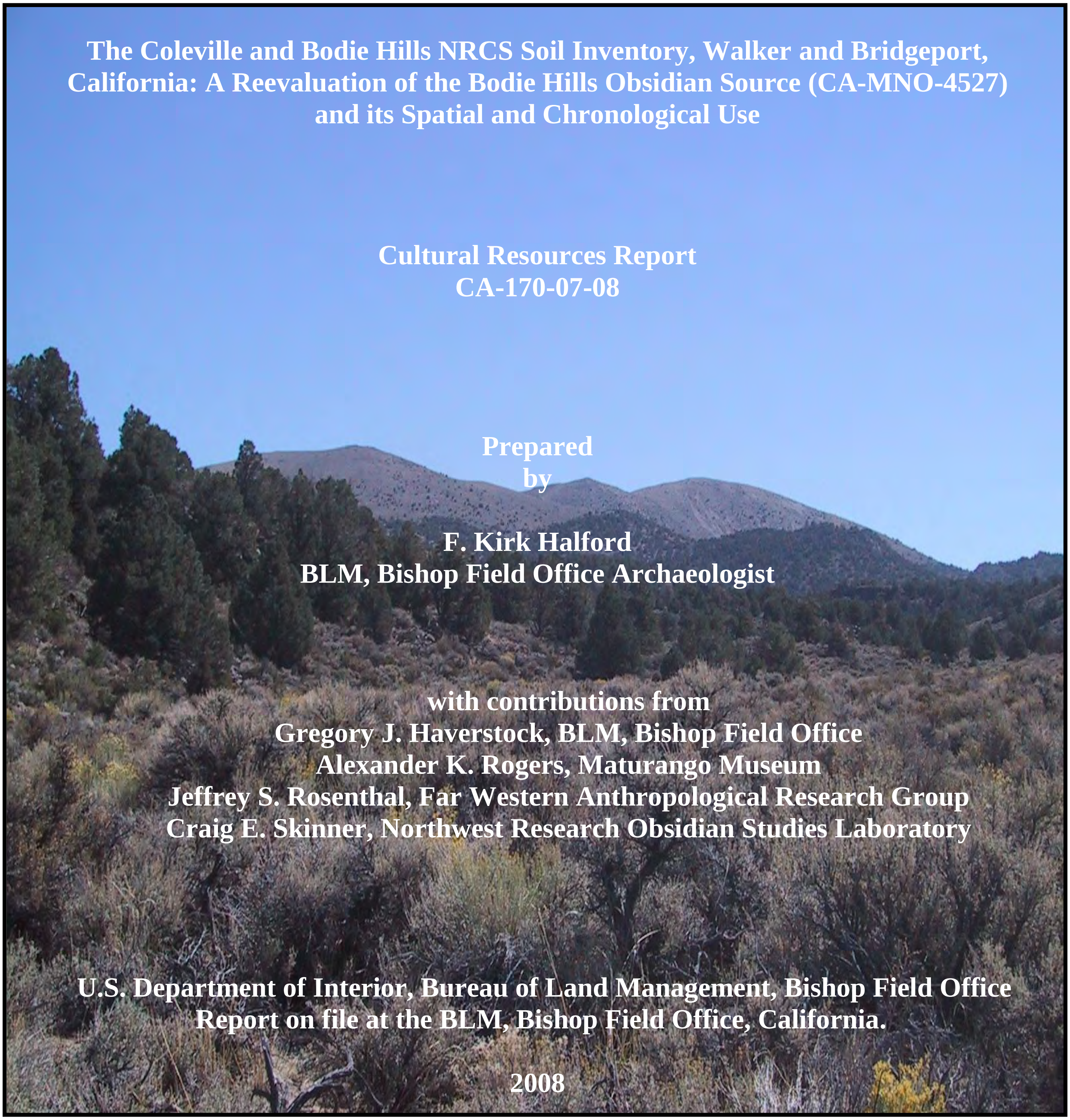


The Coleville and Bodie Hills NRCS Soil Inventory, Walker and Bridgeport, California: A Reevaluation of the Bodie Hills Obsidian Source (CA-MNO-4527) and its Spatial and Chronological Use

Cultural Resources Report
CA-170-07-08

Prepared
by

F. Kirk Halford
BLM, Bishop Field Office Archaeologist

with contributions from
Gregory J. Haverstock, BLM, Bishop Field Office
Alexander K. Rogers, Maturango Museum
Jeffrey S. Rosenthal, Far Western Anthropological Research Group
Craig E. Skinner, Northwest Research Obsidian Studies Laboratory

U.S. Department of Interior, Bureau of Land Management, Bishop Field Office
Report on file at the BLM, Bishop Field Office, California.

2008

The Coleville and Bodie Hills NRCS Soil Inventory, Walker and Bridgeport, California: A Reevaluation of the Bodie Hills Obsidian Source (CA-MNO-4527) and its Spatial and Chronological Use

Cultural Resources Report
CA-170-07-08

Prepared
by

F. Kirk Halford
BLM, Bishop Field Office Archaeologist

with contributions from
Gregory J. Haverstock, BLM, Bishop Field Office
Alexander K. Rogers, Maturango Museum
Jeffrey S. Rosenthal, Far Western Anthropological Research Group
Craig E. Skinner, Northwest Research Obsidian Studies Laboratory

U.S. Department of Interior, Bureau of Land Management, Bishop Field Office
Report on file at the BLM, Bishop Field Office, California.

2008

Acknowledgements

This report has been a long time in development; seventeen years actually. That was the first time I set foot in the Bodie Hills and from that time the area has become my focal interest for advancing research and just for the sheer fact of exceedingly abundant and great archaeology. As a federal archaeologist the opportunities don't present themselves often to do research level work, but when they do I jump at the chance. So this report represents an accumulation of those opportunities wrapped into many years of on the ground work in the Bodie Hills with scientific analyses added when the chance arose. This project represents one of those events, with an opportunity to tie the many years together in a more meaningful analysis. The greatest accomplishment is that we have fully mapped the greater Bodie Hills Obsidian Source or District (CA-MNO-4527), introduced here, and provide compelling evidence for substantive early Holocene procurement and use of Bodie obsidian.

This project has benefitted from lots of fire side and conference room chats over the years with friends and colleagues and, of course, all the work that has come before. Certain individuals were pivotal to this project including Greg Haverstock, who loves chasing after obsidian as much as I do and helped with two years of forays to define and map the Bodie Hills obsidian landscape. Craig Skinner of the Northwest Research Obsidian Studies Laboratory completed the obsidian hydration analyses and has done all my Bodie samples over the years. Geologists Angela Jayko and Dave Wagner spent a day in the field providing thoughtful insights about the formational processes of the Bodie Hills source. Jeff Rosenthal, of Far Western Anthropological Research, shared freely of his data and his time in discussions, and his and colleagues' works on the western Sierran front were a foundation for this report. Finally, Sandy Rogers, of Maturango Museum, applied his sophisticated and evolving EHT formula to the analyses and wrote two manuscripts of the results for this report.

This report has greatly benefitted from all, but any of its errors are mine alone to account for. It's a work in progress, maybe seventeen more years.

Table of Contents

Table of Contents

Page

Figures

Table of Contents

Page

Tables

Appendices

Management Summary

This report addresses archaeological evaluations conducted for the NRCS/BLM Soil Inventory. The proposed project is to excavate 64 temporary 24” wide x 6’ long x 5’ deep soil pits on lands administered by the Bureau of Land Management, Bishop Field Office (BLM) in cooperation with the Natural Resources Conservation Service (NRCS). Ten pits were proposed in the Colville Management area and 54 in the Bodie Hills Management area (Figures 1 and 2).

Each soil pit location was surveyed using a 10 meter buffer around the backhoe pit and a 20 meter wide corridor for access from existing roads to the pit. No cultural resource values were recorded in the 10 Coleville pit locations. Of the 54 locations proposed in the Bodie Hills area, 23 pits had no associated cultural resources, 5 pits were relocated to avoid cultural resource values, 13 pits are located within the Dry Lakes Plateau National Register District (DLP), 13 pits were found to be within the Bodie Hills obsidian quarry/cobble flow area and 1 pit was dropped due to wildlife concerns. None of the pits on the DLP were within sites, but were monitored during project implementation. Controlled excavations and surface collections were undertaken at the 13 pits found within the greater Bodie Hills (BH) obsidian quarry (CA-MNO-4527) on both the west and east flanks of the main and Bodie Hills West (BHW) sources (Figure 3).

The Bodie obsidian deposits (CA-MNO-4527) consist of the 1462 acre main Bodie Hills obsidian source recorded by Singer and Ericson (1977), new sources identified by the author in 2000 and 2008, and reported here as the BHW (53 acres) and Bodie Hills North (BHN, 30 acres) sources, and 2132 acres of cobble flows that originate mainly from the BHW source and flow down the alluvial fans and drainages to Bridgeport Valley to the west (Figures 4-8). The cobble flows are an expansive area of Bodie Hills obsidian deposited by alluvial activity, where prehistoric peoples tested and quarried the cobbles for tool production. In sum, over 2215 acres (8.96 km^2) of previously unreported obsidian source material was recorded as a result of this project, creating a 3677 acre (14.9 km^2) district of obsidian deposits that were exploited in prehistory.

A no adverse effect determination was rendered for the pits within the DLP National Register District and subsequently only one pit was sampled on the Plateau during soil analyses. A no adverse effect determination was also rendered for the 13 pits within the Bodies Hills obsidian flow following test excavations. Subsequently, only 8 of these pits were sampled for the soils analyses.

Introduction

This document reports the findings of Class III archaeological surveys at 64 soil pits locations proposed for sampling within the BLM, Bishop Field Office, Coleville and Bodie Hills Management Units (Figures 1 and 2). The pits were excavated with a truck mounted backhoe and each measured roughly 24” wide x 6’ long x 5’ deep. Each soil pit location was surveyed using a 10 meter buffer around the backhoe pit and a 20 meter wide corridor for access from existing roads to the pit. No cultural resource values were recorded in the 10 Coleville pit locations. Since no known cultural values occur in the Coleville portion of the project area this report will focus on the findings in the Bodie Hills area. Of the 54 locations proposed in the Bodie Hills area, 23 pits had no associated cultural resources, 5 pits were relocated to avoid cultural resource values, 13 pits are located within the Dry Lakes Plateau National Register District (DLP), 13 pits were found to be within the Bodie Hills obsidian quarry/cobble flow area and 1 pit was dropped due to wildlife concerns.

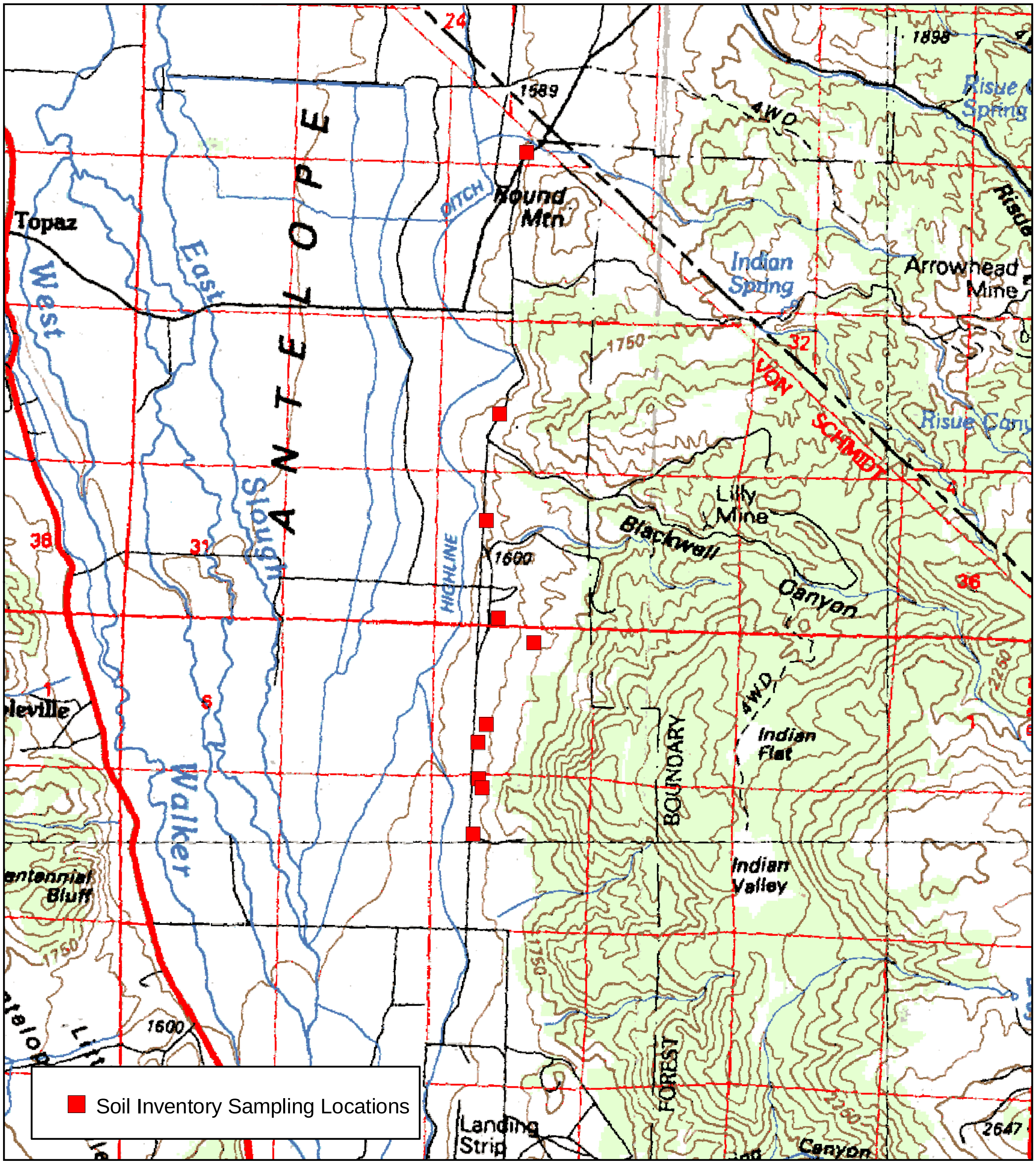
None of the pits on the DLP were within sites and only one was excavated during project implementation. Phase II controlled excavations and surface collections were undertaken at the 13 pits (pits 4, 5, 12-18, and 37-40) found within the “greater Bodie Hills obsidian quarry”, or district, on both the west and east flanks of the main and BHW sources (Figures 3-4). These pits could not be avoided by project activities due to the ground coverage of cobble flow and quarry reduction materials, which extend over an 8.96 km^2 (2215 acre) area to the west (1745 acres), east (398 acres) and north (72 acres) of the main quarry as originally mapped by Singer and Ericson (1977)(Figure 4). All cultural material was collected from the test units as well as surface materials within a 10 m wide swath, providing for access to each pit location. All collected materials (n=321) were catalogued, described and a sample of 130 items submitted to Craig Skinner of Northwest Research Obsidian Studies Laboratory (Appendix A) for obsidian hydration analyses and 26 items to Robert Yohe for obsidian laser ablation trace element analyses at the California State University, Bakersfield lab (pending analysis).

This report describes the findings of the cultural resource investigations for the NRCS/BLM Soil Inventory as well as provides substantial new data on the spatial extent of Bodie Hills obsidian deposits and their temporal use by prehistoric hunter-gathers. All previous discussions of the Bodie Hills obsidian source have focused on the source as recorded and described by Singer and Ericson (1977). Use of cobble flow materials was noted and described by Halford at CA-MNO-276 (1997), CA-MNO-3125/H and CA-MNO-3126 (2000, 2001) and in 2000 a new source (Figure 4) was identified by the author (reported here as the Bodie Hills West Source [BHW]) as well as a northern source in 2008 (reported here as the Bodie Hills North Source [BHN]). In 2000, the extent and complexity of the BHW source and cobble flows that originate from that source, and flow down the alluvial fans and drainages to Bridgeport Valley to the west, was not well understood. As a result of the current investigation it has been learned that the western cobble flows, used in Bridgeport Valley, originate from the BHW source and are distributed by alluvial activity, 4 miles to the west and cover a north/south area 2.5 miles at the western terminus of the known flow (Figure 4).

The BHW source (Figures 4-8) is a 53 acre complex near the head of Rock Springs Canyon. Cobbles originate here and have been deposited by alluvial activity 4 miles to the west covering an area of 6.85 km^2 (1692 acres). The western extent and eastern and northern additions described in this report provided 2,215 acres (8.96 km^2) of useable obsidian cobble material not previously described in detail. Also found during fieldwork were 11 small locales where obsidian cobbles are eroding out of a rhyolitic vitrophyre at elevations between 2350 m to 2700 m amsl (Figure 4). The cobble flow material is similar in size to that found at the main source; therefore size would not have been a key limiting factor in raw material selection between the flow areas and the BH main BHW and BHN sources. Further, the obsidian hydration profiles advanced in this study and previously by the author (Halford 2000, 2001) show a bimodal curve with extensive early Holocene use of the cobble deposits that are not consistent with the normal curve advanced by Singer and Ericson (1977) and others (cf. Gilreath and Hildebrandt 1997; Hall and Jackson 1989) which shows a peak of quarry use during the Newberry period ca. 2,500 years ago and which correlates to production curves for other sources in the region.

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office

Bodie Hills Soil Inventory
CA-170-07-08
Soil Inventory Unit Locations (Northern)



U.S.G.S. 100k Quads: Bridgeport and Smith Valley
Scale: 1:62 500

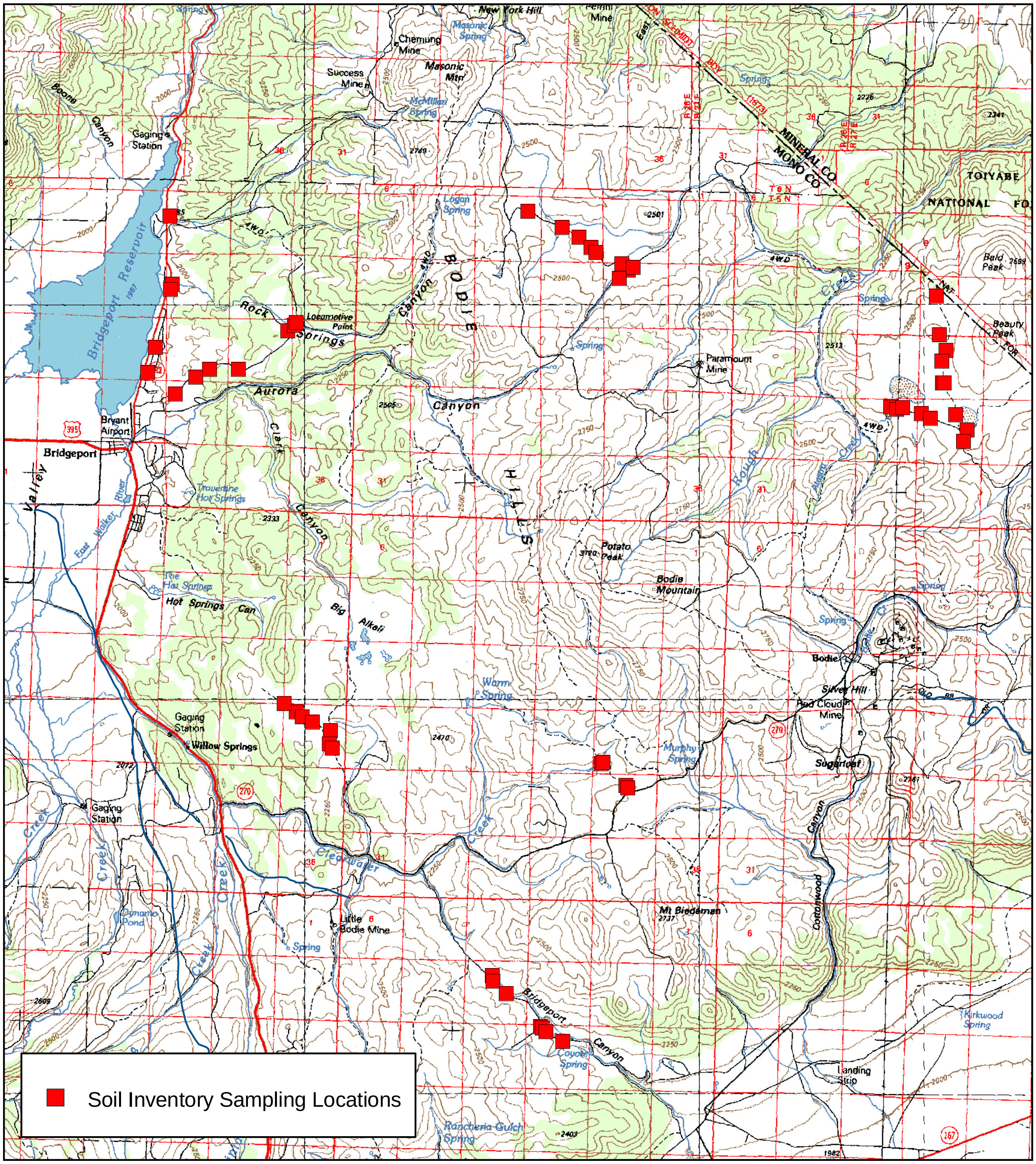
0 0.5 1 2 3 Miles

N
W E
S

Figure 1.

