# REASSESSING CHRONOLOGY OF INCA AND CAYAMBE SITES IN NORTHERN ECUADOR THROUGH OBSIDIAN HYDRATION DATING

by

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# ABSTRACT


REILLY MARIE GRIFFIN. Reassessing Chronology of Inca and Cayambe Sites in Northern Ecuador through Obsidian Hydration Dating. (Under the direction of DR. DENNIS OGBURN)

Obsidian Hydration Dating has continued to be seen as a viable dating method within archaeology to establish relative chronology for sites with obsidian artifacts. The prospect of a relatively fast and comparatively inexpensive dating method compared to established chronometric dating technologies such as radiocarbon dating could offer researchers an acceptable method to establish relative chronology for obsidian artifacts that could be used independently or as an adjunct to other chronometric methods. There are limitations and challenges with this dating technique due to factors such as elevation, aridity, and temperature which affect the hydration rate and the applied hydration band measurements of obsidian samples and the geographic locations where this technique could be applied. One of the more significant archaeological research areas where this technology has not been extensively researched is the Pambamarca region of northern Ecuador. In this research study, I apply obsidian hydration dating to compare hydration band measurements for 51 obsidian artifact specimens collected from one pre-Cayambe early site, two late Cayambe fort sites, two Inka fort sites, and one Colonial site within the Pambamarca region of northern Ecuador. The majority of hydration band measurements for the samples collected from the six Pambamarca sites demonstrate relative band thickness measurements that align with estimated site occupation dates. The findings corroborate the utility and viability of this dating method for Pambamarca obsidian samples and support the need for ongoing obsidian hydration dating research initiatives.

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# CHAPTER 1: INTRODUCTION

Obsidian hydration dating is an archaeological dating method that has been shown to be a comparatively accurate and fast relative dating method for archaeological sites in certain geographic locations and is inexpensive compared to chronometric dating technologies such as radiocarbon dating. However, there are limitations and challenges with this dating technique due to factors such as elevation, aridity, and temperature at archaeological sites especially within higher altitude locations such as the Andes of South America (Friedman et al. 1976). Yet, studies have confirmed that obsidian hydration dating accuracy can be somewhat close to that of radiocarbon dating. Eerkens et al. (2008) found "a strong correlation 'within 15% of the radiocarbon estimates' between average obsidian hydration readings and radiocarbon dates" in the Southern Nasca Region on the south coast of Peru. This suggests that obsidian hydration dating may serve an important role within archaeology as a method to establish relative chronology for obsidian artifacts and the sites where they are found.

My thesis examines the utility of using obsidian hydration dating to compare hydration band measurements to evaluate relative dating estimates for samples taken from known archaeological sites in northern Ecuador, an area where obsidian hydration dating has rarely been used. Specifically, I will examine the results from obsidian hydration dating analysis for fifty-one obsidian samples collected from one pre-Cayambe early site, two Inka sites, two late Cayambe sites, and one Colonial site within the Pambamarca region of northern Ecuador (Ogburn et al. 2009). These samples have previously undergone provenance analysis using X-ray Fluorescence (XRF) to assess geochemical composition and correlate the samples with obsidian sources from the northern highlands area of Ecuador (Ogburn et al. 2009:746). My research will attempt to use obsidian hydration dating to evaluate estimated occupation timelines for the Inka and local

Cayambe sites where the obsidian artifacts were located. Additionally, my research will assess if the Inka sites may have been occupied prior to or only during the time of the Inka incursion based upon hydration band measurements from samples from the various sites. My research will also attempt to confirm if the Cayambe sites may have been occupied somewhat earlier as well as at the same time as the Inka forts, as currently thought, or if they may have been occupied significantly earlier or later. Thus, I will be evaluating whether the relative chronology of the sites based on ceramic sequences holds up or needs to be revised.

## I. Research Hypothesis and Objectives

One of the main challenges that archaeological researchers face relates to the accurate dating of artifacts. This is evident with obsidian sourced from pre-Hispanic Inca sites especially due to the relatively short timeline associated with the Inca empire, roughly AD 1438 to AD 1532, and their brief period of occupation within the northern Ecuadorean highlands, including the Pambamarca region, which is estimated to be AD 1490 to 1534 (Bray 1992). McEwan (2006) points out the dilemma associated with both radiocarbon and obsidian hydration, as neither provides the accuracy to discern if the artifact is "early Inca or late Inca," and also acknowledges the limited use of obsidian hydration with Inca artifacts. To date, there is a paucity of data associated with obsidian hydration dating used with Inca artifacts, as researchers tend to rely on the accepted chronology rather than trying to date sites and materials, and radiocarbon dating has been mostly used when they have employed absolute dating methods.

Given the limited use of obsidian hydration dating with central Andean obsidian artifacts found within Inca period sites, my proposed research will evaluate the utility of this relative dating methodology as a relative dating technology in the absence of other confirmatory chronometric methods, such as radiocarbon dating. More specifically, my proposed research will address two key questions related to the Inka and Cayambe occupation timelines. 1) Do the relative occupation dates indicated by the obsidian hydration results match, and therefore confirm, the relative dates for the sites as determined by ceramic styles? 2) Could the occupation timelines of the Inka and Cayambe sites be longer or shorter than currently thought, based on the relative dating provided by the obsidian hydration dating analyses? This potentially would help Pambamarca archaeologists refine current assumptions about Inka occupation and the nature of contemporary and earlier Cayambe settlements at these sites.

My hypothesis is that obsidian hydration dating, as measured by hydration band thickness, could provide useful relative dating estimates for the obsidian samples collected from specific Inka and local Cayambe sites. Such relative dating findings could first be compared to current estimated occupation dates for these Inka and Cayambe sites that are based on archaeological research to date. The obsidian relative dating determinations could then be used to assess specific occupation date estimates for the Inka and Cayambe sites to inform current and future archaeological research at these sites. For example, the relative dating estimates provided for the Inka site obsidian artifacts could be compared to other archaeological research findings to assess if the Inka sites were occupied solely during Inka times or had earlier or later occupations. Similar assessments could be performed for the Cayambe sites to determine if they were possibly occupied much earlier or later than the estimated dates for the Inka occupied sites. If the results are able to confirm or indicate revising the relative timeline, this would support further use of obsidian hydration dating with central Andean site obsidian artifacts associated with the Inka imperial era. Furthermore, such findings could support the need for additional research to further understand possible occupation histories associated with the Inka and the Cayambe sites.

# CHAPTER 2: THE INKA EMPIRE

At its height, the Inka Empire extended 4300 km, south to north, and reached from the Maule River to the south of Santiago in central Chile to northern Ecuador and represented the largest prehispanic empire in the Americas (Stanish 2001). The Inkas were initially organized as a chiefdom society which had “internal social and political hierarchies” that enabled different families of high-ranking status to have power “over resources, the ability to make group decisions, or to provide sacred, military and political leadership” (D’Altroy 2015:68). The majority of their people also valued their class status with their own “kin” and “ethnic ranking” (D’Altroy 2015:291). Cuzco in the Peruvian Andes was the capital of the Inka Empire, and it is thought that in the early stages of the empire’s development, the Inka focused on “alliance-formation processes” during what was a mostly peaceful period (Stanish 2001). It is suggested that Inka imperial strategies varied based on the geopolitical characteristics of incorporated areas. For example, the highlands are thought to have had a less diverse population compared to coastal areas, and there was less exchange between autonomous polities, thereby supporting the Inka’s direct control methods (Stanish 2001). The Inka Empire of Andean South America is estimated to have been relatively short, ca. AD 1400–1532 (Ogburn et al. 2009), as it fell due to the Spanish conquest.

Despite the Inka’s preference for warfare, diplomacy was also used when it came to persuading other territories to join their empire, but they also had their soldiers and specialists go out and retrieve food and materials from neighboring regions. The Inkas also built a network of “garrisons, frontier forts, and a remarkable logistical system of roads, support facilities, and depots” (D’Altroy 2015:321). As pointed out by D’Altroy (2015:322) the Inka military also “excelled, for their battlefield command and conduct from traditional methods applied on a grander scale." Their overwhelming presence of soldiers and weapons made it easier to persuade other territories to join them as well.

## I. Inka Expansion in Northern Ecuador

During the 1400s, the Inka continued their northern imperial expansion, including their attempt to solidify their power focused within the northern frontier of Ecuador. More recent estimates using Bayesian models suggest that the Inka began their northern movement into Ecuador around cal AD 1430–1460 (Marsh et al. 2017). These efforts resulted in the building of fortified structures to support the subjugation of the indigenous Caranqui-Cayambe populations who resisted the Inka northern movement (Connell et al. 2019:1). There is agreement among most scholars that the period of Inka occupation within the northern Ecuadorian Sierra occurred over a thirty-to-fifty-year period, from approximately AD 1490 to 1534 (Bray 1992). During much of this period the Inka imperial strategy was to isolate the Caranqui-Cayambe population, and this allowed the Inka to eventually attack them and gain full control (Bray and Almeida 2014:179).

## II. Pambamarca Region

The Pambamarca region of the northern Ecuadorean highlands is located to the north and east of Quito (Ogburn et al. 2009). It is estimated that the Inkas moved north and conquered the peoples of Quito in AD 1455–1460 and arrived at the more northern Pambamarca region around 1490 C.E. (Connell et al. 2019; Cobo 1979). This region was historically comprised of highly stratified and autonomous polities of Caranqui and Cayambe societies, also referred to as the "Pais Caranqui" (Bray 1992) or simply as the "Cayambes," (Sistrunk 2010), who engaged in long-distance exchange. It is thought by some researchers that the Inka imperial efforts focused on eliminating such long-distance trade relationships to mitigate potential anti-Inca alliances, while stressing conformity and dependence on the new Inka state (Bray 1992; Stanish 2001; Sistrunk 2010).

During the Inka movement to subjugate and control the local Cayambe within the Pambamarca region, the indigenous groups resisted and built strong forts (Sistrunk 2010). It is also thought that some of the forts utilized by the Inka during their attack of the Cayambe may have actually been built and occupied prior to the Inka by the Cayambe during interregional warfare (Sistrunk 2010). Other Inka fortified sites within the Pambamarca region are thought to have been established and occupied only by the Inka, as indicated by ceramic and lithic archaeological evidence (Sistrunk 2010, Connell et al. 2019). The Inka forts were built during the period of active warfare against the Cayambe and were likely intended as "temporary military installations," compared to more permanent defensive perimeter outposts (Ogburn et al. 2009). Based upon the results of the extensive obsidian provenance analysis that Ogburn et al. (2009) conducted on ninety-nine obsidian artifacts from fortified and non-fortified sites located in the Pambamarca region, the researchers estimate that the Inka could have gained control of the Cayambe and implemented "imperial political and economic practices" within a period of ten years or less.

The research associated with the procurement of obsidian by the Inka and the Cayambe during this period of resistance is important to our understanding of the Inka imperial movement northward into the Pambamarca region. Connell et al. (2019:6) provides an overview of archaeological sites within the Pambamarca complex, including Quitoloma and Campana Pucara, and cites the work of numerous archaeological researchers, including Oberem et al. (1969), Sistrunk (2010), Fresco et al. (1990), Sullivan (2007), Bray (1990), D'Altroy (1992), and Alconini (2016), and a Spanish chronicler, Betanzos (1996). One of the key areas of focus with respect to archaeological research within the Pambamarca region pertains to obsidian provenance studies, including research to better understand procurement of obsidian for Inka imperial military sites (Ogburn et al. 2009). In their continued fight against local and Cayambe resistance, research related to obsidian procurement by Ogburn et al. (2009) suggests that the Inka were able to quickly take control of obsidian sources from the indigenous local or Cayambe groups. At the same time, there remain unanswered questions such as how and where the Inka military obtained obsidian for the purposes of their military campaign against the Cayambe. In the course of this period of resistance by the Cayambe, numerous pathways for procurement of obsidian for military purposes were possible for the Inka and local Cayambe, including the likelihood that the local subjugated people were obligated to supply the Inka army with obsidian as tribute obligations (Ogburn et al. 2009). Ogburn et al. (2009) also postulate that the Inka army could have reclaimed obsidian from existing Cayambe fortified sites, which also suggests that the Inka could have taken control of and occupied previous Cayambe forts. Ogburn et al. (2009) point out that obsidian samples from local Cayambe sites were sourced "before, during, and after the time of the Inka incursion."

# CHAPTER 3: OBSIDIAN

Obsidian, a rhyolitic volcanic glass created from the cooling of viscous lava rich in silica, possesses a hardness of 5.5 on the Mohs scale (Burger and Asaro 1977). Since crystallization does not occur during the cooling process, the conchoidal fracturing properties of the glass allow for precision chipping to produce the sharpest edge of all stone artifacts (Burger and Asaro 1977). Glassy silicic obsidian has been produced from flows associated with the Ecuadorian volcanic belt. Archaeologists have performed provenance studies and implemented stratigraphic correlations in geological mapping and source identification with obsidian artifacts (Bigazzi et al. 1992). Obsidian from archaeological sites can be matched to specific obsidian sources through geochemical provenance methods such as neutron activation analysis (NAA), x-ray fluorescence (XRF), and optical spectroscopy to identify trace element composition (Burger and Asaro 1977). Dyrdahl (2022) describes that there are twelve known obsidian sources in Ecuador, with eleven of the sources being located within relatively close proximity in the eastern Andean mountain range area called Sierra de Guamaní. Ogburn (2011:100) points out that the Mullumica, Yanaurco-Quiscatola, and Callejones sources that were largely identified by Ernesto Salazar (1980, 1992) represent the most commonly exploited obsidian sources in northern Ecuador; they are roughly 380 km from the isolated Carboncillo source in the southern highlands of Ecuador near Saraguro and 1,600 km from the northern most source in Peru.

