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Obsidian Hydration Rates for Select Sources in the Eastern Great Basin and the Archaic Occupation of Northern Utah

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Northern Utah and southern Idaho have numerous sources of obsidian (e.g., Browns Bench, American Falls, Malad, and Wildcat Hills). This article describes a replicable technique for creating regional obsidian hydration chronologies and applies it to prehistoric artifacts recovered during data recovery along the Ruby Pipeline route, which extends east-west across northern Utah. The method uses regionally-sampled hydration thicknesses to determine a source-specific quadratic equation that is separate from any project-specific data. The estimated hydration rate strongly agrees with radiocarbon and optically stimulated luminescence dates from excavations as well as with common projectile point typologies. The hydration rates, when applied to data from northern Utah, suggest that persistent occupation occurred in the area during the Early Archaic at roughly 8,400 cal B.P.

Numerous geochemically discrete sources of obsidian, such as Browns Bench, American Falls, Malad, and Wildcat Hills, can be found in northern Utah and southern Idaho, though source-specific hydration rates in the eastern Great Basin are lacking (Fig. 1). Because the high quality toolstone was, and is, readily accessible for inhabitants of the region, "the area is lousy with non-diagnostic or multicomponent [obsidian] lithic scatters" (Seddon 2001a:47). Obsidian has two large archaeological advantages over other toolstone materials—it can be geochemically sourced (Hughes 1994; Nelson and Holmes 1979), and the age of an artifact can be assessed (Friedman and Smith 1960; Friedman et al. 1997). Because water diffuses into a newly-exposed glass surface at a relatively definable rate, the width of the hydration band can be used to estimate the age of fracturing (Friedman and Smith 1960; Friedman et al. 1997). Unfortunately, archaeologists have not yet explicitly defined the rate of water absorption for obsidian sources in the northeastern Great Basin (Craig Skinner, personal communication 2011; Duke 2011). In place of source-specific hydration rates, archaeologists in the Great Basin have created relative hydration chronologies based on projectile point typologies and associated radiocarbon dates (Beck and Jones 1994, 2000; Hockett 1995; Jones and Beck 1990; Seddon 2001a, 2001b). While some of those relative chronologies are applicable to lithic scatters in northern Utah, many are not. As such, and to take advantage of the breadth of the Ruby Pipeline project (Fig. 1), the creation of regionally-appropriate and source-specific obsidian hydration chronologies was included as part of the Ruby data recovery effort (Greubel et al. 2010). If source-specific hydration chronologies can be created, many of the lithic scatters in the area could provide significant synchronic and diachronic information about the prehistory of the region.

This article describes a replicable technique for creating obsidian hydration rates and applies it to artifacts recovered during data recovery along the Ruby route. The article begins with a discussion of current trends in obsidian dating, both relative and absolute, and the potential shortcomings of each approach (e.g., mathematical circularity or a lack of regional applicability). A method for solving some of the recurring problems of both techniques is then proposed that builds a mathematical best-fit line of hydration bands from regional samples. This approach is then used to develop source-specific hydration rates, which are compared against other chronometric techniques (i.e., radiocarbon and optically stimulated thermoluminescence) and obsidian hydration bands from

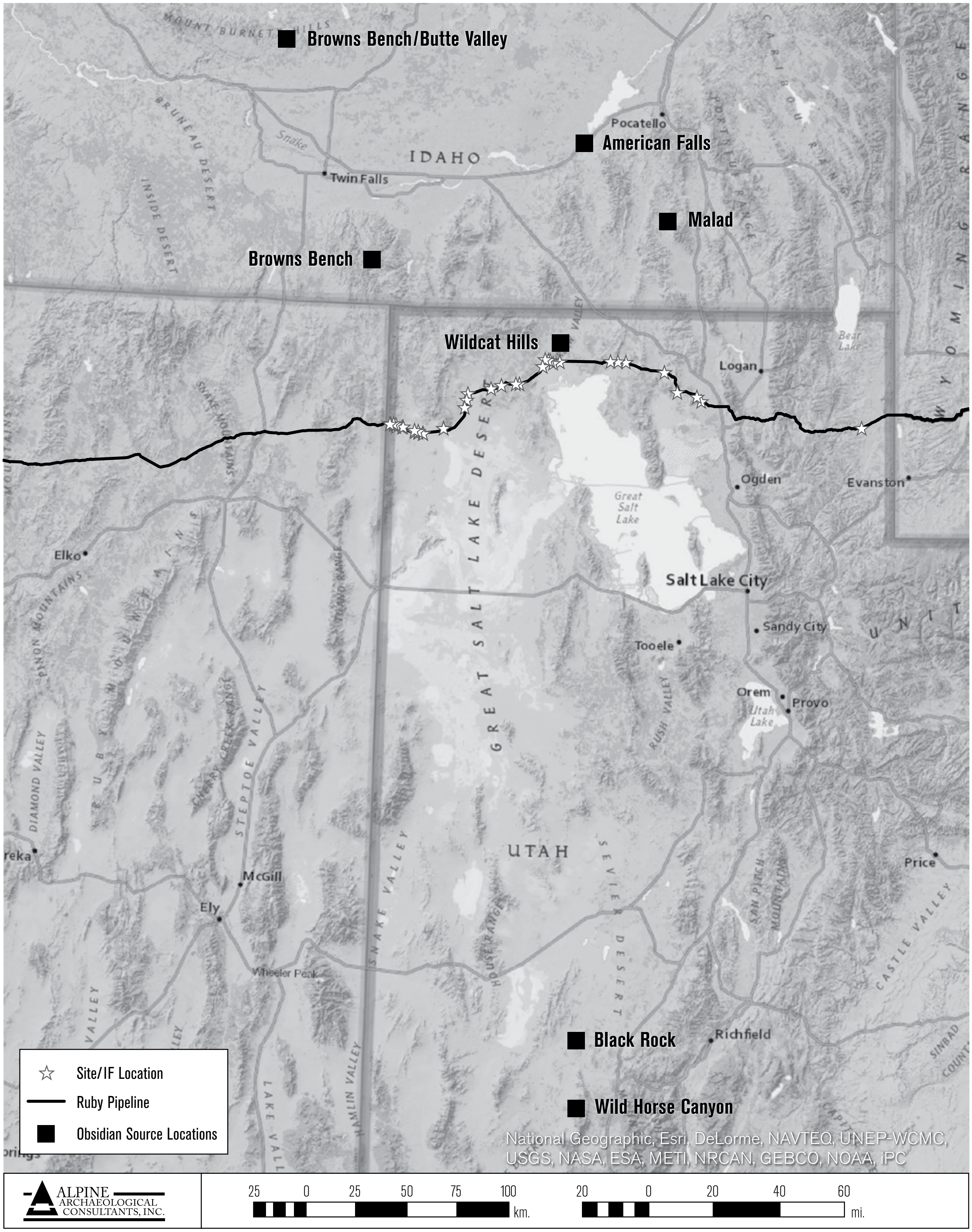

Figure 1. Select Obsidian Sources in the Northeastern Great Basin.

published work in the eastern Great Basin. Appropriate source-specific hydration rates are then applied to obsidian artifacts recovered along the route of the Ruby Pipeline to highlight the utility of a mathematically-derived hydration model.

CURRENT METHODS OF CHRONOMETRIC DETERMINATIONS

Obsidian hydration, which is the absorption of water into the exposed surfaces of obsidian, can be used as a chronological marker of human activities. Hydration studies, which came to archaeology from glass materials engineering, recognize that the rate of water absorption into obsidian is affected by numerous variables, some of which include ambient temperature, time, water vapor pressure, soil alkalinity, diurnal temperature variation, internal geochemical variability, and internal water content (Friedman and Smith 1960; Friedman et al. 1997; Glascock et al. 1999; Loyd et al. 2002; Ridings 1996; Rogers 2007a, 2008a, 2008b, 2009a; Rogers and Duke 2011; Stevenson et al. 2000). The numerous potentially affecting variables contribute in different ways to the thickness of a hydration layer. That is, some variables increase the rate of absorption (e.g., high relative humidity; Rogers 2008b), while others reduce the rate or reset the hydration clock (e.g., fire; Loyd et al. 2002). Recognizing the plethora of potentially affecting variables, the goal of obsidian hydration studies is to minimize the impact of confounding variables (e.g., diurnal temperature variation) such that time is the remaining variable with the greatest impact. If time can be isolated as a variable, then the width of the hydration layer can be used to provide an age for an artifact's exposed surface, which—if caused by human manipulation (e.g., biface edging)—provides a reasonable date for human activity.

Theoretically, glass hydration is defined by the formula

$$\text{[Equation 1]} \quad t = x^2/k$$

where t is calendar years before analysis occurs, x is the thickness of the hydration band, and k is the rate of hydration (Friedman and Smith 1960; Rogers and Yohe 2011). Because the thickness of water absorption (x) can be measured, the above equation is typically solved in two fashions—relative and absolute—both of which attempt to define k on the way to solving for t. Relative dating generally relies on intuitive links between variable hydration thicknesses and other temporal indicators. Absolute dating is typically based on experimentally-derived hydration rates from sourced obsidian. Both hydration approaches are discussed in more detail below.

Relative Dating

Relative hydration interpretations link hydration band thicknesses to other archaeological information, be it radiocarbon dates from controlled excavations (Michels 1969; Seddon 2001b) or chronologically specific artifacts (Beck and Jones 1990, 1994; Hockett 1995; Hutchins and Simons 2000). When matched to other chronological markers, the associated hydration bands provide minimum and maximum thicknesses for temporal periods, which can be used to date temporally non-specific obsidian artifacts. As an example, Hockett (1995) presented the hydration results for 109 projectile points from northeastern Nevada, which allowed him to discuss the diachronic distribution of different point styles. This is a typical foundation for a source-specific chronologically-linked relative hydration timeline, by which—by comparing the hydration width of debitage against projectile point hydration widths—prehistoric site occupations can be dated (Hockett 1995; Michels 1965; Seddon 2005). Additionally, contemporaneity of occupations can be determined by assessing whether the hydration thicknesses represent a unimodal or multimodal distribution curve from source-specific artifacts at a site (Jones and Beck 1990).