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office

Bodie Hills Soil Inventory
CA-170-07-08
Soil Inventory Unit Locations (Southern)



U.S.G.S. 100k Quads:Bridgeport and Excelsior Mountains
Scale: 1:150 000

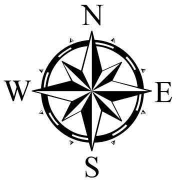
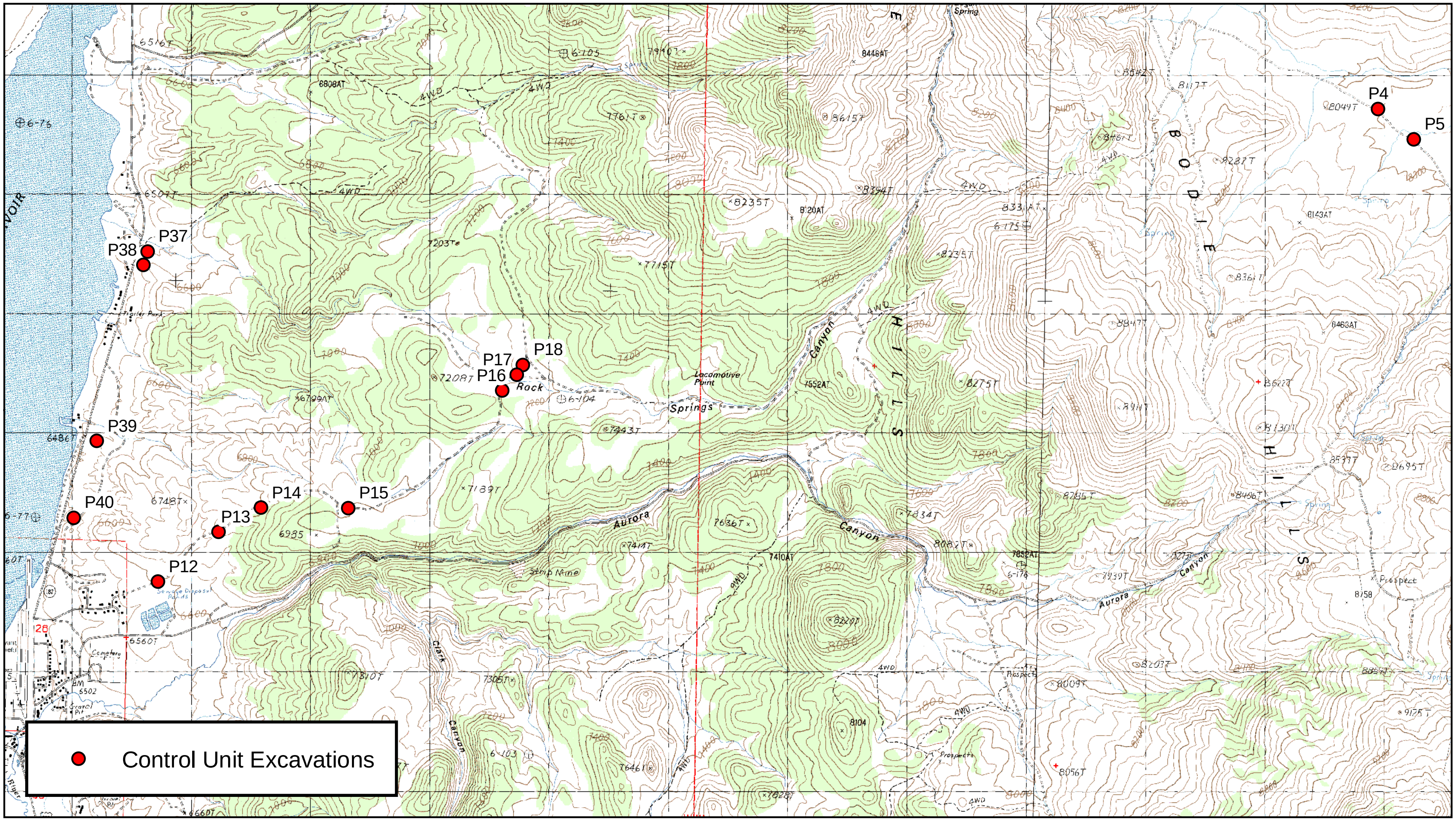


Figure 2.

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office

Bodie Hills Soil Inventory
CA-170-07-08
Control Unit Locations



U.S.G.S. 7.5' Quads: Bridgeport, CA and Dome Hill, CA/NV
Scale: 1:50 000

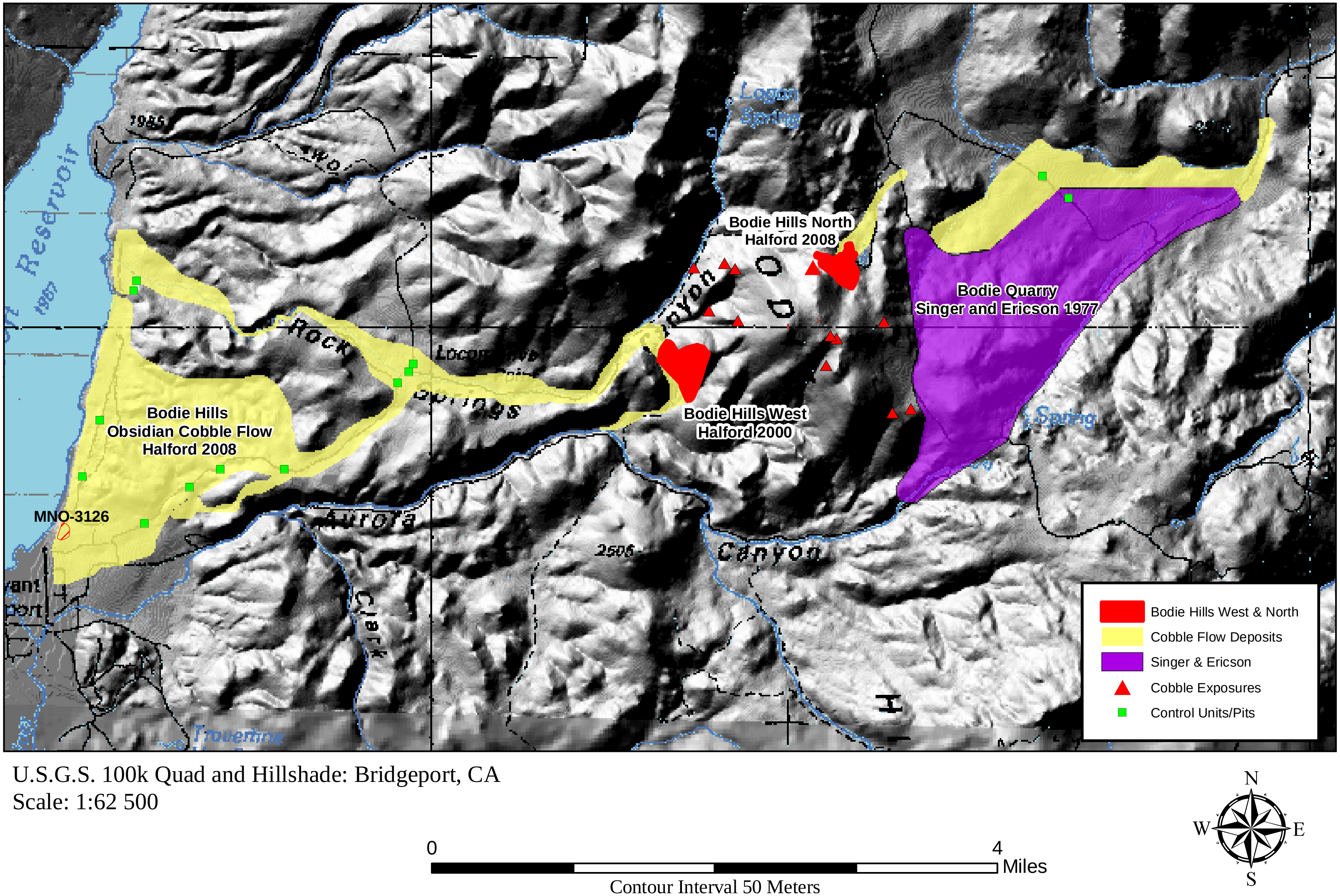
0 3 Miles
Contour Interval 40 Feet

N
W E
S

Figure 3.

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office

The Greater Bodie Hills Obsidian District
CA-170-07-08



U.S.G.S. 100k Quad and Hillshade: Bridgeport, CA
Scale: 1:62 500

Contour Interval 50 Meters

Figure 4.

Figure 5. BHW cobble flow, looking west to Bridgeport**.**

Figure 6. BHW obsidian source, looking east up flow
(main source east of ridgeline).

Figure 7. 8.5 cm cobble BHW flow.

Figure 8. 9 cm cobble BHN source.

Project Area Description

The project area is located within Antelope Valley and the Bodie Hills in sagebrush steppe and upland sagebrush steppe habitat (Figures 1 and 2). The ten Colville/Antelope Valley soil pits are located on the eastern fringe of the valley, on the footslope of the Sweetwater Mountains (Figure 1). The fifty four proposed backhoe pits within the Bodie Hills are distributed across the area (Figure 2); twelve pits located on the northwestern flank (P12-18 and 36-40) near Bridgeport Reservoir; seven pits (P19-25) on the west central flank; seven pits (P1-2 and 30-35) on the south in Bridgeport Canyon; nine (P3-11) in the north central area on the east flank of the main BH source; four (P26-29) in the central Bodie Hills; and fourteen (41-54) located on the Dry Lakes Plateau in the northeastern Bodie Hills.

Geology

The geology of the Bodie Hills has received a notable amount of attention due to significant gold bearing deposits in the area (Al-Rawi 1970; Chesterman et al. 1969; Gilbert et al. 1968; Kleinhampl et al. 1975; Silberman and Chesterman 1972). The Bodie Hills are formed of Tertiary volcanics. The balance of formative events occurred during the Pliocene Epoch (Al-Rawi 1970; Chesterman et al. 1969). The oldest rocks in the Bodie Hills are metamorphosed Paleozoic sediments. During the Mesozoic a geosyncline formed which was eventually intruded by granitic plutons which also formed the Sierran batholith. The whole region was then uplifted by the Nevadan Orogeny (ca. 155 mya; Nelson et al. 1991). The early Tertiary was a time of erosion which caused a great unconformity between pre and late Tertiary deposits (Kleinhampl et al. 1975). The Oligocene, Miocene, and Pliocene epochs (ca. 28-2 mya) were dominated by volcanic activity that formed the present topography of the Bodie Hills (Kleinhampl et al. 1975). The most recent volcanic activity, 250,000 years ago, resulted in the formation of Aurora Crater to the east of the study area (Kleinhampl et al. 1975). A number of volcanic events occurred in the Mono Crater and Inyo Crater chain that would have affected Holocene prehistoric inhabitants of the Mono Basin region and perhaps the Bodie Hills area (Hall 1983:28-47). This chain of craters and domes is located south of the study area, within and extending south from Mono Basin to Mammoth Mountain.

Soils are described as the Serita complex, on 2% to 8% slopes (Unit 11), and the Serita-Bodie association on 8% to 30% slopes (Unit 16). The Serita complex consists of Serita gravelly to very gravelly sandy loam and very cobbly sandy loam. These soils are well drained, though permeability is moderately slow, and have formed in mixed alluvial material. The surface layer is roughly 10-15 cm thick. The subsoil consists of a very cobbly sandy clay loam. The Serita-Bodie association occurs on alluvial fans and mountain slopes. This soil type consists of Serita very cobbly sandy loam on the alluvial fans and Bodie cobbly sandy loam on the mountain slopes (Fly and Associates 1981).

The project sites are characterized by an interlacing of these soil complexes and associations, but are generally dominated by the Serita complex. Subsurface investigations for this project show that the soils consist of silt and clay deposits, with clodding prevalent at 10 to 30 cm and hard pan clayey substrates being encountered at 20 to 30 cm below the surface. Ed Blake (NRCS soil scientist, personal communication 2007) who is conducting the soil classifications for the project described the soils encountered during backhoe excavations as generally being "well developed soils with clayey Bt horizons over silica cemented duripans that were present within a range of roughly 20 (50 cm) to 30 (75 cm) inches (Figure 9). The duripan layer is an old Quaternary soil that takes tens of thousands of years to form and pre-dates Holocene deposits (Ed Blake, personal communication 2007). The Bt horizon is also well documented in archaeological investigations at CA-MNO-3126 (Halford 2000; Goebel et al. 2008) where it was found that strongly developed argillic (Bt) horizons occurred from 12 to 46 cm below the surface (Goebel et al. 2008:Table 2.1).

Figure 9. Backhoe trench soil profile (note duripan layer with unmodified obsidian cobble at 46 cm below surface.

Modern Flora and Fauna

Flora: The biotic communities found within the Bridgeport Valley/Bodie Hills are common species found in the western Great Basin. The vegetation communities of the Great Basin are highly zonal, following vertical elevational gradients in temperature and precipitation, and are also significantly influenced by soil characteristics (Cronquist et al. 1972). This results in a series of horizontal altitudinal bands or zones of community types (Thompson 1990). Floristically, the Bodie Hills can be divided into two general community types; pinyon-juniper woodland and sagebrush steppe (Messick 1982:13-14).

The project area is typified by sagebrush steppe habitat. The sagebrush steppe, or Sagebrush Zone (Cronquist et al. 1972:77-161) is located at elevations between 1,524 m to 3,050 m (5,000-10,000 feet), where precipitation is greater than 17.5 cm per year. Pinyon-juniper woodlands are found on the fringe of the project area at slightly higher elevations. The Pinyon-Juniper Zone, is generally located at elevations from 1,524 m to 2,439 m (5,000-8,000 feet) with juniper only at the lower extreme and pinyon at the upper. Precipitation in the pinyon-juniper zone is greater than 30 cm per year. Dominant species (Hickman 1993; Messick 1982) in the project area include; Great Basin sage (*Artemisia tridentata* ssp. *tridentata*), low sage (*A. arbuscula*) curly leaved rabbitbrush (*Chrysothamnus viscidiflorus*), wild onion (*Allium* sp.), needlegrass (*Acnatherum* spp.), squirretail (*Elymus elymoides*), vetch (*Astragalus maculatus*), bitterroot *(Lewisia rediviva), Antennaria dimorpha*, *Chaenactis* sp., *Lepadatylon pungen*, phlox (*Phlox longifolia*), *Arabis* sp., hawksbeard *(Crepis* sp.), *Erigeron aphanactis*, buckwheat (*Eriogonum ovalifolium*), currant (*Ribes aureum* and *cereum*) and wild rose (*Rosa woodsii*). The pinyon pine, currant, wild rose, sagebrush, grasses, onion, bitterroot, hawksbeard and buckwheat species occurring in the project area today, would have provided subsistence resources for prehistoric inhabitants. These plant community associations were most likely well established in the project area at least by 5,000 to 3,000 B.P. (Halford 1998a).

Fauna: The Bodie Hills fauna include mule deer (*Odocoileus hemionus*), pronghorn (*Antilocarpa americana*), coyote (*Canus latrans*), kit fox (*Vulpes macrotes*), grey fox (*Urocyon cineroargentus*), racoon (*Procyon lotor*), bobcat (*Lynx rufus*), mountain lion (*Felis concolor*), badger (*Taxidea taxus*), five species of rabbit (black-tailed rabbit, *Lepus californicus*, *L. townsendii* and Audubon cottontail, *Sylvilagus audubonii, S. nuttalli, S. idahoensis*), several species of pocket mouse (*Peroganthus* spp.), kangaroo rats (*Dipodomys* spp.), bushy-tailed woodrat (*Neotoma cinera*), pinyon mouse (*Peromyscus trueii*), kangaroo mice (*Micordipodops* spp.), ground squirrels (*Citellus* spp.), chipmunks (*Eutamias* ssp.), golden-mantled ground squirrel (*Spermophilis lateralis*), and sagebrush chipmunk (*Eutamias minimus*). During the past, mountain sheep (*Ovis canadensis*) may have wintered in the area (Hall 1980:9-10). Avifauna include sagehen (*Centrocercus urophasianus*) and mountain quail (*Oreortyx pictus*).

Modern Climate

The climate in the Bridgeport Valley/Bodie Hills region is characterized by a temperate, semi-arid, continental weather regime typical of Great Basin environments. The towering Sierra Nevada Mountains to the west provide an orographic rain shadow effect that separates the western Sierran maritime climate from the continental climate of the Great Basin. In contrast to other Great Basin mountain ranges, the Bodie Hills are significantly influenced by Sierran weather systems and are often subjected to systems centered in the Sierra. This factor intensifies annual precipitation within the Bodie Hills (Hall 1980:7; Messick 1982:11). The mean annual precipitation at the town site of Bodie from 1965 to 1979 was 36.9 cm per year in contrast to an annual average of 15 cm at Bishop, in the Owens Valley 75 miles south. Bridgeport receives an average of 24.5 cm of precipitation per year. (Busby et al. 1979; Messick 1982). Summer temperatures range from 15^0 C to 40^0 C and winter ranges are from -20^0 C to 5^0 C (Busby et al. 1979). Throughout the Great Basin precipitation is highly variable from year to year, with cool-season precipitation (September to May) dominating in the western region. The weather regime is "primarily derived from migratory low-pressure systems following the westerlies off the northern Pacific Ocean" (Thompson 1990:203).

Paleoclimate

The Paleoenvironmental record reveals the variability of climatic change in the Great Basin region during the Holocene (Mehringer 1986; Grayson 1993). Flux in the paleoclimate of the Bodie Hills region would have affected the biotic and hydrologic resources and, therefore, indirectly affected the human inhabitants of the region during the Holocene (Madsen 1982, 2002; Rusco 1991:2.10). For instance, based on pack rat midden analyses on the flank of the Dry Lakes Plateau in the northeastern Bodie Hills, pinyon occurs in the area by 4,980 ± 80 B.P. (Halford 1998a). Geographically the Bodie Hills are located roughly midway between the White Mountains, where pinyon occurs by 8,790 B.P. (Jennings and Elliot-Fisk 1993; see also Reynolds 1996), and its northern distribution in the Pah Rah Range, where it does not appear until 200 to 300 years ago (Wigand and Nowak 1992). The earliest date for pinyon to the north, and in relatively close proximity to the Bodie Hills, comes from Slinkard Valley, near Walker and Colville, California (40 kilometers to the northwest). Pinyon is directly AMS dated at the Slinkard location to 2,150 ± 75 B.P. (SV200689CLN1(1), Beta-50521) (Nowak et al. 1994b). By 4,060 ± 110 B.P. pinyon is well established in the Bodie Hills (Halford 1998a:80-85). Though pinyon is not generally thought to have been utilized intensively until late prehistoric times (ca.

