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Obsidian hydration at high elevation: Archaic quarrying at the Chivay source, southern Peru

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ABSTRACT

We examine obsidian hydration as a means to date archaeological sites at high elevation in the central Andes, and in particular quarry sites that are difficult to date by radiocarbon means. The Chivay obsidian source lies in a volcanic depression above the Colca Valley in Arequipa, Peru (71.5355° S, 15.6423° E) at 4950 masl. We compare obsidian hydration readings from one quarry and two workshop locations. Ninety-one flakes from the quarry pit, and 61 and 33 flakes from the workshops were analyzed for hydration bands. Of these, 68 from the quarry, and 54 and 33, respectively from the workshops produced at least one culturally meaningful hydration band. As expected, obsidian appears to hydrate slowly at this high elevation. Yet, variation in hydration readings is low within stratigraphic contexts, suggesting relatively narrow windows of knapping activities in each excavation level. A small number of radiocarbon dates allow us to develop a preliminary hydration rate for Chivay obsidian in this high elevation location. Hydration data indicate that intensive quarrying began by 3800 cal. BC and stopped ca. 2300 cal. BC. By contrast, the two workshops appear to have been deposited 2900 and 1200 cal. BC, and 2700 and 2400 cal. BC. The data are consistent with an uptick in obsidian use by at least the Terminal Archaic period.

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1. Introduction

Stone quarries present particular challenges for archaeologists documenting temporal sequences. Radiocarbon dating is often precluded by an absence of datable organic materials. In addition, the overwhelming presence of early stage reduction debris at most quarrying sites means that diagnostic projectile points and other artifacts commonly used as chronological or cultural markers may be scarce.

For obsidian quarrying, however, obsidian hydration dating (OHD) can be used to date materials and construct temporal sequences. OHD can date both the timing of initial exploitation as well as diachronic changes in the intensity of exploitation. This paper describes an initial attempt to date quarrying activities at an obsidian quarry in southern Peru. Paired OHD readings and radiocarbon dates, as well as stratigraphic information, were used to examine the timing of obsidian production at a workshop where organic material was present. This information was then used to estimate the chronology at a nearby quarry, where datable

materials were absent, and at a second, more sparse and disturbed (stratigraphically mixed), workshop.

2. Background

While obsidian hydration analysis is familiar in many parts of western North America, it is still relatively uncommon in Andean archaeology (for exceptions see Bell, 1977; Bonifaz, 1985; Eerkens et al., 2008; Lynch and Stevenson, 1992; Mayer-Oakes, 1986). The reasons for this are many, but a principal cause is that many sites can be dated by a simpler method, namely, the presence of temporally-diagnostic ceramics. As well, there are concerns with the applicability of hydration analysis in high elevation contexts where diurnal temperature variation is high and seasonality is pronounced (Ridings, 1996). One way around this issue is to use OHD as a relative rather than an absolute method of dating. Yet, recent research (e.g., Liritzis, 2006; Stevenson et al., 2000), including in high elevation contexts in California (Stevens, 2005) shows that the technique still has great value as an absolute method when reasonable estimates for the Effective Hydration Temperature (EHT) can be made (Rogers, 2007, 2008).

Obsidian is found at archaeological sites throughout the Andes, but it is especially prevalent at higher elevation sites in southern

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Peru where the majority of sources are also found (Fig. 1) (Brooks et al., 1997; Burger and Asaro, 1977; Burger et al., 1998a; Burger et al., 1998b; Burger et al., 2006; Burger and Glascock, 2000; Burger et al., 2000; Craig et al., 2010; Stanish et al., 2002; Tripcevich and Contreras, 2011; Tripcevich and Mackay, 2011). The Chivay obsidian source, also referred to as the Titicaca Basin source (Burger and Asaro, 1977) and the Cotallalli source (Brooks et al., 1997), is one of the more important obsidians in the Andes. Obsidian from the source was widely transported in prehispanic times (Burger et al., 1998a; Giesso, 2003; Glascock et al., 2007; Tripcevich and Mackay, 2011). Several preceramic radiocarbon dates at a workshop test unit (Tripcevich and Mackay, 2011: 283) together with a scarcity of ceramics at the source area suggest that intensive use of the Chivay obsidian source was in place by at least the end of the Archaic period (ca. 1800 cal. BC). Concentrated obsidian production may have begun much earlier; exactly when is not yet clear. In this respect, hydration dating has the potential to provide valuable evidence unavailable through other means at this quarrying site.

The Chivay obsidian source lies at 4950 masl in a volcanic depression known locally as “Maymeja” that is part of a collapsed dome complex belonging to the Pliocene (5.3–1.8 Ma) Barroso group (Burger et al., 1998a; Klinck and Palacios, 1985; Thouret et al., 2007; Tripcevich and Mackay, 2011). While perlite and marekanites are found on deflated ridges of tuff and pumice, our pedestrian survey found the only evidence of intensive obsidian quarrying in Maymeja to be a pit referred to as Q02-2 measuring 4×5 m with a depth of 1.5 m (Fig. 2). A mound of discarded material from the quarrying occurs on the western, downslope margin of the pit and the total affected area amounts to 10×12 m.

The earliest radiocarbon-dated archaeological context with Chivay obsidian is at Asana in Moquegua (Aldenderfer, 1998: 157, 163), a site over 200 km from the source area where a few flakes were recovered immediately above a level dated to the Early Archaic at 9820–8785 cal. BC (Beta-40063; 9820 ± 150 ^{14}C yr bp). Throughout the prehispanic period, obsidian tool production in this region of the Andes was focused primarily on bifacial reduction. The functional value of obsidian is evident in the regional distribution of unmodified flakes as more informal cutting tools as well as formal projectile points, likely used in hunting or warfare.