The Mullumica flow is considered the major obsidian source of Ecuador, representing roughly 75 percent of measured artifacts (Bellot-Gurlet et al. 2008; Bigazzi et al. 1992:22-24). It is considered to be a chemically "variable source," where the obsidian was formed from hot magma that mixed imperfectly with rock of a different composition (Burger et al. 1994:230). There are also other significant nearby obsidian sources that are approximately 15 km from each other at high elevations between 3900 4200 m.a.s.l., including, the Yanaurco-Quiscatola source, located 10 km west-southwest of the Mullica flow, which include flows from two chemically indistinguishable outcrops, the Callejones flow, which is 2 km east of the Mullica flow, and the El Tablón flow located on the western section of the Cordillera Real, (Bellot-Gurlet et al. 2008:273; Bigazzi et al. 1992:24; Burger et al. 1994:230-231; Ogburn et al. 2009:742). Obsidian produced from the Callejones source is chemically distinctive, but related to the Mullumica source, and it is also variable in composition (Bellot-Gurlet et al. 2008; Bigazzi et al. 1992:24, 29; Ogburn 2011:100). However, Ogburn (2011:100-101) highlights that few artifacts have been associated with the Callejones source, including five artifacts from the nearby Pambamarca region attributed to the source by Ogburn et al. (2009). The El Tablón source which is associated with perlitized obsidian bedded with completely hydrated material is not considered an appropriate source for Prehispanic artifacts (Burger et al. 1994:230). There are other obsidian sources within the Sierra de Guamaní region, including the Potrerillos and Yurac Paccha sources, but these have not been confirmed as the source of any artifacts due to the unsuitable quality of the obsidian (Bigazzi et al. 1992; Ogburn 2011:101). Ogburn (2011:101) notes the existence of additional obsidian source deposits, including Rio Aliso, Rio Bermejo, Rio Cosanga, Cotopaxi, and Mojanda, as well as other possible sources within the Sierra de Guamaní based upon unique composition of obsidian artifacts obtained at the La Chimba and El Inga archaeological sites. With respect to the Carboncillo source, Ogburn et al. (2011:743) mentions that the archaeological distribution of obsidian artifacts from that source is more limited compared to the northern Ecuadorean sources.

# CHAPTER 4: OBSIDIAN HYDRATION DATING

Obsidian hydration dating is a method that measures the thickness of the hydration layer on chipped surfaces. Once the surface of obsidian is chipped, water begins to slowly diffuse into the obsidian through miniscule interstices creating a rind or rim known as the hydration layer, which can be detected when it reaches 1/2 micrometer in thickness (Friedman and Trembour 1983; Rogers and Stevenson 2020). The use of the obsidian hydration dating method in archaeology was first presented in 1960 by geologists Friedman and Smith (Friedman and Smith 1960). This dating method is comprised of two main processes; 1) the measurement of the hydration layer, and 2) the calculation of a date based on a calculated hydration rate. The first process involves the use of polarized optical microscopy to examine thin slices cut from the margin of the obsidian sample to measure the thickness of the hydration layer (Friedman and Smith 1960; Friedman and Trembour 1983; Rogers and Stevenson 2022). Friedman and Long (1976) reported the first equation that used principles of physics to describe the hydration rate process. The hydration rate can be calculated by the direct calibration of the hydration thickness with verified radiocarbon, potassium-argon, or cultural dates of material associated with the obsidian, or by experimental determination (Friedman and Trembour 1983). The basic hydration rate equation correlates time to rim thickness and hydration penetration rate, recognizing that obsidian anhydrous chemistry has a major influence on hydration rate (Friedman and Long 1976; Rogers and Stevenson 2022:5-6).

Obsidian hydration dating can be considered as a relative or absolute dating method depending on whether it is being used to estimate age relative to other obsidian artifacts or whether it is used to provide independent chronometric estimates. Often, the method is considered to be absolute dating, as Peregrine (2016:143) defines it as follows; “Obsidian hydration is a form of absolute dating used only on obsidian." Jones and Beck (1990:84) describe how the method is used as an adjunct to standard dating techniques instead of for the precise chronometric assessments of surface artifacts (Michels and Tsong 1980). Eerkens et al. (2008:2231, 2237) compared 240 source-specific hydration measurements from obsidian artifacts from the Southern Nasca Region (SNR) of Peru with independent radiocarbon dates and found that hydration rates were within an average of 15% of the independent dates; thereby suggesting that hydration dating is a viable method to independently estimate age.

There are geographic limitations and other considerations for the use of obsidian hydration dating including temperature, relative humidity, and other factors pertaining to where the obsidian artifacts were deposited. As temperature rises, the hydration rate rises exponentially at a rate of about 10% for each 1°C increase (Friedman and Trembour 1983). Mazer et al. (1991) found that hydration in obsidian increased by as much as twenty-five percent between 60 and 100 percent relative humidity. Additionally, Stevenson et al. (1993) and Rogers (2008) found that there are correlations between intrinsic water content, the geochemical source of the obsidian, the hydration rate, and the standard deviation of age. Rogers and Stevenson (2022) identified several critical data requirements and processes necessary for the hydration rate calculation. These include provenance of the sample, temperature measurements, and geochemical source identification so that the appropriate hydration rate can be applied (Rogers and Stevenson 2022). These researchers point out that observations by the hydration laboratory regarding hydration layer clarity and thickness variation are important in understanding any possible aging anomalies (Rogers and Stevenson 2022).

These considerations, including careful measurements of temperature and relative humidity at a site, are important factors that need to be addressed to support optimal obsidian hydration dating results going forward as an absolute dating technique (Mazer et al. 1991:504). Ridings (1996) acknowledges the findings of Evans and Meggers (1960) regarding challenges associated with this method as an absolute technique and concludes that obsidian hydration dating should work best with obsidian from sites near the Equator due to the relatively stable hydration environment. Evans and Meggers (1960:523, 537) cite technical or geological factors, such as physical and chemical variables, and archaeological factors, such as the lack of additional sample information, that have been shown to cause dating error with this method for archaeological samples. These researchers also state that to develop hydration dating as a viable absolute method, tested samples should be accompanied with additional information, such as radiocarbon dating, dendrochronology, historical records, and other information (Evans and Meggers 1960:523). Based on the findings of these and other researchers, these factors have been shown to impact the rate of formation of the hydration layer and consequently the accuracy of the hydration rate calculation.

Given these factors that impact the physical hydration layer and hydration rate calculation, there are uncertainties associated with the application of this technology to ensure accurate dating estimates for obsidian artifacts. Recognizing that obsidian hydration dating has been considered as a potential relative and absolute dating methodology, Michels and Tsong (1980) roughly four decades ago pointed out the challenges associated with establishing obsidian hydration dating as an “intrinsic chronometric technique.” In their working paper, Rogers and Stevenson (2022), following a review of published data to date on the use of obsidian hydration dating, concluded that additional research is needed to better understand the reasons for the uncertainty rates that have ranged roughly 15 – 25%. They point to the need to better understand factors such as intrinsic water content, temperature history, and hydration at the molecular level, to determine if improvements can be obtained with age precision, as these factors impact the rate of formation of the hydration layer and the calculation of absolute dates. (Rogers and Stevenson 2022).

However, some researchers consider that there is a place for obsidian hydration dating going forward. Liritzis and Laskaris (2011) assessed the progress of obsidian hydration dating over a fifty-year period and concluded that it could represent “a self-contained chronometric system, a routinely used absolute dating method in parallel and as complementary to luminescence and radiocarbon methods.” Rogers (2008:2015) cautions that there are challenges associated with this method, including factors such as “effective hydration temperature, including the effects of burial depth; relative humidity; collection unit and depth; and provision of an adequate sample size,” but concludes that when combined with radiocarbon dating, it is appropriate “for constructing coarse chronologies.” Other researchers consider obsidian hydration dating as a relative dating method versus an absolute chronometric technique. Stevenson et al. (2000:223) points out that it is considered a viable relative dating method with archaeological work in the western United States, and in particular, California. This perspective is based on a case study CA-ORA-64 that used a new model for glass hydration to obtain estimated age with radiocarbon dating as the basis for determination of the accuracy of the hydration model (Stevenson et al. 2000:233-234). Although the usefulness of this dating method as a relative technique is well established, ongoing research is required to further improve its utility as an absolute dating method.

## I. Obsidian Hydration Dating in North America and Other Continents

Obsidian hydration dating is restricted to locations with access to obsidian and consequently has been used extensively in parts of the United States, Mexico, and Central America, and on a limited basis in other regions of the world that have obsidian. Rogers and Stevenson (2022:23, 26) cited the use of obsidian hydration dating for obsidian samples in the western United States, including research sites in southeastern California and southern Nevada. Hall and Jackson (1989) reference the work of California researchers Meighan (1983), Basgall and Hildebrandt (1987), and Ericson et al. (1976), and reported the use of obsidian hydration dating with obsidian from the Casa Diablo source located in the western section of Long Valley, California where obsidian was obtained by prehistoric hunter-gatherers in California. Clark (1984) reported the use of this dating methodology in the subarctic Koyukuk River region of Alaska, including previous research by Friedman and Smith (1960) and MacNeish (1964:305-308). Hall and Jackson (1989:32) concluded that obsidian hydration dating is capable of providing meaningful results relative to the applied "cultural chronological continuum;" however, there are challenges in establishing appropriate hydration rates for specific obsidian sources, and the empirical approach will require the correlation of "hydration values and radiocarbon determinations" that are matched from respective sites.

Obsidian hydration dating has also been used in several Mesoamerican archaeological research projects (Freter 1993; Glascock et al. 1993; Cobean et al. 1991; Elam et al. 1992; Rice 1986; Aoyama and Freter 1991; Graham and Pendergast 1989). For example, Elam et al. (1994) reported their research with the Missouri University Research Reactor laboratory using obsidian hydration dating with samples from archaeological sites in the Pre-Hispanic Oaxaca region of Mexico. One of the challenges mentioned by Elam et al. (1994) was the identification of accurate hydration rate constants from experimental analysis. Despite these limitations, the hydration dating results were beneficial in providing some inference regarding timelines (Elam et al. 1994). Evans and Freter (1996) reported that the obsidian hydration dates for obsidian artifacts collected at the site of Cihuatecpan in the Teotihuacan Valley area of Mexico “provides a plausible series of chronometric markers for the occupation of Cihuatecpan,” and substantiated the “validity of the obsidian hydration dating method.” Webster et al. (1993) and Braswell (1992) cite the use of this method with obsidian samples from their Mesoamerica archaeological research at Copán, Honduras. Webster and Freter (1990) previously reported that the dating methodology had produced "mixed results in Mesoamerica.” Hammond (1989) reported the successful use of hydration dating for obsidian from the Tecep phase burial (AD 800-1100 +) at the Maya site of Nohmul, in Belize, Central America. Hurtado de Mendoza (1977) dated obsidian from the Kaminaljuyu site in the highland central valley of Guatemala to assess patterns of obsidian consumption by the Kaminaljuyu Chiefdom.

Obsidian hydration dating has been used in other parts of the world. Morgenstein and Rosendahl (1976) reported the use of hydration dating with obsidian samples sourced from archaeological sites in the Hawaiian Islands. Leach and Hamel (1984) reported the use of this dating method in New Zealand that was unsuccessful due to variations in soil temperature and archaeological sediment considerations that contributed to dating error. Nakazawa et al. (2020:3) reported the use of obsidian hydration dating as an alternative method to radiocarbon dating when combined with secondary ion mass spectrometry (SIMS) at the prehistoric Jozuka site in southern Kyushu, Japan. The use of SIMS allows for a more precise measurement of the depth profiles of hydrogen on hydrated obsidian surfaces, and when combined with the separate optical measurement of the hydration rim thickness, it was shown to improve the overall validity of the hydration rate (Nakazawa et al. 2020:3, 10). Evans (1965) reported the use of hydration dating with obsidian samples from Easter Island. Liritzis et al. (2004) applied secondary ion mass spectrometry (SIMS) to measure surface hydration layers with obsidian sourced from several sites, including Chalco, Mound 65 in Mexico, Easter Island 10-241 in Chilean territory, Ftelia and Philakopi in Greece, Hopewell in Ohio, USA, and the Xaltocan site in Mexico. They found error rates between 5-10% and concluded that Obsidian hydration dating, based upon SIMS hydrogen profiling, resulted in a level of precision associated with error rates that was "equivalent to, or less than, that of conventional calibrated radiocarbon dating" (Liritzis et al. 2004:60).

II. Obsidian Hydration Dating in Highland Ecuador and South America

Although there was early use of obsidian hydration dating from the Ecuadorean coastal area (Friedman and Smith 1960; Evans and Meggers 1960), there has been limited use of the technique in other Andean archaeological sites in recent decades. Preliminary research was reported by Bell (1977) using samples from Quito, highland Ecuador and compared with radiocarbon dating of soil samples from the same locations the obsidian was obtained. The studies found that there were likely "erroneous radiocarbon dates" and additional radiocarbon dates would need to be determined before a "reliable hydration rate" could be established for highland Ecuador (Bell 1977). Pagán-Jiménez et al. (2021) incorporated obsidian hydration dating with sets of radiocarbon dates for dating of the El Inga and San José sites in highland Ecuador.