Relative hydration chronologies are perhaps the least complex way of using hydration thickness data. That is, if an artifact can be assigned to a date range of Y–Y' B.P., and it has a hydration thickness of X, then the hydration thickness of X is assigned to the time range of Y–Y' B.P. While that simplicity makes relative chronologies easy to use, it also circumvents some of the theoretical and methodological complexities of water absorption in glass artifacts. As previously noted, glass hydration is theoretically defined by Equation 1. Mathematically, relative chronometric associations implicitly assume that hydration rates (k) are relatively constant and non-contributing within Equation 1 (e.g., if the difference in relative humidity between surface and buried artifacts is negligible, then $k=1$; Friedman et al. 1994; Liritzis and Laskaris 2011), which effectively redefines the hydration formula as $t=x^2$ and creates an argument that is mathematically circular.

The mathematical circularity of the relative chronometric method does not, however, necessarily invalidate the resultant inferences. Source-specific relative hydration chronologies are typically founded on projectile point typologies. Those point typologies are based on associations between point styles and radiometric dates from previous excavations. In many cases, the transference of associations from one excavation to a different region or a different excavation is completely valid and appropriate (e.g., a researcher may simply be interested in whether or not a component is earlier or later than another component, and the exact rate of absorption is not important). Often, however, the original excavations are from distant localities and, as highlighted by Hockett (1995), may not apply equally across interregional contexts (e.g., comparing excavations in California to sites in Utah). Additionally, relative chronometric assessments reinforce previous assumptions and do not allow archaeologists to challenge chronometric associations based on what may be inter-regionally inappropriate data.

Absolute Dating

Absolute hydration chronologies are the most mathematically complex way of using hydration thickness data. Absolute hydration interpretations explicitly rely on the theoretical foundations of glass hydration (i.e., Equation 1) by creating an experimentally-derived hydration rate (k) from source-specific obsidian (Mazer et al. 1991). Theoretically, this allows any obsidian artifact, regardless of its physical association with other temporal artifacts, to become a potential chronometric source. Classically, a laboratory-defined hydration rate (k) can be derived by immersing a freshly-broken piece of source-specific obsidian in water or a steam bath at specific temperatures for specific lengths of time (Mazer et al. 1991; Stevenson and McCurry 1990). Other ways of determining k avoid the actual laboratory and rely on mathematical best-fit lines across radiocarbon-associated band measurements, which presumes reasonable project-wide sample sizes and associations (Eerkens et al. 2008; Hull 2001; King 2004; Rogers 2009b; Rogers and Yohe 2011; Stevens 2005). However determined, and given caveats regarding the experimental parameters and sample sizes, once a hydration rate (k) is determined it can be used to date the broken glass surface.

With Equation 1, inaccuracies are created because experimental hydration rates (e.g., 100 percent humidity and high temperatures) are unlikely to reflect site-specific hydration rates (e.g., humidity varying between 75 and 95 percent and 40°F daily temperature fluctuations). To reflect site-specific hydration rates researchers must attempt to deal with the numerous environmental and geochemical factors that influence the rate and hydration thickness for each artifact. Such factors include (but are not limited to) humidity, ground temperatures, diurnal temperature variation, internal geochemistry, and wildfires (Friedman and Smith 1960; Friedman et al. 1994; Friedman et al. 1997; Loyd et al. 2002; Ridings 1996; Rogers 2007a, 2008a, 2008b, 2009a; Rogers and Duke 2011; Stevenson et al. 2000). Differences in humidity between sites can be expected to be a nearly noncontributing factor in the arid west (Mazer et al. 1991; Rogers 2008b), and geochemical differences can be mostly controlled by ensuring that obsidian analyses focus on source-specific obsidians (Glascock et al. 1999; Rogers 2008a; though see Shackley 2009). By controlling for differences in ambient temperatures it is possible to more accurately assess differences in hydration band measurements as a function of time, and hence of different occupations.

To control for the differential impact of temperature on hydration rates it is possible to calibrate the hydration measurement as if it hydrated in an environment akin to the experimental parameters (Rogers 2008c). The formula

$$\text{[Equation 2]} \quad EHT = Ta \cdot (1 - Y \cdot 3.8 \cdot 10^{-5}) + .0096 \cdot Y^{0.95}$$

has been used for that purpose (Rogers 2007b, 2009a), where *EHT* is the effective hydration temperature at the site, *Ta* is the annual average temperature at the site, and Y is a factor based on depth-modified annual and diurnal temperature variation (Equation 3). Sediments can act as a thermal blanket, which moderates temperature variability. Frequent cryoturbation is likely to have little effect on the hydration of any single artifact, however, as the positives and negatives of vertical movement probably cancel out (Rogers 2007a). As such, "applying a rim correction to each artifact based on its depth of recovery is the best chronological analysis strategy" (Rogers 2007a:12). The depth-modified temperature variation (i.e., Y) is provided by the formula:

$$\text{[Equation 3]}\quad Y=exp(-1.32z)[V_a^2=V_d^2]$$

where z is the burial depth in meters, V_a is the annual temperature variation, and V_d is the mean diurnal temperature variation (Ridings 1996; Rogers 2007a). The temperature-corrected *EHT* allows for the creation of a band correction factor (*RCF*) using the formula:

$$\text{[Equation 4]}\quad RCF=exp[-0.06(EHT\text{-}EHTr)]$$

where *EHTr* is the effective hydration temperature for the reference obsidian. When the band measurement in Equation 1 is multiplied by the *RCF* derived from Equation 4, Equation 5 can be used to represent the length of time an artifact's surface has been exposed.

$$\text{[Equation 5]}\quad t=(RCF \cdot x)^2/k$$

The *RCF* should be independently calculated for each artifact and a different k should be used for each source. Because of the vagaries of burial/excavation depth, the independent calculation of *RCF* allows for intrasite comparisons. Equally, independent *RCFs* permit intersite analyses, which should allow for discussions of mobility and regional occupations or abandonments. The use of unique source-specific hydration rates permits inter-source comparisons, and furthers discussions of regional mobility and population dynamics. Having controlled for variations in temperatures and geochemistry, in the absence of other chronometric measures (e.g., radiocarbon, dendrochronology, thermoluminescence), the measured hydration bands can be used to estimate the age of prehistoric occupations.

The development of absolute hydration rates is the most mathematically complex method of using hydration thickness data. That is, if a source-specific k is known and site-specific environmental variables can be managed, an artifact can be associated with a date range of $Y \pm z$ B.P. While considerably more specific than relative hydration chronologies, the complexity of the method (e.g., determining site- and depth-specific environmental variables) thwarts its general acceptance and use by archaeologists (Rogers 2008a). Further, estimated hydration rates do not always align with known regional archaeological chronologies (Duke 2011), in which case the hydration data are often mentioned although largely ignored. The complexity and specificity of absolute chronologies also highlights numerous variables (e.g., differential water or geochemistry within discrete flows at a single source). Because of the increase in complexity, many archaeologists are inclined to throw up their hands in defeat.

Summary of Current Methods

Both absolute and relative hydration rates have their strengths and weaknesses. The explicit use of a hydration rate garnered for absolute chronologies provides discrete date ranges, but is either prohibitively expensive (Mazer et al. 1991; Stevenson and McCurry 1990) or relies on linear best fit models that suffer from individual sample-size and location-specific constraints (Eerkens et al. 2008; King 2004; Rogers 2009b; Rogers and Yohe 2011; Stevens 2005). The information garnered from relative chronometric associations is more immediately usable, though less precise. Additionally, relative chronologies are often based on a mathematically circular method that neither corrects previously established chronologies nor increases the utility of obsidian hydration data.

A REVISED METHOD OF DEVELOPING AN OBSIDIAN HYDRATION RATE

I propose a new method for developing source-specific obsidian hydration chronologies in the eastern Great Basin. This method does not rely on an expensive experimentally-derived hydration rate nor is it founded on a relative method. This method does utilize mathematical and environmental strengths, but it lacks some of the sample-size pitfalls of project-specific best-fit lines. The new method ensures that data are aligned to regional archaeological and paleoenvironmental chronologies while allowing projectile point typologies to be challenged or reified. The new method uses regionally-sampled hydration thicknesses and early occupation dates to determine a source-specific quadratic equation (e.g., a best-fit line) that is separate from any project-specific data. A source-specific quadratic equation provides the hydration rate (k) which—when associated with an artifact's EHT-corrected hydration band—allows for the determination of age in years B.P. (e.g., Y±z B.P.) for an artifact.

Table 1

SOURCE-SPECIFIC HYDRATION THICKNESSES AND ESTIMATED HYDRATION RATES

Obsidian Source	Hydration Band (microns)	Sample Size	Hydration Rate (μ^2/yrs.)	EHT (°C.)[c]	Artifact Reference[c]
American Falls	8.4	4[b]	.0054	9.5	Skinner (2008:IF-77)
Black Rock Area	12.0[a]	712	.0111	10.1	Craig Skinner, personal communication 2012
Browns Bench	16.1[a]	270	.0199	15.4	Beck and Jones (1990:Table 13)
Browns Bench Butte Valley Group A	12.3	15[b]	.0116	8.8	Skinner (2011a:42BO1772)
Malad	9.7[a]	410	.0072	12.0	Duke (2011:Table 2)
Wildcat Hills	3.8	15[b]	.0011	8.8	Skinner (2011a:42BO78)
Wild Horse Canyon	15.2[a]	1,190	.0178	10.2	Craig Skinner, personal communication 2011

[a]None of these are considered statistical outliers given the sample in the following column.