For example, obsidian was often used to produce a type of small triangular projectile point that is recovered from sites in the region beginning approximately 3300 cal. BC (Klink and Aldenderfer, 2005) with the “Terminal Archaic” period. Temporally-diagnostic projectile points ($n = 552$) surface collected by Aldenderfer (1997) during a survey in the Ilave valley on the western side of Lake Titicaca, 200 km from the Chivay source, show that obsidian is used to produce less than 2% of the projectile points in earlier styles, but obsidian is used for 14% of the projectile points made in the small triangular style beginning in the Terminal Archaic (Craig, 2005: 475; Tripcevich, 2007: 201). Regional obsidian distributions show a marked increase during the Terminal Archaic and Formative Period. Two hundred km to the south of Chivay at the rockshelter of Qillqatani 10–20% of all chipped stone is obsidian, 80% being from the Chivay source (Aldenderfer, 2004; Tripcevich, 2007: 190–195). Terminal Archaic and Formative sites in the northern and central Titicaca Basin have a relative abundance of obsidian during (Burger et al., 2000; Stanish and Levine, 2011). It is clear that obsidian had symbolic or ritual value. For example, at Jiskairumoko in the Ilave valley on the western side of Lake Titicaca obsidian is found in Terminal Archaic burials around 2000 cal. BC as were status items such as a necklace strung with gold and turquoise (Aldenderfer et al., 2008; Craig, 2005: 574, 588–662; Craig et al., 2007), and circa AD700 it was disseminated into the fill of a ceremonial mound at the site of Tiwanaku (Giesso, 2003; Tripcevich, 2010: 69). Obsidian procurement and circulation may thus contribute to understanding the broad social transformations in the Andes that began at the end of the Archaic.

Evidence of knapping at the Chivay Source is found at many locations throughout the Maymeja area, particularly on rises overlooking wet grazing lands. Workshops with the highest concentrations of flaked obsidian are adjacent to sheltered, level camp locations with water nearby. One concentration of flakes substantially denser than the others is a mound of flaked obsidian denoted as A03-330 (Fig. 3). This workshop site or dump measures 3×4 m with a depth of at least 60 cm. A second workshop was located within a modern corral that is built among large colluvial boulders descended from the north margins of the Maymeja area.



Fig. 1. Regional map showing obsidian sources and archaeological sites mentioned in text.



Fig. 2. Excavating TU2 at the Q02-2 quarry pit with bofedal (grazing area) near A03-330 visible below and Nevado Ampato (6288 m) in the distance.

This workshop, denoted A03-201, or “Saylluta 2,” is littered with obsidian flakes, but at a lower density than observed at A03-330.

The quarry pit Q02-2, and both workshops were each tested with a single 1 × 1 m excavation unit to learn more about the nature of ancient quarrying and knapping activities. Obsidian hydration samples were collected from all three units to help reconstruct changes over time. In addition, radiocarbon samples were submitted from the densest workshop A03-330.

3. Methods

3.1. Excavation

The test units were excavated in natural stratigraphic levels when feasible, however the stratigraphy at the workshop and quarry was frequently indistinct and therefore arbitrary levels of 10–15 cm were also employed (for details see Tripcevich, 2007; Tripcevich and Mackay, 2011). The quarry and A03-330 workshop test units were placed near the crests of the respective mounds with the aim of finding the longest stratigraphic sequence that reflects changing use of the obsidian source.

The quarry is located at an aspect of 275° (west) and on a general incline of 8° slope. A 1 × 1 m test unit (TU2) was placed in the debris pile downslope of the actual quarry pit (Fig. 4). The unit consisted of fragments of obsidian of varying sizes in a dry perlitic matrix excavated to a depth of 85 cm in 12 stratigraphic levels (the deepest

being sterile). Natural obsidian fragments were scattered throughout the pile and for a substantial number of flakes and fragments encountered in the test unit it was difficult to determine if they were of cultural origin. To address this issue, we decided to analyze a sample of clearly cultural as well as ambiguous flakes ($n = 81$ total). We felt that the latter were likely cultural, but lacked diagnostic flake features indicative of knapping.

The small number of flakes at TU2 suggests that, despite the evidence for quarrying, little further knapping occurred here. Relative to the workshop, a much higher percentage of flakes displayed a wide secondary hydration band (i.e., in excess of 20 microns) on the dorsal surface, indicating reduction of original cortical material. As well, this unit revealed only two cores, the 81 flakes of possibly cultural origin, and two bifacially knapped artifacts. This test unit was placed in the discard pile from the quarrying in order to explore patterns in quarrying rate and discard over time but with no temporally-diagnostic artifacts to use as time markers and no datable organic material, connecting the quarrying evidence with specific time periods was elusive.

The A03-330 workshop lies over one-half kilometer downslope from the quarry pit (Fig. 3) and was tested with a 1 × 1 m unit (TU3). The unit was placed on the upper side of the flake mound and was excavated to a depth of 70 cm where moist soils were encountered (Fig. 5). In contrast to the quarry, the fill was almost entirely obsidian, with 339 cores recovered and a small number of preforms or bifaces ($n = 44$). This suggests that cores were used for blank production and