1,350 to historic), the occurrence of this important subsistence resource in the Bodie Hills after 5,000 B.P. may have certain implications for changing land-use strategies in the area.

A number of models addressing region specific Holocene climatic change have been developed (cf. Halford 1998a; Hemphill and Wigand 1995; Mehringer 1996; Nowak et al. 1994; Stein 1990; Wigand and Nowak 1992; Wigand et al. 1995). A broad range of proxy climatic evidence have been utilized to reconstruct Holocene environments (cf., Betancourt et al. 1990; Grayson 1993). These data sources include Pleistocene pluvial lake system histories (including remnant lakes and marsh systems), lacustrine varved sediments, tree-rings, pollen, woodrat middens, glacial deposits, geomorphological processes (erosion, deposition, and wind rates), fossil animal remains, fire histories, and stable isotope analysis. In varying degrees these data can be compared and correlated to substantiate climatic shifts and the subsequent responses of biota and hydrologic systems. Finer grained data, obtained from woodrat middens, pollen cores, and tree rings, have been utilized in correlation with large scale events, such as orbital parameters, atmospheric circulation patterns, glaciation, and pluvial lake histories (Kutzbach and Guetter 1986; Mehringer 1996; Van Devender et al. 1987), to obtain even greater resolution of paleoenvironmental and paleoclimatic changes.

In recent years the use of paleobotanical data as a proxy indicator (Betancourt et al. 1990; Mehringer 1996; Van Devender et al. 1987; Wigand et al. 1995) of late Quaternary climatic shifts has revealed the dynamics of paleoclimatic variation over space and time in great detail. Through an analysis of the elevational and latitudinal movement of semi-arid woodlands (i.e., juniper and pinyon) Wigand et al. (1995) have constructed a sequence of Holocene climatic change (cf. Betancourt et al. 1990; Mehringer 1996; Mehringer and Wigand 1990; Thompson 1990; Van Devender et al. 1987). In particular, macro-fossil and fossil pollen data collected from woodrat middens and sediment cores document the late Pleistocene and Holocene history of Great Basin woodlands and other associated species. Through these types of analyses statements about precipitation and temperature can be made and input into paleoclimatic reconstructions as outlined below and in Table 1.

Analyses of paleobotanical data (Wigand et al. 1995) suggest that the early Holocene (11.5-8 kya) is typified by the persistence of Utah juniper at elevations 500 to 1,000 meters lower than today (cf. Jennings and Elliot-Fisk 1993). By ~9.5 kya an early Holocene thermal maximum, coinciding with a long drought period, caused the upward movement of semi-arid woodlands, a replacement of subalpine woodlands (dominated by limber pine) at intermediate elevations, and movement of desert scrub into lower elevational areas previously dominated by juniper. Single-needle pinyon (*P. monophylla*) began to move north from its southern distributions in the Mojave and Sonoran Deserts, but had not yet become a major component of the semi-arid woodland.

The middle Holocene warm and dry period (8-5.5 kya) again displaced semi-arid woodlands upward in elevation as much as 300 to 500 meters in some portions of the Great Basin (Jennings and Elliot-Fisk 1993; Wigand et al. 1995). Saltbush scrub communities became dominant in the valleys. This period coincides with major desiccation of pluvial lakes and marshes (Grayson 1993; Mehringer 1986) and the lowering of Lake Tahoe beneath its sill (Lindstrom 1990). The early late Holocene (5.5-4 kya) is marked by an increase in winter and summer precipitation indicated by plant pollen and macrofossil data, with an expansion of western juniper (*J. occidentalis*) into its modern range in the northwestern Great Basin (Mehringer and Wigand 1990; Wigand and Nowak 1992). From 4 to 2 kya temperatures dropped and winter precipitation increased significantly, indicating the onset of the late Holocene Neoglacial period. Increased grass pollen and an increase in the incidence of fire indicates an abundant herbaceous understory correlated with wetter climates (Mehringer 1996).

Years B.P. (1,000)	Holocene Climatic Conditions Compared to the Present as Inferred from Vegetation Histories (Thompson 1990; Van Devender et al. 1987; Wigand et al. 1995)	Proxy-Climatic Indicators in the Bodie Hills Region (Graybill et al. 1994; LaMarche 1973, 1974; and Mono Lake, History, Stine 1990)
.15	**Mean Annual Temperatures Increasing** Pinyon-juniper woodland increases 2.5 fold in areal distribution.	**Prehistoric Low Stand:** 296 cal b.p. to 1857, level 1949 m.
.4 to .3	**Cool and Moist ("Little Ice Age")** The pinyon-juniper woodland re-expands.	**Clover Ranch High Stand:** ~375-296 cal b.p., level 1968 m. **10-Mile Road Low Stand:** 605-550 cal b.p., level 1947 m.
.9 to .6	**Warm and Dry ("Medieval Warm Epoch")** A reduction in juniper pollen occurs along with a dramatic retreat of Great Basin pinyon-juniper woodland. Tree ring data corroborates warmer temperatures.	**Rush Delta High Stand:** 680-605 cal b.p., level 1953 m. **Simis Ranch Recession:** ~ 860-680 cal b.p., level ~ 1944 m. **Post Office High Stand:** ~ 866 cal b.p., level 1960 m.
~ 1	**Cool and Dry** Increase in juniper pollen and sagebrush steppe, indicative of greater winter precipitation and a decrease in evapotranspiration.	**Lee Vining Delta Low Stand:** 1,245-866 cal b.p., level 1942 m. Smaller tree-rings indicate cooler temperatures from 1,500 to 900 ya..
1.4 to 1	**Warm and Moist** Summer shifted rainfall and warmer winters; pinyon advances rapidly; grasses increase.	**Mill Creek East High Stand:** 1,370 cal b.p., 1952 m. Wider tree-ring indices corroborate >precipitation.
~ 1.9	**Warmer and Drier** Juniper pollen decreases with an increase in desert scrub species such as Chenopods and greasewood.	**Marina Low Stand:** 1,807 cal b.p., level 1941 m. Lowest late Holocene stand. Tree-rings indicate warming.
4 to 2	**Cool and Moist ("Neoglacial Period")** Winter precipitation increases dramatically along with a decrease in summer temperatures; juniper increases; grassy sagebrush steppe is dominant.	**Dechambeau Ranch High Stand:** 3770 cal b.p., level 1980 m. Mono Lake reaches its highest stand since the early Holocene. Smaller tree-ring indices evidence cooler temps.
5.5 to 4	**Warm and Moist** Gradually increasing winter and summer rainfall; Western juniper expands into its modern range in the northwest Great Basin.	Upward migration of treeline and greater tree-ring widths in bristlecone pine, White Mountains. Pinyon occurs in the Bodie Hills (ca. 4,980 B.P.)
8 to 5.5	**Warmer and Drier** Semi-arid woodlands move upslope 300 to 500 meters; saltbush scrub becomes dominant in valleys with sagebrush steppe at intermediate elevations.	Lowering of Lake Tahoe; bristlecone pine migrates upward 150 meters in the White Mountains.
9.5 to 8	**Warm and Dry (Thermal Maximum)** Summer shifted rainfall; juniper moves up into the zone previously occupied by subalpine woodland; desert scrub moves into lower zone; pinyon begins it northward migration from the south.	Dramatic lowering and/or desiccation of pluvial lakes and marsh systems; pinyon in the White Mtns. by 8,790 B.P.
11.5 to 9.5	**Cooler and Moister** Trending towards warmer Holocene conditions; sagebrush steppe dominant; Utah juniper 500 to 1000 meters lower than today.	Juniper in the Volcanic Tablelands 2 midden, 9,830 B.P., 1341 m. (Jennings and Elliot-Fiske)
> 11.5	**Cool and Dry (Terminal Pleistocene)** Subalpine woodlands at intermediate elevations; sagebrush steppe dominant.	Pinyon-juniper woodlands in Mojave and Sonoran Deserts.

Table 1. Holocene climatic fluctuations as interpreted from paleobotanical data and correlated to proxy-climatic data in the region of the Bodie Hills (from Halford 1998a).

The mid late Holocene, ~1.9 kya, is marked by a generally warmer and dryer climate signaling the close of the Neoglacial period. Juniper pollen drops off and more xeric desert scrub vegetation such as saltbushes and greasewood experienced an increase, evidencing intensifying aridity between 1.9 and 1 kya (Wigand et al. 1995). At ~1.4 to 1.3 kya rainfall increased with a shift to summer seasonality. During this period pinyon advanced rapidly, signifying increased summer precipitation along with milder winters. At ~1 kya increased juniper pollen indicates a wetter climate and increased winter precipitation.

From .9 to .5 kya the Medieval Warm Epoch coincides with a series of droughts and rises in Mono Lake (Stine 1990, 1994). Reduced juniper and pinyon pine pollen values signal a dramatic retreat of the Great Basin woodland and increased occurrences of fire in response to drought stress. Tree ring data also corroborate this severe drought period (Graumlich 1993; Graybill et al. 1994; LaMarche 1974). At 300 to 400 years ago a pattern of stronger winter precipitation and cooler temperatures is indicative of the "Little Ice Age" (Wigand et al. 1995). A re-expansion of the juniper woodland occurred and pinyon also benefitted from this climatic amelioration. Since the "Little Ice Age" mean annual temperatures have been rising and in the past 150 years the pinyon-juniper woodland has seen a 2.5 fold increase in areal distribution (Tausch et al. 1981; Wigand et al. 1995).

Previous Research

History

The first Euro-Americans to venture into the region included Jedediah Smith in 1827, Joseph Walker in 1833, and John C. Fremont in 1844 (Busby et al. 1979:37-39). Their forays through or near the area were only brief. Walker (whom the Walker River, Lake, and Pass are named for) may have been the first white man to travel through the Bridgeport Valley during his explorations. In 1843-1844, John C. Fremont, who coined the term "Great Basin", crossed through the northern Bodie Hills into the Bridgeport Valley before following the eastern Sierra front north, crossing at Carson Pass.

As emigrants began to storm into western California gold country (i.e. the 49ers) from the east, interest in the lands east of the Sierra began to grow. In 1855, A.W. Von Schmidt began a survey of the lands in the region for the State of California. In 1873 the Von Schmidt Boundary was surveyed to the east of the study area, delineating the California/Nevada border. During the 1850's various military expeditions were sent into the region, mainly to the south in the Owens Valley, to explore the area for potential white habitation or to “subdue hostile Indians”. In 1859, Captain John W. Davidson was sent to the Owens Valley to search for stolen horses (Wilke and Lawton 1976).

During the late 1850's gold brought thousands of people from the western California and Nevada goldfields into the Eastern Sierran region. Strikes at Dogtown (1857), Monoville (1859), Bodie (1859), Aurora (1860), Lundy, and Masonic (Busby et al. 1979:45-52) enticed fortune seekers by the droves into the area, some to stay, but most to move on to the next "bonanza". Bodie became a focal point of mining activity in the region and supported a transient, mixed ethnic population of 6,000 plus during its heyday in the early 1880s (Wedertz 1969; Hardesty et al. 1991).

With the mines came an increasingly complex communication and transportation infrastructure that connected the various towns and mines in the region. Sawmills to support the mining industry first appeared in Big Meadows (Bridgeport Valley), in the 1860s. In 1863 the Mono County seat was established at Bridgeport after being moved from Aurora. Aurora was previously designated as the seat until it was learned that the town was actually within the state of Nevada (Busby et al. 1979:51). Ranches sprang up in the region to support the mines and growing towns. Some mining occurs in the area today, but ranching and tourism have become the main industry of the Bridgeport Valley and the Eastern Sierran region.

Basque sheepherders have been seasonal visitors to the region since the 1890's as an active part of the livestock industry (Busby et al. 1979:75). Evidence of their passing is apparent in aspen tree carvings. Hardesty et al. (1991:3.10) suggest that three ethnic groups associated with mining activities at Bodie may show "archaeological visibility" in the region: Overseas Chinese, Mexicans, and Native Americans. As white American population increased in the region the "…local Paiute Tribe was moved from many of their traditional use areas to other areas not claimed or settled by Europeans" (Sam 1995).

Ethnography

Ethnographically the study area falls within the territory of the Western Numic, a branch of the Uto-Aztecan linguistic family, further subdivided into two distinct language groups; Northern Paiute and Mono (Fowler and Liljeblad 1986:437). These broad language delineations are based mainly on linguistic evidence which shows the homogeneity within the dialects of the Northern Paiute groups and the dialects of the Mono speakers, but is not representative of a single tribe or political entity (Fowler and Liljeblad 1986:435; Miller 1986). The Mono speaking Owens Valley Paiute occupied the territories to the south of Mono Lake and the study area (Steward 1933) and were called the "southerners" (*pitanˑagʷˑad_*) by their Northern Paiute neighbors (Liljeblad and Fowler 1986:412).

The two groups of Northern Paiute speakers inhabiting the vicinity of the study area ethnographically and today are the Mono Lake Paiute (Cuzavi-dika [*kucad_kad_*], the brine-fly eaters) on the southern fringe of the Bodie Hills in the Mono Basin, and the Bridgeport Valley Paiute (Paxai-dika [*pakʷid_kad_*]), the chub eaters (Davis 1965; Fowler and Liljeblad 1986; Steward 1933:235), whose current reservation is located on the western fringe of the project area. Other groups that may have frequented or visited the area for trade or resource procurement (e.g., obsidian and pinenuts) include; Northern Paiute groups from Walker Valley, Smith and Mason Valleys to the north; the Mono speaking Owens Valley Paiute to the south; the Hokan speaking Washo to the northwest; and the Penutian speaking Miwok to the west of the Sierra crest (Basgall 1998; Davis 1965; Fowler and Liljeblad 1986; Hall 1980; Steward 1933).

Practicing a seasonal round, or seasonal "transhumance" (Davis 1963, 1965), groups would have visited the study area to hunt big game (deer, pronghorn, bighorn sheep), rabbits and rodents. Various plant resources could have been sought with the most prominent species including pinyon, Indian ricegrass, bitterroot, Great Basin wild rye, needlegrass, and various berries. Based on the current and past investigations (Halford 2000), the procurement of obsidian for use and perhaps trade (Basgall 1989; Bieling 1992; Singer and Ericson 1977) appears to have provided a major impetus for activities in the project area.

Rock (house) rings, seed caches, milling floors, manos, metates, lithic debitage and tools, ceramics and basketry are a few of the material culture items that may be manifest in the archaeological record that correlate to regional ethnographic uses (Davis 1965; Fowler 1986; Fowler and Liljeblad 1986; Liljeblad and Fowler 1986; Steward 1933). With the exception of ceramics, many of these material items have also been found in earlier contexts (Basgall and Giambastiani 1995; Basgall and McGuire 1988). The use of ethnographic analogy has been employed in many regional studies (Bettinger 1975, 1977a, 1982; Busby et al. 1979; Hall 1980; Jackson 1985; Rusco 1991).

Prehistory

Regional Studies

Research in the region of the study area has been focused mainly to the south in the Mono Basin (Davis 1962, 1963, 1964), Long Valley (Basgall 1983, 1989; Bettinger 1977b; Hall 1983; Jackson 1985) and the Owens Valley regions (Basgall and McGuire 1988; Basgall and Giambastiani 1995; Bettinger 1975, 1977a, 1982, 1989, 1991a; Delacorte 1999; Delacorte et al. 1995; Giambastiani 2004). Rock art sites attracted the first attention in the region (Mallery 1886; Steward 1929). The earliest systematic survey in the area was conducted by the University of California Archaeological Survey in 1953 (Meighan 1955). Clement Meighan cursorily recorded a total of 171 sites from the East Walker River south to the Benton Range and the Volcanic Tablelands of the Owens Valley (Meighan 1955).

Beginning in the 1970's, and often under the auspices of cultural resource management programs, research has focused on diachronic hunter-gatherer land-use patterns and adaptive strategies (Basgall and Giambastiani 1995; Bettinger 1977a, 1982; Delacorte et al. 1995; Gilreath 1995; Hall 1983, 1989; Jackson 1985). A wide variety of research questions and issues have arisen in, and as a result of these investigations. As Hall (1989:29) suggests, a complex prehistoric pattern has emerged from the fruits of regional research with a record of hunter-gatherer occupation reaching back into the Paleoindian period (ca. 10,000-8,000 B.P.), with "...subsequent episodes of adaptive evolution induced by varying combinations of environmental, demographic, technological, and sociological factors".

Bettinger (1975, 1977a, 1977b, 1982) developed subsistence-settlement models for the Owens Valley and Long Valley areas which reveal a high degree of variability through time. Many reasons have been posited for shifting prehistoric land use patterns including climatic/environmental influences (Bettinger 1977a; Elston 1982), population increase (Bettinger 1977a, 1991a) and the Numic expansion (Bettinger and Baumhoff 1982; Madsen and Rhode 1994). Whatever the mechanisms for change and variability, the archaeological record provides strong evidence of shifts in residential mobility and subsistence patterns through time (Basgall and Giambastiani 1995:267).

In varying ways and to different degrees, hunter-gatherer subsistence-settlement patterns have been viewed and addressed since the late 1970's through the forager and collector (Binford 1980) lens, as either generalists or specialists (Madsen and Janetski 1990). In reality, hunter-gatherers in the Great Basin most likely used a combination of these strategies, maximizing (Fowler and Fowler 1990; Kelley 1990, 1995; Madsen and Janetski 1990; O'Connell et al. 1982; Simms 1987) the use of resource patches in a potentially highly diverse and changing resource base. As Thomas (1990:278) suggests, the notion of forager versus collector should not be seen as an either/or proposition, but instead provides two "...extreme positions along a strategic continuum, along which various hunter-gatherer mobility and subsistence patterns can be scaled". Archaeologically, there are changes evident in subsistence-settlement patterns and technology during the Newberry/Haiwee interface which indicate a shift along the continuum from a forager to a collector strategy. As more research is completed in the region (Basgall 1998; Delacorte 1999; Giambastiani 2004; Zeanah et al. 2000), there is substantial evidence that subsistence strategies shifted towards an increasing use of high cost, low return resources by logistically mobile groups. This change along the strategic adaptive continuum is posited as being a result of changing demographic patterns or population pressures (Bettinger 1991), technological innovations (e.g., the advent of the bow and arrow, ceramics, changes in obsidian use profiles and tool types, etc.), and may reflect changing environmental conditions (cf. Halford 1998a; Stine 1994), or any combination of these factors (Basgall 1998).

The intensified use of selected resources, such as pinyon or ricegrass, and shifting mobility patterns are reflected archaeologically by the increased frequency of task specific camps with more permanent structures (e.g., rock rings, wickiups), milling tools, storage features and containers (e.g., ceramics), more developed waste middens, and use of localized obsidian sources and on site recycling of waste materials. Changes in flaked stone tool kits occur with increased use of expedient flake tools. Bifaces become smaller, perhaps indicating recycling, and less curation occurred. A substantial decrease in obsidian source diversity, as reflected by chemical source profiles, provides further evidence of shifting adaptive strategies during the late period, with more territorial circumscription evident. Bettinger and Baumhoff (1982) and others (cf. Madsen and Rhode 1994) have identified this shift as support of the "Numic spread" hypothesis.

Obsidian Studies

The analysis of hunter-gatherer obsidian procurement patterns has played an increasingly important role in addressing mobility and technological patterns in this region. As more intra and inter site specific evidence is collected (Basgall and Giambastiani 1995; Basgall and McGuire 1988; Delacorte et al. 1995) and the diachronic patterns of obsidian procurement, use, and trade become more apparent for the region (Basgall 1989; Basgall and Giambastiani 1995; Bettinger 1980; Bettinger et al. 1984; Delacorte et al. 1995; Giambastiani 2004; Gilreath and Hildebrandt 1997; Hall 1983; Hughes 1984, 1989; King et al. nd), shifting land use strategies become more evident. The shifts in adaptive strategies during the late Holocene (ca. 1,350 B.P. to historic), as briefly discussed previously, are reflected by chemical source studies which indicate decreased source variability, indicating decreasing mobility and providing an impetus for increased trade through time.

