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Obsidian hydration dating on the South Coast of Peru

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Abstract

We compare over 230 obsidian hydration readings from 30 individual site components from the Southern Nasca Region (SNR) with independent age estimates based on radiocarbon dates and temporally diagnostic artifacts. Although there are problems with small sample sizes, and readings must be adjusted for elevation, a very strong relationship accounting for nearly 90% of the total variation in the data set is found. This suggests that obsidian hydration dating (OHD) works in the SNR and is a viable means of independently estimating age. Residual values from our regression suggest that hydration age estimates are usually within 15% of the radiocarbon estimates. Finally, we present an equation other scholars can use to estimate age for Quispisisa obsidian in the SNR.

Keywords: Obsidian; Hydration dating; Effective hydration temperature (EHT); Nasca; Peru

1. Introduction

Obsidian hydration was developed as an archaeological dating technique in the 1960s and has seen slow development over the ensuing 40 years. It has become a mainstay in archaeometric dating in some areas, such as the western Great Basin of North America (e.g. Bettinger, 1980, 1989; Jones et al., 2003), has run into difficulties in others, such as Mesoamerica (e.g. Braswell, 1992), and has been largely ignored in still others.

For a variety of reasons, the latter situation has been true of Andean archaeology. Only a few studies have attempted to include hydration as a means of estimating site or activity age (e.g. Bell, 1977; Bonifaz, 1985; Lynch and Stevenson, 1992; Mayer-Oakes, 1986), and results have not been without controversy (Lynch, 1990:p. 23). This is certainly not for a lack of obsidian artifacts. In most regions, obsidian is a common, though not always dominant, material present in archaeological sites. Instead, the availability of less expensive and more precise dating techniques, especially ceramic seriation, and less focus on archaic-period sites where alternative dating techniques might be more useful, likely account for the lack of hydration studies in the Andes. Furthermore, recent high-profile articles, such as Ridings (1996) and Anovitz et al. (1999) have questioned the utility and accuracy of the technique. Although others have come to the defense of hydration (e.g. Hull, 2001; Rogers, 2007), the "negative press" may have resulted in a reluctance on the part of Andean scholars to utilize the technique.

In this paper we test whether obsidian hydration produces consistent and predictable dating estimates using a new data set from the Southern Nasca Region (SNR) of Peru. We compare nearly 240 source-specific hydration measurements from

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archaeological contexts with independent chronological information, including radiocarbon dates and diagnostic pottery.

2. Background

Obsidian hydration operates on the principle that like all volcanic glasses, obsidian absorbs water. This diffused water is typically visible under a microscope using high-power magnification (typically 40–80×) and appears as diffusion fronts from the exposed surface of an artifact. By measuring the thickness of these diffusion fronts (or bands or rinds), hence the amount of water absorbed, this principle can be used to determine if one artifact is older than another (relative dating). However, if the rate at which water diffuses into glass can be determined, the technique allows for more useful calendrical age estimates (absolute dating). We focus on the latter approach.

In general, the relationship between time and diffusion front thickness is described by Eq. (1):

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

where age is generally measured in years, D is a constant (though see below), and X is the hydration rind measured in microns. In short, the age increases as the square of the hydration rind thickness.

Other than time, at least three other factors affect the rate of hydration, including temperature, water vapor pressure, and glass chemistry (Friedman and Smith, 1960; Friedman and Obradovich, 1981; Jones et al., 1997; Michels and Tsong, 1980). These factors are generally expressed as a constant and subsumed into the term D in Eq. (1). However, recent research has sought to replace D with a more dynamic function that includes at least some expression of these factors (Hull, 2001; Rogers, 2007; Stevens, 2005).

While easy to control under laboratory conditions (e.g. Mazer et al., 1991; Stevenson and Scheetz, 1989), temperature is quite dynamic in real world situations, fluctuating diurnally, seasonally, and over longer time scales as well. Instead of modeling these factors independently, archaeologists have employed a solution comprising a single term, referred to as the Effective Hydration Temperature (EHT), to model the effects of temperature on hydration. For example, Rogers (2007) has expressed EHT as a function of annual mean temperature, annual temperature range, and diurnal temperature range. A depth correction factor is also occasionally used to account for the temperature of buried artifacts (Ridings, 1991; Rogers, 2007), under the assumption that underground conditions are significantly different than surface ones. However, as we discuss below, a problem in applying this correction is the lack of research on temperature with depth, and more specifically, how this affects hydration bands. Moreover, the correction tends to impose order on an assemblage in precisely the manner expected naturally in a stratified deposit. Thus it is difficult to evaluate whether depth corrections improve the analysis because depth significantly affects hydration, or whether it improves because it reinforces stratigraphic differences. In any case, we follow Rogers (2007) and construct an EHT factor for the SNR based on altitude to correct hydration measurements. We briefly examine the effects of burial depth, but ultimately leave that for future research.

The effects of water vapor pressure have not been studied as intensively. While important in controlled laboratory settings, in practice variation in water vapor pressure might not vary enough from location to location within a geographic region to have serious effects on relative rates of hydration. In the Andes, both temperature and water vapor pressure are likely to be mainly controlled by elevation. Thus, in our application of the hydration model, both these factors are subsumed under a single term.