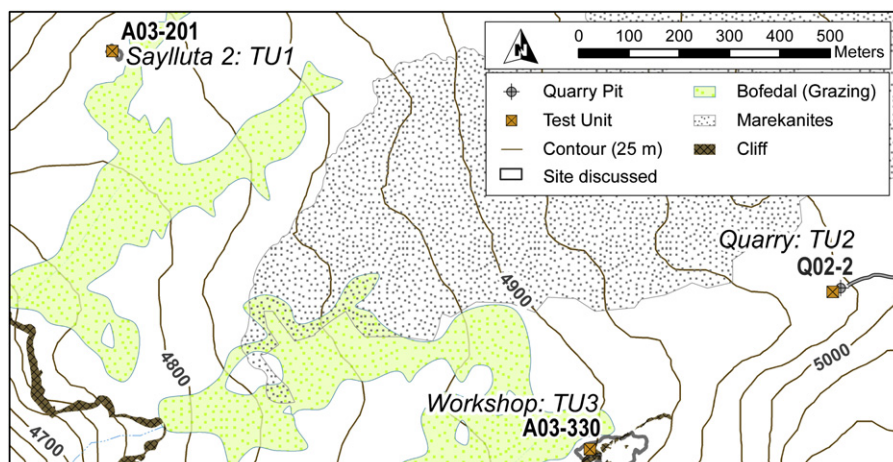


Fig. 3. Local map showing Chivay source quarry and workshops.

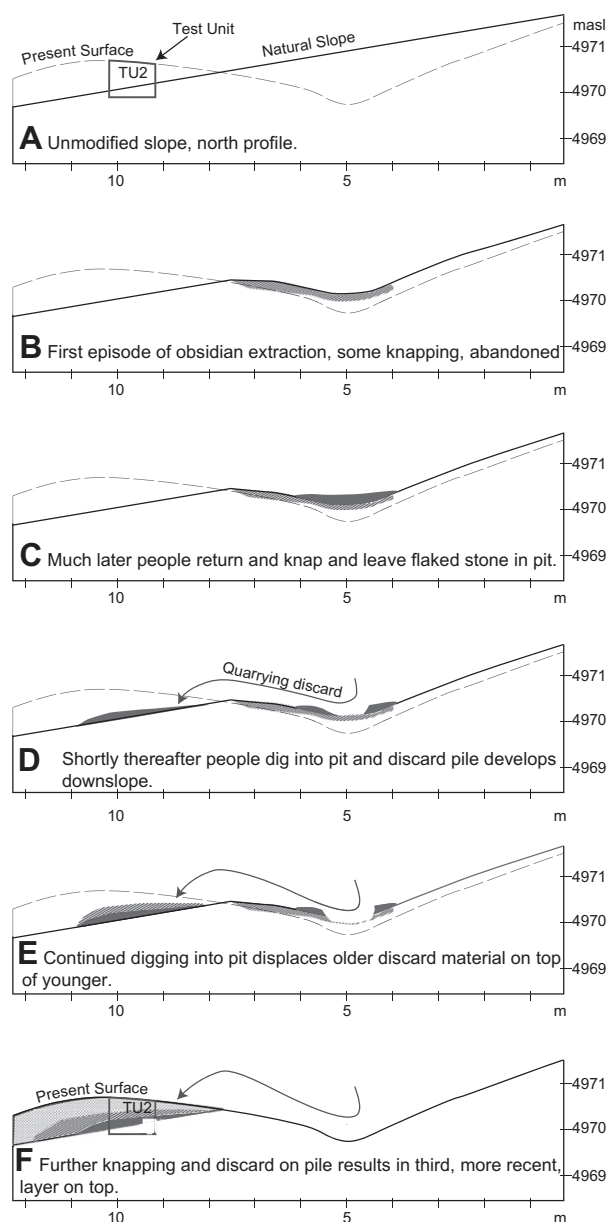


Fig. 4. Digging sequence showing Chivay Q02-2 quarry pit and position of test unit 2 relative to quarry debris layers and natural slope, north profile. The sequence depicted is inferred from test unit stratigraphy and hydration results.

relatively little advanced reduction was occurring at this workshop. Due to the sheer abundance of flaked stone, simple flakes were only collected from one quad (50 cm²) of the test unit and carried away on mule-back. Technical analysis was conducted on 1116 complete obsidian flakes from this unit (Tripcevich and Mackay, 2011).

The test unit at Saylluta 2 (TU1), the more sparse workshop, was placed on the southern half of a corral on the northwest side of Maymeja (Fig. 3) and revealed a fill of sandy local soil likely used to level out this corral in an otherwise sloping area. Unfortunately, a metal nail was encountered in level 4 of this test unit, suggesting a Hispanic period occupation or perhaps stratigraphic mixing. Hydration samples were collected in the hopes of sorting out the degree of disturbance and to date the knapping activities.

Three small charcoal samples from three different levels of TU3 at the A03-330 workshop were submitted to the NSF-Arizona Accelerator Mass Spectrometry (AMS) laboratory (Table 1).

Radiocarbon dates were used to cross-date the hydration samples, and to help establish an initial hydration rate in the Maymeja region.

3.2. Hydration analysis

Near a quarry there is often much natural obsidian present and differentiating naturally flaked stone from flakes that are cultural in origin is one of the challenges in quarry research. All of the items included this analysis were examined and determined to be either clearly cultural, clearly natural, or of ambiguous (cultural or natural) origin. Cultural flakes were defined as those with a platform and/or relatively complete and fresh-looking edges. We tried to be conservative in this regard and to separate and analyze independently flakes that we felt confident about being the result of knapping activities. Natural flakes are those with highly weathered surfaces, polished or tumbled edges, and/or evidence of flaking that is inconsistent with typical knapping (e.g., platform angles > 90°). Furthermore, some flakes were classified as likely cultural, but had irregular edge damage that could also have been the result of trampling or other activities. In many cases such edge damage probably reflects ancient knapping, but because we could not be sure, we analyzed them separately from the clearly cultural items.