Basgall and Giambastiani (1995:240-250; cf. Basgall 1989) and Giambastiani (2004) have summarized the trends in the use of obsidians on the Volcanic Tableland which are consonant with other regional data (cf. Gilreath and Hildebrandt 1997; Hall 1983; Ramos 2000). Though biface reduction occurs in all periods, the proportion of bifaces is highest in Newberry and pre-Newberry contexts (ca. pre-1,350 B.P.), signifying the importance of biface technology. Obsidian source profiles, compiled from megascopic (Bettinger et al. 1984) and X-ray fluorescence (XRF) assays, signify a higher degree of source diversity during the early and middle periods, indicating a higher degree of artifact curation and residential mobility. A shift in stone tool technologies during the Newberry-Haiwee interface (ca. 1,350 B.P.) is coincident with the introduction of the bow and arrow and an increase in seed processing. During the late period (Haiwee-Marana: 1,350 to historic) flake blank technology for the production of projectile points becomes more prevalent along with expedient tool production and use.

Due to the fact that core and early stage biface reduction, using in situ secondary deposits of Bodie Hills obsidian, were the main activities that occurred in the project sites analyzed for this report, of particular importance to the present investigation is the production curve for Bodie Hills obsidian. For the purposes of understanding prehistoric obsidian acquisition in the Bodie Hills Obsidian District, it will be necessary to ascertain the degree to which production profiles in the project area match or differentiate from the Bodie Hills and other regional models. Singer and Ericson (1977:181) provide an obsidian production curve which shows initial production to begin roughly 6000 years ago, reaching a zenith at 2,500 years ago and abruptly dropping off at 1,500 years ago (Figure 10). Though the purported drop-off in production at 1,500 years ago and their source specific hydration rate of 650 years per micron have been questioned (T. Jackson 1984), the apex for production during the Newberry Period and a decline during the late period (ca. post 1,350 B.P) is consistent with region wide obsidian source production profiles (Basgall 1989; Basgall and Giambastiani 1995; Bouey and Basgall 1984; Gilreath and Hildebrandt 1997; Hall 1983, 1984; Hall and Jackson 1989; Ramos 2000).

Evidence suggests that intensive procurement of obsidian at regional sources for use and trade occurred in the pre-Haiwee periods and not during Numic times (Basgall 1989; Basgall and Giambastiani 1995; Bettinger and Baumhoff 1982). Various quarry studies (Basgall 1989; Bouey and Basgall 1984; Gilreath and Hildebrandt 1997; Hall 1983; Singer and Ericson 1977; Ramos 2000) indicate that in the Eastern Sierran region, during the Newberry period, (ca. 3,500-1,350 B.P.) obsidian production and its movement across the landscape on a predominantly east/west axis, reached its zenith then dropped off sharply at the end of the period. However, recent studies of Bodie Hills obsidian (Halford 2000, 2001; Goebel et al 2008), including this report, indicate that a pre-Newberry, early archaic/Paleoindian, pulse of use of secondary alluvial deposits was prevalent. This will be discussed further below. Gilreath and Hildebrandt (1997) noted a similar Early Archaic pattern of “lag” deposit use at the Coso Volcanic field but did not elucidate on this factor.

The sudden decline of quarry production at roughly 1100 BP has been likened by King et al. (nd) to a “crash”. They review and test the various models of quarry production to analyze the reason for this abrupt crash, after 1000 BP, through an analysis of the movement of Bodie Hills obsidian from the source to western Sierran and foothill sites. They evaluated and tested a number of hypotheses for the zenith and decline in production, including depopulation, embedded production (i.e. acquisition was embedded in the seasonal subsistence pursuits of highly mobile groups), collapse of inter-regional exchange, and technological production changes (i.e. from a biface based technology to a blade based technology (sinsu Ericson 1982).

King et al. (nd:14-16) concluded that demographic change or depopulation can be ruled out as an explanation for the crash as their data shows that there was a shift from use of obsidian to other materials on the western foothills. Obsidian became less abundant in the assemblage, but was replaced by alternative materials. Technological change, based on Ericson’s (1982) archaeological-visibility model, was also rejected (King et al. nd:14). Ericson (1982) suggested that due to a change from a biface based production system to a blade-like production system, to accommodate increase demand for finished items in the Late Period, production was moved away from the source, reducing archaeological visibility at the source and thus providing an explanation for the drop-off of quarry production after 1000 BP shown in the source hydration profiles. King et al. (nd) argue that for this hypothesis to hold true that obsidian percentages in western foothill sites should remain high. They do not, indicating that other factors were at work.

King et al. (nd:14) also argue against embedded production or the "organization of technology model" (Ramos 2000) as a reason for the decline. While this seems to be a logical explanation due to the well documented Late Period changes in mobility and subsistence, discussed earlier, King et al. (nd) argue that the high frequency of non-local obsidian in high Sierran sites during the Late Period does not support the embedded production hypotheses. They also argue that the high frequency of obsidian found in the foothills and central valley regions of western California during the height of production, between roughly 3000 to 1000 BP, rules out either an embedded production system or logistical forays to the sources over such long distances. This leaves inter-regional, Trans-Sierran, exchange as the most plausible explanation for the increase in obsidian production during the Newberry Period, the movement of obsidians over such long distances and the collapse of this system for the abrupt decline in production in the Late Period. King et al. (nd:14) argue "that it was the rise of sedentism and logistical organization that helped fuel inter-regional exchange, as well as a variety of other non-subsistence pursuits, during the Late Archaic Period" (which they bracket as ca. 3500-1100 BP).

Following on their argument, but within a broader Holocene context as discussed further below, one can posit that quarry use followed varying trajectories over time with embedded production (Jones et al. 2003; Ramos 2000) being most prevalent in Early Archaic strategies. As subsistence and mobility patterns moved towards more logistical and sedentary systems during the later Newberry Period the need for trade systems would have become more prevalent to maintain a certain level of material and subsistence wealth. Obsidian is an abundant resource within the Eastern Sierra that would have been favorable as a cost effective currency for exchange. The apparent abrupt collapse in inter-regional exchange then suggests that socio-economic factors and territoriality played heavily in the abandonment of obsidian as a source of currency.

Use of Obsidian in the Study Area

As early as 1977 (Elston and Covington 1977; Halford 1997, 1998b, 2000, 2001), it was noted that the alluvial fan north of Aurora Canyon and south of the Masonic Road is covered by obsidian flaked stone debris mainly formed of cobbles of secondary deposits of Quaternary alluvium. Secondary geomorphic deposits of Bodie Hills obsidian cobbles occur from the BHW source down the alluvial fan to Bridgeport Valley, ranging from tear drop sized to greater than 14 cm in diameter, with an average size from 5 to 8 cm (Figures 7 and 8). This raw material was being actively harvested by hunter-gatherer groups traveling through the area. Subsequent research (Halford 2000, 2001; Goebel et al. 2008) indicates that use of the secondary deposits do not follow the pattern recognized at other regional quarry locations (Figures 10-12) with peak periods of use during the late Newberry period (ca. 2,300-1,275 B.P.). Research at CA-MNO-3125/H and CA-MNO-3126 (Halford 2000, 2001) shows a bimodal production curve with peak periods of use during the Early Archaic, dropping off through the Newberry and Haiwee periods, and peaking again during the Marana period. These trends are juxtaposed with other regional quarry data which generally show a zenith of production use from 3,000 to 1,000 B.P. under a normally distributed curve.

The studies (Halford 2000, 2001) suggest that the secondary deposits were important tool stone production areas, especially during the early period. It has been hypothesized that from the perspective of Foraging Theory (cf. Bettinger 1991; Kelly 1995; Simms 1987), the cobble flow deposits were utilized during the Early Archaic/Mohave periods by opportunistic groups or

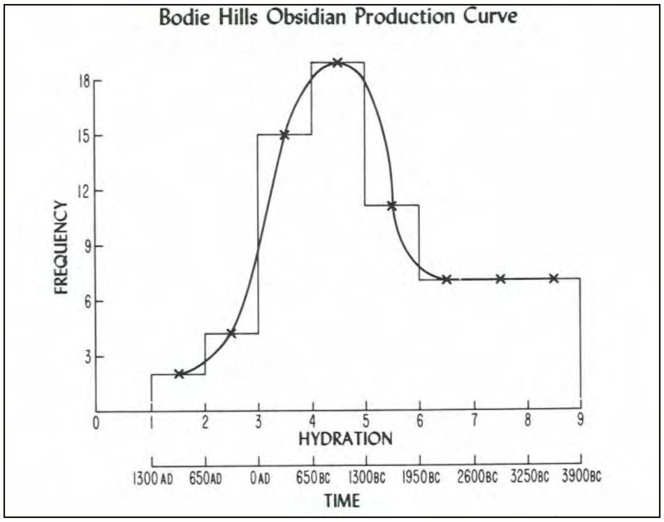


Figure 10. Singer and Ericson (1977) hydration curve.

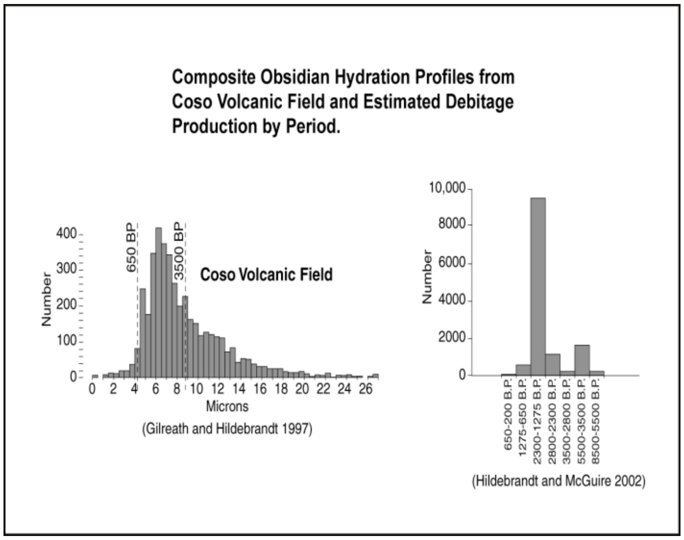


Figure11. Coso hydration curves.

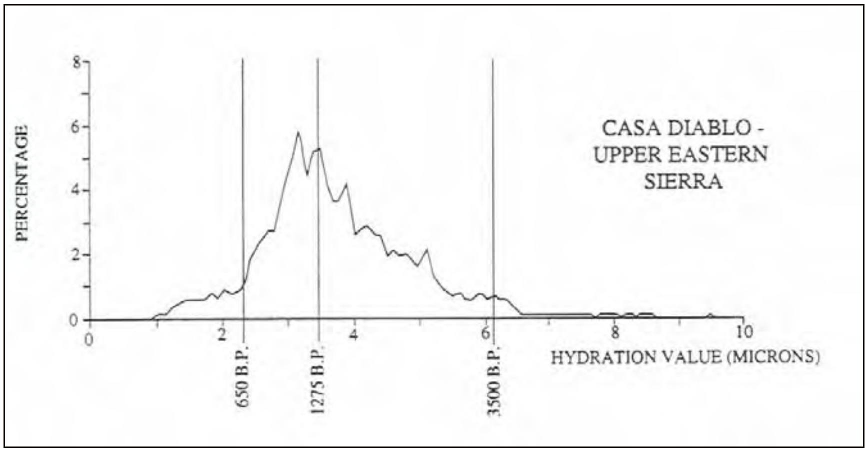


Figure 12. Casa Diablo hydration curve (Hall and Jackson 1989)

individuals exploiting a cost effective tool stone source. It follows that embedded production was practiced during early Holocene use of these cobble deposits by groups taking advantage of the wetland resources of the East Walker River (Jones et al. 2003; Madsen 2002) and the abundant spring sources and associated subsistence resources of the more mesic Bodie Hills environment (cf. Halford 1998a). Due to the abundance and quality of material in the cobble deposits there was no cost benefit for acquiring raw material from the primary source. As a result of intensive Early period use, depletion of the secondary deposits would have compelled Newberry period inhabitants to travel to the primary source to acquire raw material desirable for curation and the production of trade items (Halford 2001:36).

Temporal Periods

A number of cultural chronologies have been proposed and outlined for the region (Bettinger and Taylor 1974; Hester 1973; Lanning 1963; see also Elston 1986). For the most part the dates in each chronology are in agreement, as established from projectile point time markers in conjunction with ^{14}C assays, the main differentiation being in terminology. For the purposes of this study the chronology developed by Bettinger and Taylor (1974), for the southwestern Great Basin/eastern California, will be utilized to provide consistency with the majority of regional studies (Table 2). Some variability in dates is suggested by various researchers (cf. Basgall and McGuire 1988; Delacorte et al. 1995; Gilreath 1995) and these are provided in brackets.

Southwestern Great Basin Chronology

Temporal Phase	Time Period	Characteristic Artifacts
Marana Period	650 BP-Historic (AD 1850)	Cottonwood Triangular and Desert Side-Notched Points, Ceramics
Haiwee Period	1,350-650 BP	Rose Spring and Eastgate Series (Rosegate) Points
Newberry Period	3,150-1,350 BP [3,500-1,350 BP]	Elko Series Points, Humboldt Series
Little Lake Period	4,950-3,150 BP [7,500-3,500 BP Middle Holocene]	Little Lake Series, Pinto Series, Humboldt Series Points
Mohave Period Paleoindian	10,000-8,000 to 6,000 BP [10,000-7,500 BP Early Holocene]	Great Basin Concave and Stemmed varieties, Great Basin Transverse Points

Table 2. Following Bettinger and Taylor 1974; [Delacorte 1999 bracketed].

Mohave Period

Sites in this region dated to the Mohave Period are few at best and are often small and found in surface contexts (Elston 1986). Basgall (1988) documented a Paleoindian site in west-central Long Valley, and Hall (1989) reported on two sites on the northwestern fringe of Mono Basin. Basgall and McGuire (1988) detected evidence of an early component at the well documented and highly reported INY-30 site located in southern Owens Valley. Delacorte et al. (1995) provided a brief summary of other locations and suggested that geomorphological influences could have had an effect on early sites rendering them difficult if not impossible to identify and locate. Halford (2000,

2001) reports on Mohave Period use at CA-MNO-3126, on the west edge of the project area (Figure 4), where a fluted point base and stemmed points were recovered (see also Goebel 2008).

In general, early Holocene hunter-gatherer populations are characterized as far ranging, small groups of individuals who exploited a broad array of subsistence resources, with tool-kits being specialized in nature (Delacorte et al. 1995:1.16). Artifact curation is indicated by highly utilized and retouched bifaces, scrapers and gravers (Elston 1986). Point types are defined by Great Basin stemmed and concave varieties, and the enigmatic crescent or transverse point. Milling implements are rarely found, but this may indicate scavenging by later groups rather than lack of use (cf. Simms 1983). Mohave period groups often have been associated with lakeside adaptation and big game hunting (Willig et al. 1988; Madsen 2002), but some research suggests a broader range of adaptive strategies were pursued including plant processing (Basgall and McGuire 1988; Delacorte et al. 1995; Fowler 1986; Fowler and Fowler 1990). The highly variable resource base within the Great Basin (Fowler 1986; Fowler and Fowler 1990), both on an annual and long term basis, most likely caused shifts in adaptive strategies not easily identified in the archaeological record, but archaeological evidence indicates, that in general, a highly mobile, forager pattern (sinsu Binford 1980) was employed by Mohave period hunter-gatherers.

Little Lake Period

The Little Lake period is better represented in the archaeological record than the earlier Paleoindian/Mohave period, but in general there is a lack of unambiguous evidence and definitive artifact assemblages from this period (Basgall and Giambastiani 1995; Basgall and McGuire 1988; Bettinger 1982; Delacorte et al. 1995; Hall 1989). The Stahl site (Harrington 1957) and components of INY-30 (Basgall and McGuire 1988) are some of the best defined locations representing this period in the region. Some researchers have attributed the dearth of archaeological evidence during this period as evidence of the severe drought conditions in the Great Basin associated to the Altithermal (ca. 7,000-4,500 B.P.) (Antevs 1948, 1955). But as discussed previously, conditions were not homogeneous across the Great Basin with differential drought effects occurring from region to region. Various micro-habitats would have provided viable resource bases for hunter-gatherer groups.

Pinto and Little Lake split-stem point types have been utilized as markers for this period. Although the debate fired by Flenniken and Wilke (1989) concerning the validity of these point types persists, much regional research suggests that these styles are valid chronometric markers for the Little Lake period (Basgall and Hall 2000; see also Basgall and Giambastiani 1995; Delacorte et al. 1995; Gilreath 1995; Thomas 1981). In general, mid-Holocene subsistence, mobility, and technological patterns share an affinity with earlier rather than later occupations (Delacorte et al. 1995; Gilreath 1995). Highly curated formalized flake, core and bifacial tools made of a wide range of raw materials evidences the flexibility and mobility of these hunter-gatherer groups (Gilreath 1995; Kelly 1988). Delacorte et al. (1995:1.16) suggest that "a key difference apparent between Mohave and Pinto/Little Lake artifact inventories is the greater prevalence of milling equipment" in the Little Lake period.

Newberry Period

The Newberry period has been subdivided by some researchers into early (ca. 3,500-2,000 B.P.) and late (ca. 2,000-1,350 B.P.) phases (Delacorte et a. 1995; Hall 1989; Gilreath 1995). Temporal markers include Elko and Humboldt series projectile points. As with the Little Lake period, our understanding of the early Newberry is marred by a lack of spatio-temporal data specific to this period, but the data at hand suggest a continuation of earlier subsistence-settlement patterns. Bettinger (1977a; 1978) proposed that the period is marked by a shift in subsistence-settlement patterns from an emphasis on exploitation of riparian plant species to desert scrub species. This is evidenced by a shift in the location of lowland occupation sites from riparian to desert scrub habitats during this period in the Owens Valley. More recent evidence (Bettinger 1989; Zeanah et al. 2000) suggests that the riparian zone may have served as a seasonal base camp from which a broader range of resources was exploited than previously understood by Bettinger (1975; 1977a)

For the late Newberry, Delacorte et al. (1995:1.17) and Gilreath (1995) suggest that the east-central California region "...witnessed the emergence of complex and logistically well-organized adaptive systems", though residential mobility was still prevalent. This signals a shift, at that time, along the forager/collector continuum (Thomas 1990) from a foraging strategy to a more logistically organized collector strategy (Binford 1980) which defines the Haiwee and Marana periods (ca. 1,350-historic). Archaeological evidence is well reported for the late Newberry (Basgall and McGuire 1988; Basgall and Giambastiani 1995; Delacorte et al. 1995; Gilreath 1995; Hall 1989) with artifact assemblages indicating the variable functionality of site locations, "including long-term residential bases, smaller serially reoccupied transient camps, communal hunting/butchering localities, quarry and stone-working camps, and hunting and gathering stations" (Gilreath 1995:17).

The reduction in the diversity of raw material types used (e.g., basalts and cryptocrystalline silicates) and an increase in obsidian quarrying and trans-Sierran trade (Basgall 1989; Basgall and Giambastiani 1995; Hughes 1984, 1989; Singer and Ericson 1977) indicate shifting socio-economic patterns during the Newberry period. Obsidian biface production for use and trade becomes prevalent with a high degree of curation indicating a still actively mobile population (Kelly 1988). But at the same time caches of non-portable gear (e.g., milling features) and more elaborate house structures indicate perhaps a movement towards more sociopolitical elaboration, population increase, or shifting subsistence-mobility patterns, or a combination of any of these factors (Bettinger 1977a, 1989, 1991a; Delacorte et al. 1995). An increase in well-used milling implements reveals broadening of the diet breadth with a more intensive incorporation of floristic species (Bettinger 1991b; Delacorte et al. 1995; Kelly 1995; Simms 1987). As the period progresses there is a decrease in the diversity of obsidian sources represented in the archaeological record which indicates reduced mobility and residential centralization culminating in the Haiwee and Marana periods.