The technique has also been used in Peru and Argentina. In the Southern Nasca Region on the south coast of Peru, Eerkens et al. (2008) dated 237 obsidian artifacts, of which 158 were correlated with 15 radiocarbon-dated site components. Eerkens et al. (2008:2237) reported a correlation of obsidian hydration dating timelines within 15% of the radiocarbon estimates. Tripcevich et al. (2012:1360) reported the use of obsidian hydration for dating of the high elevation Chivay site in the Colca Valley in Arequipa, Peru, whereby radiocarbon dates were used to develop a preliminary hydration rate. Garvey et al. (2016) attempted to use obsidian hydration dating to predict radiocarbon dates from the southern Andean Las Cargas and Laguna del Maule sites within the Mendoza Province of Argentina, with limited success.

III. Prior Geochemical Characterization and Sourcing of Pambamarca Obsidian Samples

Ogburn et al. (2009) conducted extensive provenance analysis on ninety-nine obsidian samples from fortified and non-fortified sites within the Pambamarca region. This involved X-ray Fluorescence (XRF) that determined the concentrations of eleven elements; Ti, Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, and Nb, with bi-variate plots of Sr vs. Zr and Fe proving useful for differentiating the obsidian sources (Ogburn et al. 2009:746). Ogburn et al. (2009) were able to conclude that "all samples came from the obsidian sources in the northern highlands of Ecuador," with no Peruvian or Colombian obsidian sources, nor the southern Ecuadorian Carboncillo source. This is an important finding, as this suggests that obsidian was sourced from more local sources for the provisioning of the Inka army, rather than being brought from elsewhere in the empire. Ogburn et al. (2009) determined that most of the obsidian was sourced from Mullumica, including a continuous distribution of the high and low Fe varieties which suggests that multiple extraction points were used. Three obsidian artifacts were sourced from Yanaurco-Quiscatola, five of low Fe variety and were sourced from Callejones, and seven were from the unlocated La Chimba source which were characterized by very low concentrations of Sr and Ti, and an elevated concentration of Y (Ogburn et al. 2009). Ogburn et al. (2009) also noted that there was a significant variation in visual characteristics across the obsidian artifacts which precluded them from being attributed to any specific source based on color alone.

# CHAPTER 5: OVERVIEW OF PAMBAMARCA SITES AND OBSIDIAN SAMPLES

In this project, I conducted obsidian hydration dating on fifty-one selected obsidian samples that were excavated from "fortified and non-fortified sites in the Pambamarca region of northern Ecuador" (Ogburn et al. 2009) as part of the Pambamarca Archaeological Project in the northern Ecuadorian highlands. The Pambamarca Archaeological Project is comprised of an international research team focused on the investigation of Inka and local Cayambe (País Caranqui) forts and local settlements within the Pambamarca region that were occupied prior to and during the Inka imperial era. The obsidian samples are mostly comprised of flakes, flake fragments, debitage, and small cores or fragments of cores, including some with utilization scars on the flakes and cores (Ogburn et al. 2009). The samples did not include finished working tools and the artifacts were not associated with primary weapons since they typically would not have been made from obsidian (Ogburn et al. 2009). This research is also centered upon understanding obsidian and non-obsidian lithics production and the function of several Pambamarca sites (Ogburn et al. 2009). Ogburn et al. (2009) reported provenance analysis using X-ray Fluorescence (XRF) for ninety-nine obsidian samples obtained from two Inka sites and five local sites. My research focuses on obsidian artifacts from six of the seven sites studied by Ogburn et al. (2009). Figure 1 (from Ogburn et al. 2009) illustrates the relative proximity of the Inka and local Cayambe sites to each other and to the two major archaeological obsidian sources, the Mullumica, Callejones, and Yanaurco-Quiscatola flows.

## I. Quitoloma

Quitoloma represents the most studied Inka site within the Pambamarca complex. It is a large Inka fortress comprised of stone buildings and roughly 100 structures located on the southernmost point of the Pambamarca complex. Twenty-eight obsidian samples used for provenance analysis via XRF were obtained from excavated living surfaces located both inside and outside of stone buildings that may have been associated with elite and commoner sections (Ogburn et al. 2009:744). Ogburn et al. (2009:745-746) notes that the Inka occupation for this site is estimated to be ca. AD 1500–1520. The flake, debitage, and core components of these artifacts suggest that these represent good sample candidates for obsidian hydration dating, as this method could potentially confirm a chronology aligned with the period of Inka occupation (Ogburn et al. 2009:745-746).

II. Campana Pucara

Campana Pucara is an Inka fort located at the northern section of Pambamarca from which nine samples used for provenance analysis via XRF, consisting mostly of debitage and flakes, were obtained from excavations on the eastern side of the site including the main plaza and buildings, and the excavations suggest that the site may have been taken over by the Inka and reoccupied (Ogburn et al. 2009:744). The Inka occupation timeline for this site is estimated to be ca. AD 1500–1520 which is the same chronology as Quitoloma, though it has been suggested that there was also an earlier phase of occupation at Campana Pucara (Ogburn et al. 2009:745). Based on the characteristics of the samples from this site and the occupation timeline for the site, obsidian hydration dating could potentially be an effective dating method to confirm an earlier occupation.

III. Oroloma

Oroloma is a site that is estimated to have been occupied ca. AD 700–1180 by local Pre-Cayambe people who were not at war with the Inkas at the time (Ogburn et al. 2009:744). Ogburn et al. (2009:744-746) reported that the twenty-nine artifacts from this site used for provenance analysis via XRF include twenty-eight from excavations and one from surface collection, and the samples are comprised of debitage, cores, and flakes. This timeline suggests that the obsidian artifacts tested by hydration dating from this site should be older than those from the other sites, and not overlap with the Inka fort of Quitoloma.

IV. Pingulmi

Pingulmi is an expansive open Cayambe fortified settlement that dates to the end of the Cayambe period, ca. AD 1250–1520 that was occupied prior to and during the Inka incursion (Ogburn et al. 2009:744). Ogburn et al. (2009:745) reported that the fifteen obsidian artifacts from the Pingulmi site used for provenance analysis via XRF were collected from the surface and are mostly comprised of debitage and flakes. Pingulmi is a lower elevation (3000 m) fortress, which needs to be taken into consideration for comparing hydration calculations to the other sites (Ogburn et al. 2009). This timeline suggests that the artifacts tested by hydration dating could overlap with and also be slightly older than Quitoloma and Campana Pucara artifacts, but not be as old as Oroloma samples.

V. Pukarito

Pukarito is a local Cayambe fort located near 3000 m, which was built prior to the Inka arrival and used by the Cayambe during the Inka invasion, ca. AD 1250–1520 (Ogburn et al. 2009:744). The seven obsidian samples from the Pukarito site used for provenance analysis via

XRF were obtained by excavation and are mostly represented as flakes and debitage (Ogburn et al. 2009:745). Samples tested by obsidian hydration dating would be expected to approximate the dating of the Pingulmi samples.

VI. Hacienda Guachala

Hacienda Guachala is a Spanish hacienda that was built in AD 1580 following the demise of the Inka empire. The Inka controlled the area east of the Pisque River, which included Pambamarca and the location of Hacienda Guachala (Ogburn et al. 2009:744). This site is representative of the indigenous colonial people who were laborers at the hacienda. The four obsidian samples from the Hacienda Guachala site used for provenance analysis via XRF were obtained by excavation and are all flakes (Ogburn et al. 2009:746). Hydration dating for Guachala samples would be expected to give the youngest dating compared to the other sites.

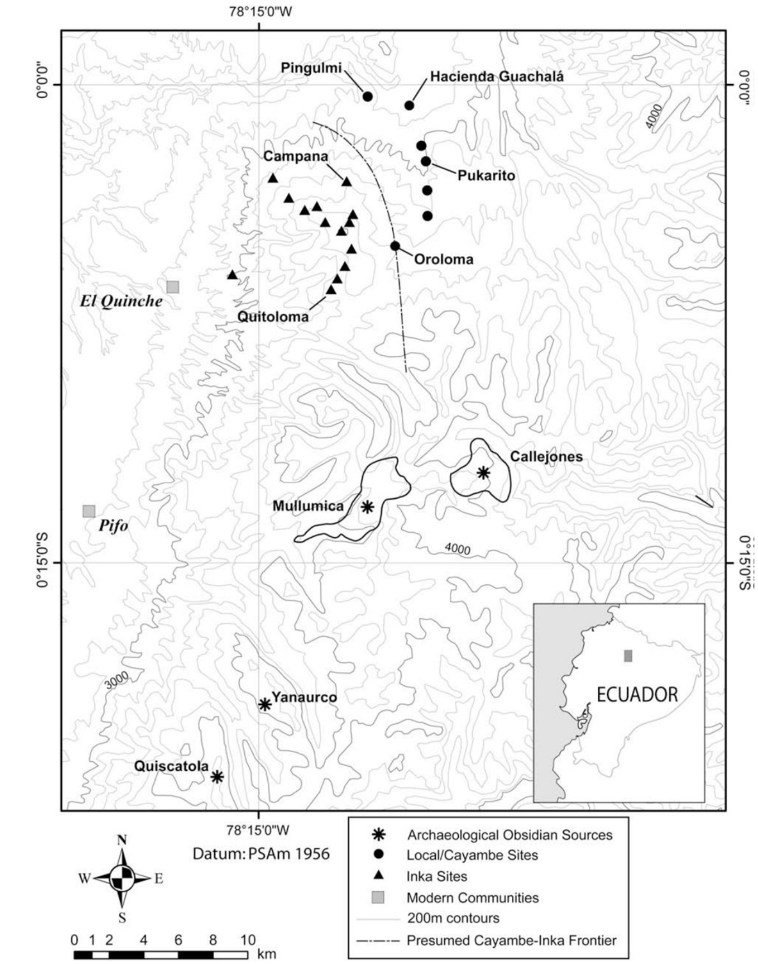



Fig. 1. Location of Inka and Cayambe sites in the Pambamarca region (Ogburn et al. 2009:742)

# CHAPTER 6: OBSIDIAN HYDRATION DATING METHODOLOGY

The principal objective of my research is to use obsidian hydration dating for fifty-one obsidian samples from one pre-Cayambe early site, two Inka sites, two late Cayambe sites, and one Colonial site within the Pambamarca region of northern Ecuador and compare the relative dates to the estimated Inka and Cayambe occupation timelines at these sites. Three to fifteen obsidian samples from each site were selected and shipped to Origer's Obsidian Laboratory (OOL) located in Rohnert Park, California to obtain obsidian hydration rim measurements.

Prior to the submission of the obsidian samples to the laboratory, the samples were examined in order to identify any possible instructions to the laboratory relative to the recommended location for hydration measurement locations. The obsidian samples were recorded and numbered according to the site location. Additional information was provided to the laboratory including the site location for each sample, a description of the type of artifact, whether they were collected via excavation or from the surface, unit and level data for the excavated samples, and the identified obsidian source.

The laboratory prepared the samples and made an appropriate one-millimeter-thick cross-section hydration cut on the rim of each obsidian sample. The cross-section was mounted on a microscope slide and the laboratory utilized a petrographic microscope to examine the birefringent rim to measure the respective thickness to the nearest 0.1-micron increment. For this research, the laboratory did not use or calculate a hydration rate to be used with the verified hydration band measurements. Therefore, my research will not incorporate a hydration rate by using a representative hydration rate for the source composition or through experimentation or calibration with other dating methodologies, such as radiocarbon dating in order to determine a calendar age for the samples (Michels et al. 1983). Instead, the laboratory findings will be used to evaluate relative chronologies only, as the determination of hydration rates, corrections for temperature variables, or calibration with other obsidian dating methodologies are beyond the scope of this project.

I. Key Assumptions and Limitations

In using obsidian hydration dating as a relative dating methodology, my research takes into account several key issues. These issues will likely impact the relative dating estimates that will be provided for each of the tested samples.

1) The first issue is that the relative dating measurements reported for the tested samples will not be calibrated to any other chronometric dating measurements, such as radiocarbon dating. Consequently, the reported hydration band measurement data will be compared to the following current estimates for the occupation timelines associated with the six sites (Ogburn et al. 2009): Quitoloma (ca. AD 1500–1520); Campana Pucara (ca. AD 1500– 1520); Oroloma (ca. AD 700–1180); Pingulmi (ca. AD 1250–1520); Pukarito (ca. AD 1250–1520); and Hacienda Guachala (AD 1580+). Radiocarbon dating has been performed for components of some of the sites. For example, exposed material from the Quitoloma site was radiocarbon dated to 1450–1650 cal AD, which provided an acceptable chronology overlap with the estimated ca. AD 1500–1520 timeline (Connell et al. 2019).

2) The second issue is that the samples from the six sites are from different obsidian sources, which could result in different hydration rates. This issue is further compounded by the fact that the samples are from different depths, having been collected by either excavation or surface collection. The samples are also from sites with different elevations, as higher elevations are associated with slower hydration rates compared to lower elevations. However, to eliminate the

flow source variability, obsidian samples used in this project only came from the Mullumica flow source, although there was a chemical variation between High Fe and Low Fe samples.

