify changes in the Alder treeline. Elsewhere in the Peruvian Andes, *Alnus* population at Marcacocha, remained relatively constant during the LIP despite rapidly growing human populations and increased woodland exploitation, suggesting controlled agroforestry practices may have been employed (Chepstow-Lusty *et al*., 2009). By *~1011 cal yrs BP (AD 939) Ambrosia* and *Artemisa* increased again along with elevated PC 1 values indicating an increase in catchment erosion and renewed human activity around the basin. Maize occurs within the record from Huarca during the LIP suggesting agricultural activity became more focused on maize during this time, this occurs with increased *Ambrosia* levels which were likely planted to stabilise the terraces around Huarca. An increased preference for maize during the LIP is also recorded at Marcacocha, which appears to override the importance of camelid herding with a reduction in *Sporormiella* and Oribatid Mites during the LIP (Chepstow-Lusty *et al*., 2009). At Ayapampa (Branch *et al*., 2007 and **Chapter 5** this volume), a period of terrace expansion and reconstruction of previous MH terraces was recorded during the LIP, this was concurrent with a temporary phase in maize cultivation. The presence of maize was also recorded at Awiskmarka with the remains of a maize cob found within deposits in a LIP style tomb (*A.Herrera pers. comm.).* This shift in agriculture appears to have been accompanied by an increase in fire activity around Huarca with an increase in micro-charcoal influx from *~878 cal yrs BP (AD 1072).* Unlike at Marcacocha, camelids still appear to have been present within the surrounding landscape also, as seen by the occurrence of *Sporormiella* through the LIP.

The first half of the LIP within the Callejón de Huaylas is characterised climatically by arid conditions within the Southern Hemisphere expression of the MCA. A double peak in less negative $^{\delta}$18O values was recorded in the Palestina cave record at 1015 cal yrs BP (AD 935) and 911 cal yrs BP (AD 1039) (Apaéstegui *et al.,* 2014), the first of these peaks corresponds to a peak in Plantaginaceae populations at *~985 cal yrs BP (AD 965),* a later Plantaginaceae peak occurs at *~791 cal yrs BP (AD 1159).* Increases in Plantaginaceae are an indicator for drier bog surface conditions which are concurrent with lower levels of terrigenous input into the basin likely due to less surface run off. This signal indicates Huarca is sensitive to regional climatic changes. This is further evidenced by ITRAX event 2 (Fig 3.18) between *~800-735 cal yrs BP (AD 1135- 1214)*, which consisted of elevated PC 1 values and reduced LnInc/Coh values indicating low organic productivity and increase soil erosion. The timing of this event coincides with increased temperatures and reduced precipitation during the latter stages of the MCA, it is possible that the increased temperatures would have caused a change in the net accumulation rate of ice and increased melting of the nearby Huandoy glacier causing greater meltwater discharge and suspended sediment deposition in the basin. Indeed, this arid period led to the retreat of glaciers elsewhere within the Cordillera Blanca and the neighbouring Cordillera Huayhuash to the south, as evidenced by a reduction in clastic sedimentation at Queshquecocha (CB) and Jahuacocha (CH) (Stansell *et al*., 2013).

During the second half of the LIP an increase in water levels are seen in Huarca basin with the presence of freshwater algae *Pediastrum* from *~585 cal yrs BP (AD 1365).* This is probably as a result of an increase in precipitation at the start of the LIA which is recorded from ~625 cal yrs BP (AD 1325), with more negative $^{\delta}$18O values within the Laguna Pumacocha and Palestina cave records and increased water levels at Lake Titicaca (Bird *et al*., 2011; Apáestegui *et al*., 2014). This corresponded to a substantial increase in SASM activity from 625-100 cal yrs BP (AD 1325-1850) and is synchronous with the cold event in the Northern Hemisphere during the LIA that led to a forcing of ITCZ to its most southerly position (Haug *et al*., 2001; Bird *et al*., 2011; Vuille *et al.,* 2012). It also coincides with glacial advance in the Cordillera Blanca starting around 600 cal yrs BP (AD 1350) as recorded by an increase in clastic sediment within Queshquecocha (Stansell *et al*., 2013). Again, showing Huarca to be sensitive to regional climate variations.

3.5.5 Late Horizon – *Inka-Aquillpo*

(500-418 cal yrs BP/ AD 1450-1532)

Wetter conditions within Huarca Basin continued into the LH, with an increase in PC 1 values between *~583-408 cal yrs BP (AD 1367-1542)* indicating a higher terrigenous input and surface runoff within ITRAX Event 1. This is also supported by the presence of *Myriophyllum* from *~426 cal yrs BP (~AD 1524)* until *~414 cal yrs BP (~AD 1536)* indicating the presence of running water once again. There is also a reduction in Cyperaceae, which may indicate water levels were considerably higher and Cyperaceae was no longer able to grow on the bog surface. This is concurrent with increased precipitation from 430 cal yrs BP (AD 1520) recorded at Quelccaya, with the reduction in $^{\delta}18$O values.

Agriculture activity during the LH at Huarca included the growth of Chenopodiaceae/Amaranthaceae and Solanaceae alongside elevated *Ambrosia* and *Artemisia* levels. There is however an absence of evidence for maize cultivation despite the Incas emphasizing maize cultivation across their empire (Ficucanne, 2007; Hastoff, 2017). The issue of picking up maize within the palaeoenvironmental records has already been discussed, it is possible that the current approach of using pollen and phytoliths is not substantial enough to pick up a maize signal (as will be discussed further in **Chapter 6**), or it could be that agricultural land around Huarca was not used for maize production.

There is also evidence for Incan agroforestry with the increase in *Alnus*, alongside the occurrence of *Escallonia* and *Polylepis*, all known to have been important tree species in pre-Hispanic times. Renewed *Alnus* populations are also seen at Laguna Compuerta and Marcacocha during the Late Horizon (Weng *et al*., 2004; Chepstow-Lusty *et al*., 2009). The expansion of Andean forest at Huarca also coincides with a reduction in burning with a decrease in micro-charcoal which never recovers again. A similar reduction in charcoal is seen at Parker, Gentry, Vargas, and Werth in the southern Amazonian region of Peru with the transition to the Colonial Period, where the sites around the lakes were likely abandoned following conquest (Bush *et al*., 2007b).

3.5.6 Colonial Period

(418-126 cal yrs BP/ AD 1532 – 1824)

Elevated levels of *Alnus* continue into the Colonial Period, likely as previously hypothesised, due to a reduction in human activity following the conquest in combination with an improving climate following the LIA, which would have raised the altitudinal range of these trees, likely to its modern limit of 3200m a.s.l. There is also a reduction in Chenopodiaceae/Amaranthaceae, Solanaceae and *Ambrosia* at this time and a decrease in PC1 values indicating a reduction in landscape disturbance around Huarca. At Marcacocha, site abandonment and population reduction were also seen, with the Oribatid Mites indicating a rapid reduction in camelid livestock immediately following the Spanish conquest (Chepstow-Lusty *et al*., 2007). Lake Pacucha to the west of Marcacocha also recorded a rapid decline in crop and *Alnus* abundance following the conquest, with a reduction in fire frequency reflecting the much less intensive use of the landscape and the associated decrease in populations (Valencia *et al*., 2010). No *Sporormiella* was recorded within the record at Huarca from the

Colonial Period, so no comment can be made on the introduction of Old-World domesticates as was seen at Marcacocha (Chepstow-Lusty *et al*., 2007) and Antaycocha (Chapter 4, this volume) with the introduction of sheep, goats, horses, and cattle opposed to camelids indicated from the Oribatid Mites records. At present day, horses graze on the basin (see Figure 3.23), however *Sporormiella* may not be picked up in the record if the grazing sites are not local to the collection site of the core due to the localised dispersal of *Sporormiella* (Davis and Shafer, 2006).

3.5.7 Present Day

(AD 1824-2018)

The basin at present day is dominated by Cyperaceae and Poaceae grassland growing on top of relatively well decomposed peat containing silt, likely deposited as a result of present-day human activity on the slopes surrounding the basin. The absence of aquatics and ferns in the pollen record reflect the drier bog conditions seen at present day, however, the basin was visited in the middle of the dry season, and it is likely the surface of the bog is wetter during Austral Summer (Nov-March). The basin is currently undergoing some drainage by the local community in Huarca village in order to create more land for village expansion (*A. Herrera pers. comm.).* This has also resulted in the drying out of the basin with further drainage canals constructed by the time the site was revisited in 2019. The canal in Figure 3.23 had been recently excavated and was situated very close to the 2018 coring location. Accelerated rate of warming since 1970 has resulted in a rapid retreat of ice masses throughout the Cordillera Blanca as a result Huarca basin is not getting as much replenishment from the glacier due to net loss of melt water threshold being crossed (Thompson, 2001; Bury *et al*., 2013). It is highly important therefore that records such as the one from Huarca exist, as the bogs and wetlands in the Peruvian Andes are very fragile environments, both to current and future climate change but also human modification, which may result in the eventual loss of these records all together.

Agricultural activity at present day includes the growth of potatoes, quinoa, and maize within the surrounding environment, however there are little indication of these within the pollen record. The terraces closest to the coring site had been abandoned in favour of the sloping agricultural fields further away to the northeast of the basin and so the pollen of these crops may not be picked up within the core. There is however an increase in Liliaceae/Alstroemeriaceae at the top of the record which reflects the recent diversification of farming into *Alstroemeria,* and other flowers for export to markets, as observed in the field (Fig. 3.24).

Figure 3.23: Drainage canal cut into Huarca basin, peat has been removed from the surface in order to create the canal and can be seen deposited on the lefthand side (Photo taken by author in 2019).

Figure 3.24 Alstroemeria growing in fields near Huarca Basin (Photo taken by author in 2018).

Chapter 4 - Antaycocha Wetland (Canta, upper Chillón Valley)

4.1 Introduction

This chapter details the results of the analysis on Antaycocha wetland, Chillón Valley. The first section details the regional archaeology of the Chillón Valley and introduces the site of Antaycocha. For the rationale behind this study and the key research questions that apply see Sections **1.1** and **1.7**. This is followed by a statement on the methodologies employed (Section **4.2**) and full descriptions of the results obtained from Antaycocha wetland (Lithostratigraphy and organic matter, µXRF, pollen, NPPs and micro-charcoal) in Section **4.3**. These results are interpreted in Section **4.3.5**, before being discussed in reference to other published works in Section **4.4** .

4.1.1 Regional Archaeology

The Chillón Valley has been classified into three zones for the purpose of reviewing cultural development: the lower valley (0-600m a.s.l.), middle valley (600-2000m a.s.l.) and the upper valley (2000-3400m a.s.l.) (following Dillehay, 1977). The three regions belong to three very different environmental zones and would have posed a unique set of challenges to pre-Hispanic societies. The lower valley is oasis-like, heavily irrigated, and intensively farmed, and is the greatest production zone for food. The middle valley is also rich in resources, such as the coca plant. The land between 500-1000m a.s.l. (also known as the *Yungas* zone) was especially important in pre-Hispanic times to the Incas, with special labour forces being placed within this part of the valley to cultivate it (Dillehay, 1977). Food resources are less concentrated in the upper valley, both at present day and in pre-Hispanic times, this is due to the higher altitude and rugged topography creating harsher growing conditions for crops (Dillehay, 1977). The cultural chronology for the Chillón Valley in comparison to the Central Andean chronology is presented in Table 4.1.

Lower Valley

On the coast, population development began from 4450 cal yrs BP (2500 BC) with the advent of permanently settled villages, both on the coast and in the lower river valleys, in a move away from hunter-gathering subsistence systems to developing agricultural activity (Cohen, 1978). The first large-scale site within the lower reaches of the Chillón Valley was Chuquitanta (1950-

1800 BC), this was situated near a wide expanse of the Chillón River and may therefore have developed to support early floodplain agricultural activities (Cohen, 1978). Excavations from the site recovered plant remains of; cotton, gourds, achira, lima beans, guavas, lucumas, jicama, and peanuts as well as potential evidence for sweet potato (Cohen, 1978), show casing a wide range of crops were grown even during these early stages of settlement development.

From the beginning of the Initial Period (3750-1095 cal yrs BP/1800-900 BC) through to the Early Intermediate Period (2150-1300 cal yrs BP/ 200 BC-650 AD for the Chillón Valley, there was a gradual expansion of the valley's population implied by the increase in number of occupation sites. This was most likely under a politically independent system with villages organised at a local level participating in inter-local trade amongst communities (Jennings and Craig, 2001; Sandweiss and Quilter, 2012). During the later phases of the EIP and through to the beginning of the MH (1750-1300 cal yrs BP/ AD 200-650) the Lima culture dominated the Central Peruvian coastal valleys, the earlier Lima sites appear to be situated in the Chancay, Ancón and Chillón Valley, based on earlier Lima style pottery remains found within sites in these valleys. Whilst later sites show a movement towards the Rímac and Lurín Valleys, with very little late Lima material culture found within the Chillón Valley (Sandweiss and Quilter, 2012; Mauricio, 2014). Some authors have accredited the population and agricultural expansion witnessed with the development of the Lima culture to the pluvial period within the climate records at the end of the EIP and beginning of MH, with a very strong El Niño year recorded in AD 600 (1350 cal yrs BP) (Sandweiss and Quilter, 2012; Mauricio, 2014; Palacios *et al*., 2014). The position of inhabited sites within the Chillón valley within the EIP suggests that the valley's irrigation system was well established during this time, with a likely expansion in the irrigation systems in the lower-middle valley during the Lima Period in response to increased precipitation and more water availability in the lower valley (Cohen, 1978; Sandweiss and Quilter, 2012; Palacios *et al*., 2014; Mauricio, 2018; Flores, 2019). One other benefit of the increased rains, and El Niño events in the mid-late Lima Period, is the deposition of silty material from the rivers to create progressively more fertile agricultural soils on the alluvial plains, transforming the coastal reaches of the valleys such as the Chillón Valley into level and productive spaces for crop cultivation (Sandweiss and Quilter, 2012).

For the following Middle Horizon, there are next to no traces of Wari sites on the central coast of Peru, except for Socos in the Chillón Valley with its poorly understood orthogonal buildings which potential place it within the MH (Isla and Guerrero, 1987; Jennings and Craig, 2001; Covey, 2008). The decline in population within costal valleys of Central Peru at the start of the MH may be linked to a series of droughts, followed by intense rain due to increased El Niño activity on the coast; making living conditions on the coast very challenging (Flores, 2019). The lower valley appears to be seemingly disconnected from the large state-scale empires both in the MH and within in the LH, with most sites dating to LH revealing little to no Inca archaeology, with limited evidence for Inca influence on ceramics and architectural forms (Dillehay, 1977). That is not to say there is an absence of any material culture at all, just more of a local influence. At Tambo Inca, on the north side of the lower valley, there is evidence for reconstruction of the site during the LH. Its position on top of a natural hill crop would have lent itself to the oversight of the lower valley population and would have served as a way station for passing military personal or 'state' representatives (Dillehay, 1977). The site of Collique has a similar vantage point allowing control of vast areas of the lower Chillón Valley, although the development of this site likely originated in the LIP and is thought to be contemporary with Canta in the upper valley (see upper valley section below). The Collique ethnic group was later conquered by the Challac ethnic group, on behalf of the Inca (Dillehay, 1977; Kalicki, 2014; Flores, 2019).

Table 4.1: Archaeological framework for the Peruvian Andes and the Chillón Valley over the last 4000 years.

Central Andes General Chronology	**Chillón Valley**
Colonial Period AD 1532-1826	
Late Horizon (Inca) AD 1438-1532	Late Horizon (Inca) AD 1438-1532
Late Intermediate AD 1100 - 1438	Late Intermediate Period AD 1100-1438
Middle Horizon (Wari) c.AD 500 - 1100	Middle Horizon (Wari) AD 650-1100
Early Intermediate 200 BC - AD 500	Lima Period AD 0-650
Early Horizon 800 - 200 BC	Early Horizon (Chavin Era) 800-200 BC
Initial Period 2000-800 BC	Initial Period 2000-800 BC

Middle Valley

Occupation in the middle valley dates from the Early Intermediate Period (2150-1300 cal yrs BP/ 200 BC-650 AD for the Chillón Valley) to the Colonial Period (418-129 cal yrs BP/AD 1532-1821) and up into the present day, with sites such as Huancayo Alto seemingly being continually occupied during that time. Situated in the middle valley approximately 50km inland, Huancayo Alto contains both elite residential zones and lower-class domestic units, a structure that likely built up over its many years of occupation (Dillehay, 1977). Drying terraces and vast storage units are also associated with the site, extending up the hill ~450m, these were guarded by several controlling walls that would have acted as gateways to the terraces and storage units. It is possible, therefore, that food was produced in excess at the site and the distribution of it was controlled with access to these structures being limited to select people (Dillehay, 1977).

The middle valley area has acted as a confluence for coastal societies and those from the Highlands since at least the EIP; with the emergence of the Lima state and pressure from coastal settlers reaching upstream into the valleys. During the later periods (LIP and LH) the opposite is true, with the highland population taking advantage of the development of the Inca expansion within the Chillón Valley to press down the valley (Flores, 2019). During the LIP, the region between the highlands and the coast had considerable cultural and economic diversity and acted as important meeting points for costal and highland culture, playing a key role in interregional exchanges of resources between the two zones of production, and leading to the development of transhumance (Covey, 2008; Kalicki *et al*., 2014).

Upper Valley

In the upper Chillón Valley (above 2000m a.s.l.), early occupation was sparse and ephemeral, and it was not until the Late Intermediate Period that populations began to expand. As with the rest of the Chillón Valley, there is very little evidence for Middle Horizon, Wari influence in the upper reaches of the valley. The canyon like, deeply incised nature of the upper valley does not provide large horizontal areas for agricultural purposes and the soils in the upper region of the valley are often poor due to the rocky landscape, this may have been a contributing factor in the later development of the valley. The steep slopes are adorned with many terraces (*andenes*) created in order to provide agricultural land, something that would have been easier to organise under the supervision of a larger scale polity such as the Inca Empire (Silva, 1996).

During the LIP, people living in the Chillón Valley, as elsewhere in Peru, moved to settlements at high elevation in defensible positions, such as ridgetops (Covey 2008; Rios 2015). Rather than a system of hierarchy and social stratification, as followed in the proceeding LH, multiple political units controlled small territories and sources of irrigation water (Farfán, 1995), with evidence for sites expanding and developing over time with no formal planning (Covey, 2008).

During the LH, in the upper Chillón Valley there is evidence for heavy Inca influence at sites such as Puramarca, Huancuna, Cantamarca, Huamantanga, Huayuncancha and Colli, as well as two larger sites of Caballo Blanco and Lucana (Dillehay, 1977). The significant increase in number of LH sites as you go up the valley, may be related to the desire to have direct control over lowland water sources, as sites at elevation would have been closer to water running off the mountaintops. For example, Caballo Blanco is located at the confluence of two large canals that descend from the highlands all the way down the valley to the lowlands (Dillehay, 1977). This would have provided the Incas with not only control of water but also the amount of crops that could be grown in the lower desert-like areas. There are also several large corrals associated with many of these sites containing coprolitic evidence for camelids, which were potentially kept as part of Inca state herds (Dillehay, 1977).

The most important site in the upper valley, and arguable the valley as a whole is Cantamarca, situated above the modern town of Canta on a high outcrop of rock above Antaycocha wetland (Fig. 4.1). At Cantamarca, occupation is recorded from the Lima Period and the early phases of the Chancay culture (1950-1300 cal yrs BP/ AD 0-650), through to the Colonial Period (418-129 cal yrs BP/AD 1532-1821), with the most intensive period of occupation during the LH (Farfán, 1988; 1995; 2011). Data is scare to suggest continual occupation at the site, however, with the site truly emerging as a settlement in the LIP. At Cantamarca, Inca presence is evidenced through the architectural styles and ceramic remains, as well as the presence of round Inca store houses likely used for storing textiles, weapons, and food (Ricci, 2015; Farfán, 2011). The Inca's occupying Cantamarca would have been able to engage in a diverse range of economic activities through the management of near-by rivers, streams, and lagoons, such as Antaycocha Lagoon (see Fig 4.2) (Farfán, 2000, 2011). Canals and catchment features were also found within Cantamarca archaeological site which would have allowed for the collection and distribution of water around the urban zone. The site has been divided into two sectors, Cantamarca A and Cantamarca B, Cantamarca A refers to the settlement that occupies the west side and summit slopes of Cantamarca hill, Cantamarca B is located towards the east side of the site adjacent to the northern tributary of the Rantao stream. This stream flows into the Antaycocha and Torococha wetlands below the archaeological site (Farfán, 2000, 2011).

Figure 4.1: Cantamarca archaeological site on top of the hill and Antaycocha basin in the front lefthand side of the image. Photo taken by author (2018)

4.1.2 Study Area and Site Description

Antaycocha basin is situated near the village of Canta at 3601m a.s.l. proximal to the upper limit of the *Quechua* environmental zone (Fig 4.2). The site consists of an infilled basin (Fig. 4.3), which is approximately 125m long and 145m wide and has been dammed at one end, the dam wall is thought to be an Inca or Late Intermediate Period construction (*C.Farfan pers comm.*). Sediment has built up behind the wall and formed an ombrotrophic bog, the surface of which is very wet. Unlike normal ombrotrophic bogs, the mire is not only fed by rainfall, as a stream, of relatively high velocity, enters the site at the back. Water flows out of the mire over the top of the wall and feeds a smaller wetland area, known as Torococha. This basin is almost complete dry in the dry season (March-September). Vegetation onsite is a mix of shorter grasses and mosses, and large reeds, which are present towards the centre of the mire (Fig 4.4). The slopes surrounding the wetland area would have once been cultivated and used for camelid pasture; relic terraces are visible around the site at presence day. Some of the terraces are heavily eroded and no cultivation is currently practiced on them.

The sequence recovered from the mire contains large amounts of macrofossils, including large reeds near the base of the sequence, suggesting it may have once been a reed swamp. The height of the dam wall reaches 3m at its highest point, however the sediment sequence was approximately 6m deep (5.97m), suggesting a lake or wetland was present in the basin before the dam was constructed. As well as the presence of terraces around the site, corrals, Inca store houses, and an archaeological site of Cantamarca, are present on the hill above the basin. The archaeological site consists of multi-period occupation structures ranging from the Early Intermediate Period to the Late Horizon (see Section **4.1.1**).

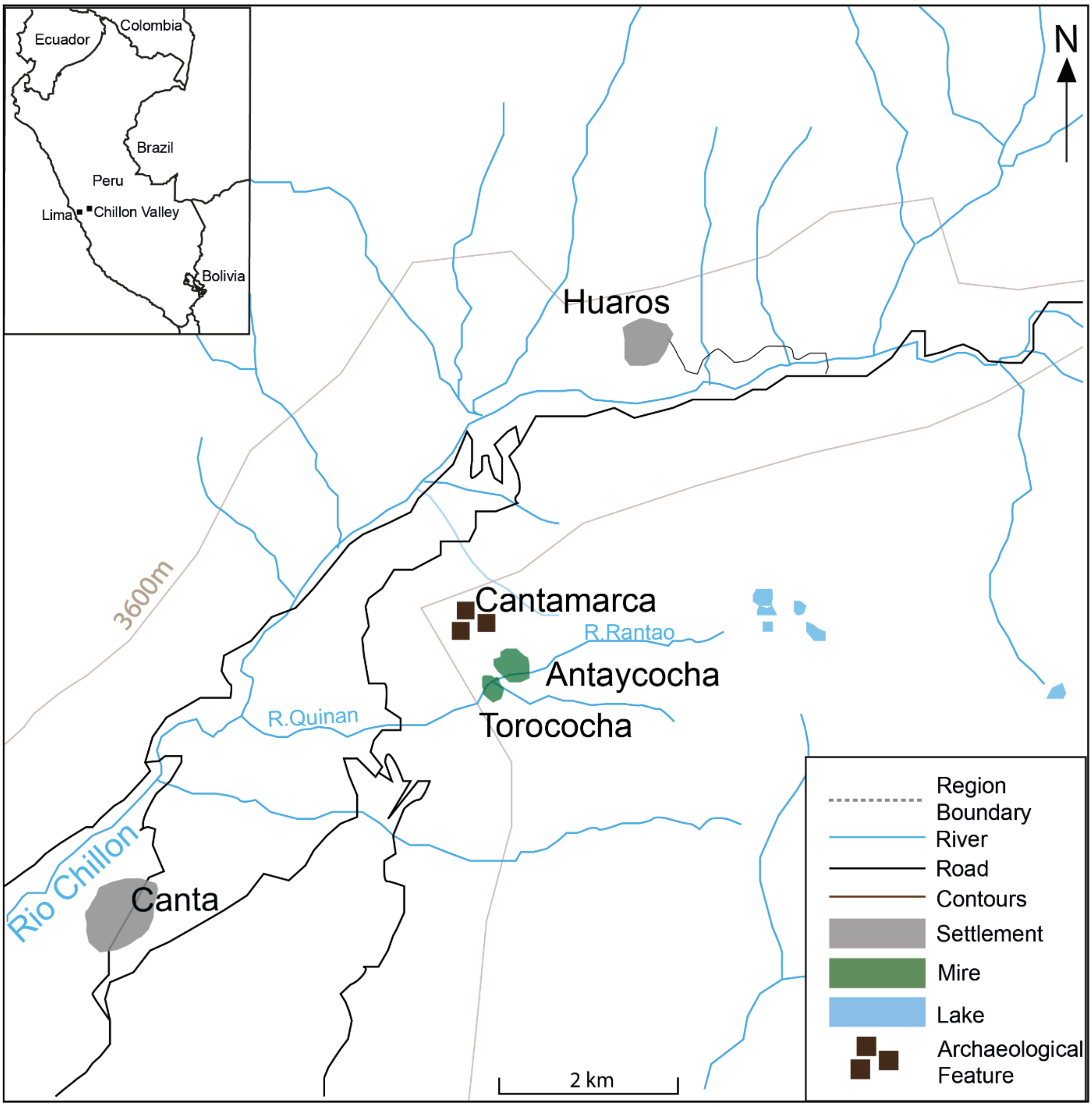


Figure 4.2: Location of Antaycocha basin and surrounding landscape features.

Figure 4.3: Antaycocha basin taken from the southern side of the basin. Photos taken by author (2019)

Figure 4.4: Antaycocha basin from the NW side of the basin. Photos taken by author (2019)

4.2 Methodology

The analysis for Antaycocha followed those outlined in **Chapter 2** for pollen, NPP, and micro-charcoal analysis and micro-XRF scanning. The core from Antaycocha contained very loose unconsolidated sediment at the top of the core with some sections of material missing between 0-90cm (See Table 4.4). Consequently, the ITRAX core scanner could not scan the top 90cm of the sequence with scanning starting on the 80-130cm core section. Additionally, the pollen record starts at 40cm due to a lack of suitable material for pollen extraction within the top core section. To aid with the calculation of pollen concentration, *Lycopodium* was added to all samples from Antaycocha. Microcharcoal counts were conducted alongside pollen and NPP counting and are relative to the 300 Total Land Pollen counts.

4.3 Antaycocha Basin

Approximately six meters (5.97m) of sediment was recovered from Antaycocha basin (Fig. 4.5), comprising primarily of organic lake sediment rich in herbaceous detrital material including large reeds near the base of the sequence, suggesting a reed swamp may have once been present at Antaycocha. Some lenses of peat are also present within the sequence (Fig. 4.6), indicating periods of slower sediment accumulation and infilling of the lagoon in the past. The following sections detail the palaeoenvironmental analysis carried out on the Antaycocha sequence. No previous investigations of this sort have been carried out on the basin, radiocarbon dates were obtained in order to date the sequence, the age of which was previously unknown, the results are presented in Section **4.3.4**. Upon first visit to the Antaycocha wetland, the cores were labelled Cantamarca, after the archaeological site, preliminary work followed this naming, including the submission of radiocarbon dates, hence the lab codes CAN-X, since then, in consultation with Dr Carlos Farfán, the true name of the basin, Antaycocha has been discovered and adopted.

4.3.1 Results of the Laboratory Sedimentology and Organic Matter Content Analysis

The ~6m sequence from Antaycocha consisted of 49 units (Fig. 4.5 and Table 4.2) primarily consisting of lake sediments and detrital plant material. At the base of the sequence (Unit 1 and 2), organic matter content is very low reaching a minimum of 6% at 552cm, this corresponds to lake sediments rich in silts and clays without the presence of any plant material. The basal 50cm corresponds to ~3000-500 years BP with a large proportion of this dating to the Early Intermediate Period and Early Horizon (554-586cm *~1915-1426 cal yrs BP; ~AD 35-524* (EIP) and 587-590cm *~2695-2138 cal yrs BP*; *~188-745 BC* (EH)).

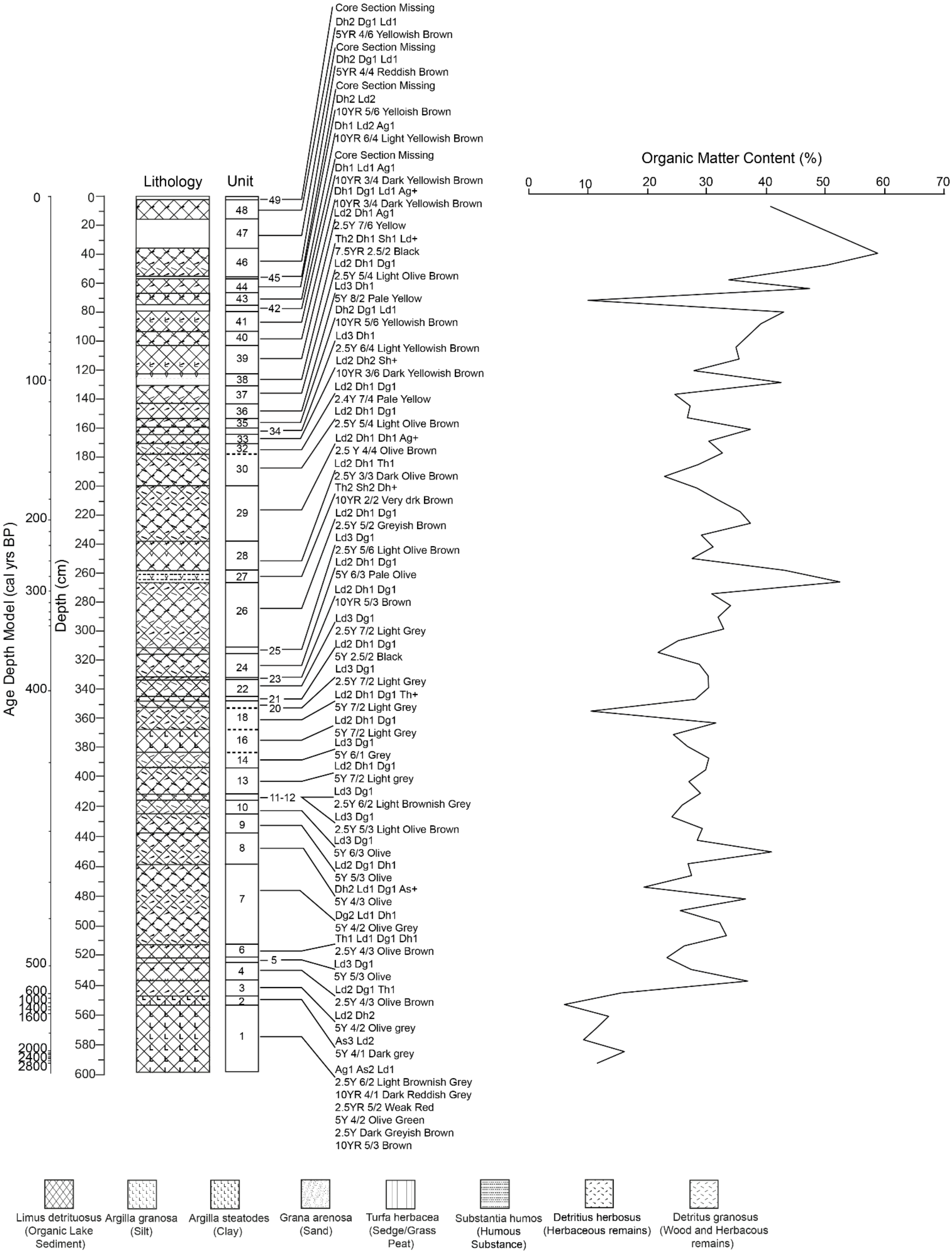


Figure 4.5: Lithostratigraphic diagram and organic matter curve for Antaycocha

At 547cm, *~516 cal yrs BP (AD 1435)*, the sequence transitions to a lake sediment rich in herbaceous detrital material (Unit 3) with organic matter content increasing to 37%. Following this, from 537-525cm, *~507-499 cal yrs BP (AD 1443-1451)* (Unit 4) lenses of herbaceous peat are deposited within a lake sediment unit, suggesting the water table was lower at this time, with potentially areas of ponded, slower moving water, across the wetland. Lake sediments, with an absence of peat, were deposited between 525-522cm, *~499-497 cal yrs BP (AD 1451-1453)* as the water table increased again, some herbaceous and woody remains are also present within this unit (Unit 5). Peat formation, still within the presence of lake sediments, resumes at *~497 cal yrs BP (AD 1453)* until *~492 cal yrs BP (AD 1458)* (Unit 6), organic matter decreases slightly at this time to 23%, despite the presence of peat. In Unit 7 *(~492-453 cal yrs BP/ AD 1458-1497*), the woody and herbaceous detrital matter increases, corresponding to an increase in organic matter content to a maximum of 37% at 480cm before dropping to 19% towards the top of the unit at 472cm, indicating and increase in plants growing within the lake setting. The amount of detrital plant material remains high in Unit 8, although primarily composing of herbaceous detritus, with organic matter increasing to a maximum of 41% at 448cm (*~446 cal yrs BP/AD 1504*).

From *~442-418 cal yrs BP (AD 1508-1532)* (Units 9-14)*,* the sequence consists primarily of lake sediments, with some herbaceous and ligneous detrital material, with an average organic matter content of 27%, the reduction in detritus at this time may indicate a high energy environment within the lake basin. In Unit 15 (383-364cm), silt was deposited with an absence in detrital plant material, indicating catchment erosion into the basin at the time (*~418-416 cal yrs BP/ AD 1532-1534*), organic matter content remains elevated at 30%, similar to those values seen in Units 9-14. At *~416 cal yrs BP (AD1534)* lake sediment with some herbaceous and ligneous detritus is deposited again, until *~406 cal yrs BP (AD 1544)* (Units 16-18). Organic matter increases through these units from 27% at 376cm to 32% at 360cm. Following this organic matter content reduces to 10% in a small unit (Unit 19), dated to *~406 cal yrs BP (AD 1544)*, containing silts alongside lake sediment. This short live unit punctuates a period of lake sediment deposition, which continues into Units 20-26 *(~406-290 cal yrs BP/ AD 1544-1560)*. Organic matter content fluctuates through this period with a minimum of 22% (312cm) and a maximum of 34% (280cm).

Herbaceous peat is formed from *~290-238 cal yrs BP (AD 1560-1712)* (Units 27 and 28), indicating a lower energy environment within the basin, with a decrease in water depth. Organic matter increases in Unit 27 to 53%, the second highest peak in organic matter within the record, by the top of Unit 28 organic matter decreases again to ~30%. This is followed by a period of lake sediment deposition, with lower organic matter content (23% at 192cm), between *~282-152 cal yrs BP (AD 1712-1798)* (Units 29-30), before peat, alongside lake sediments, formed again at *~152 cal yrs BP (AD 1798)* (Unit 31). The sequence then transitions back to predominately lake sediment (Units 32-34), with some herbaceous and ligneous detritus at *~151 cal yrs BP (AD 1799),* this continues to be deposited until *~138 cal yrs BP (AD 1812).* Organic matter content is ~35% at this time. Following this, the amount of detritus in the core increases with greater grass, sedge, and woody plant macro-remains visible in the core (Unit 35), until *~132 cal yrs BP (AD 1818).* The amount of detrital material decreases again from *~132-105 cal yrs BP (AD 1818-1845)*, with a greater lake sediment fraction (Units 36-37), corresponding with a reduction in organic matter content to ~26%.

From *~105-93 cal yrs BP (AD 1845-1858)*, another period of peat formation occurs (Unit 38), this time without any real presence of lake sediments, suggesting a much shallower water depth and a relatively stable environment at this time. There is a resulting increase in organic matter within this unit to a maximum of 43%. Units 39-42 (*~AD 1858-1981*) consist of very mixed sediment containing silts, lake sediments and some herbaceous and ligneous detritus, suggesting some erosion in the catchment and an in-washing of mineral matter, with a sharp reduction in organic matter at 72cm to 10%. There is a gap in the record at 75-79.5 cm where no sediment was recovered (Unit 42). The final six units *(~AD 1984-2000)* consist of alternating layers of detritus rich lake sediments and missing core sections (See Units 45, 47 and 49). The detrital rich units contain higher organic matter with the maximum value reached for the whole core occurring at 40cm (59%).

Table 4.2: Lithostratigraphic descriptions of the core from Antaycocha.

Depth(cm)	**Unit**	**Troels- Smith**	**Colour**
0-2.5	49	Core section missing	
2.5-16	48	Dh2 Dg1 Ld1	5YR 4/6 Yellowish Brown
16-36	47	Core section missing	
36-55	46	Dh2 Dg1 Ld1	5YR 4/4 Reddish Brown
55-56.5	45	Core section missing	
56.5-67	44	Dh2 Ld2	10YR 5/6 Yellowish Brown
67-75	43	Dh1 Ld2 Ag1	10YR 6/4 Light Yellowish Brown
75-79.5	42	Core section missing	
79.5-93	41	Dh2 Ld1 Ag1	10YR 3/4 Dark Yellowish Brown
93-103	40	Dh2 Dg1 Ld1 Ag+	10YR 3/4 Dark Yellowish Brown
103-122	39	Ld2 Dh1 Ag1	2.5Y 7/6 Yellow
122-130	38	Th2 Dh1 Sh1 Ld+	7.5YR 2.5/2 Black
130-142	37	Ld2 Dh1 Dg1	2.5Y 5/4 Light Olive Brown
142-153	36	Ld3 Dh1	5Y 8/2 Pale Yellow
153-159	35	Dh2 Dg1 Ld1	10YR 5/6 Yellowish Brown
159-164	34	Ld3 Dh1	2.5Y 6/4 Light Yellowish Brown
164-170	33	Ld2 Dh2 Sh+	10YR 3/6 Dark Yellowish Brown
170-176	32	Ld2 Dh1 Dg1	2.5Y 7/4 Pale Yellow
176-178	31	Th2 Ld1 Dh1	10YR 3/4 Dark Yellowish Brown

178-200	30	Ld2 Dh1 Dg1	2.5Y 5/4 Light Olive Brown
200-238	29	Ld2 Dh1 Dg1 Ag+	2.5Y 4/4 Olive Brown
238-258	28	Ld2 Dh1 Th1	2.5Y 3/3 Dark Olive Brown
258-266	27	Th2 Sh2 Dh+	10YR 2/2 V. dark Brown
266-311	26	Ld2 Dh1 Dg1	2.5Y 5/2 Greyish Brown
311- 315	25	Ld3 Dg1	2.5 Y 5/6 Light Olive Brown
315-331	24	Ld2 Dh1 Dg1	5Y 6/3 Pale Olive
331-333	23	Ld2 Dh1 Dg1	10YR 5/3 Brown
333-345	22	Ld3 Dg1	2.5 Y 7/2 Light Grey
345-348	21	Ld2 Dh1 Dg1	5Y 2.5/2 Black
348-352	20	Ld3 Dg1	2.5Y 7/2 Light Grey
352-353.5	19	Ld3 As1 Dg1	2.5Y 4/4 Olive Brown
353.5-362	18	Ld2 Dh1 Dg1 Th+	5Y 7/2 Light Grey
363-364.5	17	Ld3 Dh1	5Y 5/3 Olive
364.5-378	16	Ld2 Dh1 Dg1	5Y 7/2 Light Grey
378-384	15	As3 Ld1	2.5Y 5/4 Light Olive Brown
384-394.5	14	Ld3 Dg1	5Y 6/1 Grey
394.5-412	13	Ld2 Dh1 Dg1	5Y 7/2 Light Grey
412-413	12	Ld3 Dg1	2.5Y 6/2 Light Brownish Grey
413-416	11	Ld3 Dg1	2.5Y 5/3 Light Olive Brown
416-425	10	Ld3 Dg1	5Y 6/3 Olive
425-438	9	Ld2 Dg1 Dh1	5Y 5/3 Olive
438-459	8	Dh2 Ld1 Dg1 As+	5Y 4/3 Olive
459-513	7	Dg2 Ld1 Dh1	5Y 4/2 Olive Grey
513-522	6	Th1 Ld1 Dg1 Dh1	2.5Y 4/3 Olive Brown (Lake Sediment) 10Yr 2/2 V. dark Brown (Peat)
522-525	5	Ld3 Dg1	5Y 5/3 Olive
525-537	4	Ld2 Dg1 Th1	2.5Y 4/3 Olive Brown (Lake Sediment) 10Yr 2/2 V.dark Brown (Peat)
537-547	3	Ld2 Dh2	5Y 4/2 Olive Grey
547-553	2	As3 Ld2	5Y 4/1 Dark Grey
553-597	1	Ag1 As2 Ld1	Bands of various colours: 2.5Y 6/2 Light Brownish Grey 10YR 4/1 Dark Reddish Grey 2.5YR 5/2 Weak Red 5Y 4/2 Olive Green 2.5Y Dark Greyish Brown 10YR 5/3 Brown

4.3.2 Results of the micro-XRF Geochemical Analysis

The Antaycocha core was scanned at 500µm for the full 5.97m sequence, using the same methodology employed on the Huarca core (see **Chapter 2**, Section **2.2** for methods). Log elemental ratios were calculated in Microsoft Excel, using counts per second (cps) to normalise the data where appropriate to analyse trends in single elemental signals. Resulting values are presented in Lncps, where each element has a raw count per second value which has then been converted into a log ratio. The µXRF diagram was zoned based on cultural chronology, changes in the lithostratigraphy and the major changes within the elemental ratios themselves, this resulted in five zones (Fig 4.6 and 4.7).

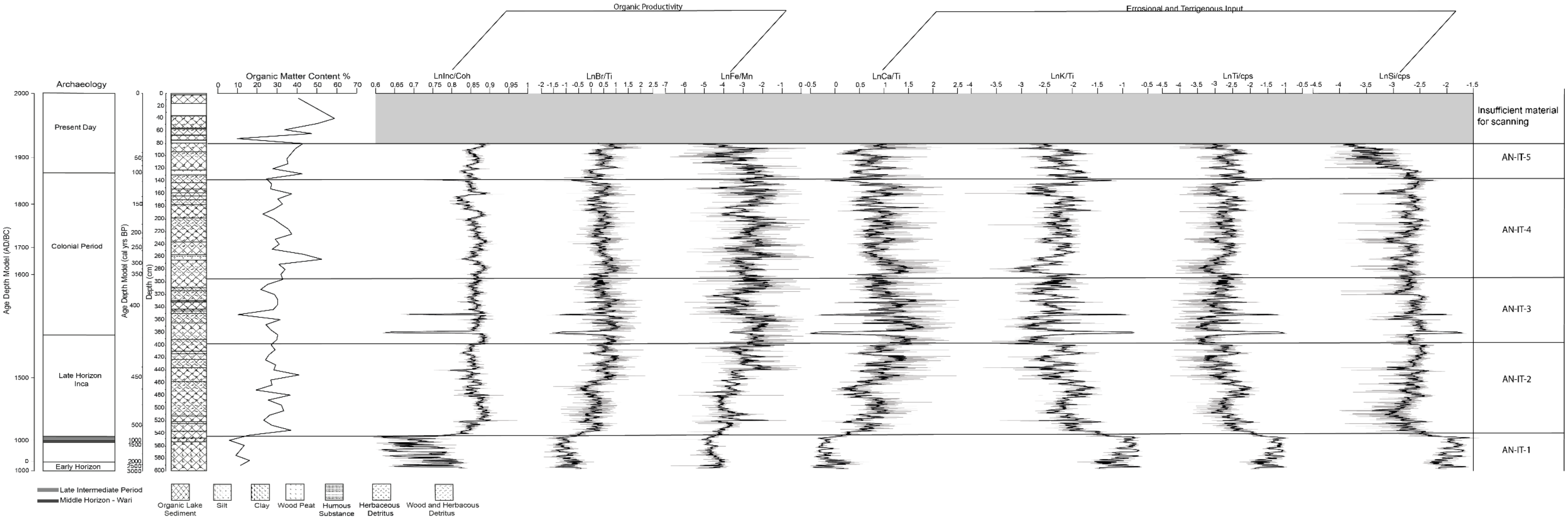


Figure 4.6: Micro-XRF geochemical data showing organic productivity and erosional and terrigenous input signals from Antaycocha, elemental ratios are presented as log values.

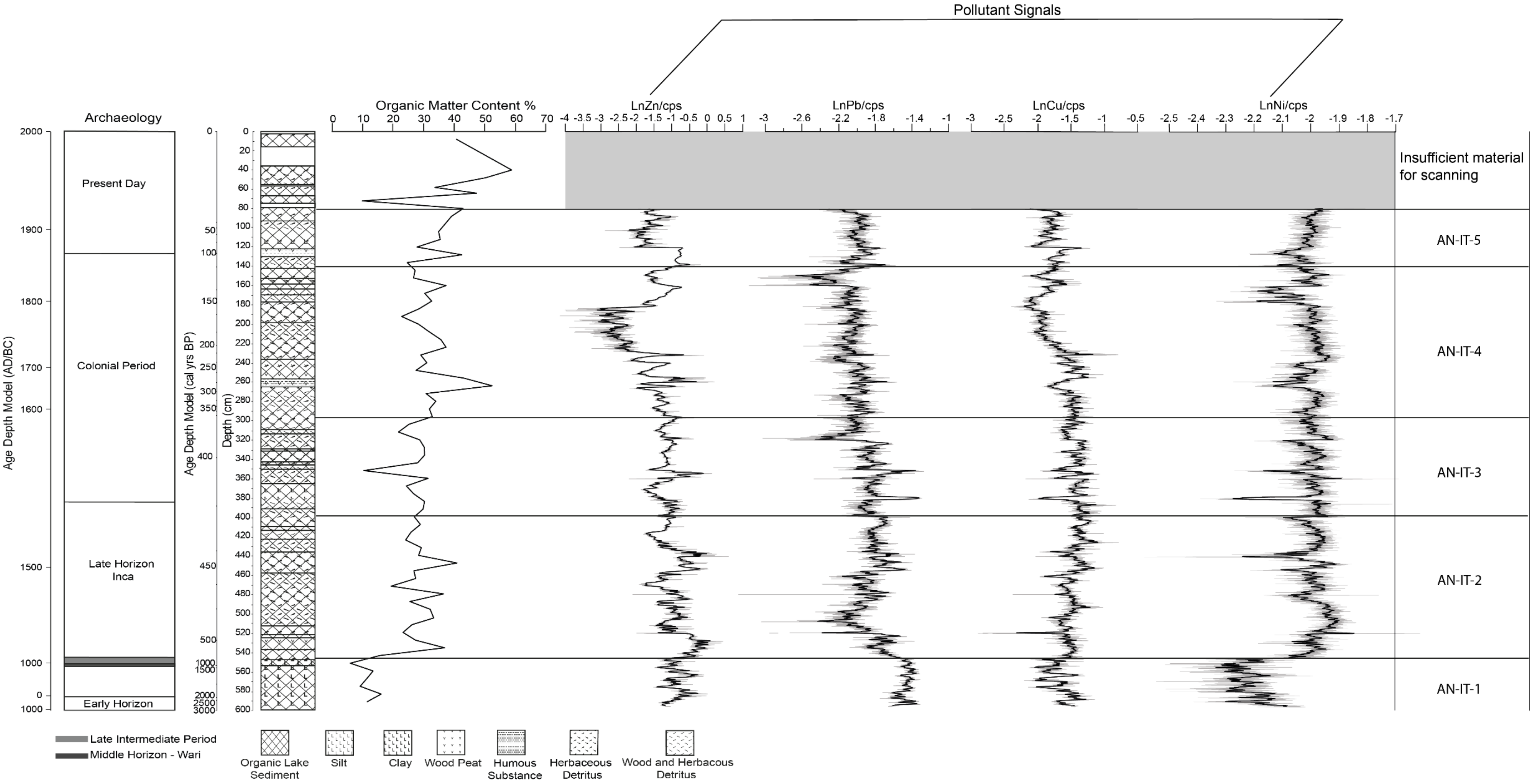


Figure 4.7: Micro-XRF geochemical data showing pollutant signals from Antaycocha, elemental ratios presented as log values.