Haiwee/Marana Periods

The Haiwee and Marana periods (often referred to as the late period) are marked by "...settlement centralization, sociopolitical elaboration, and subsistence intensification" (Delacorte et al. 1995:1.17; Gilreath 1995), and are associated by some researchers with the expansion of Uto-Aztecan speakers across the Great Basin (Bettinger and Baumhoff 1982; Madsen and Rhode 1994). It has been suggested that the increased utilization of micro-habitats such as the pinyon zone (Bettinger 1977a, 1989), the Volcanic Tableland (Basgall and Giambastiani 1995; Giambastiani 2004), and high altitude sites, (Bettinger 1991a) along with the changes apparent in the use and movement of obsidian, is evidence of this shift.

During the Late Period (Haiwee-Marana: 1,350 B.P. to historic) flake blank technology for the production of projectile points becomes more prevalent, with a marked reduction in formal bifaces and formed flake tools, concomitant with an increase in expedient tool production and use. In general, artifact curation and caching show a marked decline. The reduction of source variability implies more site scavenging and the use of local obsidians. Scavenging was evidenced at CA-MNO-3126 and CA-MNO-3125/H where a spike in Marana use (Figure 24) at the sites indicates scavenging of earlier deposits (Halford 2000). These late period trends correlate to patterns of reduced mobility as evidenced in the archaeological record (Basgall and Giambastiani 1995; Bettinger 1977a; Bettinger and Baumhoff 1982). Changing land use strategies indicative of the late period are associated with major technological shifts, including the introduction of the bow and arrow, an intensification of seed procurement (e.g., pinyon pine nuts, rice grass, needlegrass, etc.), the introduction of Owens Valley brownware in the Marana period, and more elaborate and permanent house features. An increase in trans-Sierran sociopolitical interaction is evidenced by the expansion in long distance trade of marine shell ornaments. In general, the pattern emerging from the late period archaeological record closely matches the ethnographic pattern of Numic speakers.

Research Near The Study Area

Archaeological Research in the Bridgeport Valley/Bodie Hills

The majority of archaeological research in proximity to the project area is found in the “gray literature” or in M.A. theses. In the 1960s Emma Lou Davis (1964) completed some of the earliest archaeological reconnaissance in and near the Bodie Hills. Meighan (1955) recorded a number of sites along the East Walker River corridor during an early regional survey of the area. Busby et al. (1979) and Kobori et al. (1980) provide a Class I and Class II cultural resource overview of the Bodie Planning Unit. Completed in 1979 and 1980, the random sample and probabilistic surveys employed by Kobori et al. (1980) were undertaken to provide an archaeological resource overview of the Bodie/Colville Planning Units for the BLM. They surveyed 22,385 acres using two mile long belt transects. Hall (1980) performed a Class II random sample survey of the Bodie Hills geothermal area, which encompasses the southwestern Bodie Hills on the fringe of Bridgeport Valley. He surveyed 90 quadrats totaling 6,729 acres. Bieling's (1992) M.A. Thesis and CRM projects, conducted by Sonoma State University (see Fredrickson 1991) for Caltrans, address sites in the northwestern portion of Bridgeport Valley. Singer and Ericson (1977) provided the first quarry analysis of the Bodie Hills obsidian source, and Ericson (1982) discusses obsidian exchange systems. Burton (1995) excavated two sites (CA-MNO-2749 and CA-MNO-2751) on the western edge of Bridgeport Valley on By-Day Creek. Halford (2000, 2001) studied two sites on the western fringe of the project area (Figure 4) and Goebel et al. (2008) completed data recovery at one of the sites in 2005. Halford (1998b) conducted a targeted study of the Travertine ACEC to the south of the project area which was followed up by a more focused effort by Mills (2003). Upland research in the Bodie Hills has been conducted by Halford (1998a), who provides paleoenvironmental and obsidian analyses, and Rusco (1991) who conducted research of prehistoric archaeological sites in the Bodie mining district. Hardesty et al. (1991) provide the most comprehensive overview of historical archaeology in the Bodie Hills.

In general, these investigations indicate that prehistoric cultures traveled through and inhabited the area for 9,000 to 10,000 years. Hall (1980:ix) describes a chronology spanning the Holocene (ca. 9,000 years), but found evidence for the use of the area to be focused around the past six millennia. Other researchers including Bieling (1992), Busby et al. (1979), Halford (1998a; 2000; 2001), Goebel et al. (2008) and Rusco (1991) found more conclusive evidence of Early Archaic (ca. 9,000-7,000 B.P.) and Mohave period use of the area, but also see an increase in utilization later in the Archaic period (ca. post 7,000 B.P.) with the zenith of occupation occurring during the Newberry period (ca. 3,500-1,350 B.P.).

Bieling's (1992) thesis research in the western Bridgeport Valley area, in association with cultural resource management studies conducted by Sonoma State University (see Fredrickson 1991), corroborates the regional land use strategies. Hydration data from his study, in correlation with temporally diagnostic elements, indicates that occupation of the western Bridgeport Valley occurred through the Holocene (ca. the past 10,000 years). The Newberry period, associated with Elko Series projectile points, represents the highest percentage of the hydration sample (e.g., 61%). The obsidian hydration profile and diagnostic artifacts indicate that the late archaic, represented by the Haiwee (1,350-650 B.P.) and Marana (650 B.P.-Historic) shows a marked drop off in use of the area. Only 16% of the hydration values fall within the late period.

The early and mid archaic are marked by highly mobile groups practicing a biface technology which maximized the use of bifacial tools through curation and rejuvenation (Kelly 1988). Curation of formal tools and high mobility is indicated by a greater proportion of tools originating from non-Bodie Hills obsidian sources, while debitage profiles are dominated by Bodie Hills obsidian. Eighty seven percent of the obsidian lithic material subjected to x-ray fluorescence analysis, for Bieling’s (1992) study, was assigned to the Bodie Hills obsidian source. A higher proportion of Bodie Hills (96%; n=48) characterized the debitage sample tested. Bieling (1992:97) concludes that the materials recovered from the sites analyzed (MNO-564, 566, 2455, 2456, 2466, 2488, and 2489) indicate that in all instances site use was characterized by activities associated with hunting and retooling activities, with camps formed by highly mobile groups who optimized the use of resource patches.

In contrast to Bieling’s findings, Burton (1995) reports that late period occupations were most prevalent at the two locations he investigated. MNO-2749 was classified as a Marana period pinyon procurement camp, while evidence from MNO-2751 indicated that this site was utilized mainly during the Haiwee period. Although the highest percentage (42%) of artifacts subjected to obsidian hydration analyses fit into the Newberry period, other classes of data led Burton (1995) to assign the main occupation of MNO-2751 to the Haiwee period. Obsidian hydration data (n=47) along with the occurrence of Elko and Desert Side-Notched points indicate that the site was used from the Newberry period through the Marana period.

During investigations at the Travertine Hot Springs (Halford 1998b), located just over 1 mile south of the project area, fourteen sites in a 200 acre area were identified. Of these, nine were formally recorded and are located mainly in the pinyon/juniper zone. Based on a small sample of diagnostic projectile points (n=6) and 120 hydration samples, a chronology for the Travertine area was established that is in agreement with Bieling’s (1992) and Hall’s (1980) findings and other area research (Halford 1998a, 1988b; Rusco 1991); use of the area occurred for the past six to eight millennia, but the Newberry period appears to have been the apex with a decline in use during the late period. Fifty nine percent of the hydration samples were assigned to the Newberry period, 26% to the Haiwee, and 9% to the Marana. Mills (2003) conducted and reported on excavations at one of these sites (CA-MNO-3114/H) a site found to contain significant data related to the protohistoric period and Native American use and adaptation of Euro-American material goods and to the disruption of their lifeways.

As discussed further below, more recent investigations by Halford (2000, 2001) and Goebel et al. (2008) indicate fairly dominant early use (Early Archaic/Paleoindian) use of sites such as CA-MNO-3126 located within the Bodie Hills obsidian cobble flow terminal zone. Halford (1998a) saw use through the Holocene on the Dry Lakes Plateau. The various studies and chronologies indicate a complex of hunter-gatherer use patterns and time-periods of use through within the Bodie Hills, an area which offered significant resource values for both subsistence and material pursuits. The site densities in the Bodie Hills, with an average of up to 15 sites per km^2 (Halford 1998a:112-114), was one of the most highly used locales of the western Great Basin.

Studies Within 1 Mile of the Project Area

Cultural Resource reports specific to within 1 mile of the project area (Figure 13) include Basgall and Richman (1998), Busby et al. (1979), Elston and Covington (1977), Goebel et al. (2008), Halford (1993, 1997, 2000, 2001), Hall (1980), Kobori et al. (1980), Meighan (1955), Singer and Ericson 1977. Camboia (nd) also conducted a 496 acre sample survey of eight, 62 acre quadrats (Figure 14) for MA thesis work that was never finalized, but is reported on here. The work focused on analyzing the spatial dimensions of the Bodie Hills obsidian source and its temporal use. He recorded 29 sites including five cobble exposures which were defined as sources. Brief reviews of the more germane reports to this study follow.

Elston and Covington (1977):

In 1977, Elston and Covington completed an “intensive archaeological investigation” of the then proposed 40 acre Bridgeport Indian Housing Project, where the current Indian Colony is today. A systematic surface collection and subsurface testing strategy was employed to determine the significance of cultural resources identified on the Colony lands. Obsidian or “ignimbrite” artifacts of local material (Bodie Hills obsidian) dominate the assemblages recorded. Elston and Covington (1977) found that “...material occurs on the surface of the study area in a nearly continuous scatter of varying density” and that “concentrations of material form no discernable patterns...”, other than cobble assaying activities. Three 1x2 meter subsurface test units “...demonstrated that artifacts are incorporated in the top 20 cm or so of the fan deposits, but does not contain an in situ buried cultural component” due to the dynamic movement and mixing of the substrate.

Elston and Covington (1977) determined that the 40 acre study area “...is not a single site but a relatively small portion of an aboriginal resource area containing hundreds, perhaps thousands, of small overlapping sites;” a phenomenon most closely conforming to Davis’ (1964) notion of a “use area”. This led Elston and Covington (1977) to conclude that “the archeological remains in the study area are not unique, that similar material can be found over the entire fan and that artifacts are confined wholly to the surface and upper 25 cm of the soil where they have become incorporated through natural soil mixing”. Due to the intense disturbance by historic activities, the salvage of existing information, through their efforts, and the similarity of the artifact classes to numerous other locations in the area, the site or use areas on the 40 acre Colony were not recommended for inclusion on the NRHP. The area addressed in Elston and Covington’s (1977) report was never given a formal trinomial designation.

Halford (1977):

Elston and Covington’s (1977) findings are consistent with the analysis conducted on a 40 acre parcel adjacent to the north edge of the Colony by Halford (1997). Halford (1997) conducted surface and subsurface investigations at CA-MNO-276. The site was extended from Meighan’s (1955) original recording, but was limited to the project area as it was found that the site was actually a part of a complex of locations or “use areas” as described by Elston and Covington (1977) and which is consistent with the findings of the study conducted by Halford (2000) of a parcel west of the Colony and the current investigation. For all practical purposes the complex of reduction locations found in this area of the Bodie Hills can only be segregated by landforms and a reduction in artifact densities between activity loci and locations. It is now known that all of the use areas described here occur at the western terminus of the Bodie Hills cobble flow area (Figure 4).

MNO-276 represents a core reduction and early to mid stage biface reduction location of secondary deposits of Bodie Hills obsidian. This is indicated by the high percentage (97%) of early to mid stage debitage recorded during surface sampling of the site. The debitage frequency distribution is dominated by primary and secondary decortication flakes (70%) with single faceted platforms and simple dorsal scar morphology. As with MNO-3125/H and MNO-3126 (Halford 2000, 2001; Goebel et al. 2008), the alluvial/colluvial deposits of obsidian on site, originating from the BHW obsidian source, provided the raw material utilized. Cores and early stage bifaces (Stage 1 to Stage 3) represent the highest percentage (83%) of diagnostic tools recorded.

Seven subsurface exploratory excavation units, placed along an east/west axis indicated that subsurface remains were not prevalent at the site and that it is mainly a surface manifestation with vertical migration occurring. Units were excavated to a depth of 40 to 50 cm, when possible, where a rocky impenetrable substrate was encountered. Fifty two obsidian artifacts were recorded in the 7 test units for an average of 7.4 artifacts per unit. The reduction profile was heavily weighted (96%) towards early to mid stage core and biface reduction activities.

The core and biface reduction trajectories prevalent on site MNO-276 are indicative of Little Lake period and Newberry period activities as previously discussed (cf. Basgall 1989; Bieling 1992; Bouey and Basgall 1984; Singer and Ericson 1977). The reduction trajectories on this site fit into the regional pattern for middle archaic, Newberry period, obsidian procurement and use patterns. The reduction profile indicates a focus on biface production and is an example of use of secondary deposits of obsidian cobbles far removed from the source.

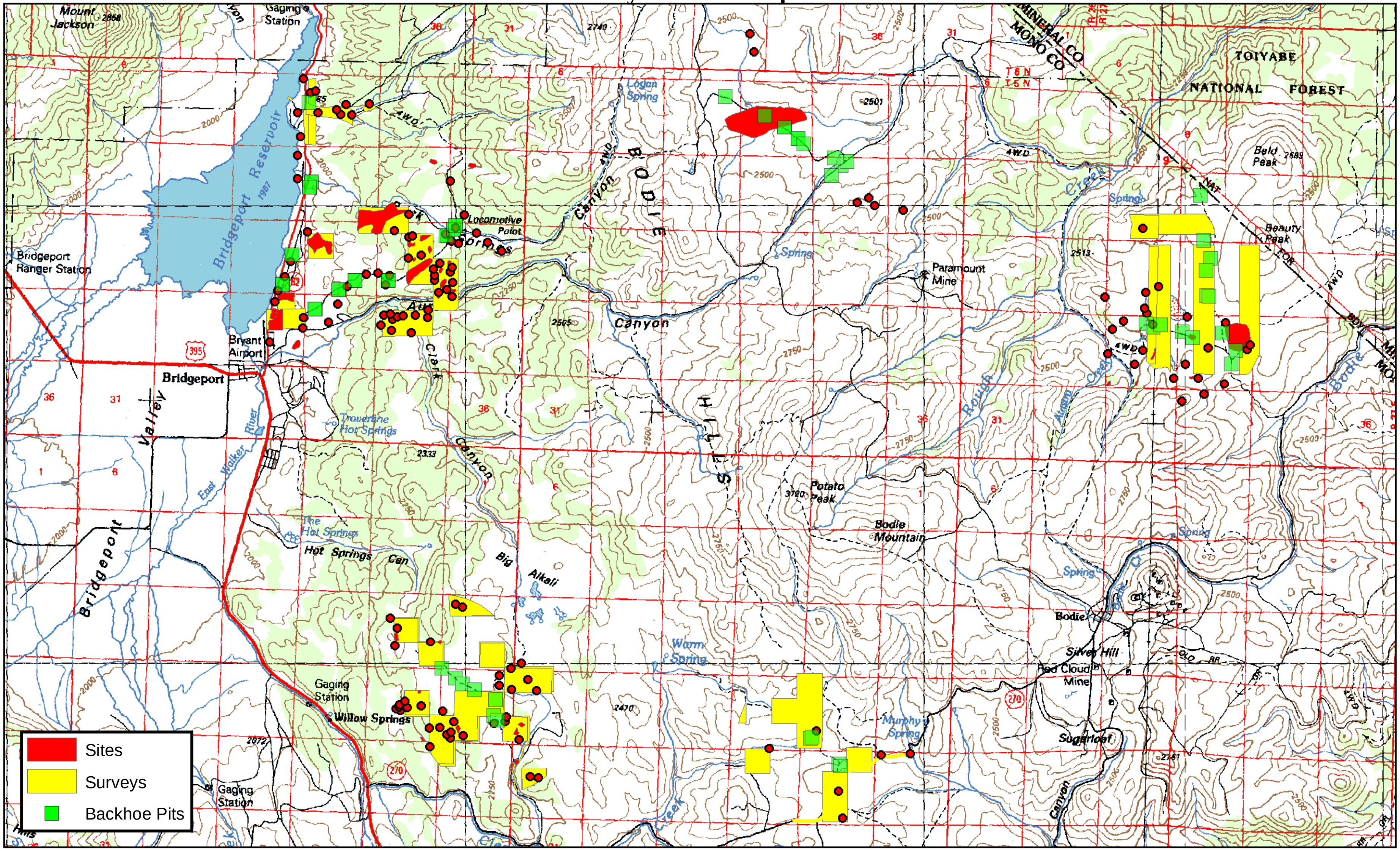
Due to the redundancy of data classes found at this site, parallels to other sites in the area, and the lack of substantial subsurface deposits, it was determined that the analysis by Halford (1997) sufficiently addressed the data potential for the site. As a result, the site was determined ineligible for listing on the NRHP, with SHPO concurrence.

Basgall and Richman (1998):

Basgall and Richman (1998) report on surface inventories of California Department of Transportation (Caltrans) right-of-way corridors, including State Highway 182. They recorded and updated many sites along the SH 182 corridor, including MNO-3125/H and MNO-3126 which are

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office

Bodie Hills Soil Inventory
CA-170-07-08
Previous Site and Survey Location Map within 1 Mile of Backhoe Pits



U.S.G.S. 100k Quads: Bridgeport and Excelsior Mountains
Scale: 1:125 000

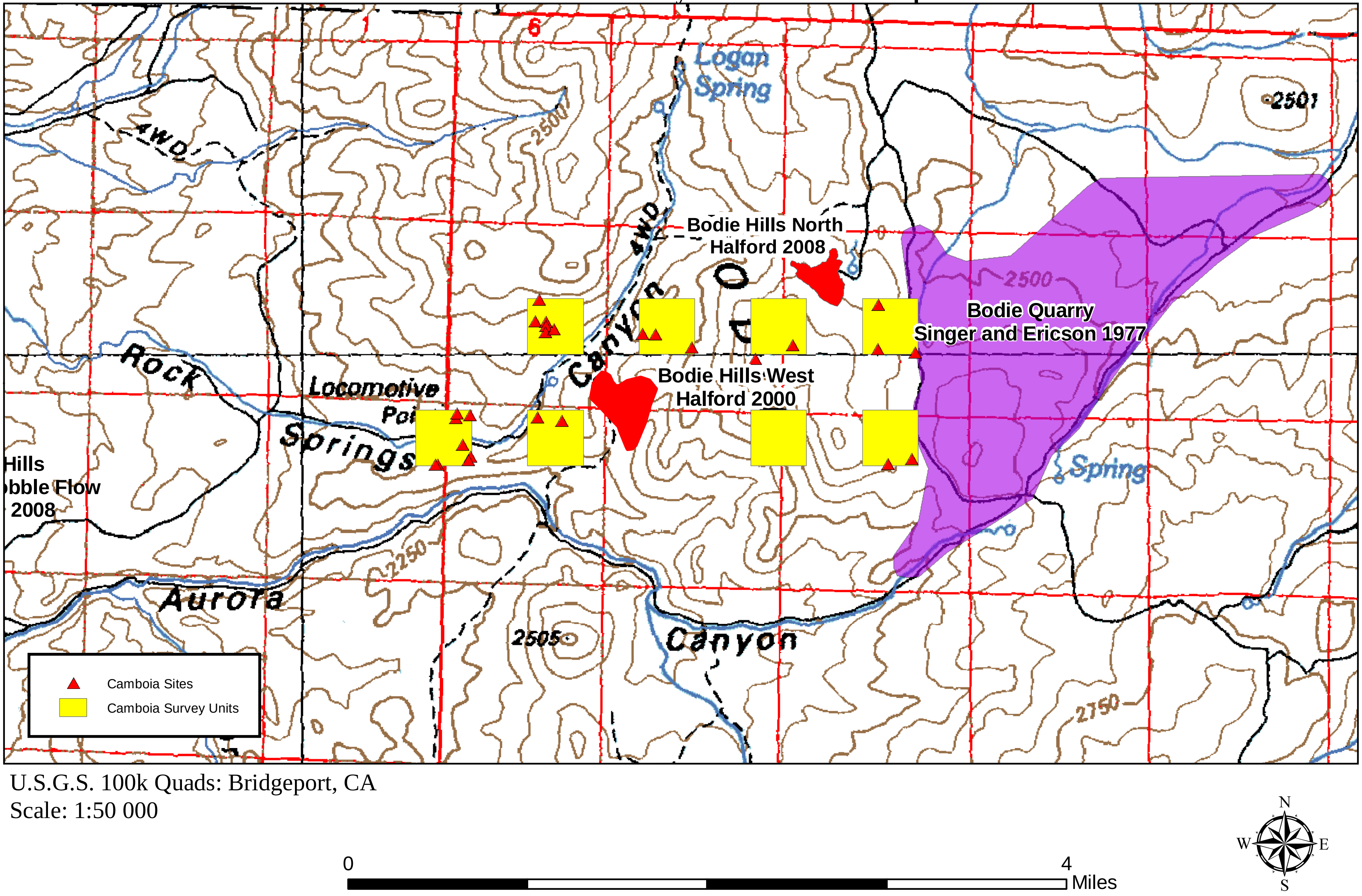
0 8 Miles

N W E S

Figure 13.