The effect of the glass chemistry on hydration is less well understood. Empirical data indicate that certain obsidians hydrate faster than others within the exact same depositional environment (Ericson, 1989; Findlow et al., 1982; King, 2004). The way archaeologists generally deal with this is through the construction of separate hydration curves for different obsidians using empirical data (e.g. Bettinger, 1989; Ericson, 1989; Meighan, 1976). These effects are then summarized into a constant, expressed as part of D in Eq. (1). As we show below, this does not prove to be a large problem in the SNR because obsidian comes predominantly from a single geochemical source.

An issue related to glass chemistry is the intrinsic water content of obsidian (e.g. Stevenson et al., 1993, 2000). Studies indicate that the amount of water within obsidian can vary even within obsidian nodules from a single source, and that this water content can significantly affect age estimates. To our knowledge, this factor has not yet been addressed in the Andes and its effects are, as yet, unknown.

3. Sample

Our sample of hydration measurements comes from 237 individual obsidian artifacts from the SNR. Of these, 158 artifacts are from 15 radiocarbon-dated site components. Site components are defined as stratigraphically or spatially restricted areas (e.g. individual houses) of sites that date to relatively narrow windows of time. Nine site components come from the stratified site of Upanca (Vaughn and Linares Grados, 2006). Two additional components come from Marcaya (Vaughn, 2004; Vaughn and Glascock, 2005), two from Pajonal Alto (Conlee, 2003), and one each from Higosñoc and Uchuchuma (Vaughn, 2005). All of these samples come from excavated contexts. All radiocarbon dates were calibrated using the on-line version of the Calib 5.0 program (Stuiver and Reimer, 1993).

An additional 79 obsidian artifacts were surface collected from 15 different sites or site loci in the SNR recorded by one of us (KS) during the Proyecto Nasca Sur (for a summary of the surveys see Schreiber and Lancho Rojas, 2003). All these loci represent single-component locations, where diagnostic ceramics representing only one time period were located. For dating purposes we used the median age for traditionally recognized culture historical periods (see Table 1). In

Table 1
Culture historical periods, ages, and median age used for developing a hydration rate in the SNR

Horizons/periods	Local period	Culture	Approximate calendar years	Median age BP
Late horizon	*Inca*	Inca	A.D. 1476–1532	500
LIP	*Tiza*	Tiza	A.D. 1000–1476	750
Middle horizon	*Loro*	Loro, Wari	A.D. 750–1000	1125
EIP	*Nasca*	Late Nasca	A.D. 550–750	1350
		Middle Nasca	A.D. 450–550	1500
		Early Nasca	A.D. 1–450	1825
Early horizon	*Formative*	Proto Nasca	100 B.C.–A.D. 1	2050
		Paracas	800–100 B.C.	2350

most cases, these periods have been independently established with radiocarbon dates from excavated deposits, though occasionally the dates are based on analogies to neighboring regions outside the SNR.

Fig. 1 shows the locations of these sites across the SNR. Note that some of the sites in the map contain multiple but spatially and temporally discrete components from where obsidian samples were drawn (e.g. stratigraphic levels, separate loci). Elevation among the sites ranges from 375 to 1600 masl, a factor which will become significant below regarding estimation of EHT.

Prior to cutting for hydration, each obsidian artifact was analyzed by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) to determine source provenance. There is no local source of obsidian in the SNR, and all material was imported to the region. The vast majority of obsidian in our sample (ca. 90–95%) derives from a single source, Quispisisa, located approximately 100 km east–northeast of the SNR (Burger and Glascock, 2000).

4. Methods

Hydration analysis was undertaken at the ArchaeoMetrics Obsidian Hydration Laboratory under the direction of TRC, who personally cut, mounted, and measured all the artifacts under discussion here. Based on visual inspection, a clean part of the artifact was chosen for analysis. For pieces of debitage the platform was cut to determine if there was difference between the dorsal and ventral surfaces, or in some cases the actual platform. Weathered specimens are addressed in the same manner, however, step-fractures are usually targeted for unweathered hydration readings. For projectile points the base or notched area was generally cut. This cutting strategy was employed specifically to identify and measure artifacts with more than one hydration band (see below).

Two parallel cuts (ca. 1 mm apart) were made to remove a thin section of obsidian from the artifact. This was accomplished using a lapidary saw mounted with two 4-inch diameter diamond-impregnated 0.004″ blades. Obsidian slices were then mounted with Lakeside thermoplastic cement onto