[b]These regional archaeological samples are too small to have a high degree of confidence in the results.

[c]These are the corrected effective hydration temperatures and references for the artifact that presented the hydration measurement in the first column.

Using Equation 1, k—which is the "linear dependence of hydration band thickness on the square root of time"—can be mathematically described based on regional archaeological chronologies (Rogers and Yohe 2011:2). More explicitly, Equation 1 provides a line that passes through $y = 0, x = 0$, which is the present moment, though it can be adjusted to pass through A.D. 1950 (i.e., $y = -60, x = 0$; King 2004:139). To solve for k, regional archaeological data can be used to create a best-fit line. I propose that the quadratic equation for eastern Great Basin sources be fixed by the largest culturally-associated hydration band measurement for source-specific obsidian that is EHT-corrected and matched to the absolutely earliest known cultural date. Or rather, that Equation 1 be modified to mathematically solve for a source-specific k (i.e., $k = x^2/t$) by using regional chronologies to define t.

This approach may work in the eastern Great Basin because of the impact of the hydrologically-defined Great Salt Lake basin. The Great Salt Lake basin once held Pleistocene Lake Bonneville, which overflowed into the Snake River Valley in roughly 16,800 cal B.P. (Currey 1990; Currey et al. 1984), at which point it drained to the Provo shoreline (i.e., 4,800 ft. asl). The ebb and flow of waters into and out of the basin would have had a dramatic impact on people in the area if they were there, though there "is no direct evidence that humans were present to see the lake at either the Bonneville or the Provo levels" (Simms 2008:103). Around 12,800 cal B.P., "the Younger Dryas marked an abrupt return to nearly full glacial conditions in the northern hemisphere. Lake Bonneville was reborn and rose to the Gilbert level, a shoreline at 4,260 ft." (Simms 2008:99). While evidence from Paisley Caves in Oregon indicates the presence of humans 14,300 years ago in the Great Basin (Hockett et al. 2008), the first known cultural occupation of the eastern Great Basin occurred between 13,100 and 12,800 cal B.P. (Goebel et al. 2011; Simms 2008). Well-dated sites in the eastern Great Basin include the Buhl burial at 12,700 cal B.P., Danger Cave at 11,700 cal B.P., Bonneville Estates Rockshelter by 13,000 cal B.P., Smith Creek Cave from 13,000–12,700 cal B.P., and the Dugway Old River Bed just after 13,000 cal B.P. (Simms 2008; Fig. 1). Based on those dates, the earliest human occupation of the eastern Great Basin occurred at roughly 13,000 cal B.P., which is shortly before the Gilbert shoreline (Goebel et al. 2007; Hockett et al. 2008; Simms 2008).

Source-specific hydration bands can be found in numerous published sources and in hydration lab databases. The method presented here presumes that a representative sample of culturally modified obsidian, whether debitage or tools, has been regionally collected and analyzed. The eastern Great Basin sources shown in Table 1 were all identified by Northwest Obsidian Research Laboratories from obsidian samples in the Ruby project corridor (Skinner 2008, 2009, 2011a, 2011b, 2012a, 2012b). Because there is little reason to expect that the prehistoric use of obsidian sources has a normal distribution, all of the obsidian hydration maximums in Table 1 are the largest hydration bands that were culled from regional summaries and obsidian databases. An effort was made to ensure that all the maximums are both associated with cultural occupations and are not

Table 2

BUFFERED HYDRATION RATES FOR SELECT OBSIDIAN SOURCES

Obsidian Source	Fast Hydration Rate (μ^2/yrs.)	Hydration Rate[a] (μ^2/yrs.)	Slow Hydration Rate (μ^2/yrs.)
Black Rock Area	.0125	.0111	.0099
Browns Bench	.0224	.0199	.0179
Malad	.0082	.0072	.0064
Wild Horse Canyon	.0200	.0178	.0159

[a]Because the rates are based on exponential equations, the hydration rate is not a median rate between the positive and negative rates.

statistical outliers, though three of the sources in Table 1 have regional sample sizes that are too small to assure a high degree of confidence in the results (i.e., American Falls, Butte Valley Group A, and Wildcat Hills).

To compensate for potential errors in regional sampling and hence identification of the largest hydration band, a margin of error is constructed by using the margin of measuring error for the hydration thickness, which is typically on the order of ± 0.1 µ, and ± 10 percent buffering for the date of the earliest occupation of the eastern Great Basin (i.e., either 14,300 or 11,700 cal B.P.; Table 2). Hypothetically, if the hydration rate is faster than predicted by the best-fit line, then the maximum hydration band represents a more recent date, while a slower rate of hydration would equate to an earlier date. Additionally, and assuming an occupation in the eastern Great Basin at 13,000 cal B.P., a fast hydration rate from Table 2 for Browns Bench obsidian would equate to a hydration band of 17.1 µ, and a slow rate would equate to a band of 15.3 µ. Because hydration rates are exponential curves, the width of the buffered hydration ages varies through time; i.e., the margin of error increases as the hydration thickness increases, and the largest calculated margins of error occur at the cultural hydration maximum. The largest hydration band, given a reasonable margin of error, represents a regional sample from published and unpublished sources.

The margin of error shown in Table 2 also compensates for any generational lag time between Paleoarchaic occupation of the eastern Great Basin and the use of an obsidian source. This paper assumes that the earliest inhabitants of the eastern Great Basin quickly located and utilized obsidian sources for flaked stone tools. The earliest occupants of the Great Basin were highly mobile and are thought to have utilized a large number of resources (Jones et al. 2003; Kelly and Todd 1988; Simms 2008; Smith 2010). In the process of locating and utilizing edible resources, there is no reason to assume that any number of obsidian or other toolstone sources were not also located, even if it took multiple generations. The margin of error used in the estimated rates for Paleoarchaic-era artifacts brackets a time span that would certainly cover multiple generations of immigrants into the eastern Great Basin.

Table 3

RUBY HYDRATION BAND DATA IN µ BY OBSIDIAN SOURCE

Source(s)	Sample Size	Minimum	Mean	Standard Deviation	Maximum
American Falls	2	6.15	7.29	–	8.42
Black Rock Area	1	–	2.72	–	–
Browns Bench	122	2.08	8.22	2.13	11.74
Browns Bench-Butte Valley Group A	5	6.03	8.44	2.08	12.30
Malad	112	1.28	3.92	1.85	8.69
Wildcat Hills	15	1.81	2.58	0.83	3.83
Wild Horse Canyon	1	–	11.34	–	–
Unknown Vitrophyre	1	–	7.70	–	–
Total	**259**	**1.28**	**6.16**	**2.99**	**12.30**

ASSESSING THE REVISED CHRONOMETRIC METHOD

Chronometric Comparisons

The accuracy of the hydration rate can be corroborated with site-specific comparisons between the hydration-derived dates and other dating methods used during the Ruby project (Mueller 2013; Omvig 2013). A total of 333 obsidian artifacts was recovered at 19 sites and 36 isolated finds (IFs) during Ruby. The obsidian artifacts were subjected to either trace element (sourcing) or hydration analyses (or both) by Northwest Research Obsidian Studies Laboratory. Roughly 20 percent of the artifacts (i.e., 74 of 333) did not have a measurable hydration band or they were not measured at the request of private landowners. The artifacts with measureable bands produced thicknesses as small as 1.3 microns from the Malad area and as large as 12.3 microns from the Browns Bench-Butte Valley Group A source (Table 3). The year that an artifact's hydration band was measured