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office

Bodie Hills Soil Inventory
CA-170-07-08
Camboia Survey and Site Location Map



U.S.G.S. 100k Quads: Bridgeport, CA
Scale: 1:50 000

Figure 14.

further analyzed in this document. As discussed above, the blending of use areas is common for this locality of the Bridgeport Valley, on the fan of Aurora Canyon, where reduction debris extends across an extensive area making conventional designation of site boundaries untenable (cf., Elston and Covington 1977; Goebel 2008; Halford 1997, 2000, 2001).

Halford (2000, 2001):

Halford (2000, 2001) reported on the analyses of sites CA-MNO-3125/H and CA-MNO-3126 for the Bridgeport Land Sale; two sites where cobble reduction activity was prevalent through the Holocene. Contrary to most previous findings in the area and region Halford forwarded that:

> The most intriguing result of this investigation is the bimodal production curve which shows peak periods of use during the Early Archaic with a significant drop off in production during the Newberry period, peaking again during the Marana period. These trends are juxtaposed with other regional quarry data which generally show a zenith of production use from 3,000 to 1,000 B.P. under a normally distributed curve. The data from this study suggest that secondary deposits were important tool stone production areas, especially during the early period. The hydration curve also suggests that more intensive Early and Marana period use occurred in the Bridgeport Valley area than has been indicated by previous studies (Bieling 1992; Burton 1995; Elston and Covington 1977; Fredrickson 1991; Halford 1997, 1998b; Hall 1980), which all point to a zenith during the Newberry period. It is clear that Early Archaic/Mohave period occupations dominate the use of the project area and that Marana period use increased as well. Increased use during the Marana period is perhaps a result of subsistence intensification/diversification often associated with this period (cf., Delacorte et al. 1995; Gilreath 1995; Zeanah et al. 2000). The most important implication of this study is that secondary deposits of obsidian need to be given more scrutiny in the development of regional models of hunter-gatherer behavior. This study points to more intensive use during early Archaic and Paleoindian periods than previously understood (Halford 2000:45).

Goebel et al. (2008)

Goebel et al. (2008) conducted research at CA-MNO-3126 for a data recovery project for the Bridgeport Land Sale. Their data corroborate and advance Halfords' (2000, 2001) findings at the site during the earlier studies. Early Archaic and Paleoindian period use was found to be prevalent with 70% of the hydration readings (n=237) having rim values of >6.2 µm. It was determined that the site is located on a "…geomorphic surface older than 50,000-140,000 years…" (Goebel et al. 2008:20) correlated to the strongly developed argillic (Bt) soil horizons of the Tahoe glacial period. The river terrace on which the site sits is an alluvial deposit potentially formed during the Sherwin glacial period (>700,000 years ago). Therefore, it was concluded that the site is a surface manifestation "… and that buried artifacts recovered from within the alluvial deposit are the result of bioturbation−post-depositional mixing…" (Goebel et al. 2008:71), similar to the findings of Elston and Covington (1977) and later Halford (1997). These conclusions are important to the current study as the same type of depositional horizons were encountered (as described earlier) indicating that the culturally modified obsidian cobble deposits are mainly surface manifestations with artifact movement and mixing down to 20-30 cm below the surface.

Previously Recorded Sites Within 1 Mile Radius Of The Project Area

Literally, hundreds of sites occur within the Bodie Hills proper with site densities averaging up to 15 sites per km^2 (Halford 1998a). For the purposes of this analysis the 13 control unit locations were buffered within a 1 mile radius (Figure 13). Survey within one mile of the control units includes nine reports (Elston and Covington 1977; Goebel et al. 2008; Halford 1993, 1997, 2000, 2001; Hall 1980; Kobori et al. 1980; Singer and Ericson 1977) and one unfinished MA thesis project (Camboia nd)(Figure 14). The acreage from these surveys within the 1 mile radius zone encompasses 1769 acres. Eighty one previously recorded sites occur within this zone, including roughly ½ of the 1462 acre Bodie Hills obsidian source mapped by Singer and Ericson (1977). The site density is greater than 11 sites per km^2, based on the cumulative data from these reports.

Research Design

Management Objectives

As detailed from the previous section numerous sites occur near the Bodie Hills project area, especially in the Rock Springs Canyon area (Figures 13 and 14). During the survey, soil pits were relocated to avoid sites, but within the Rock Springs Canyon and eastern portions of the project area it was found that obsidian cobbles and flaked stone debris was distributed across the area and could not be avoided. Based on previous research in cobble zone (Halford 1997, 2000, 2001), a hypothesis was advanced that the cobble flow was part of a larger complex now called the greater Bodie Hills Obsidian District (Figure 4). It has been discovered as a result of the current study that the new quarry site recorded by the author in 2000, the Bodie Hills West (BHW) source, is the origination of the western cobble flows. The cobbles are distributed west down the drainages and fans leading from the BHW source to their terminus at the East Walker River/Bridgeport Reservoir (Figure 4).

Due to the fact the Bodie Hills obsidian source played a significant role in California prehistory (cf. Bouey and Basgall 1984; Gilreath and Hildebrandt 1997; Halford 1998a, 2000, 2001; King et al. nd; Rosenthal 2006; Rosenthal and McGuire 2004), and 13 of the soil pits (pits 4, 5, 12-18, and 37-40) were found within what is now called the "greater Bodie Hills obsidian quarry" or Bodie Hills Obsidian District, eligibility was assumed under Criterion D (NPS Bulletin 15:1991; see also 36 CFR 60.4). Under this criterion a site must possess information which can contribute to our understanding of human history or prehistory and yield data which have a significant bearing on regional research issues. Therefore, the analyses conducted for this report were designed to determine affects to the Bodie Hills Obsidian District as a result of the proposed undertaking.

Research Objectives and Questions

To address affects at the 13 pit locations on the Bodie Hills Obsidian District a number of research issues and questions germane to the current state of knowledge of human prehistory in the region can be evaluated. The first goal is to determine spatial and structural integrity of the pit site(s). It is important to determine if historic activities, geomorphic processes, or other natural processes, such as cryoturbation of bioturbation have affected the archaeological deposits. Deposit integrity is critical to determining if a certain location is a contributing element to the site or larger district. This of course will also have a direct bearing on determining the chronological and functional attributes of the site(s) and whether periods of use and associated activities can be successfully segregated.

Chronology is important to establish for determining whether the temporal use of the various pit locations corresponds to our understanding of local and regional use patterns. To this end various questions may be addressed. Are multiple periods of use represented or does cobble assaying at each location represent a discrete moment in time? Does use reach an apex during the Newberry period, following the local and general regional pattern or is the bimodal pattern reported by Halford (2000, 2001; Goebel et al. 2008) further supported? Obsidian hydration has been an important chronometric tool for developing regional and local site chronologies and for establishing time lines for shifting adaptive strategies. It will be the main method employed in this study to create chronological control.

On a functional level, what types of activities occurred at each location and what can it tell us about technology, subsistence, exchange, or changing land-use strategies. What type of use patterns occurred and are they indicative of residential or logistical mobility, or a forager versus collector strategy (sinsu Binford 1980)? Was occupation short-term or long-term?

Of particular importance to this investigation are issues concerning obsidian acquisition and use. Obsidian studies have been of great importance in the Eastern Sierran region and have provided a foundation for developing research perspectives and hypotheses of hunter-gatherer adaptive strategies and changing land-use patterns. Since the main activity at the pit locations appears to have been quarrying of secondary deposits of Bodie Hills obsidian many questions important to obsidian acquisition and use may be addressed. Issues such as trade, mobility, territoriality, and technology, among others, may be evaluated. The models of quarry production and collapse of production discussed earlier, i.e. demographics/depopulation, embedded production, inter-regional exchange, and technological production changes, may be addressed.

Not much attention has been given to secondary sources and their role in obsidian production and trade, therefore emphasis will be focused on the following questions. What are the chronological dimensions? How does the production curve fit into the regional and local model? Is there an apex of production apparent during the Newberry period or is there variability as shown by Halford (2000, 2001; see also Goebel at al. 2008)? What type of reduction trajectories occurred and do they reflect changing adaptive strategies from a core/biface based to a flake based technology associated with late period technological, subsistence, and mobility adaptations? How do the periods of use, reduction trajectories and activities fit into the local and regional pattern? And finally, an overarching question, does the data provide any new information on hunter-gatherer behavior.

Methods

Each soil pit location was surveyed using closely spaced, 5 meter, transects. A 10 meter buffer around the backhoe pit and a 20 meter wide corridor for access from existing roads to the pit was surveyed. Following survey it was determined that the 13 pits found to be within the Bodie Hills obsidian quarry/cobble flow area (Figures 2-4) would be subjected to Phase II subsurface excavations. None of the pits on the DLP were within sites, but were monitored during project implementation. Controlled excavations and surface collections were undertaken at the 13 pits found within the greater Bodie Hills (BH) obsidian quarry on both the west and east flanks of the main and BHW sources. These pits were also monitored during backhoe operations. Excavations were conducted in 10 cm arbitrary levels below ground surface. All matrix was screened through 6 mm mesh and all artifacts bagged and recorded by unit level. Units were laid out as 1 m^2 at each pit location and excavated in 1x.50 m portions upon determination that soils mirrored previous studies (Halford 2000; Goebel et al. 2008) and that cultural remains were contained in the first 10-20 cm, indicating that cultural deposits are surface manifestations originating on old surfaces as discussed previously and below.

Flaked stone was characterized by quantitative morphological attributes based on cortex percent, dorsal scar morphology, platform characteristics, termination type, longitudinal curvature and flake shape. Categories include primary decortication, secondary decortication, early, mid, late stage thinning, biface thinning, alternate, linear, bipolar, pressure and broken flakes. Tools were quantified into morphological categories including cores, hammerstones, Stage 1 to Stage 4 Bifaces, projectile points (or Stage 5 Bifaces), formed flake tools, and edge modified flakes. Full operational definitions for these flake and tool categories can be found in Appendix B.

One hundred and thirty one obsidian samples from the 13 pits from surface and subsurface contexts were submitted for obsidian hydration analyses to Craig Skinner of the Northwest Research Obsidian Studies Lab, Corvallis, Oregon. One projectile point was also submitted. Due to the fact that past studies (Halford 1998b, 2000, 2001; Goebel et al. 2008) have shown that Bodie Hills obsidian dominates (≥ 90%) the flaked and tool stone assemblages in the western Bodie Hills, no samples were submitted for XRF, though 26 samples were submitted to Robert Yohe at California State University, Bakersfield for laser ablation studies (pending analysis).

Results

Inventory of the 10 Coleville pit locations yielded no cultural values, either sites or isolates. As a result the Coleville portion of the project will be given no further consideration in this report. Of the 54 locations proposed in the Bodie Hills area, 23 pits had no associated cultural resources, 5 pits were relocated to avoid cultural resource values, 13 pits are located within the Dry Lakes Plateau National Register District (DLP), 13 pits were found to be within the Bodie Hills obsidian quarry/cobble flow area and 1 pit was dropped due to wildlife concerns. None of the pits on the DLP were within sites, but were monitored during project implementation, of which only one pit was excavated on the DLP. Controlled excavations and surface collections were undertaken at the 13 pits found within the greater BH obsidian quarry on both the west and east flanks of the main and BHW sources (Figure 3).

At each pit location within the BH obsidian quarry/cobble flow area a 1x1 or 1x.50 meter control unit was excavated to determine if subsurface deposits were extant and to determine if they were analogous to or different than the surface assemblages. All flaked stone within each control unit and from a 10 meter wide swath from the control unit/pit location to the road was collected. Soil profiles for all excavated units matched those reported by Halford (2000) and Goebel et al. (2008) and also found during backhoe pit excavations (Figure 9). The soils are well developed with clayey Bt horizons over silica cemented duripans. The argillic, Bt horizon begins at 10-15 cm below the surface and overlays the duripan layer which was present within a range of about 20 (50 cm) to 30 (75 cm) inches (Ed Blake, NRCS soil scientist, personal communication 2007). The duripan layer is an old, silica rich, Quaternary soil that takes tens of thousands of years to form and pre-dates Holocene deposits. In some pits obsidian cobbles were found embedded in the duripan (Figure 9), but no culturally modified artifacts were found, further indicating the ancient origination of these deposits.

Flaked Stone Analyses

The data show that primary reduction was the main activity at the 13 test locations (Table 3 and Figure 15), with primary decortication, secondary decortication and early stage interior reduction flakes representing 74% of the flaked stone reduction profile. The high frequency of broken flakes (14%) indicates that hard hammerstone, primary reduction of obsidian cobbles/cores was the focal reduction activity within the cobble flow area at all pit locations. This reduction trajectory closely parallels that reported by Elston and Covington (1977), Halford (1997, 2000, 2001) and Goebel et al. (2008) for three sites analyzed on the western fringe of the cobble flow. Interestingly, no formal tools were recovered with the exception of one isolated Rose Spring/retouched Elko Corner-Notched projectile point.

Of note is the employment of unifacial biface technology in the Bodie Hills. This reduction trajectory was found to be most prevalent within the Bodie Hills cobble flow zone, but was also employed regularly at the main sources. In general, the size of Bodie Hills raw material is relatively small (see Figures 7 and 8) compared to other regional sources such as Casa Diablo, Truman Queen, Mono Glass Mountain, Coso and others, manifesting in cobble form. The limitations in size and the bi-convex nature of a majority of the cobbles, lends itself to making a unifacial biface trajectory highly efficient for the reduction of Bodie Hills obsidian.

0708 - Bodie Hills Soil Pits - Surface and Subsurface Collection

FLAKED STONE MORPHOLOGICAL FREQUENCY DISTRIBUTION

UNIT	PDEC	SDEC	EST	MST	LST	BRK	CORE	Total
P4	28	20	3	1	4	4	0	**60**
P5	5	1	0	0	0	0	0	**6**
P12	7	4	4	0	0	6	0	**21**
P13	0	7	3	1	0	0	0	**11**
P14	8	5	2	5	1	2	0	**23**
P15	9	8	2	3	0	3	0	**25**
P16	5	3	2	4	0	4	0	**18**
P18	9	7	2	0	1	5	0	**24**
P37	3	7	0	0	1	1	0	**12**
P38	9	6	4	3	0	5	0	**27**
P39	24	11	12	8	1	12	1	**69**
P40	4	4	4	1	0	2	1	**16**
	111	**83**	**38**	**26**	**8**	**44**	**2**	**312**

PDEC=primary decortication; SDEC=secondary decortication; EST=early stage interior; MST=mid-state interior; LST=late stage interior; BRK=broken

Table 3.

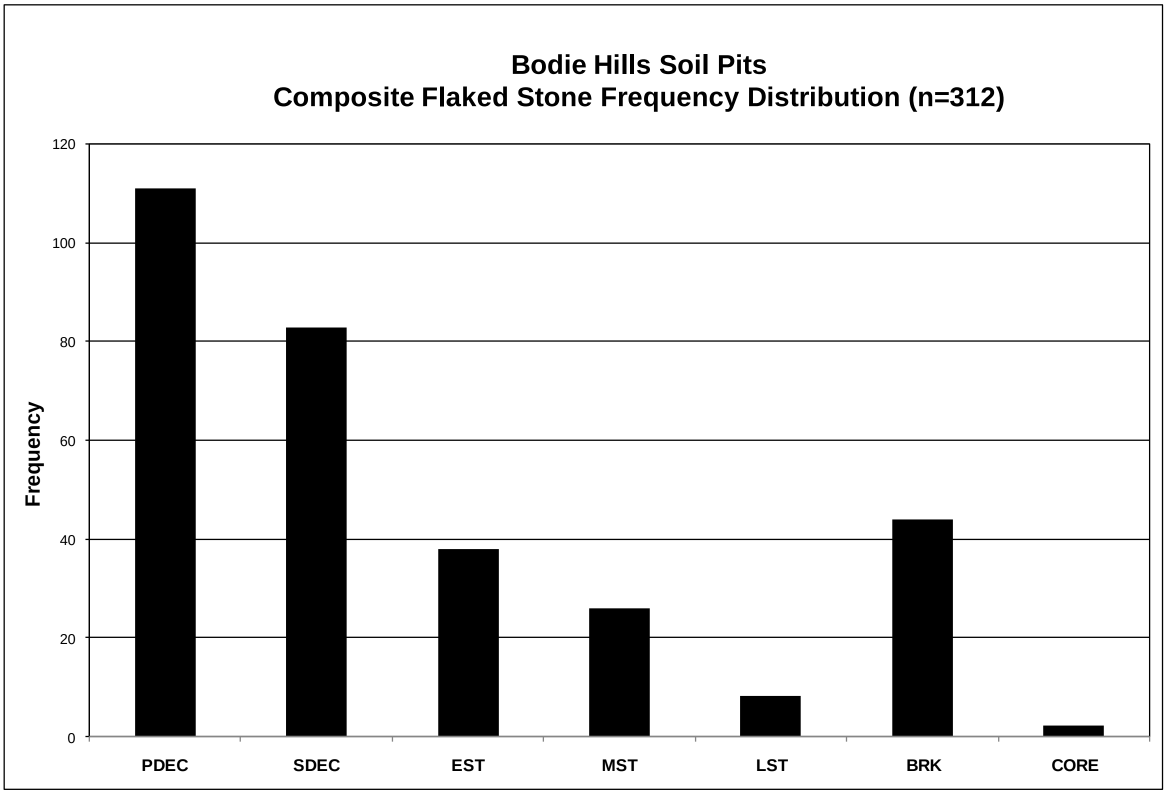


Figure 15.

Obsidian Hydration Analyses

A sample of 131 obsidian flaked stone artifacts was submitted to Craig Skinner of the Northwest Research Obsidian Studies Lab for obsidian hydration analyses (Appendix A). Of the sample submitted, ten or more samples were selected from each control unit. In two cases (P5 and P17) less than 10 items were recovered and therefore a smaller sample was analyzed from these locations (see Appendix A). The composite sample includes 16 broken, 49 primary decortication, 35 secondary decortication, 15 early stage, 12 mid stage, 1 late stage, 1 bipolar core, 1 isolated projectile point and 1 natural cobble. Interestingly, no bifaces or formal tools were recovered from the control unit samples. This along with the reduction debris recovered suggests that bifaces were transported from the quarrying locales at an early stage and refined off site. A recently recorded site, located at a spring complex roughly 2 miles northeast of the BHW source, provides support for such a hypothesis. Habitation debris, stage 3 bifaces and production debris was abundant at the site.

Of the 131 samples submitted, 116 returned hydration readings and 11 artifacts provided double band readings for a total sample size of 127 values. One 15.5 µm value outlier value was trimmed as well as the one isolated projectile point recovered. The remaining hydration sample analyzed included 125 readings from 114 artifacts. The composite hydration profile (Figure 16), segregated by .5 µm, ranges indicates that the cobble flow deposits were utilized through the Holocene (ca. the last 10,000 years before present) with spikes at 6.5 µm, 4.5 µm and 3 µm (years B.P. following Halford 2000: Table 11).