Obsidian hydration dating was undertaken at the Archaeometrics Obsidian Hydration Laboratory under the direction of TRC. A clean part of each flake was chosen to remove a thin section of obsidian for analysis with a lapidary saw. This section was then mounted onto a glass slide and manually ground to a thickness between 30 and 50 μm on a glass plate using a slurry of water and 600 silicon abrasive grit. For most pieces the platform section was cut to determine if there was difference between the dorsal and ventral surfaces. Indeed, as discussed below, many pieces displayed a thick dorsal band, which we interpret as original cortex, and a thin ventral band, which we interpret as cultural and indicative of quarrying.

Ground slides were measured using a Meiji petrographic microscope. Once a defined hydration rim or band was observed on a color monitor screen, the band was centered in the middle of the monitor, to reduce parallax, and measured using a Lasico digital filar eyepiece micrometer. Typically, 10 band thickness measurements were taken on each specimen. However, imperfections in the stone, weathering, and damage to the surface from the saw or grinding occasionally reduced this number to as few as three readings. Hydration values were recorded to the nearest 0.1 μm, and both the mean and standard deviation for each specimen was calculated.

In some cases, more than one distinct hydration band related to cultural activity was observed on a single specimen. In this study, seven double, and one triple band were recorded. These extra bands represent instances where an artifact has been fractured more than once and retains traces of each fracturing episode. Such multi-banding can be caused by reworking of older artifacts and/or damage of an artifact (e.g. by thermal fracturing) as it lies within a site's deposit. If an older artifact is reworked, it is the smaller band that more accurately dates the deposit from which it comes. If an artifact was later damaged by fracturing, it may be the larger band that is of interest. Because of this ambiguity, we generally did not rely on artifacts with multiple bands to estimate the age of cultural activities at the quarry or workshops.

4. Results

Flakes from the quarry pit were notably different than flakes from the workshops in their hydration composition. In particular, the hydration analysis detected a large number of "natural" flakes from the quarry, where the only visible band was in excess of 20 microns, often as much as 30 to 70 microns. At this elevation, such hydration

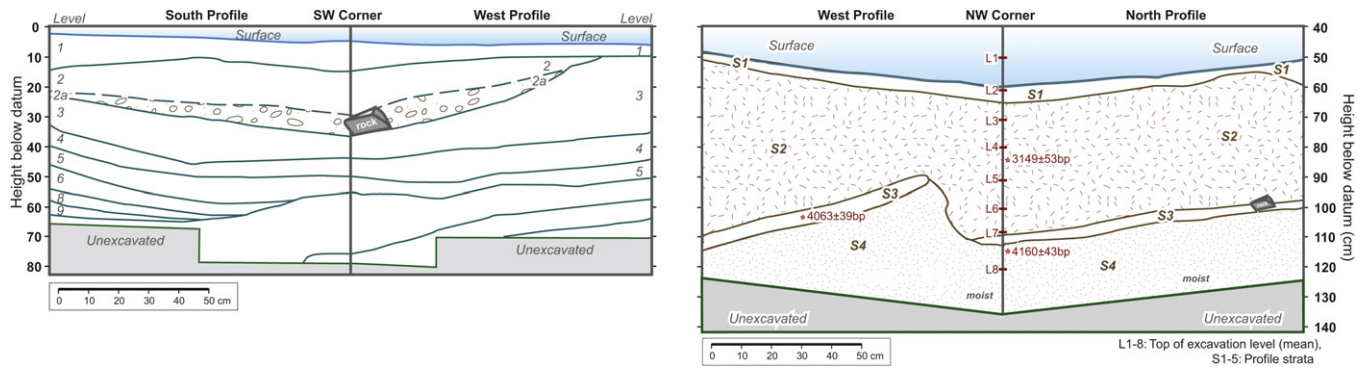


Fig. 5. Profile drawings from TU2 at the quarry pit (left) and TU3 at the A03-330 workshop (right) stratigraphic sequences.

bands would convert to dates well in excess of 20,000 to 50,000 years, much greater than the earliest documented occupations in the Andes. Indeed, during much of the Pleistocene the Maymeja area would have been deep under glaciers and inaccessible.

The spatial distribution of flakes with extra large hydration rinds also suggests that they are natural. The count of such flakes is shown in the last column in Table 2. While only 3.1% of the sampled flakes at the workshops display such large readings, over 23% at the quarry do. This suggests that much of the debris at the quarry was already fractured and was too small to be of use to ancient miners, and hence, left behind while in search of larger nodules. The small number of natural flakes at the workshops could represent either materials removed from the quarry and carried to the workshop but not further reduced (i.e., manuports), or truly natural flakes that cover the surface of the Maymeja region.

On the other hand, the two workshops have a high percentage of flakes where the evidence of cultural origin is more equivocal, especially in the upper levels of the workshops. Table 2 summarizes the hydration data from these items (in the 7th, 8th, and 9th columns). As shown the average hydration readings are typically lower, as would be expected of items that are trampled at a later point in time, and the spread of readings is higher, as measured by the coefficient of variation ($CV = \text{standard deviation divided by the mean}$). The relative frequency of these flakes is much lower at the quarry (25%) than in the workshops combined (61%). This suggests that trampling and other disturbance was less extensive at the quarry than in the workshop.

Table 2 also shows the average microns, CV of micron readings, and count of recorded hydration bands for clearly cultural artifacts, by context and level (one clear outlier from level 6 at the quarry was removed from the analysis). As seen, CV values are generally small, below 0.15, for nearly all unit-level samples, suggesting relatively good temporal contexts. That is, there is no evidence for mixing from highly divergent temporal periods in any of the unit-level samples.