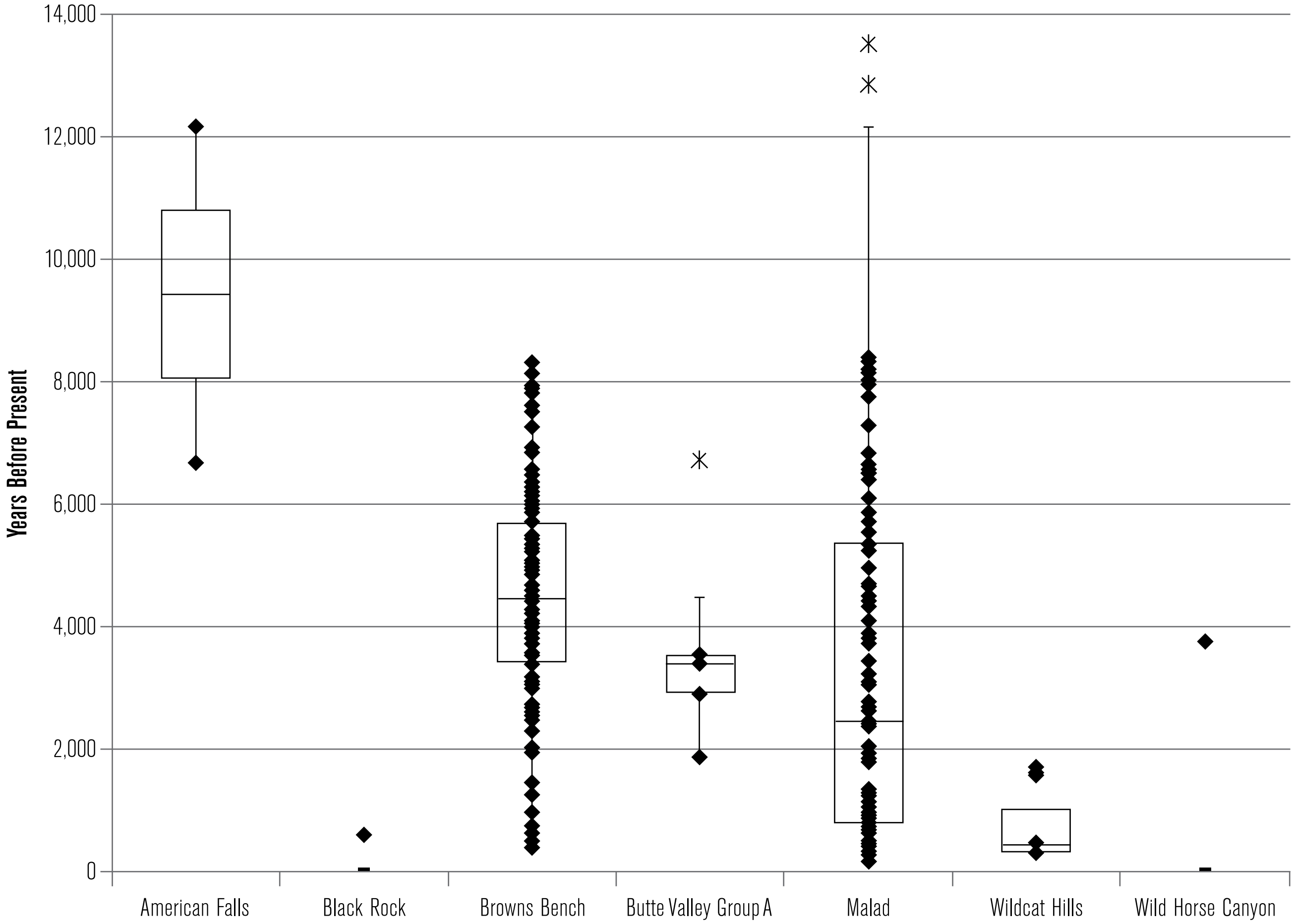

Figure 2. Box and whisker plots for hydration-estimated ages of Ruby obsidian samples.

can be calibrated to 1950 by subtracting the appropriate number of years from Equation 1 (King 2004). Thus, for the Ruby samples that were measured in 2010, 60 years were subtracted from Equation 1. In this way, all of the obsidian dates are equivalent to calibrated radiocarbon years, and the following obsidian dates are presented in years before present (i.e., 1950). When appropriately corrected, these hydration measurements can be compared against optically-stimulated luminescence (OSL) and radiocarbon dates recovered from excavations.

Utilizing the source-specific hydration rates in Table 1 and regional historic weather data from the Western Regional Climate Center's historical records (see http://www.wrcc.dri.edu) as applied via Equations 2–4, each of the Ruby obsidian artifacts with a measureable hydration band and an identified source was assigned to an age range via Equation 5 (Fig. 2). The historic weather data for each site, which were based on nearby weather stations that had greater than 50 years of data and were in similar elevational and ecological settings, were used to create site-specific EHTs. Because of sparse and discontinuous historical weather collection in northern Utah and region-wide weather patterns, historical weather data from Nevada were used for sites west of the Grouse Creek Mountains. The development of artifact-specific EHTs is, perhaps, the most difficult part of applying the estimated hydration rate. Two factors are likely to be the cause of any errors in EHTs—poor historical weather data near the pipeline route and the environment-moderating effects of the Great Salt Lake as its margins changed throughout prehistory (cf. Rogers 2008c). However, recent paleoenvironmental modeling by Eckerle and others (2012:82) indicates that the annual

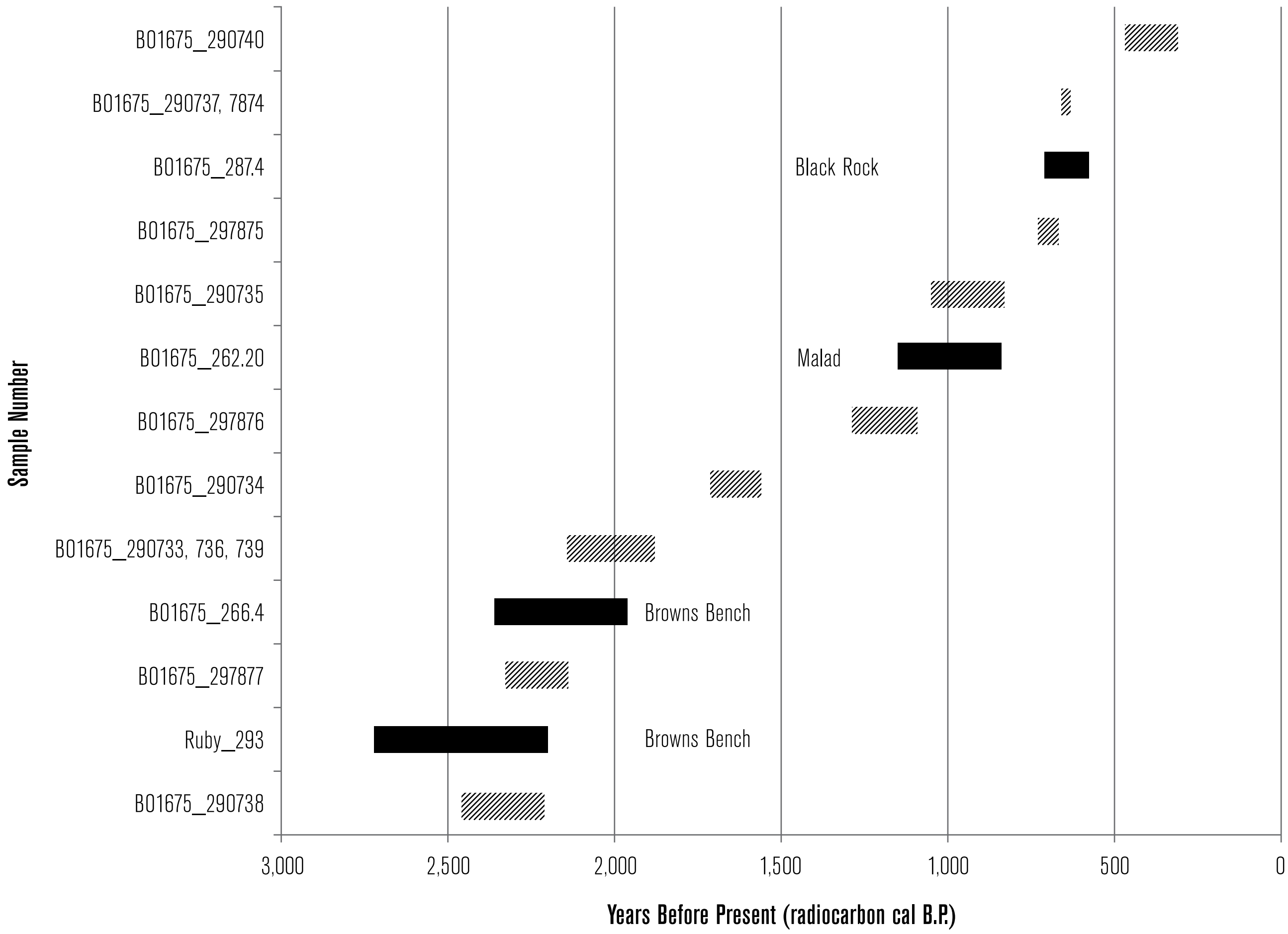

Figure 3. Comparison of radiocarbon (hatched) and obsidian hydration dates (solid) from site 42BO1675.

effective precipitation near the northern edge of the Great Salt Lake fluctuated near modern values for most of the last 11,000 years and certainly since 5,500 cal B.P. If the EHT also fluctuated near modern levels for most of prehistory, then any changes in the EHTs will have only a minimal impact on the calculations used here. If the Great Salt Lake did not have a moderating affect on the environment, and because a positive correlation exists between the thickness of a hydration band and the likelihood of introducing errors into calculated EHTs (Rogers 2008c), the expanding age buffers shown above help minimize potential errors in the estimated age ranges.

Strong correlations exist between the hydration rates in Table 1 and other chronometric methods used during the Ruby project (Mueller 2013; Omvig 2013). Thermal features at site 42BO1675 provided radiocarbon dates that ranged from 2,500 to 300 cal B.P. (Omvig 2013). Using the regionally-constructed hydration rates and artifact-specific EHT calculations, four obsidian hydration dates from three different sources (i.e., Black Rock, Browns Bench, and Malad) strongly conform to those radiocarbon dates (Fig. 3). Additionally, the cultural remains at site 42BO1751 were bracketed by two optically-stimulated luminescence (OSL) dates of roughly 7,250 and 4,600 cal B.P. (Mueller 2013). With few exceptions, the 26 obsidian hydration dates, which are based on the regionally-sampled Browns Bench obsidian hydration rate, conform to those OSL dates (Fig. 4). The comparison of different dating techniques at multiple sites does not provide absolute proof of accuracy for the hydration rates in Table 1, though it certainly increases confidence in the results.