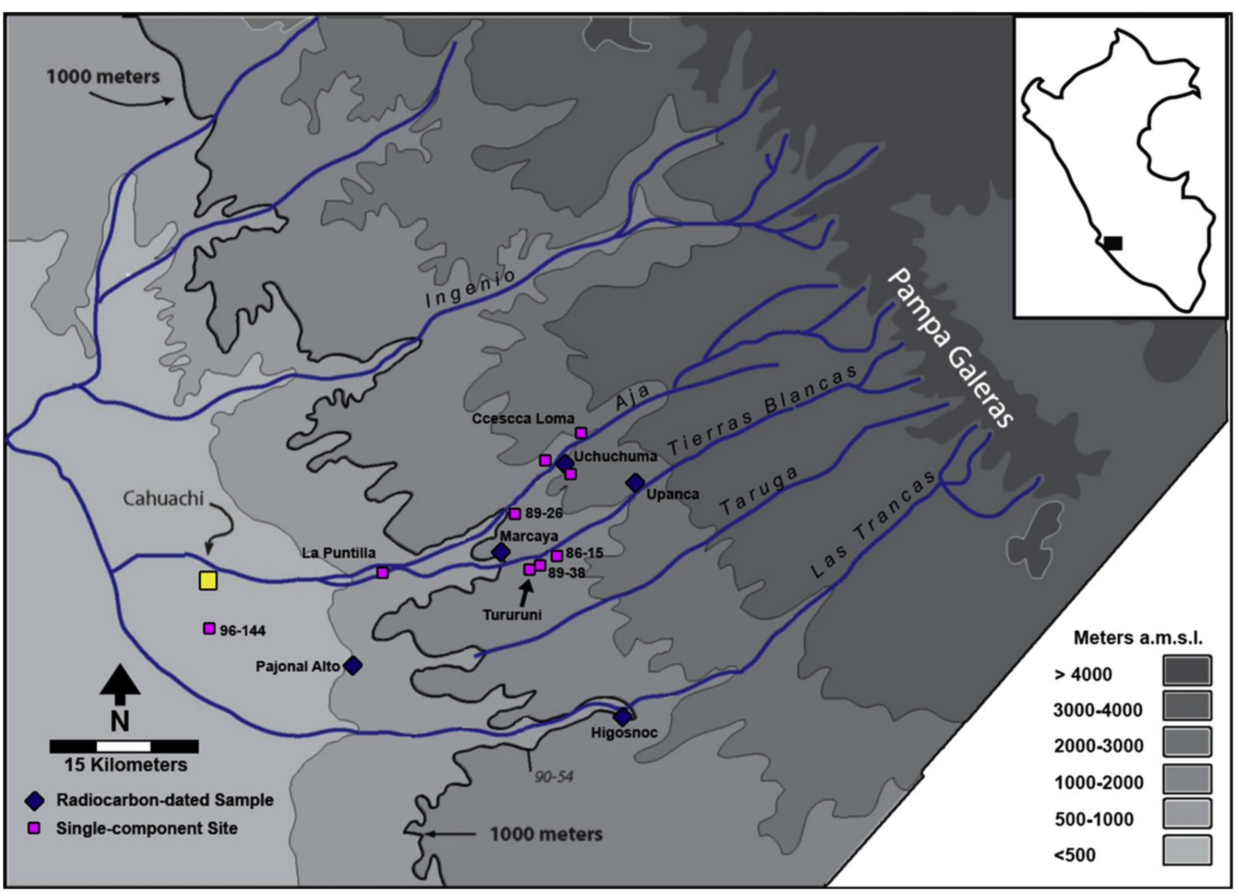

Fig. 1. Study area, places mentioned in text, and sites from which samples were drawn.

sequentially numbered microscope slides. Generally, five specimens were mounted on each slide. Samples were then manually ground on a glass plate using a slurry of water and 600 silicon abrasive grit to a thickness between 30 and 50 mm, depending on opacity and/or unique source-specific qualities.

Prepared slides were measured using a Meiji petrographic microscope fitted with a Lasico digital filar eyepiece micrometer. Once a defined hydration rim or band was observed on a color monitor screen, the hydration rim was centered in the middle of the monitor, to reduce parallax, and measured using a micrometer. Typically, 10 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 0.01 μm, and both the mean and standard deviation for each specimen was calculated.

In some cases, more than one distinct hydration band was observed on a single specimen. Double, or in rare cases triple, bands represent instances where an artifact has been fractured more than once and retains traces of each fracture surface. Such fracturing episodes must be separated in time by significant margins, such that they form visually distinct hydration bands, and can be caused by scavenging and reworking of older artifacts and/or damage of an artifact (e.g. by trampling) as it lies on a site surface. If an older artifact is scavenged and reworked, it is the smaller band that more accurately dates the deposit from which it comes, and by extension the other artifacts associated with it. If an artifact was later damaged by trampling, it may be the larger band that more accurately dates associated artifacts. When multiple rims were observed, each was independently measured using the micrometer and reported.

5. Estimating EHT for the SNR

As mentioned earlier, the sites included in our database span a range of elevations within the SNR. Because environmental conditions, including temperature, are known to change with elevation, we cannot directly compare hydration measurements from sites at different elevations. Instead, it is necessary to correct for local EHT at the different sites. To estimate EHT according to the equations provided by Rogers (2007), daily maximum and minimum readings are needed for at least 10 years.

Unfortunately, published modern climatic data for Peru are not as extensive and easily accessible as they are in the USA. We were able to find such data for a limited number of weather stations on the National Climatic Data Center (NCDC) web pages. However, the location of modern weather stations tends to follow the distribution of more densely populated places. In Peru, this tends to be either coastal (less than 500 m) or highland (greater than 2500 m) with very little in between. Many of our archaeological samples are found between these extremes, and we have few modern population centers with similar types of weather-recording centers to help estimate EHT in these locations.