AN-IT-5 (140-80cm) (*~2955-516 cal yrs BP/ 1005 BC- AD 1454*)

This zone is characterised by low values of organic productivity indicators, corresponding with low organic matter content values, LnInc/Coh is particularly low compared to the rest of the record (0.57), LnBr/Ti and LnFe/Mn are also more negative (minimum -1.9 and -6.7 respectively). LnCa/Ti follows this signal with lower values, towards negative, within this zone (minimum -0.5). LnNi/cps is also markedly more negatively than in the rest of the record (minimum -2.5). The other erosional and terrigenous input indicators present elevated signals within zone one. LnK/Ti (-0.6), LnTi/cps (-0.9) and LnSi/cps (-1.4) are all more positive. LnPb/cps values are elevated (maximum -1.3), whilst LnCu/cps (minimum -2.2, maximum -1.1) and LnZn/cps (-1.5 minimum, maximum 0.4) fluctuate.

AN-IT-4 AN-IT- (296-140cm) (*~516-425 cal yrs BP/ AD 1454-1525*)

Organic productivity indicators increase markedly in this zone, whilst erosional and terrigenous signatures decrease. LnInc/Coh reaches some of its highest values for the whole record within this zone (maximum 0.9). LnFe/Mn increases overall throughout this zone (minimum -6.2, maximum -0.8), as does LnCa/Ti (minimum -0.2, maximum 2). LnK/Ti and LnTi/cps decrease through the zone to a minimum of -3.1 and -4.2 respectively. LnSi/cps initially decreases to a minimum of -3.9 before increasing again to a maximum of -2. LnZn/cps fluctuates throughout this zone, however there is an overall decreasing trend towards the top of the zone (maximum 0.4, minimum -2.1). LnPb/cps initially decreases to -3 before increasing again (maximum -1.3). LnNi/cps values are higher than in the previous zone but fluctuate throughout (minimum -2.2 and maximum -1.6).

AN-IT-3 (400-296cm) (*~425-386 cal yrs BP/ AD 1525-1564*)

This zone has two main deflections from the overall trend in data within most of the records, within the organic productivity indicators this presents itself as a decrease to more negative values, and within the erosional and terrigenous input ratios an increase to more positive values. LnIn/Coh decreases to a minimum of 0.6, LnBr/Ti minimum of -1.7 and LnCa/Ti a minimum of -0.5. This deflection is not picked up within the LnFe/Mn, which initially increase to a maximum of 0.2, before decreasing to a minimum of -6, or the LnZn/cps curve which fluctuates (minimum -2.1, maximum 0.1). LnPb/cps follows the increased peaks to more positive numbers seen in the erosional and terrigenous input curves (maximum -1.2), whilst LnCu/cps and LnNi/cps follow the trend seen in the organic productivity indictors to more negative number (minimum -2.1 and -2.4 respectively).

AN-IT-2 (548-400cm) (~*386-119 cal yrs BP/ AD 1564-1831*)

This zone is characterised by relatively stable organic productivity and erosional and terrigenous input indicators, and a decrease in LnZn/cps values to the most negative values within the whole record (minimum -4). More fluctuations are seen within the LnFe/Mn (minimum -5.9, maximum 0.1) and Ln Ca/Ti (minimum 0, maximum 2.4) curves. Values of LnK/Ti are more negative towards the base and top of this zone (maximum -4.1) but increase in the middle of the zone (maximum -1.4). LnPb/cps decreases, with a negative peak in the record near the top of the zone (minimum -4). LnCu/cps also decreases overall throughout the zone (maximum -0.7, minimum -2.4). LnNi/cps decreases to a minimum of -2.3, before increasing again (maximum -1.8) and decreases for a second time to a minimum of -2.3.

AN-IT-1 (597-548cm) (~*119-0 cal yrs BP/ AD 1831-1978*)

LnSi/cps, LnK/Ti and LnFe/Mn decrease in this zone (minimum of -4.3, -3.8 and -6.7 respectively). LnK/Ti (minimum -3.1, maximum -1.5) LnTi/cps (minimum -4.1, maximum -1.9) both fluctuated. LnZn/cps values are initially high (maximum -0.2), before decreasing again (minimum -2.9). A similar pattern is seen within the LnCu/cps curve (maximum -1.2, minimum -2.1). LnPb/cps initially decreases before increasing (minimum -2.5, maximum -1.7), values fall off again at the very top of the zone.

4.3.1.1 Statistical Analysis of mico-XRF data of Antaycocha

Statistical analysis was carried out on the µXRF dataset from Antaycocha using Principal Components Analysis (PCA). As with the Huarca data set, a KMO (Kaiser-Meyer-Olkin) and Bartlett's test was first run on the data using SPSS (version 28.0.1.0) to check it was suitable for PCA. The KMO had a satisfactory score of 0.905, (above 0.6 is considered suitable for PCA), and the significance of the Bartlett's test was 0.00, meaning the null hypothesis could be rejected and no identity matrix exists (anything below 0.05 is acceptable). PCA was then carried out using Minitab (21.1.0); first the PCA was run with no limits on the number of factors (or components) extracted, this revealed components 1 (55%), 2 (14.4%), 3 (8%), and 4 (5%) to explain 82.3% of the variability in the data. A further PCA was then run to extract these four components. As with Huarca, only elements with cps of 300 or higher were selected for the PCA, in this case the elements included were: Si, K, Ca, Ti, Mn, Fe, Ni, Zn, Br, Rb, Sr, Ba, W, Pb, and Mo inc and Mo coh (Fig. 4.8).

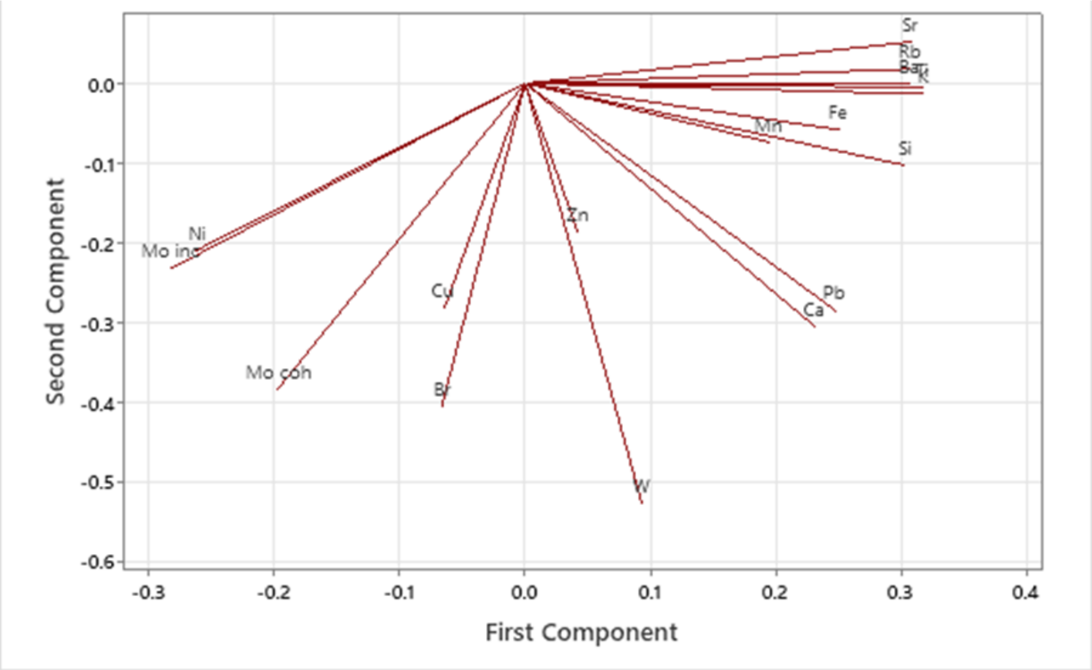


Figure 4.8: Loading plot of elements used within PCA for Antaycocha (created using Minitab 21.)

The results of the PCA revealed principal component 1 (PC1) to mainly be influenced by terrigenous elements found in the earth's crust, for example Si, Sr, Rb, K, Ca, Mn, Fe, and Si. Principal component 2 (PC2) was comprised of elements related to organic productivity, such as Mo inc, Mo coh and Br, Ni also plotted with this group (Fig. 4.9). The third component (PC3) contained elements pertaining to pollution signals including Cu, Zn and Pb, this resulted in the plotting of Figure 4.10.

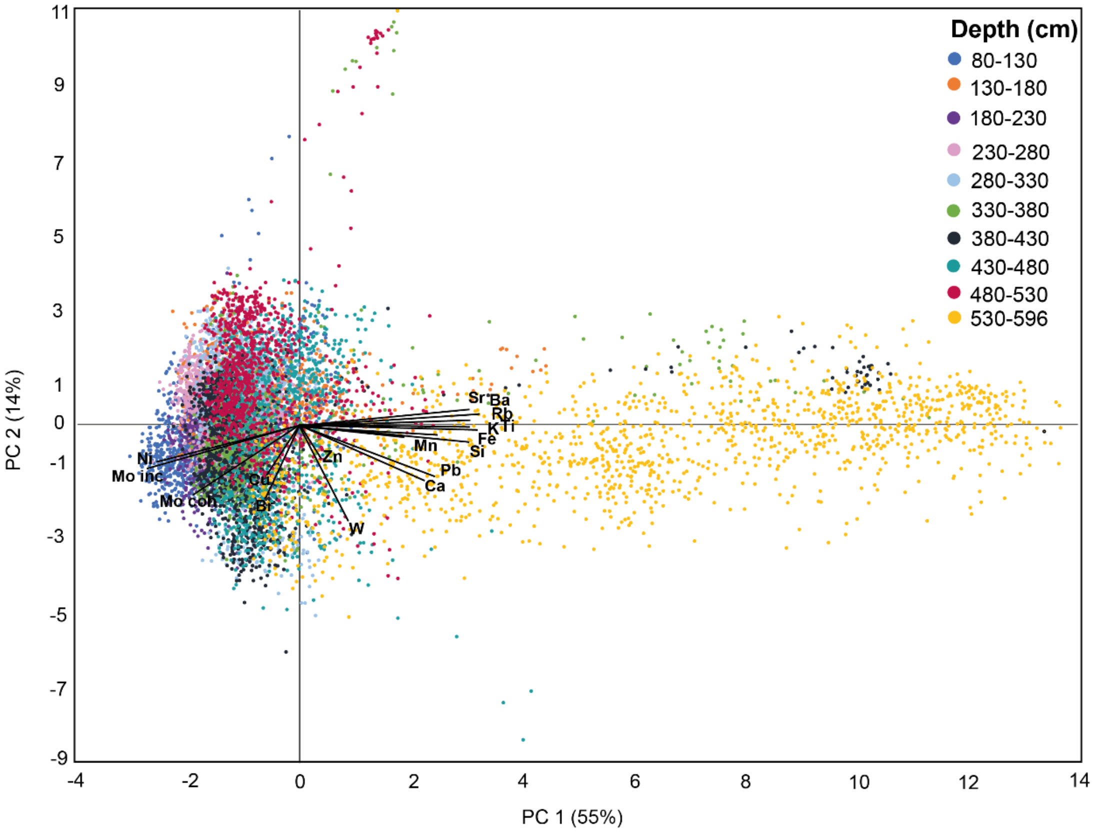


Figure 4.9: Biplot for Antaycocha showing the results of the loading plot and elemental score data illustrating PC1 and PC2 groupings. Core sections are colour coded according to depth (cm). (Created using Minitab 21.1 data, graph plotted in Microsoft Excel).

A biplot of elements was produced (Fig. 4.9) and colour coded according to 50cm intervals down core; this revealed a large number of points were being pulled in a positive direction by PC 1, these mainly correlated to the bottom 50cm of the core. As the elemental plots revealed (Fig. 4.7 & 4.8), the signature at the base of the core is very different to that within the rest of the sequence (see also Fig. 4.11). The direction of the points on the plot towards more positive PC 1 values suggests a large input in terrigenous material rich in mineral content, as PC axis 1 is being largely influenced by elements such as Ti, Rb, Sr, and K. This influx of terrigenous material is also supported by the organic matter content and the lithostratigraphy for the bottom 50cm of the core (Fig. 4.5). In contrast, the core section above (480-530cm) plots to the lefthand side of the biplot (negative PC1) near the organic productivity elements, this corresponds to the sharp increase in organic matter seen after 450cm due to the inclusion of detrital plant material within the lake sediments. Overall, the core sections above 450cm plot closer to those elements in PC2, however there are some points that plot with the more positive PC1 values at the base of the core, for example, there are some points in the section from 330-380cm which plot around 6-8 on PC1, these points may correlate with the excursions in erosional indicators around 380cm and 350cm, which are also picked up in the PC1 axis curve seen in Figure 4.10. The trends in these data will be explored further in Section **4.3.5**.

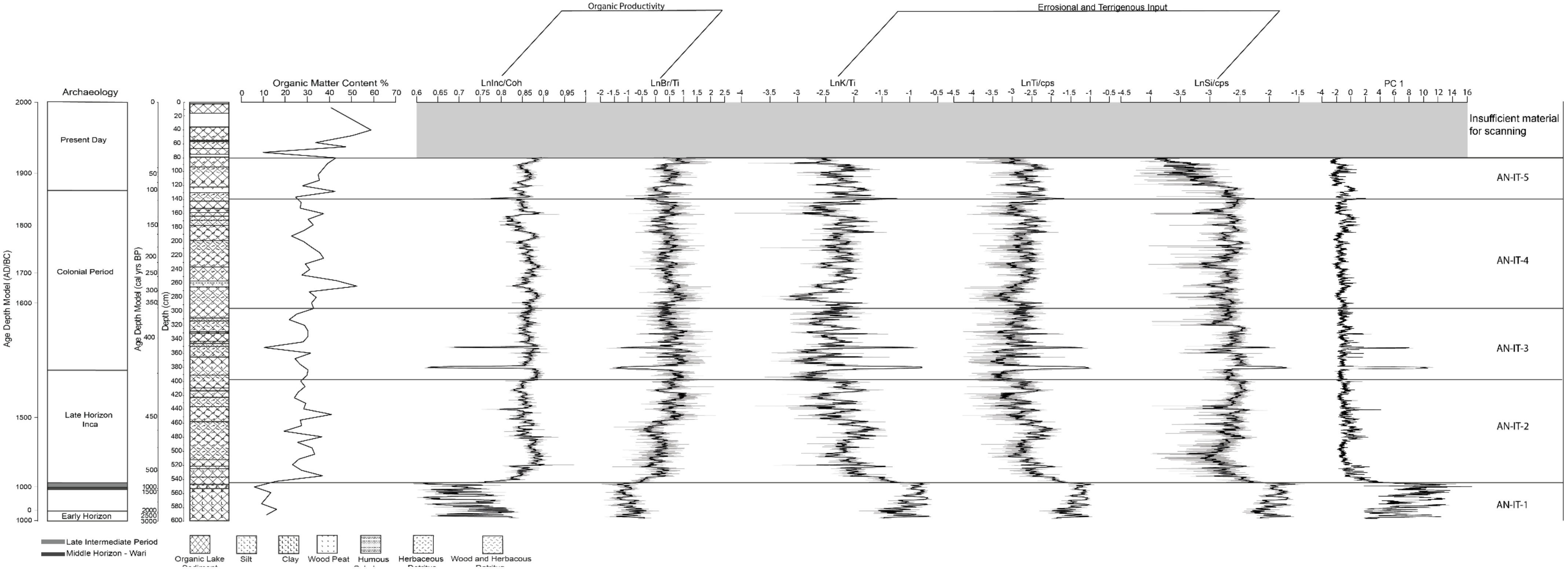


Figure 4.10: Micro-XRF elemental ratio plots for Antaycocha with PC1 axis. PCA was carried out in Minitab (21.1), elemental ratios were calculated in Excel.

4.3.3 Results of the Palaeoecological Analyses

Pollen samples were taken every 8cm throughout the core, where material permitted, it was not possible to take pollen samples from the top 40cm of the core due to the unconsolidated nature of the sediment and very little material being collected during sampling. Due to the age of the sequence dating to the past 500 years for the top 5.5m of sediment, the pollen sampling resolution provides a very high-resolution record with one pollen sample approximately every 7-8 years with a sediment influx rate of 1yr /cm. This does however also result in a dilution effect on the amount of pollen contained within each sample, with total land pollen counting being below 300 grains within several samples from this sequence. Some caution needs to be taken therefore when interpreting the pollen diagram, and the changing percentages in pollen present.

The results of the pollen counts were transformed into a percentage pollen diagram (Fig. 4.11 & 4.12), pollen accumulation diagram (Fig. 4.15) and a concentration diagram (Fig 4.16) using Tilia 2.6.1. (Grimm, 2019). The percentage pollen diagram was divided into five local pollen assemblage zones (LPAZ) based on visual assessment and stratigraphically constrained cluster analysis (CONISS, Grimm, 2019).

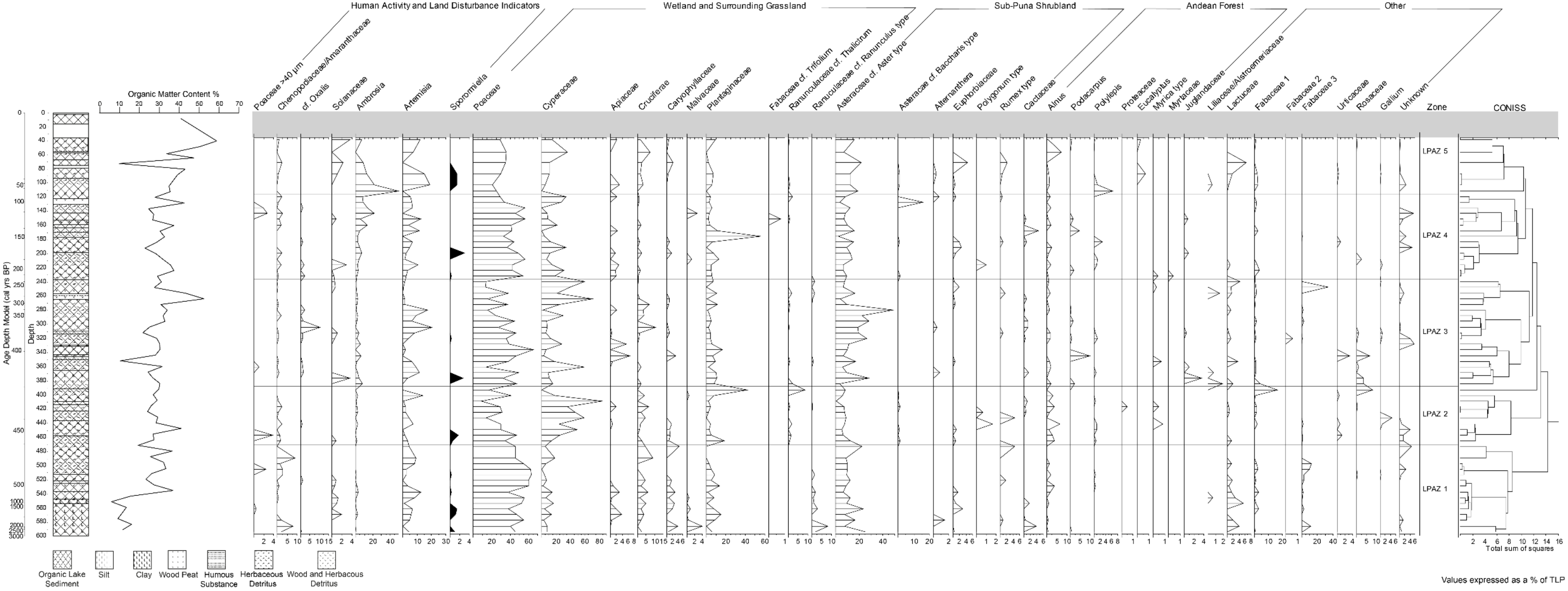


Figure 4.11: Antaycocha full taxa pollen diagram, pollen values are expressed in % of total land pollen produced in Tilia 2.6.1 (Grimm, 2019) Cluster analysis (CONISS) was used to zone the diagram in Local Pollen Assemblage Zones.

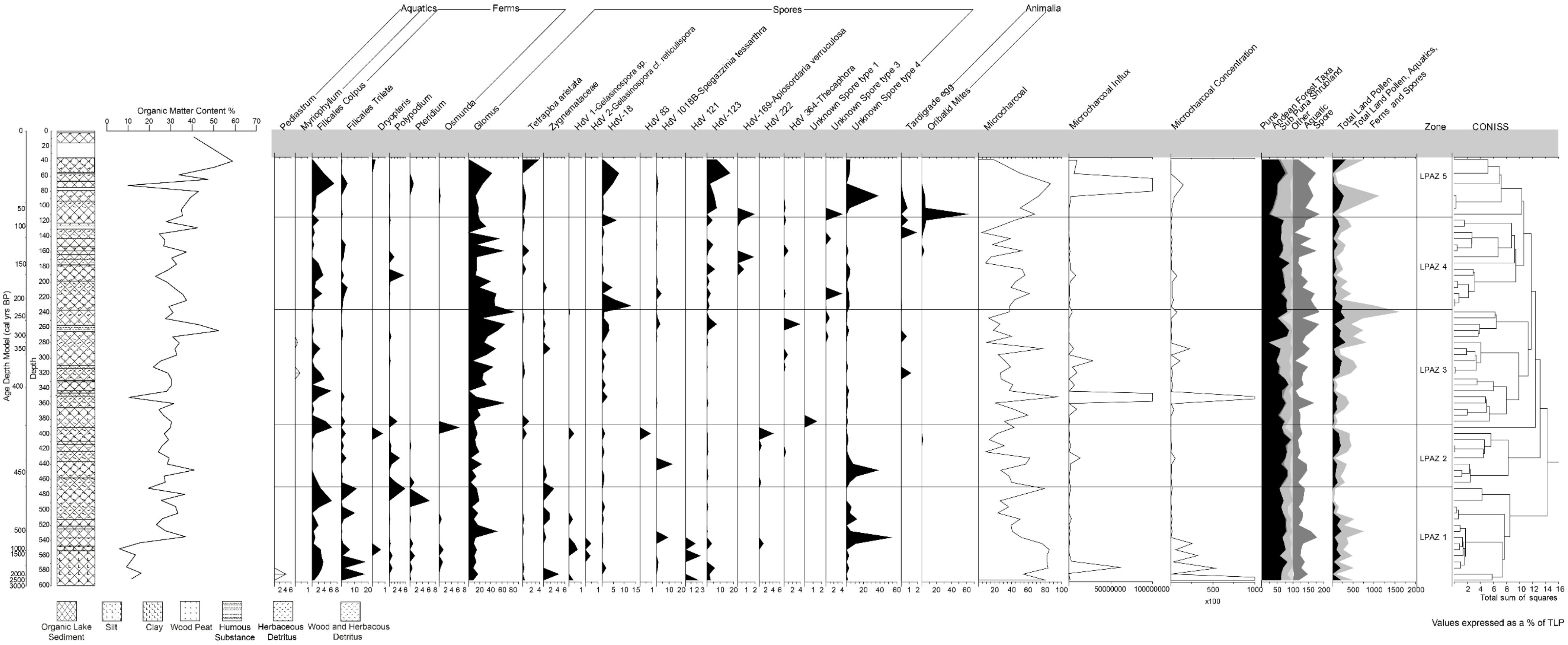


Figure 4.12: Antaycocha Aquatics, Ferns and Spores (NPPs) and microcharcoal diagram, values are expressed as a % of total land pollen produced in Tilia 2.6.1 (Grimm, 2019). Cluster analysis (CONISS) was used to zone the diagram in Local Pollen Assemblage Zones.

LPAZ 1 (597-470cm) (*~2954-460 cal yrs BP/ 1006 BC/ AD 1490*)

Poaceae-Asteraceae-Artemisia

This zone is dominated by herbaceous taxa, Poaceae (50%), Asteraceae (25%), *Artemisia* (minimum 0, maximum 13%), Cyperaceae (8%) and Cruciferae (3%), Caryophyllaceae (1%) and Apiaceae (1%) present in low values. Andean forest taxa are represented in small values by *Alnus* (1%), *Podocarpus* (1%) at the base of the zone and *Polylepis* (1%). Plantaginaceae decrease towards the top of the zone (maximum 15%, minimum 0%), as does Ranunculaceae *cf. Ranunculus* type (maximum 8%, minimum 0%). Cactaceae is present towards the base of this zone (4%), with Lactuceae (2%) and Fabaceae 3 (maximum 13%), present throughout most of the zone. Chenopodiaceae/Amaranthaceae decreases from 8% to 0% before increasing again towards the top of the zone to 9%. Poaceae >40% and *cf. Oxalis* occur twice (maximum of 3% and 1% respectively). Solanaceae is also present (2%). *Pediastrum* occurs for the only time in the record in this zone (4%). Filicales Colpus and Filicales Trilete fluctuate but are present throughout (Maximum 6% and 17% respectively). *Polypodium* and *Pteridium* increase towards the top of the zone (maximum 6% for both), there is only one occurrence of *Dryopteris* (1%). Zygnemataceae values fluctuate throughout, (maximum 4%, minimum 0%). There is the only occurrence of HdV 2-*Gelasinospora cf. Reticulispora* (<1%) and HdV 121 (2%) within this zone. *Glomus* increases to a maximum of 50% in the middle of the zone before fall off again (minimum 6%). *Sporormiella* is also present (2%). Micro-charcoal is initially high before decreasing (maximum 85%, minimum 3%). There is a peak in micro-charcoal influx and concentration at the base of this zone (60,983 grains cm^{-2} year^{-1} and 203,183 grains per cm^{3} respectively). This corresponds with a peak in Total Land Pollen concentration (48,314 grains per cm^{3}).

LPAZ 2 (470-388cm) (*~460-420 cal yrs BP/ AD 1490-1530*)

Cyperaceae-Poaceae-Plantaginaceae

Dominated by high levels of Cyperaceae (maximum 84%). Poaceae decreases from 47% to a minimum of 9%. Plantaginaceae initially decreases (minimum 0%) before increasing towards the top of the zone to 42%. Other herbaceous taxa include *Artemisia* (14%), Asteraceae (7%), Cruciferae (6%) and *Ambrosia* in trace amounts (1%). Ranunculaceae *cf. Thalictrum* appears in the record for the first time in this zone, increasing to 8%. There is one occurrence of Malvaceae towards the top of the zone (1%). Andean forest taxa are represented by *Alnus* (2%), *Polylepis* (1%), *Myrica* type (1%), and the only occurrence of Proteaceae within the record (1%). Fabaceae 1 and Rosaceae both increase towards the top of the zone (maximum of 17% and 8% respectively). *Gallium* occurs in maximum abundance within this zone (5%). There is a peak in Poaceae >40% (4%) in the lower half of the zone and

Chenopodiaceae/Amaranthaceae (1%) is present throughout most of the zone in small values. Solanaceae occurs once at the beginning of the zone (1%) followed shortly afterwards by *cf. Oxalis* (1%). Filicales Colpus decreases at the beginning of the zone (minimum 0%) and remains low before increasing again at the top of the zone (maximum 6%). Filicales Trilete is present is low values (1%). *Dryopteris* and *Osmunda* are present at this top of this zone only (1% and 6% respectively). *Glomus* remains relatively stable (~12%); *Sporormiella* occurs once at the beginning of the zone (3%). There is one occurrence of Oribatid Mites (2%) towards the top of the zone. Micro-charcoal fluctuates, but general decreases (maximum 63%, minimum 9%). There is a small peak in micro-charcoal influx (13,615 grains cm^{-2} year^{-1}) and concentration (5106 grains per cm^{3}) in the middle of the zone. Total land Pollen Concentration remains low (~1171 grains per cm^{3}).

LPAZ 3 (388-237cm) (*~420-233 cal yrs BP/ AD 1530-1715*)

Poaceae-Asteraceae-Cyperaceae

This zone is characterised by high levels of Poaceae (minimum 14%, maximum 65%) and relatively high levels of Asteraceae (Minimum 3%. Maximum 50%). Cyperaceae fluctuates throughout the zone but with some notable peaks up to a maximum of 70%. *Artemisia* is also relatively abundant (10%). Apiaceae (1%), Cruciferae (2%) Caryophyllaceae (1%) and *Ambrosia* (1%) represent the other herbaceous taxa. Ranunculaceae *cf. Thalictrum* and Ranunculaceae *cf. Ranunculus* type are both present in low values (1% for both). *Alnus* is present in lower values than the zone before (maximum 2%) whilst *Podocarpus* peaks in the lower half of the zone (maximum 10%). *Polylepis* (1%) and *Myrica* type (1%) are also present, and Juglandaceae occurs for the first time within this zone (maximum 4%). Liliaceae/Alstroemeriaceae occurs for the first time in the record in this zone (maximum 2%). Fabaceae 3 peaks at the top of the zone reaching the highest values in the record (maximum 34%). There is on occurrence of Poaceae >40% (1%), whilst Chenopodiaceae/Amaranthaceae is present throughout in low values (1%). *cf. Oxali*s (maximum 11%) and Solanaceae (4%) are also present. *Myriophyllum* occurs for the only time within the record within this zone (1%). *Glomus* levels fluctuate but generally increase to a maximum of 55%. Values of HdV 18 (3%) and HdV 123 (7%) increase though this zone. *Sporormiella* occurs twice (maximum 4%). Micro-charcoal has two main peaks within this zone (95% and 77%), the first of which corresponds with a notable peak in micro-charcoal influx (284,891 grains cm^{-2} year^{-1}) and concentration (124,640 grains per cm^{3}).

LPAZ 4 (237-116cm) (~*235-82 cal yrs BP/ AD 1715-1868*)

Poaceae-Cyperaceae-Plantaginaceae

Dominated by high levels of Poaceae (45%). Cyperaceae levels fluctuate throughout (maximum 20%, minimum 0%). Asteraceae values decrease from the previous zone (12%). Plantaginaceae increases to its highest values, with a peak in the middle of the zone (maximum 55%). Other herbaceous taxa include *Artemisia* (10%), *Ambrosia* (22%), Apiaceae (2%), and Cruciferae (1%). The only occurrence of Fabaceae *cf. Trifolium* is in this zone (1%) and Asteraceae *cf. Baccarhis* type peaks to its highest values near the top of the zone (maximum 16%). Peaks of Euphorbiaceae (2%), *Polygonum* (1%), and Cactaceae (5%) all occur. *Alnus* (1%), *Podocarpus* (maximum 5%), *Polylepis* (3%) and Juglandaceae (1%) are present in low numbers. Poaceae >40% peaks at the top of the zone (maximum 3%), Chenopodiaceae/Amaranthaceae is present in low values (2%). Filicales Colpus and Filicales Trilete are both present (maximum 4%). *Glomus* fluctuates though the zone (minimum 0%, maximum 63%). HdV 169-*Apiosordaria verruculosa* occurs for the first time in the record (2%) and Oribatid Mites occur at the top of the zone (maximum 6%). Micro-charcoal values fluctuate from 61% to 5%.

LPAZ 5 (116-40cm) (~*AD 1868-1989*)

Poaceae-Cyperaceae-Asteraceae

This zone is dominated by herbaceous taxa, Poaceae (30%), Cyperaceae (15%), Asteraceae (15%), *Artemisia* (15%), *Ambrosia* (minimum 0% and maximum 21%) and Plantaginaceae (5%). Apiaceae (2%), Cruciferae (maximum 7%), Caryophyllaceae (2%) and Ranunculaceae *cf. Thalictrum* (1%) are also present. Andean forest taxa are represented by *Alnus* (maximum 7%), *Polylepis* (maximum 6%), and the only occurrence of *Eucalyptus* in the record (1%). Lactuceae (7%) and Euphorbiaceae (4%) reach their highest values in this zone. Solanaceae increases towards the top of the zone (maximum 4%). Chenopodiaceae/Amaranthaceae is present in low values throughout (1%). No *cf. Oxalis* or Poaceae >40µm occur in this zone. Several NPPs increase in this zone; Filicales Colpus (7%), *Dryopteris* (>1%), *Pteridium* (1%), *Tetraploa aristata* (4%), HdV 18 (8%), and HdV 123 (17%). There is also a peak in Oribatid Mites (maximum 61%) and S*porormiella* is present within the first half of the zone (3%). Micro-charcoal increases to 80% with a corresponding peak in micro-charcoal influx (218,901 grains cm^{-2} $year^{-1}$) and concentration (14,593 grains per cm^3) before decreasing towards the top of the zone. Influx of Total Land Pollen also increases at this time to 34,250 grains cm^{-2} $year^{-1}$.

From the Antaycocha pollen sequence, four different types of Fabaceae pollen grains were identified, however only one of these could be identified to sub-family level, Fabaceae *cf. Trifolium*. The other three types have been recorded as Fabaceae 1, Fabaceae 2 and Fabaceae 3 and correspond to three distinctly different types of pollen grains. See Figure 4.13, for the distinction between the pollen types.

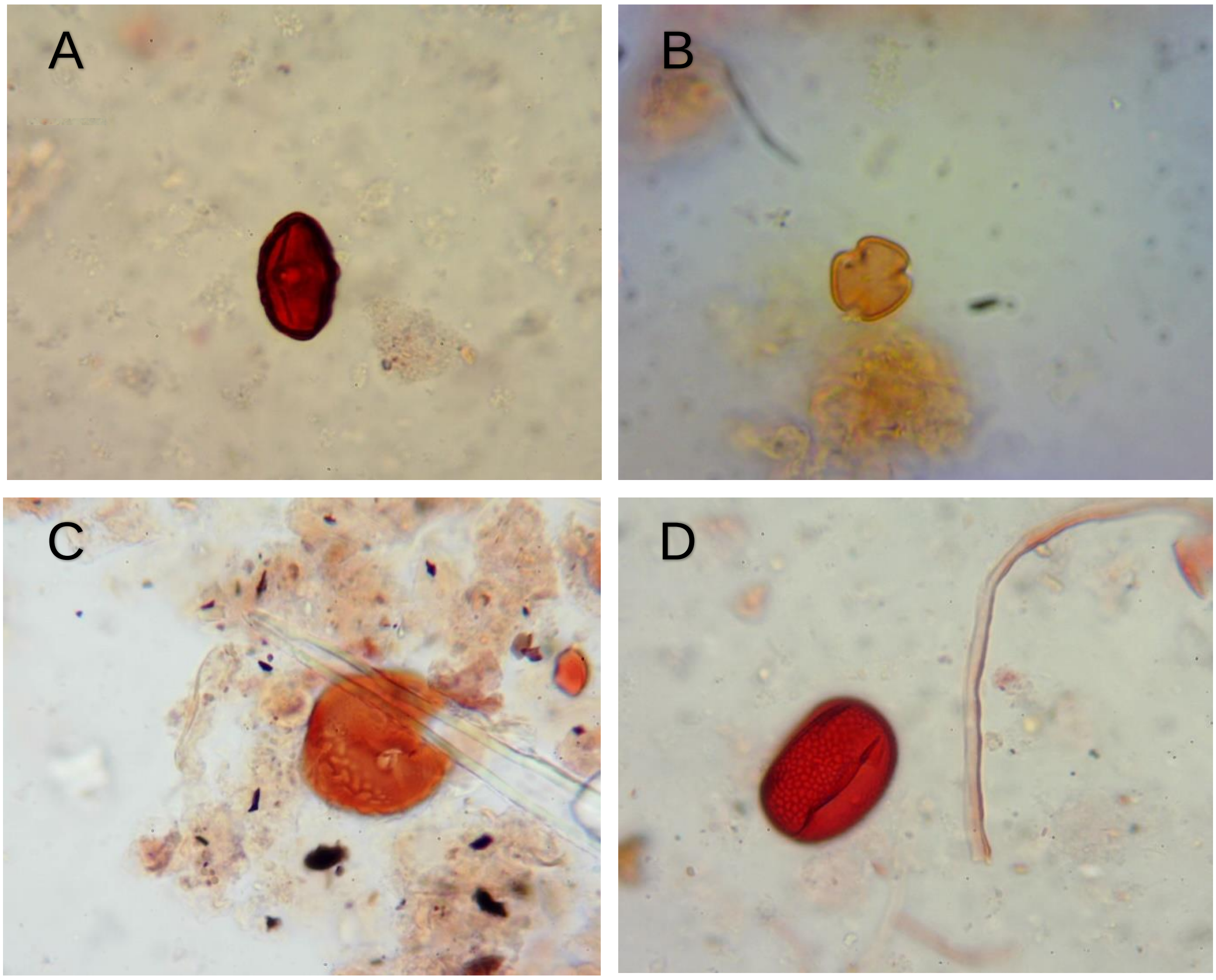


Figure 4.13: A) Fabaceae cf. Trifolium. B) Fabaceae 1. C) Fabaceae 2. D) Fabaceae 3. Microphotographs taken at 400x magnification.

There were also a number of spores encountered which could not be identified and given a type number, these were recorded as unknown 1, unknown 2, etc. examples some of the unknown types are presented in Figure 4.14 below.

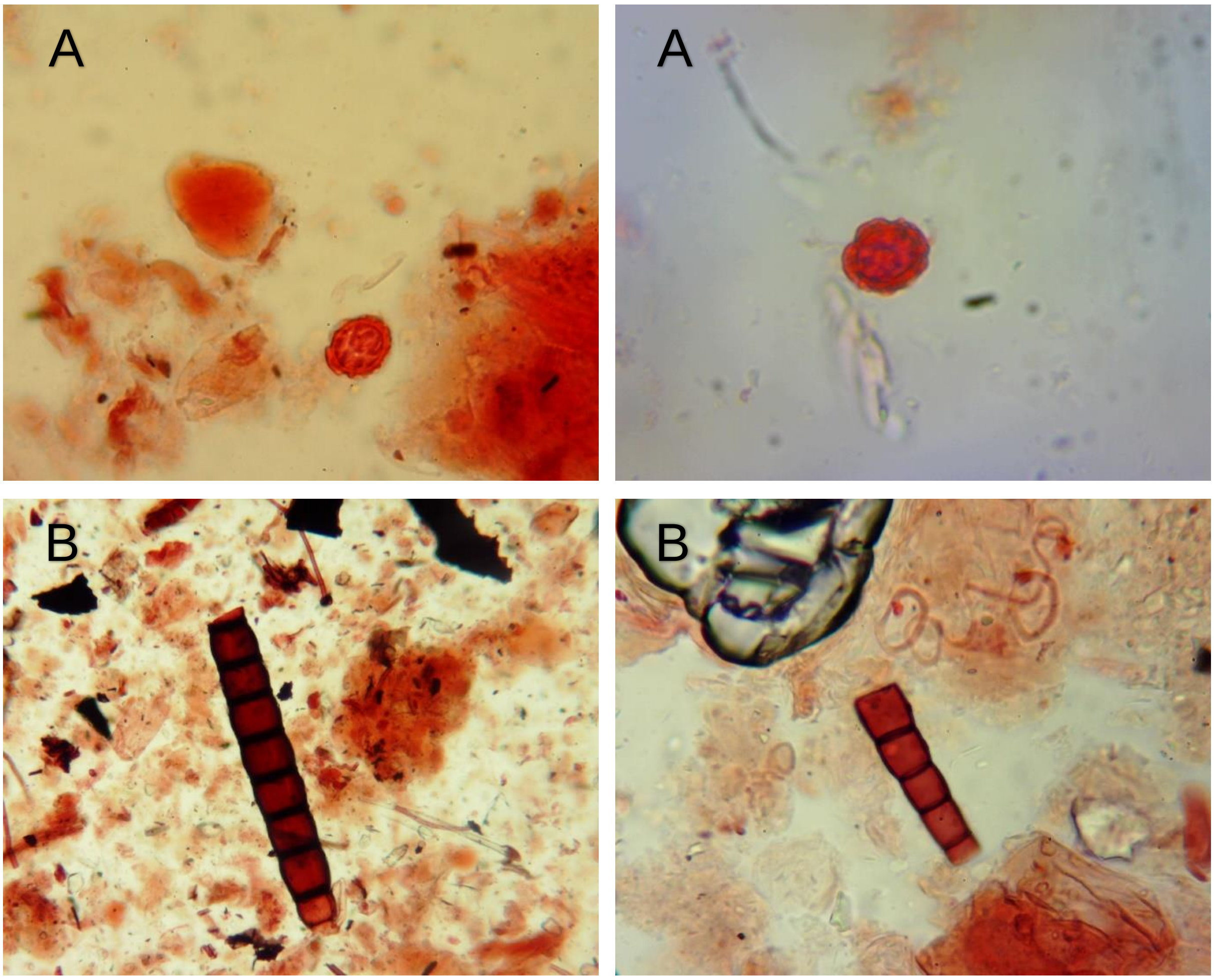


Figure 4.14: A) Unknown spore 3. B) Unknown spore 4. Microphotographs taken at 400x magnification.

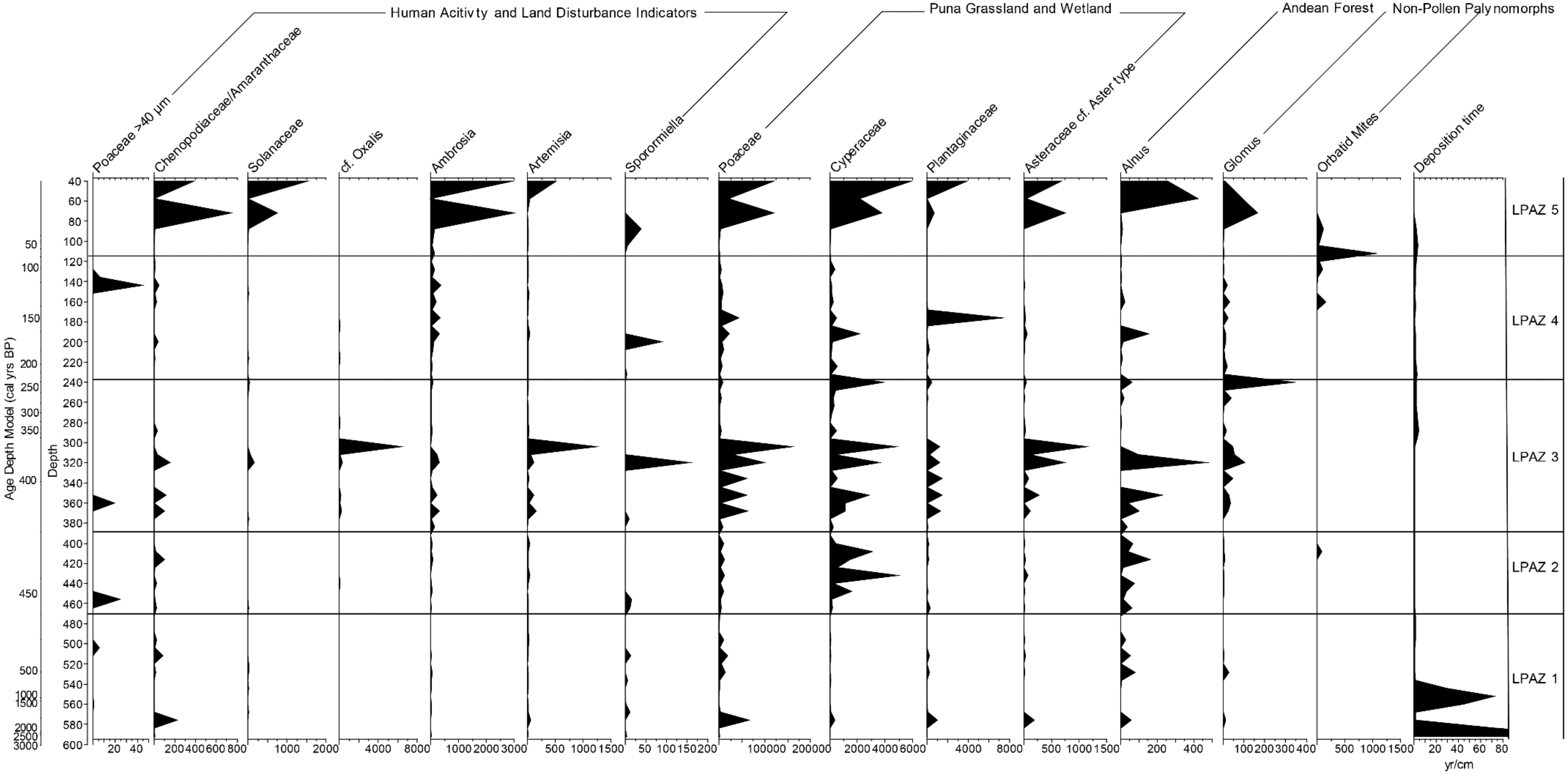


Figure 4.15: Pollen accumulation diagram for selected taxa from Antaycocha presented as grains cm^{-2}year^{-1}, diagram produced in Tilia 2.6.1 (Grimm, 2019).