3) The third issue is that the obsidian hydration testing will not use an established hydration rate for the hydration laboratory to use to provide relative dates for the samples. Even though geochemical testing was previously conducted on the samples (Ogburn et al. 2009), this information will not be used by the laboratory, as the laboratory analysis will primarily focus on hydration band measurements for each of the samples.

# CHAPTER 7: RESULTS

Origer's Obsidian Laboratory, in their report of March 23, 2023, provided the results of their obsidian hydration band measurements for the Pambamarca obsidian samples submitted. Of the fifty-one obsidian artifact samples from the six sites submitted to Origer's Obsidian Laboratory for analysis, thirteen samples did not provide suitable or normal hydration band measurements. These included four samples that exhibited no visible hydration bands, three samples with hydration bands that were too diffuse for measurement, and two samples with variable width hydration bands. There were also four samples that contained more than one hydration band, suggesting damage or reworking of the specimens. Thirty-eight of the fifty-one samples provided normal hydration band measurements. The laboratory provided six hydration band measurements and a mean measurement for each of forty-six evaluable samples. The laboratory also provided the level associated with the excavation depth or surface collection for the respective samples. Table 1 provides a summary of the sample dataset and the hydration band measurements provided by Origer's Obsidian Laboratory.

**Table 1. Origer's Obsidian Laboratory Report Dataset**

| Lab# | Site# | Sample | Description | Unit | Level | Remarks | Measurements | Mean | Source |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Pukarito | PM-1 | Debitage | | Surface | | 7.0 7.0 7.1 7.1 7.2 7.4 | 7.1 | Mullumica (high Fe) |
| 2 | Pukarito | PM-3 | Debitage | 1 | 1 | | 1.4 1.4 1.4 1.5 1.5 1.5 | 1.5 | Mullumica (high Fe) |
| 3 | Pukarito | PM-4 | Debitage | 3 | 1 | | 1.2 1.2 1.2 1.2 1.2 1.3 | 1.2 | Mullumica (high Fe) |
| 4.1 | Pukarito | PM-5 | Debitage | 3 | 6 | Band 1 | 1.2 1.2 1.2 1.2 1.2 1.2 | 1.2 | Mullumica (high Fe) |
| 4.2 | Pukarito | PM-5 | Debitage | 3 | 6 | Band 2 | 7.3 7.3 7.4 7.5 7.6 7.6 | 7.5 | Mullumica (high Fe) |
| 5 | Campana | PM-8 | Debitage | 1 | 3 | | | NVB | Mullumica (high Fe) |
| 6 | Campana | PM-9 | Debitage | 1 | 3 | | 1.2 1.3 1.3 1.3 1.4 1.4 | 1.3 | Mullumica (high Fe) |
| 7 | Campana | PM-10 | Debitage | 1 | 3 | | 1.2 1.2 1.2 1.2 1.2 1.2 | 1.2 | Mullumica (low Fe) |
| 8 | Campana | PM-11 | Debitage | 1 | 3 | | 3.6 3.6 3.6 3.7 3.7 3.7 | 3.7 | Mullumica (high Fe) |
| 9 | Campana | PM-12 | Debitage | 1 | 1 | | 2.9 2.9 3.0 3.0 3.0 3.1 | 3.0 | Mullumica (low Fe) |
| 10 | Campana | PM-13 | Debitage | 1 | 1 | | 1.2 1.2 1.2 1.2 1.3 1.3 | 1.2 | Mullumica (low Fe) |
| 11 | Campana | PM-14 | Debitage | 4 | 2 | | | NVB | Mullumica (high Fe) |
| 12 | Campana | PM-15 | Debitage | 1 | 2 | | 1.2 1.3 1.3 1.3 1.3 1.3 | 1.3 | Mullumica (high Fe) |
| 13 | Pingulmi | PM-17 | Debitage | | Surface | Weathered | | VW | Mullumica (high Fe) |
| 14 | Pingulmi | PM-18 | Debitage | | Surface | | 2.9 2.9 3.0 3.0 3.0 3.1 | 3.0 | Mullumica (high Fe) |
| 15 | Pingulmi | PM-19 | Debitage | | Surface | | 1.2 1.2 1.2 1.2 1.3 1.3 | 1.2 | Mullumica (high Fe) |
| 16 | Pingulmi | PM-20 | Debitage | | Surface | Weathered | 2.8 2.9 2.9 2.9 3.0 3.0 | 2.9 | Mullumica (low Fe) |
| 17 | Pingulmi | PM-22 | Debitage | | Surface | Weathered | | NVB | Mullumica (high Fe) |
| 18 | Pingulmi | PM-23 | Debitage | | Surface | | 3.4 3.5 3.5 3.6 3.6 3.6 | 3.5 | Mullumica (low Fe) |
| 19 | Pingulmi | PM-24 | Debitage | | Surface | | | DH | Mullumica (high Fe) |
| 20 | Pingulmi | PM-26 | Debitage | | Surface | Weathered | 3.1 3.1 3.2 3.3 3.3 3.4 | 3.2 | Mullumica (low Fe) |
| 21 | Pingulmi | PM-27 | Debitage | | Surface | | 1.3 1.3 1.3 1.4 1.4 1.4 | 1.4 | Mullumica (high Fe) |
| 22 | Pingulmi | PM-28 | Debitage | | Surface | | 1.8 1.9 1.9 1.9 1.9 2.0 | 1.9 | Mullumica (high Fe) |
| 23 | Pingulmi | PM-29 | Debitage | | Surface | | 4.4 4.4 4.5 4.5 4.6 4.6 | 4.5 | Mullumica (low Fe) |
| 24 | Pingulmi | PM-30 | Debitage | | Surface | | 1.4 1.4 1.4 1.4 1.4 1.5 | 1.4 | Mullumica (high Fe) |
| 25 | Oroloma | PM-32 | Debitage | 11 | 2 | | 1.1 1.1 1.1 1.1 1.1 1.1 | 1.1 | Mullumica (high Fe) |
| 26 | Oroloma | PM-33 | Debitage | 11 | 2 | | 1.6 1.6 1.6 1.6 1.7 1.7 | 1.6 | Mullumica (high Fe) |
| 27 | Oroloma | PM-37 | Debitage | 11 | 2 | | 1.1 1.2 1.2 1.3 1.3 1.3 | 1.2 | Mullumica (high Fe) |
| 28 | Oroloma | PM-38 | Debitage | 11 | 2 | | 1.4 1.4 1.4 1.4 1.4 1.5 | 1.4 | Mullumica (low Fe) |
| 29 | Oroloma | PM-41 | Debitage | 11 | 3 | | 1.9 1.9 2.0 2.1 2.1 2.1 | 2.0 | Mullumica (low Fe) |
| 30.1 | Oroloma | PM-42 | Debitage | 11 | 3 | Band 1 | 1.2 1.2 1.3 1.3 1.4 1.4 | 1.3 | Mullumica (high Fe) |
| 30.2 | Oroloma | PM-42 | Debitage | 11 | 3 | Band 2 | 5.0 5.1 5.1 5.1 5.1 5.2 | 5.1 | Mullumica (high Fe) |
| 31 | Oroloma | PM-43 | Debitage | 11 | 2 | | 1.3 1.4 1.4 1.4 1.5 1.5 | 1.4 | Mullumica (high Fe) |
| 32 | Oroloma | PM-45 | Debitage | 11 | 2 | | 1.1 1.1 1.1 1.1 1.1 1.1 | 1.1 | Mullumica (high Fe) |
| 33 | Oroloma | PM-51 | Debitage | 11 | 3 | | | NVB | Mullumica (high Fe) |
| 34.1 | Oroloma | PM-52 | Debitage | 11 | 3 | Band 1 | 2.0 2.0 2.0 2.0 2.0 2.1 | 2.0 | Mullumica (low Fe) |
| 34.2 | Oroloma | PM-52 | Debitage | 11 | 3 | Band 2 | 3.0 3.0 3.1 3.1 3.1 3.2 | 3.1 | Mullumica (low Fe) |
| 35 | Oroloma | PM-53 | Debitage | 11 | 3 | | | DH | Mullumica (high Fe) |
| 36 | Oroloma | PM-54 | Debitage | 14 | | | 1.8 1.8 1.8 1.8 1.9 2.0 | 1.9 | Mullumica (high Fe) |
| 37 | Oroloma | PM-55 | Debitage | 14 | | | 1.6 1.6 1.6 1.6 1.6 1.7 | 1.6 | Mullumica (high Fe) |
| 38 | Quitoloma | PM-61 | Debitage | 1 | 5 | | 1.6 1.6 1.7 1.7 1.7 1.8 | 1.7 | Mullumica (high Fe) |
| 39 | Quitoloma | PM-62 | Debitage | 1 | 5 | | 2.8 2.8 2.8 2.9 3.0 3.0 | 2.9 | Mullumica (low Fe) |
| 40 | Quitoloma | PM-65 | Debitage | 1 | 4 | Weathered | 2.0 2.1 2.2 2.2 2.2 2.3 | 2.2 | Mullumica (low Fe) |
| 41 | Quitoloma | PM-66 | Debitage | 1 | 4 | | 1.1 1.2 1.2 1.2 1.2 1.2 | 1.2 | Mullumica (low Fe) |
| 42 | Quitoloma | PM-69 | Debitage | 1 | 3 | | 2.4 2.4 2.4 2.4 2.5 2.5 | 2.4 | Mullumica (low Fe) |
| 43 | Quitoloma | PM-74 | Debitage | 2 | 4 | | 1.1 1.1 1.1 1.1 1.1 1.1 | 1.1 | Mullumica (high Fe) |
| 44 | Quitoloma | PM-75 | Debitage | 2 | 5 | | 1.1 1.1 1.1 1.2 1.2 1.2 | 1.2 | Mullumica (low Fe) |
| 45 | Quitoloma | PM-76 | Debitage | 1 | 6 | | 1.1 1.2 1.2 1.2 1.2 1.3 | 1.2 | Mullumica (low Fe) |
| 46 | Quitoloma | PM-77 | Debitage | 3 | 1 | | 1.0 1.0 1.0 1.0 1.1 1.1 | 1.0 | Mullumica (high Fe) |
| 47 | Quitoloma | PM-79 | Debitage | 1 | 1 | Weathered | | DH | Mullumica (high Fe) |
| 48.1 | Quitoloma | PM-80 | Debitage | 1 | 1 | Band 1 | 1.1 1.1 1.2 1.2 1.2 1.2 | 1.2 | Mullumica (low Fe) |
| 48.2 | Quitoloma | PM-80 | Debitage | 1 | 1 | Band 2; | 1.5 1.5 1.5 1.6 1.6 1.6 | 1.6 | Mullumica (low Fe) |
| 48.3 | Quitoloma | PM-80 | Debitage | 1 | 1 | Band 3 | Approx. 12.0 | VW | Mullumica (low Fe) |
| 49 | Guachala | PM-86 | Debitage | 4 | 5 | Weathered | | VW | Mullumica (high Fe) |
| 50 | Guachala | PM-87 | Debitage | 4 | 5 | | 2.1 2.1 2.2 2.2 2.2 2.2 | 2.2 | Mullumica (high Fe) |
| 51 | Guachala | PM-88 | Debitage | 4 | 5 | Weathered | 1.8 1.9 1.9 2.0 2.1 2.1 | 2.0 | Mullumica (high Fe) |

DH = Diffuse Hydration Data
NVB = No Visible Band
VW = Variable Width

# CHAPTER 8: DATA ANALYSIS AND DISCUSSION

In preparation for the initial data analysis, I incorporated the estimated occupation dates within the dataset reported by Origer's Obsidian Laboratory (Table 1) to provide a reference point for the estimated site dates across all of the fifty-one samples and sorted the sample data according to estimated site date. Of the fifty-one samples, each of four samples provided two different evaluable band measurements. These include sample PM-5 from Pukarito, samples PM-42 and PM-52 from Oroloma, and PM-80 from Quitoloma which has three bands. Nine of the fifty-one samples did not provide valid hydration band measurements due to the bands not being exhibited or being too diffuse or weathered to obtain useful measurements. It should also be noted that the excavation levels reported in Table 1 are not precisely comparable for samples across the different sites, and they are presented as rough measurements for the different excavation level depths from site to site.