Examining the different units, samples from the A03-330 workshop show a pattern of increasing average hydration rind thickness with depth, consistent with the notion that knapping debris accumulated over time with little subsequent stratigraphic mixing. Figs. 6 and 7 plots the data for the workshop (red squares) by average hydration reading and level, showing a relatively strong linear

correlation ($R^2 = 0.84$). Three radiocarbon dates anchor the sequence, suggesting use between 1210 and 2870 BC. The hydration data point to two major periods of obsidian reduction, one corresponding to an age equivalent to 1.9 microns and the other around 2.3 microns. Calibrated radiocarbon dates on associated charcoal suggest ages of approximately 1494–1212 BC and 2872–2567 BC, respectively.

At the quarry, we had expected the debris to show an inverted hydration sequence, with the oldest materials near the surface and the youngest near the bottom. As shown in Fig. 6, this result only partially held. Samples from the shallower levels (less than 40 cm) displayed slightly larger hydration bands than those in the deeper levels (greater than 60 cm), as expected, but were smaller than the hydration readings in the middle two levels (40–60 cm). Instead, a more parabolic distribution is suggested by the data points, though the correlation is still poor ($R^2 = 0.02$ for a linear correlation and $R^2 = 0.17$ for a binomial one). This may reflect the removal of some older materials from the pit, which was deposited in the middle levels of the discard pile, but underlain by younger materials (Fig. 4). In any case, the difference between the shallower and deeper levels is not great, and the discard pile appears to represent the remains of obsidian quarrying activity over a small amount of time. More importantly, the data suggest systematically early obsidian exploitation at the quarry, with little exploitation later in time. Because EHT is the same for the quarry and workshop sites, and all obsidian is from the same source, we suggest that obsidian should hydrate the same in both contexts. Given the radiocarbon dates at the workshop, we suggest all the quarrying debris is older than 2000 BC. Further, the maximum average hydration reading for a stratigraphic level occur in level 6 (56 cm below datum), at 2.83 μ . Using the rate developed below, this converts to an age of approximately 3800 BC. This suggests that obsidian quarrying was in full swing by at least the Terminal Archaic period (ca. 3300 BC), and perhaps slightly earlier. The minimum of hydration readings occurs in level 8 (66 cm below datum) at 2.44 μ which converts to an age of approximately 2300 cal. BC. Thus, it appears that this particular pit was abandoned some 1500 years after it was started.

Finally, although smaller in number, the hydration samples from the Saylluta 2 obsidian workshop show little change with depth. This result is consistent with the notion that the samples represent a disturbed and mixed deposit, as indicated by the metal nail in level 4 (at approximately 10 cm). Such disturbance is not unexpected for a corral that is periodically trampled by camelids and has been filled in to create a level surface. The large number of recently fractured pieces supports this notion, as well as reflecting the position of this corral at the base of a colluvial slope. At the same time, the CVs on the samples from this workshop are relatively small. This suggests that the workshop was used over a fairly narrow window in prehispanic times and prior to historic disturbances. The average hydration readings on clearly culturally flaked

Table 1
Radiocarbon dates from Test Unit 3 at the A03-330 Workshop.

Level	Lab Code	Lot#	Uncal. bp	Error	Calibrated BC range	
4	AA57940	162.8	3149	±53	1494	1212
6	AA61375	164.5	4063	±39	2639	2453
7	AA57940	166.79	4160	±43	2872	2567

Table 2
Hydration results by unit and level.

Location	Level	Cm Below Datum	Cultural			Ambiguous			Count ($\mu > 20$)
			Avg. (μ)	CV	Count	Avg. (μ)	CV	Count	
Quarry	2	15	2.67	0.03	4	4.70	0.99	3	3
	3	24	2.53	0.12	6	1.63	n/a	2	4
	4	35.5	2.60	0.08	7	2.00	0.34	5	5
	6	56	2.83*	n/a	1	n/a	n/a	0	1
	7	59	2.74	n/a	2	2.26	n/a	1	1
	8	66	2.44	0.12	12	2.08	n/a	1	1
	10	72	2.63	0.08	8	2.30	n/a	2	3
	11	74	2.49	0.04	6	2.05	n/a	1	3
A03-330 workshop	3	72	2.21	n/a	1	2.08	0.21	9	1
1494–1212 Cal. BC	4	81	2.13	n/a	2	1.72	0.22	8	1
	5	93	2.31	0.14	3	2.32	0.20	6	
	6	101	2.47	0.13	13	1.95	0.17	7	1
2872–2567 Cal. BC	7	108	2.58	0.16	10	n/a	n/a	0	
Saylluta 2 workshop	2	5	2.54	n/a	1	1.89	0.24	10	0
	3	8	2.60	0.06	4	1.96	0.06	7	0
	7	23	2.50	0.10	3	2.07	0.14	9	0

Averages calculated in microns (μ). CV: coefficient of variation = s/\bar{x} . CV not calculated for samples with counts less than 3. * – One outlier of 4.2 microns removed from calculations. Radiocarbon dates calibrated using Calib 6.0 Southern Hemisphere calibration (Stuiver and Reimer, 1993).

items suggest an age commensurate with the deeper levels of the A03-330 workshop and the upper levels of the quarry, that is, around 2400 to 2700 BC.

5. Discussion

Hydration results largely conform with expectations based on data from the excavations, suggesting OHD is a reliable means for dating in this high elevation context. Thus, we had expected hydration bands to increase with depth within the A03-330 workshop and we expected stratigraphic mixing at Saylluta 2. Both results were confirmed through hydration. Furthermore, we expected more natural flakes in the quarrying pit debris than in the workshops. This too, was confirmed. One expectation that was not met was a reverse hydration sequence with depth in the spoils of the quarry pit. We believe this is largely due to the narrow temporal window of quarrying and the general precision associated with OHD (see also Liritzis and Laskarisa, 2011). Errors associated with OHD are generally in the range of 5–25% of the absolute date (Rogers, 2010; Rogers and Duke, 2011), which is probably greater than the span of time represented at the quarrying pit.