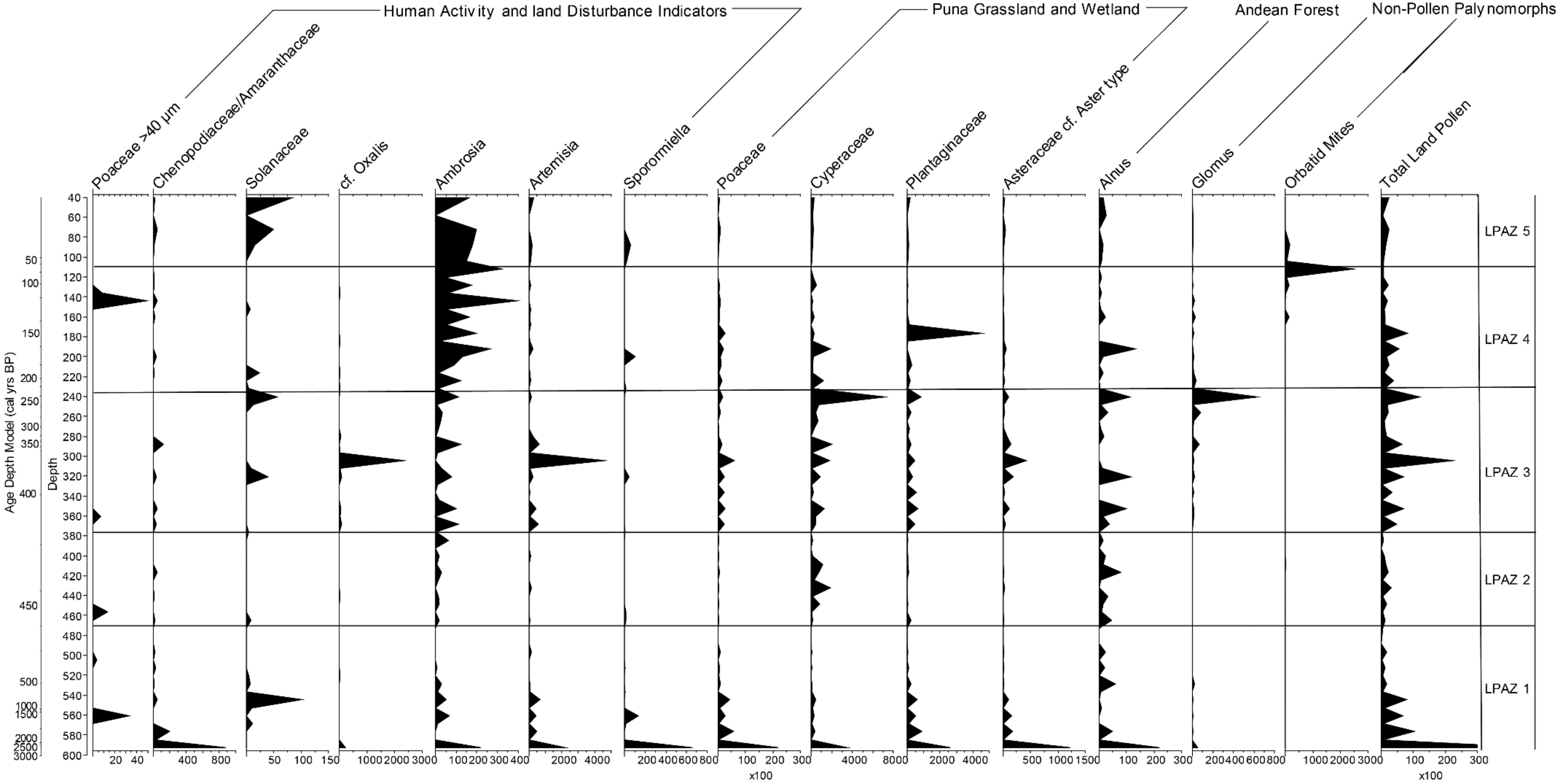


Figure 4.16: Pollen concentration diagram for selected taxa from Antaycocha presented as grains per cm^3, diagram produced in Tilia 2.6.1 (Grimm, 2019).

4.3.4 Results of the Radiocarbon Dating Programme

The 5.97m sequence from Antaycocha underwent a programme of radiocarbon dating; five samples were submitted for dating, where possible samples were submitted as picked sedge and grass material (three out of five samples), where there was not enough plant macrofossils for picking, bulk organic lake sediment samples were submitted. The radiocarbon dating programme revealed the basin to be at least 2853-2763 cal yrs BP, with the base of the sequence being older than this basal radiocarbon date taken at 5.9m; this has been modelled to be *~2955 cal yrs BP at* 5.97m (see Table 4.3). The majority of the sequence dates to the last 550 years with the radiocarbon date at 5.5m being 540-495 cal yrs BP (Table 4.3). Consequently, a large volume of sediment has accumulated over a relatively short period of time resulting in a high-resolution palaeoecological record.

An age-depth model for Antaycocha was created using Oxcal v4.4 and is presented below in both AD/BC and cal yrs BP (Fig 4.17) (Ramsey, 2009). A combination of the PostBomb curve (Bomb13SH12.14c) (Hua et al. 2013) and IntCal 20 atmospheric calibration curve (Reimer *et al.*, 2020) was used as the radiocarbon dating programme returned both a modern date and radiocarbon ages (see Table 4.3). The age-depth model returned a satisfactory ‘Amodel’ value of 105.9, suggesting the model is a good fit for the dates provided (Table 4.4).

Table 4.3: Results of the radiocarbon dating programme at Antaycocha.

Lab No.	**Sample ID Code**	**Sample Depth (cm)**	**Radiocarbon Age BP**	**Calibrated date cal. BP (95% confidence)**	**d13C ‰**	**Material Dated**
SUERC-92957	CAN-2-88	88-89	n/a (modern date)	-12- -31	-27.7	Bulk Organic Lake Sediment
SUERC-92958	CAN-5-300	300-301	366±37	503-315	-24.4	Picked Sedge Material
SUERC-92959	CAN-7-504	504-505	413±37	525-320	-26.2	Picked Sedge Material
SUERC-97576 (GU57263)	CAN-8-550	550-551	475±26	540-495	-25	Picked Sedge Material
SUERC-97577 (GU57264)	CAN-10-590	590-591	2714±26	2853 - 2763	-25.5	Bulk Organic Lake Sediment

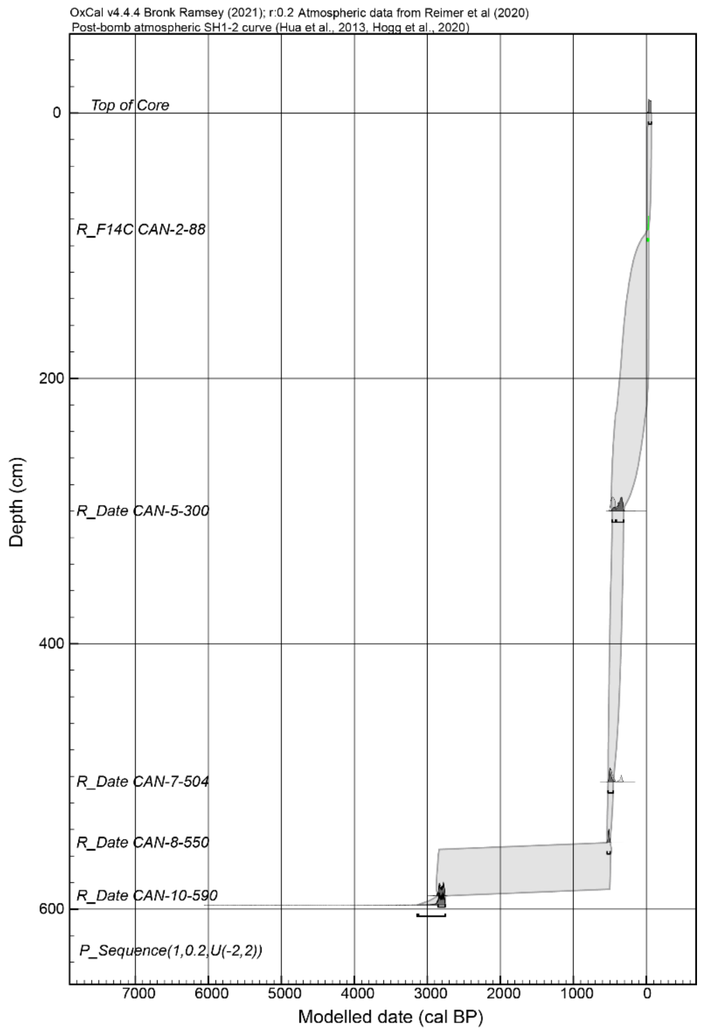


Figure 4.17: Age-depth model for Antaycocha basin. For ages used for R_Dates and the model agreement, see Table 4.4 (below).

Table 4.4: Results from the Antaycocha age-depth modelling.

Name	**Unmodelled (BP)**			**Modelled (BP)**			**Midpoint (cal. BP)**	**Indices** **A_{model} = 105.9** **A_{overal}l = 106.4**	
	from	**to**	**%**	**from**	**to**	**%**	**Rounded**	**A**	**C**
P_Sequence (1,0.2,U(-2,2))	-2	2	95.4	-2.02	-1.85	95.4		100	99.8
Boundary Bottom				3157	2753	95.4	2955		58.4
R_Date Can-10-590	2857	2759	95.4	2853	2758	95.4	2805.5	99.9	77.3
R_Date CAN-8-550	538	496	95.4	536	496	95.4	516	102.6	99.5
R_Date CAN-7-504	524	321	95.4	524	453	95.4	488.5	125.3	99.4
R_Date Can-5-300	498	315	95.4	470	310	95.4	390	97.9	98.6
Curve PostBomb									
R_F14C CAN-2-88	-12	-32	95.4	-12	-31	95.4	-21.5	92.6	95.6
Basin Surface				-30	-68	95.4	-49		99.9
2018				-67	-68	95.4	-67.5		100

4.3.5 Interpretation of Palaeoenvironmental Data

In addition to the pollen taxon described in Table in 3.6 in Section **3.3.3**, the following families and genera were found in the Antaycocha sequence (Table 4.5). The additional taxon mainly pertain to vegetation in the surrounding catchment and contribute to the vegetation history of Antaycocha, noticeably there appears to be more diversity in the Andean forest taxa, these will be considered in Section **4.3.5.2** below. To aid in the interpretation of the palynological and micro-XRF analysis Figure 4.18 has been created to allow comparison between the chronology, lithostratigraphy, XRF zones and LPAZ.

Table 4.5: Plant ecology of additional pollen taxon from Antaycocha. Categorisation of ecology types based on Brako and Zarucchi (1993) and the Missouri Botanical Garden's Tropicos database (www.tropicos.org).

Pollen taxon / type	**Plant Ecology**	**Palaeoecological Grouping**
Oxalis	Surrounding dryland. Agricultural land, disturbed ground, rocky slopes	Human Activity and Land Disturbance
Malvaceae	Surrounding dryland. Rocky slopes, disturbed ground, grassland and riversides	Puna Grassland and Wetland
Fabaceae *cf. Trifolium*	Surrounding dryland and within the basin. Disturbed ground, rocky slopes and bog surface	Puna Grassland and Wetland
Cactaceae	Surrounding dryland. Rocky slopes, shrublands and grasslands	Sub-Puna Shrubland
Proteaceae	Surrounding dryland. Disturbed ground, rocky slopes and shrubland	Andean Forest
Myrica type	Surrounding dryland. Forests and riversides	Andean Forest
Myrtaceae	Surrounding dryland. Disturbed ground and shrubland	Andean Forest
Juglandaceae	Surrounding dryland. Cultivated land and disturbed areas	Andean Forest
Urticaceae	Surrounding dryland. Disturbed ground, grassland, riversides, and rocky slopes	Other

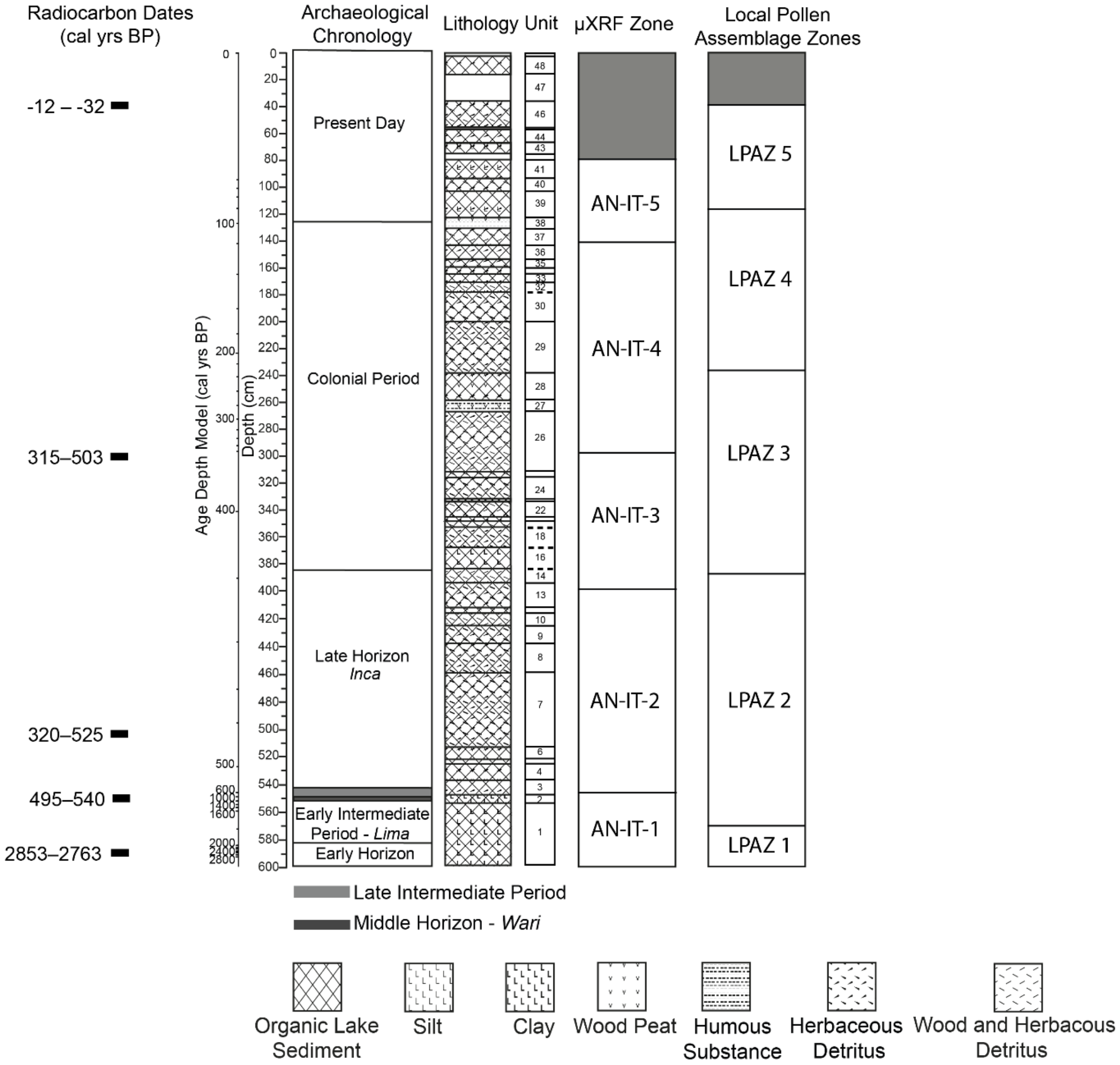


Figure 4.18 Comparison of chronology, lithostratigraphic units, µXRF zones, and local pollen assemblage zones for Antaycocha

4.3.5.1 Sediment History

At the base of the sequence (Unit 1), organic matter content is very low reaching a minimum of 6% at 552cm, this corresponds to lake sediments rich in silts and clays without the presence of any plant material. The bottom 50cm covers a period of ~500-3000 years ago with a large proportion of this dating to the Early Intermediate Period and Early Horizon (554-586cm *~AD 35-524; ~1915-1426 cal yrs BP* (EIP) and 587-590cm *~188-745 BC; ~2695-2138 cal yrs BP* (EH)). It is likely, at this time, a natural basin existed without much interference from human activity, as occupation in this section of the valley was sparse and ephemeral at this time (*C. Farfán pers. comms.)*. The stream running into the basin may have been flowing faster, without modifications to slow the flow; this would have led to a high-energy environment unsuitable for the growth of aquatic plants. Although, the presence of *Pediastrum*, freshwater algae, at 584cm *(~1690 ca yrs BP/ AD 260*) may indicate areas of slow-moving water or pooling of water towards the edges of the basin away from the inflowing stream.

Within the sediment record from Antaycocha, there are only two centimetres of material which have been modelled to date to the Middle Horizon (552-553cm, *~1199-971 cal yrs BP/ AD 751-979*), within Units 2 and 3, suggesting sediment accumulation during this period was slow. This may be as a result of a lack in human activity within the catchment during the MH, with no Huari-style ceramics having been found at the near-by archaeological site, Cantamarca (Farfán, 2000, 2011). It may also be due to a stabilisation of the environment during the Medieval Climate Anomaly (~1050-650 cal yrs BP/ ~AD 900-1300) (Bird *et al*., 2011; Apaéstegui *et al*, 2014), where a reduction in precipitation may have led to less water running into the basin via the stream, consequently bringing a lower sediment load with it, as well as less surface run-off from the surrounding slopes. One other possibility is that during the Late Intermediate Period, when human activity in the area increased, the basin was modified in order to encourage the build-up of water for a reservoir and during this modification, sediment was removed from the basin in order to create a greater water depth, this last hypothesis is harder to prove, however. These hypotheses will be discussed further in Section **4.4**.

After 550cm, organic matter increases, with the inclusion of detrital plants within the lake sediment, reflecting a stabilisation of the basin environment to one that was more hospitable to aquatic plant growth. Although no aquatic pollen was found within the second half of LPAZ 1 (Units 3-7), there are remains of plant macrofossils, in the form of detrital herbaceous and wood remains. Poaceae levels are high during the second half of the zone and may represent grasses growing in shallower water on the lake shore with several genera of Poaceae being recorded to grow on riversides and in semi-submerged settings in the Peruvian Andes including: *Nasella* (bunch grasses), *Stipa* (feather grasses), *Cortaderia* (pampa grass) and *Calamagrostis* (reed grasses) (Brako and Zarucchi, 1993). Cyperaceae levels are low in LPAZ 1 indicating Poaceae was dominant water-dwelling plant at this time.

The palaeoenvironmental sequence from Antaycocha indicates a period of anthropogenic modification to the basin in order to encourage the build-up of water after 550cm. This is supported by changes in the µXRF data, with a proposed change in source area of material entering the basin at this time. Prior to 550cm, *~516 cal yrs BP (~AD 1434),* the µXRF record from Antaycocha is rich in erosional and terrigenous input indicators including Ti, Si, and K, as well as pollutants including Zn and Pb. It is likely this mineral rich material was brought into the basin via the Rantao River flowing through the site, bringing weathered material from the volcanic rock outcrops, rich in silica and potassium, on the hills above the basin (INGEMMET, 2022). The Pb and Zn potentially also originated from the hills above the basin, with the Quebrada de Rantao highlands situated above Antaycocha, being rich in mines and natural mineral deposits (*Farfán pers. comms.*). It is unlikely that mining took place in the valley during the Early Horizon and Early Intermediate Period, due to the sparse and ephemeral population, therefore these minerals would have entered the waterways via natural erosion from precipitation (*Farfán pers. comms*). After 550cm, there is a switch in the µXRF data with those elements pertaining to organic productivity becoming more prevalent in the record, this is supported by the PCA with the data points for the core sections above 550cm mainly plotting towards PC 2 within the biplot (Fig 4.9). A more local source of material is proposed within the µXRF zone AN-IT-2 (*~516-425 cal yrs BP/ AD 1454-1525*), with Fe content increasing with organic matter suggesting material may have originated from the surrounding vegetated slopes of the basin shore during this time. An increase in human activity around the basin, as supported by the increased presence of Chenopodiaceae/Amaranthaceae and Poaceae >40µm in the latter half of LPAZ 1, would likely have destabilised the slopes around the basin causing soil erosion. An increase in soil input into Antaycocha is also supported by a peak in *Glomus* at 530cm, shortly after the increase in organic matter at 550cm.

This major transition within the Antaycocha record coincides with a late-Late Intermediate/early Inca date *~516 cal yrs BP (~AD 1434)*, when occupation at Cantamarca is known. (Farfán, 2011). It is at this point in time, that the stone wall, which acts as a dam for Antaycocha was likely constructed. This would have enhanced the carrying capacity of the natural basin as the construction of the three-meter wall, would largely increase the amount of water that could have been stored within the basin. Potentially allowing the people occupying Cantamarca settlement to provide sufficient water for cultivation and domestic consumption. The construction of a wall at this time may be related to a decline in climatic conditions with the onset of the Little Ice Age, as from the late-Late Intermediate Period and through the Late Horizon, palaeoclimate records for Peru show an increase in precipitation (Bird *et al*., 2011; Kanner *et al*., 2013; Apaéstegui *et. al,* 2014). The construction of more reservoirs in the area, as also documented by Farfán (2011), may have been a response to an increase in rainfall, in order to capture the water and prevent it from running down slope.

Following this, during LPAZ 2 and the second half of the LH (*~460-420 cal yrs BP/ AD 1490-1530*), there is an increase in Cyperaceae, with a decrease in Poaceae, suggesting a change in vegetation on the shores of the lake during this time. There is also an increase in Ranunculaceae *cf. Thalictrum* and the presence of *Polygonum type* during this zone, both of which grow within damp conditions, with some species of *Polygonum* living within fully submerged settings, this could therefore be indicative of a wetter basin environment during this time (Brako and Zarucchi, 1993). Within the lithostratigraphy for the units which correspond to LPAZ 2 (Units 7-14), detrital plant remains were recorded, specifically within Units 8 and 13 plant macrofossil remains of *Phragmites* were found, indicating a reed swamp may have been present at this time. This corresponds to peaks in Poaceae towards the bottom and top of LPAZ 2, and the presence of *Phragmites* within the basin may also be recorded within the Poaceae pollen curve. It is possible that the wall was constructed in order to attempt to raise the water level of this reed swamp. Due to the error margins on the age depth model from Antaycocha and the high resolution of analysis, the building of the wall and the presence of the reed swamp may be concurrent with each other, opposed to the reeds colonising the basin after the building of the wall, as it is likely the people of Cantamarca maintained the basin in some way to allow for the build-up and collection of water.

Within µXRF zone AN-IT-3, which correspond to the first half of LPAZ 3 and Units 14-26 *(~425-386 cal yrs BP/ AD 1525-1564),* there are two excursions within the ratio graphs which are pronounced and differ from the background signal for this zone, for the terrigenous and erosion signal elements this presents itself as a more positive (increased) signal, whereas for the organic productivity indicators this signal shows a more negative (decreased) deflection. The first of these signatures at 580cm (*~416 cal yrs BP/ AD 1534*) is not picked up within the lithostratigraphy or the organic matter content, showing the µXRF data to be more sensitive to increased mineral content within the sediments. The second peak at 350cm (*~405 cal yrs BP/ AD 1545*) corresponds with a decrease in organic matter content, however. As these two peaks are also recorded in the PC 1 axis (Fig 4.10) and in the Zn and Pb curves (Fig 4.7), this mineral material likely originated from the hills above the basin, with the stream running into Antaycocha having carried a higher sediment load during these points in time. The timing of these two peaks broadly coincides with more negative $^{\delta}$18O values within the Laguna Pumacocha record, indicating higher precipitation levels which would have increased the stream flow and erosion of minerals from the hillside above Antaycocha (Bird *et al*., 2011). There is also increased lithic concentration in the Lima marine core record at this time (Rein *et al*., 2004). It is possible, that the increased erosional input correlates with stronger SASM activity recorded in the LIA and shows the µXRF data from Antaycocha to be sensitive to regional climatic variations. These periods of increased mineral content within the sediments at Antaycocha correlate with lower amounts of Cyperaceae, which may indicate a decrease in growing area at the edge of the lake basin and an increase in water levels with the higher precipitation.

In Units 27 and 28, *~290-238 cal yrs BP (AD 1560-1712),* herbaceous peat was deposited, this corresponds with an increase in organic matter and increase in Cyperaceae suggesting a lowering of the water table and the build-up of peat, the surface of which was likely colonised by Cyperaceae. Ranunculaceae *cf. Thalictrum* and Ranunculaceae *cf. Ranunculus type* are also present within the record at this time, and likely contributed to the vegetation on the bog surface. This lower energy environment also corresponds to a decrease in erosional and terrigenous input signals and an increase in Br/Ti values at the transition to AN-IT-4, suggesting less landscape disturbance during this time. At *~235 cal yrs BP (AD 1715)* Poaceae returns to being the most dominant plant on the lake shore with a reduction in Cyperaceae due to a rise in water levels with a return to open water lake conditions in Units 28-30. Peat formed again *at ~150 cal yrs BP (AD 1800)* (Unit 31) with an increase in Plantaginaceae populations, most likely represented here by *Plantago tubulosa* a key species within Peruvian *bofedales* vegetation communities (Polk *et al*., 2014). The water table would have lowered at this time to allow the colonisation of the bog surface by Plantaginaceae. *Polypodium*, a terrestrial fern, is present within the record at this time and may have been able to grow on the drier surface edges of the bog.

Water levels increase again from *~151-105 cal yrs BP (AD 1799-1845)* with the deposition of lake sediments in Units 31-37. There is a reduction in both Cyperaceae and Poaceae at this time, meaning the water depth may have been too high to support semi-aquatic plant growth. The Total Land Pollen (TLP) abundance is low at the time however with poor pollen preservation recorded 144 cm (*~123 cal yrs BP/ AD 1827*), which explains the reduction in both families at this time. A further lens of herbaceous peat was deposited between *~105-93 cal yrs BP (AD 1845-1858)* signalling a reduction in the water table, this is supported by an increase in Cyperaceae at the top of LPAZ 4. There is a reduction in variability within the µXRF data during zones AN-IT-4 and AN-IT-5 which may signal the stabilisation of the environment with less catchment erosion, a lower energy environment would also have allowed for the build-up of peat. This period of reduced erosional activity correlates with the Colonial Period and continues through to present day, when human activity in the area reduced in intensity (Farfán, 2011).

With the transition to LPAZ 5, Poaceae and Cyperaceae decrease again, this is also most likely linked to a reduction in the TLP due to low pollen preservation. During Units 39-49 sediments are rich in lake sediments some of which are low in organic matter. Of note, is the reduction in organic matter at 72cm (AD 1982), this corresponds with an in washing of fine silty mineral content seen within the lithostratigraphy. Unfortunately, the record does not extent that far, and so the nature of this erosional input cannot be characterised using the µXRF data. The timing of this event coincides with one of the strongest El Niño events on record which took place during AD 1982-1983. This is the highest magnitude event on both the Southern Oscillation Index (SOI) and the Multivariate ENSO Index (MEI) scale since records began in AD 1950 (Maasch, 2008). It is possible therefore that Antaycocha basin is again picking up an

El Niño signal. However, modern El Niño events normally present themselves as increased precipitation on the coast and increased aridity in the highlands (Maasch, 2008; Sandweiss and Quilter, 2012). This fine erosional material may therefore represent a dust event and the blowing of sediment off the surrounding slopes under very dry conditions.

The presence of detrital rich lake sediment continues until modern day, some areas of Antaycocha today have formed an omnitrophic bog, however these peat deposits were not picked up within the core taken for this research project. Where water runs through the site there is some ponding of water and lake sediments till remain present within the basin that is now full of sediment up to the top of the three-metre wall (as seen in Fig. 4.3 and 4.4).

4.3.5.2 Vegetation History

The pollen record from Antaycocha can also provide information on the changes within the dryland vegetation surrounding the basin, as well as giving some indication of the levels and characteristics of human activities over the past 2500 yrs. Within the bottom 50cm of Antaycocha sequence (prior to *~516 cal. BP/ ~AD 1434*) there are indicators of human activity and land disturbance which may reflect the ephemeral human presence known within the local landscape from the archaeological record (Dillehay, 1972; Cohen, 1978; Farfán, 2011). For example, the presence of *Sporormiella,* an herbivore dung fungus, within the EH and EIP may reflect local pastoral farming and transhumance activities. *Sporormiella* has poor dispersal capabilities due to the low height as which the spores are released from the dung surface, consequently the *Sporormiella* within the record at Antaycocha is likely to come from a highly localised source (Davis and Shafer, 2006; Chepstow-Lusty *et al.*, 2019). Chenopodiaceae/Amaranthaceae and Solanaceae also occur in the pollen record during the EH and EIP, which may represent early agricultural activity in the region. Identifying pollen grains to below family level for Chenopodiaceae/Amaranthaceae, however, is difficult, so its presence within the record at this time may also represent the growth of wild genera, such as *Atriplex* (Chenopodiaceae) and *Guillerninea* (Amaranthaceae) (National Research Council, 1989). At this time of low levels of human activity, the landscape around Antaycocha was dominated by herbaceous taxa. The rocky slopes immediately adjacent to the wetland would have been covered in Malvaceae, potentially genera of *Malva*, *Malvastrum*, *Nototriche* or *Tarasa,* all of which are known to live within the higher reaches (above 3500m a.s.l.) of the Lima region today (Brako and Zarucchi, 1993), Apiaceae, Cruciferae, Caryophyllaceae and *Alternanthera*. Euphorbiaceae is also present until *~506 cal yrs BP (AD 1444)*, with *Euphorbia* being the main genera found in the Lima highlands, in particular *Euphorbia peplus* and *Euphorbia raphanorrhiza* have been recorded at present day growing on rocky slopes and in disturbed areas (Brako and Zarucchi, 1993). The presence of Fabaceae and Cactaceae within these earlier periods (EH and EIP) may reflect a lower density of grazing, as both families contain shrubs with thorny branches, unpalatable to grazing camelids. Within the Lima region *Opuntia* and *Oroya* are two key genera of Cactaceae which grow at higher elevation (up to 4000m a.s.l.) (Brako and Zarucchi, 1993).

During the first half of LPAZ 1 there is a very low abundance of Andean Forest taxa, with *Alnus* (most likely *Alnus accuminata* the native species to the Peruvian highlands) present in low amounts and one occurrence of *Podocarpus* at *~2840 cal yrs BP (890 BC)*. This may be a result of the treeline for *Alnus acuminata* and *Podocarpus* being situated below Antaycocha, with its modern-day limit being around 3200m a.s.l. (Brack Egg, 1990). This coupled with very wet conditions during the EH and EIP with increased precipitation within the Peruvian palaeoclimate records from ~2500-1500 years ago, would have meant an even more suppressed tree line to lower elevations, with only limited grains reaching the basin if the wind direction permitted them (Bird *et al.*, 2011; Kanner *et al*., 2013). Micro-charcoal levels are also high prior to *~516 cal. BP (~AD 1434)* however, therefore, the lack of trees may be related to early land clearance in the development of farming within the area. From *~506 cal yrs BP (AD 1444)*, *Alnus* increases and *Polylepis* occurs in the record for the first time, this timing coincides with the Late Horizon Inca Period with both trees being economically important to the Inca (Chepstow-Lusty and Winfield, 2000). *Alnus*, increases within the LH have been seen elsewhere in Peru, including at Marcacocha and La Compuerta, as well as Huarca in this volume of research (Chapter 3) (Weng *et al*., 2004, 2006; Chepstow-Lusty *et al*., 2009).

With the transition to the Late Horizon *(~512 cal yrs BP/ AD 1438*); there is also an apparent increase in landscape disturbance, with an increase in abundance of *Artemisia* and an increase in *Glomus*, indicating disturbed soils, as well as an increase in agro-pastoral activity. The presence of Poaceae >40µm within the top of LPAZ 1 and in LPAZ 2 during the Late Horizon likely represents *Zea mays* growing within the surrounding agricultural terraces. Higher presence of Chenopodiaceae/Amaranthaceae within the second half of LPAZ 1 also suggests higher agricultural activity either through the presence of cultivated Quinoa (*Chenopodium quinoa*), *Kañiwa* (*Chenopodium pallidicaule*) and *Kiwicha* (*Amaranthus caudatus*), or through arable weeds such as *Atriplex* (National Research Council 1989).

The presence of *Sporormiella* and one occurrence of Oribatid Mites within the record during the Late Horizon provides evidence for camelids within the immediate environment, potentially using the reservoir of water within Antaycocha basin for drinking water. The landscape was probably heavily grazed at this time with an absence of Cactaceae and Fabaceae seen in the earlier part of the sequence, and an increased presence of herbs, including the introduction of Urticaceae with potential species including *Urtica flabellata*, *Urtica magellanica* and *Urtica* *urens* (Brako and Zarucchi, 1993). *Rumex* is also present within the zone, indicating areas of disturbed ground and most likely presented by species *Rumex conglomeratus, Rumex crispus* or *Rumex obtusifolius*. The occurrence of *Polygonum*, likely represented by *Polygonum aviculare* or *Polygonum hydropiperoides*, both recorded in the Lima Region at elevations above 3500m a.s.l., also coincides with increased human activity indictors including the presence of *Oxalis* with the potential growth of cultivated *Oxalis tubulosa. Polygonum aviculare* is an arable weed and may have grown on the agricultural terraces alongside ambrosia and cultivated Chenopodiaceae/Amaranthaceae.

Higher levels of *Alnus* continue into LPAZ 2 with a peak in abundance around ~442 cal yrs BP (AD 1508). There is an increase in the diversity of Andean forest taxa within LPAZ 2 and the second half of the LH. As well as the occurrence of *Polylepis*, Proteaceae and *Myrica* type occur in the record for the first time (~430 cal yrs BP/ AD 1520 and ~442 cal yrs BP/ AD 1508 respectively). The *Oreocallis* genus is the most prevalent within Proteaceae to grow in the highlands of Lima today; *Oreocallis* is known to tolerate habitat disturbance and may have expanded in response to increased human activity within the Inca Period (Pennington, 2007). Whilst *Myrica pubescens*, a key *Myrica* species, is known for its medicinal uses and its growth may have been encouraged by the Inca for its useful properties (Kew, 2022).

During the transition to the Colonial Period at 418 cal yrs BP (AD 1532), the pollen record appears to show a reduction in maintenance of the landscape surrounding Antaycocha. The increase in Asteraceae, for example, may signal the colonisation of the terraces and slopes surrounding the basin by shrubland. *Baccharis sp*. (Asteraceae) is seen growing in these areas today alongside *Lupinus sp*. (Fabaceae) and various genera of Cactaceae. *Artemisia* also increases in abundance during the Colonial Period indicating disturbed but uncultivated ground. *Oxalis* is most abundant during the Colonial Period at *~AD 1560 (~390 cal yrs BP)*, which may represent a development of the cultivation of Oca (*Oxalis tuberosa*) after the conquest under local colonial populations. Oca is known to be grown in the region today and is a staple of the crop assemblage grown by campesinos in the highlands. However, other agricultural activity, for example Maize (*Zea mays*) is sparser during the first half of the Colonial Period during LPAZ 3. The presence of *Oxalis* may therefore represent the growth of wild herbs, e.g., *O. nubigena, O. latifolia, O. spiralis or O. corniculata*, all of which have been recorded in the Lima region above 3000m a.s.l. (Brako and Zarucchi, 1993). These genera like to grow on disturbed ground and on rocky slopes, such as those surrounding the basin and so, as with Asteraceae, may have colonised the unmanaged ground. There is an increase in the abundance of other herbs including Apiaceae, Caryophyllaceae, Urticaceae and *Gallium* after *~404 cal yrs BP/ AD 1546* which may also be indicative of less landscape management during the Colonial Period.

Even if cultivation ceased at the beginning of the Colonial Period there is still evidence of landscape disturbance, and potential human activity through LPAZ 3 and LPAZ 4. *Sporormiella* is present within the record during the Colonial Period and up until present day, likely representing a mixture of camelids and cows, with the introduction of other herbivores in addition to camelids occurring post-conquest. Ancient corrals, likely built in the LIP or LH during the occupation of Cantamarca (*C. Farfán pers. comm*.), are still used today in the landscape surrounding Antaycocha for herds of cows. In addition to *Sporormiella*, an increase in *Glomus* during Colonial Period signifies greater catchment disturbance and landscape erosion, at a time where a lot of sediment is being deposited over a relatively short period of time.

At the beginning of LPAZ 3 there is also still a signature for agroforestry within the pollen record with the presence of *Alnus*, *Podacarpus*, *Polylepis* and *Myrica* type as well as Juglandaceae, of which *Juglans neotropica* and *Juglans peruviana* are cultivated in the Peruvian Andes today and referred to locally as Tocte nut or Andean Walnut (National Research Council, 1989; Kew, 2022). By *~396 cal yrs BP (AD 1554)* there is a reduction in tree taxa and a subsequent peak in micro-charcoal which may indicate colonial landscape clearance and use of trees for firewood. A peak in micro-charcoal at *~400 cal yrs BP (AD 1550)* coincides with a peak in PC axis 1 and therefore may be due to an increase in catchment erosion and an in washing of charcoal already situated within the soil, however the later peak in micro-charcoal within LPAZ 3 has no corresponding peak in PC axis 1 and therefore more likely represents a localised burning event.

During the second half of the Colonial Period, within LPAZ 4 *(~235-82 cal yrs BP/ AD 1715-1868)*, there appears to be an increase in agricultural activity with higher levels of Solanaceae, potentially representing cultivated *Solanum tuberosum* and other cultivated potatoes species (e.g., *Solanum andigenum, Solanum stenotomum* and *Solanum goniocalyx*) (National Research Council, 1989). Within the upper reaches of the Lima Region (3000-4000m a.s.l) two thirds of the Solanaceae species recorded at present day pertain to *Solanum* but other wild genera include *Salpichora*, *Lycopersicon*, *Dunalia*, so it may also represent wild growth of Solanaceae. At the top of the zone Poaceae >40µm is present, which may represent late colonial growth of Old-World crops such as wheat or barley, known in the Peruvian Andes from the middle of the 16th century (Milstead, 1928; Capparelli *et al*., 2005). The presence of Juglandaceae also continues into LPAZ 4.

Human activity appears to be greater than any period in the past during the present day; however, this is being greatly influenced by the abundance of *Ambrosia*. This is likely to represent growth on the relic abandoned terraces at the edge of the basin as a ruderal weed, opposed to *Ambrosia* being purposefully planted to help stabilise the terraces for cultivation, as has been recorded elsewhere in Peru (Chepstow-Lusty and Winfield, 2000; Weng *et al*., 2004; 2006; Chepstow-Lusty, 2011). This is supported by the presence of other herbs that grow in disturbed areas such as *Rumex*, Cruciferae, Apiaceae, Euphorbiaceae and Urticaceae as well as *Alternanthera*. There is also an increase in *Sporormiella* around *~AD 1910 (~40 cal. BP)*, and an earlier peak in Oribatid Mites at *~ AD 1876 (~74 cal yrs BP),* signalling an increase in herbivore activity around the basin from the late 19th Century. This is likely in the form of cows and camelids being kept in the corrals surrounding the site, with *Sporormiella* being washed into the basin, opposed to being directly deposited in it from animals using the basin for drinking water, as water levels at present day are relatively low.

Eucalyptus occurs in the record from *~AD 1972*, with an apparent decrease in *Polylepis* with the introduction of *Eucalyptus*, a trend seen elsewhere in the Peruvian Andes, as *Polylepis* has decreased in value since the planting of *Eucalyptus* began in the early 20th century (Chepstow-Lusty and Winfield, 2000). *Alnus* increases though the zone, likely reflecting its lower modern altitudinal limit, with it growing in the river valley below Antaycocha as recorded at present day.

4.4 Discussion

4.4.1 Early Horizon - Late Intermediate Period

(~2954 -516 cal yrs BP/1006 BC- AD 1434)

After the mid-Holocene Arid Period (7000-5000 cal yrs BP), the basin at Antaycocha started accumulating sediment *~2954 cal yrs BP (1005 BC)* during a relatively wet period (within Andean palaeoclimate). The precipitation across the Peruvian Andes increased, resulting in reestablishment of the Quelccaya ice cap and a rise in water levels in Lake Titicaca (Abbot *et al.,* 1997; Bird *et al.,* 2011; Stroup *et al*., 2015). From 2200 cal yrs BP, there was a further increase in precipitation with a decrease in $^{\delta}$18O seen at Lake Pumacocha ~100km NE of Antaycocha. Higher precipitation would have led to more water entering the catchment and subsequently, the build-up of water within a natural hollow in the ground. Accumulation of sediment was relatively slow until *~743 cal yrs BP*, averaging 55yrs/cm (maximum 143yrs/cm at base of the core). Potentially this could have been as a result of a higher energy depositional environment and water running across the basin would have flushed sediment out and carried it with the river as it flowed to the lower Torococha basin. Elsewhere in the Peruvian Andes, Marcacocha started developing organic lake sediments from ~3980 cal yrs BP, which may also have been as a result of increased precipitation in the region (Chepstow-Lusty *et al*., 1996, 1998).

From the archaeological record human occupation is known to be ephemeral during this time, with the Lima polity of the Early Intermediate Period being largely concentrated in the lower valley and on the coast (Mauricio, 2014). It is therefore likely that there were no human modifications to the stream entering the basin at this time *2750-1450 cal yrs BP (800BC – AD 500)*, and water could run freely from the hill tops above down into the basin, resulting in Erosional Event One within the basin (Fig 4.19). The µXRF data suggests the main source of sediment for this time was from the hillsides above the basin within the Quebrada de Rantao, due to the elevated Pb and Zn levels, likely originating from weathered natural deposits, along with more K, Ti and Si. Despite the lack of archaeological evidence for sustained human occupation within the upper reaches of the Chillón Valley during the EH and EIP (Farfán, 1995; 2011; Covey, 2008), there are some indicators for human activity and landscape disturbance within the Antaycocha sequence, in particular the presence of *Sporormiella* within the early parts of the record may reflect local pastoral farming and transhumance activities, with Antaycocha being well placed as a passing place on the route from the highlands down to the lower reaches of the valley. The presence of Cactaceae and other families containing thorny shrubs, such as Fabaceae, further indicates the area around Antaycocha may have had a ‘transient’ role at this time with low quality grazing land. The presence of Chenopodiaceae/Amaranthaceae and Solanaceae may reflect early agricultural activity in the region during the EIP and EH, however this may also represent wild growth as discussed in **Section 4.3.5.2**.

A very short section of the core dates to the Middle Horizon under the current age depth model (553-552cm, *~1199-971 cal yrs BP/ AD 751-979*). From 1050 cal yrs BP (AD 900), the Peruvian Andes experienced a prolonged period of marked aridity with more positive $^{\delta}$18O values recorded at Laguna Pumacocha and dust event signals evident in the Huascarán and Quelccaya ice core records. This dry signal has been accredited to the Southern Hemisphere expression of the MCA, and a weakening of the SASM, as well as a more northly position of the ITCZ (Haug *et al*., 2010; Bird *et al*., 2011; Vuille *et al*., 2012; Kanner *et al*., 2013; Apaéstegui *et al*., 2014). A reduction in precipitation would have led to less water availability and a lower carrying load capacity of the stream bringing sediment into the basin. The lack of material dated to between *~971 cal. yrs, BP (AD 979)* at 552cm and *~744 cal yrs BP (AD 1206)* at 551cm may therefore represent a ~230 year hiatus in sediment accumulation in the basin under very arid conditions. A lowering of lake levels has been recorded elsewhere at this time at Marcacocha and Lake Titicaca (Abbot *et al*., 1997; Chepstow-Lusty *et al*., 2003).

4.4.2 Late-Late Intermediate Period - Late Horizon

(~516-418 cal yrs BP/ AD 1434-1532)

Following on from the Middle Horizon there is a renewed deposition of sediment from *~516 cal yrs BP (AD 1434)*. This late-Late Intermediate Period date coincides with suspected permanent occupation of Cantamarca, situated on the hill outcrop above Antaycocha (Farfán, 2011). It also falls after the onset of the LIA in the Peruvian Andes, with the minimum date for the onset at 625 cal yrs BP (AD 1325). The LIA in Peru is signalled by minimum values in $^{\delta}$18O within the Palestina and Huagapo cave records and in the Laguna Pumacocha Lake record (Bird *et al*., 2011; Kanner *et al*., 2013; Apáestegui *et al*., 2014), and the largest increase in tropical Andean SASM rainfall since the late-Glacial period (Bird *et al*., 2011). This abundance of rain would have increased sediment loading into the basin; this is implied by a continuation of the pre-516 cal yrs BP (AD 1434) signature within the PC 1 axis (see Fig 4.19), until *~514 cal yrs BP (AD 1436).* It is at this time that the dam wall was most probably constructed at Antaycocha, in order to optimise the water holding capacity in response to increased rainfall. The construction of a dam would have allowed the water levels in Antaycocha to increase, using the natural topography of the slopes around the basin on the other three sides to trap the water (see Fig 4.19). The total measured depth of the wall within the field was three meters; it was originally expected that these three metres, would equate to the last ~500 yrs given the dam wall was likely Late Intermediate – Inca in date (*C.Farfán pers. comms*). However, analysis of the sediment sequence, via radiocarbon dating, has revealed another 1.5m of sediment dates to the LIP (see **4.3.4**). The modification of Antaycocha would have been part of a larger scale adaptation to the increased precipitation, with modifications to the Rantao stream, in the form of sluice gates to control the flow of water having been recorded above Antaycocha (Farfán, 2011).

An increase in human activity within the landscape surrounding Antaycocha, from the late-Late Intermediate Period and into the Late Horizon, is also evidenced through an increase in soil disturbance indicators, e.g., presence of *Artemisia* and *Glomus* in higher abundance, and the presence of cultivars and *Sporormiella*. The pollen record potentially provides evidence for multi-cropping on the terraces surrounding the basin during the LH (in LPAZ 1 and 2), with evidence for *Zea mays*, Chenopodiaceae/Amaranthaceae (either as a crop or an arable weed), Solanaceae (possibly *Solanum tuberosum*) and *Oxalis* (possibly *Oxalis tuberosa*). The presence of arable agriculture on the terraces around Antaycocha is supported by the presence of *Ambrosia* and *Polygonum* (*cf. Polygonum aviculare*), both arable weeds, with *Ambrosia* being used to stabilise soil conditions in pre-Hispanic times (Chepstow-lusty *et al*., 2003).

Within the Late Horizon, an intensified level of grazing at Antaycocha is inferred from the presence of *Sporormiella* and Oribatid Mites. *Sporormiella* within the record indicates camelids were present in the immediate environment, due to the localised dispersal nature of *Sporormiella* (Davis and Shafer, 2006). The apparent co-operation of camelid herding, and arable agriculture differs to signals seen elsewhere in the Peruvian Andes for the late-Late Intermediate Period and Late Horizon. At Marcacocha, an increased preference for crops such as maize overrode the importance of camelid herding during this time with camelids being moved to higher pastures, in order to decrease competition for land and resources (Chepstow-Lusty *et al*., 2009).