To estimate EHT at locations between the coast and highlands, we examined climate data for 12 weather stations between Lima and Tacna, including the modern city of Nasca. Fig. 2 plots EHT as a function of elevation. As expected, EHT decreases significantly with altitude, suggesting artifacts at higher elevations will hydrate slower than those at lower elevations. Also seen in Fig. 2, there is evidence of a linear correlation between EHT and elevation ($R^2 = 0.69$). We take advantage of this correlation, and use it to derive EHT estimates for sites in mid-elevation zones between the coast and highlands. Eq. (2) describes the relationship between elevation (measured in meters asl) and EHT (measured in °C):

$$\text{EHT} = -0.0023(\text{Elevation}) + 22.1 \tag{2}$$

From Eq. (2), we determine that EHT values in our sample range between 21.2 °C (at 375 m; for site N96-144) and 18.4 °C (at 1600 m for the site of Upanca).

A comparison of our calculated relationship between EHT and elevation, and that produced in the only analogous study we know of in the Andes, shows some difference. Lynch and Stevenson (1992) report a 6.1 °C decrease in EHT with every 1000 m increase in elevation, while our study indicates only 2.3 °C decrease per 1000 m. However, their study was based on observations exclusively over 3000 m in elevation while the majority of ours are under this mark. If we examine only the weather stations over 2500 m in Fig. 2, there does seem to be a slightly greater decrease in temperature with elevation (4.7 °C per 1000 m).

This may indicate that the relationship between EHT and elevation in the Andes is non-linear, with temperature change accelerating with elevation. If so, the slope of the line defined by Eq. (2) would be slightly less (i.e. closer to 0) for the sites in the SNR (since they are all below 2500 m). Even if we halve the slope from −0.0023 to −0.0011, age estimates for even the oldest specimens in our sample change less than 600 years and the vast majority would change less than 200. Given the inherent error in hydration age estimates (see below) the effect of

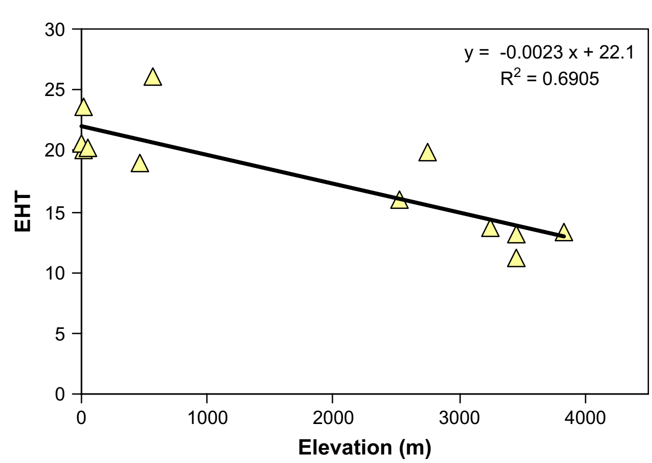

Fig. 2. EHT calculations as a function of elevation showing linear correlation.

such a change in the relationship between elevation and EHT, at least for the SNR, is minimal. In any case, until additional weather station and EHT data are available, particularly between 500 and 2500 m, Eq. (2) represents our best estimate of the effect of elevation on EHT, and hence, estimated age.

6. Results

Although some specimens displayed diffuse rims, all of the artifacts submitted for hydration returned measurable hydration bands. Of the 237 artifacts, 27 (11%) had double hydration bands, and a single piece had three bands. We restrict the analysis below to only those artifacts assigned to the Quispisisa source.

Overall, there is a clear correlation between hydration band and estimated age, whether we correct for small sample sizes, outliers, altitude, burial depth, or not. We address this issue in greater detail in the discussion. Fig. 3 shows the data, uncorrected for any of these factors, with each point representing the straight average of hydration readings for a particular site or site component (if double bands were present, the smaller band was always used). To account for the parabolic relationship between hydration rind and time, the *X*-axis is non-linear, each unit representing the square of time. Clearly, the independent age estimates using radiocarbon dates or diagnostic artifacts predicts the average hydration, overall 66% of the variability (R^2 of 0.66). This suggests that obsidian hydration is measuring some component of age and that the technique holds promise in the SNR.

The figure also suggests that sites with small samples of artifacts ($n = 1$ or 2) are contributing significantly to this variability. These samples show greater variance about the regression line than either the radiocarbon-dated components or the single-component sites dated by diagnostic artifacts. Moreover, visual inspection of the data shows that a small number of readings are clear outliers within their particular context (e.g. seven readings from a Late Nasca site are 4.0, 4.0, 4.2, 4.4, 4.8, 5.6, and 11.8; where 11.8 is clearly anomalous). While we do not doubt the accuracy of the hydration technique

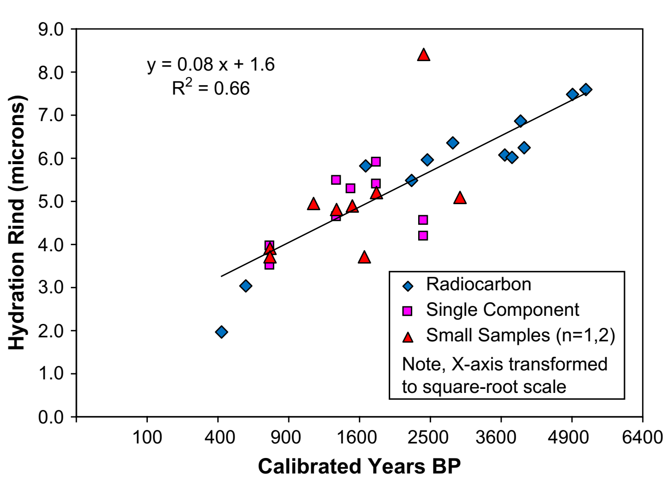

Fig. 3. Results without correcting for effective hydration temperature or outliers. Note that the x-axis has been transformed to the square of years BP.