The radiocarbon and OSL dates could have served as the foundation for the development of a project-specific

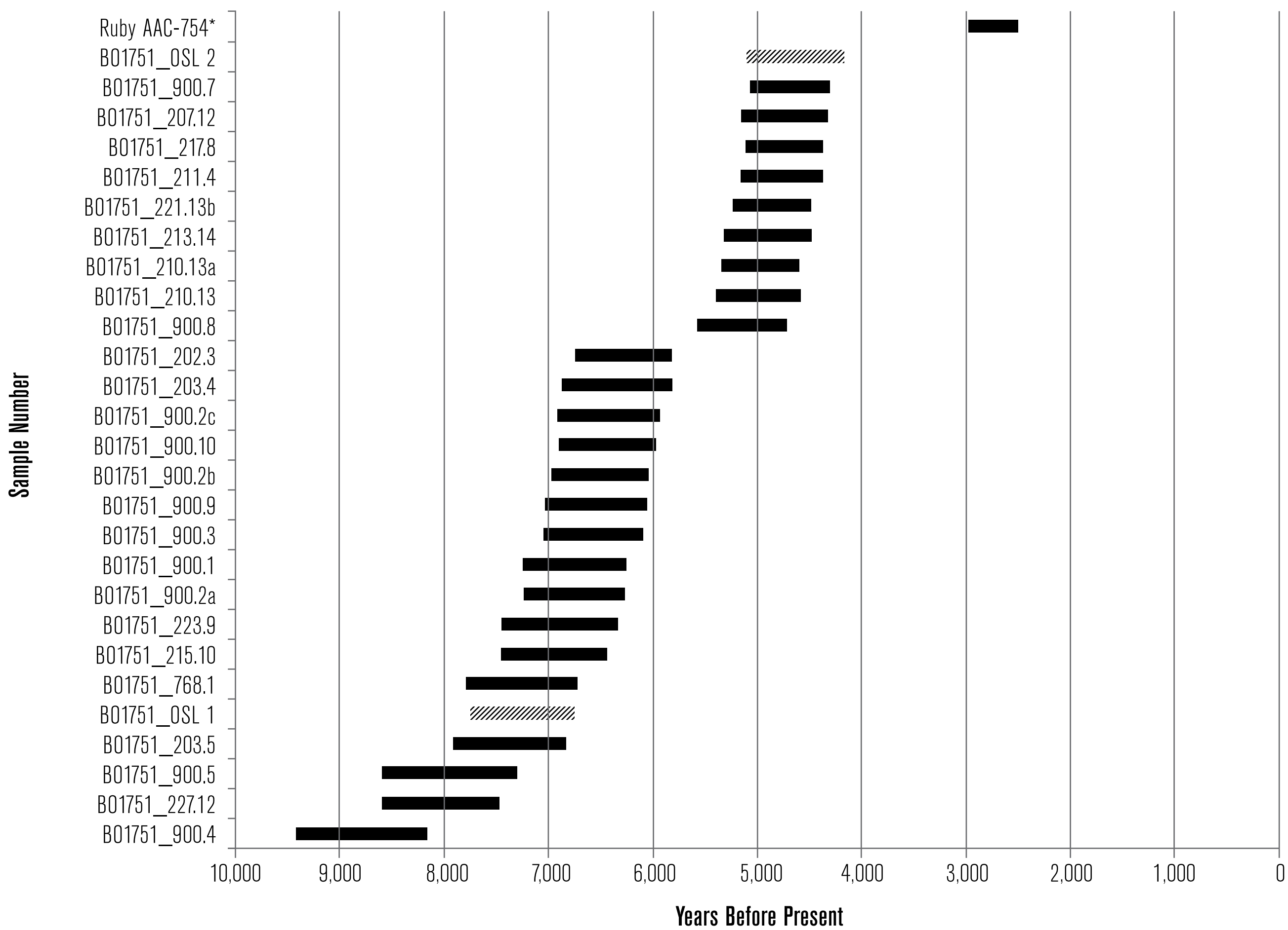

Figure 4. Comparison of OSL (hatched) and obsidian hydration dates (solid) at site 42BO1751.

best-fit hydration line, though it would have been less specific than the hydration rate developed from regional samples. The pairing of hydrated obsidian artifacts with radiocarbon, or the OSL in this case, is a typical method for estimating project-wide hydration rates (Eerkens et al. 2008; King 2004). If such had been done for Ruby, the artifacts at site 42BO1751 would have likely been given a median OSL date as the basis for the hydration rate. The multimodal distribution of hydration thicknesses at 42BO1751 would have highlighted the presence of multiple occupations (Jones and Beck 1990), though it would have lacked the temporal distinctiveness that is shown with the Browns Bench hydration rate from Table 1 (Mueller 2013). Additionally, the radiocarbon dates from site 42BO1675 are stratigraphically mixed and could not be used to create a site-specific, let alone a project-specific, hydration rate (Omvig 2013). For the Ruby project, neither OSL nor radiocarbon dates would have allowed for the creation of a satisfactory project-specific hydration rate. Alternatively, the creation of a hydration rate from regional obsidian samples is shown to strongly correlate with both the radiocarbon and OSL dates recovered from excavations (Mueller 2013; Omvig 2013).

Projectile Point Comparison

The revised chronometric method can be compared against published hydration bands on projectile points. Because projectile points were not used to construct the hydration rate, they can be used as a confirmation of its applicability. Specifically, band thickness data from Browns Bench (Beck and Jones 1990; Hockett 1995) and Wild Horse Canyon (Hull and Bevill 1994; Seddon 2005) obsidian projectile points can be used to verify the utility of two of the estimated hydration rates.

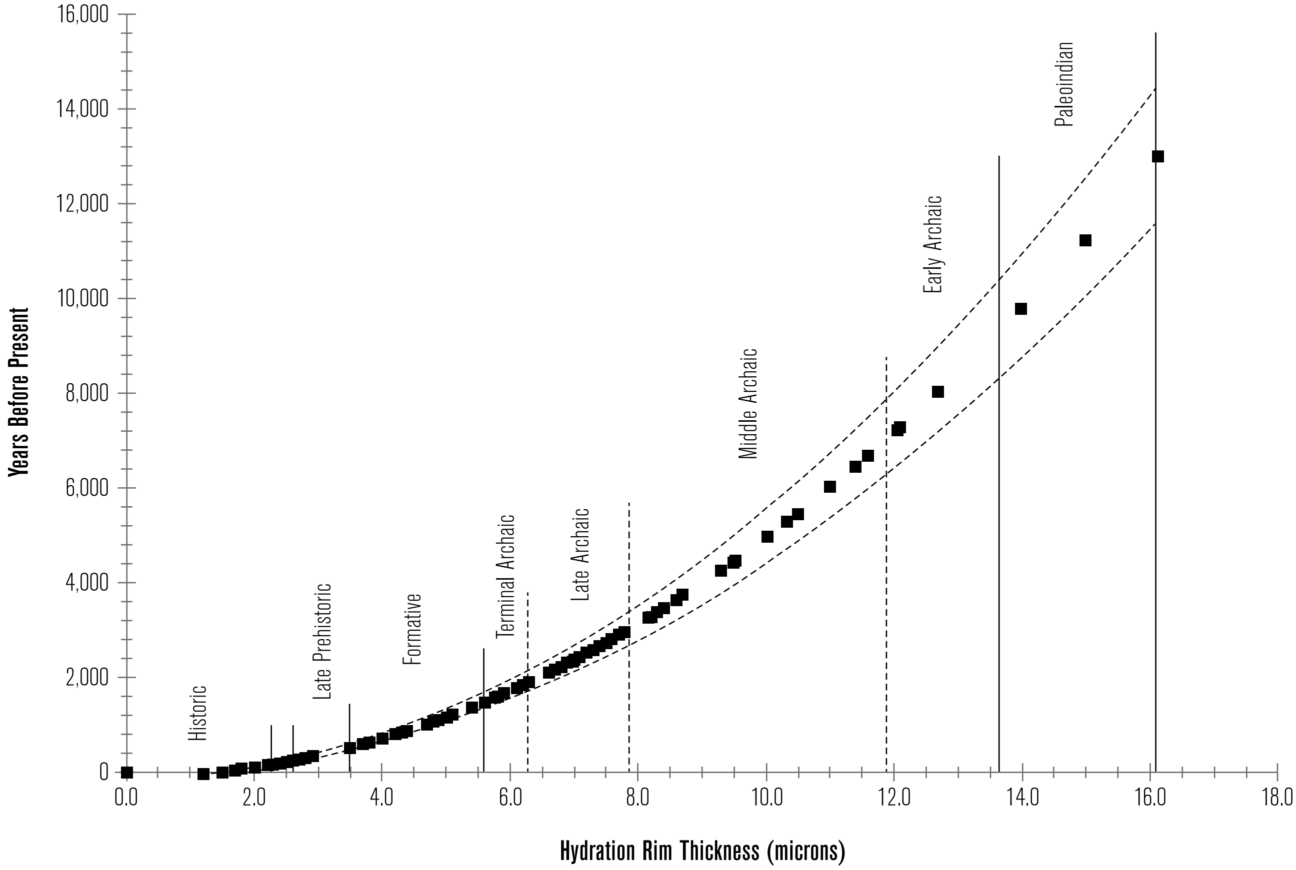

Figure 5. EHT-corrected hydration thicknesses with buffered age ranges from Browns Bench-sourced projectile points.

Browns Bench Projectile Point Chronology

Browns Bench obsidian is frequently recovered in eastern Nevada and western Utah, and 109 published band measurements from Hockett (1995) and Beck and Jones (1990) were corrected for their EHTs following Rogers (2008c). The standard hydration temperature or EHT for artifacts from the Long Valley area (Beck and Jones 1990), which includes the hydration band maximum, is 15.4°C., based on 122 years of weather station data from the Western Regional Climate Center's historical records (see http://www.wrcc.dri.edu). An EHT was constructed for each projectile point based on its specific location relative to topography and environment. If a specific location was not provided to determine the EHT of Browns Bench projectile points, then 15.4°C. was used in Equation 4, as that is also the average EHT of 26 weather stations across northeastern Nevada.