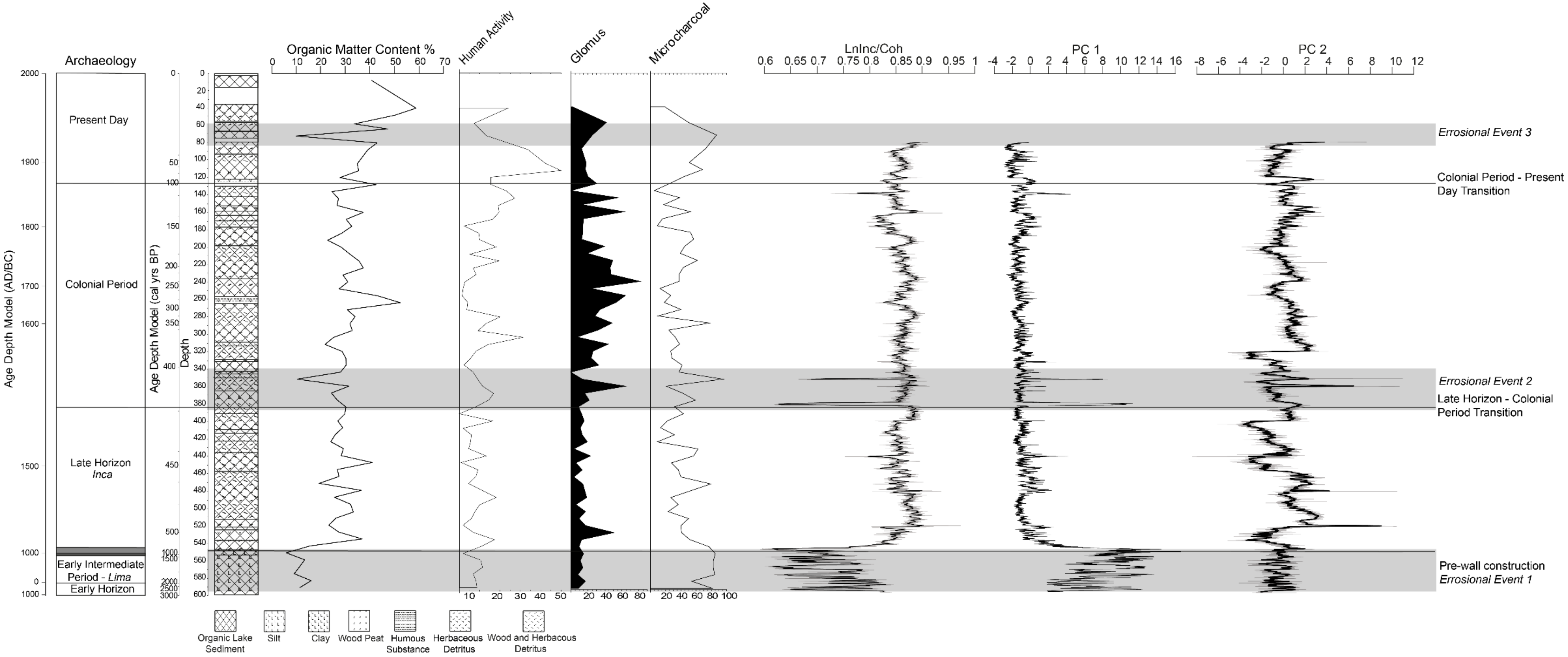


Figure 4.19: Synthesis diagram for Antaycocha showing the chronology, lithostratigraphy, organic matter content, key palaeoecological data from the human activity and land disturbance pollen group (see Fig 4.11), including glomus as an indicator for soil erosion, and summary µXRF data. LnInc/Coh is included as an indicator for organic productivity.

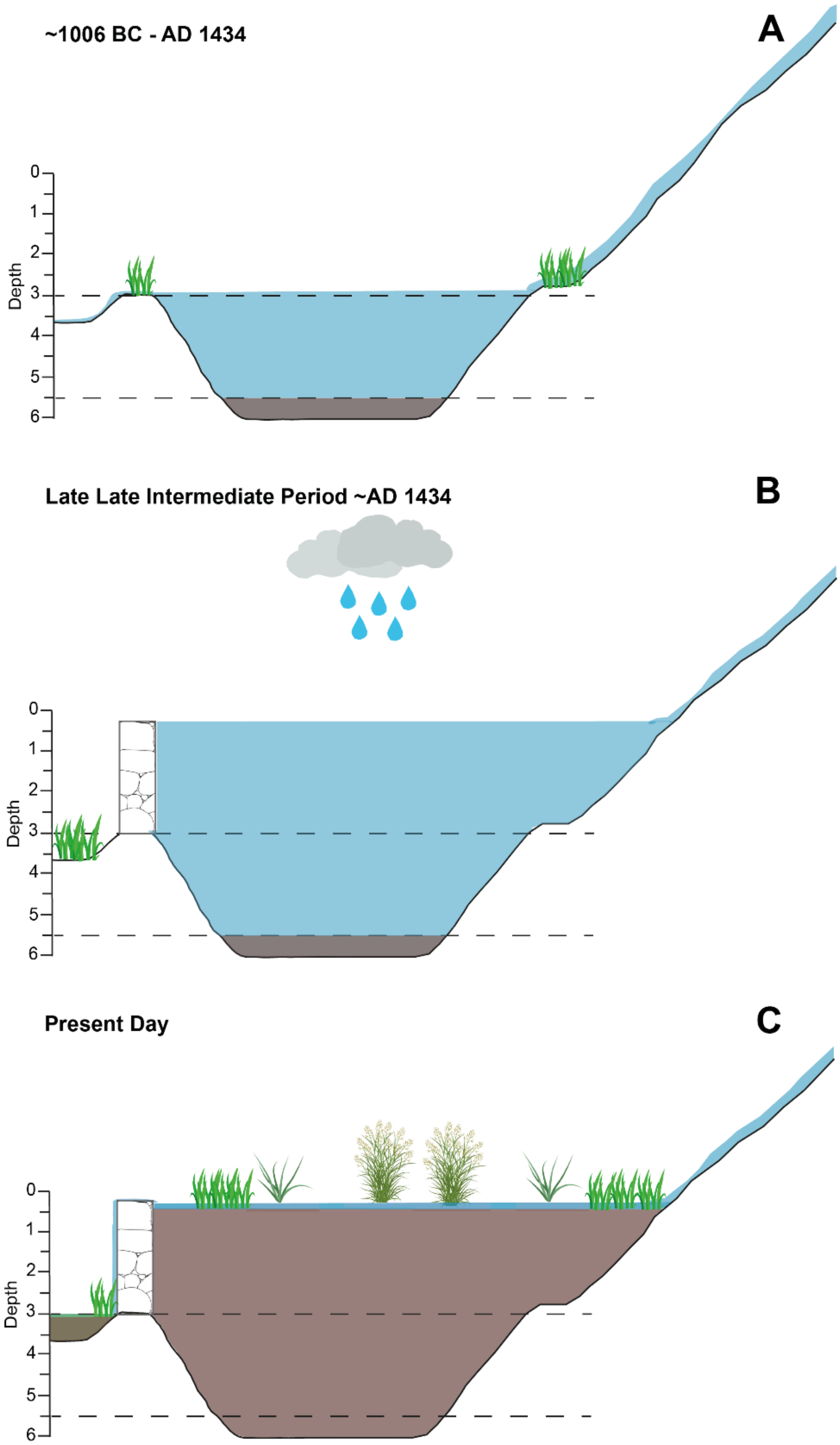


Figure 4.20: Schematic drawing of the development of Antaycocha basin based on palaeoenvironmental analysis of the sequence. The bottom dashed line on each of the drawings illustrates the depth the sediment prior to construction of the wall. The upper dashed line indicates the base of the wall height as measured in the field. Drawn by author.

Other potential human activities within the LH include agroforestry, with a rise in *Alnus*, *Polylepis*, *Myrica* type populations and the presence of Proteaceae. The cooler wetter conditions of the LIA, during the LH, would have likely supressed the treeline, as is seen for several records across the Peruvian Andes during the EH and EIP (Weng *et al*., 2004; 2006; Bush *et al*., 2015). The expansion of Andean forest taxa such as *Alnus*, was likely encouraged by the Inca to increase important recourses e.g. timber, building materials, and fuel (Chepstow-Lusty *et al*., 2009), however this may have occurred at lower elevation closer to the valley bottom floor near Canta. Due to the vast amount of pollen produced by *Alnus*, which would have increased with larger Alder populations, it is still possible the pollen was carried on the wind to Antaycocha at higher elevations. Elsewhere in Peru, at Laguna Compuerta and Marcacocha, there is also renewed *Alnus* populations during the LH (Weng *et al*., 2004; Chepstow-Lusty *et al*., 2009). It is worth noting that *Alnus* populations do not expand in quite the same way as seen at Huarca (see **Chapter 3**, this volume), where the expansion seems to be much greater, likely due to Antaycocha's position at higher elevation above the *Alnus* treeline. The sheltered river valley of the Rantao stream above and below Antaycocha may have allowed the growth of a more diverse range of tree species than on the exposed slopes surrounding Huarca.

4.4.3 Colonial Period

(418 -124 cal yrs BP/AD 1532-1826)

With the onset of the Colonial Period, human activity, in the form of agriculture, seems to decrease at Antaycocha. There is a reduction in Maize (*Zea Mays*) and an increase in shrubland taxa (Asteraceae, Cactaceae and Rosaceae). *Oxalis* is abundant in the Colonial Period, but with the initial reduction in other human activity indicators (Fig. 4.19), this may represent the growth of wild herbs (e.g., *O. nubigena, O. latifolia*, and *O. spiralis*). There is still the presence of animal husbandry, indicated by *Sporormiella* within LPAZ 3 and 4. This likely represents a mixture of camelids and old-world domesticates such as cows and sheep, with the corrals first constructed in the LIP-LH around Antaycocha still in use today (*C. Farfan pers. comm*.). Even if arable agriculture ceased, there is evidence for continued agroforestry practices from the LH. Juglandaceae is introduced to the pollen record at the start of the Colonial Period, potentially representing cultivation of Andean Walnut in the landscape around Antaycocha. By *~396 cal yrs BP (AD 1554),* there is a reduction in forest taxa however, which may indicate a clearing of the landscape by colonial settlers as this timing corresponds with a peak in micro-charcoal.

The declining importance of agricultural activities may be resultant from a shift in focus of human activity during the Colonial Period. From the µXRF data there is an apparent increase in the amount of Pb and Zn within the core during the Colonial Period (Fig 4.19). With Pb increasing from the early LH in AN-IT- 2 (*~491 cal yrs BP/AD 1459*) and showing distinctive peaks within AN-IT-3 (at ~ *416 cal yrs BP/ AD 1534* and *~404 cal yrs BP/ AD 1546*). Elevated levels of Zn and Pb are recorded in sediment cores and ice core records from elsewhere in the Andes from the beginning of the Late Horizon through to the Colonial Period (AD 1532- 1800's) (Abbott *et al*., 2003; Abbott and Wolfe, 2003; Cooke *et al*., 2007, 2009; Cooke and Abbott, 2008; Eichler *et al*., 2015, 2017; Guédron *et al*., 2021). This increase in pollutants, along with Cu, Ag, Au, and Hg, has been linked with Incan and Hispanic mining activities across the altiplano of Peru and Bolivia (Cooke *et al*., 2009; Eichler, *et al*., 2017; Kennedy and Kelloway, 2020). Within the Lake Titicaca record the most intensive period of mining, inferred from Cu and Pb isotopes, centred on the Late Horizon until the end of the Colonial Period (~AD 1500-1830). A similar pattern is seen at Laguna Pirhuacocha and Llamacocha in the Junín region; the former is situated near Cerro Pasco, a major mine still in use today, and the latter near the mining region of Morococha, situated to the east of the Chillón Valley (Cooke *et al*., 2007, 2009; Guédron *et al*., 2021). The increase in mining activities is thought to have accelerated with the arrival of the Spanish as silver metallurgy became more prolific and an important part of the Spanish economy, as a result the production of less-valuable copper declined. Peru and Bolivia dominated silver production during AD 1500-1700 and by the end of the 19th century were a major world producer of non-ferrous metals including Sb, Zn, W, Ag, Au, Cu, Pb and Cd (Eichler *et al*, 2015).

The elevated levels of Zn within Antaycocha through the Colonial Period and into Present Day (with the transition of AN-IT-4 to AN-IT-5), likely reflect the increase in colonial mining activities in the region. Until 30-40 years ago there was a large presence of mining trucks on the roads around Antaycocha leading up to the mines within the Quebrada de Rantao, with activity ceasing sometime in the 1980's (*C.Farfán pers. comm.).* The other records of mining from the Andes which used isotopic analysis also recorded an increase in mercury (Hg) from the middle Colonial Period onwards (Cooke *et al*., 2009; Kennedy and Kelloway, 2020; Guedron *et al*., 2021), due to a change in silver smelting practices. Hg is however, outside the detection limits of the ITRAX scanner (Thomson *et al*., 2006), and is not picked up within the µXRF analysis. Further work on the isotopic signatures of Hg, as well as Zn and Pb, would further corroborate the findings related to increased Colonial Period mining activity.

With the transition to the Colonial Period, the sequence from Antaycocha shows evidence for two distinctive peaks in PC1 (Fig. 4.19), and the terrigenous and erosional input indicators (Fig. 4.11), at *~416 cal yrs BP (AD 1534)* and *~405 cal yrs BP (AD 1545).* This has been identified as a second erosional event (Erosional Event Two), with the µXRF signature being similar to that of pre-wall construction. The first of these peaks does not correspond with any changes in the lithostratigraphy or organic matter content, showing the µXRF data to be more sensitive to increased mineral content. The second peak, however, corresponds with a decrease in organic matter. The timing of this erosional event coincides with more negative $^{\delta}18O$ values in the Laguna Pumacocha record and increased lithic concentration in the Lima marine core during the pluvial LIA period (Rein *et al*., 2005; Bird *et al*., 2011). An advance in ice was also seen during the LIA at Nevado Huaguruncho, Pasco Region, between ~200-400 years ago (AD 1550-1750) under colder and wetter conditions; an advance of that size was last recorded under Late Glacial conditions (Stansell *et al*., 2015). An increase in precipitation would have increased erosion and led to more minerogenic material entering Antaycocha. The nature of the µXRF signature at this time suggests the material was mainly being brought in via the stream from the hilltops above the basin as there is also an increase in Pb at this time. The increase in Pb has been hypothesised above to be of anthropogenic origin related to colonial mining, it is possible that more Pb was exposed due to mining but the increase in precipitation carried this signature into Antaycocha basin.

4.4.4 Present Day

(124-0 cal yrs BP AD 1826-2000)

During the present day (from 124 cal yrs BP/ AD 1826) there is a further reduction in agricultural activity around Antaycocha with the disused terraces around the basin being colonised by *Ambrosia*, as a ruderal weed, *Rumex*, *Euphorbia*, Fabaceae (e.g., *Lupinus*), Urticaceae and *Alternanthera*. There is a presence of herbivores within the landscape as evidenced by a peak in Oribatid Mites *~74 cal.yrs. BP (AD 1876)* and an increase in *Sporormiella ~40 cal yrs BP (AD 1910).* Today the corrals around Antaycocha are used for cows opposed to camelids, this likely reflects an increase in herding of cows by the local population, with farming taking place at lower elevations closer to local farmsteads at present day. The diverse agroforestry practices seen within the Colonial Period are replaced with the growth of *Eucalyptus*, an invasive species planted from the early 20th century onwards due to its fast-growing nature (Chepstow-Lusty and Winfield, 2000).

As with the previous periods, there is evidence for periods of climate change within the last 200 years. Around AD 1982 an in washing of fine silty material is recorded in the lithostratigraphy and organic matter content (Erosional Event 3, Fig 2.18), the timing of this event coincides with one of the strongest El Niño events since records began during AD 1982-1983 (Maasch, 2008). Within the western Andes at present day El Niño signals normally present themselves as very wet and increased flooding on the coast and arid conditions with the failure of rains in the highlands (Sandweiss and Quilter, 2012). This inclusion of fine mineral material may therefore reflect a dust event. Unfortunately, due to the unconsolidated nature of the sediment at the top of the core, it was not possible to retrieve µXRF data for the top part of the core and so it is not possible to characterise the nature of this erosional event further using the µXRF data. It is possible however that Antaycocha was sensitive to strong El Niño signals.

Chapter 5 - Ayapampa Wetland (Pampachiri, Chicha-Soras Valley)

5.1 Introduction

Chapter 5 details the results of the analysis on Ayapampa Wetland, Chicha-Soras Valley, Apurímac. Section **5.1.1** contains an overview of the regional archaeology in order to provide a cultural context for the palaeoenvironmental work. The study area and specific research sites are described in Section **5.1.2**. This is followed by a brief statement on the methodologies used (Section **5.2**). A full description of the results from Ayapampa Wetland (phytolith analysis), is provided in Section **5.3.3**, as well as an overview of previous work carried out on the wetland (Section **5.3.1, 5.3.2**). These results are then interpreted (Section **5.3.4**), and finally the results of all the analysis from Ayapampa wetland are discussed in Section **5.3**.

5.1.1 Regional Archaeology

The Chicha-Soras Valley was first settled with some permanence during the Initial Period (3750-2850 cal yrs BP/ 1800-900 BC), although evidence for human activity is limited until the Middle Horizon (1400-950 cal yrs BP/ AD 550-1000). The neighbouring valley of Sondondo, ~40km to the west within the Ayacucho Region, has provided evidence for Early Horizon (2750-2150 cal yrs BP/ 800-200 BC) and Early Intermediate Period (2150-1400 cal yrs BP/ 200 BC – AD 550) occupations. For the earlier periods, the archaeology of the Chicha-Soras Valley will be considered in reference to work elsewhere in the region and the Andahuaylas area. More valley specific archaeology is provided for the Middle Horizon (1400-950 cal yrs BP/ AD 550-1000), Late Intermediate Period (950-512 cal yrs BP/ AD 1000-1438) and the Late Horizon (512-418 cal yrs BP/ AD 1438-1532). A comparison of the Chicha-Soras cultural development to the general Andean chronology is provided in Table 5.1. The Middle Horizon, Wari cultural phase starts earlier in the Chicha-Soras Valley than in the two previous study areas (Callejón de Huaylas and Chillón Valley), due to its proximity to the Wari heartlands in Ayacucho (<150 km away). The Late Intermediate Period is split into two different cultural traditions, the Huamanaga during the early, Late Intermediate Period and Chanka during the late, Late Intermediate Period. The Chicha-Soras Valley then experienced a high-level of influence by the Inca Empire in the Late Horizon. Finally, the Valley fell into Spanish rule following the conquest during the Colonial Period (418-124 cal yrs BP/ AD 1532-1826).

Table 5.1: Cultural chronology for the Chica-Soras Valley in comparison to the Central Andean Chronology (based on Finucane et al., 2007; Meddens and Branch, 2010; Meddens and Schreiber, 2010).

<table>
<tr><th>Central Andes General Chronology</th><th>Chicha-Soras Valley</th></tr>
<tr><td colspan="2">Colonial Period AD 1532-1826</td></tr>
<tr><td>Inca
AD 1438-1532</td><td>Inca
AD 1438-1532</td></tr>
<tr><td rowspan="2">Late Intermediate
AD 1100 - 1438</td><td>Chanka
AD 1200-1438</td></tr>
<tr><td rowspan="2">Huamanga
AD 1000-1200</td></tr>
<tr><td rowspan="3">Middle Horizon
c.AD 500 - 1100</td></tr>
<tr><td>Wari
AD 550-1000</td></tr>
<tr><td rowspan="2">Huarpa
200 BC- AD 550</td></tr>
<tr><td>Early Intermediate
200 BC - AD 500</td></tr>
<tr><td>Early Horizon
800 - 200 BC</td><td>Chavin Era
800-200 BC</td></tr>
</table>

Early Intermediate Period – Huarpa (2150-1400 cal yrs BP/ 200 BC- AD 550)

Occupation in the Chicha-Soras Valley during the EH and EIP appears to have been in the form of low-density populations, with little direct evidence for human activity until the Middle Horizon. Information can be gained about the nature of human activity during the EIP from the adjacent Sondondo Valley and the Andahuaylas area to the northeast (Schreiber, 1992). Although the Huarpa culture was dominant in the Ayacucho region at this time, it is unclear how much presence they had within the Chicha-Soras valley, some 140km away from the core Huarpa territory. Huarpa-type material has been recovered from Tororayoq-Huahuerqa on the east bank of the Rio Soras and within agricultural terracing at the site of Huaylla in the Andamarca area of the Sondondo Valley, however (Huarcaya, 2013). If the Huarpa culture, named after Huarpa style ceramics of red and black simple motifs on matte white, did have influence over the Chicha-Soras Valley it is likely the small rural communities present within the Huarpa core were also employed within the Chicha-Soras Valley (Leoni, 2005).

Despite its prominence in the MH, the site of Huari, and consequently the Wari polity, has its origins in the EIP. The site of Huaqanmarka, an apparent prelude to the development of Huari, is situated on a hilltop to the west of the core of Huari and was occupied during the EIP, as evidenced by Huarpa style ceramics (Valdez and Valdez, 2017). The hilltop location although relatively inaccessible, would have had added security benefits and provided an excellent vantage point of the surrounding landscape. In addition to Huaqanmarka, the remains of two other settlements, Chupapata and Sullucruz within the Huari area suggests a nucleation of populations towards the end of the EIP (Valdez and Valdez, 2017). Elsewhere in the Ayacucho and Apurímac Regions some sites were abandoned, whilst others grew bigger resulting in a fewer but bigger settlement pattern during the transition to the MH.

During the latter stages of the EIP, Late Nasca pottery remains are found within the Southern Central Andes indicating contact with coastal populations. This influence of pottery styles appears to have continued into the MH with Nasca design elements being incorporated into Wari style (Valdez and Valdez, 2013). Contact with the Nasca culture appears to have been somewhat of a stimulus for development in the highlands and a shift from rural to predominately urban lifestyles. The interaction between the Nasca and the highlands is further evidenced by the presence of cranial modification in burials at sites such as Nawinpukio in the Ayacucho Valley, a common practice amongst the Nasca (Finucane, 2008). Although the archaeological record from the Chicha-Soras Valley during the EIP does not provide clear evidence for the level of human activity, it is likely human impact on the landscape was low at this time, before the development of state-scale polities and widescale transformation of the landscape for agricultural development. This can be tested through the analysis of Ayapampa in terms of indicators for cultivation (in the pollen and phytolith record) and for landscape erosion (via the lithostratigraphy and pollen record).

Middle Horizon – Wari (1400-950 cal yrs BP/ AD 550- 1000)

Due to the proximality of the Chicha-Soras Valley to the capital of the Wari Empire, Huari, the MH started earlier than within the Callejón de Huaylas or the Chillón Valley. The Wari cultural traditions appear to have evolved from those of the Huarpa, with a continuation in some cultural and political traditions, opposed to a complete substitution by a new culture (Leoni, 2008). From 1400 cal yrs BP (AD 550), the cultural centre at Huari, in the nearby region of Ayacucho, experienced large-scale transformation, becoming not only the most influential centre in the Ayacucho Valley, but also across the Central Andes (Valdez and Valdez, 2013, 2017). From the archaeological evidence, it is apparent Huari was the first centre to have organised areas for craft production, merchants, military, religious personal and bureaucrats and to support a large population size within the Southern-Central Highlands (Valdez and Valdez, 2017). The plan and layout of Huari suggests it grew quite rapidly without formal planning with new suburbs created to accommodate newcomers and the migration of people into the city from the Hinterlands (Valdez and Valdez, 2017).

It is during the MH that the Chicha-Soras Valley first came into prominence, likely acting as a route down to the coast to settlements around Nazca and Ica (Barnes, 1981). The Chicha-Soras Valley was extremely agriculturally productive during the MH, with the construction of terraces leading to widescale transformation of the landscape (Kemp *et al*., 2006; Branch *et al*., 2007). Agricultural systems seem to have been managed through religious structures emphasizing the importance of kin-relationships and ancestor veneration (Meddens and Branch, 2010). At Yako, the remains of picks and spades made of basalt for agricultural tools and animal bones, including camelids, indicate to a largely agriculture oriented economic system (Meddens and Branch, 2010). The largest site excavated within the Chicha-Soras Valley is that of Chiqnajota, at this site carbonized maize cobs were found in association with late-MH pottery vessels, obsidian, flakes, and artefacts as part of an offering deposit, indicating maize, and cultivation, were significant to MH communities (Meddens and Branch, 2010). Indeed, human bone residue analysis from the nearby Ayacucho Valley confirms maize, as well as maize fed animals, constituted the subsistence base during the development of the Wari State (Finucane *et al*., 2006; Finucane, 2009; Valdez *et al*., 2010). Wari control over the Chicha-Soras Valley was likely relatively direct, unlike the more ephemeral presence within the Callejón de Huaylas and the Chillón Valley, resulting in heavy investment in the development of imperial infrastructure including settlements, roads and agricultural systems (Schreiber, 2004).

Late Intermediate Period – Huamanga and Chanka (950-512 cal yrs BP/AD 1000-1438)

The LIP in Apurímac is split into two distinctive cultures, the Huamanga (950-750 cal yrs BP/ AD 1000-1200) and the Chanka (750-512 cal yrs BP/ AD 1200-1438). The transition for the MH into the LIP is characterised by increased warfare and conflict as evidenced by the increase in trauma wounds within LIP burials (Tung, 2008). Osteological analysis reveals violence was not confined to a certain gender or age bracket, with men, women and children all receiving lethal attacks (Tung, 2008). This higher level of violent conflicts was likely due to the fragmentation of the Wari political regime and the emergence of newly autonomous groups leading to intense instability in the highlands (Tung, 2008).

During the LIP, life in the Chicha-Soras Valley appeared to continue as usual, with the pattern of complete disruption of agricultural infrastructure and the abandonment of occupation sites which was widespread across the rest of Ayacucho and Apurímac, not witnessed to the same extent within the Chicha-Soras Valley (Finucane *et al*., 2007; Meddens and Branch, 2010). Instead, the LIP was a period of population expansion and the construction of new sites, including Pampa Marka during the Huamanga cultural transition (Barnes, 1981; Meddens *et al*., 2022). As well as an increase in settlement numbers, sites within the LIP also grew in size with sites such as Laymi, about 1.2km northwest of San Pedro de Larcy measuring 25ha and Auquimarca 4 km east of Pomacocha reaching 23ha, with the latter being the largest fortified site within the region (Meddens and Vivanco, 2018).

During the Chanka cultural tradition of the late, Late Intermediate Period (~750-512 cal yrs BP/ AD 1200-1438), there was a demographic shift with populations aggregating into high elevation hilltop settlements (above 3500m a.s.l.) in a reorganization of subsistence strategies, focused on high-altitude agro-pastoralism (Kellet, 2013). Lower valley areas were likely still utilised for agriculture but the *Suni* and *Puna* areas above 3500m a.s.l. nearer to the hilltop settlements experienced more intensive land use (Kellet, 2010). Large numbers of camelid bones were recovered in association with hilltop habitation sites near Andahuaylas in the Chanka heartlands, along with corrals, suggesting the Chanka focused on raising domesticated camelids opposed to hunting wild guanaco or vicuña (Kellet, 2013). The increase in hilltop settlements has also been attributed to the increase in warfare and conflict within the LIP, due to hilltop sites being more defensible (Tung, 2008; Kellet, 2013)

Cultural development within the LIP is set against regional climate change with drought conditions prevailing across the highlands from ~1150 cal yrs BP (AD 900) to around 600 cal yrs BP (AD 1350) as indicated by Quelccaya ice core record, Palestina cave record and the Lake Titicaca lake levels. Binford *et al*., (1997) argued there was a 10-15% reduction in net precipitation between AD 1030-1280 (Thompson *et al*., 2013; Apáestegui *et al*., 2014). This would have had a considerable impact on agricultural productivity, especially those reliant on rainfed irrigation systems. Of particular significance is the effect this would have had on crops such as maize which require a higher degree of soil moisture than other highland crops (Hastorf and Johannessen, 1993). A reduction in maize cultivation productivity may have been a contributing factor in the move towards other crops able to grow at higher altitudes (e.g., quinoa, *kiwicha*, potatoes and other tubers) and more camelid herding (Lane, 2006; Kellet, 2013). However, within the Chicha-Soras Valley the LIP seems to be a period of considerable remodelling and renovation of agricultural terraces at lower elevation with an increase in maize production as evidenced by the previous work on Ayapampa (see Section **5.3.1**). There are also a number of archaeological sites in association with agricultural terracing and irrigation infrastructure such as Taccarampa, Apuraccay, Cupo, Aputacca, Montaccahua on the west bank, and on the east side of the river, Kulkunchapampa and Huaychuapata, as well as the defensive sites of Puyca, Auquimarca, Chuntaya / Jasinchilla, and Qasinchilla (Keely and Meddens, 1993). The nature of agricultural activity within the LIP will be explored further through the results of the chapter. At the end of the LIP the Chanka, from Soras, Andamarca, Lucanes, Parinacocha and Andahuaylas, resisted the Inca and attempted to invade Inca territories, however, their attack on Cusco failed and eventually they were instead incorporated into the Inca Empire (Barnes, 1981; Meddens and Schreiber, 2010).

Late Horizon – Inca (512-418 cal yrs BP/ AD 1438-1532)

Inca presence in the Chicha-Soras Valley was very pervasive with marked evidence of Inca architecture and material culture at all domestic sites currently investigated within the valley. The Chicha-Soras Valley was incorporated into the Inca Empire very early in the consolidation of Inca authority, with the Soras ethnic group being conquered during the reign of Pachacuti Inca Yupanqui in the mid-15th century AD (Meddens and Schreiber, 2010). The Incas reorganised Soras settlements adding new Inca buildings to already established settlements and created entirely new settlements. There was also a reduction in the high-altitude mountain top sites prevalent in the LIP and an expansion in the size and number of mid-valley, slope settlements (Meddens and Schreiber, 2010). Substantial settlements occupied in the LIP, including Chiqna Jota, Qasapampa, Laymi and Taccarampa, appear to have been occupied into the LH indicating the Inca did not cause widescale abandonment of settlements but made use of already established infrastructure adding provincial Inca architectural elements (Meddens and Schreiber, 2010).

Although it is believed the majority of the terracing in the Chicha-Soras Valley was developed by the LH, with major periods of construction in the MH and some reconstruction in the LIP (Branch *et al*., 2007), more marginalised steeper slopes appear to have been brought into production during the LH (Meddens and Schreiber, 2010). Irrigation systems also appear to have expanded during the LH, potentially in response to an increase in available water during the LIA, this will be explored further in the discussion (Section **5.3**) (Keely and Meddens, 1993; Bird *et al*., 2011). Following the Spanish conquest, the number of towns in the Chicha-Soras Valley reduced and the surviving population concentrated into a smaller number of Spanish style settlements (Meddens and Schreiber, 2010). This likely had a resulting effect on the management of agricultural systems within the valley, with a reduction in labour force to maintain them, the post-conquest trend will also be explored further through the results of this study.

5.1.2 Study Area and Site Descriptions

The Chicha-Soras Valley, in which Ayapampa mire, the third site analysed in this thesis, is situated, forms a natural border for the Apurímac and Ayacucho region. Ayapampa and the associated agricultural terraces, which have previously been sampled, are situated on the Apurímac side of the Rio Soras (Fig 5.1). Vegetation within the Chicha-Soras Valley mainly comprises of *Puna* grasslands, which dominates areas in the valley above 3,800m; below this altitude, the lower elevations have been cleared for agriculture (Silva, 2005). Grazing is commonly practiced in the valley, and arable agriculture takes the form of the Andean staples, potatoes, quinoa, and maize.

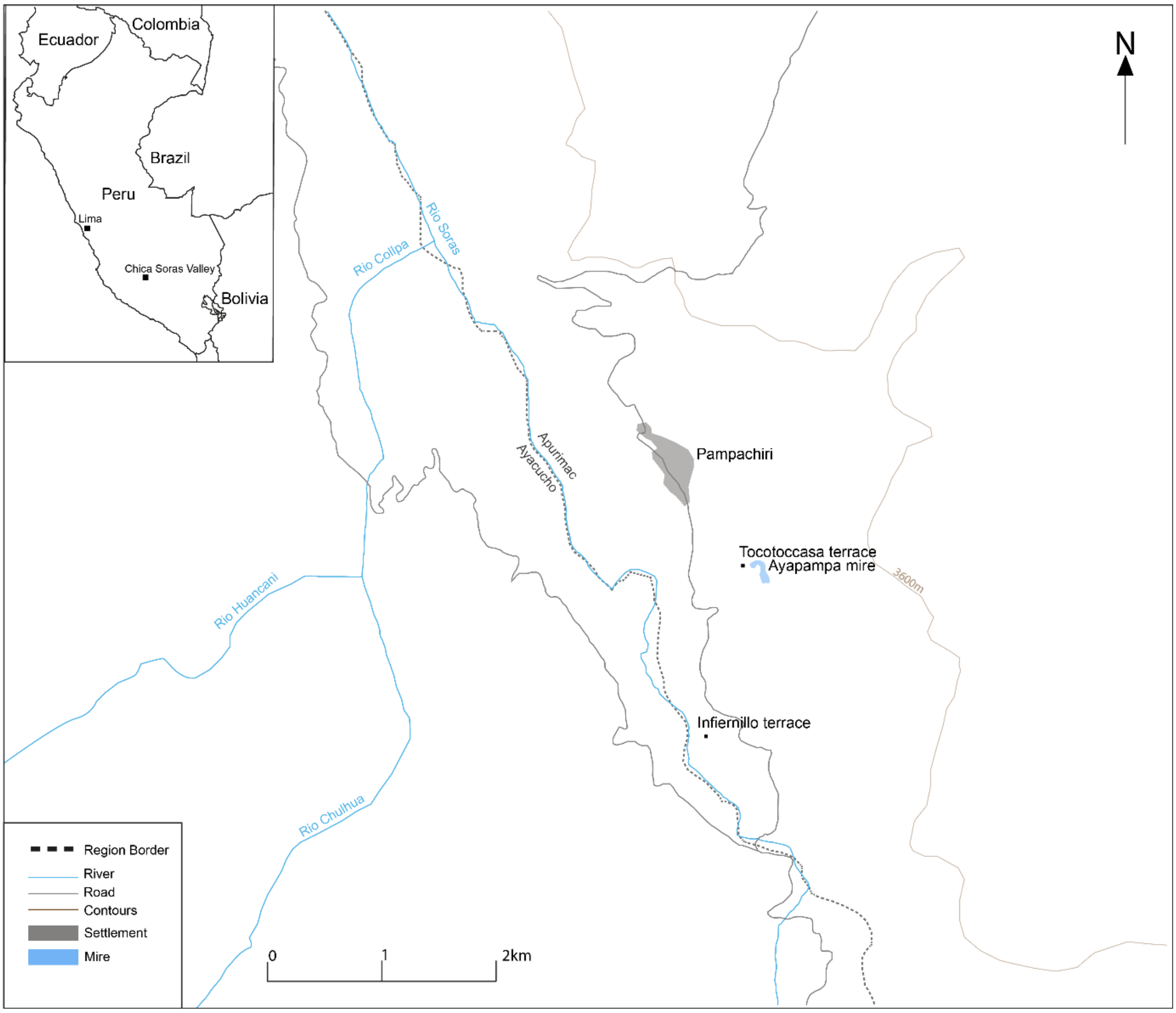


Figure 5.1: Location of sites within the Chicha-Soras Valley, Apurímac.

Ayapampa mire (Fig 5.2), situated near the village of Pampachiri in the Chicha-Soras Valley, sits at 3360m a.s.l., placing it in the *Quechua* environmental zone. The basin is approximately 150m long and 50m wide and has a single outflow stream that drains in the west to the Rio Soras. The site is currently not influenced by a high level of human activity as there is no planted agriculture currently practiced on the terraces visible around the site (Fig. 5.3). One of the terraces (Tocotoccasa TOC), situated within 20m of the Ayapampa basin (14^{o} 11' 40.1" S, 73^{o} 32' 18.9" W, 3417m a.s.l.), has previously been excavated and analysed for its soil properties, phytoliths, as well as radiocarbon dating (Kemp *et al*., 2006; Branch *et al*., 2007; Handley, 2016). The previous analysis from this terrace will be used in comparison to the new phytolith data presented here from Ayapampa mire. In addition to TOC, a second terrace, Infiernillo (INF), has also previously been analysed. This terrace is 1km to the southeast of Ayapampa at an altitude of 3447m a.s.l. (14^{o}12' 29.4" S, 73^{o}32' 25.1" W). The data previously published (Kemp *et al*., 2006) and analysed by the author as part of their master's thesis (Handley, 2016), from INF will also be used in comparison with new data presented herein.

Figure 5.2 Ayapampa mire, with abandoned terraces in the background behind the site.

Figure 5.3 An example of the artificial agricultural terraces within the landscape surrounding Ayapampa Mire.

5.2 Methodology

Core samples previously obtained from the Ayapampa Mire were collected using a Russian peat sampler (semi-circular, 5cm diameter) and described using the Troels-Smith method (1955) outlined in **Chapter 2**. These sediments were analysed for organic matter content, pollen and microscopic charred particles (Branch *et al*., 2007), and an assessment of the phytolith content (Handley, 2016). The new body of phytolith analysis on the sequence from Ayapampa followed the protocol outlined in **Chapter 2**. A total of 36 samples were taken, including eight samples from below the hiatus to take the phytolith record back to ~3000 cal yrs BP. In addition to the new phytolith analysis carried out on Ayapampa sequence, results from previous phytolith analysis (Handley, 2016) of two terrace sequences are presented in Section **5.3.1**. The collection of samples from the terraces involved cutting a trench (1-10 m) perpendicular to the terrace wall, description of the soil profile within a 1m wide section (Hodgson, 1976), and the extraction of bulk samples at 5cm vertical intervals from the section permitted analysis of percentage organic carbon, and total and available phosphate (Branch *et al.,* 2007), and phytoliths (Handley, 2016).

5.3 Ayapampa Mire and associated terraces

Section **5.3** (and the corresponding subsections) provides details of previous work carried out on Ayapampa Mire in relation to Silva, (2005), Kemp *et al.,* (2006), Branch *et al.,* (2007), and Handley, (2016) as well as new phytolith analysis on Ayapampa Mire carried out for this body of work. Previous analysis on the basin includes the production of a full sequence pollen, organic matter and micro-charcoal records (Silva, 2005; Branch *et al.*, 2007) and a pilot phytolith study (Handley, 2016); the results of these are included below for reference. As mentioned in Section **5.3**, in addition to Ayapampa Mire, previous work also included the analysis of two agricultural terraces (TOC and INF) for the macro-and micromorphology of the soil (Kemp *et al*. 2006), geochemical analysis (in the form of total phosphate and available phosphate on TOC) (Branch *et al*., 2007) and phytolith analysis (Handley, 2016). The results of the phytolith analysis from the terraces is summarised below in Section **5.3.2**.

5.3.1 Results of Previous Work

A programme of radiocarbon dating was carried out on Ayapampa Mire in preparation for the Kemp *et al*. (2006), and Branch *et al*. (2007), publications. Six peat samples from Ayapampa were submitted to the Waikato Radiocarbon Dating Laboratory, New Zealand and one to Beta Analytic Inc., USA (Table 5.2). TOC and INF also have radiocarbon dates associated with certain soil horizons within the excavated terrace profile. For TOC, one sample containing macro-charcoal was submitted to SUERC, East Kilbride. For INF, three large fragments of charcoal were submitted, to SUERC, from the same horizon to help test the *in-situ* nature of the charcoal within soil profiles, in turn testing the reproducibility of the radiocarbon ages (Kemp *et al.*, 2006) (Table 5.2). The radiocarbon ages received were calibrated using the IntCal13 calibration curve (Reimer *et al*., 2013) in OxCal v.4.2 (Bronk Ramsey and Lee, 2013) and an age-depth model for the Ayapampa sequence was created (Fig. 5.4). Due to the core sequence containing a large sandy lithological unit, assumed to be because of catchment erosion, the model was run with a hiatus in the model spanning the depths of this unit, without this hiatus in the sequence it was not possible to create a stable age-depth model that took account of all of the depths. It is unknown whether the erosional unit is one singular event or a phase of erosion, and so by using a hiatus within the model it models the two halves of the P-sequence individually and does not attempt to model the dates across the sandy unit. Resulting in three radiocarbon dates contributing to the lower half of the model and four to the upper part of the model. This provides satisfactory model agreement, with an Amodel value of 98, and is considered to be a good fit to the data. The resulting age depth model can be seen in Figure 5.4.

Table 5.2: Results of the radiocarbon dating programme for Ayapampa mire, TOC and INF terraces (Branch et al., 2007).

Lab No.	**Sample Depth (cm)**	**Radiocarbon Age BP**	**Calibrated date (95% confidence)**	**δ^{13}C ‰**	**Material Dated**
SUERC-1531	TOC 70cm	1368 ±25	615–695 AD	-27.3	Charcoal
SUERC-1533	INF 70cm	1167 ±25	770–900 AD	-22.8	Charcoal
SUERC-1535	INF 70cm	1186 ±25	770–900 AD	-21.3	Charcoal
SUERC-1692	INF 70cm	1200 ±38	760–900 AD	-24.5	Charcoal
Wk-12220	42-52	193 ±45	310-0 cal. BP	-27.9 ±0.2	Bulk Peat
Wk-12221	95-105	388 ±40	520-310 cal. BP	-28.3 ±0.2	Bulk Peat
Wk-12222	194-204	712 ±40	730-560 cal. BP	-27.5 ±0.2	Bulk Peat
Wk-12223	235-245	755 ±64	800-620 cal. BP	-27.0 ±0.2	Bulk Peat
Wk-12224	295-305	2075 ±60	2020-1880 cal. BP	-28.2 ±0.2	Bulk Peat
Wk-12225	345-355	2228 ±58	2338-2049 cal. BP	-28.1 ±0.2	Bulk Peat
Beta-142326	417-427	3460 ±90	3970-3485 cal. BP	-24.1 ±0.2	Bulk Peat

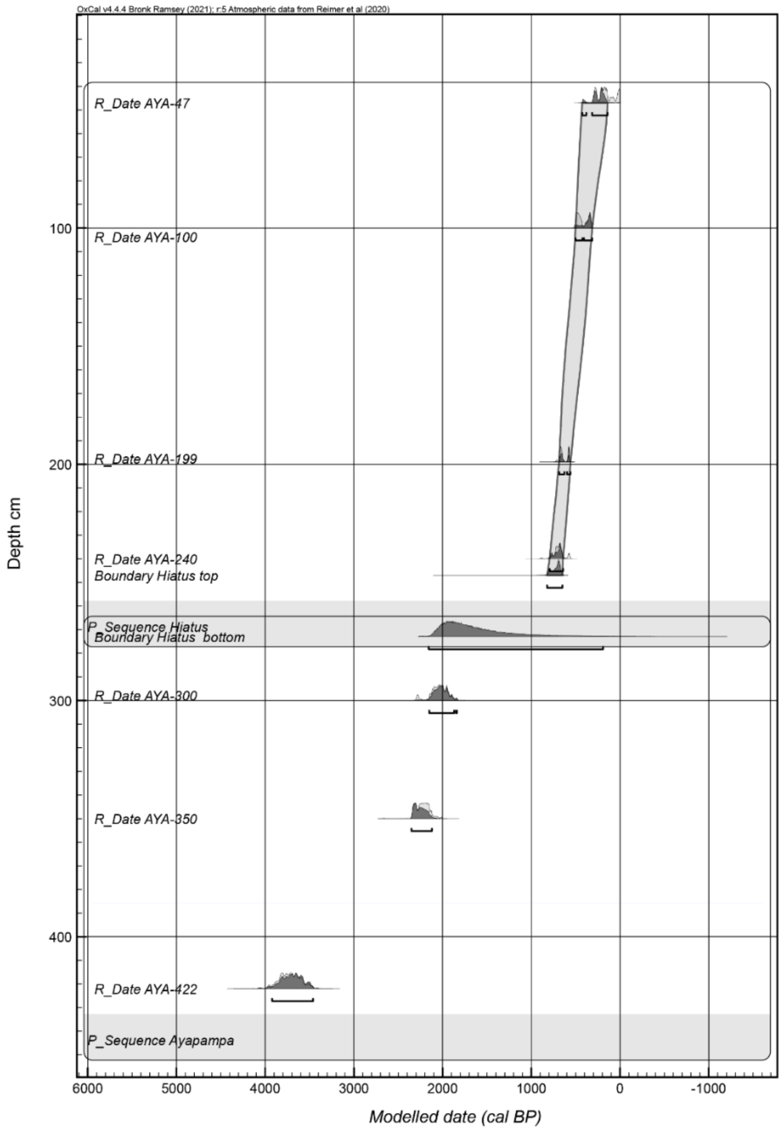


Figure 5.4 Age-depth model for Ayapampa sequence based on the new modelled dates using IntCal20.

The radiocarbon dates for Ayapampa show the sequence dates back to at least 3970-3485 cal yr BP, as this is the age of the basal radiocarbon date at 417-427cm, with the base of the sequence at 459cm being older than this (Fig. 5.4). The terrace dates reveal the presence of Middle Horizon terraces in both soil sequences. Within INF the 2bAH soil horizon (Fig. 5.5) dates to 1190-1050 cal yr BP (AD 760-900), and in TOC the 2bAH soil horizon (Fig. 5.6) dates to 1335-1255 cal yr BP (AD 615-695). Huamanga type pottery was also found in association with the 2bAH buried horizon at INF. Revealing a period of terrace development took place during the Middle Horizon, this was followed by further disturbance likely resulting from terrace reconstruction during late, Late Intermediate (~AD 1200-1400) (Branch *et al*., 2007).

Results of the palaeoecological investigation (Fig. 5.5) of the wetland indicated that prior to *~2064 cal yrs BP* (114 BC) (LPAZ 1 and 2) the landscape surrounding Ayapampa was largely dominated by Poaceae, perennials and shrubs of *Asteroideae/Cardueae*. The wetland vegetation mainly composed of Cyperaceae and Plantaginaceae, likely represented by *P. tubulosa or P. rigida* both commonly found on *bofedales* within the Peruvian highlands (Polk *et al*., 2014). From *~2284 cal yrs BP* (334 BC), Cyperaceae expanded with the renewal of peat formation when water levels were lowered. Chenopodiaceae/Amaranthaceae and Solanaceae were both present in high proportions within LPAZ 1 and 2, during a period of landscape instability inferred by the deposition mineral-rich fluvial sediment, indicating these may represent cultivated quinoa and potatoes during the Initial Period (3750-2750 cal yrs BP/ 1800-800 BC) and Early Horizon (2750-2150 cal yrs BP/ 800-200 BC). A significant period of landscape erosion took place within the basin during the EIP (2150-1400 cal yrs BP/ 200 BC-AD 550), MH (1400-950 cal yrs BP/ AD 550-1000) and into the early part of the LIP (950-512 cal yrs BP/ AD 1000-1438) cultural periods, as indicated by the deposition of a thick unit of sandy clay.