## I. Analysis of Hydration Band Measurements Across all Samples

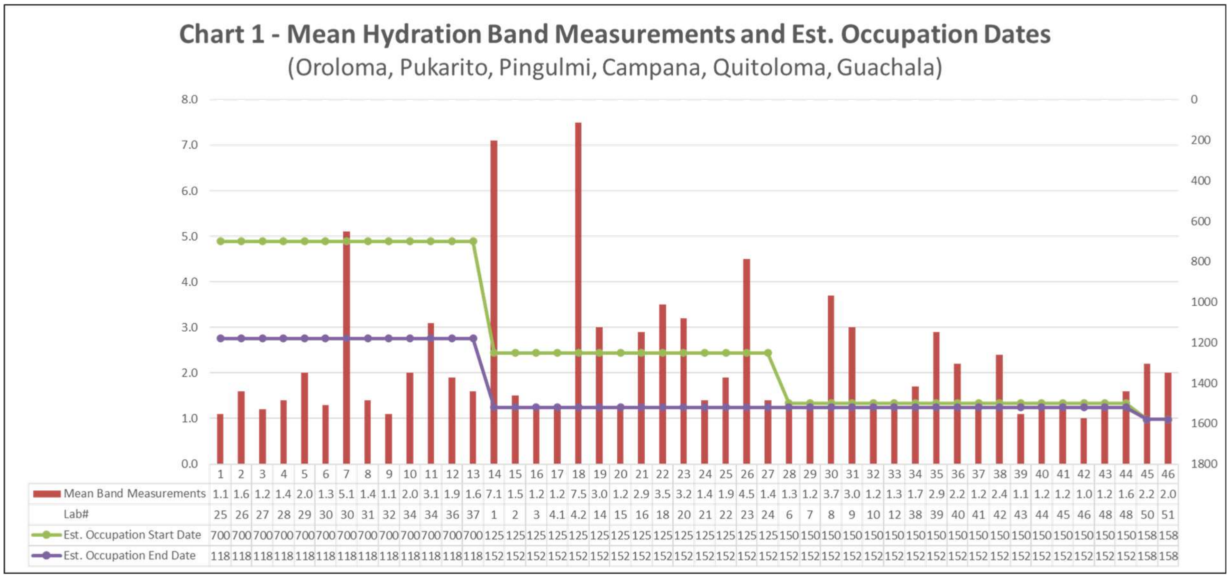
For the first phase of my analysis, I included the forty-two samples that provided hydration band measurements, including the four samples that provided more than one hydration band measurement. The laboratory pointed out that the multiple bands could be caused by the reworking of the obsidian or by damage. This resulted in a total of forty-six hydration band measurements. I then calculated the mean estimated occupation dates for each of the six sites to serve as a point of reference and then correlated the date with each of the respective Lab # samples analyzed by the laboratory. This first analysis phase included the two hydration band measurements for the four samples that contained more than one hydration band, keeping in mind that multiple bands have certain implications for understanding relative dates.

Table 2 provides a summary of the fifty-one samples by site, including their individual and mean hydration band measurements, and estimated site occupation date.

**Table 2. Obsidian Samples by Site, Hydration Band Measurements, and Estimated Occupation Date**

| Lab# | Sample | Site# | Job# | Description | Level | Remarks | Measurements | Mean | Mean Est. Occupation Date |
|---|---|---|---|---|---|---|---|---|---|
| 25 | PM-32 | Oroloma | OOL-1371 | Debitage | 2 | | 1.1 1.1 1.1 1.1 1.1 1.1 | 1.1 | AD 940 |
| 26 | PM-33 | Oroloma | OOL-1371 | Debitage | 2 | | 1.6 1.6 1.6 1.6 1.7 1.7 | 1.6 | AD 940 |
| 27 | PM-37 | Oroloma | OOL-1371 | Debitage | 2 | | 1.1 1.2 1.2 1.3 1.3 1.3 | 1.2 | AD 940 |
| 28 | PM-38 | Oroloma | OOL-1371 | Debitage | 2 | | 1.4 1.4 1.4 1.4 1.4 1.5 | 1.4 | AD 940 |
| 29 | PM-41 | Oroloma | OOL-1371 | Debitage | 3 | | 1.9 1.9 2.0 2.1 2.1 2.1 | 2.0 | AD 940 |
| 30.1 | PM-42 | Oroloma | OOL-1371 | Debitage | 3 | Band 1 | 1.2 1.2 1.3 1.3 1.4 1.4 | 1.3 | AD 940 |
| 30.2 | PM-42 | Oroloma | OOL-1371 | Debitage | 3 | Band 2 | 5.0 5.1 5.1 5.1 5.1 5.2 | 5.1 | AD 940 |
| 31 | PM-43 | Oroloma | OOL-1371 | Debitage | 2 | | 1.3 1.4 1.4 1.4 1.5 1.5 | 1.4 | AD 940 |
| 32 | PM-45 | Oroloma | OOL-1371 | Debitage | 2 | | 1.1 1.1 1.1 1.1 1.1 1.1 | 1.1 | AD 940 |
| 33 | PM-51 | Oroloma | OOL-1371 | Debitage | 3 | | | NVB | AD 940 |
| 34.1 | PM-52 | Oroloma | OOL-1371 | Debitage | 3 | Band 1 | 2.0 2.0 2.0 2.0 2.0 2.1 | 2.0 | AD 940 |
| 34.2 | PM-52 | Oroloma | OOL-1371 | Debitage | 3 | Band 2 | 3.0 3.0 3.1 3.1 3.1 3.2 | 3.1 | AD 940 |
| 35 | PM-53 | Oroloma | OOL-1371 | Debitage | 3 | | | DH | AD 940 |
| 36 | PM-54 | Oroloma | OOL-1371 | Debitage | | | 1.8 1.8 1.8 1.8 1.9 2.0 | 1.9 | AD 940 |
| 37 | PM-55 | Oroloma | OOL-1371 | Debitage | | | 1.6 1.6 1.6 1.6 1.6 1.7 | 1.6 | AD 940 |
| 1 | PM-1 | Pukarito | OOL-1371 | Debitage | Surface | | 7.0 7.0 7.1 7.1 7.2 7.4 | 7.1 | AD 1385 |
| 2 | PM-3 | Pukarito | OOL-1371 | Debitage | 1 | | 1.4 1.4 1.4 1.5 1.5 1.5 | 1.5 | AD 1385 |
| 3 | PM-4 | Pukarito | OOL-1371 | Debitage | 1 | | 1.2 1.2 1.2 1.2 1.2 1.3 | 1.2 | AD 1385 |
| 4.1 | PM-5 | Pukarito | OOL-1371 | Debitage | 6 | Band 1 | 1.2 1.2 1.2 1.2 1.2 1.2 | 1.2 | AD 1385 |
| 4.2 | PM-5 | Pukarito | OOL-1371 | Debitage | 6 | Band 2 | 7.3 7.3 7.4 7.5 7.6 7.6 | 7.5 | AD 1385 |
| 13 | PM-17 | Pingulmi | OOL-1371 | Debitage | Surface | Weathered | | VW | AD 1385 |
| 14 | PM-18 | Pingulmi | OOL-1371 | Debitage | Surface | | 2.9 2.9 3.0 3.0 3.0 3.1 | 3.0 | AD 1385 |
| 15 | PM-19 | Pingulmi | OOL-1371 | Debitage | Surface | | 1.2 1.2 1.2 1.2 1.3 1.3 | 1.2 | AD 1385 |
| 16 | PM-20 | Pingulmi | OOL-1371 | Debitage | Surface | Weathered | 2.8 2.9 2.9 2.9 3.0 3.0 | 2.9 | AD 1385 |
| 17 | PM-22 | Pingulmi | OOL-1371 | Debitage | Surface | Weathered | | NVB | AD 1385 |
| 18 | PM-23 | Pingulmi | OOL-1371 | Debitage | Surface | | 3.4 3.5 3.5 3.6 3.6 3.6 | 3.5 | AD 1385 |
| 19 | PM-24 | Pingulmi | OOL-1371 | Debitage | Surface | | | DH | AD 1385 |
| 20 | PM-26 | Pingulmi | OOL-1371 | Debitage | Surface | Weathered | 3.1 3.1 3.2 3.3 3.3 3.4 | 3.2 | AD 1385 |
| 21 | PM-27 | Pingulmi | OOL-1371 | Debitage | Surface | | 1.3 1.3 1.3 1.4 1.4 1.4 | 1.4 | AD 1385 |
| 22 | PM-28 | Pingulmi | OOL-1371 | Debitage | Surface | | 1.8 1.9 1.9 1.9 1.9 2.0 | 1.9 | AD 1385 |
| 23 | PM-29 | Pingulmi | OOL-1371 | Debitage | Surface | | 4.4 4.4 4.5 4.5 4.6 4.6 | 4.5 | AD 1385 |
| 24 | PM-30 | Pingulmi | OOL-1371 | Debitage | Surface | | 1.4 1.4 1.4 1.4 1.4 1.5 | 1.4 | AD 1385 |
| 5 | PM-8 | Campana | OOL-1371 | Debitage | 3 | | | NVB | AD 1510 |
| 6 | PM-9 | Campana | OOL-1371 | Debitage | 3 | | 1.2 1.3 1.3 1.3 1.4 1.4 | 1.3 | AD 1510 |
| 7 | PM-10 | Campana | OOL-1371 | Debitage | 3 | | 1.2 1.2 1.2 1.2 1.2 1.2 | 1.2 | AD 1510 |
| 8 | PM-11 | Campana | OOL-1371 | Debitage | 3 | | 3.6 3.6 3.6 3.7 3.7 3.7 | 3.7 | AD 1510 |
| 9 | PM-12 | Campana | OOL-1371 | Debitage | 1 | | 2.9 2.9 3.0 3.0 3.0 3.1 | 3.0 | AD 1510 |
| 10 | PM-13 | Campana | OOL-1371 | Debitage | 1 | | 1.2 1.2 1.2 1.2 1.3 1.3 | 1.2 | AD 1510 |
| 11 | PM-14 | Campana | OOL-1371 | Debitage | 2 | | | NVB | AD 1510 |
| 12 | PM-15 | Campana | OOL-1371 | Debitage | 2 | | 1.2 1.3 1.3 1.3 1.3 1.3 | 1.3 | AD 1510 |
| 38 | PM-61 | Quitoloma | OOL-1371 | Debitage | 5 | | 1.6 1.6 1.7 1.7 1.7 1.8 | 1.7 | AD 1510 |
| 39 | PM-62 | Quitoloma | OOL-1371 | Debitage | 5 | | 2.8 2.8 2.8 2.9 3.0 3.0 | 2.9 | AD 1510 |
| 40 | PM-65 | Quitoloma | OOL-1371 | Debitage | 4 | Weathered | 2.0 2.1 2.2 2.2 2.2 2.3 | 2.2 | AD 1510 |
| 41 | PM-66 | Quitoloma | OOL-1371 | Debitage | 4 | | 1.1 1.2 1.2 1.2 1.2 1.2 | 1.2 | AD 1510 |
| 42 | PM-69 | Quitoloma | OOL-1371 | Debitage | 3 | | 2.4 2.4 2.4 2.4 2.5 2.5 | 2.4 | AD 1510 |
| 43 | PM-74 | Quitoloma | OOL-1371 | Debitage | 4 | | 1.1 1.1 1.1 1.1 1.1 1.1 | 1.1 | AD 1510 |
| 44 | PM-75 | Quitoloma | OOL-1371 | Debitage | 5 | | 1.1 1.1 1.1 1.2 1.2 1.2 | 1.2 | AD 1510 |
| 45 | PM-76 | Quitoloma | OOL-1371 | Debitage | 6 | | 1.1 1.2 1.2 1.2 1.2 1.3 | 1.2 | AD 1510 |
| 46 | PM-77 | Quitoloma | OOL-1371 | Debitage | 1 | | 1.0 1.0 1.0 1.0 1.1 1.1 | 1.0 | AD 1510 |
| 47 | PM-79 | Quitoloma | OOL-1371 | Debitage | 1 | Weathered | | DH | AD 1510 |
| 48.1 | PM-80 | Quitoloma | OOL-1371 | Debitage | 1 | Band 1 | 1.1 1.1 1.2 1.2 1.2 1.2 | 1.2 | AD 1510 |
| 48.2 | PM-80 | Quitoloma | OOL-1371 | Debitage | 1 | Band 2; weathered | 1.5 1.5 1.5 1.6 1.6 1.6 | 1.6 | AD 1510 |
| 48.3 | PM-80 | Quitoloma | OOL-1371 | Debitage | 1 | Band 3 | Approx. 12.0 | VW | AD 1510 |
| 49 | PM-86 | Guachala | OOL-1371 | Debitage | 5 | Weathered | | VW | AD 1580 |
| 50 | PM-87 | Guachala | OOL-1371 | Debitage | 5 | | 2.1 2.1 2.2 2.2 2.2 2.2 | 2.2 | AD 1580 |
| 51 | PM-88 | Guachala | OOL-1371 | Debitage | 5 | Weathered | 1.8 1.9 1.9 2.0 2.1 2.1 | 2.0 | AD 1580 |

I then plotted the mean hydration band measurements for each sample and the mean estimated occupation date for the site associated with the respective sample based on the order of sites listed in Table 2. Chart 1 illustrates the respective estimated occupation dates for the forty-two samples and the total forty-six hydration band measurements. The estimated occupation start and end dates are plotted as the top green and bottom purple plot lines and are aligned with the mean hydration band measurements plotted as red bars for the samples that correspond to the estimated site timelines.