When comparing the radiocarbon dates at the A03-330 workshop with the hydration readings (Fig. 6), it is clear that obsidian is hydrating at a very slow rate. For example, previous work examining the hydration rate of Quispisisa obsidian in the Nasca region

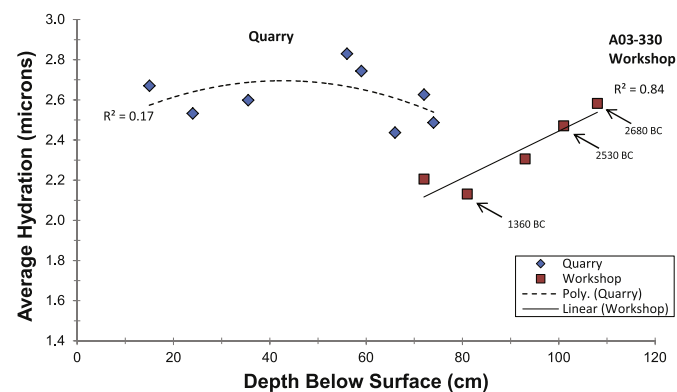


Fig. 6. Average hydration bands by depth below surface for the quarry and A03-330 workshop with associated radiocarbon dates for the latter.

(ca. 600 masl) would predict a thickness of over 8 microns for artifacts dating to 2000 BC. We lack detailed climatic data for the Maymeja region, but we estimate an effective hydration temperature of about 5C for the Maymeja region (using data presented in Eerkens et al., 2008; Lynch and Stevenson, 1992). Chemical reactions within obsidian slow considerably with colder temperatures, thus, the slow hydration rate is largely expected (Friedman and Trembour, 1983; Stevens, 2005). However, the slow hydration rate could also be caused by chemical properties of Chivay obsidian, such as lower concentrations of intrinsic water (Liritzis, 2006; Rogers and Duke, 2011; Stevenson et al., 2000; Stevenson et al., 1993). In sum, we lack the chemical, climatic and comparative hydration data to determine the ultimate cause of the slow hydration rate at Maymeja. Future research should seek to collect the appropriate information to control these factors.

Although the number of data points is small, we use the radiocarbon dates at A03-330 to establish a preliminary hydration rate for Chivay obsidian in the Maymeja region. In general, much experimental and empirical data indicate that time varies as the square of the diffusion front thickness as described by Eq. (1):

$$\text{Age} = DX^2 \quad (1)$$

where age is measured in years, D is a constant dependent primarily on EHT and intrinsic water content, and X is the hydration rind measured in microns (Friedman and Smith, 1960; Friedman and Trembour, 1983; Jones et al., 1997; Michaels and Tsong, 1980;

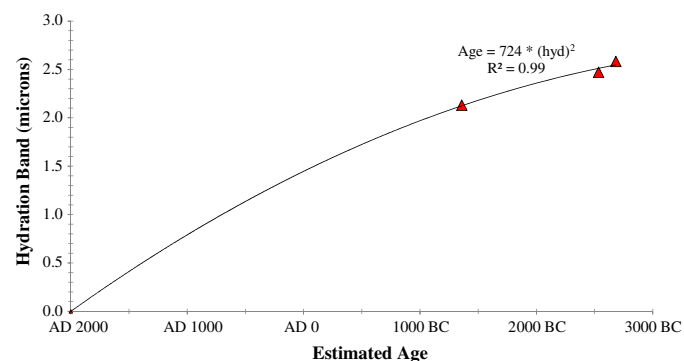


Fig. 7. Comparison of hydration averages vs. radiocarbon dates at A03-330.

Rogers, 2007; Stevenson et al., 1993). Using this result, we apply a binomial regression to the hydration–radiocarbon pairs at A03–330, anchoring the curve at the origin. Using this regression we construct Eq. (2), which best describes the hydration rate for Chivay obsidian at Maymeja (i.e., at 5000 m), given available information:

$$\text{Age} = 724 * X^2 \quad (2)$$

where age estimate is given in calibrated radiocarbon years before present. Again, with such a small number of radiocarbon–hydration pairs, additional data are needed to test and refine this proposed hydration rate. As well, to construct a correction for elevation, more hydration–radiocarbon pairs are needed from lower elevations. Following the work of Rogers and Duke (2011), we are also exploring the possibility of using induced hydration to see if we can independently derive an estimate for the rate of hydration in Chivay obsidian.

Using this hydration rate, we place the earliest use of the quarry at 3800 BC. As discussed above, other researchers have noted a significant uptick in Chivay obsidian use for the production of projectile points away from the quarry (e.g., Craig, 2005; Klink and Aldenderfer, 2005: 475; Tripcevich, 2007: 201) beginning in the Terminal Archaic (ca. 3300 BC). Given the tentative nature of our hydration rate, the inherent precision of hydration dating (5–25% of the absolute date), and the limited number of absolute dates on Terminal Archaic occupations in the highlands, we believe these independent lines of data are highly consistent with one another.

6. Conclusion

The hydration data indicate that intensive quarrying for obsidian was in full swing at Maymeja by 3800 BC. However, as with most mining behaviors, intensive quarrying does not mark the beginning of exploitation, but only a point when easy-to-obtain pieces near the surface are no longer available. The added labor of extractive mining and the maintenance of a pit with slumping sides, when other nodules, albeit smaller, are available on the surface even today, leads us to presume that obsidian exploitation at Chivay began much earlier. The hydration data indicate that pit excavation began during an early episode of exploitation prior to the formation of both workshops.