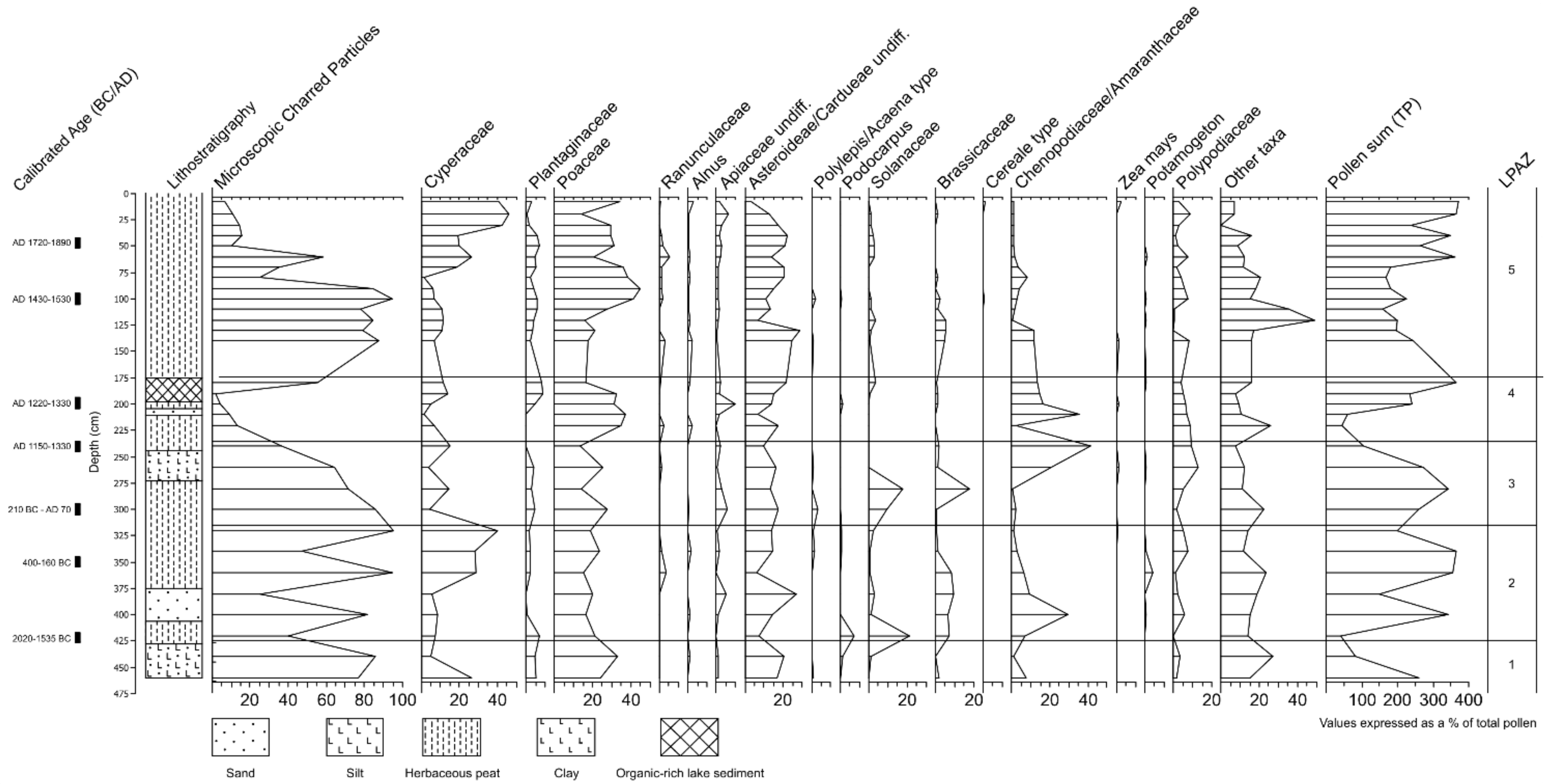


Figure 5.5 Selected taxa pollen diagram from Ayapampa mire (adapted from Branch et al., 2007)

Chenopodiaceae/Amaranthaceae and *Zea mays* (maize) are present within the upper part of LPAZ 3, concurrent with the landscape erosion signal, signifying a prolonged period of cultivation. Peat formation resumed at *~692 cal yrs BP* (AD 1258) with an increase in grass dominated wetland vegetation. The presence of Chenopodiaceae/Amaranthaceae may indicate cultivation during the LIP, this is supported by the presence of Solanaceae and *Zea mays* during the second half of LPAZ 4 indicating a continuation of farming practices throughout the LIP. The increase in mineral rich sediment from *~611-553 cal. BP* (AD 1339-1397) indicates a further period of landscape erosion within the basin during the LIP. The LH (512-418 cal yrs BP/ AD 1438-1532) is poorly constrained by the pollen record (~118-158 cm; LPAZ 5) but is characterised by possible evidence for cultivation of Solanaceae, Chenopodiaceae/Amaranthaceae and *Zea mays*, as well as the marked increase in microscopic charred particles (micro-charcoal) providing overwhelming evidence for vegetation burning. With the transition to the Colonial Period (418-124 cal yrs BP; AD 1532-1826) and into the Republican Period (AD 1826 to the present day) there is a significant reduction in burning concurrent with decreased landscape erosion and a demise in the frequency of cultivars. This is probably a result of the reduction in human-activity, including the cultivation and management of the terraces, following the Spanish conquest. Populations within the Chicha-Soras Valley are known to have reduced during the Colonial Period which would have led to a reduction in workforce to maintain these agricultural structures. At present day there is a signal for the cultivation of European cereals along with *Zea mays*, however Chenopodiaceae/Amaranthaceae and Solanaceae levels remain low following the Colonial Period reduction.

5.3.2 Results of Previous Phytolith Work

As part of the previous work carried out on the mire and the terraces (Handley, 2016), a number of phytolith samples have been analysed. For TOC and INF, the author carried out a full sequence analysis as part of their master's thesis (Handley, 2016). Thirteen samples were analysed for TOC and fourteen for INF at a resolution of every 5cm from the A horizon to the base of the sequence in order to cover the buried Middle Horizon terraces. The results of this analysis are presented in the form of phytolith diagrams (Fig. 5.5 and 5.6) below. For the full results and raw counts, see Handley (2016). Within the same publication, a pilot study on the preservation of phytoliths within Ayapampa was carried out. The aim of this pilot study was to ascertain whether it would be possible to carry out a full phytolith counts on the samples from the basin and to provide presence and absence information on the main phytolith morphotypes. The results of this pilot study can be seen in Table 5.3, from this it was decided there was a good level of phytolith preservation, with some samples reaching 300 phytoliths in just one transect of the phytolith slide. Based on this, phytolith analysis involving full counts (300 phytoliths in total) was carried out for this body of work. The vegetation and environmental history interpretation based on the phytoliths from Ayapampa will be discussed in relation to the new phytolith analysis. Table 5.3 is provided for reference; no further interpretation of this data will be presented within this section. A brief summary of the results and interpretation of the phytolith analysis on the terrace sequences will be provided below as no further analysis has been carried out on these as part of this new body of work. The naming of phytoliths has been updated in Table 5.3 and Figures 5.6 and 5.7 to follow the International Code for Phytolith Nomenclature (ICPN) 2.0. (ICPT, 2019), for consistency with this new body of work and to allow comparison between datasets. At the time of completion of Handley (2016), only ICPN 1.0 was published (Madella *et al.,* 2005).

Table 5.3: Results of the phytolith assessment carried out on Ayapampa as part of Handley (2016), represented as presence (Green) and absence (White) of phytolith morphotypes.

Depth (cm)	**Phytolith Morphotypes**											
	Rondel	Wavy Topped Rondel	Saddle	Bilobate	Polylobate	Bulliform Flabellate	Crenate	Elongate Entire	Elongate Sinuate	Cyperaceae Cone	Acute Bulbosus	Total Phytoliths
143-144	🟩		🟩	🟩			🟩	🟩			🟩	75
151-152	🟩	🟩	🟩	🟩			🟩	🟩	🟩			127
159-160	🟩		🟩				🟩	🟩				42
167-168	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	300+
175-176	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	300+
182-183	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			300+
191-192	🟩	🟩	🟩	🟩			🟩	🟩			🟩	144
199-200	🟩		🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	160
207-208	🟩		🟩	🟩		🟩	🟩	🟩			🟩	119
215-216	🟩		🟩	🟩	🟩		🟩	🟩	🟩		🟩	154
223-224	🟩		🟩	🟩			🟩	🟩	🟩	🟩	🟩	233
231-232	🟩		🟩	🟩	🟩		🟩	🟩	🟩			69
240-241	🟩		🟩	🟩		🟩	🟩	🟩	🟩			182
247-248	🟩		🟩	🟩		🟩	🟩		🟩		🟩	300+
255-256	🟩		🟩	🟩			🟩	🟩			🟩	49
263-264	🟩		🟩	🟩			🟩	🟩	🟩		🟩	178

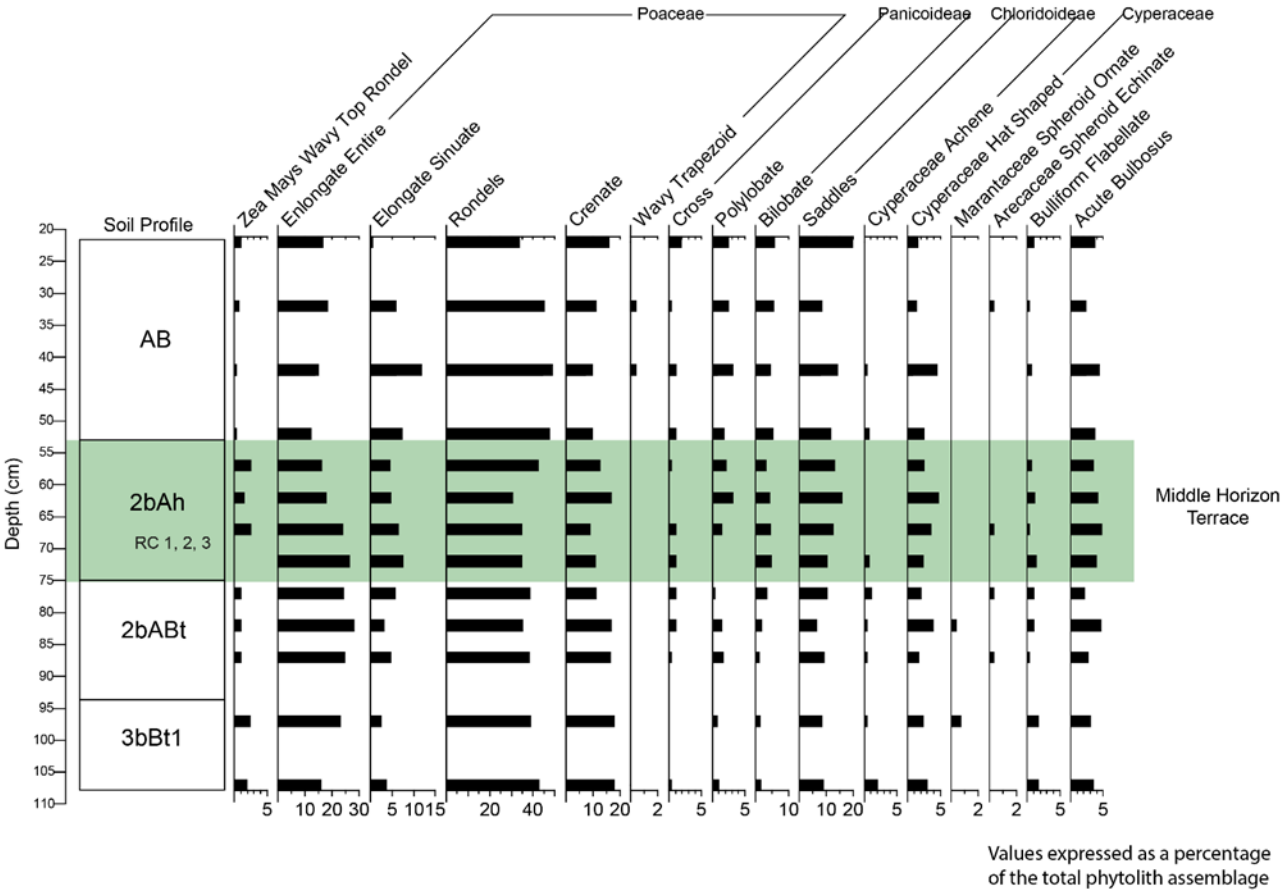


Figure 5.6 Phytolith diagram for INF terrace adapted from Handley (2016). Phytoliths are expressed as a percentage of the total phytolith assemblage, excluding Acute Bulbosus as this is a non-diagnostic morphotype found in most terrestrial plants. The green band is representative of the buried Middle Horizon terrace. Diagram produced using Tilia 2.6.1 (Grimm, 2019)

Grasses, confirmed by the presence of grass silica-short cell phytoliths (GSSCP) and elongate entire and elongate sinuate phytoliths, dominate the INF profile (Fig. 5.6), indicating the growth of grasses on the terrace surface as well as within the general environment. These are primarily made up of the Pooideae subfamily (Poaceae), seen by the high values of rondel phytoliths, indicating a large number of C3 grasses in the environment surrounding the terrace. C3 grasses commonly grow within the higher altitudes of the Andes, as they thrive in environments with greater water moisture availability and lower temperatures and are found within the *Puna*-grasslands within the Chicha-Soras Valley (Twiss, 1992). There is also evidence for C4 grasses through the presence of Chloridoideae sub-family (Poaceae) and Panicoideae sub-family (Poaceae) phytoliths. The presence of sedges, along with bulliform flabellates, indicate a presence of a wet environment on the terraces or in near-by soils. Bulliform flabellates are produced under an excess of water within the growing conditions, such as in wetland grasses (Piperno, 2006). Wavy top rondels from *Zea mays* were found throughout the profile, although percentages were higher within the horizon dating to the Middle Horizon, indicating that maize was cultivated on this terrace sequence in the past. A further cultivation signal may be provided through the presence of cross-shaped phytoliths; however, no size-metric analysis (Piperno, 2006: pp.49) was carried out on these samples to confirm whether the cross-shaped phytoliths are derived from domesticated maize or wild Panicoid grasses.

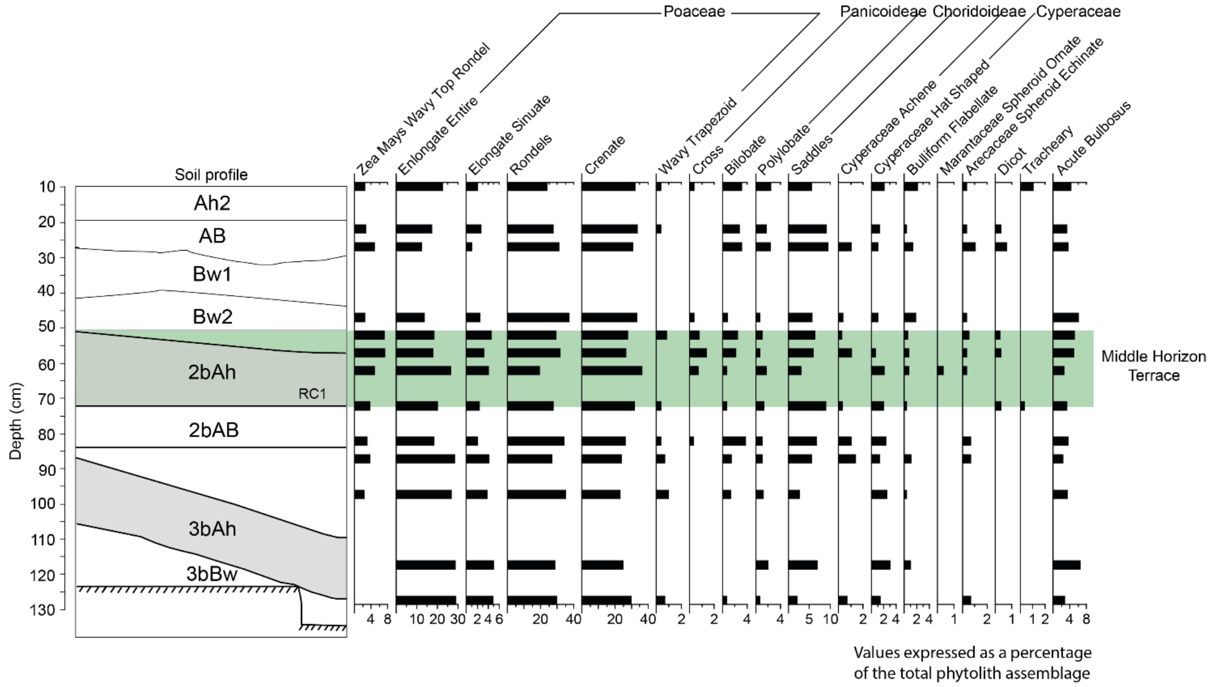


Figure 5.7 Phytolith diagram for TOC terrace adapted from Handley (2016). Phytoliths are expressed a percentage of the total phytolith assemblage, excluding Acute Bulbosus as this is a non-diagnostic morphotype found in most terrestrial plants The green band illustrates the buried Middle Horizon terrace. RC1 notes the radiocarbon sample taken at 70cm. Diagram produced using Tilia 2.6.1 (Grimm, 2019)

The phytolith assemblage from TOC (Fig. 5.7) is similar to that at INF with Pooideae sub-family (Poaceae) taxa dominating the sequence, however within TOC there is a greater proportion of rondels, potentially indicating a larger amount of C3 grasses growing in the surrounding landscape. This greater proportion of C3 grasses could be due to the close proximity of TOC to the edge of Ayapampa mire were wetland grasses grow. There is a lower proportion of saddles, and therefore C4 photosynthetic pathway plants, in the form of the subfamily Chloridoideae (Poaceae), at TOC. Sedges and bulliform flabellates are also present at TOC indicating similar wet conditions to those present further from the basin at INF. A greater proportion of maize phytoliths occur at TOC with *Zea mays* wavy top rondels recorded throughout the profile, although again in higher proportions within the Middle Horizon terrace. This likely represents the growth of maize on the terrace, due to the *in-situ* nature of phytolith deposition. Some cross-shaped phytoliths were also recorded within the TOC profile, primarily within the soil horizon dating to the MH, however like at INF, no discriminant function analysis (see Piperno, 2006: pp.49) was carried out on the cross-shaped phytoliths to determine if they are from cultivated maize or other wild Panicoideae sub-family (Poaceae) grasses. It has been suggested that the terraces may have first been used for the growth of quinoa before later being used for maize in the MH and LH (Branch *et al.*, 2007); however, plants within the

Chenopodiaceae/Amaranthaceae family produce little-no phytoliths and so this hypothesis was not able to be proven or disproven through the phytolith work (Handley, 2016). Previous attempts to recover pollen and fungal spores from the terraces were also futile (Branch *et al*., 2007), so any further work on these terrace profiles may have to look to other methods, such as ancient plant DNA (aDNA), to answer questions associated with cultivation succession.

Interestingly in both terrace profiles, INF and TOC, spheroid echinates (Fig. 5.7) were found, these are almost exclusively produced by plants within the Arecaceae (palm) family, and indicate the presence of palm residues, the naturally occurring source for which is ~150km away in Andean forests on the eastern flanks of the Andes at elevations between 700-2000m a.s.l. A second type of spherical phytolith, spheroid ornate was also recorded (Fig. 5.8), these are characteristic of the Marantaceae family, another plant family normally found at lower elevation. The presence of these spheroid phytoliths within the soil profiles from TOC and INF may suggest the presence of transported, or foreign soil. This concept has been explored elsewhere in the context of Incan Ushnu platforms from the Ayacucho region (Ogburn 2014, Branch *et al.*, 2014). However, due to their inclusion in a non-ritual, agricultural setting suggests it is more likely Arecaceae and Marantaceae plants themselves were transported to higher elevations as part of long-distance Amazonian-Andes exchange networks, a defining element of the Middle Horizon (Suarez and George, 2011). The agricultural context is particularly significant as previous finds of these families in archaeological sites in Peru have been restricted to domestic occupation or formal ritual contexts (Branch *et al*., 2014; Duncan *et al*., 2009; Hu, 2016; Perry *et al*., 2006). The agricultural context in which the palm phytoliths were found in the Infiernillo and Tocctoccasa terraces makes it most likely that they derive from the timber tips of agricultural tools made from *Chonta* (palm wood), either from a foot plough or a hoe; such tools have been recorded in a contemporary context near Cusco (Handlet *et al*., in prep). Marantaceae in contrast to palm, is less obvious to explain as an exotic product within a highland agricultural context. Marantaceae includes the important lowland cultivar of arrowroot (*Maranta arundinacea*), which has been identified in in a preceramic context in Peru from starch grains at the costal site of Buena Vista (Chillón Valley) dating to ~4400 cal. BP (Duncan et al. 2009), but the use of arrowroot in a pre-Hispanic context in the Andes is relatively unknown. Its presence at Ayapampa maybe due to the practice of ritual mixing where ritual items are brought together from local ecological zones and distant geographical environment, a practice which has great antiquity within the Andes (Ferreira, 2014). The inclusion of both Arecaceae and Marantaceae phytoliths within the record at Ayapampa confirms the existence of exchange networks across distances of at least 130 km from the Middle Horizon onwards.

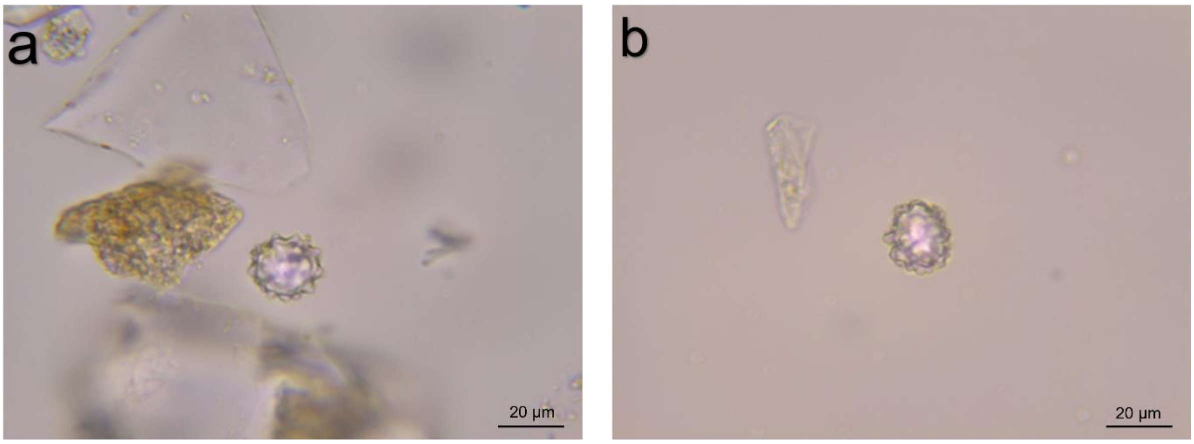


Figure 5.8 a) Arecaceae Spheroid Echinate. b) Marantaceae Spheroid Ornate. Microphotographs taken at x400 magnification

5.3.3 Results of the Phytolith Analysis

Phytolith samples were taken from Ayapampa Mire up to a depth of 304cm, as this was determined to cover the last 2500 years, in line with the other analysis from Huarca basin (**Chapter 3**) and the major developments in the archaeological record. The results of the phytolith counts were transformed into a percentage phytolith diagram of all morphotypes (Fig. 5.9) using Tilia 2.6.1 (Grimm 2019). The diagram was zoned using stratigraphically constrained cluster analysis (CONISS) and visual assessment of the stratigraphy, resulting in the creation of six local phytolith zones. Summary diagrams are also presented below (Fig. 5.10 and 5.12) in order to aid interpretation of the vegetation communities present at each site.

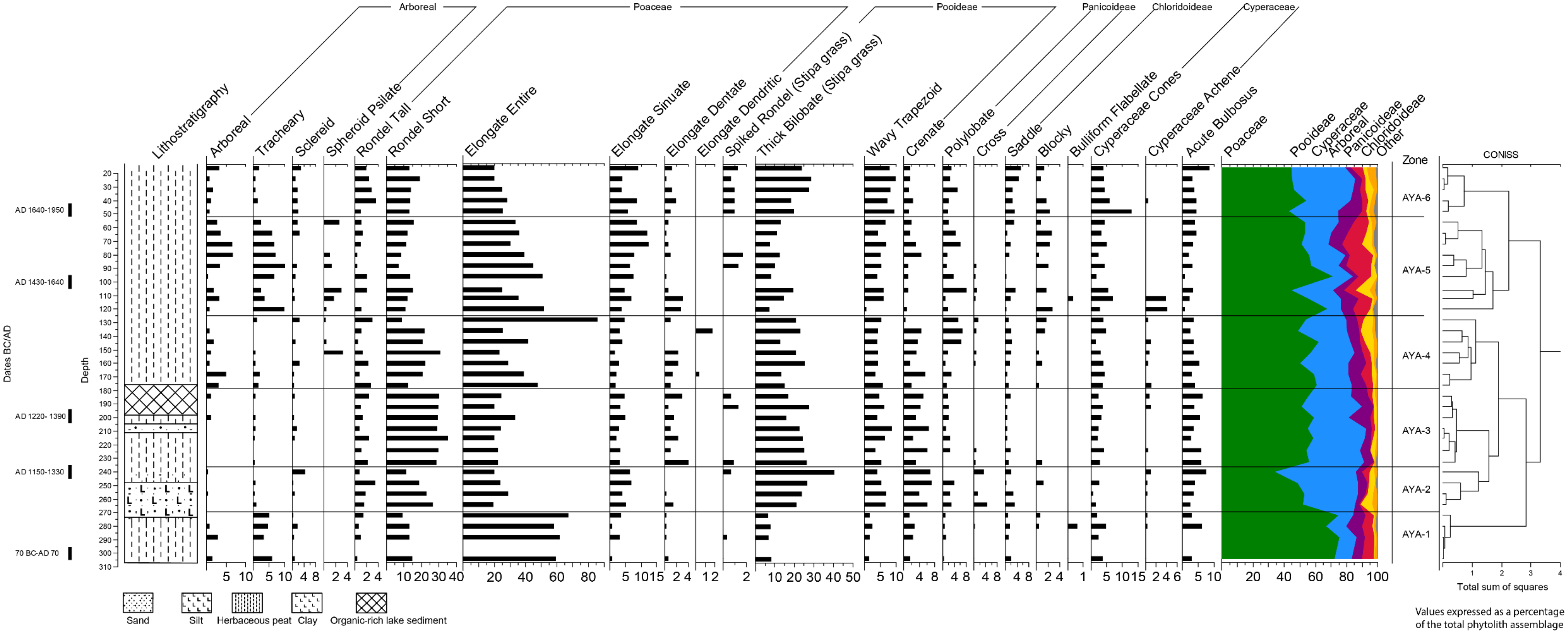


Figure 5.9 Detailed phytolith diagram for Ayapampa. Values expressed as a percentage of the total phytolith assemblage. Acute Bulbosus have not been included in this count, as they are non-diagnostic and found in most terrestrial plants. Diagram produced using Tilia 2.6.1 (Grimm, 2019).

Table 5.4: Phytolith assemblage descriptions for Ayapampa Basin. Values rounded to the nearest whole percentage.

Depth cm	**Phytolith Assemblage Zone**	**Chronology**	**Cultural Period**	**Phytolith Assemblage**	**Summary of phytolith taxa**
16-52	AYA-6	159-36 cal yr BP AD 1791-1914	Colonial Period-Present day	Poaceae - Pooideae	Non-diagnostic Poaceae 48%; Pooideae 35%; Cyperaceae 6%; Chloridoideae 4%; Arboreal 4%; Panicoideae 3%; Other 1%
52-125	AYA-5	433- 159 cal yr BP AD 1517-1791	Late Horizon - Colonial Period	Poaceae - Pooideae	Non-diagnostic Poaceae 60%; Pooideae 25%; Arboreal 11%; Cyperaceae 5%; Panicoideae 4%; Chloridoideae 1%; Other 1%
125-180	AYA-4	565-433 cal yr BP AD 1385-1517	Late Intermediate Period- Late Horizon	Poaceae - Pooideae	Non-diagnostic Poaceae 65%; Pooideae 26%; Arboreal 4%; Panicoideae 4%; Cyperaceae 3%; Chloridoideae 1%; Other <1%
180-237	AYA-3	679-565 cal yr BP AD 1271-1385	Late Intermediate Period	Poaceae - Pooideae	Non-diagnostic Poaceae 60%; Pooideae 33%; Cyperaceae 3%; Panicoideae 2%; Arboreal 1%; Chloridoideae 1%; Other <1%
237-269	AYA-2	1809-679 cal yr BP AD 141- 1271	Early Intermediate Period - Late Intermediate Period	Poaceae - Pooideae	Non-diagnostic Poaceae 50%; Pooideae 40%; Panicoideae 5%; Cyperaceae 2%; Arboreal 2%; Chloridoideae 2%; Other 1%
269-304	AYA-1	2026-1809 cal yr BP 76 BC – AD 141	Early Intermediate Period	Poaceae - Pooideae	Non-diagnostic Poaceae 77%; Pooideae 11%; Arboreal 6%; Other 3%; Cyperaceae 3%; Chloridoideae 1%; Panicoideae <1%

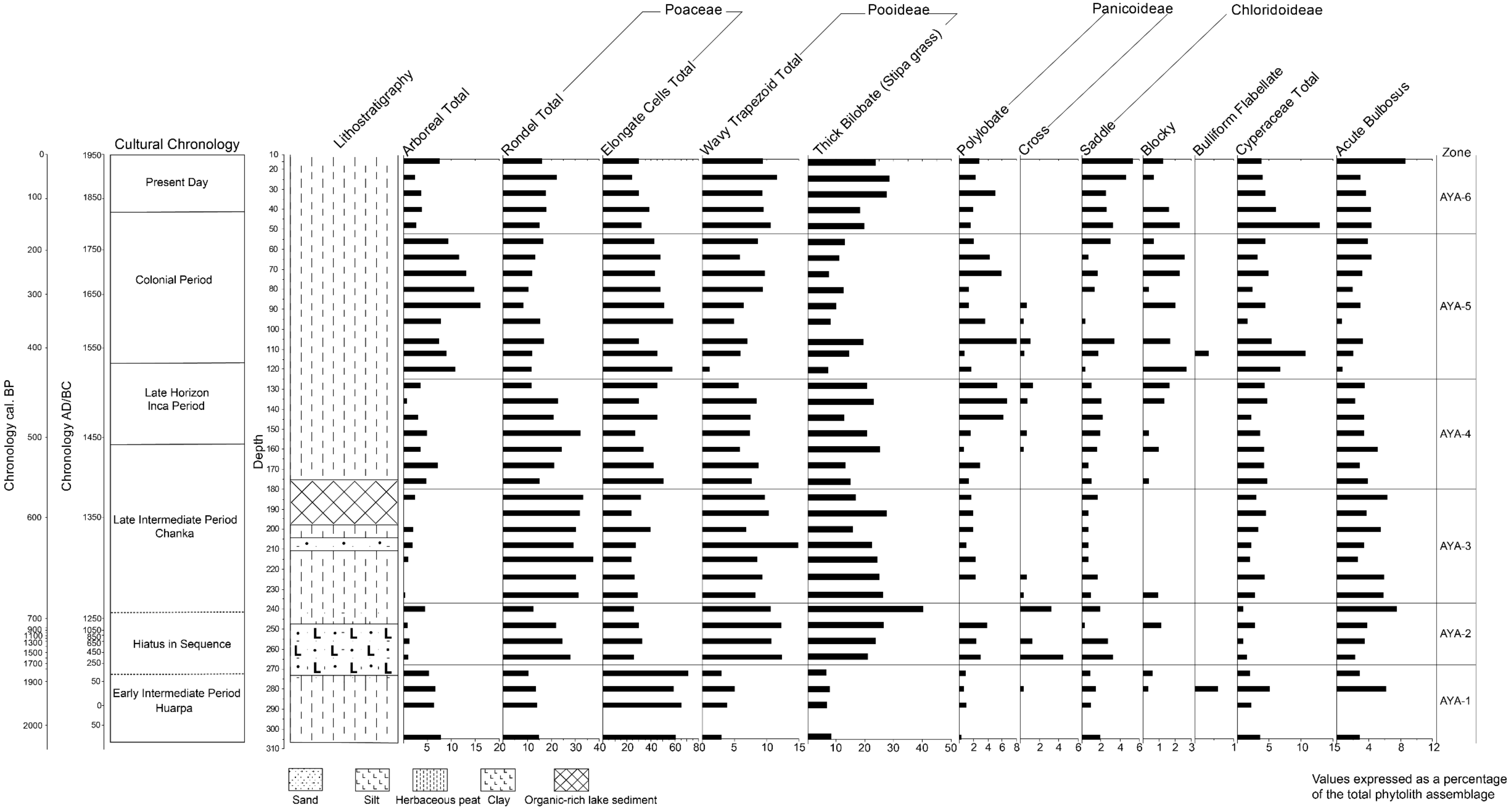


Figure 5.10 Summary Diagram for Ayapampa, percentage totals have been used where appropriate (see methodology Section 2.1). Values expressed as a percentage of the total phytolith assemblage. Acute Bulbosus have not been included in this count, as they are non- diagnostic and found in most terrestrial plants. Diagram produced using Tilia 2.6.1 (Grimm, 2019).

AYA-1 (304-269cm) (~*2026-1890 cal yrs BP/ BC 76 - AD 141*)

Poaceae – Pooideae

Grass phytoliths are dominant throughout this zone, especially those of non-diagnostic forms that occur in all Poaceae taxa, such as epidermal elongate cells (on average 64%). Phytoliths from the Poaceae sub-family Pooideae, including rondels and bilobates pertaining to *Stipa* grass and wavy trapezoids, occur in lower numbers but in total form the second highest abundant group (~11%). Phytoliths from the two other Poaceae sub-families represented in the assemblage, Panicoideae and Chloridoideae, are present in low values (<1% and 1% respectively). Arboreal phytoliths, here represented by tracheary, sclereid and non-diagnostic arboreal phytoliths, are also present in low numbers (~6%). Cyperaceae, including cones and very low values of achene bodies totalled 3% of the assemblage in this zone. There is only one occurrence of bulliform flabellates at 280cm (<1%) and two of blocky phytoliths at 272 and 280cm (~1%) within this zone.

AYA-2 (269-237cm) (~*1809-679 cal yrs BP/ AD 141 - AD 1271*)

Poaceae – Pooideae

Non-diagnostic Poaceae phytoliths decrease in this zone (from 57- 39%) and there is a greater abundance of Pooideae (~40%). This is mainly due to the increase in the number of thick bilobate from *Stipa* grass (from 20 to 40%). There is only one occurrence of spiked rondels from *Stipa* grass at 240cm (1%). The abundance of Panicoideae and Chloridoideae phytoliths also increases in AYA-2 (5% and 2% respectively), with cross phytoliths being at their highest values for the whole record during this zone (maximum 4%). Arboreal phytoliths decrease with very low numbers of non-diagnostic Arboreal and tracheary phytoliths (Arboreal total ~2%). Sclereid phytoliths, however, do reach their highest values at the top of this (4% at 240cm). Cyperaceae phytolith decrease slightly with less Cyperaceae cones than in the previous zone (~2%). There is one occurrence of blocky phytoliths at 248cm (1%).

AYA-3 (237-180cm) (*~679-565 cal yrs BP/ AD 1271 - AD 1385*)

Poaceae – Pooideae

Non-diagnostic Poaceae remains dominant in AYA-3; short rondels increase at the beginning of the zone and then remain stable (~30%), elongate entire phytoliths are present in similar abundance to in AYA-2 (~24%) and elongate dentate increases in abundance reaching its highest values for the whole record at the beginning of AYA-3 (4%). Total Pooideae phytoliths decrease to ~33%, this is largely due to the reduction in thick bilobates (maximum 26%, minimum 16%) from higher values in AYA-2. There are three occurrences of spiked rondels within AYA-3, still in low numbers (maximum 1%), while wavy trapezoids and crenates remain around ~5% and ~4% respectively. Cyperaceae increases with higher values of Cyperaceae achene (~ 1%) and Cyperaceae cones (~3%). Abundance of the Poaceae sub-family Panicoideae decrease in AYA-3, with lower values of polylobates (~2%) and cross-shaped phytoliths only occurring at the start of the zone (~1% 233-224cm). Chloridoideae phytoliths also decrease with saddles present in low values (~1%). Arboreal phytoliths are present in low numbers (~1%), with only two occurrences of non-diagnostic arboreal phytoliths in the top half of the zone (1% at 184cm and 200cm). There is one occurrence of blocky phytoliths at 233cm (~1%).

AYA-4 (180-125cm) (*~565-433 cal yrs BP/ AD 1385- AD 1517*)

Poaceae – Pooideae

Overall abundance of non-diagnostic Poaceae phytoliths increases in AYA-4 to ~65%, with elongate entire reaching its highest values for the whole sequence of the top of the zone (86%). Short rondels initially decrease (12%) before increasing again (maximum 30%). Elongate sinuate increases though the zone from 2%-4%. The only occurrence of elongate dendritic for the sequence occurs in AYA-4 (<1% at 168cm and ~2% at 136cm). Pooideae phytoliths decrease in abundance to ~26%, with less wavy trapezoid phytoliths (~4%). Stipae thick bilobate values fluctuate though the zone (minimum 13%, maximum 25%). Arboreal phytoliths increase again in this zone (~4%). Arboreal non-diagnostic phytoliths initially increase (maximum 5%) before decreasing again (minimum 0%). Tracheary and sclereid phytoliths are present in slightly higher values than in the previous zone (~1% for both). AYA-4 is the first occurrence in the sequence of spheroid psilate phytoliths from 152cm (~1%). Panidoideae phytoliths increase through the zone, with Polylobate increasing from 1% to 7% and cross-shaped phytoliths reappearing in the sequence at 160cm (~1%). Cyperaceae phytoliths are present in similar numbers to the previous zone (~3%), as are Chloridoideae phytoliths (~1%). Blocky phytoliths increase, reappearing at 160cm (<1%) and increasing to 1%.

AYA-5 (125-52cm) (*~433-159 cal yrs BP/ AD 1517- AD 1791*)

Poaceae – Pooideae

Grass phytoliths remain dominant through AYA-5, non-diagnostic Poaceae decreases in abundance from the previous zone back to ~60%, similar levels to those seen in AYA-3. Elongate sinuate phytoliths increase however though the zone from 4% to 12%. Elongate dentate decreases from 3% at the beginning of the zone to >1%. Pooideae phytoliths are the second most commonly occurring group (~25%); thick bilobates initially increase (maximum 19%) before decreasing again (minimum 6%). Wavy trapezoids are present in relatively high values (5%) and crenate phytoliths increase in the middle of the zone (maximum 4%). There are two occurrences of spiked rondels in this zone (1% at 88cm and 2% 80cm). Arboreal phytoliths occur in greater abundance in AYA-5 (~11%), with an increase in non-diagnostic arboreal (~3%), tracheary (~6%), and spheroid psilate (~1%). Overall Cyperaceae phytolith percentages are higher in this zone (~5%) than in AYA-4, this is partly influenced by the two peaks in Cyperaceae achene at 120cm (2%) and 112cm (3%) at the beginning of the zone. Phytoliths from the Panicoideae sub-family are present in similar values to the previous zone. Cross-shaped phytoliths are present until 88cm (~0.5%) before disappearing from the record for the rest of the sequence. Chloridoideae sub-family phytoliths are also present in low numbers (~1%). There is one occurrence of bulliform flabellate phytoliths in this zone at 112cm (<1%).

AYA-6 (52-16cm) (*~159-36 cal yrs BP/ AD 1791- AD 1914*)

Poaceae – Pooideae

Non-diagnostic Poaceae phytoliths decrease in AYA-6 (~48%), with elongate entire phytoliths decreasing from 35% to 20%. Short rondels remain relatively stable (~15%), while tall rondels increase from the previous zone (maximum 4%). Pooideae sub-family phytoliths increase reaching their second highest values for the record (~35%). Thick bilobates increase from AYA-5 (~23%), as do wavy trapezoids (~9%). Cyperaceae values reach the highest in the record (~6%), with Cyperaceae cones peaking at 48cm (13%). For the first time Chloridoideae are more abundant than Panicoideae phytoliths with saddles increasing to 5%, polylobates are present at ~3%. Arboreal phytoliths occur in lower values (~4%). Blocky phytoliths are present in low values (~1%).

5.3.4 Interpretation of Palaeoenvironmental Data

The phytolith assemblage from Ayapampa provides further evidence for the environmental history of Ayapampa Mire. To aid in the interpretation of the palaeoenvironmental data from Ayapampa, Figure 5.11 was created in order to allow for comparison between the different stratigraphic units, phytoliths zones, and local pollen assemblage zones. The dominating vegetation type recorded in the phytolith record throughout the sedimentary sequence was Poaceae grassland, this supports the pollen work with a high proportion of Poaceae pollen occurring throughout the sequence (Fig. 5.5). The high abundance of C3 Pooideae grasses throughout the Ayapampa sequence is indicative of the high-altitude location of the basin, 3360m a.s.l., with C3 grasses very common in the highlands because of the higher moisture availability and lower temperatures (Twiss, 1992; Aleman *et al*., 2014). The Pooideae subfamily grasses could be represented by *Festuca*, *Agrostis*, *Bromus, Dissanthelium* or *Calamagrostis*, all genera recorded to grow in the highlands of Apurímac today (Brako and Zarucchi, 1993). The presence of *Stipa* grasses in the surrounding landscape was confirmed by the presence of thick bilobates from *Stipa* grass (See **Chapter 2**, Section **2.4**).

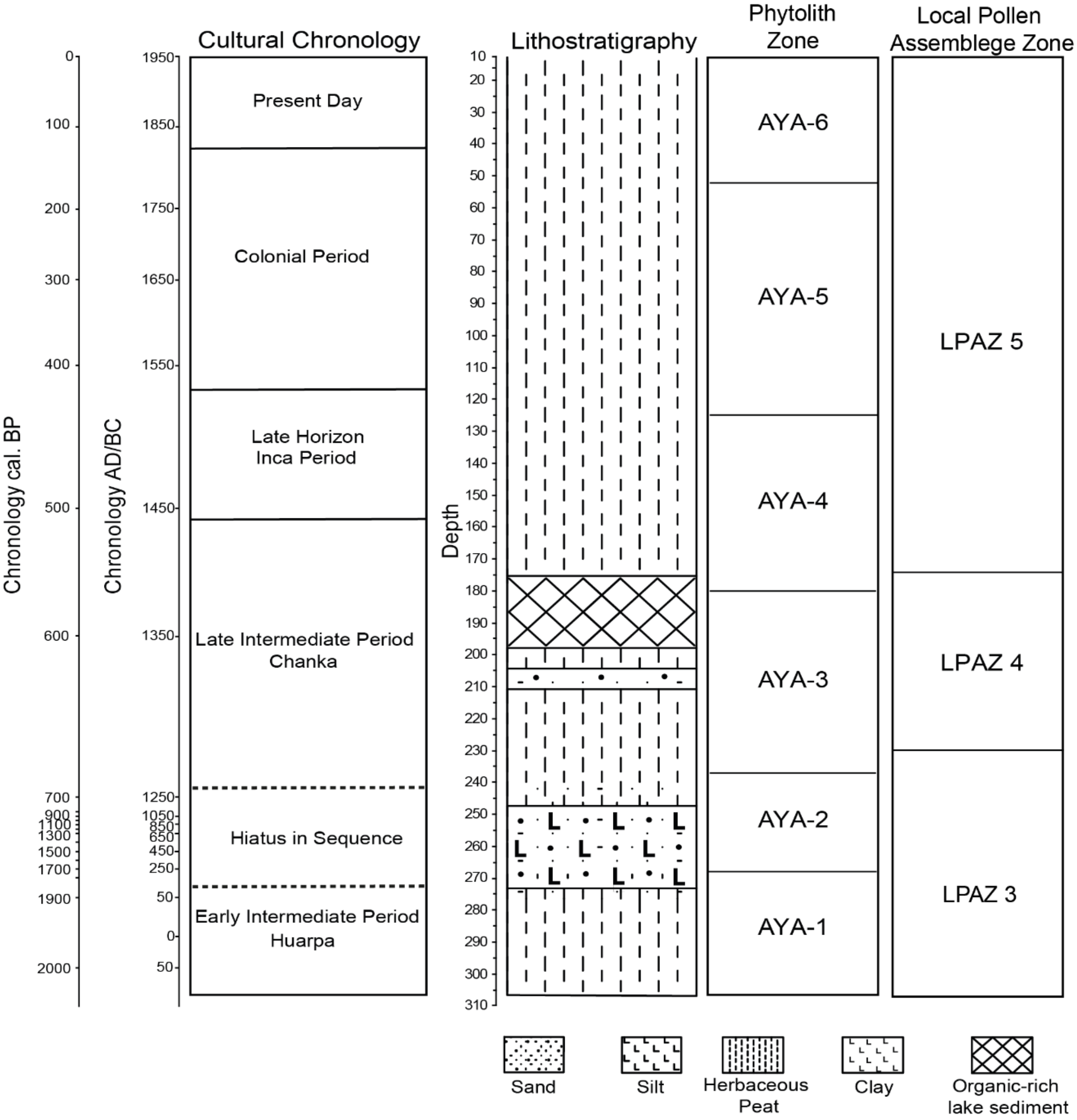


Figure 5.11 Ayapampa zone guide showing cultural chronology, lithostratigraphy, phytolith zone and LPAZ.

During the EIP the phytolith record indicates a high proportion of Poaceae grasses alongside elevated arboreal and Cyperaceae phytolith levels (Fig. 5.10). The increased arboreal phytoliths are concurrent with increases in *Alnus* and *Polylepis* at 310cm (~*2046 cal yrs BP/ BC 96*) within the pollen record, indicating the presence of Alder woodland in the environment. The high levels of Cyperaceae and Poaceae represent the main wetland vegetation community at this time, during relatively stable conditions before the presence of any large-scale human modification of the landscape. Cyperaceae is likely represented by *Cyperus* (*C.sesleriodies*) and *Eleocharis* (*E. albibracteata*), both recorded within Apurímac today, with *Eleocharis* commonly found on the surface of bogs (Brako and Zarucchi, 1993). Interestingly, Pooideae phytoliths were less common during AYA-1, despite the EIP generally being accepted as a period of increased precipitation, with the increase in moisture availability providing a suitable habitat for C3 Pooideae grasses (Twiss, 1992; Bird *et al*. 2011; Kanner *et al*., 2013; Apaéstegui *et al*., 2014). This signal may be the result of an over-representation of non-diagnostic Poaceae phytoliths resulting from a large coverage of them on the basin surface, leading to direct deposition of phytoliths from these plants into the basin. This potential over-representation will be discussed further in Section **5.3.**

Following this, Cyperaceae decreases in the pollen record from *~2000-676 cal yrs BP* (*BC 50-AD 1274*) during LPAZ 3, with an increased presence of *Potamogeton*, pondweed, suggesting higher water levels were present within the basin. This is supported by an increased abundance of Pooideae phytoliths, indicative of wetter environmental conditions. Due to the mineral rich lithology during this interval, it has been difficult to create an age depth model, therefore the timing of this wet period is uncertain. It may reflect the wetter transition from the EIP to the MH as recorded by the Palestina and Huagapo cave records and the Lake Pumacocha record (Bird *et al*. 2011; Kanner *et al*., 2013; Apaéstegui *et al*., 2014). However, this time interval also covers the MH, the second half of which was subjected to very arid conditions and a reduction in water availability across the Peruvian Highlands during the MCA. Due to the potential hiatus in the sequence this period may not have been picked up within the record at Ayapampa. Indeed, a reduction in water would have led to less surface runoff and a reduction in the sediment load entering the basin at this time, as hypothesised for the Huarca sequence during the MH (**Chapter 3**, this volume).

The high proportion of cross-shaped phytoliths within AYA-2 corresponds with the supposed timing for the MH and likely represents cultivated maize during a key period of terrace construction. This is supported by the presence of *Zea mays* wavy topped rondels in TOC within the buried MH terrace samples. *Zea mays* was also recorded in the Ayapampa pollen sequence during LPAZ 3. There are very few wild species for Panicoideae grasses recorded for the Apurímac highlands above 3000m a.s.l., with only two potential wild species found; *Axonopus elegantulus* and *Setaria pampeana* (Brako and Zarucchi, 1993). This further supports the notion the cross-shaped phytoliths present within the Ayapampa record come from domesticated maize, any further work on the basin could include the use of discriminant function analysis (see Piperno, 2006: pp.49), in order to confirm this theory.