When the band data from published projectile points are corrected for their respective EHTs and the age is calculated (Fig. 5), the resulting projectile point time periods clearly conform to expectations based on previous archaeological chronologies (Fig. 6 and Table 4). Outliers are apparent in all stylistic categories, but those are to be expected. Thinner than expected outliers can be explained by wildfires and other environmental vagaries (e.g., changing vegetation) that limit or reset the hydration band (Loyd et al. 2002; Rogers 2007a, 2008b). Thicker than average hydration bands for projectile points may be a product of the reworking of older points, environmental vagaries, earlier attempts at a point style (Lyman et al. 2008, 2009), or simply a result of mistyped projectile points. Using the estimated hydration rate, the majority of the Desert Side-notched points were dated to the Historic (175– 50 cal B.P.) and Protohistoric (1,750–350 cal B.P.) periods (26 and 42 percent, respectively). Seventy-three percent of the Rosegate points were confined to the Formative era (1,550–600 cal B.P.), with caveats regarding the older

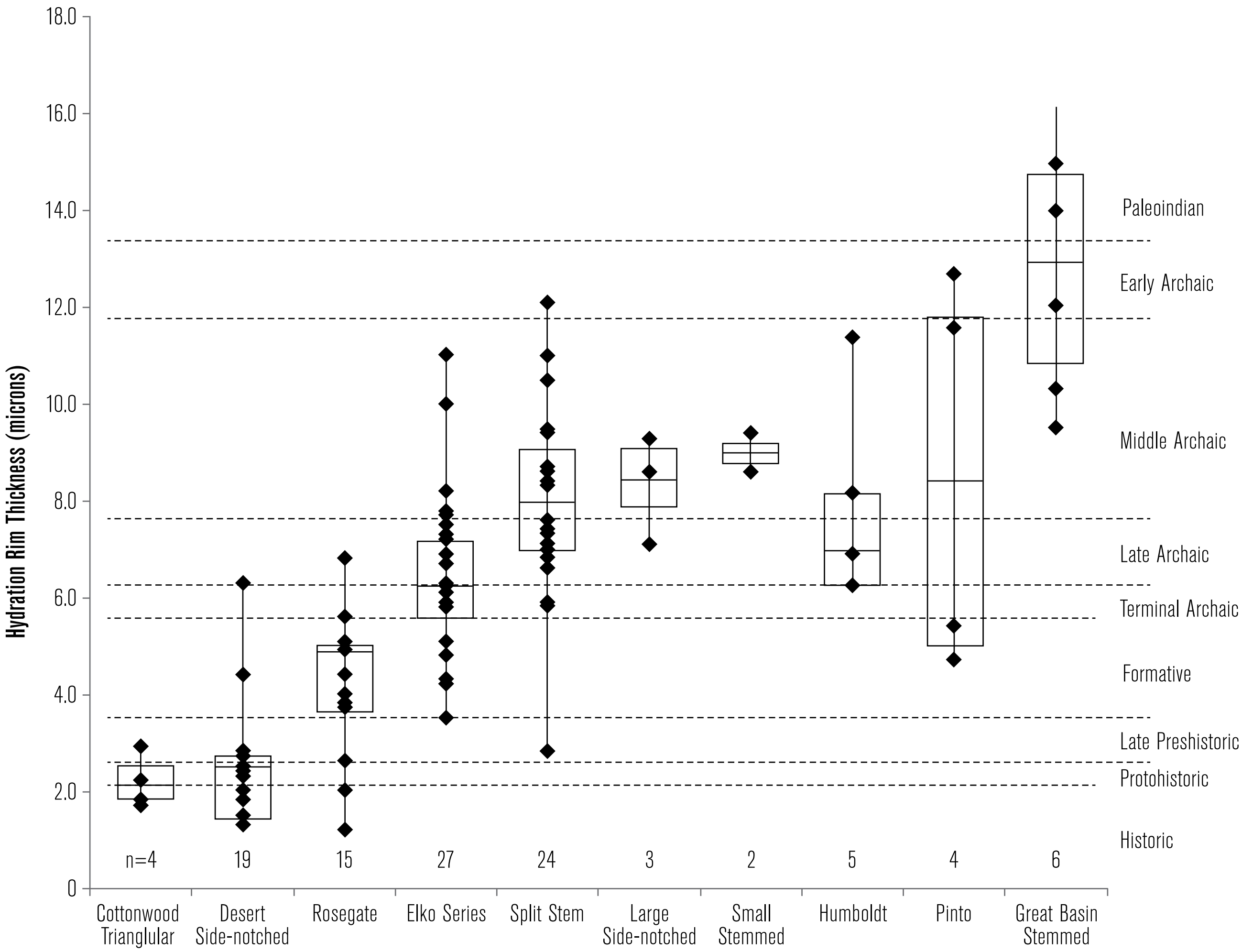

Figure 6. Browns Bench-sourced projectile point styles from northeastern Nevada with a box-and-whisker interquartile range.

and younger outliers being a product of environmental or stylistic vagaries. Similarly, 70 percent of the Elko series points were well-confined to the Late and Terminal Archaic eras (3,000–2,000 cal B.P. and 2,000–1,550 cal B.P., respectively) and 83 percent of the Split-stem points are Middle (7,000–3,000 cal B.P.) and Late Archaic era points. The overlap of the Elko and Rosegate points highlights the technological transition from atlatl to bow and its impact on projectile point styles that is described by Lyman et al. (2008) for Gatecliff Shelter.

Wild Horse Canyon Projectile Point Chronology

Wild Horse Canyon obsidian is frequently recovered in west-central Utah, and 212 published projectile point band measurements are used here (Hull and Bevill 1994; Seddon 2001b). The artifact-specific EHT for the thickest Wild Horse Canyon band was determined to be 10.2°C based on 123 years of weather station data from the Western Regional Climate Centers historical records (http://www.wrcc.dri.edu). As with the Browns Bench projectile points, artifact-specific EHTs were calculated for Wild Horse Canyon projectile points if locations could be culled from the literature. If a specific location was not provided to determine the EHT for the projectile points, then 9.6°C. was used as the average EHT in the Black Rock and Milford areas of Utah.

When the band data from published projectile points are corrected for EHTs and the age is calculated (Fig. 7), the results clearly conform to expectations based on previous archaeological chronologies (Fig. 8 and Table 4). The Desert Side-notched points are typically dated to the Protohistoric or Historic eras, where 81

Table 4

AGE RANGES OF SELECT EASTERN GREAT BASIN PROJECTILE POINTS[a]

Obsidian Projectile Point	n	Hydration Age Range at 1 Standard Deviation	Justice's (2002a, b) Age Range	Holmer's (1986) Age Range
Cottonwood Triangular	5	80–450[b]	200–900	100–600
Desert Side-notched	35	Present–600	Present–650	200–650
Small Side-notched[c]	6	350–600[b]	600–1,120	650–1,000
Rosegate series	112	300–1,000	600–1,400	800–1,500
Elko Series	77	1,100–3,350	1,200–3,800	800–8,800[e]
Large side-notched	15	1,550–3,600[b]	4,300–8,900[d]	3,900–5,000
Gypsum and other stemmed	17	1,550–4,150[b]	2,900–4,500	1,390–5,200
Humboldt	11	1,250–4,450[b]	1,400–8,900	6,800–8,900
Pinto and Gatecliff[f]	32	1,450–5,100	3,500–8,300	3,500–9,300
Great Basin Stemmed[g]	7	4,000–11,200[b]	8,900–12,900	9,300–12,000

[a]All ages are presented in cal B.P., with Justice's (2002a, 2002b) and Holmer's (1986) dates converted using Fairbanks0107 calibration curve (Fairbanks et al. 2005).

[b]Sample is too small to have a high level of confidence in the results.

[c]Includes the Nawthis Side-notched, Uinta Side-notched, and Bear River Side-notched.

[d]Includes San Rafael (5,300–4,300 cal B.P.), Northern Side-notched (8,900–5,700 cal B.P.) and Sudden Side-notched (7,400–4,500 cal B.P.).

[e]Holmer (1986) identifies three florescences of Elko from 2,000–800, 5,700–3,200, and 8,900–7,400 cal B.P.

[f]Holmer (1986) and Justice (2002a:86) divide this category into early and late variants of Pinto and Gatecliff, respectively.

[g]Holmer (1986) and Justice (2002a:86) include Lake Mohave points as a Great Basin Stemmed variant.

percent date from 350 to 50 cal B.P. The Eastgate, Rose Spring, and Rosegate interquartile ranges are nearly indistinguishable (Fig. 8), and 78 percent of the aggregated Rosegate types are mainly Formative and Late Prehistoric (1,550–600 cal B.P. and 600–350 cal B.P., respectively). Ninety-four percent of the Elko series projectile points date from the Middle Archaic through the Formative eras (7,000–600 cal B.P.). The overlap of the Elko and Rosegate series points again highlights the atlatl to bow technological transition (Lyman et al. 2008; Lyman et al. 2009), even though the Browns Bench and Wild Horse Canyon hydration rates are different.

Aggregated Chronology

Aggregating the age estimates for Browns Bench and Wild Horse Canyon projectile points allows for an assessment of their utility as chronological markers. While the hydration rates are not themselves directly comparable, the thicknesses can be converted to chronometric ages using the source-specific estimated rates. Once converted to dates, the projectile points can be aggregated into a single dataset (Fig. 9). That dataset of 300-plus projectile points from the eastern Great Basin can then be used to support or refute previous projectile point typologies (Table 4).

Many of the aggregated obsidian projectile point age ranges strongly align with the most commonly used chronological references for the eastern Great Basin (Table 4). Cottonwood Triangular points (550–80 cal B.P.) are equivalent to Holmer's (1986) age ranges as well as to the later portion of Justice's (2002a) dates. Eighty-three percent of the Desert Side-notched points strongly match both references. Half of the Rosegate points coincide with the chronologies of Justice (2002a) and Holmer (1986), although (with two exceptions) the remainder are younger than might be expected. Seventy-nine percent of the Elko series dates match Justice's (2002b) more restrictive Late Archaic dates, and with four younger exceptions, the rest fall within Holmer's (1986) long temporal span. The stemmed points, which include Gypsum, are highly consistent (76 percent) with typically referenced dates (Holmer 1986; Justice 2002a). Humboldt points coincide with the later portion of Justice's (2002a) dates (82 percent), but clearly do not match Holmer's (1986) dates. Six of the 10 projectile point groups in Table 4 are strong matches to the most typically-used temporal references (Holmer 1986; Justice 2002a).