The intensive quarrying around 3800 BC suggests that people were perhaps searching for specific attributes of buried material. Larger nodule size would seem to be an obvious characteristic, but perhaps others, such as less weathered raw material or pieces with less thermal cracking, were also important. We know from regional distributions that use of Chivay obsidian expanded in later pre-Inka periods of Andean prehistory when populations were even larger (Burger et al., 1998a; Giesso, 2003; Glascock et al., 2007; Tripcevich and Contreras, 2011). Yet, despite extensive survey there is little evidence for quarrying activities during later periods. There are several possible explanations for the lack of evidence of later quarrying. First, it is possible that later inhabitants only needed smaller nodules and were able to exploit secondary lag sources to meet their needs (e.g., marekanites or colluvially transported materials) for smaller artifacts. Second, later quarrying may have been intensive at primary sources but highly localized, and those sites have not yet been found. Third, later populations may have been able to scavenge existing Archaic sites for obsidian and did not need to quarry for obsidian, although the abundance of obsidian at post-Archaic sites challenges that explanation. To date sample sizes remain small and further research will be needed to address these interesting topics.

References

- Aldenderfer, M.S., 1997. Jiskairumoko and Early Sedentary Settlement in the southwestern Lake Titicaca Basin, 37th Annual Meeting of the Institute for Andean Studies, Berkeley, CA.
- Aldenderfer, M.S., 1998. Montane Foragers: Asana and the South-central Andean Archaic. University of Iowa Press, Iowa City.
- Aldenderfer, M.S., 2004. Preludes to power in the highland Late Pre-ceramic period. In: Vaughn, K.J., Ogburn, D., Conlee, C.A. (Eds.), *Foundations of Power in the Prehispanic Andes*, pp. 13–35.
- Aldenderfer, M.S., Craig, N.M., Speakman, R.J., Popelka-Filcoff, R., 2008. Four-thousand-year-old gold artifacts from the Lake Titicaca basin, southern Peru. *Proceedings of the National Academy of Sciences* 105, 5002–5005.
- Bell, R.E., 1977. Obsidian hydration studies in highland Ecuador. *American Antiquity* 42, 68–78.
- Bonifaz, E., 1985. New approximation for the hydration-age of obsidians of the llalo region of Ecuador. *Current Research in the Pleistocene* 2, 43–44.
- Brooks, S.O., Glascock, M.D., Giesso, M., 1997. Source of volcanic glass for ancient Andean tools. *Nature* 376, 449–450.
- Burger, R.L., Asaro, F., 1977. Trace Element Analysis of Obsidian Artifacts from the Andes: New Perspectives on Pre-Hispanic Economic Interaction in Peru and Bolivia — LBL6343. Lawrence Berkeley Laboratory, Berkeley. <http://escholarship.org/uc/item/2kr0k9c1>.
- Burger, R.L., Asaro, F., Salas, G., Stross, F., 1998a. The Chivay obsidian source and the geological origin of Titicaca Basin type obsidian artifacts. *Andean Past* 5, 203–223.
- Burger, R.L., Asaro, F., Trawick, P., Stross, F., 1998b. The Alca Obsidian Source: the origin of raw material for Cuzco Type obsidian artifacts. *Andean Past* 5, 185–202.
- Burger, R.L., Fajardo Rios, F.A., Glascock, M.D., 2006. Potreropampa and Lisahuacho obsidian sources: geological origins of Andahuaylas A and B type obsidians in the Province of Aymaras, Department of Apurimac. *Peru. Nawpa Pacha* 28, 109–127.
- Burger, R.L., Glascock, M.D., 2000. Locating the Quispisisa obsidian source in the department of Ayacucho, Peru. *Latin American Antiquity* 11, 258–268.
- Burger, R.L., Mohr Chávez, K.L., Chávez, S.J., 2000. Through the glass Darkly: prehispanic obsidian procurement and exchange in southern Peru and Northern Bolivia. *Journal of World Prehistory* 14, 267–362.
- Craig, N., Speakman, R.J., Popelka-Filcoff, R.S., Aldenderfer, M., Flores Blanco, L., Vega, M.B., Glascock, M.D., Stanish, C., 2010. Macusani obsidian from southern Peru: a characterization of its elemental composition with a demonstration of its ancient use. *Journal of Archaeological Science* 37, 569–576.
- Craig, N.M., 2005. The Formation of Early Settled Villages and the Emergence of Leadership: A Test of Three Theoretical Models in the Rio Ilave, Lake Titicaca Basin, Southern Peru, Ph.D. Dissertation, Anthropology, University of California at Santa Barbara.
- Craig, N.M., Speakman, R.J., Popelka-Filcoff, R.S., Glascock, M.D., Robertson, J.D., Shackley, M.S., Aldenderfer, M.S., 2007. Comparison of XRF and PXRF for analysis of archaeological obsidian from southern Peru. *Journal of Archaeological Science* 34, 2012–2024.
- Eerkens, J.W., Vaughn, K.J., Carpenter, T.R., Conlee, C.A., Grados, M.L., Schreiber, K., 2008. Obsidian hydration dating on the south coast of Peru. *Journal of Archaeological Science* 35, 2231–2239.
- Friedman, I., Smith, R.L., 1960. A new dating method using obsidian: part I, the development of the technique. *American Antiquity* 25, 476–522.
- Friedman, I., Trembour, F., 1983. Obsidian hydration dating update. *American Antiquity* 48, 544–547.
- Giesso, M., 2003. Stone tool production in the Tiwanaku heartland. In: Kolata, A.L. (Ed.), 2003. *Tiwanaku and Its Hinterland: Archaeology and Paleoecology of an Andean Civilization*, vol. 2. Smithsonian Institution Press, Washington, DC, pp. 363–383.
- Glascock, M., Speakman, R.J., Burger, R.L., 2007. Sources of archaeological obsidian in Peru: descriptions and geochemistry. In: Glascock, M., Speakman, R.J., Popelka-Filcoff, R.S. (Eds.), *Archaeological Chemistry: Analytical Techniques and Archaeological Interpretation*. Oxford University Press, Washington, DC, pp. 522–552.
- Jones, M., Sheppard, P.J., Sutton, D.G., 1997. Soil temperature and obsidian hydration dating: a clarification of variables affecting accuracy. *Journal of Archaeological Science* 24, 505–516.
- Klinck, B.A., Palacios, M.O., 1985. Mapa Geológico del Cuadrángulo de Chivay, Hoja 32-s. Instituto Geológico Minero y Metalúrgico, Scale. 1:100000.
- Klink, C., Aldenderfer, M., 2005. A projectile point chronology for the south-central Andean highlands. In: Stanish, C., Cohen, A., Aldenderfer, M. (Eds.), *Advances in Titicaca Basin Archaeology-1*. Cotsen Institute of Archaeology, Los Angeles, California, pp. 25–54.
- Liritzis, I., 2006. SIMS-SS A new obsidian hydration dating method: analysis and theoretical principles. *Archaeometry* 48, 533–547.
- Liritzis, I., Laskarisa, N., 2011. Fifty years of obsidian hydration dating in archaeology. *Journal of Non-Crystalline Solids* 357, 2011–2023.
- Lynch, T.F., Stevenson, C.M., 1992. Obsidian hydration dating and temperature controls in the Punta-Negra region of Northern Chile. *Quaternary Research* 37, 117–124.
- Mayer-Oakes, W.J., 1986. El Inga: a Paleo-Indian site in the Sierra of Northern Ecuador. *Transactions of the American Philosophical Society* 76, 1–235.
- Michaels, J.W., Tsong, I.S.T., 1980. Obsidian hydration dating: a coming of age. *Advances in Archaeological Method and Theory* 3, 405–444.
- Ridings, R., 1996. Where in the World does obsidian hydration dating work? *American Antiquity* 61, 136–148.