Lower proportion of arboreal phytoliths, with an increase in Poaceae, though AYA-3 is potentially as a result of landscape clearance for renewed agricultural activity. The microscopic charred particles, suggest this was not as a result of burning, however. Despite this, the phytolith results, along with the high Poaceae pollen values and low arboreal taxa, suggests the landscape was relatively open at this time. During the late, Late Intermediate Period in

AYA-4 there is an increase in arboreal phytoliths again, suggesting an increase in trees within the surrounding environment. At this time (*~553 cal yrs BP/ AD 1397*), *Alnus* also increases within the pollen record, likely reflecting an expansion of Alder woodland under milder climatic conditions (Thompson *et al*., 2003).

At the transition from the LIP into the LH there is an increase in cross-shaped phytoliths within the record during AYA-4, again the timing of this suggests this represents cultivated maize and is consistent with the presence of *Zea mays* wavy topped rondels in the pilot study for Ayapampa (Table 5.3), between 168-167cm and 152-151cm. Further *Zea mays* wavy topped rondels were also recovered from 192cm through to 175cm within the pilot study, indicating the growth of maize from the middle of the LIP onwards (Handley, 2016). Results from the previous pollen work also support this, indicating maize was grown on the terraces around Ayapampa at *~614 yrs BP* (*AD 1336*) during a period of major terrace reconstruction, as evidenced by the increase in mineral matter being eroded into the basin (See Fig 5.8). This is further evidenced by the presence of *Zea mays* wavy top rondels within the AB horizon of INF and TOC, although there is no direct date for these samples, they represent a later phase of maize cultivation following the redevelopment of the MH terraces.

The increase in polylobate phytoliths within the LH and through into the Colonial Period may be due to an increase in precipitation during the LIA in South America; Panicoideae grasses tend to grow in more humid environments, with a moderate amount of soil moisture (Twiss, 1992; Piperno, 2006; Weisskopf *et al*., 2014; Nuemann *et al*., 2017). The presence of bulliform flabellate phytoliths in AYA-5 and *Potamogeton during LPAZ 5* also supports this. A higher number of bulliform phytoliths are usually produced where water availability is high (Fisher *et al*., 2013).

The abundance of C4 Chloridoideae phytoliths increased during the Colonial Period and though to present day, is likely a reflection of the drier climatic conditions within the Chicha-Soras Valley today, with Chloridoideae grasses favouring hot and dry conditions (Twiss, 1992; Aleman *et al*., 2014; Weisskopf *et al*., 2014). Chloridoideae genera recorded in Apurímac today include *Chloris, Eragrostia, Bouteloua, Pappaphorium* and *Muhlenbergia* (Brako and Zarucchi, 1993). During the Colonial Period with the transition to AYA-6 (Fig. 5.10), *~159 cal yrs BP* (*AD 1791*), there is an increase in Cyperaceae phytoliths, this coincides with an increase in Cyperaceae within the pollen record and signals the start of a hydrological change within Ayapampa basin to drier surface conditions. The signal is more pronounced within the pollen recorded, however, with Cyperaceae phytoliths falling off again towards the top of AYA-6. The pollen record is likely to be more sensitive to changes in Cyperaceae as a smaller number of phytoliths are produced and only two diagnostic morphotypes were encountered within the Ayapampa sequence. The comparison of phytoliths and pollen records from lake sediments will be discussed further in Section **5.3**.

There is a further increase in the abundance arboreal phytoliths during AYA-5, which spans most of the Colonial Period *(~433-159 cal yr BP/ AD 1517-1791*), again this corresponds with an increase in *Alnus* from 80cm as well as the presence of *Polylepis* and *Podocarpus*. This may be the result of less landscape disturbance in a period of supressed burning and a reduction of cultivars because of decreased population following the Spanish conquest, in conjunction with more amenable climatic conditions allowing for the expansion of *Alnus* populations. Arboreal phytoliths decrease in abundance again towards the top of AYA-5 and are lower still in AYA-6, suggesting a reduction in Andean forest coverage. This may have been due to an increase in human activity, within the regional landscape, towards the present day. Although it is not clear from the pollen diagram, it is likely the modern arboreal phytoliths are also represented by *Eucalyptus*, as introduced at the other two sites in this study (Huarca and Antaycocha) from the Colonial Period onwards.

5.3 Discussion

The use of mire-based pollen and phytolith studies in conjunction with phytolith analysis of surrounding soils, such as those on the agricultural terraces immediately adjacent to Ayapampa, provides a much more detailed understanding of spatio-temporal changes in human-environment interactions. This study has proven that the analysis of phytoliths, in addition to pollen, allows for the identification of grass taxa to a higher taxonomic value. Poaceae pollen is difficult to differentiate into sub-taxa, with the exception of cultivated grasses, and is normally reported as a single Poaceae category (Bush, 2002; Dickau *et al*., 2013). Poaceae produces greater morphological variability within its phytoliths, however, with sub-taxa being morphologically distinguishable from each other (e.g., Pooideae, Chloridoideae, Panicoideae, Stipeae, as encountered within this study) (Twiss, 1992; Fredlund and Tieszen, 1994; Piperno and Persall, 1998; Iriarte, 2003; Piperno, 2006; Dickau *et al*., 2013). This allows for the provision of extra information on changes in grassland composition and climatic conditions in the past (Iriarte and Paz, 2009; Contreras and Zucol, 2019). Phytoliths should therefore be used in conjunction with pollen in order to get the greatest floristic diversity and improve understanding on complete environmental dynamics (Iriarte and Paz, 2009; Dickau *et al*., 2013; Plumpton *et al*., 2019). Another added benefit is the addition of phytoliths from mires, and lakes, can provide a very fine temporal resolution, in comparison to those deposited in soils, as they are often preserved in non-bioturbated sediments, and translocation through the sedimentary sequence is rare (Crifò and Strömberg, 2020).

One caveat of phytolith analysis is that GSSCP can often become over-represented in phytolith assemblages due to their abundant production across several plant parts including glumes, stems and leaves, as well as their affinity for good preservation due to their low surface area (Hodson *et al*., 2005; Novello *et al*., 2012; Dickau *et al*., 2016; Crifò and Strömberg, 2020). This may have led to overrepresentation of Poaceae phytoliths, such as during AYA-1 at Ayapampa.

Conversely, morphotypes such as Cyperaceae cones are often rapidly broken and dissolved into soils, meaning they are not abundant within the fossil record leaving a lack of Cyperaceae phytoliths (Iriarte and Paz, 2009). This is of particular importance to the interpretation of the phytolith record at Ayapampa in a landscape dominated by Cyperaceae and could lead to the underrepresentation of Cyperaceae within the phytolith analysis. The smaller-spatial scale of phytolith analysis means the results from Ayapampa mainly reflects the vegetation communities on the basin surface, and in the immediate surroundings, such as on the terraces. This is also a reason for the higher proportion of Poaceae phytoliths opposed to arboreal phytoliths, with trees likely colonising the slopes around the basin further away from the coring site.

In relatively open environments, such as that at Ayapampa, the increase in a certain phytolith morphotypes may indicate the transportation of phytoliths from further distances a result of burning activities which may alleviate the phytoliths into the air (Crifò and Strömberg, 2020). Burning of the terrace surfaces appears to have been a common occurrence at Ayapampa (Branch *et al*., 2007). For most of the record the increases in phytolith morphotypes does not seem to be coupled with the microscopic charred particles (MCP) record, for example there is an increase in Poaceae at 200cm (*~614 cal yrs BP/ AD 1336*), when MCP is at a record low point. However, at 98cm (*~376 cal yrs BP/ AD 1574*), there is a peak in MCP with an increase in Poaceae phytoliths, potentially indicating a burning of grasslands in the surrounding landscape at Ayapampa. This is something else to consider when interpreting the record from Ayapampa. Below is a discussion of the human-environment and environment-climate interaction recorded at Ayapampa for each of the key archaeological periods within the Chicha-Soras Valley.

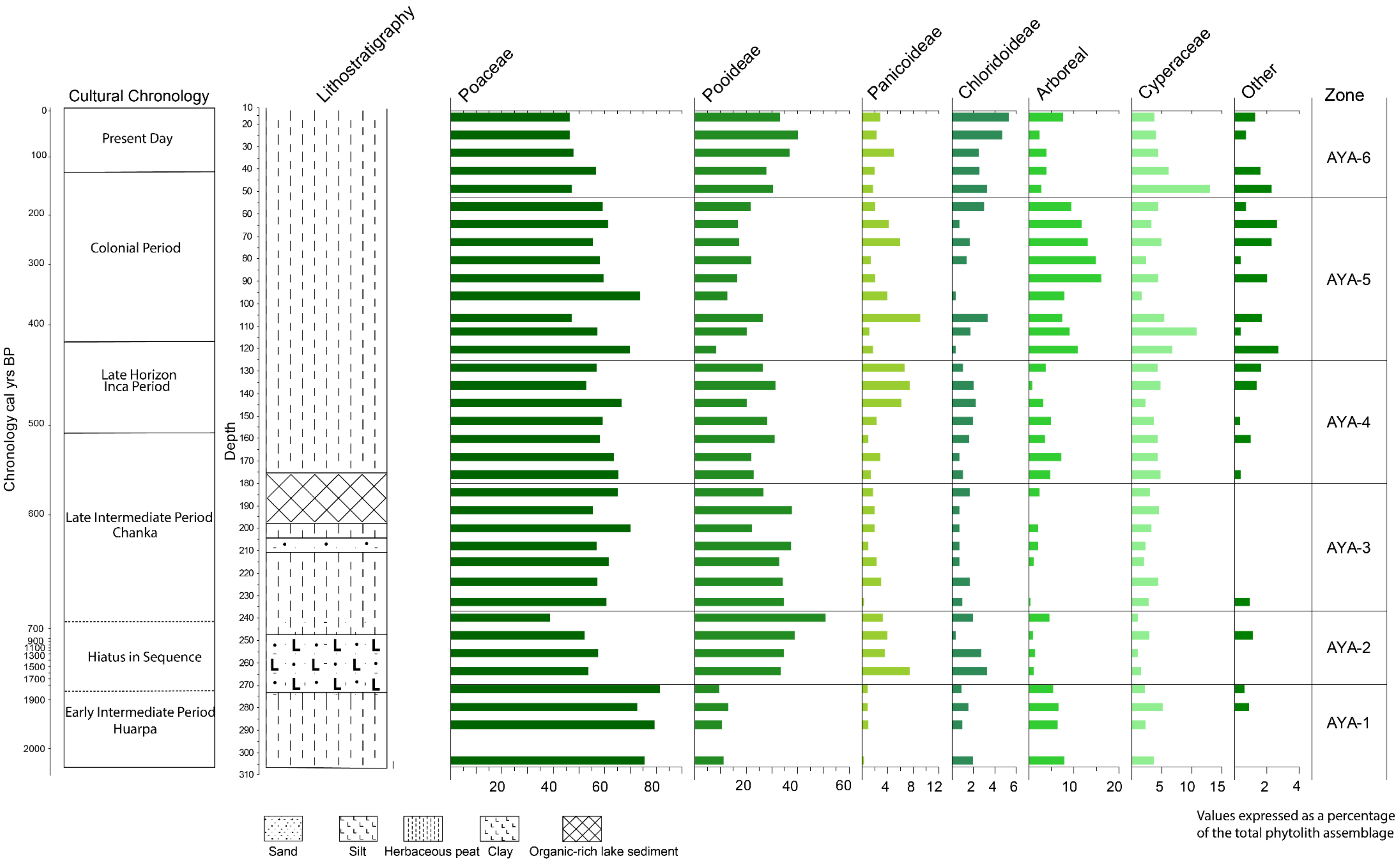


Figure 5.12 Summary diagram of Ayapampa phytolith groupings. Diagram produced using Tilia 2.6.1 (Grimm, 2019).

5.3.1 Early Intermediate Period - Huarpa

(2150-1400 cal yrs BP/ 200 BC- AD 550)

Although the archaeological record from the Chicha-Soras Valley is sparse during the EIP, there is some evidence to suggest the landscape around Ayapampa was already cultivated during this time, prior to major terrace construction. This was primarily in the form of the presence of Chenopodiaceae/Amaranthaceae during LPAZ 1 and LPAZ 2 of the Ayapampa pollen record. Although the Ayapampa phytolith record only extends back to *~2026 cal yrs BP (BC 76),* cross-shaped phytoliths are present within the record during the EIP. This may represent the growth of wild Panicoideae grasses, although as previously mentioned very few wild species have been recorded from Apurímac, or it could represent growth of maize alongside potatoes and quinoa. This is further supported by the presence of maize phytoliths within the 2bAbt and 3bBt1 horizons at INF, representing the pre-terrace ancient land-surface. These could either represent translocation of phytoliths within soil from the 2bABt horizon or cultivation prior to terrace construction within or before the Middle Horizon.

5.3.2 Middle Horizon – Wari

(1400-950 cal yrs BP/ AD 550- 1000)

Domesticated maize has been recorded on the coast of Peru at Paredones and Huaca Prieta from as early as 6775-6504 cal yrs BP (4825-4554 BC) (Grobman *et al*., 2012), however it was not grown on any substantial scale within the Chicha-Soras Valley until the MH. Maize formed the foundation of the subsistence economy of the Wari polity and later within the Inca Empire. The importance of maize extended beyond the role of subsistence to ritual significance, including the consumption of maize beer (*chicha*) (Valdez *et al*., 2010; Cadwallader *et al*., 2012). Isotopic evidence from mummies placed within caves near Ayacucho suggests maize cultivation and consumption remained the foundation of Ayacucho, and undoubtedly Apurímac, subsistence economy until the Spanish conquest (Finucane, 2007). The absence of *Zea mays* wavy topped rondels within this new analysis from Ayapampa basin sequence, but presence within the terraces, may be due to their low production and consequently dispersion. It may also reflect the removal of maize cobs, in which wavy top rondels are formed, from the agricultural fields during harvest, with the rest of the plant being left behind to decompose on the terrace surfaces. This would result in a greater deposition of cross-shaped phytoliths within the mire basin, as hypothesised elsewhere within an Amazonian setting (Watling *et al*., 2015; Dickau *et al*., 2016). The presence of *Zea mays* wavy top rondels within the buried MH terraces in conjunction with the presence of some *Zea mays* wavy top rondes from previous work, and to some extent cross shaped phytoliths in this body of work, in sediments dating to the MH provides unequivocal evidence the Wari invested in maize cultivation as part as their agricultural strategy in the Chicha-Soras Valley.

During the MH, water levels at Ayapampa Mire may have been artificially raised in order to mitigate regional drought with the onset of the MCA, at a time when efforts towards cultivation on the surrounding terraces were intensifying, this is supported by the construction of the stone wall across the drainage outflow (Meddens and Branch, 2010). The irrigation canals feeding the terraces downstream pick up water from immediately below the wall across the drainage outflow, showing the basin played an important part in the water source for agriculture around the basin. The presence of Cyperaceae and bulliform flabellate phytoliths, even on INF distal to the wetland setting, suggests the presence of irrigation canals on the terraces, which would have kept the soils well-watered, even in times of reduced precipitation. Irrigation of the terraces would have also increased the moisture holding capacity of the soil and impressive drainage systems associated with the terraces would have enabled water to move from one terrace to the next. This would have insured the success of maize cultivation, a crop which is susceptible to drought because of shallow rooting and requires nutrient-rich soils with adequate moisture.

Also, of note for the Middle Horizon is the occurrence of Arecaceae and Marantaceae phytoliths within the terrace profiles at INF and TOC (Fig. 5.6 and 5.7), although these occur throughout both profiles the highest abundance is concentrated within the buried MH terrace surfaces. Arecaceae typically grows in warm, moist montane forests (cloud forest) on the eastern side of the Peruvian Andes below 3500m a.s.l. (Henderson *et al*., 1995; Galeano *et al*., 2008). Today, 17 species of palm are strictly Andean, whilst the remainder (123 species) are from lower elevations including Andean/Sub-Andean settings, strictly Subandean and Amazonia (Kahn and Moussa, 1994). The presence of one or possibly more species of this family at Pampachiri is surprising and suggests contact with the eastern Andes. Evidence for trade between Andean and Amazonian communities has a long history with communities sourcing timber, palm fronds, crops and food impossible to be grown within their immediate environment (Kimura, 1985; Suarez and George, 2011). The agricultural context in which the palm phytoliths were found in the INF and TOC terraces makes it most likely that they derive from the timber tips of agricultural tools, either from a foot plough or a hoe. Marantaceae, here assumed to be *Maranta arundinacea* (arrowroot) or *Calathea allouia* (leren), in contrast to palm, is less obvious to explain as an exotic product within a highland agricultural context. It may be that this tropical rhizome finds its origin within ritualistic contexts. Offerings to high altitude mountain deities frequently included the presence of a range of lowland elements, with the importance of obtaining exotic items from distance sources having great antiquity in pre-Hispanic Peru (Gutiérrez and Fernández, 2014). Arrowroot starch grains have come from flaked stone tools of Late Horizon date from the site of Yanawilka (3050-3090m a.s.l. and ~4.5km northwest of Vilcashuaman). The nearest source for arrowroot was estimated to be ~80.5km away (Hu, 2016). The presence of both palm and Marantaceae here confirms the existence of exchange networks across distances of ~130 km, from at least the Middle Horizon.

5.3.3 Late Intermediate Period - Huamanga and Chanka

(950-512 cal yrs BP/AD 1000-1438)

Within the first half of the LIP there is a reduction in evidence for human activity around Ayapampa, with a reduction in *Zea mays* within the pollen record and a reduction in cross-shaped phytoliths in the phytolith record. Palaeoclimatic records indicate declining precipitation levels 950-650 cal yrs BP (AD 1000-1300, early Late Intermediate Period) suggesting a sustained period of aridity during the MCA (Bird *et al*., 2011; Kanner *et al*., 2013), this coupled with the increase in warfare as evidenced by the increase in trauma wounds within LIP burials (Tung, 2008), likely led to instability in subsistence practices in the valley. This higher level of violent conflicts was likely due to the fragmentation of the Wari political regime and the emergence of newly autonomous groups leading to intense instability in the highlands during the LIP (Tung, 2008).

The renewal of peat formation at ~692 *cal yrs BP* (*AD 1258*) in the Ayapampa Mire broadly coincides with more variable climate from the late, Late Intermediate Period from 650 cal yrs BP (AD 1300), thought to be due to the increased frequency and magnitude of ENSO, or changes in the influence of the SASM and ITCZ at the onset of the LIA (Rein *et al*., 2005; Kanner *et al*., 2013; Thompson *et al*., 2013, 2017; Apáestegui *et al.,* 2014). Potentially as a result of higher precipitation in the late, Late Intermediate Period, the second half of the LIP witnessed a period of extensive remodelling, reuse and expansion of the earlier terraced agricultural systems, associated with the further construction of large-scale irrigation management systems (Branch *et al.,* 2007; Kemp *et al*., 2006; Kendall and Rodriguez, 2009). Perhaps the climate changes, together with increased population pressure, may have initiated a social response with the re-expansion of agricultural. Certainly, the proportion of cross- shaped phytoliths increases, and the presence of *Zea mays* wavy top rondels is recorded within Ayapampa during the late, Late Intermediate Period.

5.3.4 Late Horizon – Inca

(512-418 cal yrs BP/ AD 1438-1532)

Cultivation continued into the Late Horizon with the presence of the Incan Empire in the Chicha-Soras Valley. Irrigation systems also seem to have expanded during the LH, potentially in response to an increase in available water during the LIA (Bird *et al*., 2011). Indeed, the increased presence of polylobate phytoliths, potentially representing C4 panicoid grasses (as opposed to C3), during the Late Horizon suggests the climatic conditions were wetter at this time. Temporal resolution for this section of the core, as well as within the terrace sequences, limits precise comment on the nature of human activity around Ayapampa during the LH. However, maize, as in the preceding Wari Period, is considered to be a stable crop of the Inca Empire subsistence strategies, with the presence of maize storage facilities (in the form of collcas) being a key part of Incan agricultural architecture, along with the building of corrals, irrigation canals and terraces (Finucane *et al*., 2006; Finucane, 2007). The presence of *Zea mays* wavy top rondels within the Ayapampa at 151cm (*~493 cal yrs BP/ AD 1457*) and an increase in cross-shaped phytoliths during the Late Horizon certainly seems to support the growth of maize on the terraces around the basin during the LH. It is possible this was in conjunction with potatoes (Solanaceae) and quinoa (Chenopodiaceae/Amaranthaceae), as both families appear in the pollen diagram during the LH.

5.3.5 Colonial Period – Present Day

(418-0 cal yrs BP/ AD 1532-2001)

Post-Spanish conquest the terraces within the Chica-Soras Valley were largely abandoned and left to deteriorate due to a lack of maintenance as well as climate change (Rodriguez and Nickalls, 2002). Irrigation systems also fell into disrepair, with poor co-ordination among users and insufficient maintenance within the present day. This is largely due to a lack of workforce and the communities within the Chica-Soras Valley being less homogenous than in the past (Rodriguez and Nickalls, 2002). Through the Colonial Period at Ayapampa the presence of cultivars reduces, with an absent in cross phytoliths during the second half of AYA-5 and in AYA-6 (Fig. 5.9), and an absence of *Zea mays* pollen from Ayapampa during the Colonial Period. There is also a reduction in Chenopodiaceae/Amaranthaceae, suggesting quinoa was also no longer cultivated.

Phytoliths are better at identifying the variability in herbaceous and grassland taxa than they are arboreal taxa due to the non-diagnostic function of arboreal phytoliths (Plumpton *et al*., 2019). Therefore, subtle changes in tree communities may not be picked up, that can be otherwise surmised from pollen data, e.g., the preference for *Eucalyptus* over *Alnus* and other traditional Andean tree species such as *Polylepis* and *Podocarpus* since the Colonial Period. However, the phytolith record does record an increase in arboreal taxa during the Colonial Period, which is likely a result of less landscape disturbance, a reduction in human activity and a recolonisation of the slopes around Ayapampa by trees during a period of reduced burning. The abundance of C4 Chloridoideae phytoliths increased during the Colonial Period and though to present day, is most probably a reflection of the drier climatic conditions within the Chicha-Soras Valley today, with Chloridoideae grasses favouring hot and dry conditions (Twiss, 1992; Aleman *et al*., 2014; Weisskopf *et al*., 2014). The move towards drier conditions is also supported by the increase in Cyperaceae phytoliths concurrent with an increase in Cyperaceae within the pollen record, reflecting lower water levels and signalling the start of a hydrological change within Ayapampa basin.

Chapter 6 - Discussion

6.1 Introduction

This chapter will explore the key findings from the preceding chapters and consider these in relation to the wider archaeological, palaeoenvironmental and palaeoclimatic context drawing upon previously published research from Peru. This research project aimed to characterise the socio-economic responses to climate and environmental change across a transect (north to south) of the Peruvian Andes. The study has illustrated that the levels of human activity (intensity) and the nature of land use was not locally or regionally consistent throughout the past 2000-3000 years (see Fig. 6.1); this has largely been correlated to changes in the level of social organisation and climatic variability. The types of land-use and human induced environmental modification encountered within this study are wide ranging, including the creation of agricultural terraces, irrigation canals, reservoirs, wet pastures, crop cultivation, agroforestry, camelid herding, burning, and mining. The extent to which these represent an adaptation to climatic variability and cultural change will be discussed in detail within this chapter. Each of the key cultural periods over the past 2500 years is considered in turn, paying special attention to the research questions outlined in Section **1.7**

6.2 Early Horizon – Early Intermediate Period

At the transition from the Initial Period to the Early Horizon, Ayapampa and Antaycocha basins began to accumulate sediments (~*3970* and *~2954 cal yrs BP* respectively) during a period of increased precipitation following the mid-Holocene South American arid period (7000-5000 cal yrs BP). This increase is evidenced by a decrease in $^{\delta}$18O values in the Lake Pumacocha record and a reestablishment of the Quelccaya ice cap alongside an increase in water levels at Lake Titicaca (Abbott *et al*., 1997, 2003; Binford *et al*., 1997; Bird *et al*., 2011; Thompson *et al*., 2000, 2003, 2013). Within this pluvial period, sites elsewhere in the Peruvian Andes also began to collect sediments including Lake Challacaba, near Lake Titicaca (~4300 cal yrs BP), Lake Huaypo (4257-4496 cal yrs BP) and Laguna Pomacochas *(~3530 cal yrs BP*), and Marcacocha started accumulating organic lake sediment (~*3910 cal yrs BP*) (Chepstow-Lusty *et al*., 2003, 2007; Williams *et al*., 2011; Sublette-Mosblech *et al*., 2012; Gosling and Williams, 2013; Bush *et al*., 2015). Although each basin has its own unique set of geomorphological and environmental controls it is interesting that several sites across the Andes initiated sedimentation in this period of increased precipitation following the mid-Holocene period of aridity. Although Huarca formed much earlier, around *~11,470 cal yrs BP*, an open water lake developed in the basin around *~4265 cal yrs BP*, indicating a response to the wetter climate, which was recorded at all three sites (Huarca, Antaycocha and Ayapampa), albeit over a range of ~1300 years.

Within this period of increased precipitation, agricultural activity intensified in the Callejón de Huaylas. Although evidence for agricultural activity is present in the records from the Chillón Valley and Chicha-Soras Valley during the EH and EIP (Fig 6.1), it is relatively limited and probably conducted on a much smaller scale than in the Ancash Region. An interpretation supported by archaeological evidence (Schreiber, 1992; Farfán, 2000, 2011; Leoni, 2008; Meddens and Scheiber, 2010). At Huarca, landscape disturbance and agricultural activity had already begun prior to the Early Horizon (pre-2750 cal yrs BP/ 800 BC), with cultivation mainly focused on pseudocereals (quinoa, *kañiwa* and *kiwicha*) and potatoes. This agrees with the record from Ayapampa as well as at sites elsewhere in Peru, which show significant levels of Chenopodiaceae/Amaranthaceae, concurrent with increases in *Ambrosia*, at Laguna Tuctuna, Laguna Paca, Laguna Junín, and Laguna Pomacocha (Fig. 1.2), from 4000 cal yrs BP (Hansen *et al*., 1994). At Antaycocha, evidence for human activity during these early periods is sparser. The occurrence of *Sporormiella* in the record suggests the presence of local pastoral farming, although the quality of the grazing land around Antaycocha at this time was probably low, as evidenced by the elevated levels of Cactaceae. This indicates a transient role of herbivores in the landscape at this time. The presence of Chenopodiaceae/Amaranthaceae and Solanaceae may reflect early agricultural activity in the region during the EIP and EH, however, due to the limited archaeological evidence for human activity in the surrounding landscape it may also represent wild growth of *Atriplex* (Chenopodiaceae) and *Guillermina* (Amaranthaceae) (National Research Council, 1989).

Unlike at other sites in the Andes, no maize pollen was recorded at Huarca or Antaycocha during this early period of agricultural development. At Ayapampa, there is potential evidence for maize cultivation in the form of cross-shaped phytoliths, and *Zea mays* wavy top rondels in the lower levels of INF terrace. Increased importance of maize is recorded at Lake Pacucha (Fig. 1.2), from 3000 cal yrs BP, and slightly later at Lake Compuerta, from 2600 cal yrs BP (Weng *et al*., 2006; Valencia *et al*., 2010). Maize is also recorded in the Samaca basin, lower Ica Valley (Fig. 1.2), on the south coast, during the Early Nasca ~AD 0-400. It is during this period that maize reaches its maximum representation (Beresford-Jones, 2011). Perhaps, the conditions around Huarca were too wet, and potentially cold, for the cultivation of maize, with a preference of farmers towards potatoes and quinoa. At Antaycocha, the lack of settled and developed communities in the highlands may be the cause of a later presence of maize in the landscape around the basin.

The intensification of land-use around Huarca during the Chavin cultural tradition (EH) and into the Recuay cultural phase (EIP), signified by an increase in Chenopodiaceae/Amaranthaceae, and later the occurrence of *Sporormiella* and *Ambrosia*, alongside increased surface run off, led to a major phase of erosion within Huarca basin from *~2623 cal yrs BP (673 BC)* until *~1213 cal yrs BP/ AD 727*. This corresponds with a major period of societal development in the region and the start of continuous occupation at sites including Pueblo Viejo de Huandoy and Keushu during the Recuay cultural phase (Lau, 2022, Herrera, 2007; Herrera *et al*., 2009). The greater evidence for human activity in the landscape around Huarca during the EIP is attributed to the higher level of social organisation under a more developed polity, potentially because of its proximity to the heartlands of the preceding Chavin culture (Lau, 2002, 2006, 2016; Arkush and Tung, 2013).

6.3 Middle Horizon

During the Middle Horizon, wide scale modification took place within the landscape surrounding Huarca (including Awiskmarka) and Ayapampa. At both sites there is evidence for construction of agricultural terraces and irrigation systems, and at Ayapampa this is associated with the cultivation of maize. An increase in minerogenic sediment input into Ayapampa has been linked to a period of agricultural intensification and terrace development at the start of the MH (Branch *et al*., 2007). The construction of terraces at Awiskmarka was accompanied by other social developments such as funerary structures in the form of *chullpas* (Herrera *et al*., 2009; Gerdau-Radonic and Herrera, 2010). It is likely that the Water Catchment Features (WCF) associated with the terraces at Awiskmarka were also formed at this time, which included the irrigation of pastureland to create wet meadows (*bofedales*) for grazing animals (Herrera *et al*., 2009). Construction of silt dams and reservoirs was recorded elsewhere in Ancash in the Cordillera Negra, which led to large areas of the upper *Suni* and *Puna* region being turned into rich camelid grazing land (Lane, 2009). There is also evidence for repair, erosion, and changes in the form of the canals associated with the archaeological site at Keushu, suggesting intensified use of water resources across Ancash during the MH (Gerdau-Radonic and Herrera, 2010).

The increase in water-related technology in the Middle Horizon may be due to the onset of a period of aridity from 1050-850 cal yrs BP (AD 900-1100) as recorded in the Laguna Pumacocha and Palestina cave records, with an evident need to control water at this time.

Additional evidence for this arid event is provided by a low-water event recorded in Lake Pacucha at *~850 cal yrs BP (AD 1100)*, as demonstrated by a relatively high carbonate content and very low diatom preservation. This broadly coincides with drought events recorded in the Quelccaya and Huascarán ice caps (Thompson *et al*., 2000, 2013; Hillyer *et al*., 2009; Bird *et al*., 2011; Apaéstegui *et al.,* 2014). As previously discussed, this dry signal has been accredited to the Southern Hemisphere expression of the MCA, and a weakening of the SASM, as well as a more northly position of the ITCZ (Haug *et al*., 2010; Bird *et al*., 2011; Vuille *et al*., 2012; Kanner *et al.,* 2013; Apaéstegui *et al.,* 2014). However, due to uncertainty in the precise timing of WCF, and irrigation canal construction across Ancash (Herrera, 2017), and in the Chica-Soras Valley (Branch *et al*., 2007), it is difficult to establish whether the increase in water technology was a response to the reduction in water during the MCA or the increase in available water at the end of the EIP and in the beginning of the MH.

Another possible consequence of the MCA was the reduction in sediment deposition at Huarca, Antaycocha, and Ayapampa. At all three sites there is very little sediment which dates (based on current age-depth models) to the Middle Horizon. A reduction in precipitation would have led to less surface run off and a decrease in sediment input into the basins. Indeed, at Huarca, this was concurrent with low µXRF PC axis 1 values, indicating less terrigenous sediment input and reduced landscape erosion. A reduction in water levels was also recorded at Lake Titicaca and Marcacocha, although both appear to have a continuous record during this period (Abbott *et al*., 1997; Chepstow-Lusty *et al*., 2003). The new results presented here are highly significant therefore because they appear to indicate that the basins were highly sensitive to regional climate variability and a reduction in precipitation during the MCA. Given that the potential hiatus in the sediment sequences indicates major hydrological changes in the basins in response to lower precipitation (and possibly higher temperatures), this would have had significant implications for the human communities living proximal to the wetlands during the MH. A reduction in water levels and a drying out of the basins would have led to less water availability for grazing and agriculture during a time of increasing demand due to widespread socio-economic developments. The timing of these events is particularly important in light of the archaeological record, which suggests that the state-scale empires of the Wari and Tiwanaku collapsed towards the end of the Middle Horizon, the cause of which has been linked to drought (Ortloff and Kolata, 1993; Binford *et al*., 1997; Arnold *et al*., 2021). It also has implications for the present day and potentially provides an analogue for the current projected decrease in water availability in the high Andes, which will undoubtedly have an impact on the hydrology and sustainability of wetlands.

Due to the reduction in sediment accumulation, the palaeoenvironmental data from Huarca and Antaycocha does not reveal much information about the nature of land-use during the MH. At Huarca, an increase in *Alnus* populations at *~1117 cal yrs BP (AD 833)* provides potential evidence for agroforestry practices within the local environment. This is supported by an increase in *Alnus* at Lake Pacucha around 1200 cal yrs BP (AD 750), despite being absent in the record for over 3000 yrs. This has been attributed by Valencia *et al*., (2010), to Wari agroforestry practices to increase timber resources. There is more substantial evidence for an increase in the intensity of agricultural activity during the MH within the Chicha-Soras Valley. During this period, there was an increase in maize cultivation, as evidenced by the presence of maize phytoliths within Ayapampa and the MH terrace palaeosols. The growth of maize has been seen elsewhere in the Chicha-Soras Valley at Chiqnajota by the presence of carbonised maize cobs that were directly associated with Middle Horizon deposits (Meddens and Branch, 2010). The presence of Cyperaceae and bulliform flabellate phytoliths from the terraces, even in terrace INF that is some distance from the wetland, suggests the presence of irrigation canals, which would have been essential for maintaining soil moisture. Irrigation of the terraces would have increased the moisture holding capacity of the soil, which is particularly important for the cultivation of maize, as it requires a higher degree of soil moisture than other highland crops (Hastorf and Johannessen, 1993; Suarez and George, 2011). The construction of agricultural terraces and irrigation systems for maize cultivation at this time may have been a response to higher precipitation at the start of the MH. Communities within the Chicha-Soras Valley, and possibly across the Peruvian Andes, may have responded by adapting their agricultural practices to intensify production and yield.

6.4 Late Intermediate Period

The timing of the transition from the Middle Horizon into the Late Intermediate Period occurred earliest in the Ancash Region; here the end of Wari influence is thought to have occurred around 1150 cal yrs BP (AD 900) (Lau, 2004, 2011, 2016). Within the Huarca record there is a temporary reduction in Chenopodiaceae/Amaranthaceae and an absence of *Ambrosia* and *Artemisia* suggesting a decrease in agricultural activity. This is accompanied by a reduction in *Alnus* potentially indicating a reduction in agroforestry practices, and/or a deterioration in climatic conditions at the beginning of the LIP. At Laguna de los Condores, North Peru, the transition to the LIP also witnessed reduced human activity in the form of forest recovery from 750 cal yrs BP (AD 1200), which extended until the present day, alongside a reduction in maize cultivation (Åkesson *et al*., 2020). By *~1011 cal yrs BP (AD 939), Ambrosia* and *Artemisia* increased again within the Huarca record, along with elevated µXRF PC axis 1 values indicating catchment erosion and renewed human activity around the basin. A pause within agricultural activity is also seen at Ayapampa. Within the first half of the LIP, there is a reduction in *Zea mays*; lower precipitation, coupled with increased warfare in the Chicha-Soras Valley, probably led to instability and fragmentation of large-scale subsistence practices in the Valley at this time. However, the complete disruption of agricultural infrastructure and the abandonment of occupation sites, which was widespread across the rest of Ayacucho and Apurímac, does not appear to have been witnessed to the same extent within the Chicha-Soras Valley (Finucane *et al*., 2007; Meddens and Branch, 2010).

After the initial decrease in human activity there appears to be a shift in agricultural practices at Huarca, and to some extent Ayapampa. An erosional event occurs within the Huarca record (*~800-735 cal yrs BP/ ~AD 1135-1214*), indicated by elevated µXRF PC axis 1 values and an increase in terrigenous input into the basin. Unlike the other erosional events within the Huarca sequence, which take place during pluvial periods (see Fig. 3.18), this occurs during the arid MCA and may therefore reflect an increase in anthropogenic landscape disturbance. This may be related to the reconstruction of terraces on the slopes around Huarca, as has been postulated for Ayapampa later in the LIP (Kemp *et al*., 2006; Branch *et al*., 2007). Of significant note to support this theory, is the first occurrence of *Zea mays* within the Huarca sequence following this erosional unit (Fig. 6.1). This suggests human modification of the landscape took place to support a more maize-orientated agricultural system. The increased preference for maize during the LIP was also recorded at Marcacocha (Chepstow-Lusty *et al*., 2009). The shift in agriculture appears to have also been accompanied by an increase in fire activity around Huarca (based upon micro-charcoal concentrations) from *~878 cal yrs BP (AD 1072),* suggesting the use of fire was a key component in agricultural practices during this time of agricultural development.

At Antaycocha, human activity appeared to intensify during the late, Late Intermediate Period with the construction of the dam wall. Although it is difficult to precisely date the structure itself, the combination of the geochronological, sedimentological and palaeoecological evidence presented from the sequence (See **Chapter 4**) clearly demonstrates a late, Late Intermediate Period / early Late Horizon construction date (*~616 cal yrs BP/ AD 1434*). Paleoclimatic records indicate that during the period of dam construction at Antaycocha, changes in the hydrological cycle caused intensification of the SASM and a resulting increase in precipitation during the LIA (600-70 cal yrs BP/ AD 1350-1880) (Kanner *et al*., 2013; Apaéstegui *et al*., 2014; Thompson *et al*., 2017). It is highly likely therefore, that the creation of a reservoir of water, because of damming the lake, was a response to an increase in precipitation at this time. The evidence for agricultural acitvity in the landscape around Antaycocha concurrent with the dam construction, including the presence of *Zea mays*, Solanaceae, *Oxalis*, Chenopodiaceae/Amaranthaceae and *Ambrosia*, suggests a strong relationship between cultivation and the utilisation of water resources. The increase in water at Antaycocha would have allowed for the distribution of water to the nearby agricultural terraces as well as for consumption by animals, as evidenced by the presence of *Sporormiella.* The engineering effort required to construct a stone wall dam at Antaycocha clearly suggests that wetlands were regarded as important resources to ensure the success of agro-pastoral systems, by providing a more sustainable water supply. Indeed, access to water during the pre-Hispanic era has been cited by Rostworowski (1989), to be more important than access to land, illustrating how wetland reservoirs would have been a vital resource in the past.

In contrast, the onset of the LIA within the Callejón de Huaylas does not appear to coincide with any substantial increase in water technology, with most of the water catchment and control features (canals, silt dams, reservoirs, irrigation channels, terraces etc.) having been developed in the earlier MH (Lane, 2009; Herrera *et al*., 2009). It is highly likely the *bofedales* and WCF that were developed in the MH, continued to be used in the LIP. This is supported by the notion that there was an increase in importance of camelid herding in the Ancash highlands at this time, which used irrigated grasslands for pasture (Herrera, 2003; Lane, 2009; Aguilar, 2019) There is also an increase in *Sporormiella* at Huarca during this time, which provides supporting evidence for grazing. At Ayapampa, it is interesting to note the agricultural terraces adjacent to the wetland appear to have undergone a period of extensive restoration during the late, Late Intermediate Period (*~750-512 cal yrs BP/ AD 1200-1438*). At this time, the Chicha-Soras Valley was experiencing significant changes in demography and population growth, alongside evidence for increased warfare; the reconstruction of terraces may therefore have been a response to socio-economic need against a background of climatic change, in the form of increased precipitation during the LIA.

6.5 Late Horizon

With the transition to the Late Horizon Inca Period, there is increased evidence for the cultivation of maize at Antaycocha and Ayapampa (Fig. 6.1). The presence of maize alongside Chenopodium/Amaranthaceae, *Oxalis,* and Solanaceae within the Antaycocha record suggests the potential for multi-cropping practices occurring on the agricultural terraces adjacent to the basin. A similar strategy seems to be in place at Ayapampa, with the growth of maize on the terraces confirmed by the presence of maize phytoliths; however, Chenopodiaceae/Amaranthaceae and Solanaceae also occur within the pollen record during the LH. Indeed, the Inca are thought to have utilised a full suite of cultivars over a wide altitudinal range (potatoes, maize, quinoa, oca, beans, manioc, sweet potato, avocado,

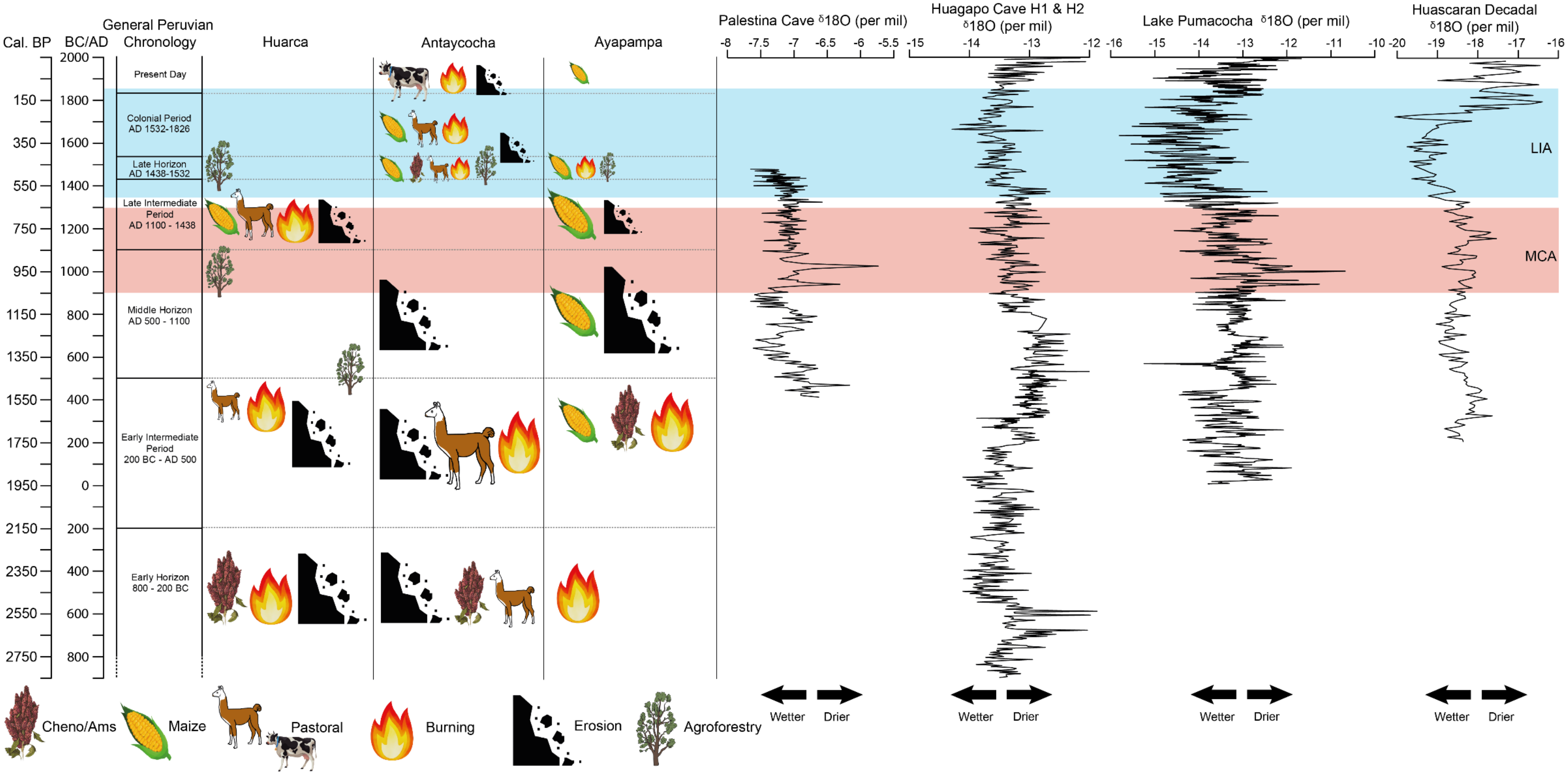


Figure 6.1: Summary of the land use changes at Huarca, Antaycocha, and Ayapampa and key palaeoclimatic records from the Peruvian Andes (Bird et al., 2011; Kanner et al., 2013; Thompson et al., 2013; Apaéstegui et al., 2014). Land use indicator symbol size represents the duration of time the indicator is present within the palaeoenvironmental record.

squash, and chili peppers among others), often choosing the most suitable crops depending on the regional climatic conditions (Reyes-Knoche, 2012). Interestingly, there is an absence of maize pollen within the Huarca record during the LH. It is possible that climatic conditions around Huarca were considered unsuitable for maize cultivation, although issues with pollen productivity and transportation in relation to the Huarca core maybe more of a likely explanation for the absence of maize pollen within the Huarca records (see Section **3.5**).

In addition to using a full suite of crops, the Inca also understood the need to store food, and produce surplus, whether this was a sign of status or because they were guaranteeing food supplies for the population. *Collcas* (storehouses) were a common part of the Incan agricultural system (Reyes-Knoche, 2012), and the presence of storehouses has been recorded in the landscape around Antaycocha in association with Cantamarca archaeological site, which was predominately occupied during the LH (Farfán, 2011). Undoubtedly, the community present within the landscape at Antaycocha understood the need to mitigate risk, with an agricultural system built towards increased sustainability in the form of terraces, storehouses, and water management features, including the creation of the Antaycocha reservoir following the construction of the dam wall at the end of the LIP/beginning of the LH. The archaeological record from across Peru indicates the Inca placed great emphasis on water management at a catchment scale, and introducing measures to safeguard its distribution, transportation, and storage, including constructing extensive hydraulic systems; managing this resource would have been vital for the sustainability of the Empire (Dean, 2011; Reyes-Knoche, 2012). This period of agricultural development was set against a backdrop of increased precipitation during the LIA (Bird *et al*., 2011; Kanner *et al*., 2013; Apaéstegui *et. al*, 2014). The increase in hydraulic systems was most likely a response to the increase abundance of water coupled with socio-economic pressures. Both Huarca and Antaycocha recorded a signal for wetter conditions during the LH; for example, at Huarca, increased precipitation is indicated by elevated µXRF PC axis 1 values and increased erosion as well as the presence of *Myriophyllum*, alongside a reduction in Cyperaceae between ~*584-408 cal yrs BP (AD 1367-1542)*.

As well as agriculture, there is also evidence the Inca invested in the practice of agroforestry at two of the sites in this study. *Alnus*, which starts to increase in abundance around Huarca in the LIP, increased further during the LH alongside *Escallonia* and *Polylepis*. A similar rise in *Alnus* is recorded at Antaycocha at this time. This occurs alongside greater diversity of Andean forest taxa including *Polylepis*, *Myrica*, Proteaceae, and during the late, Late Horizon Juglandaceae and *Podocarpus*. Renewed *Alnus* populations were also recorded at Laguna Compuerta, Lake Pacucha, and Marcacocha during the Late Horizon (Weng *et al*., 2004; Chepstow-Lusty *et al*., 2000; 2009; Sublette-Mosblech *et al*., 2012). An anthropogenic origin for the increase in Andean forest taxa is supported by the wetter climatic conditions, as the treeline would normally be supressed under these conditions (Chepstow-Lusty and Winfield, 2000). The expansion of *Alnus* and other taxa was therefore probably encouraged by the Inca in order to increase vital resources of timber, building materials and fuel to support a rapidly growing Empire (Krajick, 1998; Hughes, 1999).