The chart illustrates plots for the hydration band measurements for the samples across all estimated site dates to be used as a simple reference of the mean hydration band measurements across all sites and their respective estimated site dates. For example, the first sample plot is for Oroloma Lab # 25 that had a mean band measurement of 1.1 microns, and which corresponds to an estimated occupation date of AD 700-1180. Since my hypothesis is that obsidian hydration dating could provide acceptable relative dating estimates for the tested obsidian samples collected from specific Inka and local Cayambe sites, I then compared the mean hydration band measurements across all sites and their estimated occupation dates to assess if there were any observed trends based on the hydration band measurements alone. Considering my hypothesis, if the samples tested are associated with artifacts used during the estimated Inka occupation dates, could we expect to observe higher hydration band measurements with samples from the Oroloma, Pukarito, and Pingulmi sites versus the Campana, Quitoloma, and Guachala sites? The hydration band measurements of the samples plotted against the associated estimated occupation dates demonstrate the thickest hydration bands for three of the samples; sample 7 (Lab # 30.2, Band 2 measurement), sample 14 (Lab # 1), and sample 18 (Lab # 4.2, Band 2 measurement). My assumption is that the Band 2 measurements for samples Lab # 30.2 and Lab # 1 are valid measurements, even though they represent second band measurements from the same sample. Although this could be associated with damage or the reworking of the obsidian, these band measurements were considered in my analysis. From these data plots in Chart 1, I observed that hydration band measurements from several of the samples from Pukarito, Pingulmi, Campana, and Quitoloma were found to have thicker hydration band measurements compared to other samples from Quitoloma and Guachala. Although some of the samples from Oroloma were found to have hydration band measurements similar to some of the Quitoloma and Guachala site samples, there does appear to be a correlation between the samples with the thickest band measurements and the sites associated with the older estimated occupation dates. This is reflected in the peaks in the sample plots in Chart 1 that depict hydration band measurements.

To further assess the hydration band measurements for the samples across the six Pambamarca sites, I examined the number of evaluable samples, range of hydration band measurements, and mean band measurements plotted in Chart 1, to identify any observations across the six sites that could impact the analysis of findings across and within the six sites. Table 3 illustrates a wide range in the number of samples across the six sites that provided evaluable hydration band measurements; from two samples from Guachala to thirteen evaluable samples from Oroloma. There was also a wide range of band measurements within the sites, with the most variance in measurements observed with the earlier sites; Oroloma, Pukarito, and Pingulmi.

**Table 3. Comparison of Sample Size and Band Measurements Across the Six Pambamarca Sites**

| Site | # Evaluable Samples with Band Measurements | Range of Band Measurements (Microns) | Range of Mean Band Measurements (Microns) | Est. Site Occupation Date |
|---|---|---|---|---|
| Oroloma | 13 | 1.1 to 5.2 | 1.1 to 5.1 | AD 700-1180 |
| Pukarito | 5 | 1.2 to 7.6 | 1.2 to 7.5 | AD 1250-1520 |
| Pingulmi | 9 | 1.2 to 4.6 | 1.2 to 4.5 | AD 1250-1520 |
| Campana | 6 | 1.2 to 3.7 | 1.2 to 3.7 | AD 1500-1520 |
| Quitoloma | 11 | 1.0 to 3.0 | 1.0 to 2.9 | AD 1500-1520 |
| Guachala | 2 | 1.8 to 2.2 | 2.0 to 2.2 | AD 1580 |

Based on the measurement recorded in Table 3, I was able to observe a correlation of thicker hydration band measurements with earlier estimated occupation timelines, as the mean hydration band measurements are thicker for many of the samples from the older sites. However, it should be noted that there was also a variance in band measurements within the respective sites. For example, some of the samples that were evaluated produced two evaluable band measurements. Across the sites, there was also a significant variance with respect to surface collection versus excavation, and the level for the sample. A case in point is the fact that there were thirteen Oroloma samples tested, including two samples that had two bands. The majority of the Oroloma samples were obtained from excavation levels 2 to 3. Comparatively, there were only five Pukarito samples tested, one with two bands, one of which had a relative high mean hydration band measurement of 7.5 microns that was from level 6, and one that was obtained from the surface that had a high mean hydration band measurement of 7.1 microns. Also, all of the nine evaluable Pingulmi samples were obtained by surface collection, with two of the evaluable samples being weathered. This difference in sample size compared between the Pukarito samples and the Oroloma and Pingulmi samples could be a factor in the relatively high hydration band measurement for the Pukarito samples. Additionally, given that Pukarito has a long occupation (AD 1250-1520), it should be considered that the occupation could have been longer since two of the four Pukarito samples had band thickness measurements of 7.1 to 7.5 microns. The 7.1-micron measurement was from a surface collected sample. The higher temperature of the surface artifact could have resulted in an increased hydration rate and a thicker band compared to two of the other Pukarito samples. The six Campana samples tested were excavated from an excavation level of 1 to 3. Whereas there were eleven Quitoloma samples tested that were excavated from a level of 1 to 6, with one of the samples being weathered and presenting two bands and another sample being weathered. Of note is the fact that there were only two evaluable Guachala samples, one which was weathered and both which were obtained from an excavation level of 5.

To further assess possible reasons why the mean hydration band measurements varied with obsidian samples across the six sites, I examined the data for each of the six sites to potentially explain differences in hydration band measurements due to stratigraphic and elevation considerations for the site location of the samples. This is important to assess any factors that could possibly contribute to the measurements that were verified by the laboratory analysis.

II. Analysis of Oroloma Samples (Early Cayambe Site)

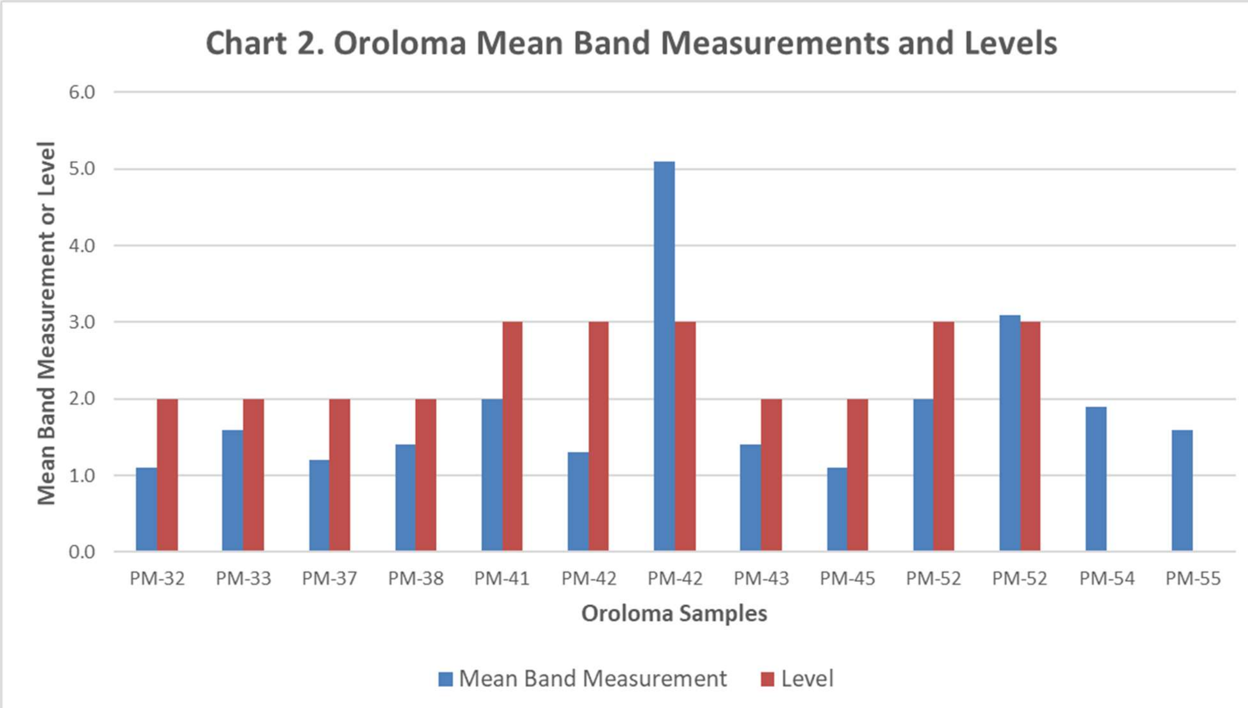
<u>Initial Assumptions</u>:

Given the estimated occupation date for the Oroloma site, AD 700-1180, it was expected that the hydration layers for the samples should be the thickest of all the samples across the six sites. It was also considered that there could be some overlap with the samples from the Late Cayambe sites, but there should be no overlap with the Inka site samples due to the roughly 320-year separation in occupation timelines. If there are unanticipated deviations in hydration layer thickness for the Oroloma samples, various implications would need to be assessed. For example, Oroloma is at a slightly higher elevation, 3200 m, versus the 3000 m elevation for the two Late Cayambe sites and this could affect the hydration rate for the samples. The Oroloma samples were also obtained by excavation and surface collection which could impact the relative dating since they are likely exposed to a higher temperature and different moisture content than buried samples. Surface obsidian has a higher hydration rate than buried artifacts primarily due to the higher temperature.

Analysis:

There were thirteen samples from Oroloma that provided hydration band measurement that ranged from 1.1 to 5.2 microns. The excavation level ranged from level 2 to 3 for the evaluable samples from excavations. There were also two samples that provided two bands; sample PM-42 provided a mean band 1 measurement of 1.3 microns and a band 2 measurement of 5.1 microns. Sample PM-52 provided a mean band 1 measurement of 2.0 microns and a band 2 measurement of 3.1 microns. The site elevation is 3200 m.

For Oroloma, I compared each of the eleven samples that were associated with a hydration band measurement and stratigraphic depth level, as illustrated in Chart 3.




The depth levels varied from level 2 to level 3 and there is some correlation between a thicker band measurement and depth level 3 with 4 of the five samples obtained from level 3.

<u>Research Findings and Discussion</u>:

The research findings demonstrated a range in mean hydration band measurements of 1.1 to 2.0 for the nine samples that provided single band measurements. This did not correlate with my initial assumptions that the Oroloma samples would have the thickest hydration bands. The eleven Oroloma samples tested included two samples that had two bands that did correlate with thicker band measurements of 3.1 to 5.1 microns, but these were associated with second band measurements from the two samples. The majority of the Oroloma samples were obtained from an excavation level depth of 2 to 3 as six samples were obtained from level 2 and five from level 3. There was a correlation of a thicker hydration band with the samples from level 3 in four of the five samples collected at level 3. Comparatively, there were only five Pukarito samples tested, one with two bands, one of which had a relative high mean hydration band measurement of 7.5 microns, and one that was obtained from the surface that had a high mean hydration band measurement of 7.1 microns. With the exception of the one surface collected Pukarito sample that had a mean band measurement of 7.1 microns and the second Pukarito sample that had a band 2 measurement of 7.5 microns, the Pukarito mean band measurements were similar to six of the Oroloma samples. Seven of the Oroloma samples had thicker band measurements than the Pukarito samples. There was also an observed overlap in hydration band measurements between individual samples from Oroloma, Pukarito, and Pingulmi sites, which is expected given the narrow 450-year difference between mean occupation timelines between the Oroloma and Pukarito and Pingulmi sites.

III. Analysis of Pukarito Samples (Late Cayambe Site)

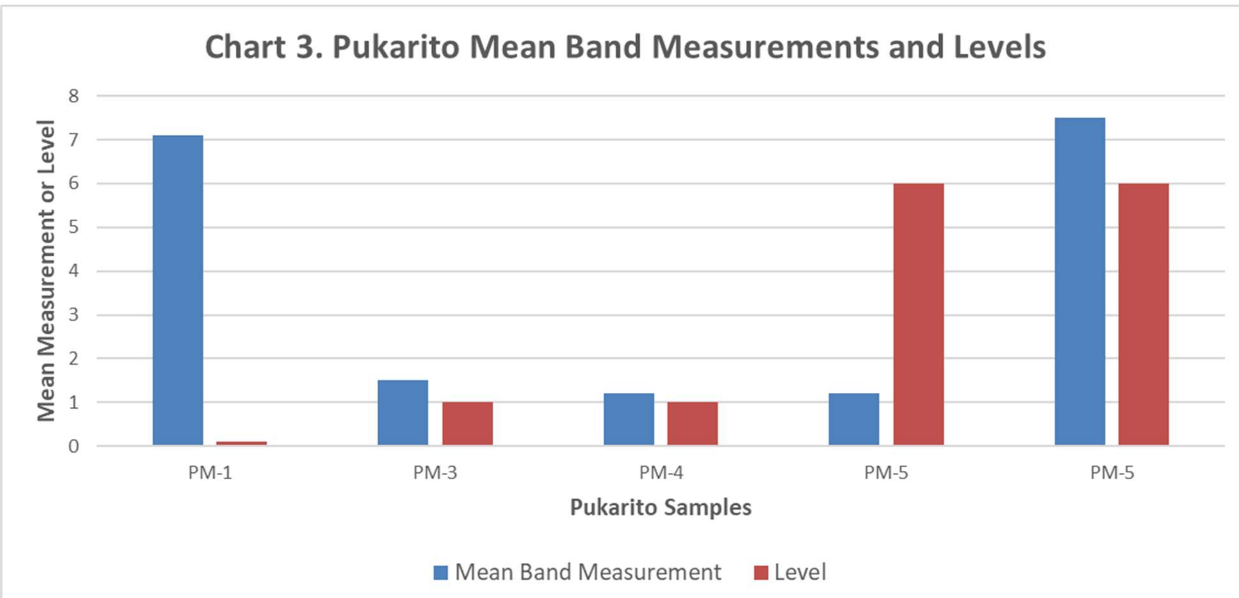
Initial Assumptions:

The Pukarito estimated occupation dates of AD 1250-1520 overlap the estimated occupation dates of the Inka sites, although Pukarito's occupation date exceeded that of the Inka sites by 250 years. It was expected that the hydration layers for the Pukarito samples may have some differences, given the more expanded occupation timeline; however, there should be an overlap with the samples associated with the Inka sites. It was expected that some Pingulmi and Pukarito samples will have thicker hydration layers than those from the Inka sites and that they should not have thinner layers than those sites. There could be deviations in the hydration layer thickness for the Pingulmi samples since they are associated with a lower elevation (3000 m) and were surface collected versus excavated. These factors have been shown to affect the process of hydration and may impact the dating results.