in such cases, we doubt the accuracy of such readings in dating the context under inspection. Such anomalous readings likely represent cases of artifact scavenging from older sites, breakage later in time, or more ephemeral occupations of sites separated in time from the component we are trying to examine.

Using Chauvenet's criteria (see Taylor, 1982), we flagged 16 unusual readings and inspected each one within the context of other readings from that site component (as one might do with anomalous radiocarbon dates). In 14 cases we decided to use the larger second hydration band, rather than the smallest one. In these cases, including a number of buried artifacts from Upanca, the younger hydration band was too small given the other readings. It is possible that these artifacts were trampled or broken while lying on the site surface before being buried, giving rise to smaller-than-expected readings on the smallest band. The larger second bands in these cases seem to better date the deposit. In two cases (including the aforementioned Late Nasca case), we discarded altogether anomalously large readings.

We also corrected hydration readings using the estimated EHT derived from Eq. (2). Because Upanca, at 1600 masl, was the first site where we applied hydration, and because the site accounts for just over half of all our readings, we decided to use it as our baseline for EHT correction. Thus, hydration readings from this site were not adjusted for altitude, but all others were relative to it. Doing so required the fewest number of modifications in our data set. In practice, because Upanca was our highest site in terms of elevation, all other hydration readings from lower elevations were adjusted downwards using Eq. (2) and those presented by Rogers (2007). In other words, sites from lower elevations have higher EHT and obsidian from there is expected to hydrate faster than at Upanca (thus overestimating age using unadjusted readings).

Once we had cleaned our data set, removing site components with small samples ($n = 1$–2), removing clear outliers, and adjusting for altitude using EHT, we were left with 220 readings from 21 site components. Average hydration readings from these 21 components show a remarkable relationship to independent estimates of age by either radiocarbon dating or diagnostic artifacts. Hydration readings account for 89% of the variability in age estimates. Fig. 4 shows this relationship, with the trendline forced through the origin (since hydration readings at 0 BP should be 0 mm).

For artifacts from excavated contexts, we further examined the effects of burial depth corrections, using the formulas provided by Rogers (2007). This correction adds slightly to the measured hydration rind, with the amount added increasing with depth due to the presumed lower soil temperatures encountered in deeper stratigraphic levels. Here we used the present day ground surface as the baseline, and adjusted (upwards) readings from deeper contexts. Though this correction did account for an additional 5% of the variability in the data set (giving an R^2 of 0.94), several factors gave us pause in applying it to the SNR data.

First, burial depth is not constant and it changes as artifacts become more deeply buried over time. Because rates of deposition are unlikely to be constant, it will be difficult to account

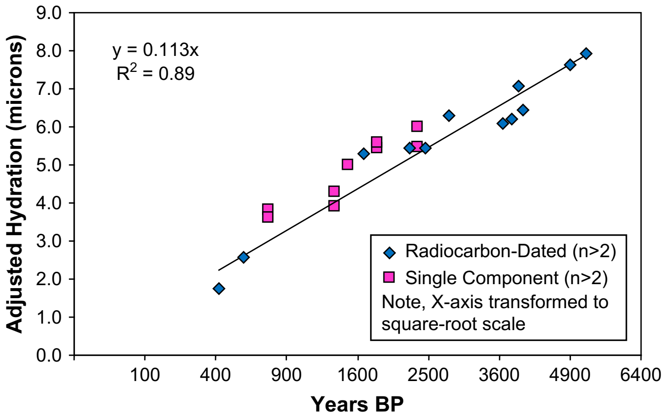

Fig. 4. Correlation between hydration and independent age estimate for cleaned data set, removing outliers and small samples, and correcting for elevation.

for this, even in the absence of turbation and other factors that can move artifacts through the stratigraphic column. We felt that a number of artifacts in our sample had been lying on the surface for some time before being trampled and then buried, as evidenced by secondary hydration bands. Because we could not account for this length of time, it is difficult to estimate the importance of burial depth on hydration finds. Second, there are few systematic studies investigating the effects of burial depth on rates of hydration. Unlike for altitudinal corrections, accounting for burial depth should almost always increase the amount of variability explained in the model, regardless of taphonomy or temperature effects. This is simply a result of how sites are formed and deposition of sediments. We expect deeper artifacts to have larger hydration rinds because in most cases they should be older. Artificially increasing the measurements of deeper artifacts through depth correction reinforces this trend. Thus, the small amount of variation accounted for by depth corrections (5%; though admittedly, this 5% is nearly 45% of all the remaining variation) did not seem warranted given these other reservations. While we recognize that burial depth may have an important effect on hydration rind thickness, we leave precise estimation of this effect for future research.