6.6 Colonial Period

A reduction in human activity with the arrival of the Spanish is recorded across several paleoenvironmental sequences in the Andes (Weng *et al*., 2006, 2007; Bush *et al*., 2007a, 2007b; Chepstow-Lusty *et al*., 2007, 2009; Valencia *et al*., 2010). This supports the evidence for an initial reduction in population during the Colonial Period, as a result of the introduction of Old-World diseases such as smallpox, measles, typhoid and cholera, for which pre-Hispanic indigenous populations had no immunity (Denevan, 1976; Cook, 1981; Nunn and Qian, 2010). Population decrease was greatest in the first century post-conquest (Denevan, 1992; Nunn and Qian, 2010), after which populations recovered slightly. The highlands potentially did not experience as much of a population collapse post-conquest as areas on the coast and in the tropical lowland areas as the high elevation cooler climates would have lessened the impacts of disease (Cook, 1981). A lower population density, due to a large dispersed rural population, would have also slowed the spread of disease; nonetheless the impact of the Spanish contact was definitely felt within the three study regions.

The records from Huarca, Antaycocha, and Ayapampa indicate a less intensive use of the landscape post-conquest (Fig. 6.1). At Huarca, there is a reduction in Chenopodiaceae/Amaranthaceae, Solanaceae and *Ambrosia* concurrent with a decrease in µXRF PC axis 1 values, indicating a decline in agricultural activity and landscape disturbance. The reduction in cultivars was also recorded at Antaycocha, alongside an increase in shrubland taxa. However, the record at Antaycocha indicates there is a continuation in pastoral activities, either camelids or potentially the introduction of Old-World domesticates that are farmed in the region today, as well as agroforestry practices. With the increase in pastoralism, it is possible the presence of Fabaceae within the pollen record at this time also represents cultivated Alfalfa (*Medicago sativa*), which was used in the highlands as fodder during the Colonial Period, as an introduced crop by the Spanish (Guillet, 1987; Trawick, 2003; Lane, 2009; Thornton *et al*., 2011). Alfalfa is grown today on the terraces in the Sondondo Valley near Andamarca, with the proceeds from the sale of the cattle feed going towards the repairs of terraces and irrigation systems (Kendal and Drew, 2015). In the Cordillera Blanca, it has been suggested that terraces situated near silt reservoirs, such as that at Awiskmarka, may have been used for the production of fodder during fallow periods (Lane, 2009). If this is the case at Awiskmarka, other methods of analysis would be needed to detect palaeoecological signals for plants such as Alfalfa as Fabaceae plants do not produce diagnostic phytoliths. At Ayapampa, the terraces in the surrounding landscape were largely abandoned during the Colonial Period with a reduction in cultivars recorded throughout that period. The phytolith record suggests there was also a re-colonisation of the slopes around the basin by trees in response to a reduction in burning and agricultural activity. Lake Pacucha also recorded a rapid decline in crops, with a reduction in fire frequency at this point in time, reflecting a much less intensive use of the landscape across several regions of the Peruvian Andes (Valencia *et al*., 2010).

At the beginning of the Colonial Period, Antaycocha experienced a period of increased erosion, with two distinctive peaks in µXRF PC axis 1; this was most likely as a result of increased flow of the stream entering Antaycocha bringing in a higher sediment load. The timing of this event is concurrent with more negative $^{\delta}$18O values in Laguna Pumacocha (Fig. 6.1), increased lithic concentration in the Lima marine record, and the readvance of glaciers at Nevado Huaguruncho (Rein *et al*., 2005; Bird *et al*., 2011; Stansell *et al*., 2015). The paleoclimatic evidence suggests the transition to the Colonial Period was significantly wetter, leading to higher levels of erosion recorded at Antaycocha. This increase in moisture was felt not only in the Andes but also within Amazonian sites, both in the North (San Jorge) and South of Peru (Parker, Gentry, Vargas and Werth) (Bush *et al*., 2007a, 2007b; Kelly *et al*., 2017). Although it is highly debated as to the origin and cause of the increase in precipitation at this time (e.g., increase in SASM intensity linked to cooler tropical Atlantic SSTs, a change in the position of the ITCZ, and increased ENSO activity), it is clear there was some similarity between the weather systems in the tropical Atlantic and the Pacific at this time (Rein *et al*., 2002, 2005; Thompson *et al*., 2003, 2013, 2017; Reuter *et al*., 2009; Bird *et al*., 2011; Kanner *et al*., 2013; Apaéstegui *et al*., 2014).

6.7 Present Day

At the present day, all three sites have witnessed a change in agricultural activities around the basin (Fig 6.1), with Huarca having a greater diversity of crop types and the introduction of flower grown for export. At Antaycocha and Ayapampa, the former terraces on the slopes around the site have been abandoned and colonised by species of *Ambrosia*, *Alternanthera*, *Rumex*, *Euphorbia*, Fabaceae (e.g., *Lupinus*) and Urticaceae. The diverse agroforestry practices of the Late Horizon and early Colonial Period have largely been replaced by *Eucalyptus*, as is also the case at Huarca. The distribution of traditional Andean trees, including *Polylepis* (*Queñual*), has been heavily impacted by pre-Hispanic and Colonial land-use, with only very limited stands of traditional Andean trees remaining in some areas (Williams *et al*., 2011; O'Donnell *et al*., 2016).

Results of recent ethnography work in the Ancash highlands has shown that the main socio-economic and environmental challenges to peasant communities include a lack of water for agriculture, increasing temperatures, glacial retreat, soil degradation, increase pests and use of agrochemicals, lack of agricultural land, and lack of state intervention (Branch *et al*, in press). Glacial run off is currently almost the only supply of dry-season water within glaciated regions such as the Cordillera Blanca, with non-glacial fed streams almost completely drying up when the dry season ends (Carey, 2010). Glacial outflow initially creates increased water flow that can be harnessed and used to create wetlands and replenish existing ones with water. Many glaciers, especially in the Cordillera Blanca, however, are now past their outflow peak, leading to water shortages in both the dry and wet season (Carey, 2010; Bury *et al*., 2013; Mark *et al*., 2017; O'Donnell *et al*., 2016). Accelerated glacier loss has resulted in disconnected, patchy, fragmented ecosystems, with climate change leading to the desiccation of peat deposits across the Andes (Yager *et al*., 2021). In addition to this, overgrazing, mineral extraction, fuel production, and peat harvesting for domestic and industrial uses has resulted in land management practices that are damaging to the integrity of palaeoenvironmental records and causing widescale degradation of wetlands (Davies *et al*., 2015). For example, in Ccarhuancho in the Ica Valley, without human modification, such as the construction of irrigation canals, ~40% of the wetlands would be degraded or destroyed (Verzijl and Quispe, 2013). Wetlands are a vital resource to highland communities as they can store and purify water, regulate regional hydrology, capture carbon, and enhance local livelihoods (Verzijl and Quispe, 2013; Yager *et al*., 2021). The understanding of how pre-Hispanic society mitigated against environmental change is a vital resource for wetland conservation. The response of these communities, in particular during the arid Middle Horizon and Late Intermediate Period, is a powerful analogue for today, as many Peruvian farmers will undoubtedly live without a reliable water source in the future. This study has illustrated how past societies adapted and managed climatic stress in the form of terrace building, irrigation systems, construction of reservoirs, and use of wet pasture meadows (*bofedales*). At the present day, very few practices employ ancient highly sophisticated socio-political organisation around irrigation, with a replacement in traditional agricultural systems by 'grey infrastructure' (Coxon *et al*., 2021; Yager *et al*., 2021). One element that has remained in some regions, such as Ayacucho and in the Chillón Valley (Lima Region), and illustrates that rural communities are still appreciative of the vulnerability of natural resources, is the water festivals (*Yaku Raymi*). These are orientated around the cleaning of irrigation canals (*Yarqa Aspiy*) and providing offerings (*pagapu*) to the earth to invoke rain (Dean, 2011; Reyes-Knoche, 2012; Kendall and Drew, 2015). Many rural communities understand that the future holds environmental uncertainties including temperature extremes, retreat of glaciers and unpredictable rainfall. They are deeply concerned about water availability and resulting water-conflicts, which have previously been resolved by human modification, management of wetlands and water conservation (Jurt *et al*., 2015; Brügger *et al*., 2021; Branch *et al*., 2022).

As this body of research has demonstrated, wetlands are also highly important resources in terms of preserving long-term histories of human-environmental interactions, which can act as an analogue for possible impact of current and projected future climate change. The three wetlands within this study have proven to be highly sensitive to regional climate change over the past 2500 years. Of particular significance is the potential El Niño signature within the Antaycocha sequence. Around AD 1982 an erosional event was detected in the core sequence, through elevated µXRF PC axis 1 values. The timing of which corresponds with one of the strongest El Niño events since records began, during AD 1982-1983 (Maasch, 2008). Antaycocha's location on the western flank of the Andes means it is well placed to detect changes in ENSO within the Pacific. Unfortunately, due to the unconsolidated nature of the top of the sediment core it was not possible to scan the last 30 years of the sequence to see if the basin record detected any other El Niño events, such as those in AD 1991-1992, AD 1997-1998 or 2002-2003 (Maasch, 2008). It would be interesting to see if any other wetlands within the valleys on the western flank of the Andes record similar recent climatic events, as it may also help with the interpretation of past erosional signals. The collection of further mid-elevation wetland records would enhance our understanding of how the highlands respond to El Niño events, and their relationship to weather systems on the coast. Additional sites from across each of the study areas would also generate greater inter- and intra-regional understanding of climate and environmental change.

Chapter 7 - Conclusions and Recommendations

This thesis aimed to assess the socio-economic responses of pre-Hispanic societies to Late-Holocene climate and environmental change and evaluate the impact of human communities practicing traditional agriculture on the surrounding landscape and environment. The key research questions, outlined in Section **1.7**, primarily focused on identifying changes in the intensity of agricultural activity and landscape erosion using a range of proxy methods, which may have resulted from climatic variability and /or changes in socio-economic activities.

The importance of wetlands for reconstructing the historic environment and evaluating human-environmental interactions has been demonstrated through the multi-proxy investigation of three wetlands situated in regions of Ancash, Lima, and Apurímac. These wetlands are located within the key agricultural belt of the Peruvian Andes (3000-4000m asl). The combined use of palaeoecological analysis (pollen, NPPs, phytoliths and micro-charcoal) and geochemistry (µXRF core scanning), integrated with archaeological and palaeoclimatic data, has provided unequivocal evidence for periods of agricultural intensification and de-intensification in the past in response to variability in climatic conditions (precipitation and temperature), and changing levels of societal, economic and technological organisation and development. These key findings are summarised below.

- The results of the sedimentological and geochronological analysis have demonstrated environmental changes within the wetlands took place during the transition from the Initial Period to the Early Horizon, in response to the wetter climatic conditions. The accumulation of sediment within Antaycocha at *~2954 cal yrs BP* and Ayapampa at *~3970 cal yrs BP* occurred following the mid-Holocene Arid Period, during a period of increased precipitation. Although Huarca formed much earlier, the lithostratigraphy of the basin revealed the development of an open water lake around *~4265 cal yrs BP* also concurrent with this climatic transition, showing the basins to be sensitive to hydrological changes.

- The records from the three wetlands were also highly sensitive to the extended period of drought during the Medieval Climate Anomaly, with a decrease in precipitation and surface runoff leading to a reduction in sediment accumulation within each of the basins. This resulted in a potential hiatus within the sedimentary sequences from each of the basins. The lowering of water levels would have had significant impact on the resources available for agriculture and grazing, potentially resulting in water-related stress for the late, Middle Horizon and early, Late Intermediate Period (~1050-950 cal yrs BP/ AD 900-1100) societies.

- This research has revealed agricultural intensification occurred in the past in response to wetter climatic conditions, such as during the early, Middle Horizon and late, Late Intermediate Period, illustrating a strong link between water availability and agricultural productivity in the past. Increased agricultural activity around Antaycocha during the late, Late Intermediate Period is signalled by the presence of *Zea mays*, Solanaceae, *Oxalis*, Chenopodiaceae/Amaranthaceae, *Ambrosia* and *Sporormiella,* which coincided with the damming of the wetland and the construction of a reservoir within the basin. This period of agricultural intensification also occurred at Ayapampa with the reconstruction of terraces and the increase in maize cultivation, as evidenced by the presence of maize phytoliths.

- The combination of the geochronological, sedimentological, and palaeoecological analysis of Antaycocha clearly demonstrated a late, Late Intermediate Period / early Late Horizon date (*~616 cal yrs BP/ AD 1434*) for the construction of the dam wall. This was concurrent with the onset of the Little Ice Age and the resulting increase in precipitation. The creation of a reservoir would have ensured the success of the agro-pastoral system associated with the community at Cantamarca and provided greater security for a growing population within the Valley during the late, Late Intermediate Period and Late Horizon.

- There is considerable evidence within the palaeoenvironmental records for agroforestry practices during the Late Horizon. The increase in Andean forest taxa during a period that was getting increasingly wetter, during the Little Ice Age, suggests these trees were planted above their natural altitudinal range and encouraged to grow to provide vital resources of timber, building, material and fuel to support a growing Empire.

- The phytolith analysis from Ayapampa and Awiskmarka further improved the understanding of past environmental conditions due to the *in-situ* nature of phytolith deposition and the higher taxonomic resolution within certain plant families (i.e., Poaceae). The abundance of C4 Chloridoideae phytoliths within Ayapampa during the Colonial Period-Present day is a reflection of the drier climatic conditions within the Chicha-Soras Valley today, with Chloridoideae grasses favouring hot and dry conditions.

- Finally, the records highlighted periods of reduced human activity, in relation to societal reorganisation, as well as climate variability. Two distinct periods of reductions in agricultural activity took place with the transition from the Middle Horizon to the Late Intermediate Period, and from the Late Horizon into the Colonial Period. These periods of reduced agricultural activity were signalled by a reduction in cultivars and associated land disturbance indicators (*Ambrosia* and *Artemisia*), and changes in abundance of forest taxa, as well as a decreases in landscape erosion.

This body of research, in conjunction with published archaeological and palaeoclimatic data, has shown that pre-Hispanic societies responded to changes in climate by adapting agricultural practices, including the construction of reservoirs and agricultural terraces, and in doing so were able to deal with variability in natural resources, such as water availability. Understanding how pre-Hispanic societies mitigated the risk posed by climate variability is important for future land-use, and water and soil conservation practices. The present-day rate of resource depletion and land degradation that is taking place across the Peruvian Andes is exceeding that which took place during the pre-Hispanic era. There is an urgent need therefore for smaller-scale, less intensive, agricultural practices akin to traditional and more sustainable pre-Hispanic systems. Additionally, wetlands such as Huarca, Antaycocha, and Ayapampa can play an important role in climate change regulation, providing a nature-based solution for landscape management helping to store water, regulate water flow as well as capture carbon. It is highly important these wetlands are conserved, not only for future water management but also because they provide a valuable archive of human-environmental interactions.

The research has demonstrated the need for an enhanced database of palaeoenvironmental records for the Peruvian Andes. The archaeological and palaeoenvironmental record indicates past societies supported their populations through highly innovative agricultural systems, including the use of terraces, canals, reservoirs, and silt dams, and that these systems were remarkably resilient, as evidenced by the apparent persistence of human occupation in many highland areas. However, the relationship between increased climate variability and the resilience of pre-Hispanic societies is still not fully understood. The following recommendations would help to further enhance our understanding of how humans responded to past climate variability as well as any adaptation strategies they implemented to mitigate the impact, which has important implication for future land, soil, and water management practices.

- There remains a paucity of palaeoenvironmental data for the Peruvian Andes. The sampling of more sites within the Ancash, Lima, and Apurímac Regions, situated near archaeological sites or remains of past agricultural systems (e.g., agricultural terraces and silt damns) will enable the development of significantly improved inter- and intra-regional models of land-use and environmental change, which will provide the basis for further testing of the hypothesises put forward within this research.

- The collection of multiple cores from within one wetland, i.e., a central core to obtain the wider landscape and vegetation history, and cores closer to the wetland edge and proximal to archaeological or agricultural features, would ensure the nature of past land-use and environmental change is captured in its entirety. This would also help resolve problems arising from the extra-local dispersal of *Zea mays* pollen and *Sporormiella*.

- This study has successfully demonstrated the application of phytolith analysis in conjunction with pollen analysis from lake and mire sequences for identifying the presence of maize and increasing the taxonomic resolution of Poaceae into subfamilies. The employment of phytolith analysis at more wetlands of palaeoenvironmental significance would develop greater understanding of the plant communities and diversity present within the predominately grassland environments of the mid-high Andes.

- The development of a more extensive modern phytolith reference collection from the Andes would also permit the identification of phytoliths to higher taxonomic resolution. This would allow for better identification of sub-species of Poaceae and Cyperaceae as well as potentially being able to identify arboreal taxa, at least to family level, as has been developed within other regions.

- Further analysis is required to enhance our understanding of the function of agriculture terraces due to many key Andean cultivars (including potatoes, quinoa, *kañiwa*, oca, and other tubers) not producing diagnostic phytoliths. This would help resolve remaining questions including: Did past farmers employ multi-cropping practices to ensure sustainable yields in case of crop failure? Did farmers preferentially choose certain cultivars to suit certain climatic conditions? Suggested methods include:

  - Starch grains to identify the presence of potatoes and other starch-rich tubers,
  - Sedimentary ancient DNA (*seda*DNA) to identify a broader range of plants to a higher taxonomic level, (i.e., beyond the family level most often achievable through pollen and phytolith analysis),
  - N-alkanes, which along with *seda*DNA, allow for the identification of a broader range of cultivars due to plants having specific n-alkane and n-alkene distributions within their leaf waxes.

- The analysis of coprostanols as faecal biomarkers would provide greater understanding of past pastoral activities. It not only has the ability to confirm the presence of camelids, as is currently possible via the presence of *Sporormiella* and Oribatid Mites, but also to predict variations in camelid herd sizes and therefore shifts in the intensity of pastoral activity. This in turn may provide greater understanding of the role and importance of pastoral activities within mixed agro-pastoral economies. The size of herds may also reflect human population sizes as there would be a need for more camelid resources (meat, wool, ability to carry heavy loads) during periods of cultural development.

- Although this research has demonstrated the presence of sedimentary sequences within the Peruvian Andes that provide considerable potential for ultra-high-resolution analysis of environmental change, there is a need for additional radiocarbon dates from these sequences to improve the precision of age models, enabling us to better constrain the onset and termination of key cultural periods.

- There is also a desperate need for radiocarbon dates originating from archaeological excavations to build robust chronologies of the formation, development, and abandonment of sites. Chronologies based on radiocarbon dates, in addition to traditional pottery and architectural typologies, would allow for a more accurate correlation between land-use practices, climate change and societal development, ultimately enabling the development of a more precise understanding of past human-environmental interactions.

References

Abbott, M.B., Binford, M.W., Brenner, M., and Kelts, K.R. (1997) A 3500 14C High-Resolution Record of Water-Level changes in Lake Titicaca, Boliva/Peru. *Quaternary Research* 47, pp. 169-180.

Abbott, M.B., and Wolfe, A.P. (2003) Intensive pre-Incan metallurgy recorded by lake sediments from the Bolivian Andes. *Science* 301, pp.1893-1895.

Abbott, M.B., Wolfe, B.B., Wolfe, A.P., Seltzer, G.O., Aravena, R., Mark, B.G., Polissar, P.J., Rodbell, D.T., Rowe, H.D., and Vuille, M. (2003) Holocene paleohydrology and glacial history of the central Andes using multiproxy lake sediment studies. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 194(1-3), pp.123-138.

Aguilar Díaz, M. (2019) Paisajes políticos y ushnu en el orden social y espacial de Choquerecuay, s. XV-XVI. *Ñawpa Pacha*, 39(1), pp.1-30.

Åkesson, C.M., Matthews-Bird, F., Bitting, M., Fennell, C.J., Church, W.B., Peterson, L.C., Valencia, B.G., and Bush, M.B. (2020) 2,100 years of human adaptation to climate change in the High Andes. *Nature ecology & evolution*, 4(1), pp.66-74.

Aleman, J.C., Canal-Subitani, S., Favier, C., and Bremond, L. (2014) Influence of the local environment on lacustrine sedimentary phytolith records. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 414, pp.273-283.

Alves, D. T. (2017) *Dark Earth plant management in the Lower Tapajós*. Unpublished PhD Thesis, University of Exeter.

Apaestegui, J., Cruz, F.W., Sifeddine, A., Vuille, M., Espinoza, J.C., Guyoy, J.L., Khodri, M., Strikis, N., Santos, R.V., Cheng, H., Edwards, L., Carvalho, E., and Santini, W. (2014) Hydroclimate variability of the northwestern Amazon Basin near the Andean foothills of Peru related to the South American Monsoon System during the last 1600 years. *Clim. Past*. 10, pp.1967-1981.

APSA Members (2007) *The Australasian Pollen and Spore Atlas V1.0*. Australian National University, Canberra. [WWW] http://apsa.anu.edu.au/ (Last accessed 15/01/2022)

Arkush, E., and Tung, T. A. (2013) Patterns of war in the Andes from the Archaic to the Late Horizon: insights from settlement patterns and cranial trauma. *Journal of Archaeological Research*, 21(4), pp.307-369.

Arnold, T.E., Hillman, A.L., Abbott, M.B., Werne, J.P., McGrath, S.J., and Arkush, E.N. (2021) Drought and the collapse of the Tiwanaku Civilization: New evidence from Lake Orurillo, Peru. *Quaternary Science Reviews*, 251, pp.106693.

Astudillo, F.J. (2018) Soil phytoliths as indicators of initial human impact on San Cristóbal Island, Galápagos. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 490, pp.522-532.

Ball, T.B., Davis, A.L., Evett, R.R., Ladwig, J.L., Tromp, M., Out, W.A., and Portillo, M. (2016) Morphometric analysis of phytoliths: Recommendations towards standardization from the International Committee for Phytolith Morphometrics. *Journal of Archaeological Science*, 68, pp.106–111.

Barboni, D., Bonnefille, R., Alexandre, A., and Meunier, J.D. (1999) Phytoliths as paleoenvironmental indicators, west side Middle Awash Valley, Ethiopia. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 152(1-2), pp.87-100.

Barboni, D., Bremond, L., and Bonnefille, R. (2007) Comparative study of modern phytolith assemblages from inter-tropical Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 246(2-4), pp.454-470.

Barnes, M. (1981) The Chicha Project. *South American Explorer* pp.10-15.

Bell, M., and Walker, M.J.C. (2004) *Late Quaternary Environmental Change: Physical and Human Perspectives* (2nd ed.). Essex: Pearson Education Ltd.

Bengtsson, L., and M. Enell (1986) Chemical analysis. *In Berglund, B.E. ed. (1986), Handbook of Holocene Palaeoecology and Palaeo-hydrology. Chichester: John Wiley and Sons Ldt., pp.423–451.*

Bernabé, J.A.R. (2015). *Establecimientos incas en el subtramo Lampas–Pueblo Viejo en la región Ancash*. Ministerio de Cultura.

Beresford-Jones, D., Arce, S.T., Whaley, O.Q., and Chepstow-Lusty, A. (2009) The Role of Prosopis in Ecological and Landscape Change in the Samaca Basin, Lower Ica Valley, South Coast Peru from the Early Horizon to the Late Intermediate Period. *Latin American Antiquity,* 20, pp.303-332.

Beresford-Jones, D. (2011) Tracing Human Ecology: The Archaeobotanical and Malacological Record in *Beresford-Jones ed. (2011) The Lost Woodlands of Ancient Nasca: A Case- study in Ecological and Cultural Collapse. British Academy Scholarship Online pp.84-107.*

Bernabé, J.A.R. (2017). La ruta inca a los Huaylas. Estudio de la vialidad inca en la pampa de Lampas-Choquerecuay, en el departamento de Ancash, Perú. *Boletín del Museo Chileno de Arte Precolombino*, 22(2), pp.47-63.

Binford, M.W., Kolata, A.L., Brenner, M., Janusek, J.W., Seddon, M.T., Abbot, M., and Curtis, J.H. (1997) Climate Variation and the Rise and Fall of an Andean Civilization. *Quaternary Research,* 47, pp.235-248.

Bird, B.W., Abbott, M.B., Rodbell, D.T., and Vuille, M., (2011) Holocene tropical South American hydroclimate revealed from a decadally resolved lake sediment d18O record. *Earth Planet. Sci. Lett.* 310**,** pp.192-202.

Birks, H.H., and Birks, H.J.B. (2006). Multi-proxy studies in palaeolimnology. *Vegetation History and Archaeobotany*, 15(4), pp.235-251.

Bozarth, S.R. (1992) Classification of opal phytolith formed in selected dicotyledons native to the great plains *in Rapp Jr, G. and Mulholland, S.C. eds. (1992) Phytolith Systematics. New York: Plenum Press, pp.193-214.*

Brack Egg, A. (1999) *Diccionario Enciclopéddico de plantas utiles del Perú*. Centro de Estudios Regionales Andinos, Cusco.

Brako, L., and Zarucchi, J.L. (1993) Catalogue of the flowering plants and gymnosperms of Peru. Catálogo de las angiospermas y gimnospermas del Perú. *Monographs in systematic botany from the Missouri Botanical Garden*, 45, pp.1-1286.

Branch, N.P., Canti, M., Clark, P., and Turney, C. (2005) *Environmental Archaeology: Theoretical and Practical Approaches*. London: Hodder Education

Branch, N.P., Kemp, R.A., Silva, B., Meddens, F.M., Williams, A., Kendall, A., and Pomacanchari, C.V. (2007) Testing the sustainability and sensitivity to climatic change of terrace agricultural systems in the Peruvian Andes: a pilot study. *Journal of Archaeological Science*, 34(1), pp.1-9.

Branch, N.P., Ferreira, F., Lane, K., Wade, A., Walsh, D., Handley, J., Herrera, A., Rodda, H., Simmonds, M., Meddens, F., and Black, S. (in press) Adaptive capacity of farming communities to climate change in the Peruvian Andes: past, present and future (preliminary findings of the ACCESS project). *Revista de Glaciares y Ecosistemas de Montaña.*

Bronk Ramsey, C. (2009) Bayesian analysis of radiocarbon dates. *Radiocarbon*, 51(1), pp.337–360.

Bronk Ramsey, C., & Lee, S. (2013). Recent and Planned Developments of the Program OxCal. *Radiocarbon*, 55(2-3), pp.720–730.

Brügger, A., Tobias, R., and Monge-Rodríguez, F.S. (2021) Public perceptions of climate change in the Peruvian Andes. *Sustainability*, 13(5), pp.2677.

Brunschön, C., Haberzettl, T., and Behling, H. (2010) High-resolution studies on vegetation succession, hydrological variations, anthropogenic impact and genesis of a subrecent lake in southern Ecuador. *Vegetation History and Archaeobotany,* 19, pp.191-206.

Bunting, M.J. (2007) Pollen in wetlands: using simulations of pollen dispersal and deposition to better interpret the pollen signal. *Biodiversity and Conservation,* 17, pp.2079-2096.

Burger, R., Lee-Thorp, J., and van der Merwe, N., (2003) Rite and crop in the Inca state revisited: an isotopic perspective from Machu Picchu and beyond. *In: Burger, R., Salazer, L. (Eds.), The 1912 Yale Peruvian Scientific Expedition Collections from Machu Picchu, Human and Animal Remains, No. 85. Yale University Publications in Anthropology, New Haven, pp.119-137.*

Bury, J., Mark, B.G., Carey, M., Young, K.R., McKenzie, J.M., Baraer, M., French, A., and Polk, M.H. (2013) New geographies of water and climate change in Peru: Coupled natural and social transformations in the Santa River watershed. *Annals of the Association of American Geographers*, 103(2), pp.363-374.

Bush, M.B. (2002) On the interpretation of fossil Poaceae pollen in the lowland humid neotropics. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 177, pp.5–17.

Bush, M.B., Hansen, B.C.S., Rodbell., D.T., Seltzer, G.O., Young., K. R., Blanca, L., Silman, M.R., and Gosling, W.D. (2005) A 1700-year history of Andean climate and vegetation change from Laguna de Chochos, Peru. *Journal of Quaternary Science* 20(7-8) pp.703-714.

Bush, M.B., and Weng, M.B. (2006) Introducing a new (freeware) tool for palynology. *Journal of Biogeography* 34 pp. 377-380.

Bush, M.B., Silman, M.R., and Listopad, C.M.C.S. (2007a) A regional study of Holocene climate change and human occupation in Peruvian Amazonia. *Journal of Biogeography*, 34(8), pp.1342-1356.

Bush, M.B., Silman, M.R., De Toledo, M.B., Listopad, C., Gosling, W.D., Williams, C., De Oliveira, P.E., and Krisel, C. (2007b) Holocene fire and occupation in Amazonia: records from two lake districts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362(1478), pp.209-218.

Bush, M. B., Mosblech, N.A.S., and Church, W. (2015) Climate change and the agricultural history of a mid-elevation Andean montane forest. *The Holocene*, 25(9), pp.1522–1532.

Bustamante, M.G., Cruz, F.W., Vuille, M., Apaéstegui, J., Strikis, N., Panizo, G., Novello, F.V., Deininger, M., Sifeddine, A., Cheng, H., Mosquet, J.S., Guyot, J.L., Santos, R.V., Segura, H., and Edwards, R.L. (2016) Holocene changes in monsoon precipitation in the Andes of NE Peru based on δ18O speleothem records. *Quaternary Science Reviews*, 146, pp.274-287.

Cabanes, D. (2020) Phytolith analysis in Paleoecology and Archaeology. *In Henry, A.G. ed. (2020) Handbook for the Analysis of Micro-Particles in Archaeological Samples. Cham: Springer, pp. 255-288.*

Cadwallader, L., Beresford-Jones, D.G., Whaley, O.Q., and O'Connell, T.C. (2012) The signs of maize? A reconsideration of what δ13C values say about palaeodiet in the Andean region. *Human Ecology*, 40(4), pp.487-509.

Campbell, J.F.E., Fletcher, W.J., Hughes, P.D., and Shuttleworth, E.L. (2016) A comparison of pollen extraction methods confirms dense-media separation as a reliable method of pollen preparation. *Journal of Quaternary Science*, 31(6), pp.631-640.

Campos, J.L.P.S., Cruz, F.W., Ambrizzi, T., Deininger, M., Vuille, M., Novello, V.F. and Stríkis, N.M. (2019) Coherent South American Monsoon variability during the last millennium revealed through high-resolution proxy records. *Geophysical Research Letters*, 46(14), pp.8261-8270.

Capparelli, A., Lema, V., Giovannetti, M., and Raffino, R. (2005) The introduction of Old World crops (wheat, barley and peach) in Andean Argentina during the 16th century AD: archaeobotanical and ethnohistorical evidence. *Vegetation History and Archaeobotany*, 14(4), pp.472-484.

Caramancia, A., Quilter, J., Huaman, L., Villanueva, F., and Morales, C.R. (2018) Micro-remains, ENSO, and environmental reconstruction of El Paraíso, Peru, a late preceramic site. *Journal of Archaeological Science,* 17, pp.667-677.

Cardich, A. (1985) The fluctuating upper limits of cultivation in the central Andes and their impact on Peruvian prehistory. *Advances in World Archaeology*, 4, pp.293-333.

Carey, M. (2010) The Story of Vanishing Water Towers *in Carey, M. ed. (2010). In the shadow of melting glaciers: Climate change and Andean society. Oxford: Oxford University Press. pp.147-164.*

Carreras Rivery, Raquel and Escalera, Andrés (1998) Identificación de la madera de las vasijas de libación inca (keros) pertenecientes a la colección del Museo de América. *Anales del Museo de América*, 6, pp.217-222.

Chagué-Goff, C., Chan, J. C. H., Goff, J., and Gadd, P. (2016) Late Holocene record of environmental changes, cyclones and tsunamis in a coastal lake, Mangaia, Cook Islands. *Island Arc*, 25, pp.333– 349.

Chepstow-Lusty, A., Bennett, K.D., Switsur, V.R., and Kendall., A. (1996) 4000 year of human impact and vegetation change in the central Peruvian Andes- with event paralleling the Maya record? *Antiquity,* 70, pp.824-833.

Chepstow- Lusty, A., Bennet, K.D., Fjeldså, J., Kendall, A., Galiano, W., and Tupayachi Herrera, A. (1998) Tracing 4,000 years of Environmental History in the Cuzco Area, Peru, from the Pollen Record. *Mountain Research and Development*,18, pp.159-172.

Chepstow-Lusty, A., and Winfield, M. (2000) Inca Agroforestry: Lessons from the Past. *Ambio,* 29**,** pp.322-328.

Chepstow-Lusty, A., Frogley, M.R., Bauer, B.S., Bush, M.B., and Tupayachi Herrera, A. (2003) A late Holocene record of arid events from the Cuzco region, Peru. *Journal of Quaternary Science,* 18, pp.491-502.

Chepstow-Lusty, A., Bauer, B.S., and Frogley, M.R. (2004) Human Impact and Environmental History of the Cuzco region. *in Bauer, B.S. ed. (2004) Ancient Cuzco Heartland of the Incas. Austin: University of Texas Press. pp.23-30.*

Chepstow-Lusty, A., Frogley, A., Bauer, B.S., Leng, M.J., Cundy, A.B., Boessenkool, K.P., and Gioda, A. (2007) Evaluating socio-economic change in the Andes using oribatid mite abundances as indicators of domestic animal densities. *Journal of Archaeological Science*, 34, pp.1178-1186.

Chepstow-Lusty, A., Frogley, A., Bauer, B.S., Leng, M.J., Boessenkool, K.P., Carcaillet, C., Ali, A.A., and Gioda, A. (2009) Putting the rise of the Inca Empire within a climatic and land management context. *Clim. Past*. 5, pp.375-388.

Chepstow-Lusty, A. (2011) Agro-pastoralism and social change in the Cuzco heartland of Peru: A brief history using environmental proxies. *Antiquity*, 85, pp.570-582.

Chepstow-Lusty, A., Frogley, M. R., and Baker, A. S. (2019) Comparison of Sporormiella dung fungal spores and oribatid mites as indicators of large herbivore presence: evidence from the Cuzco region of Peru. *Journal of Archaeological Science*, 102, pp.61-70.

Cohen, M.N. (1978) Archaeological plant remains from the central coast of Peru. *Ñawpa Pacha*, 16 (1), pp.23-50.

Cook, N.D. (1981) *Demographic Collapse: Indian Peru, 1520-1620*. Cambridge: Cambridge University Press.

Cooke, C.A., Abbott, M.B., Wolfe, A.P., and Kittleson, J.L. (2007) A millennium of metallurgy recorded by lake sediments from Morococha, Peruvian Andes. *Environmental Science and Technology*, *41*(10), pp.3469-3474.

Cooke, C.A., Abbott, M.B., and Wolfe, A.P. (2008a) Late-Holocene atmospheric lead deposition in the Peruvian and Bolivian Andes. *The Holocene*, 18(2), pp.353-359.

Cooke, C.A., and Abbott, M.B. (2008b) A paleolimnological perspective on industrial-era metal pollution in the central Andes, Peru. *Science of the total environment*, 393(2-3), pp.262-272.

Cooke, C.A., Wolfe, A.P., and Hobbs, W.O. (2009) Lake-sediment geochemistry reveals 1400 years of evolving extractive metallurgy at Cerro de Pasco, Peruvian Andes. *Geology*, 37(11), pp.1019-1022.

Contreras, S.A., and Zucol, A.F. (2019) Late Quaternary vegetation history based on phytolith records in the eastern Chaco (Argentina). *Quaternary International*, 505, pp.21-33.

Correa-Metrio A., Cabera, K.R., and Bush, M.B. (2010) Quantifying ecological change through discriminant analysis: A paleoecological example from the Peruvian Amazon. *Journal of Vegetation Science,* 21(4), pp.694-704.

Costanza, R., Graumlich, L., Steffen, W., Crumley, C., Dearing, J., Hibbard, K., Leemans, R., Redman, C., and Schimel, D. (2007) Sustainability or collapse: what can we learn from integrating the history of humans and the rest of nature? *Ambio*, 36(7), pp.522–527.

Covey, R.A. (2008a) The Inca Empire *in Silverman, H. and Isbell, W. eds (2008) Handbook for South American Archaeology. New York: Springer, pp.824.*

Covey, R. A. (2008b) Multiregional perspectives on the archaeology of the Andes during the Late Intermediate Period (c. AD 1000–1400). *Journal of Archaeological Research*, 16(3), pp.287-338.

Coxon, C., Gammie, G., and Cassin, J. (2021) Mobilizing funding for nature-based solutions: Peru's drinking water tariff. *In Cassin, J., Matthews, J.H., and Gunn, E.L. eds. (2021) Nature-based Solutions and Water Security. Elsevier, pp. 241-262.*

Crifò, C., and Strömberg, C.A. (2020) Small-scale spatial resolution of the soil phytolith record in a rainforest and a dry forest in Costa Rica: applications to the deep-time fossil phytolith record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 537, pp.109107.

Croudace, I.W., Rindby, A., and Rothwell, R.G. (2006) ITRAX: description and evaluation of a new multi-function X-ray core scanner *in Rothwell, R.G. ed. (2006) New Techniques in Sediment Core Analysis. London: The Geological Society of London pp.65-77.*

Croudace, I.W., and Rothwell, R.G. (2015) *Micro-XRF Studies of Sediment Cores: Applications of a non-destructive tool for the environmental sciences* (Vol. 17). Springer.

Davis, O.K., and Shafer, D.S. (2006) Sporormiella fungal spores, a palynological means of detecting herbivore density. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 237, (1), pp.40-50.

Davies, S.J., Lamb, H.F., and Roberts, S.J. (2015) Micro-XRF Core Scanning in Palaeolimnology: Recent Developments in *Croudace, I. W., and Rothwell, R. G. eds. (2015). Micro-XRF Studies of Sediment Cores: Applications of a non-destructive tool for the environmental sciences (Vol. 17). Springer, pp.189-222.*

Davies, H., Fyfe, R., and Charman. D. (2015) Does peatland drainage damage the palaeoecological record? *Review of Palaeobotany and Palynology*, 221, pp.92-105.

Denevan, W.M. (1976) *The Native Population of the Americas in 1942* Madison: University of Wisconsin Press.

Denevan, W.M. (1992) The Pristine Myth: The Landscape of the Americas in 1492. *Annals of the Association of American Geographers*, 82, pp.369-385.

Dickau, R., Iriarte, J., Quine, T., Soto, D., and Mayle, F. (2016) Reconstructing pre-Colombian agricultural Practices in the Bolivian savannah: Stratigraphic and phytolith evidence from raised fields at Campo España, western Llanos de Moxos. *Cadernos do LEPAARQ (UFPEL),* 13(25), pp.223-267.

Dillehay, T. D. (1977) Tawantinsuyu Integration of the Chillon Valley, Peru: A Case of Inca Geo-Political Mastery. *Journal of Field Archaeology*, 4(4), pp.397-405.

Dransart, Penelope Z. (2002) *Earth, Water, Fleece and Fabric: An Ethnography and Archaeology of Andean Camelid Herding*. London: Routledge.

Duncan, N.A., Pearsall, D.M. and Benfer Jr, R.A. (2009) Gourd and squash artifacts yield starch grains of feasting foods from preceramic Peru. *Proceedings of the National Academy of Sciences*, 106(32), pp.13202-13206.

Eichler, A., Gramlich, G., Kellerhals, T., Tobler, L., and Schwikowski, M. (2015) Pb pollution from leaded gasoline in South America in the context of a 2000-year metallurgical history. *Science Advances*, *1*(2), e1400196.

Eichler, A., Gramlich, G., Kellerhals, T., Tobler, L., Rehren, T., and Schwikowski, M. (2017) Ice-core evidence of earliest extensive copper metallurgy in the Andes 2700 years ago. *Scientific reports*, *7*(1), pp.1-11.

Escalante, C., and Valderrama, R. (2014) Sacred mountains and rituals in the Andes *in Meddens, F.M., Willis, K., McEwan, C. and Branch, N. eds. (2014) Inca Sacred Space: Landscape, site and symbol in the Andes. London: Archetype Publications*. *pp.147-156.*

Ezell, K.C., Pearsall, D.M., and Zeidler, J.A. (2006) Root and tuber phytoliths and starch grains document manioc (Manihot esculenta) arrowroot (Maranta arundinacea) and llerén (Calathea sp.) at the real alto site Ecuador. *Economic Botany*, 60(2), pp.103-120.

Faegri, K., and Iversen, J. (1989) *Textbook of pollen analysis*. 4th ed. Oxford: Blackwell.

Farfán, C. (1988). Informe preliminar de los trabajos arqueológicos en Cantamarca. Actas del VI Congreso Peruano: Hombre y Cultura Andina. *In: Iriarte, F. ed. (1988) Tomo 3, UIGV y CONCYTEC: Lima. pp.147-167.*

Farfán, C. (1995). *Asentamientos prehispánicos de la cuenca alta del Chillón*. Gaceta Arqueológica Andina, 24, Instituto Andino de Estudios Arqueológicos, INDEA, 31-61, Lima.

Farfán, C. (2011). Arquitectura prehispánica de Cantamarca-Canta. *Arquitectura prehispánica tardía: construcción y poder en los Andes centrales*. Fondo Editorial UCSS y Universidad Católica Sedes Sapientiae.

Fedoroff, N.V., Battisti, D.S., Beachy, R.N., Cooper, P.J., Fischhoff, D.A., Hodges, C.N., Knauf, V.C., Lobell, D., Mazur, B.J., Molden, D., and Reynolds, M.P. (2010) Radically rethinking agriculture for the 21st century. *Science*, 327(5967), pp.833-834.

Fehren-Schmitz, L., Haak, W., Mächtle, B., and Reindel, M. (2014) Climate change underlies global demographic, genetic and cultural transitions in pre-Columbian Southern Peru. *PNAS,* 111, pp.9443-9448.

Ferreira, F. (2014) “Ritual mixing”: an ethnographic approach to combination of fills from different origins in Inca ushnu platforms *in Meddens, F.M., Willis, K., McEwan, C. and Branch, N. eds. (2014) Inca Sacred Space: Landscape, site and symbol in the Andes. London: Archetype Publications*.pp.119-126.

Finucane, B.C., Valdez, J.E., Calderon, I.P., Pomacanchari, C.V., Valdez, L.M., and O'Connell, T. (2007) The end of empire: new radiocarbon dates from the Ayacucho Valley, Peru, and their implications for the collapse of the Wari state. *Radiocarbon*, 49(2), pp.579-592.

Finucane, B.C. (2007) Mummies, maize, and manure: multi-tissue stable isotope analysis of late prehistoric human remains from the Ayacucho Valley, Peru. *Journal of Archaeological Science*, 34(12), pp.2115-2124.

Finucane, B.C. (2008) Trophy heads from Nawinpukio, Perú: Physical and chemical analysis of Huarpa-era modified human remains. *American Journal of Physical Anthropology*, 135(1), pp.75-84.

Fisher, E.C., Albert, R.M., Botha, G., Cawthra, H.C., Esteban, I., Harris, J., Jacobs, Z., Jerardino, A., Marean, C., Neumann, F.H., Pargeter, J., Poupart, M., and Venter, J. (2013) Archaeological Reconnaissance for Middle Stone Age Sites Along the Pondoland Coast, South Africa. *T. Paleoanthropology*, pp.104-137.

Flores, G.M. (2019) The Cultural Trajectory of the Central Peruvian Coast, The Territory and Its People in the Valleys of Pre-Hispanic Lima. *In Engel, E.A. ed. (2019) A Companion to Early Modern Lima, Brill. pp. 25-45.*

Fonkén, M. M. (2014) An introduction to the bofedales of the Peruvian High Andes. *Mires and Peat*, 15 (5), pp.1-13.

Fredlund, G. G., and Tieszen, L. T. (1994) Modern phytolith assemblages from the North American great plains. *Journal of Biogeography*, 21, pp.321-335.

Galeano, G.S., José, M., Mejía, K., Pintaud, J.C., and Millán, B. (2008) Novelties in the genus Ceroxylon (Arecaceae) from Peru, with description of a new species. *Rev. peru. biol*., 15, pp.65-72.

Garreaud, R.D., Vuille, M., and Clement, A. C. (2003) The climate of the Altiplano: observed current conditions and mechanisms of past changes. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 194(1-3), pp.5-22.

Garreaud, R.D., Vuille, M., Compagnucci, R., and Marengo, J. (2009) Present-day South American climate. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 281(3-4), pp.180-195.

Gebregiorgis, D., Giosan, L., Hathorne, E.C., Anand, P., Nilsson-Kerr, K., Plass, A., Lückge, A., Clemens, S.C., and Frank, M. (2020) What can we learn from X-ray fluorescence core scanning data? A paleomonsoon case study. *Geochemistry, Geophysics, Geosystems*, 21(2), e2019GC008414.

Gerdau-Radonic, K., and Herrera, A. (2010) Why dig looted tombs? Two examples and some answers from Keushu (Ancash highlands, Peru). *Bulletins et Memoires de la Societe d'Anthropologie de Paris*, 22(3), pp.145-156.

Giannitto, D.A. (2020) *A Reconstruction of Vegetation and Environmental History of the Huarca Bofedal in the Cordillera Blanca, Ancash, Peru Over the Last 2,000 Years*. Unpublished Undergraduate Dissertation. University of Reading.

Grimm, E.C. (2019) TILIA 2.6.1., Springfield: Illinois state museum.

Grobman, A., Bonavia, D., Dillehay, T.D., Piperno, D.R., Iriarte, J., and Holst, I. (2012) Preceramic maize from Paredones and Huaca Prieta, Peru. *PNAS*, 109(5), pp.1755-1759.

Guédron, S., Tolu, J., Delaere, C., Sabatier, P., Barré, J., Heredia, C., Brisset, E., Campillo, S., Bindler, R., Fritz, S.C., and Baker, P.A. (2021) Reconstructing two millennia of copper and silver metallurgy in the Lake Titicaca region (Bolivia/Peru) using trace metals and lead isotopic composition. *Anthropocene*, 34, p.100288.

Guillet, D. (1987) Terracing and Irrigation in the Peruvian Highlands. *Current Anthropology*, 28(4), pp.409-430.

Haas, J., Creamer, W., Huamán Mesía, L., Goldstein, D., Reinhard, K. and Rodríguez, C.V. (2013) Evidence for maize (Zea mays) in the Late Archaic (3000–1800 BC) in the Norte Chico region of Peru. *Proceedings of the National Academy of Sciences*, 110(13), pp.4945-4949.