Some of the projectile point categories do not match traditional chronological periods (Table 4). The small side-notched points that are typically associated with Formative occupations (i.e., Nawthis, Bear River, and Uinta points), and San Rafael or other large side-notched points, are—according to the estimated hydration rate—both later in time than is traditionally believed. The dates for Humboldt points do not overlap with Holmer's (1986) Humboldt, though they do with the dates for Holmer's (1986:101) McKean complex between 5,000–3,000 cal B.P. Thirty-three percent of the Pinto/Gatecliff category aligns with the later portion of both Holmer's (1986) and Justice's (2002a) age ranges, which is closer to the age range of Gatecliff (i.e., 5,000–3,300 cal B.P.). The Great Basin Stemmed points tend to be later in time than should be expected (57 percent). The projectile point categories that do not align well with previously established dates tend to represent

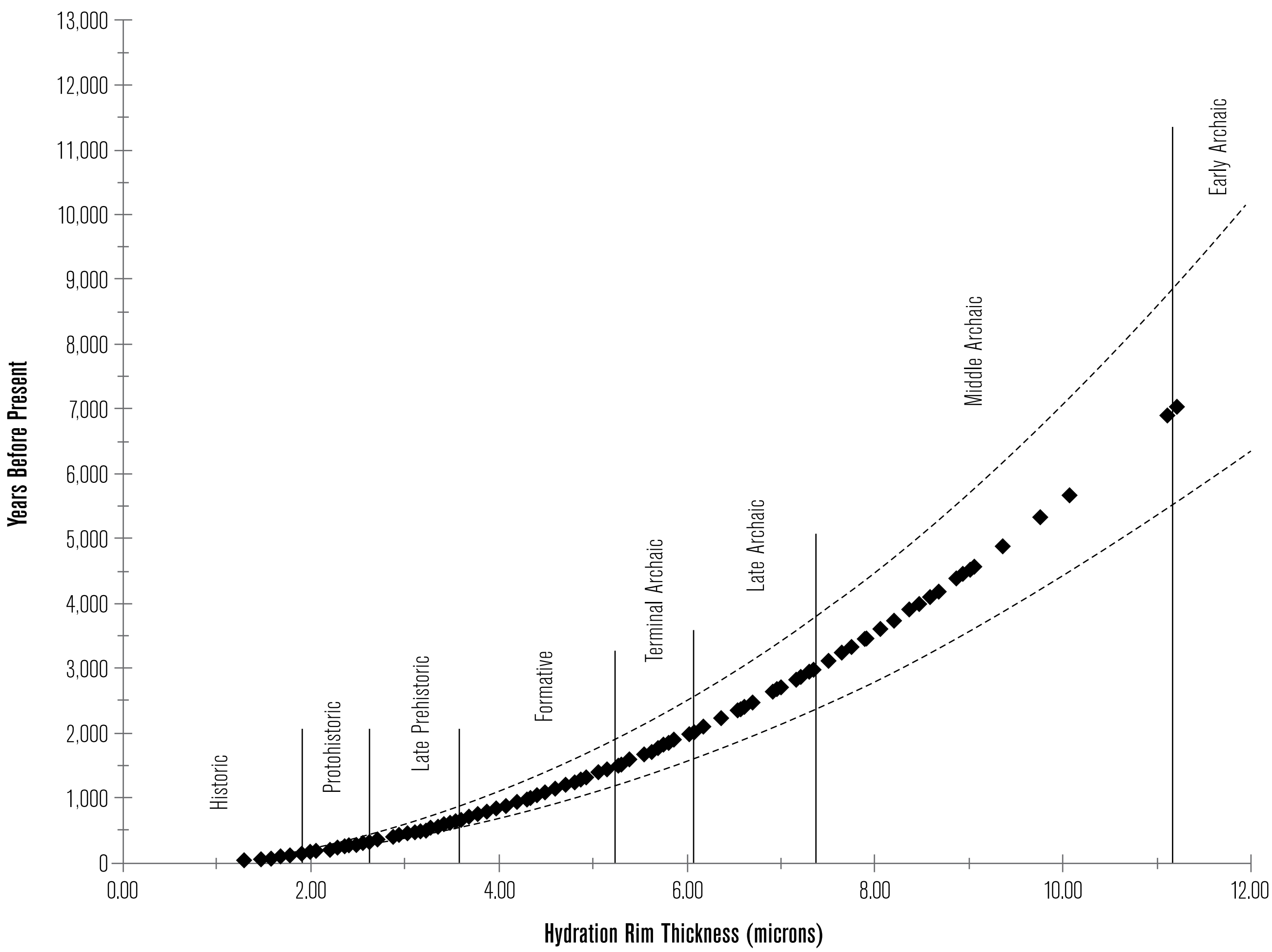

Figure 7. EHT-corrected hydration thicknesses with buffered age ranges from Wild Horse Canyon-sourced projectile points.

younger than expected dates, which may suggest that the hydration thickness was reset by wild fires (Loyd et al. 2002), or that the traditional chronological periods should be expanded. However, as indicated in Table 4, the small sample sizes of projectile points are the largest likely contributing factor to the discrepancies.

Given caveats regarding the size of the samples used here, the aggregated projectile point data for Browns Bench and Wild Horse Canyon appear appropriate when compared to traditionally utilized chronological periods. A comparison of dates derived from hydration thicknesses to typical projectile point date ranges does not, however, guarantee the accuracy of the estimated source-specific hydration rates constructed above, though it does suggest there is a high degree of correlation. When the dataset of over 300 projectile points from the eastern Great Basin is compared with a regionally-appropriate hydration rate, the resulting date ranges generally support previous projectile point chronologies (Table 4).

APPLYING THE HYDRATION RATES TO THE DISCUSSION OF THE RUBY SAMPLE

Taken as a single assemblage that ignores the poor American Falls dataset and the unknown vitrophyre, the Ruby obsidian sample indicates that persistent occupation of northern Utah occurred during the Early Archaic period (9,000–7,000 cal B.P.), at roughly 8,400 cal B.P., up to the Protohistoric (Shoshone) period (350–175 cal B.P. or A.D. 1600–1776; Fig. 2). Three data points in the Malad assemblage, which are from separate sites and isolated finds (IFs), suggest an earlier Paleoarchaic occupation related to those described by others in

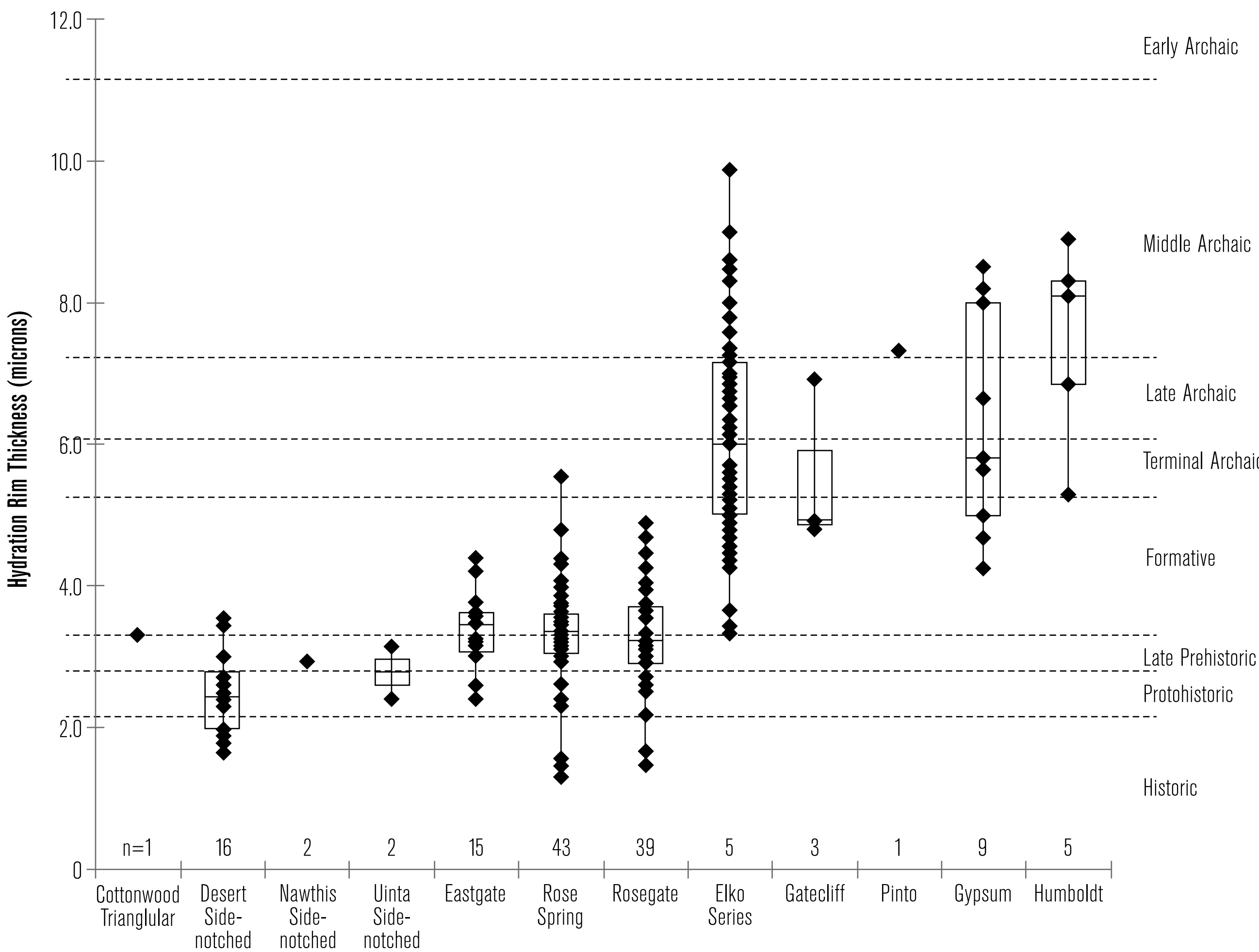

Figure 8. Wild Horse Canyon-sourced projectile point styles from west-central Utah overlain with a box-and-whisker interquartile range.