Finally, Fig. 4 also suggests that obsidian is hydrating at a fast rate. In our experience with western North America obsidian sources, the rate of hydration in the SNR is on par with Coso obsidian, which hydrates faster than most other obsidians in the region (e.g. Eerkens and Rosenthal, 2004; Fredrickson et al., 2006; Hughes, 1988; King, 2004). This rapid rate of hydration is good for dating purposes because it gives greater resolution to differentiate relative ages for a given degree of precision (e.g. ±0.1 mm for a fast-hydrating obsidian gives better temporal resolution than for a slow-hydrating one).

7. Discussion and conclusions

There is a strong correlation between average obsidian hydration readings and radiocarbon dates in the SNR. As well, for single-component sites there is a strong linear correlation between average hydration readings and expected dates based on temporally diagnostic pottery. These correlations exist for even the uncleaned and uncorrected hydration data (Fig. 3), but are more pronounced when small samples and outliers are removed from the analysis, and when we adjust for elevation (Fig. 4). Together, the analyses strongly suggest that hydration bandwidth is reliably recording age in the SNR, and demonstrate the utility of obsidian hydration for dating sites of unknown age.

As shown in Fig. 3, small sample sizes ($n < 3$) can provide accurate age estimates, but appear to be far less reliable in recording age than contexts where three or more artifacts were measured. This finding is undoubtedly a result of sampling problems and point out the importance of taking reasonably large samples to minimize the contribution of unusual or erroneous readings in final age estimations. As well, we found it was important to inspect the data for other clear outliers. In several cases, the majority of hydration measurements provided a consistent estimate of age close to that expected from the ^{14}C or diagnostic artifacts, but there were one or two readings clearly out of context. After removing these values from the analysis, or more often, using the second hydration band instead of the smaller first one, the estimate was much closer to the expected age. This shows that, like most archaeological data, it is important to carefully inspect the data prior to estimating age, much like one would inspect radiocarbon dates and reject clearly erroneous measurements. Table 2 shows the effects of these various corrections on the R^2 value for the linear correlation between average hydration band and independently estimated age using ^{14}C or diagnostic artifacts (expressed as the square root of age).

Table 2 also shows that correcting for the altitude at which artifacts were collected significantly improves the linear correlation between hydration band and the square root of estimated age. Sites at higher elevations, where temperatures are on average colder, hydrate slower than their lower-elevation counterparts. Adjusting for this factor increases the R^2 value. Note that R^2 could have increased or decreased with this correction, since there is no inherent altitudinal patterning in sites of different ages. That R^2 increased suggests to us that there is a real and noticeable effect of altitude and EHT on hydration.

Finally, we also corrected for burial depth as suggested by Rogers (2007). This factor increases the values of deeper hydration readings relative to those closer to the site surface.

Table 2
Pearson's R correlation values for hydration data using different correction factors

Correction	R^2
No correction	0.66
Removing small samples ($n = 1-2$)	0.68
Removing outliers	0.78
Removing outliers and small samples	0.80
Removing outliers; altitude correction	0.82
Removing outliers and small samples; altitude correction	0.89
Removing outliers and small samples; altitude and depth correction	0.94

We are less enthusiastic about this correction because it tends to weight artifacts by stratigraphic position. Thus, if obsidian artifacts in a stratified site all had the same hydration values (e.g. 2.0 mm), using the depth correction would impose order on the assemblage precisely in the way expected, increasing the hydration values of the deeper artifacts. Such a correction might cause a correlation between age and hydration reading when no such correlation should exist. In the SNR, using the depth correction increases the R^2 value of our correlation as much as the altitudinal correction does. Thus, both factors isolated account for approximately the same amount of variation in the original data set.

As mentioned in the opening section, obsidian chemistry seems also be a factor in the rate of hydration. In the SNR, 90–95% of all obsidian comes from the Quispisisa source. Our analyses have focused only on obsidian from this source. We do not have enough data to derive hydration curves for other glass types. However, we do have anecdotal data that suggests that glasses are hydrating at different rates. For example, in a Late Intermediate Period component at the site of Pajonal Alto, we encountered obsidian in relatively high quantities from both the Quispisisa and Jampatilla sources ($n = 7$ and 5, respectively; for further discussion of these sources see Burger and Glascock, 2000; Burger et al., 1998). While the Quispisisa specimens average 3.03 mm (3.2, 3.2, 3.1, 3.0, 3.0, 2.9, 2.8), the Jampatilla pieces show a distinct range (2.1, 1.8, 1.8, 1.8, 1.8), averaging 1.85 mm. Assuming the absolute age is the same for these artifacts, this finding suggests that Jampatilla obsidian hydrates significantly slower than Quispisisa.

Based on our analyses, Eq. (3) presents a means to estimate the age of an artifact made from Quispisisa obsidian in the SNR. The equation corrects for EHT by incorporating the altitude at which an artifact was found. We note that an additional correction for burial depth is possible using the formula provided by Rogers (2007). However, because the effects of burial depth on EHT have not been independently established or verified, we are hesitant to include that factor here.

$$\text{Age} = 78\left(X \cdot e^{(0.00014*A - 0.23)}\right)^2 \quad (3)$$

Where age is expressed in calibrated years BP, X is the hydration reading in microns, e is euler's constant, which is equal to 2.71828, and A is the altitude of the site in meters above sea level. For a given hydration reading (e.g. 3.0 mm), this equation will result in younger age estimates at lower elevations and more ancient ones at higher elevations.