Handley, J. (2016) *Examining the Relationship between the Environment and Late Holocene Societal Change in the Peruvian Andes.* Unpublished Masters Dissertation. University of Reading

Handley, J., Branch, N., Meddens, F., Simmonds, M., and Iriarte, J. (in prep) Pre-Hispanic terrace agricultural practices and long-distance transfer of plant taxa in the southern-central Peruvian Andes revealed by phytolith and pollen analysis.

Hansen, B.C.S., Seltzer, G.O., and Wright Jr, H.E. (1994) Late Quaternary vegetational change in the central Peruvian Andes. *Palaeoegeography, Palaeoclimatology, Palaeoecology,* 109, pp.236-285.

Hansen, B.C.S., and Rodbell, D. (1995) A Late Glacial/Holocene Pollen Record from the Eastern Andes of Northern Peru. *Quaternary Research,* 44, pp.216-227.

Hastorf, C. A., Johannessen, S. (1993) Pre-Hispanic political change and the role of maize in the Central Andes of Peru. *American Anthropologist,* 95, pp.115-138.

Hastorf, C. A. (2017) *The social archaeology of food: Thinking about eating from prehistory to the present*. Cambridge: Cambridge University Press.

Heiri, O., Lotter, A. F., and Lemcke, G. (2001) Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology*, 25(1), pp.101-110.

Henderson, A., Galeano, G., Bernal, R. (1995) *Field guide to the palms of the Americas*. Princeton: Princeton University Press.

Henke, L. M. K., Lambert, F. H., & Charman, D. J. (2017) Was the Little Ice Age more or less El Niño-like than the Medieval Climate Anomaly? Evidence from hydrological and temperature proxy data. *Climate of the Past*, 13, pp.267–30

Herrera, A. (2003) Patrones de asentamiento y cambios en las estrategias de ocupación en la cuenca sur del Río Yanamayo, Callejón de Conchucos. *In Asencios, B.I. ed. (2003) Arqueología de la sierra de Ancash: propuestas y perspectivas*. *Instituto Cultural Runa, Lima*, *pp.221-250*.

Herrera, A. (2005) Las kancha circulares: Espacios de interacción social en la sierra norte del Perú. *Boletín de arqueología PUCP*, 9, pp.233-255.

Herrera, A. (2007) Social Landscapes and Community Identity: the Social Organisation of Space In the North-Central Andes *In Herrera, A., Kohring, S., and Wynne-Jones, S eds. (2007) Socialising Complexity: Structure, Interaction and Power in Archaeological Discourse. Oxbow Books, pp.161-185.*

Herrera, A., Janin, S., and Ramel, J.M. (2009) *The hydrology of ancient Peruvian terracing: The case of Awkismarka / Pueblo Viejo de Huandoy Proyecto de Investigación Arqueológico Wanduy.* University de los Andes, Bogotá.

Herrera, A. (2017) Turismo patrimonial, identidad y desarrollo en el Perú. *Indiana,* 34, pp.199–231.

Herrera, A., Acosta, D., and Bria, R. (in prep) Investigations at Awkismarka *in Herrera, A. ed. Water, Ancestors and Memory. Volume 1: Archaeological Investigations in the Callejón de Huaylas and the Western Escarpment of the Cordillera Negra.*

Hilbert, L., Neves, E.G., Pugliese, F., Whitney, B.S., Shock, M., Veasey, E., Zimpel, C.A., and Iriarte, J. (2017) Evidence for mid-Holocene rice domestication in the Americas. *Nature ecology and evolution*, 1(11), pp.1693-1698.

Hillyer, R., Valencia, B.G., Bush, M.B., Silman, M.R., and Steinitz-Kannan, M. (2009) A 24,700-yr paleolimnological history from the Peruvian Andes. *Quaternary Research,* 71, pp.71-82.

Hodgson, J.M., 1976. *Soil Survey Field Handbook: Describing and Sampling Soil Profiles*, Technical monograph no. 5. Soil Survey of England and Wales: Harpenden

Hodson, M.J., White, P.J., Mead, A., and Broadley, M.R. (2005) Phylogenetic variation in the silicon composition of plants. *Annals of Botany*, 96(6), pp.1027-1046.

Hu, D. (2016) *Labor under the Sun and the Son: Landscapes of Control and Resistance at Inka and Spanish Colonial Pomacocha, Ayacucho*, Unpublished PhD Thesis, University of California, Berkeley.

Hua, Q., Barbetti, M., and Rakowski, A. J. (2013). Atmospheric Radiocarbon for the Period 1950-2010. *Radiocarbon,* 55(4), pp.2059–2072.

Huarcaya, R.M. (2013) Ocupación Prehispanica en el área del distrito de San Pedro de Larcay, Sucre - Ayacucho*. Arqueología y Sociedad,* 25, pp. 215–258.

Hughes, J.D. (1999) Conservation in the Inca empire. *Capitalism Nature Socialism*, 10(4), pp.69-76.

Hurley, J.V., Vuille, M. and Hardy, D.R., (2019) On the interpretation of the ENSO signal embedded in the stable isotopic composition of Quelccaya Ice Cap, Peru. *Journal of Geophysical Research: Atmospheres*, 124(1), pp.131-145.

International Committee for Phytolith Taxonomy (ICPT) (2019) International Code for Phytolith Nomenclature (ICPN) 2.0, *Annals of Botany*, 124(2), pp.189–199

Ikehara, H.C., Paipay, J.F., and Shibata, K. (2013) Feasting with Zea mays in the middle and late formative north coast of Peru. *Latin American Antiquity*, 24(2), pp.217-231.

INGEMMET (2022) *GEOCATMIN: Geological and Mining Cadastral Information System* [WWW] www.geocatmin.ingemmet.gob.pe (last accessed 28/12/2021)

Iriarte, J., and Paz, E.A. (2009) Phytolith analysis of selected native plants and modern soils from southeastern Uruguay and its implications for paleoenvironmental and archaeological reconstruction. *Quaternary International*, 193(1-2), pp.99-123.

Iriarte, J., Glaser, B., Watling, J., Wainwright, A., Birk, J.J., Renard, D., Rostain, S., and McKey, D. (2010) Late Holocene Neotropical agricultural landscapes: phytolith and stable carbon isotope analysis of raised fields from French Guianan coastal savannahs. *Journal of Archaeological Science*, 37(12), pp.2984-2994.

Iriarte, J., Elliott, S., Maezumi, S.Y., Alves, D., Gonda, R., Robinson, M., de Souza, J.G., Watling, J., and Handley, J. (2020) The origins of Amazonian landscapes: Plant cultivation, domestication and the spread of food production in tropical South America. *Quaternary Science Reviews*, 248, pp.106582.

Isbell, W. H. (1991). Honcopampa: Monumental ruins in Peru's north highlands. *Expedition*, 33(3), Article 27.

Isbell, W.H. (2008) Wari and Tiwanaku: International Identities in the Central Andean Middle Horizon*. In Silverman, H. and Isbell, W. eds (2008) Handbook for South American Archaeology. New York: Springer, pp.731-760.*

Isla, E., and Guerro, D. (1987) Socos: Un sitio Wari en el valle de Chillón. *Gaceta Arqueológica Andina*, 14(4), pp.23–28

Jenkins, E., Jamjoum, K., Nuimat, S., Stafford, R., Nortcliff, S., and Mithen, S. (2016) Identifying ancient water availability through phytolith analysis: an experimental approach. *Journal of Archaeological Science*, 73, pp.82-93.

Jennings, J., and Craig, N. (2001) Politywide analysis and imperial political economy: The relationship between valley political complexity and administrative centers in the Wari empire of the central Andes. *Journal of Anthropological Archaeology*, 20(4), pp.479-502.

Jennings, J., and Yépez Álvarez, W. (2015) Understanding Middle Horizon Peru *in Jennings, J. and Yépez Álvarez, W. eds, (2015) Tenahaha and the Wari State: A View of the Middle Horizon from the Cotahuasi Valley. Tuscaloosa: The University of Alabama Press, pp.1-15.*

Jurt, C., Burga, M.D., Vicuña, L., Huggel, C., and Orlove, B. (2015) Local Perceptions in Climate Change Debates: Insights from Case Studies in the Alps and the Andes. *Climate Change*, 133, pp.511–523.

Kahn, F., and Moussa, F. (1994) Diversity and conservation status of Peruvian palms. *Biodiversity and Conservation,* 3, pp.227-241.

Kalicki P.I., Kalicki T.O., and Kittel P.I. (2014) The influence of El Niño on settlement patterns in Lomas de Lachay, central coast, Peru. *Interdiscip. Archaeol. Nat. Sci. Archaeol*. 5, pp.147-160.

Kanner, L.C., Burns, S.J., Cheng, H., Edwards, R.L., and Vuille, M. (2013) High-resolution variability of the South American summer monsoon over the last seven millennia: insights from a speleothem record from the central Peruvian Andes. *Quaternary Science Rev*iews, 75**,** pp.1-10.

Keeley, H.C.M, and Meddens, F.M. (1993) Prehispanic agricultural terrace systems in the Chicha-Soras Valley, Peru *Bulletin of the Institute of Archaeology,* 29, pp.121-138.

Kellett, L.C. (2010) Chanka settlement ecology: hilltop sites, land use and warfare in late pre-Hispanic Andahuaylas, Peru. Unpublished PhD thesis, University of New Mexico.

Kellett, L.C. (2013) Collapse, Climate change and conflict: a profile of crisis and response in late Andean Highland Prehistory. *Tough Times: The Archaeology of Crisis and Recovery*. *British Archaeological Reports (BAR),* 20.

Kelly, T., Lawson, I.T., Roucoux, K.H., Baker, T.R., Jones, T.D., and Sanderson, N.K. (2017) The vegetation history of an Amazonian domed peatland. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 468, pp.129-141.

Kemp, R., Branch, N., Silva, B., Meddens, F., Williams, A., Kendalls, A., and Vivanco, C. (2006) Pedosedimentary, cultural and environmental significance of paleosols within pre-hispanic agricultural terraces in the southern Peruvian Andes. *Quaternary International,* 158, pp.13-22.

Kendall, A. (1992) Los patrones de asentamiento y desarrollo rural prehispánico entre Ollantaytambo y Machu Picchu (No. 1). *Universidad Nacional de San Antonio Abad*.

Kendall, A. (1996) An archaeological perspective for Late Intermediate period Inca development in the Cuzco region. *Journal of the Steward Anthropological Society*, 24(1&2), pp.121-156.

Kendall, A., and Rodríguez, A. (2009) *Desarrollo y perspectivas de los sistemas de andenería de los Andes centrales del Perú*. Cuzco: Institut français d'études andines.

Kendall, A. (2013) Applied archaeology in the Andes: The contribution of pre-Hispanic agricultural terracing to environmental and rural development *strategies in Davies, M. I., and M'Mbogori, F. N. eds. Humans and the environment: new archaeological perspectives for the twenty-first century. Oxford: Oxford University Press. pp.153-170.*

Kendall, A., and Drew, D. (2015) Peruvian Andes the Work of the Cusichaca Trust *in Isendahl, C. and Stump, D. eds. (2015) The Oxford Handbook of Historical Ecology and Applied Archaeology. Oxford: Oxford University Press, pp.422-440.*

Kennedy, S.A., and Kelloway, S.J. (2020) Identifying metallurgical practices at a colonial silver refinery in Puno, Peru, using portable X-Ray fluorescence spectroscopy (pXRF). *Journal of Archaeological Science: Reports*, *33*, pp.102568.

Kimura, H. (1985) Andean exchange: a view from Amazonia. *In: Masuda, S., Shimada, I and Morris. C. eds. (1985) Andean Ecology and Civilization, Tokyo: University of Tokyo Press, pp.491-504.*

Kock, S.T., Schittek, K., Mächtle, B., Maldonado, A., Vos, H., Lupo, L.C., Kulemeyer, J.J., Wissel, H., Schäbitz, F. and Lücke, A. (2020) Multi-centennial-scale variations of South American summer monsoon intensity in the southern central Andes (24–27 S) during the late Holocene. *Geophysical research letters*, 47(4), e2019GL084157.

Krajick, K. (1998) Green farming by the Incas? *Science,* 281(5375), pp.322.

Kuentz, A., Ledru, M.P., and Thouret, J.C. (2011) Environmental changes in the highlands of the western Andean Cordillera, southern Peru, during the Holocene. *The Holocene,* 22**,** pp.1215-1226.

Lane, K., and Herrera, A. (2005) Archaeology, landscapes and dreams: Science, sacred offerings, and the practice of archaeology. *Archaeological Review from Cambridge*, 20(1), pp.111-129.

Lane, K. (2006) Through the looking glass: Re-assessing the role of agro-pastoralism in the northcentral Andean highlands. *World Archaeology*, 38(3), pp.493-510.

Lane, K. (2009) Engineered highlands: The social organization of water in the ancient north-central Andes (AD 1000–1480). *World Archaeology*, 41(1), pp.169-190.

Lane, K. (2017) Agua, Limo y Represas: Almacenaje Geológico Prehispánico en la Cordillera Negra, Andes Norcentrales, Perú. *Revista de Glaciares y Ecosistemas de Montaña,* 2, pp.41-50.

Lau, G.F. (2001) Investigaciones arqueológicas en Chinchawas, Peru. *Unay Runa Revista de Ciencias Sociales,* 5, pp.21-25

Lau, G.F. (2002) Feasting and ancestor veneration at Chinchawas, North Highlands of Ancash, Peru. *Latin American Antiquity*, 13(3), pp.279-304

Lau, G.F. (2004) The Recuay culture of Peru's north-central highlands: a reappraisal of chronology and its implications. *Journal of Field Archaeology*, 29(1-2), pp.177-202.

Lau, G.F. (2005) Core–periphery relations in the Recuay hinterlands: economic interaction at Chinchawas, Peru. *Antiquity*, 79(303), pp.78-99.

Lau, G.F. (2007) Animal Resources and Recuay Cultural Transformations at Chichawas Ancash, Peru. *Andean Past*, 8(1), Article 22.

Lau, G.F. (2011) *Andean expressions: art and archaeology of the Recuay culture*. City of Iowa: University of Iowa Press.

Lau, G.F. (2012) Intercultural relations in northern Peru: the north central highlands during the Middle Horizon. *Boletín de Arqueología PUCP*, 16, pp.23-52.

Lau, G.F. (2016) *An archaeology of Ancash: Stones, Ruins and Communities in Andean Peru*. Routledge.

Legendre, P. and Legendre, L. (1998) Numerical Ecology. 2nd ed. Amsterdam: Elsevier

Leoni, J.B. (2005) Ritual and society in early intermediate period Ayacucho: A view from the site of Nawinpukyo. *In Isbell, W. and Silverman, H. eds. (2008) Andean archaeology III. Boston, MA: Springer. pp. 279-306.*

Lisztes-Szabó, Z., Kovács, S., Balogh, P., Daróczi, L., Penksza, K., and Peto, A. (2015) Quantifiable differences between phytolith assemblages detected at species level: analysis of the leaves of nine Poa species (Poaceae). *Acta Societatis Botanicorum Poloniae*, 84(3), pp.369-383

Liu, L., Li, D., Jie, D., Liu, H., Gao, G., and Li, N. (2019) Translocation of Phytoliths Within Natural Soil Profiles in Northeast China. *Frontiers in Plant Science*, 10:1254

Liu, L., Jie, D., Liu, H. Gao, G., Li, D., and Li, N. (2021) Phytolith transport and its influence factor in different soil types in northern temperate region. *Quaternary International*, 599–600, p.170-183

Lombardo, U., Ruiz-Pérez, J., and Madella, M. (2016) Sonication improves the efficiency, efficacy and safety of phytolith extraction. *Review of Palaeobotany and Palynology*, 235, pp.1-5.

Lombardo, U., Iriarte, J., Hilbert, L., Ruiz-Pérez, J., Capriles, J.M., and Veit, H. (2020) Early Holocene crop cultivation and landscape modification in Amazonia. *Nature*, 581(7807), pp.190-193.

Longman, J., Veres, D., and Wennrich, V. (2019) Utilisation of XRF core scanning on peat and other highly organic sediments*. Quaternary International*, 514, pp.85-96.

Lowe, J.J., and Walker, M. (2015) *Reconstructing Quaternary Environments*. Oxon: Routledge.

Löwemark, L., Chen, H.F., Yang, T.N., Kylander, M., Yu, E.F., Hsu, Y.W., Lee, T.Q., Song, S.R., and Jarvis, S. (2011) Normalizing XRF-scanner data: a cautionary note on the interpretation of high-resolution records from organic-rich lakes. *Journal of Asian Earth Sciences,* 40(6), pp.1250-1256.

Löwemark, L., Bloemsma, M., Croudace, I., Daly, J.S., Edwards, R.J., Francus, P., Galloway, J.M., Gregory, B.R., Huang, J.J.S., Jones, A.F., and Kylander, M. (2019) Practical guidelines and recent advances in the Itrax XRF core-scanning procedure. *Quaternary International*, 514, pp.16-29.

Maasch, K., A. (2008) El Niño and Interannual Variability of Climate in the Western Hemisphere. *In D. H. Sandweiss and J. Quilter eds. (2008) El Niño, Catastrophism, and Culture Change in Ancient America, Dumbarton Oaks Research Library* and Collection, Washington, DC, pp. 33–55.

Madella, M., Jones, M. K., Echlin, P., Powers-Jones, A., and Moore, M. (2009) Plant water availability and analytical microscopy of phytoliths: implications for ancient irrigation in arid zones. *Quaternary International*, 193(1-2), pp.32-40.

Madella, M., and Lancelotti C. (2012) Taphonomy and Phytoliths: A user manual, *Quaternary International*, 275, pp.76-83.

Madella, M., Lancelotti, C., and Garcia-Granero, J.J. (2016) Millet microremains – an alternative approach to understand cultivation and use of critical crops in prehistory. *Archaeological and Anthropological Sciences* 8, pp.17-28.

Maezumi, S.Y., Alves, D., Robinson, M., de Souza, J.G., Levis, C., Barnett, R.L., Almeida de Oliveira, E., Urrego, D., Schaan, D. and Iriarte, J. (2018) The legacy of 4,500 years of polyculture agroforestry in the eastern Amazon. *Nature plants*, 4(8), pp.540-547.

Mark, B.G., French, A., Baraer, M., Carey, M., Bury, J., Young, K.R., Polk, M.H., Wigmore, O., Lagos, P., Crumley, R., and McKenzie, J.M. (2017) Glacier loss and hydro-social risks in the Peruvian Andes. *Global and Planetary Change*, 159, pp.61-76.

Martin, A.C., and Harvey, W.J. (2017) The Global Pollen Project: a new tool for pollen identification and the dissemination of physical reference collections. *Methods Ecol Evol*, 8, pp.892–897.

Mauricio, A.C. (2018) Reassessing the impact of El Niño at the end of the Early Intermediate Period from the perspective of the Lima culture. *Ñawpa Pacha*, 38(2), pp.203-231.

McMichael, C.N.H., Witteveen, N.H., Scholz, S., Zwier, M., Prins, M.A., Lougheed, B.C., Mothes, P., and Gosling, W.D. (2021) 30,000 years of landscape and vegetation dynamics in a mid-elevation Andean valley. *Quaternary Science Reviews*, 258, pp.106866.

Meddens, F.M., and Schreiber, K.J. (2010) Inka Strategies of Control: A Comparison of the Chicha and Sondondo Valleys, Peru. *Ñawpa Pacha*, *Institute of Andean Studies*, 30(2), pp.127-165.

Meddens, F.M, and Vivanco P.C. (2018) The late Intermediate Period ceramic traditions of Ayacucho, Apurimac and Huancavelica: current thoughts on the Chanca and other regional polities. *Ñawpa Pacha, Institute of Andean Studies,* 38(1), pp.3-56.

Middleton, G.D. (2017) Collapse in the Andes *in Middleton, G.D. (2017) Understanding Collapse: Ancient History and Modern Myths Cambridge: Cambridge University Press.* pp. 276-298.

Milstead, H.P. (1928) Distribution of crops in Peru. *Economic Geography*, *4*(1), pp.88-106.

Minitab 21 Statistical Software (2022). [Computer software]. State College, PA: Minitab, Inc.

MOLAS (1994) Archaeological Site Manual. *Museum of London, 3rd Edition*.

Moore, P.D and Webb, J.A. (1978) *An illustrated guide to Pollen Analysis* London: Hodder and Stoughton.

Moore, P.D. Webb, J.A. and Collinson, M. E (1991) *Pollen Analysis.* Oxford: Blackwell Scientific Publications.

Moseley, M.E. (1992) *The Incas and Their Ancestors* London: Thames and Hudson Ltd.

National Research Council (1989). *Lost crops of the Incas: little-known plants of the Andes with promise for worldwide cultivation*. National Academies Press.

Netolitsky, F. (1929) Die Kieselkorper die Kalksalze als Zellinhald-skorper. *In (K. Linsbauer, ed. Handbuch der Pflanzenanatomie, 3. Berlin: Gebruder Borntraeger*, *pp.1-19.*

Neumann, K., Fahmy, A. G., Müller-Scheeßel, N., and Schmidt, M. (2017) Taxonomic, ecological and palaeoecological significance of leaf phytoliths in West African grasses. *Quaternary International*, 434, pp.15-32.

Novello, A., Barboni, D., Berti-Equille, L., Mazur, J.C., Poilecot, P., and Vignaud, P. (2012) Phytolith signal of aquatic plants and soils in Chad, Central Africa. *Review of Palaeobotany and Palynology*, 178, pp.43-58.

Novello, A., and Barboni D. (2015) Grass inflorescence phytoliths of useful species and wild cereals from sub-Saharan Africa*. Journal of Archaeological Science,* 59, pp.10-22.

O'Donnell, C., Recharte, J., and Taber, A. (2016) Climate change, mountain people and water resources – the experiences of the Mountain Institute, Peru. *Unasylva,* 246(67), 2016/1

Ogburn, D. (2014) From Cusco to the Four Quarters and Vice Versa: Connecting Sacred Spaces in the Inca Empire through the Movement of Stone, Sand and Soil. *in Meddens,, F.M., McEwan, C., Willis, K., and Branch, N. (eds.) Inca sacred space: landscape, site and symbol in the Andes. Archetype Publications, London.* pp.91-98.

Orrison, R., Vuille, M., Smerdon, J.E., Apaéstegui, J., Campos, J.L.P., Cruz, F.W. and Della Libera, M.E. (2022) South American Monsoon variability over the last millennium in paleoclimate records and isotope-enabled climate models. *Climate of the Past Discussions*, pp.1-30.

Ortloff, C.R., and Kolata, A.L. (1993) Climate and Collapse: Agro-Ecological perspectives on the Decline of the Tiwanaku State. *Journal of Archaeological Science,* 20, pp.195-221.

Palacios, J., Maquera, E., and Toledo, C. (2014) Tecnología hidráulica, ampliación de la frontera agrícola y asentamientos no monumentales durante la época Lima. *Boletín de arqueología PUCP*, 18, pp.59-80.

PalDat (2022) *A Palynological Database* [WWW] www.paldat.org (last accessed 15/01/2022)

Parr, J. F., Lentfer, C. J., and Boyd, W. E. (2001) A Comparative Analysis of Wet and Dry Ashing Techniques for the Extraction of Phytoliths from Plant Material. *Journal of Archaeological Science*, 28(8), pp.875–886.

Pennington, R.T. (2007) Oreocallis. *In Prance, G.T., Plana, V., Edwards, K.S., Pennington, R. T. eds. (2007) Proteaceae. Flora Neotropica Monograph. Vol. 100. New York: The New York Botanical Garden Press. pp. 31-35.*

Perez, C., Nicklin, C., and Dangles, O. (2010) Climate Change in the High Andes: Implications and Adaptation Strategies for Small-scale Farmers. *The International Journal of Environmental, Cultural, Economic and Social Sustainability,* 6, pp.71-88.

Perry, L., Sandweiss, D.H., Piperno, D.R., Rademaker, K., Malpass, M.A., Umire, A., and De la Vera, P. (2006) Early maize agriculture and interzonal interaction in southern Peru. *Nature*, 440(7080), pp.76-79.

Piperno, D.R. (1988) *Phytolith Analysis: An Archaeological and Geological Perspective* California: Academic Press, Inc. pp.30-107.

Piperno, D.R., and Pearsall, D.M. (1998) The silica bodies of tropical American grasses: morphology, taxonomy, and implications for grass systematics and fossil phytolith identification. *Smithsonian Contributions to Botany*, pp.1-40

Piperno, D.R. (2001) Phytoliths *in Smol, J.P., Birks, H.J., and Last W.M. eds. (2001) Tracing Environmental Change Using Lake Sediments Volume 3 Terrestrial, Algal and Siliceous Indicators Netherlands: Springer. pp.235-263.*

Piperno, D.R. (2006) *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists* Oxford: Altamira Press.

Piperno, D.R., and McMichael, C. (2020) Phytoliths in modern plants from Amazonia and the Neotropics at large: Implications for vegetation history reconstruction. *Quaternary International*, 565, pp.54-74.

Plumpton, H., Whitney, B., and Mayle, F. (2019) Ecosystem turnover in palaeoecological records: The sensitivity of pollen and phytolith proxies to detecting vegetation change in southwestern Amazonia. *The Holocene*, 29(11), pp.1720-1730.

Plumpton, H. J., Mayle, F. M., and Whitney, B. S. (2020) Paleoecological potential of phytoliths from lake sediment records from the tropical lowlands of Bolivia. *Review of Palaeobotany and Palynology*, 275, 104113.

Polk, M.H., Young, K.R., Cano, A., and León, B. (2019) Vegetation of Andean wetlands (bofedales) in Huascarán National Park, Peru. *Mires and Peat*, 24(1), pp.1-26,

Ponte, V. (2014) *Arqueología en la Cordillera Negra del Callejón de Huaylas Perú*. Áreade Influencia Minea Pierina. Lima, Barrick.

Portillo, M., Valenzuela, S., and Albert, R.M. (2012) Domestic patterns in the Numidian site of Althiburos (northern Tunisia): The results from a combined study of animal bones, dung and plant remains. *Quaternary International,* 275, pp.84-96.

Pulgar Vidal, J. (1987) *Geografia del Peru, Las Ocho Regiones Nataurales del Peru*, Editorial Universo, Lima.

Quilter, J. (2014). *The Ancient Central Andes*. Abingdon: Routledge.

Rashid, I., Mir, S. H., Zurro, D., Dar, R. A., and Reshi, Z. A. (2019) Phytoliths as proxies of the past. *Earth-Science Reviews*, 194, pp.234-250.

Reimer, P., Austin, W., Bard, E., Bayliss, A., Blackwell, P., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R., Friedrich, M., Grootes, P., Guilderson, T., Hajdas, I., Heaton, T., Hogg, A., Hughen, K., Kromer, B., Manning, S., Muscheler, R., Palmer, J., Pearson, C., van der Plicht, J., Reimer, R., Richards, D., Scott, E., Southon, J., Turney, C., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., and Talamo, S. (2020) The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon*, 62.

Rein, B., Lückge, A., and Sirocko, F. (2002) A major Holocene ENSO anomaly during the Medieval period. *Geophysical Research Letters*, 31, L17211, pp.1-4.

Rein, B., Lückge, A., Reinhardt, L., Sirocko, F., Wolf, A., and Dullo, W. C. (2005). El Niño variability off Peru during the last 20,000 years. Paleoceanography, 20(4). PA4003.

Reuter, J., Stott, L., Khider, D., Sinha, A., Cheng, H., and Edwards, R. L. (2009) A new perspective on the hydroclimate variability in northern South America during the Little Ice Age. *Geophysical Research Letters,* 36, L21706, pp.1-5.

Ricci, K. (2015) Orccomarca: Un asentamiento prehispánico en la cuenca alta del río Chillón. *Historia y Región*, *3*, pp.79-98.

Rindos, D. (1984) *The Origins of Agriculture* Orlando: Academic press

Ríos, G.C. (2015) Los Chaclla en el Valle de Arahuay. Un mecanismo de control Inca de la cuenca alta del Rio Chillón. *Arqueología y Sociedad*, 30, pp.185-203.

Roberts, N. (2014) *The Holocene: An Environmental History*, 3rd ed. Chichester: Wiley Blackwell.

Rodbell, D.T., and Seltzer, G.O. (2000) Rapid ice margin fluctuations during the Younger Dryas in the tropical Andes. *Quaternary Research*, *54*(3), pp.328-338.

Rodríguez, A., and Nickalls, T. (2002) Rehabilitation of pre-Hispanic terraces in the Peruvian Andes. *ICARDA Caravan (ICARDA),* 16, pp.32-34.

Rostworowski, M. (1989) *Costa peruana prehispánica*, Lima: Intituto de Estudos Peruanos.

Rothwell, R.G., and Croudace, I.W. (2015a) Twenty Years of XRF Core Scanning Marine Sediments: What do geochemical Proxies Tell Us? *In Croudace, I. W., and Rothwell, R. G. eds. (2015) Micro-XRF Studies of Sediment Cores: Applications of a non-destructive tool for the environmental sciences (Vol. 17). Springer. pp.25-102.*

Rothwell, R.G., and Croudace, I.W. (2015b) Micro-XRF studies of Sediment Cores: A Perspective on Capability and Application in the Environmental Sciences in *Croudace, I. W., and Rothwell, R. G. eds. (2015) Micro-XRF Studies of Sediment Cores: Applications of a non-destructive tool for the environmental sciences (Vol. 17). Springer. pp.1-24.*

Roucoux, K.H, Lawson, I.T., Jones, T.D., Baker, T.R., Honorio Coronado, E.N., Gosling, W.D., and Lähteenoja, O. (2013) Vegetation development in an Amazonian peatland. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 374, pp.242-255.

Royal Botanical Gardens of Kew (2022) *Plants of the World Online* [WWW] www.powo.science.kew.org (last accessed 18/01/2022).

Russo, R.O. (1990) Evaluating Alnus acuminata as a component in agroforestry systems. *Agroforest Syst*, 10, pp.241–252.

Sandweiss, D.H., Maasch, K.A., Burger, R.L., Richardson, J.B., Rollins, H.B., and Clement, A. (2001) Variation in Holocene El Niño frequencies: Climate records and cultural consequences in ancient Peru. *Geology,* 29**,** pp.603-606.

Sandweiss, D.H., Maasch, K.A., Fred, Andrus, C.F.T., Reitz, E.J., Richardson 3rd, J.B., Riedinger-Whitmore, M., and Rollins, H.B. (2007) Mid-Holocene climate and culture change in coastal Peru *in Anderson D.G., Maasch, K.A., and Sandweiss, D.H. eds. (2007) Climate Change and Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions. London: Academic Press pp.35-50.*

Sandweiss, D.H., and Richardson, J.B. (2008) Climate Change, El Niño and the Rise of Complex Society on the Peruvian Coast during the Middle Holocene. *In Sandweiss, D.H.*

and Quilter, J. eds. (2008) El Niño, Catastrophism, and Culture Change in Ancient America. Washington DC: Dumbarton Oaks pp. 59-75.

Sandweiss, D.H., and Quilter, J. (2012). Collation, correlation, and causation in the prehistory of coastal Peru *in Cooper, J., and Sheets, P. (2012) Surviving Sudden Environmental Change: Answers from Archaeology. Colorado: University Press of Colorado pp.117-142.*

Sandweiss, D.H., Andrus, C.F.T., Kelley, A.R., Maasch, K.A., Reitz, E.J. and Roscoe, P.B. (2020) Archaeological climate proxies and the complexities of reconstructing Holocene El Niño in coastal Peru. *Proceedings of the National Academy of Sciences*, 117(15), pp.8271-8279.

Schauwecker, S., Rohrer, M., Acuña, D., Cochachin, A., Dávila, L., Frey, H., Giráldez, C., Gómez, J., Huggel, C., Jacques-Coper, M., and Loarte, E. (2014) Climate trends and glacier retreat in the Cordillera Blanca, Peru, revisited. *Global and Planetary Change*, 119, pp.85-97.

Schittek, K., Forbriger, M., Mächtle, B., Schäbitz, F., Wennrich, V., Reindel, M., and Eitel, B. (2015) Holocene environmental changes in the highlands of the southern Peruvian Andes (14°S) and their impact on pre-Columbian cultures. *Clim. Past*., 11, pp.27-44.

Schittek, K., Forbriger, M., Berg, D., Hense, J., Schäbitz, F., and Eitel, B. (2018) Last Millennial environmental dynamics in the western Peruvian Andes inferred from the development of a cushion-plant peak hillock. *Perspectives in Plant Ecology, Evolution and Systematics,* 30, pp.115-124.

Schelenberg, H. C. (1908) Wheat and barley from the North Kurgan, Anau. *In Pumpelly, R. ed. (1908) Explorations in Turkestan Vol. 3. Washington: Carnegie Institution, pp.471-473*.

Schreiber, K. (1992) *Wari Imperialism in Middle Horizon Peru.* University of Michigan, Museum of Anthropology, Anthropological Papers 87. Ann Arbor.

Schreiber, K. (2004) Sacred landscapes and imperial ideologies: The Wari empire in Sondondo, Peru. *Archaeological Papers of the American Anthropological Association*, 14(1), pp.131-150.

Segura, R.L., and Shimada, I. (2010) The Wari Footprint on the Central Coast: A view from Cajamarquilla and Pachacamac *in Jennings, J. ed. (2010) Beyond Wari Walls: Regional*

Perspectives on Middle Horizon Peru. Albuquerque: University of New Mexico Press pp.113-135.

SENAMHI (2020) Mapa Climático del Peru [WWW] https://www.senamhi.gob.pe/?&p=mapa-climatico-del-peru (last accessed 27/10/2022).

Shillito LM. (2011) Taphonomic observations of archaeological wheat phytoliths from Neolithic Catalhoyuk, Turkey, and the use of conjoined phytolith size as an indicator of water availability. *Archaeometry,* 53, pp.631-641.

Shillito, LM. (2013) Grains of truth or transparent blindfolds? A review of current debates in archaeological phytolith analysis. *Veget Hist Archaeobot* 22, pp.71–82

Shumilovskikh, L.S., Shumilovskikh, E.S., Schlütz, F., and van Geel, B. (2021) NPP-ID: Non-Pollen Palynomorph Image Database as a research and educational platform. *Vegetation History and Archaeobotany*, pp.1-6

Silva, J.E. (1996) *Prehistoric settlement patterns in the Chillón river valley*, *Peru*. Unpublished PhD Thesis. University of Michigan.

Silva, B.N. (2005) *Late Glacial and Holocene Environmental Changes in the Peruvian Andes: Implications for human Society.* Unpublished PhD thesis. Royal Holloway University.

Silverman, H. and Proulx, D. (2008) *The Nasca*. Oxford: Blackwell Publishers.

SPSS (2021) *IBM SPSS Statistics for Windows*, Version 28.0 Armonk, NY: IBM Corp.

Stansell, N.D., Rodbell, D.T., Abbott, M.B., and Mark, B.G. (2013) Proglacial lake sediment records of Holocene climate change in the western Cordillera of Peru. *Quaternary Science Reviews*, 70, pp.1-14.

Stansell, N.D., Rodbell, D.T., Licciardi, J.M., Sedlak, C.M., Schweinsberg, A.D., Huss, E.G., Delgado, G.M., Zimmerman, S.H., and Finkel, R.C. (2015) Late glacial and Holocene glacier fluctuations at Nevado Huaguruncho in the eastern cordillera of the Peruvian Andes. *Geology*, *43*(8), pp.747-750.

Sterken, M., Sabbe, K., Chepstow-Lusty, A., Frogley, M., Vanhoutte, K., Verleyen, E., Cundy, A., and Vyverman, W. (2006) Hydrological and land-use changes in the Cuzco region (Cordillera Oriental, South East Peru) during the last 1200 years: a diatom-based reconstruction. *Arch. Hydrobiol.*, 165, pp.289-312.

Stockmarr, J. A. (1971) Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, 13, pp.615-621.

Strömberg, C.A.E., Di Stilio Verónica, S., Song, Z., and De Gabriel, J. (2016) Functions of phytoliths in vascular plants: An evolutionary perspective. *Functional Ecology*, 30(8), pp.1286–1297.

Strömberg, C.A., Dunn, R.E., Crifò, C., and Harris, E.B. (2018) Phytoliths in paleoecology: analytical considerations, current use, and future directions. *In Croft, D.A., Su D., Simpson S., eds. (2018) Methods in Paleoecology: Reconstructing Cenozoic Terrestrial Environments and Ecological Communities. Vertebrate Paleobiology and Paleoanthropology, Springer, pp.235-287.*

Stroup, J.S., Kelly, M.A., Lowell, T.V., Smith, C.A., Beal, S.A., Landis, J.D., and Tapia, P.M. (2015) Late Holocene fluctuations of Quelccaya Ice Cap, Peru, registered by nearby lake sediments. *Journal of Quaternary Science*, 30(8), pp.830-840.

Suarez, A.C., and George, J.J. (2011) *Handbook to life in the Inca world.* New York: Facts on File.

Sublette-Mosblech, N.A., Chepstow-Lusty, A., Valencia, B.G., and Bush, M.B. (2012) Anthropogenic control of late-Holocene landscapes in the Cuzco region, Peru. *The Holocene*, 22, pp.1361-1372.

Swindles, G.T., Kelly, T.J., Roucoux, K.H. and Lawson, I.T. (2018) Response of testate amoebae to a late Holocene ecosystem shift in an Amazonian peatland. *European Journal of Protistology*, 64, pp.13-19.

Szpak, P., Chicoine, D., Millaire, J.F., White, C.D., Parry, R., and Longstaffe, F.J., (2016) Early Horizon camelid management practices in the Nepeña Valley, north-central coast of Peru. *Environmental Archaeology*, 21(3), pp.230-245.

Tantaleán, H., and Maestro, C.P. (2003) Pueblo Viejo: un centro administrativo Inca en el Callejón de Cuaylas in *Asencios, B. I. ed. (2003) Arqueología de la sierra de Ancash: propuestas y perspectivas. Instituto Cultural RVNA*.

Teeling, D. (in prep) *Quantifying responses to abrupt climate change in the Andes, South America*. Unpublished PhD thesis, University of Reading.

Thapa, R., and Blair, M.W. (2018) Morphological assessment of cultivated and wild amaranth species diversity. *Agronomy*, *8*(11), p.272.

Thomson, J., Croudace, I.W. and Rothwell, R.G. (2006) A geochemical application of the ITRAX scanner to a sediment core containing eastern Mediterranean sapropel units. *Geological Society, London, Special Publications*, 267(1), pp.65-77.

Thompson, L.G. (2000) Ice core evidence for climate change in the Tropics: implications for our future. *Quaternary Science Reviews*, 19(1-5), pp.19-35.

Thompson, L.G., Mosley-Thompson, E., and Henderson, K.A. (2000) Ice-core palaeoclimate records in the tropical South America since the Last Glacial Maximum. *Journal of Quaternary Science*, 15, pp.377-394.

Thompson, L.G. (2001) *Huascaran ice core data, IGBP PAGES/World Data Center A for Paleoclimatology, Data Contribution Series #2001-008*, NOAA/NGDC Paleoclimatology Program, Boulder CO, USA,

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Lin, P.N., Henderson, K., and Mashiotta, T.A. (2003) Tropical glacier and ice core evidence of climate change on annual to millennial time scales*. In Diaz, H. (2003) Climate variability and change in high elevation regions: past, present and future. Dordrecht: Springer pp.137-155.*

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Zagorodnov, V.S., Howat, I.M., Mikhalenko, V. N., and Lin, P. N. (2013) Annually resolved ice core records of tropical climate variability over the past~ 1800 years. *Science*, 340(6135), pp.945-950.

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., and Porter, S.E. (2017) Ice Core Records of Climate and Environmental Variability in the Tropical Andes of Peru: Past, Present and Future. *Revista de Glaciares y Ecosistemas de Montaña*, 3, pp.25-40.

Thornton, E.K., DeFrance, S.D., Krigbaum, J., and Williams, P.R. (2011) Isotopic evidence for Middle Horizon to 16th century camelid herding in the Osmore Valley, Peru. *International Journal of Osteoarchaeology*, 21(5), pp.544-567.

Trawick, P.B. (2003) *The Struggle for Water in Peru: comedy and tragedy in the Andean commons*. Standford: Stanford University Press.

Tropicos (2022) *Peru Checklist* Missouri Botanical Gardens [WWW] www.legacy.tropicos.org/Project/PEC (Last Accessed: 24/01/2022)

Troels-Smith, J. (1955) *Karakterisering af lose jordater (Characterization of unconsolidated sediments)* Danmarks: Geologiske Undersagelse, Raekke.

Tschauner, H. (2003) HoncoPampa: Arquitectura de elite del Horizonte Medio en el Callejón de Huaylas *in Asencios, B. I. ed. (2003) Arqueología de la sierra de Ancash: propuestas y perspectivas. Instituto Cultural RVNA*.

Tung, T. (2008) Violence After Imperial Collapse: A Study of Cranial Trauma Among Late Intermediate Period Burials from the Former Huari Capital, Ayacucho, Peru. *Ñawpa Pacha,* 29, pp.101-117.

Turner, R., Kelly, A., and Roberts, C.N. (2008) A critical assessment and experimental comparison of microscopic charcoal extraction methods. *In Fiorentino, G. and Magri, D., editors, Charcoal from the past: cultural and palaeoenvironmental implications. Proceedings of the Third International Meeting of Anthracology, Cavallino (Lecce), 28 June–1 July 2004. BAR International Series 1807, Archaeopress, 265–72.*

Twiss, P.C. (1992) Predicted World Distribution of C3 and C4 Grass Phytoliths *in Rapp, Jr., G. and Mulholland, S.C. eds. (1992) Phytolith Systematics. New York: Plenum Press pp.113-127.*

Urrego, H., Niccum, B.A., La Drew, C.F., Silman, M.R., and Bush, M.B. (2011) Fire and drought as drivers of early Holocene tree line changes in the Peruvian Andes. *Journal of Quaternary Science,* 26, (1) pp.28-36.

Valencia, B.G., Urrego, D.H., Silman, M.R., and Bush, M.B. (2010) From ice age to modern: a record of landscape change in and Andean cloud forest. *Journal of Biogeography,* 37, pp.1637-1647.

Valdez, L., Bettcher, K.J., and Valdez, J.E. (2010) Production of maize beer at a Wari site in the Ayacucho Valley, Peru. *Arqueologia Iberoamericana,* 5, pp.23-35.

Valdez, L.M., and Valdez, J. (2013) Highland and Coastal Cultural Interaction: New Evidence from the Ancient City of Huari, Ayacucho, Peru. *In Patton, M., and Manion, J. eds (2013) Trading Spaces: The Archaeology of Interaction, Migration and Exchange. Proceedings of the 46th Annual Chacmool Archaeology Conference. Calgary: Chacmool Archaeology Association, pp.91-108.*

Valdez, L. and Valdez, J. (2017) From Rural to Urban: Archaeological Research in the Periphery of Huari, Ayacucho Valley, Peru*. Journal of Anthropology*, Volume 2017, pp.1-14.

van Geel, B. (1978) A palaeoecological study of Holocene peat bog sections in Germany and the Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae cormophytes and animals. *Rev. Palaeobot. Palynol*., 25, pp.1-120.

Van Geel, B. (2001) Non-Pollen Palynomorphs in *J. P. Smol, H. J. B. Birks & W. M. Last (eds.), (2001) Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators. Dordrecht: Kluwer Academic Publishers,*

van Geel, B., Gelorini, V., Lyaruu, A., Aptroot, A., Rucina, S., Marchant, R., Sinninghe Damsté, J.S., and Verschuren, D. (2011) Diversity and ecology of tropical African fungal spores from a 25,000-year palaeoenvironmental record in southeastern Kenya. *Rev. Palaeobot. Palynol*., 164, pp.174-190.

Verzijl, A., and Quispe, S.G. (2013) The System Nobody Sees: Irrigated Wetland Management and Alpaca Herding in the Peruvian Andes. *Mountain Research and Development*, 33(3), pp.280-293.

Vuille, M., Burns, S.J., Taylor, B.L., Cruz, F.W., Bird, B.W., Abbott, M.B., Kanner, L.C., Cheng, H., and Novello, V.F. (2012) A review of the South American monsoon history as recorded in stable isotopic proxies over the past two millennia. *Climate of the Past*, *8*(4), pp.1309-1321.

Watling, J., and Iriarte, J. (2013) Phytoliths from the coastal savannas of French Guiana. *Quaternary International*, 287, pp.162-180.

Watling, J., Saunaluoma, S., Pärssinen, M., and Schaan, D. (2015) Subsistence practices among earthwork builders: Phytolith evidence from archaeological sites in the southwest Amazonian interfluves. *Journal of Archaeological Science: Reports*, 4, pp.541-551.

Weisskopf, A., Harvey, E., Kingwell-Banham, E., Kajale, M., Mohanty, R., and Fuller, D.Q. (2014) Archaeobotanical implications of phytolith assemblages from cultivated rice systems, wild rice stands and macro-regional patterns. *Journal of Archaeological Science*, 51, pp.43-53.

Weltje, G.J. and Tjallingii, R. (2008) Calibration of XRF core scanners for quantitative geochemical logging of sediment cores: Theory and application. *Earth and Planetary Science Letters*, 274(3-4), pp.423-438.

Weng, C., Bush, M., and Chepstow-Lusty, A. (2004) Holocene changes in Andean alder (*Alnus acuminate*) in highland Ecuador and Peru. *Journal of Quaternary Science,* 19(7*),* pp.685-691.

Weng, C., Bush, M., Curtis, J.H., Kolata, A.L., Dillehay, T.D., and Binford, M.W. (2006) Deglaciation and Holocene climate change in the western Peruvian Andes. *Quaternary Research,* 66**,** pp.87-96.

Williams, J.J., Gosling, W.D., Coe, A.L., Brooks, S.J., and Gulliver, P. (2011) Four thousand years of environmental change and human activity in the Cochabamba Basin, Bolivia. *Quaternary Research*, 76(1), pp.58-68.

Winsborough, B.M., Shimada, I., Newsom, L.A., Jones, J, G., and Segura, R.A. (2012) Paleoenvironmental catastrophies on the Peruvian coast revealed in lagoon sediment cores from Pachacamac. *Journal of Archaeological Science,* 39, pp.602-614.

Yager, K., Prieto, M., and Meneses, R.I. (2021) Reframing Pastoral Practices of Bofedal Management to Increase the Resilience of Andean Water Towers. *Mountain Research and Development*, 41(4), pp.A1-A9.

Zegarra, A.V. (2005) Wari Hydraulic Works in the Lucre Basin. *In McEwan, G.F. ed. (2005) Pikillacta: The Wari Empire in Cuzco. Iowa City: University of Iowa Press. pp. 85–98.*

Zucol, A.F., Martínez, G., Martínez, G.A., and Costa Angrizani, R. (2022). Landscape and environmental conditions for the late Holocene in the eastern Pampa-Patagonia transition (Argentina): a phytolith analysis of the El Tigre archaeological site. *Vegetation History and Archaeobotany*, 31(1), pp.17-36.

Zurro, D., Garcia-Granero, J.J., Lancelotti, C., and Madella, M. (2016) Directions in current and future phytolith research. *Journal of Archaeological Science*, 68, pp.112–117.

Zurro, D. (2018) One, two, three phytoliths: Assessing the minimum phytolith sum for archaeological studies. *Archaeological and Anthropological Sciences*, 10(7), pp.1673-1691.