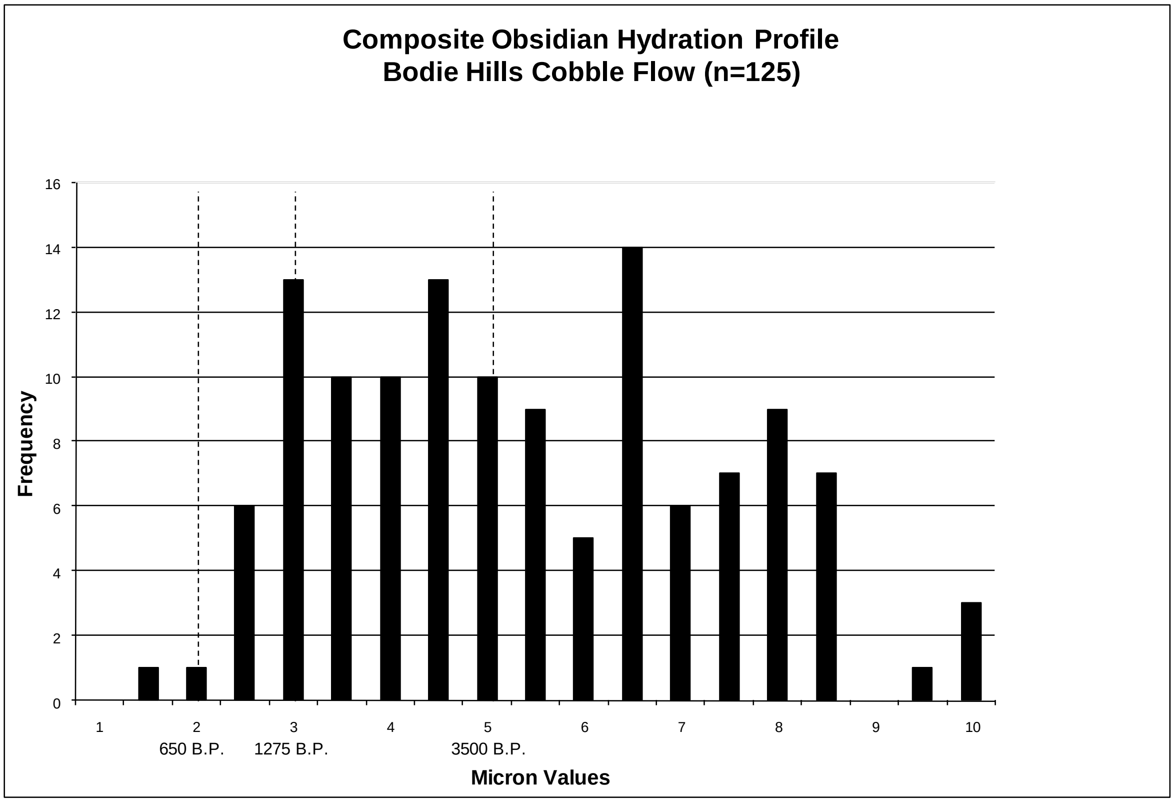


Figure 16.

These data can be further analyzed by employing descriptive statistics of hydration ranges based on a sample of 82 projectile points from various project sites in the Bridgeport Valley/Bodie Hills area (Table 4). While the data set shows wide ranges, especially for dart forms (Elko and pre-Elko point forms), the sample mean does increase as would be expected for each time period and perhaps is the best statistic by which to measure hydration data against in circumstances where projectile point sample sizes are adequate to create such a measure. The one sigma range provides a viable means by which to analyze the data set as there is a close fit and very little overlap in ranges, especially in the later time periods (Newberry-Marana).

As illustrated in Table 4, significant overlap occurs between point series especially in terms of the Elko and Little Lake series. This trend was also recognized by Gilreath and Hildebrandt (1997:64-84) in their treatment of the Coso volcanic field. They found overlapping temporal ranges between "thick Elko, Little Lake and Great Basin Stemmed", suggesting that these forms were used contemporaneously. More likely this is a factor of the many variables that can affect the rate of hydration (cf. Rogers 2007a, 2008b) especially as artifact age increases. As a result of the fuzziness in early period designations they placed point forms into a broad, "Early period" category pre-dating 5,500 B.P. These early period discrepancies could be a result of sampling error, typological mis-classification, limited sample size, limitations inherent in obsidian hydration, artifact history, effects of fire, or any combination of these. A larger data set will be needed in attempts to resolve this problem. Nonetheless, using the mean as an indicator there is clearly a correlation between the temporal designation of diagnostic point types and their hydration rim measurement (i.e., the older the point type the large the mean value). For the purposes of this study, and in order to compare and contrast the hydration data against previous studies at CA-MNO-3125/H and CA-MNO-3126 (Halford 2000, 2000;

Goebel et al. 2008), the hydration ranges for time periods proposed by Halford (2000, 2001) (Table 5) are employed.

Period	**Series**	**Hydration Range**	**1 σ**	**2 σ**	**n**	**×**	**sd**	**cv**
Marana	DSN/CTN	1.3-2.8	1.4-2.2	1.0-2.6	18	1.8	0.39	0.22
Haiwee	RSG	2.1-3.7	2.3-3.4	1.7-3.9	13	2.8	0.55	0.20
Newberry	ELK	2.7-7.2	3.6-5.8	2.5-6.9	34	4.7	1.1	0.23
Little Lake	LLSS	3.5-7.2	3.8-6.4	2.5-7.7	12	5.1	1.3	0.26
Mohave	GBS/GBC	5.4-8.1	5.7-7.9	4.6-9.0	5	6.9	1.1	0.16

Table 4. Bodie Hills Hydration Range for Temporal Periods based on 82 samples taken from Bieling 1992; Burton 1987, 1995; Halford 1998a, 1998b, 2000; and Skinner and Thatcher 1999 (from Halford 2000, 2001). (DSN/CTN=Desert Side Notched/Cottonwood Series; RSG=includes Rose Spring and Eastgate variants; ELK=Elko Series, includes contracting stemmed variants (Gypsum, Gatecliff, Elko); LLSS=Gatecliff Split Stemmed; GBS/GBC=Early Stemmed variants/concave base variants.

Hydration Ranges for the Bridgeport Project Area (Micron Values Unconverted)				
Marana	Haiwee	Newberry	Little Lake	Early Archaic/Mohave
1.2-2.0 µm	2.1-3.0 µm	3.1-5.1 µm	5.2-6.2 µm	6.3-9.3 µm
100-650 B.P.	650-1350 B.P.	1350-3500 B.P.	3500-4950 B.P.	4950- 10500 B.P.

Table 5. Hydration ranges for Bodie Hills obsidian, using the Casa Diablo hydration rate (Hall and Jackson 1989; years B.P. derived using a 1.195 EHT conversion factor).

The proposed hydration ranges for the recognized regional temporal periods are provided in Table 5 above. The ranges were formulated based on the temporal designation of each sample using the Casa Diablo rate after correcting for EHT. When applying a given hydration rate, the differences of effective temperature from the point of origin for the derivation of the hydration rate (i.e., Long Valley for the Casa Diablo rate) and location where the rate is applied must be considered. In a study near Sonora Junction, Basgall (1998:29) calculated a correction factor, using Lee's (1969; see also, Stevenson et al. 1989) integration method, for the differences in EHT between Long Valley and Sonora Junction based on temperature data derived from Bridgeport. The correction factor derived by Basgall (1998) is 6% per degree C. The EHT in Bridgeport is 9.72 degrees C, while that for Long Valley is 12.97 degrees C, a difference of 3.25 degrees C. Therefore, a correction factor in micron measurements of +19.5%, or 1.195 was multiplied against the raw micron values derived from the Bridgeport/Bodie Hills project area when using the Casa Diablo formula.

Casa Diablo Obsidian Hydration Rate

(Hall 1984; Hall and Jackson 1989)

$$Y = 129.656x^{1.826}$$

(Where y=years B.P. and x=microns µm)

This rate can be used to provide a relative age and can be converted into an estimated absolute age. Though absolute age conversions should be viewed cautiously due to the complexity of variables which may affect the rate of hydration (cf. Hall and Jackson 1989; Jackson 1984, Rogers 2007a, 2007b, 2008a, 2008b), they provide a useful, albeit relative, parameter for interpreting site chronology. Figure 17 shows the hydration temporal distribution using the ranges proposed by Halford (2000) and employing the raw data. Distributed in this way the data emphasize the trends shown in Figure 16 above, with a bimodal distribution indicating that quarrying of the cobble flow deposits was most prevalent during the Early Archaic and Newberry periods.

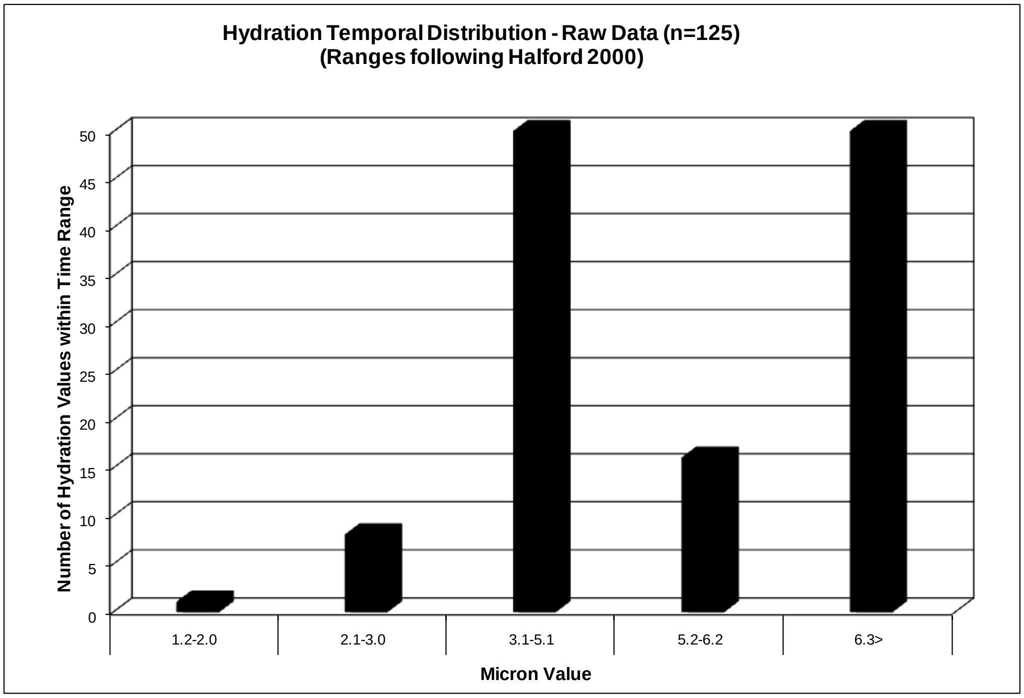


Figure 17.

Application of Recent Hydration Rate Derivations

Rogers (2006, 2007, 2008, 2008c) has devised a new methodology for calculating EHT which is detailed in Appendix C in two manuscripts. It specifically accounts for average annual temperature from a base station, annual variation, diurnal variation, and burial depth. The equation for EHT is:

$$EHT = T_a \times (1 - Y \times 3.8 \times 10^{-5}) + .0096 \times Y^{0.95}$$

(see Appendix C and Rogers (vd) for in-depth discussion of the method)

The data set from this study and the 2000 study of CA-MNO-3125/H and CA-MNO-3126 (Halford 2000, 2001) was provided to Rogers for application and testing of his method. As shown in Table 6 and Figure 18, adjusting for EHT using the Rogers method shifts the hydration values to larger micron values, as expected. The greater the elevation differences from the base station the greater the percent difference. Base parameters were calculated from five weather stations near Bridgeport and data from the Bridgeport RAWs station, located at an altitude of 6,440 ft above mean sea level, was utilized (Appendix C). All data was derived from the Western Regional Climate Center.

Table 6 shows how the Rogers formula adjusts for artifact depth.

Raw and Converted Hydration Values Calculated Using Rogers (vd) Appendix C

Unit	Level	z, meters	Mean Rim, µm	Elev, ft	EHT Corr Rim, µm	~ % Difference
P4	Unit surface	0	4.4	8000	5.49	25%
P4	Unit surface	0	11.1	8000	13.78	24%
P4	Unit surface	0	3.2	8000	4.02	25%
P4	Unit surface	0	3.1	8000	3.89	25%
P4	Unit surface	0	10.2	8000	12.63	24%
P4	0-10	0.05	5.0	8000	6.68	34%
P4	0-10	0.05	5.4	8000	7.26	34%
P4	0-10	0.05	3.8	8000	5.06	33%
P4	10-20	0.15	7.3	8000	10.23	40%
P4	10-20	0.15	4.5	8000	6.38	42%
P4	10-20	0.15	8.1	8000	11.44	41%
P12	Unit surface	0	4.5	6600	4.61	2%
P12	Unit surface	0	2.8	6600	2.82	1%
P12	Unit surface	0	7.5	6600	7.63	2%
P12	Unit surface	0	4.5	6600	4.54	1%
P12	Unit surface	0	4.6	6600	4.66	1%
P12	0-10	0.05	5.8	6600	6.34	9%
P12	0-10	0.05	6.4	6600	7.01	10%
P12	0-10	0.05	5.9	6600	6.49	10%
P12	0-10	0.05	3.7	6600	4.08	10%
P12	0-10	0.05	7.7	6600	8.46	10%

Table 6.

Date Formulations Derived from Obsidian Hydration Equations

On-going research of Bodie Hills hydration rates from sites on the western slope of the Sierra, west northwest of the Bodie Hills obsidian source has yielded a suite of radiocarbon/obsidian hydration pairings from buried contexts as well as projectile point data (Rosenthal and Waechter 2002; Rosenthal and McGuire 2004; Rosenthal 2006; Jeff Rosenthal, personal communication 2008). As can be seen in Table 7 the rim values in general fit well with the raw rim values within the time frame assigned to the values. Of the 22 pairings 68% (n=15) fit within the ranges proposed by Halford (2000, 2001; Table 5) and 86% are within the 1 sigma range (Table 4). When accounting for the .2 µm standard error for obsidian hydration readings 77% (n=17) of the rim values fall within the proposed rim ranges. All (100%) fall within the broad ranges for projectile point types shown in Tables 4 and 5. Based on these types of data sets Rosenthal and Waechter (2002) (see also Rosenthal and McGuire 2004) advanced and evaluated five hydration rates for Bodie Hills obsidian. Two of these formulas were developed for high elevation locales using the projectile point hydration data from Halford (2000, 2001; Table 4). These are reviewed here and were applied to the project dataset (see Rogers Appendix C).

The two Rosenthal and Waechter (2002:101) hydration rates most applicable to this study are their B and C rates which were developed for high elevation sites (i.e., > 4000 ft. elevation). Rogers (2008, Appendix C:2-3) using the same data sets advanced an alternative quadratic rate and proposes that "… the quadratic form is still the best fit, giving the smallest overall error in age estimation… The rate constant in the equation is computed by a linear best fit between x^2 and t, and is the average of the rate constant computed with t independent and with x^2 independent." These rates were evaluated by Rogers employing his EHT conversion formula (Appendix C) and comparison shown in Table 9 and Figure 19

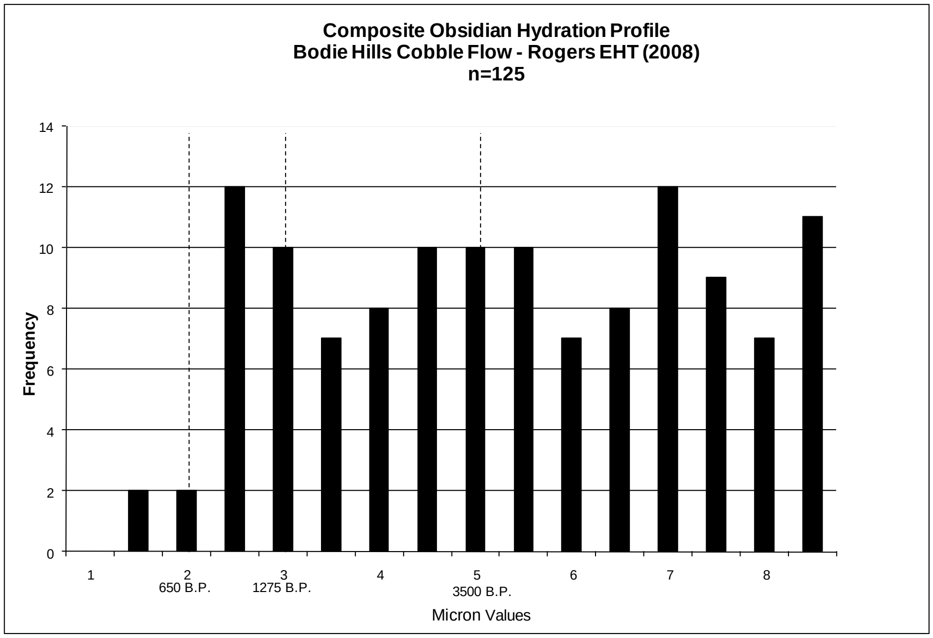


Figure 18.

Radiocarbon and Bodie Hills Hydration Pairs from Central California

Site	Context	Elevation meters amsl	^{14}C BP	+/-	median intercept (cal BP)	Mean Rim Value (µ)	
CAL-991	Component 991A1, 0-20 cm	1005	250	60	300	1.3[1]	White 1988
TUO-2197	Unit 4/5, Feature 3, 30-35 cm	870	270	70	330	2.2	Waugh and Rondeau 1990
			270	50	340		
TUO-407	Unit N401/E97: Feat 6 fill, 20 cm	610	320	110	363	1.9	Van Bueren et al. 1987
CAL-114/H	Unit 7; Feature 2, 38-73 cm	1050	360	80	400	1.9[2]	Stewart and Gerike 1994
AMA-56	Feature 1B: 60-76 cm	65	1160	60	1080	3.1	Wohlgemuth and Meyer 2002
CAL-789	Unit S44/W30: 20-50 cm	450	1220	40	1160	3.6	Rosenthal and McGuire 2004
CAL-789	Unit S10/E20: 30-40 cm	450	1270	40	1210	3.4	Rosenthal and McGuire 2004
PLA-695/H	Unit 95Q: 130-140 cm	670	1340	60	1255	3.8	Baker 2000
SAC-60	Burial 38-11, 122 cm	2	1550	150	1465	4.0	Ericson 1977
PLA-695/H	Unit 95F: 70-90 cm	670	2170	70	2175	4.5	Baker 2000
SJO-142	Burial 18, 71 cm	0	2495	120	2560	4.8	Ericson 1977
CAL-789	Feature 1, 60-80 cm	450	2510	40	2580	3.9	Meyer et al. 1999
SJO-68	Burial 23, 120 cm	0	3775	160	4155	4.9	Bouey 1994; Ragir 1972
SJO-68	Cremation 1, 119 cm	0	4350	250	4950	5.5	Bouey 1994; Ericson 1977;
			4100	250	4600		Ragir 1972
			4052	160	4540		
CAL-629/630	90N/26E, Feat. 232, Black Clay: 203-212 cm	305	8510	150	9050	7.3[3]	La Jeunesse and Pryor 1996
			8630	145	9370		
CAL-629/630	96N/25E, Green Clay, : 225-235 cm	305	9040	90	9990	7.3	La Jeunesse and Pryor 1996
CAL-629/630	93N/24E, Feat 212, Black Clay: 170-200 cm	305	9230	100	10195	7.4	La Jeunesse and Pryor 1996
CAL-629/630	86N/23E, Black Clay: 190-200 cm	305	9240	150	10200	8.2	La Jeunesse and Pryor 1996

[1] excludes outlier of 3.0; [2] excludes outlier of 4.4µ; [3] excludes one outlier of 10.4µ; outliers removed using Chauvenet's Criterion

Table 7. Data provided by Jeff Rosenthal, personal communication 2008.