Having shown that obsidian hydration dating works in the SNR, and having provided an equation to estimate age, it is worth considering in which contexts this dating technique will be useful in the SNR. The parabolic relationship between time and hydration band size, and the fixed error in reading hydration bands under a microscope, means that hydration dating is most sensitive on the more recent end of time. Thus, an error of ±0.1 mm is equivalent to far fewer years for a young artifact than a very old one. This means that hydration dating will be most precise for younger sites.

Paradoxically, our need for accurate dating in the SNR is less acute for younger contexts due to the presence of temporally diagnostic ceramics in most sites dating to the last 2800 years. Thus, the greatest need for new dating techniques is in preceramic sites predating 2800 BP. Charcoal and/or other datable materials may not be available at such sites. Although hydration dating has greater error in this time range, we believe the ability to distinguish time is still fine enough to make hydration dating a worthwhile investment. As well, even on later-period sites where diagnostic ceramics are present, hydration dating may illuminate or highlight preceramic occupations that are otherwise difficult to detect. Hydration dating may also prove useful in dating special-purpose sites where diagnostic ceramics are rare, such as sites associated with mining (Eerkens et al., 2008; Vaughn et al., 2007).

Examining the residual values from our regression, errors on our hydration age estimates are an average of 15% of the independently estimated age. For an LIP site this would give an age estimate within about ±75–150 years of the independent date, a reasonably precise measure. For a 5000-year-old site, this error would place a hydration estimate within ±750 years of such an age estimate, a much broader expanse. The reader should note, however, that this is the error in predicting the mean calibrated radiocarbon date or the mean age for a culture historical period with diagnostic ceramics. These dating methods also have built in errors. Thus, with hydration we are trying to predict a second number that also has some degree of uncertainty. In reality, hydration dating is probably much more accurate in predicting *true* age of the archaeological assemblage than the 15% reported above. However, since true age is unknown, we cannot model or estimate the actual errors using hydration dating, only the errors relative to some other dating technique.

In any case, whether such an error rate is acceptable depends, of course, on the questions being posed of the archaeological record. However, we believe that in many cases even this large error will prove useful to archaeological investigations in the SNR. This is particularly true for preceramic sites, where there is little else to date (for recent analogs in North America see Eerkens and Rosenthal, 2004; Eerkens et al., 2007), and surface sites where there is no charcoal or diagnostic ceramics.

In sum, it is clear that obsidian hydration dating holds much potential on the coast of Peru. Given that the technique also works well in the deserts of North America, but not so well in the jungles of Mesoamerica, we suspect aridity plays a key role in the accuracy and precision of hydration dating overall. We hope that this initial study will convince other Andeanists of the utility of the technique for dating. Given that hydration labs can be set up for little start-up costs, the technique is relatively low-tech, and that hydration dates can be obtained inexpensively (currently between $15 and 20 per artifact in most service labs), there is much to be gained from developing hydration as a dating technique in the region.

Future work in the SNR should seek to test the curve we propose with Eq. (3). The addition of hydration measurements from radiocarbon-dated sites over 3000 m should also prove interesting, to see if the technique continues to work well in highland settings. As well, we should establish hydration curves for other geochemical sources.

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References

Anovitz, L.M., Elam, J.M., Riciputi, L.R., Cole, D.R., 1999. The failure of obsidian hydration dating: sources, implications, and new directions. Journal of Archaeological Science 26, 735–752.

Bell, R.E., 1977. Obsidian hydration studies in highland Ecuador. American Antiquity 42, 68–77.

Bettinger, R.L., 1980. Obsidian hydration dates for Owens Valley settlement categories. Journal of California and Great Basin Anthropology 2, 286–292.

Bettinger, R.L., 1989. Establishing an hydration rate for fish springs obsidian. In: Hughes, R.E. (Ed.), Current Directions in California Obsidian Studies, Contributions of the University of California Archaeological Research Facility No. 48, Berkeley, pp. 59–68.

Bonifaz, E., 1985. New approximation for the hydration-age of obsidians of the Ilalo region of Ecuador. Current Research in the Pleistocene 2, 43–44.

Braswell, G., 1992. Obsidian hydration dating, the Coner phase and revisionist chronology at Copan, Honduras. Latin American Antiquity 3, 130–147.

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., Schreiber, K., Glascock, M.D., Ccencho, J., 1998. The Jampatilla obsidian source: identifying the geological source of Pampas type obsidian artifacts from southern Peru. Andean Past 5, 225–239.

Conlee, C.A., 2003. Local elites and the reformation of late intermediate period sociopolitical and economic organization in Nasca, Peru. Latin American Antiquity 14, 47–65.

Eerkens, J.W., Rosenthal, J.S., 2004. Are obsidian subsources meaningful units of analysis?: temporal and spatial patterning of subsources in the Coso Volcanic Field, southeastern California. Journal of Archaeological Science 31, 21–29.