- Rogers, A.K., 2007. Effective hydration temperature of obsidian: a diffusion theory analysis of time-dependent hydration rates. *Journal of Archaeological Science* 34, 656–665.
- Rogers, A.K., 2008. Obsidian hydration dating: accuracy and resolution limitations imposed by intrinsic water variability. *Journal of Archaeological Science* 35, 2009–2016.
- Rogers, A.K., 2010. Accuracy of obsidian hydration dating based on obsidian–radiocarbon association and optical microscopy. *Journal of Archaeological Science* 37, 3239–3246.
- Rogers, A.K., Duke, D., 2011. An archaeologically validated protocol for computing obsidian hydration rates from laboratory data. *Journal of Archaeological Science* 38, 1340–1345.
- Stanish, C., Burger, R.L., Cipolla, L.M., Glascock, M.D., Quelimá, E., 2002. Evidence for early long-distance obsidian exchange and watercraft use from the southern Lake Titicaca Basin of Bolivia and Peru. *Latin American Antiquity* 13, 444–454.
- Stanish, C., Levine, A., 2011. War and early state formation in the Northern Titicaca Basin, Peru. *Proceedings of the National Academy of Sciences* 108, 13901–13906.
- Stevens, N.E., 2005. Changes in prehistoric land use in the alpine Sierra Nevada: a regional exploration using temperature-adjusted obsidian hydration rates. *Journal of California and Great Basin Anthropology* 25, 187–205. <http://escholarship.org/uc/item/2b11g5dr>.
- Stevenson, C.M., Gottesman, M., Macko, M., 2000. Redefining the working assumptions of obsidian hydration dating. *Journal of California and Great Basin Anthropology* 22, 223–236. <http://escholarship.org/uc/item/1z21m5rd>.
- Stevenson, C.M., Knaus, E., Mazer, J.J., Bates, J.K., 1993. Homogeneity of water content in obsidian from the Coso volcanic field: implications for obsidian hydration dating. *Geoarchaeology* 8, 371–384.
- Stuiver, M., Reimer, P.J., 1993. Extended ¹⁴C database and revised CALIB radiocarbon calibration program. *Radiocarbon* 35, 215–230.
- Thouret, J.-C., Wörner, G., Gunnell, Y., Singer, B., Zhang, X., Souriot, T., 2007. Geochronologic and stratigraphic constraints on canyon incision and Miocene uplift of the Central Andes in Peru. *Earth and Planetary Science Letters* 263, 151–166.
- Tripcevich, N., 2007. Quarries, Caravans, and Routes to Complexity: Prehispanic Obsidian in the South-Central Andes, Ph.D. Dissertation, Anthropology, University of California at Santa Barbara.
- Tripcevich, N., 2010. Exotic goods and socio-political change in the south-central Andes. In: Dillian, C., White, C. (Eds.), *Trade and Exchange: Archaeological Studies from History and Prehistory*. Springer, New York, 59–73.
- Tripcevich, N., Contreras, D.A., 2011. Quarrying evidence at the Quispisisa obsidian source, Ayacucho, Peru. *Latin American Antiquity* 22, 121–136.
- Tripcevich, N., Mackay, A., 2011. Procurement at the Chivay obsidian source, Arequipa, Peru. *World Archaeology* 43, 271–297.