Analysis:

There were four samples from Pukarito that provided mean hydration band measurements that ranged from 1.2 to 7.5 microns, including sample PM-5 that contained a band 2 measurement of 7.5 microns. One obsidian sample was obtained from surface level, two from depth level 1, and two from level 6. The site elevation is roughly 3000 m, slightly below the Oroloma site elevation.

For Pukarito, I compared each of the four samples that were associated with a hydration band measurement and stratigraphic depth level, as illustrated in Chart 4.




Two of the five Pukarito samples had mean band measurements of 7.1 to 7.5 microns which suggests that they could be obsidian from an earlier occupation timeline compared to the other three samples that had mean band measurements of 1.2 to 1.5 microns. The one surface collected sample, PM-1, had a mean band thickness of 7.1 microns, suggesting that is associated with an earlier date than samples PM-3 and PM-4. Sample PM-5 had a band 2 measurement of 7.5 and a depth level of 6. This possibly could suggest that some of the obsidian was churned or mixed at this site; however, the Pukarito sample size is small and would preclude any absolute determinations from this analysis.

Research Findings and Discussion:

There were only five Pukarito samples tested, one with two bands, one of which had a relative high mean hydration band measurement of 7.5 microns, and one surface collected sample, PM-1, that had a high mean hydration band measurement of 7.1 microns. The Pukarito site has an elevation of approximately 3000 m. There was a wide range of hydration band measurements from 1.2 to 7.5 microns. The wide range of hydration band measurements, including the surface collected sample PM-1, could possibly be due to obsidian being churned or mixed. There was a narrower range in hydration band measurements of 1.2 to 4.5 microns compared to the Pukarito samples. Five of the nine Pingulmi samples had a band measurement of 3 microns or greater. This could possibly be influenced by a faster hydration rate at the lower altitude. Several of the Pukarito and Pingulmi samples exhibited overlap in hydration band measurements. Factors that may impact the difference in mean hydration band measurements for the samples from the Pukarito and Pingulmi sites could be 1) that the Pingulmi samples were surface collected at a relatively low elevation level, 2) the relatively small sample size of the Pukarito samples, and 3) the fact that two of the Pukarito samples were obtained at an excavation level of 6 versus the 3000 m elevation of the surface collected Pingulmi samples. Lastly, for the samples with the thicker band measurements, there exists the possibility that the dates of occupation could actually be longer than the current estimated dates.

IV. Analysis of Pingulmi Samples (Late Cayambe Site)

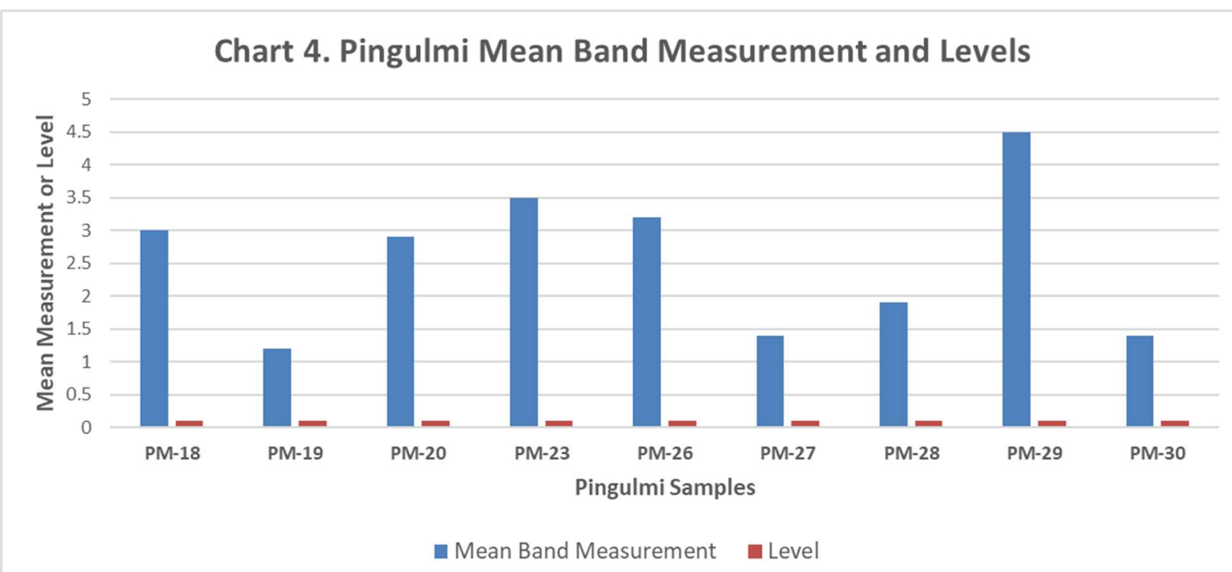
Initial Assumptions:

As with Pukarito, the Pingulmi estimated occupation dates of AD 1250-1520 overlap the estimated occupation dates of the Inka sites. It was also expected that the hydration layers for the

Pingulmi samples may have some differences but should overlap with the band measurements of the Pukarito and Inka site samples. Some of the Pingulmi and Pukarito samples were expected to have thicker hydration layers than those from the Inka sites and not have thinner layers than those sites. It was also expected that there could be deviations in the hydration layer thickness for the Pingulmi samples since they are associated with a lower elevation (3000 m) and were surface collected versus excavated. These factors are known to affect the process of hydration and may impact the dating results.

Analysis:

There were nine samples from Pingulmi that provided mean hydration band measurements that ranged from 1.2 to 4.5 microns. All nine obsidian samples were surface collected. The site elevation is roughly 2700 m, about 300 meters below the Pukarito site elevation which is associated with the same occupation date. For Pingulmi, I compared each of the nine samples that were associated with a hydration band measurement and the same surface level, as illustrated in Chart 5.



Five of the nine samples had band thickness measurements of roughly 3 microns or greater, with sample PM-29 having a band measurement of 4.5 microns. As with Pukarito, there were band measurements with some samples within a 1-to-2-micron thickness. However, five of the nine samples demonstrated a layer thickness of approximately 3 microns or greater. My analysis considers the fact that lower elevations result in a faster hydration rate. Since the Pingulmi site sits roughly 300 m lower than the Pukarito site, and since both are associated with the same estimated occupation date, the five samples with layer thickness measurements of 3 microns or greater could possibly be associated with a hydration rate was slightly faster compared to the that of the Pukarito samples. Unfortunately, my analysis is unable to explore this possibility due to the limited number of Pukarito samples.

Research Findings and Discussion:

There were nine Pingulmi samples that were obtained by surface collection, with two of the evaluable samples being weathered. The Pingulmi site had a lower elevation level of roughly 2700 m. There was a narrower range in hydration band measurements of 1.2 to 4.5 microns compared to the Pukarito samples. Five of the nine Pingulmi samples had a band measurement of 3 microns or greater which could possibly be influenced by the faster hydration rate at the lower altitude. Several of the Pingulmi and Pukarito samples were found to have overlapping hydration band measurements. Some factors that could explain the difference in mean hydration band measurements for the Pingulmi and Pukarito samples could be 1) that the Pingulmi samples were surface collected at a relatively low elevation level, 2) the larger sample size of the Pingulmi versus Pukarito samples, and 3) the lower 2700 m elevation of the Pingulmi site and the fact that all of the Pingulmi samples were surface collected.

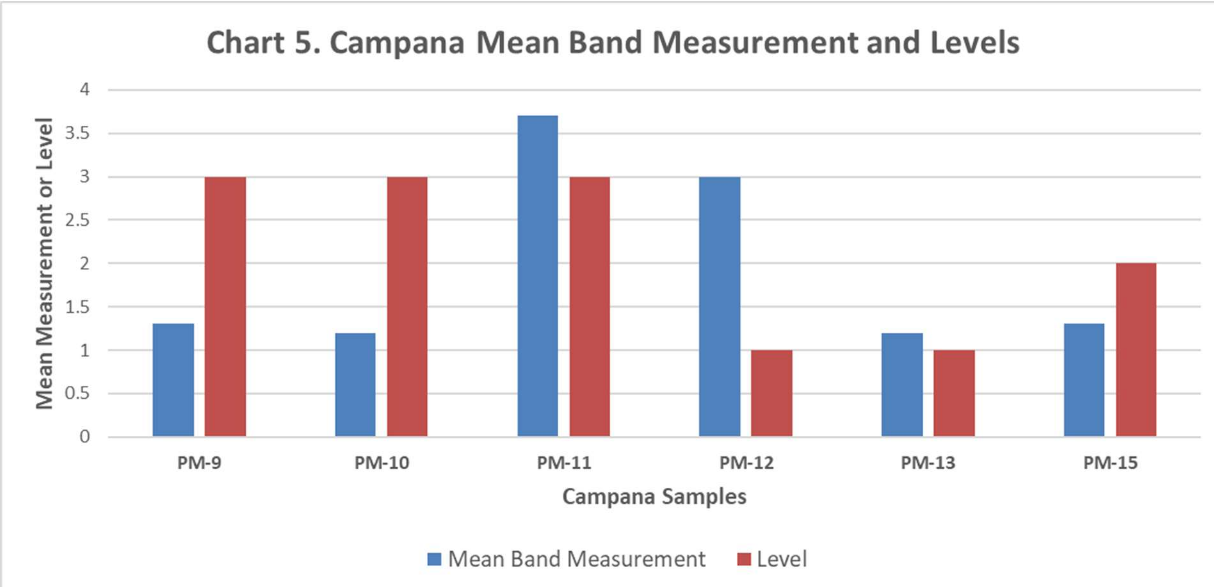
V. Analysis of Campana Samples (Inka Site)

Initial Assumptions:

Given that the Campana and Quitoloma Inka sites were occupied during the same time period, AD 1500-1520, the hydration layers for the tested samples were expected be about the same thickness. The hydration rims of the Quitoloma samples were expected to be around the same thickness as the thinnest rims of Campana Pucara. If the hydration dating were to find a range of thicknesses across the samples, then possible implications could be that there was a more expanded occupation timeline or there were different hydration rates. This was considered by selecting all Mullumica source obsidian samples.

Analysis:

There were six samples from Campana that provided mean hydration band measurements that ranged from 1.2 to 3.7 microns. The depth level ranged from 1 to 3 with three of the six samples having a depth level of 3. The site elevation is roughly 3300 m, about 300 meters above the Pukarito site elevation. For Campana, I compared each of the six samples that were associated with a hydration band measurement and the range of surface levels, as illustrated in Chart 6.




Two of the six samples had band thickness measurements of 3.0 to 3.7 microns, with four of the samples having a narrow range from 1.2 to 1.3 microns. It is noted that there appears to be no correlation between the depth level and the band thickness, although two of the samples, PM-9 and PM-10 had depth levels of 3 and similar band thicknesses ranging from 1.3 to 1.2 microns, respectively. Compared to the sites with earlier estimated occupation dates, the Campana samples did not have the thicker bands found with the earlier sites as the thickest band was 3.7 microns.

<u>Research Findings and Discussion</u>:

The six Campana samples tested were excavated from levels 1 to 3. For the Campana samples, there was no correlation between the hydration band thickness and the depth levels for the samples. For the Quitoloma samples, there was minimal correlation with depth level and the band thickness of the samples. There were thinner bands observed for the Quitoloma samples compared to the late Cayambe sites, Pukarito and Pingulmi. This difference could be attributed to the difference in sample sizes and excavation depths between the two sites. Also, Quitoloma is at a higher elevation of roughly 3600 m compared to Campana at 3300 m. This could possibly be a factor in the thinner hydration band measurements for the Quitoloma samples compared to the Campana samples, as the hydration rate would be expected to be faster at the lower Campana elevation. Both Quitoloma and Campana demonstrate thinner hydration band measurements compared to hydration band measurements from samples from the earlier Pukarito and Pingulmi sites.