Eerkens, J.W., Ferguson, J.R., Glascock, M.D., Skinner, C.E., Waechter, S.A., 2007. Reduction strategies and geochemical characterization of lithic assemblages: a comparison of three case studies from western North America. American Antiquity 72, 585–597.

Eerkens, J.W., Vaughn, K.J., Linares-Grados, M., Edwards, M.J., 2008. La Ballena: a mining base camp in the southern Nasca region, Peru. Antiquity, 315. Project Gallery. Available from: <http://antiquity.ac.uk/ProjGall/315.html>.

Ericson, J.E., 1989. Toward flow-specific obsidian hydration rates: Coso Volcanic Field, Inyo County, California. In: Hughes, R.E. (Ed.), Current Directions in California Obsidian Studies, Contributions of the University of California Archaeological Research Facility No. 48, Berkeley, pp. 13–22.

Findlow, F.J., Martin, P.M., Ericson, J.E., 1982. An examination of the effects of temperature variation on the hydration characteristics of two California obsidians. North American Archaeologist 3, 37–49.

Fredrickson, D.A., Loyd, J., Jones, T., Schroder, S., Origer, T., 2006. The Coso–Casa Diablo hydration conundrum. Proceedings of the Society for California Archaeology 19, 151–156.

Friedman, I., Smith, R., 1960. A new method using obsidian dating: part I, the development of the technique. American Antiquity 25, 476–522.

Friedman, I., Obradovich, J., 1981. Obsidian hydration dating of volcanic events. Quaternary Research 16, 37–47.

Hughes, R.E., 1988. The Coso Volcanic Field reexamined: implications for obsidian sourcing and hydration dating research. Geoarchaeology 3, 253–265.

Hull, K.L., 2001. Reasserting the utility of obsidian hydration dating: a temperature-dependent empirical approach to practical temporal resolution with archaeological obsidians. Journal of Archaeological Science 28, 1025–1048.

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.

Jones, G.T., Beck, C., Jones, E.E., Hughes, R.E., 2003. Lithic source use and paleoarchaic foraging territories in the Great Basin. American Antiquity 68, 5–38.

King, J., 2004. Re-examining Coso obsidian hydration rates. Proceedings of the Society for California Archaeology 14, 135–142.

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.

Lynch, T.F., 1990. Glacial-age man in South America? A critical review. American Antiquity 55, 12–36.

Mayer-Oakes, W.J., 1986. El Inga: a Paleo-Indian Site in the Sierra of Northern Ecuador. Transactions of the American Philosophical Society 76 (4), 1–235.

Mazer, J.J., Stevenson, C.M., Ebert, W.L., Bates, J.K., 1991. The experimental hydration of obsidian as a function of relative humidity and temperature. American Antiquity 56, 504–513.

Meighan, C.W., 1976. Empirical determination of obsidian hydration rates from archaeological evidence. In: Taylor, R.E. (Ed.), Advances in Obsidian Glass Studies. Noyes Press, Park Ridge, New Jersey, pp. 106–119.

Michels, J.W., Tsong, I.S.T., 1980. Obsidian hydration dating: a coming of age. In: Schiffer, M.B. (Ed.), Advances in Archaeological Method and Theory, vol. 3. Academic Press, New York, pp. 405–444.

Ridings, R., 1991. Obsidian hydration dating: the effects of mean exponential ground temperature and depth of artifact recovery. Journal of Field Archaeology 18, 77–85.

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.

Schreiber, K.J., Lancho Rojas, J., 2003. Irrigation and Society in the Peruvian Desert: the Puquios of Nasca. Lexington Books, Lanham, MD.

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.

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.

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.

Stevenson, C.M., Scheetz, B.E., 1989. Induced hydration rate development of obsidians from the Coso Volcanic field: a comparison of experimental procedures. In: Hughes, R.E. (Ed.), Current Directions in California Obsidian Studies, Contributions of the University of California Archaeological Research Facility No. 48, Berkeley, pp. 23–30.

Stuiver, M., Reimer, P.J., 1993. Extended 14C database and revised CALIB 3.0 14C age calibration program. Radiocarbon 35, 215–230.

Taylor, J., 1982. An Introduction to Error Analysis. University Science Books, Mill Valley, CA.

Vaughn, K.J., 2004. Households, crafts, and feasting in the ancient Andes: the village context of Early Nasca craft consumption. Latin American Antiquity 15, 61–88.

Vaughn, K.J., 2005. Crafts and the materialization of chiefly power in Nasca. In: Vaughn, K.J., Ogburn, D.E., Conlee, C.A. (Eds.), The Foundations of Power in the Prehispanic Andes. Archeological Papers of the American Anthropological Association, vol. 14, Washington D.C., pp. 113–130.

Vaughn, K.J., Glascock, M.D., 2005. Exchange of Quispisisa obsidian in the Nasca region: new evidence from Marcaya. Andean Past 7, 93–110.

Vaughn, K.J., Linares Grados, M., 2006. Three thousand years of occupation in Upper Valley Nasca: excavations at Upanca. Latin American Antiquity 17, 595–612.

Vaughn, K.J., Linares-Grados, M., Eerkens, J.W., Edwards, M.J., 2007. Hematite mining in the ancient Americas: Mina Primavera, a 2,000 year old Peruvian mine. Journal of Operation Management 59, 16–20.