northern Utah (Goebel et al. 2007; Hockett et al. 2008; Russell and Stuart 2002; Simms 2008). The Early Archaic period occupation of northern Utah likely reflects a stable adaptation as a response to paleoenvironmental changes. Recent work indicates that lake levels reached a high in the Bonneville Basin by about 8,400 cal B.P. (Eckerle et al. 2012; Patrickson et al. 2010). Faunal remains from Homestead Cave support an interpretation of cool and moist environmental conditions during this time, though the Early Archaic was still warmer than the preceding Paleoarchaic period (Madsen et al. 2001). The 8,400 cal B.P. high stand of the Great Salt Lake was followed by a warming trend and a decrease in effective moisture that may have isolated economically-important plants and animals in wetlands along the shore of the Great Salt Lake (Madsen et al. 2001; Simms 2008). The shifting lake margins and effective precipitation regimes in western Utah likely spurred shifts in subsistence and settlement patterns.

Dominant settlement and subsistence patterns in Utah are typically tied to pluvial resources (Madsen et al. 2001; Schmitt et al. 2002; Schroedl 1991; Simms 2008). Paleoarchaic Western Stemmed Tradition sites (11,500–9,500 cal B.P.) have been linked to large, extinct lakes and vast wetlands in the Great Salt Lake Desert of west-central Utah (Duke 2011; Haynes 1996; Schroedl 1991). After the wetlands of west-central Utah dried and people abandoned the area during the Early Archaic (Duke 2011:80), the obsidian hydration results indicate that people persistently occupied or used the northern

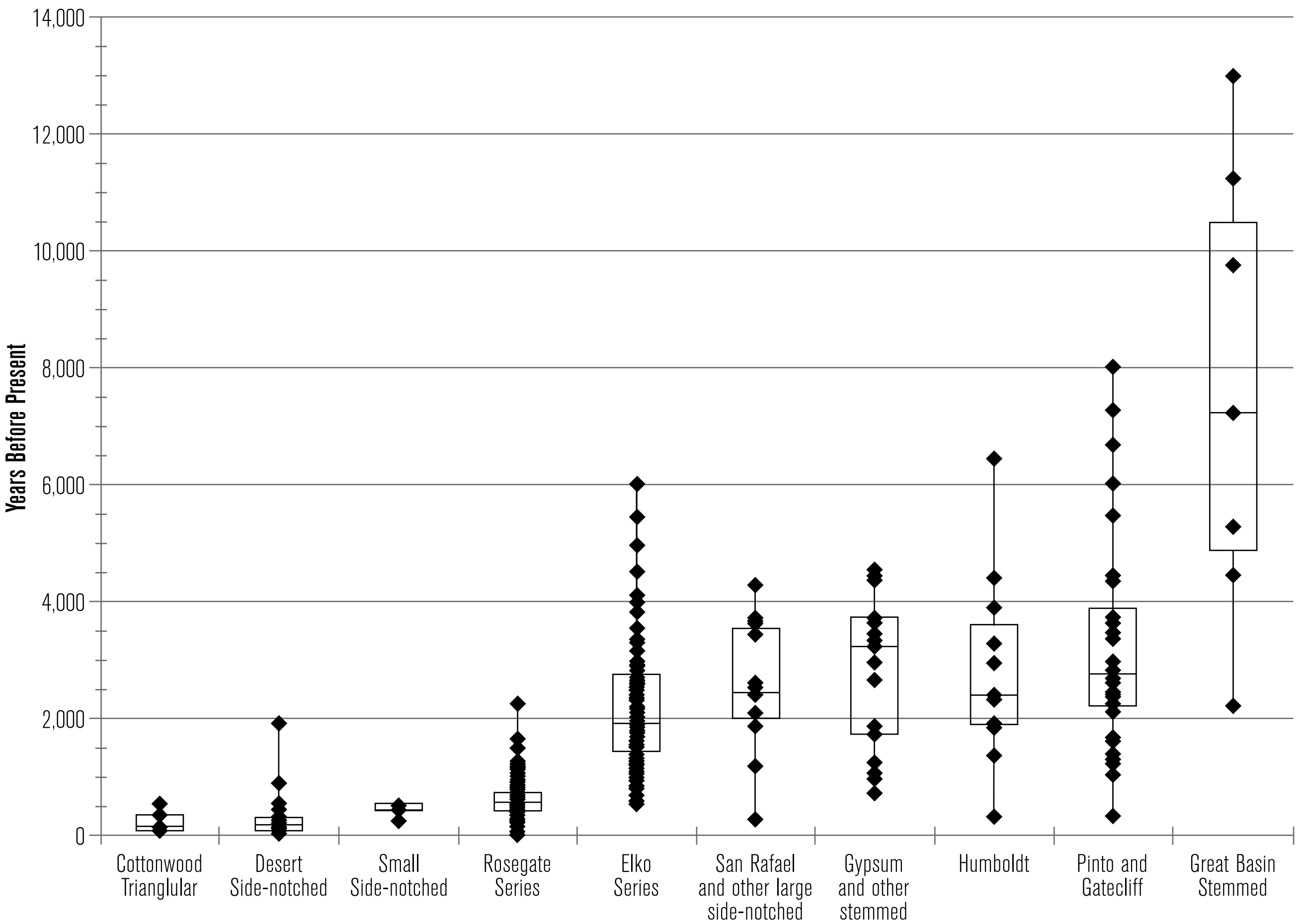

Figure 9. Obsidian projectile point styles from the eastern Great Basin with a box-and-whisker interquartile range.

margin of the Great Salt Lake. Without overemphasizing the environmental and technological changes that marked the Paleoarchaic-Early Archaic transition, the obsidian hydration data again emphasize the way in which Archaic populations occupied the eastern Great Basin at roughly 8,400 cal B.P. (Schroedl 1991).

SUMMARY

The delineation of an obsidian hydration rate for obsidian sources used in northern Utah (e.g., Malad, American Falls, and Browns Bench) was an important research goal of the Ruby Data Recovery Project (Greubel et al. 2010:52). This paper outlines a replicable technique for constructing regionally-appropriate hydration rates. The paper began with a discussion of current trends in obsidian dating, both relative and absolute, and the potential shortcomings of each approach. An alternative method of circumventing some of the recurring problems of both techniques was proposed. The creation of source-specific chronologies was done for all of the obsidian sources identified in a sample gathered along the Ruby Pipeline route, which included the Browns Bench, American Falls, Malad, Wildcat Hills, Wild Horse Canyon, and the Black Rock areas (Fig. 1). Some of the sources (i.e., American Falls, Wildcat Hills, Browns Bench Butte Valley Group A) suffer from small sample sizes, and as a consequence the estimated hydration rates are likely in error (Table 1). The hydration rates were then compared to two different dating techniques at two different sites in northern Utah (Mueller 2013; Omvig 2013). The results indicate a strong degree of consistency with both radiocarbon and OSL dating techniques. The estimated rate was then applied to a suite of projectile point types from Browns Bench and Wild Horse Canyon to test its efficacy. Overall, the results strongly agree with well-accepted projectile point date ranges, which can be viewed as support for the methodology described above.

Neither of those approaches, however, ensures that the rates are 100 percent accurate. For these rates to be accurate, archaeologists should continue to search for the thickest cultural hydration bands (i.e., x) and earliest occupations in the eastern Great Basin (i.e., t) in an effort to confirm k. Continued application of the estimated hydration rates at sites across the Great Basin (with appropriate corrections for regional weather) will be necessary to increase the sample sizes of various projectile points for chronometric determinations and to provide an appropriate test for the rates described here. Additionally, it is unclear how variation in the prehistoric climate of the region might affect the calculations of artifact/site-specific EHTs. If the hydration rates prove to be in error after further application, the mathematical foundation of the estimated rates makes them easy to correct at a source-specific level. While the hydration rates are admittedly conjectural, it appears that strong source-specific obsidian hydration rates can be created with regional environmental and cultural data.

In general, the Ruby Pipeline project was structured to address diachronic and synchronic research questions of prehistoric and historical importance in northern Utah, questions in which the obsidian hydration rates comprised a basic element. The project emphasized the systematic collecting and testing of obsidian through all phases of fieldwork (Greubel et al. 2010; Landt et al. 2009; Mueller et al. 2009; Reed et al. 2012). While cherts and quartzites were the dominant raw materials encountered along the route of the pipeline in Utah, over 300 pieces of obsidian were collected from 19 sites and 36 IFs. The Ruby dataset, while a relatively small sample in a regional sense, spurred ideas that can be applied to diachronic questions beyond northern Utah. Some of the estimated hydration rates presented here (i.e., Black Rock, Browns Bench, Malad, Wild Horse Canyon) have a considerable potential for facilitating the further assessment of regional chronologies across the Great Basin. The method described here has the potential to gather widely dispersed temporal information from many archaeological sites across Utah, Nevada, southern Idaho, and California. It also has temporal depth, in that it can provide new information on sites that are 13,000 years old as well as on historical sites with ethnographic Shoshone habitations. The data can be applied to both old museum collections as well as materials from new archaeological surveys. As such, information gathered during the pipeline project could provide significant synchronic and diachronic information on many sites in the Great Basin.

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