VI. Analysis of Quitoloma Samples (Inka Site)

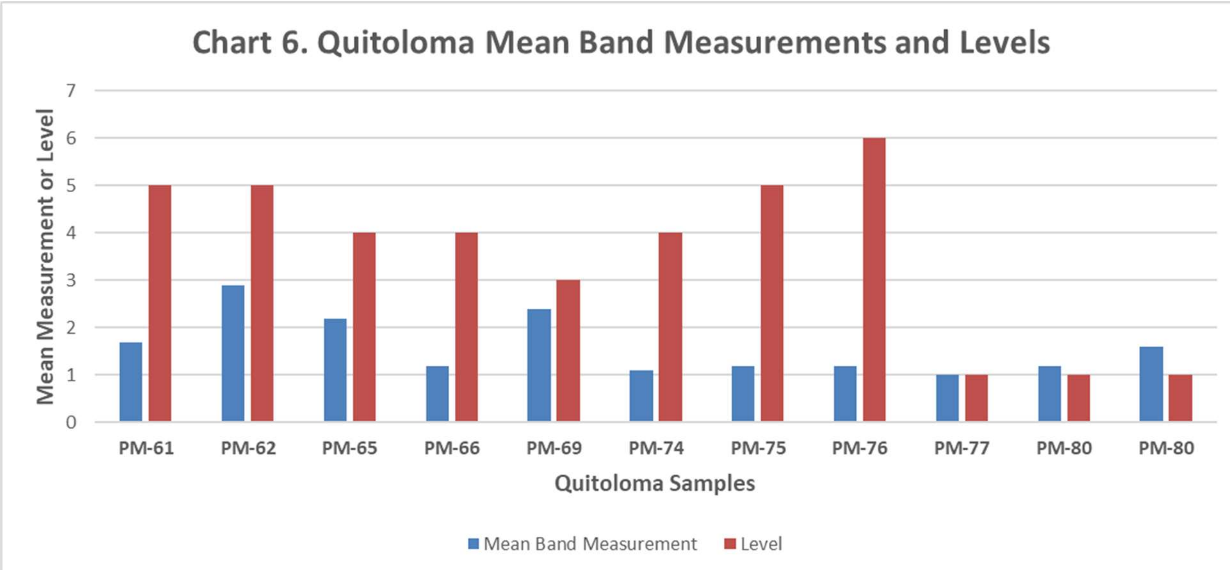
Initial Assumptions:

The hydration rims of the Quitoloma samples should be around the same thickness as the thinnest rims of Campana Pucara. If the hydration dating were to determine a range of thicknesses across the samples from Quitoloma and Campana, then possible implications could be that there was a more expanded occupation timeline. There could be other factors that could be relevant to differences in the hydration band measurements for the samples from both Inka sites, including the relative sample size, elevation differences, and collection level depths.

Analysis:

There were ten samples from Quitoloma that provided mean hydration band measurements that ranged from 1.0 to 2.9 microns, and an additional sample that provided two band measurements or 1.2 and 1.6 microns, respectively. The depth level ranged fairly uniformly across the eleven samples from 1 to 6. The site elevation is roughly 3600 m, about 300 meters above the Campana site and roughly 600 meters above the Pukarito site elevation.

For Quitoloma, I compared each of the ten samples that were associated with a hydration band measurement and the range of surface levels, as illustrated in Chart 7.




The Quitoloma samples had a rather narrow range of band thickness measurements of 1.0 to 2.9 microns, with eight of the samples having a narrow range from 1.0 to 1.7 microns even though the depth levels ranged from 1 to 6. There appears to be minimal correlation between the depth level and the band thickness, although two of the samples, PM-77 and PM-80 had depth levels of 1 and similar band thicknesses ranging from 1.0 to 1.2 microns, respectively. Compared to the sites with earlier estimated occupation dates, including Campana, the Quitoloma samples demonstrate thinner bands with none of the thicknesses exceeding 2.9 microns. This is important given that there were a larger number of samples from Quitoloma (ten samples) compared to the other five sites.

<u>Research Findings and Discussion</u>:

There were eleven Quitoloma samples tested that were excavated from a level of 1 to 6, with one of the samples being weathered and presenting two bands and another sample being weathered. For the Quitoloma samples, there was minimal correlation with depth level and the band thickness of the samples. There were thinner bands observed for the Quitoloma samples compared to the late Cayambe sites, Pukarito and Pingulmi. The hydration rims of the Quitoloma samples were predicted be around the same thickness as the thinnest rims of Campana Pucara. The results found that six of the eleven Quitoloma band measurements were roughly the same thickness as the thinnest hydration bands of the Campana samples; 1.2 to 1.3 microns. Additionally, the thickest two hydration bands for the Quitoloma samples were 2.4 and 2.9 microns, whereas the two thickest bands for the Campana samples were 3.0 and 3.7 microns. As stated in the original assumptions, this slight difference in mean band thickness between the two sites could be attributed to the difference in sample sizes and excavation depths between the two sites. Quitoloma is also at a higher elevation of roughly 3600 m compared to Campana at 3300 m. This could possibly be a factor in the thinner hydration band measurements for the Quitoloma samples compared to the Campana samples, as the hydration rate would be expected to be faster at the lower Campana elevation. Additionally, both sites have relatively narrow bands, but the thicker bands for some of the Quitoloma and Campana samples could suggest earlier occupation dates or possibly the scavenging of obsidian from older sites.

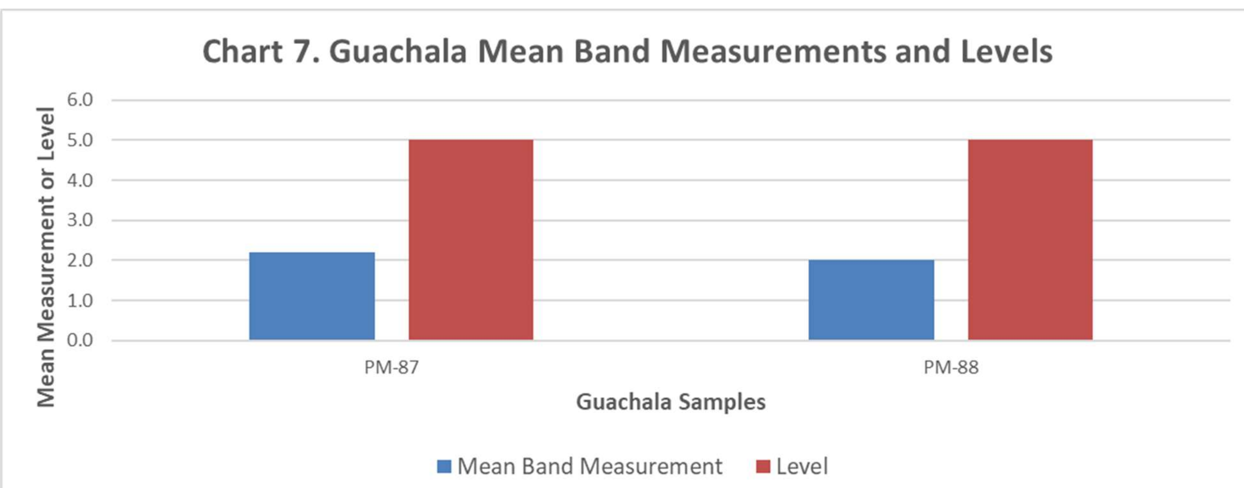
VII. Analysis of Hacienda Guachala Samples (Colonial Site)

<u>Initial Assumptions</u>:

Due to the estimated occupation date for this site beginning in AD 1580, it was expected that the Guachala samples would possibly have the thinnest hydration layers of all tested samples. Since the Guachala site is closest to the Inka sites and represents an occupation date that is only 60 years after the end of the Inka occupation of the Pambamarca forts, there exists the possibility that relative dating could be close to that of the Inka site samples. Since this site was known to have native laborers at the site, it is expected that the excavated flaked samples would provide dating congruent with the post AD 1580 occupation. Furthermore, it was expected that the relative dating of the Guachala samples would differ the most from the Oroloma samples, in view of the 400-880-year difference between the respective occupation dates. Very importantly, there were thinner bands observed for the Quitoloma samples compared to the late Cayambe sites, Pukarito and Pingulmi, which conforms to my original hypothesis and questions regarding possible differences in rim thickness that would be confirmed by obsidian hydration dating with samples across the six sites.

Analysis:

There were two suitable obsidian samples from Guachala that provided mean hydration band measurements that ranged from 2.0 to 2.2 microns. The depth level for both samples was 5. The site elevation is slightly over 3100 m. One of the two evaluable samples was weathered. For Guachala, the number of samples is very small, although the mean hydration bands are somewhat similar to Campana and Quitoloma. For Guachala, I compared the two samples that were associated with a hydration band measurement and the range of surface levels, as illustrated in Chart 8.




Research Findings and Discussion:

The Guachala samples correlated closely with the estimated occupation dates of Campana and Quitoloma. The two samples were collected at a depth of level 5 at a site elevation of approximately 3100 m. This aligns with my initial assumptions given that there would be similar hydration band measurements to the Quitoloma and Campana samples since there is only a 70-year difference in the estimated occupation dates between the Guachala and the Quitoloma and Campana sites. Although there were only two evaluable Guachala samples, there were similarities across the samples from the three sites in terms of excavation level depths. Although the Guachala samples had slightly thicker bands than Quitoloma and Campana, there are several possible factors that could have impacted this difference. First, the lower elevation could have resulted in a faster hydration rate for the Guachala samples. Rodriguez (2010:52) points out that "Hacienda Guachala is located at a lower altitude than the fortresses and the climate is more temporate." Guachala's location and climate may suggest that the obsidian layers would hydrate quicker and would also explain why they are thicker than the thin layers seen at Quitoloma and Campana. It is also possible that there could have been an earlier occupation that occurred at the site. It is also a possibility that the obsidian collected at Guachala could have been older obsidian flakes that were obtained from some other site.

# CHAPTER 9: CONCLUSION

The first phase of my analysis examined hydration band measurements across all sites to identify any key observations or trends with implications for occupation dates. This analysis found that there were thicker hydration bands on samples from the Pukarito, Pingulmi, Campana, and some of the Quitoloma and Guachala artifacts which suggested earlier occupation dates. With respect to the range of mean hydration band measurements, there is a trend observed of a narrower range of mean measurements and a declining upper mean hydration band thickness within each site range starting with the Pukarito site samples and continuing to the Quitoloma site samples, as illustrated in Chart 2. There is also a trend observed with a decline in actual hydration band measurements across all sites from Pukarito to Quitoloma, as evidenced in Chart 1. This is an interesting data trend in that mean hydration band measurements declined and the range of mean band thicknesses narrowed across the sites as the estimated site occupation dates transitioned to younger occupation dates.

The next phases of my research focused on examining similarities and differences in hydration band measurements with samples from each site, while comparing other variables such as relative sample size, method of collection, stratigraphic depth level of the collected samples, and elevation level of the site. Recognizing the challenges of applying obsidian hydration methodology to the narrow range of estimated occupation dates associated with these sites within the Pambamarca region, my initial assumptions allowed for the possibility that the hydration band measurements could be limited or irrelevant in terms of accuracy. With respect to applying these research findings across all sites, this is particularly relevant given that the difference in mean estimated occupation dates varied by only 640 years from the oldest site, Oroloma to the youngest site, Guachala.

In my analysis of hydration band measurements for the six Pambamarca sites, there were several interesting findings. For the Oroloma site, there was a correlation of a thicker hydration band with the samples in four of the five samples collected at level 3, as two had significant band thicknesses and seven were thicker than any from Pukarito. This suggests that there is evidence from the obsidian hydration dating technique to suggest that some of the samples were associated with the assumed AD 700-1180 occupation date of Oroloma. The higher elevation and the level 2-3 depth could have resulted in a slower hydration rate, and this could explain some of the thinner hydration bands compared to Pukarito while allowing for an earlier occupation date. Recognizing the lower elevation and the depth level of the samples at Pukarito, two of the five samples from that site had thicker bands, which could suggest an earlier occupation timeline than AD 1250-1520. The Pingulmi samples demonstrated a narrower range of hydration band measurements compared to the Pukarito samples. Although more than half of the Pukarito samples had relatively thick bands compared to Pingulmi, the lower elevation of the Pingulmi site could have resulted in an accelerated hydration rate leading to thicker bands. This difference in elevation and band thickness between the sites could support an occupation timeline for Pingulmi that is similar to that of Pukarito, AD 1250-1520. Compared to the earlier sites, Campana and Quitoloma demonstrated thinner hydration bands, and when considering differences in sample size, elevation, and excavation depths, most of the samples suggest a later occupation date for both sites that correspond to the estimated date of AD 1500-1520. The fact that the Guachala and Quitoloma samples were found to have similar mean hydration band measurements supports an occupation timeline for Guachala of AD 1580, although the thicker bands on samples at Guachala might indicate instead the reuse of obsidian from older occupation sites.

With respect to my initial hypothesis and critical questions, this evidence supports the possibility that some of the samples from the Inka sites may have been associated with earlier occupation dates. However, the majority of hydration band measurements for the two Inka site samples demonstrate thinner hydration bands compared to the Pukarito and Pingulmi sites which suggests a correlation with an occupation date during the time of the Inka incursion. Also, the relative occupation dates indicated by the obsidian hydration results for the majority of the Pukarito, Pingulmi, Campana, Quitoloma, and Quachala samples do match in terms of relative hydration band measurements, and therefore confirm, the relative dates for the sites as determined by ceramic styles. Regarding whether or not the occupation timelines of the Inka and Cayambe sites could be longer or shorter than currently thought, there is not enough data to answer this question due to the small sample sizes. Overall, thicker hydration band measurements were observed with samples from sites associated with earlier estimated occupation timelines, as the mean hydration band measurements are thinner for the Pukarito, Pingulmi, and Campana samples.

My primary objective was to determine if obsidian hydration dating could be shown to be a viable relative dating methodology with samples associated with Pambamarca archaeological research. Based on my research findings, I did observe correlations of mean sample hydration band measurements with estimated occupation dates associated with the six Pambamarca sites. The overlap in hydration band measurements across samples from similar occupation timelines was an important finding. The fact that five or six sites demonstrated a continual decline in hydration band measurements when moving from older to younger sites provides a basis for an initial proof of concept for this dating technique with Pambamarca obsidian. My research findings support further research with this dating technique with future Pambamarca archaeological initiatives to assess the utility of this dating method at these sites and elsewhere in Ecuador.

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