Table Reg Chrono-9a: Projectile Point Hydration by Type, below 4000 feet Elevation

Type	mean	range	ct.	S.D.	C.V
Cottonwood	1.7	1.1-2.5	11	0.46	0.27
Desert Side Notched[1]	2.1	1.0-4.3	69	0.65	0.31
Contracting-stem Arrow[2]	3.0	1.7-4.2	17	0.61	0.21
Corner-notched Arrow	3.0	1.1-4.5	24	0.77	0.26
Concave Base Dart[3]	4.4	1.8-6.2	30	1.02	0.23
Small Stemmed Dart	4.5	3.4-5.7	10	0.82	0.18
Contracting-stem Dart	4.9	3.2-7.1	23	1.07	0.22
Corner-notched Dart[4]	4.8	1.1-8.8	78	1.36	0.28
Side-notched Dart[5]	5.4	3.2-8.1	13	1.43	0.26
Large Stemmed Dart	5.9	3.3-8.9	14	1.77	0.30
Wide Stem	5.3	3.4-8.1	8	1.67	0.32

Notes: outliers removed using Chauvenet's Criterion: [1] 4.5, 4.8; [2] 6.0; [3] 1.4; [4] 9.1, 9.1; [5] 11.1

Table Reg Chrono-9b: Projectile Point Hydration by Type, above 4000 feet Elevation

Type	mean	range	ct.	S.D.	C.V
Cottonwood[1]	1.3	0.9-1.7	6	0.25	0.19
Desert Side Notched[2]	1.6	0.9-3.6	35	0.73	0.46
Contracting-stem Arrow	2.0	1.4-2.8	6	0.50	0.25
Corner-notched Arrow	2.2	1.2-4.1	22	0.79	0.36
Concave Base Dart[3]	1.9	1.4-3.7	9	0.71	0.37
Contracting-stem Dart	3.3	2.2-4.5	4	1.19	0.36
Corner-notched Dart	2.8	1.0-5.6	46	1.04	0.37
Side-notched Dart[4]	3.5	1.3-5.4	9	1.54	0.44
Large Stemmed Dart	3.2	1.4-5.0	2	2.54	-
Wide Stem	5.9	5.0-7.2	5	0.97	0.16
Basally-thinned Concave Base	6.6	6.3-6.9	2	0.42	-

Notes: outliers removed using Chauvenet's Criterion: [1] 6.5; [2] 4.1; [3] 4.3; [4] 7.3

Table 8. Data Compiled by Rosenthal (personal communication 2008)
(see also Rosenthal and Waechter 2002; Rosenthal and McGuire 2004; Rosenthal 2006).

below. As can be seen from the data in Figure 19 it does not appear that there is a statistically significant difference between the various rates. An Analysis of Variance (ANOVA) single factor test was applied to evaluate this hypothesis and confirmed that there is no statistically significant variation between the three rates when employing Rogers' EHT adjustment [F (2,369) = 0.74, p = 0.48].

$$\text{Equation B (2a): } y = 169.39x^2 - 50$$

$$\text{Equation C (2b): } y = 101.35x^{2.2175}$$

$$\text{Rogers Equation (2c): } t = 177x^2$$

(y and t = years B.P. and x the hydration rim mean value)

To further evaluate this notion the various methods for analyzing the same data set were compiled into one graph (Figure 20). Using the micron spans and dates proposed by Halford (2000, 2001) four of the five datasets were transformed employing the Rogers (Appendix C) EHT formula. For application of the Casa Diablo rate the EHT derived value from Rogers conversion was also multiplied by the 1.195 factor applied by Halford in 2000 to adjust for the difference in elevation from the Casa Diablo reference locale and this study's reference locale. Application of ANOVA statistics shows that there is significant variance between the Casa Diablo rate as compared to the Rogers and Rosenthal and Waechter rates [F (3,349) = 4.1, p = 0.006]. Comparing the various age calculations against the micron ranges shown in Table 5 the Rosenthal and Waechter equation C ($101.35x^{2.2175}$) appears to have the best fit for the project area. All the rates over estimate ages at the earlier points of the micron range (>9 µm), indicating that rate validity occurs only up to 9 µm.

EHT Corr Rim, u	Age BP, eq. 2a	Age BP, eq. 2b	Age BP, eq. 2c
5.49	5053	4421	5332
13.78	32106	34039	33601
4.02	2686	2215	2859
3.89	2507	2055	2672
12.63	26981	28079	28246
6.68	7498	6825	7888

Table 9. Date conversions (age ^{14}C years B.P.) employing Rogers EHT (Appendix C) and proposed hydration rate formulas.

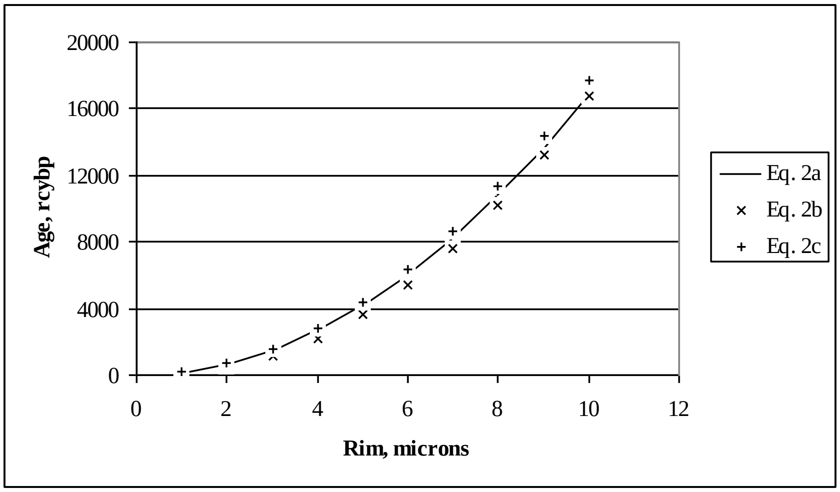


Figure 19. Comparison of Bodie Hills age equations (from Rogers Appendix C).

Statistical variance between the rates aside, all treatments of the data indicate that bimodality is prevalent in use of the Bodie Hills obsidian cobble flow area, as shown in Figure 20, with pulses during the Early Archaic (back to Paleoindian times) and the Middle Archaic/Newberry Period. Bimodality was a pattern established in earlier studies of cobble flow deposits at site CA-MNO-3126 (Halford 2000, 2001, Goebel 2008), but with even more emphasis of Early Archaic use and less on Newberry

Period use. When factoring for EHT and employing hydration rates the data show that during the Early Archaic and Newberry periods exploitation of the cobble flow areas was prevalent.

When the data are adjusted to factor for the time span of each time period the Newberry period shows the highest percentage of use as shown in Figure 21. The problem with this approach is that it filters out nuances of the specific periods of use indicated by finer grained evaluation of the hydration data (by .5 µm) ranges as discussed below. Also, due to the limitations of hydration as an absolute chronological indicator, it is tenuous at best to make statements about specific time periods of use. Until such time as when the vagaries of hydration chronology can be further refined, the analyses applied here suggest it is best employed as a relative chronological marker similar to the application of the projectile point sequence.

As shown in this analysis, the general use trends portrayed by the hydration data can be well established with significant use during the Early and Middle Archaic periods. And, no matter how the data is analyzed, this trend holds true as shown by Figure 20. When viewed by control unit (Figure 22), and adjusting for EHT and using the Rogers hydration rate, eleven of the control units have a mean hydration of >5,000 years rcybp. This further supports the argument that Early Archaic use of the cobble flow deposits was prevalent.

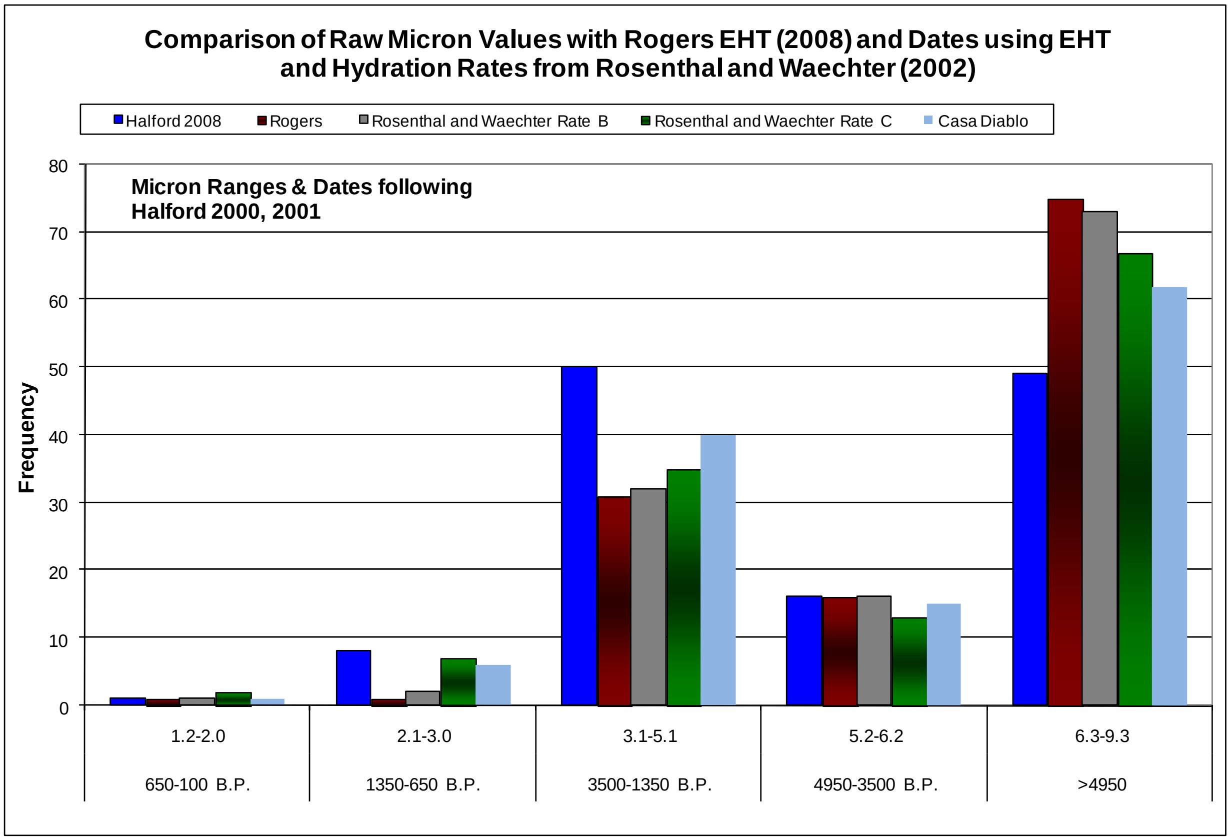


Figure 20.

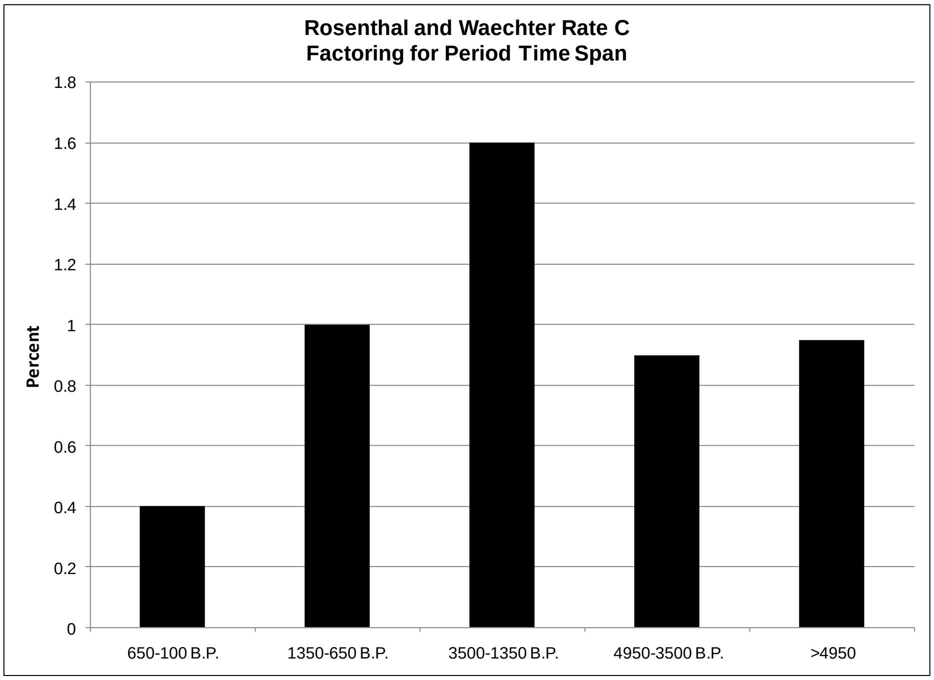


Figure 21.

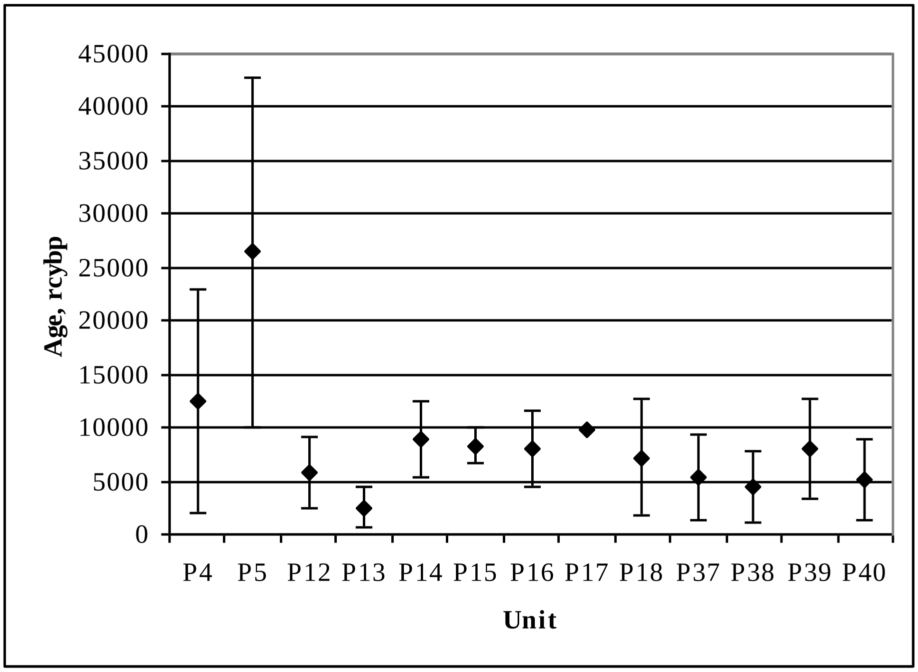


Figure 22. Mean and standard Deviations by CU (from Rogers Appendix C).

Comparison to Other Research in the Bodie Hills Area

To more accurately evaluate the cobble flow usage over time, and for comparative purposes to other datasets, the cobble data collected from the 13 test units in this study are viewed from a .5 µm range. The data show usage through the Early and Middle Archaic periods with peaks in the Early Archaic, the mid and late Newberry periods (Figure 23). When analyzing the raw data from this study and two previous investigations (Goebel et al. 2008; Halford 2000, 2001) the Early Archaic trend is shown to be very strong (Figures 22-25). Goebel et al. (2008) in particular show a pronounced trend of cobble flow exploitation during the early Holocene at CA-MNO-3126 where they focused excavations at the Paleoindian loci of the site. When the raw hydration data from the three studies is combined, as shown in Figure 26, the Early Archaic and Paleoindian use trends are even more pronounced.

When compared to the dataset from the Singer and Ericson (1977) study (Figure 27) of the main Bodie Hills obsidian source there is a marked difference in the use of the main source area juxtaposed against the cobble flow deposits. To analyze whether or not this was a factor of rate application, the Rosenthal and Waechter (2002) rate C was applied to the Singer and Ericson dataset. The peak for their data still occurred at ~2500 B.P. and the use trends portrayed by their data held true. This provides further support for hydration’s efficacy as a relative dating method as discussed earlier, i.e. that interpretations are not wholly dependent on rate application. It also corroborates the analyses discussed previously and shown in Figure 20, where the general use trends are consistent despite what hydration rate formula is applied to the data, if any at all.

The composite dataset for the cobble flow deposits (Figure 26) shows marked use in the early and mid Holocene. The curves from the various cobble flow data sets (Figures 23-26) show a trend that is bimodal and/or negatively skewed towards the Early Archaic and Paleoindian periods. Separately and in composite form, the datasets provide three independent studies supporting a prevalent if not dominant use of the cobble flow deposits during the mid and early Holocene, Early Archaic period. When all the data are combined into a larger dataset of hydration values (n=579) and analyzed (Figure 26) the support for the Early Archaic use trend becomes even stronger.

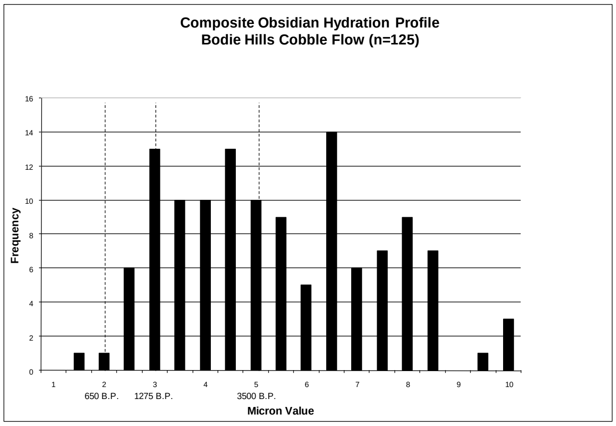


Figure 23.

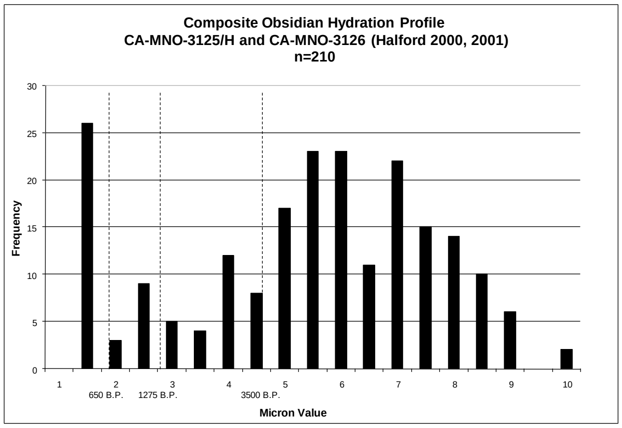


Figure 24.

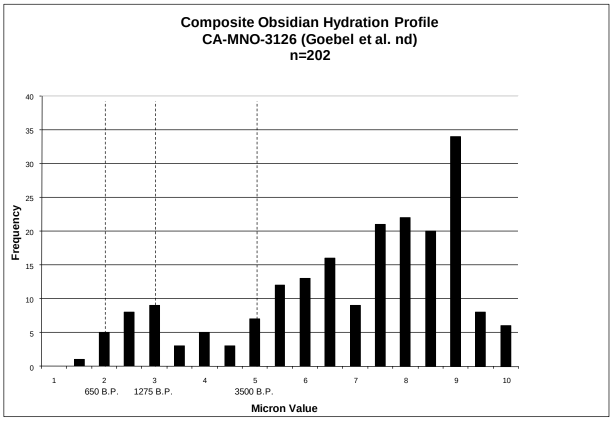


Figure 25.

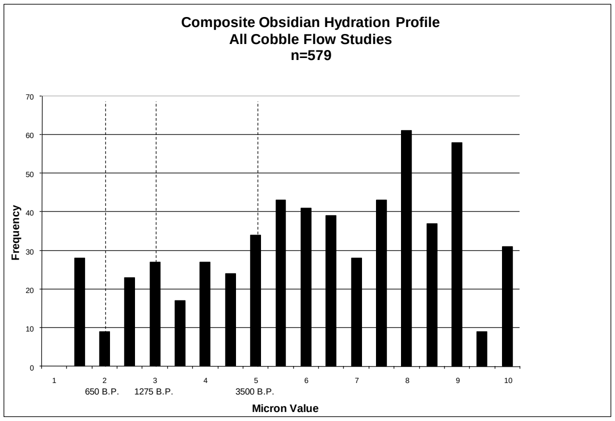


Figure 26.

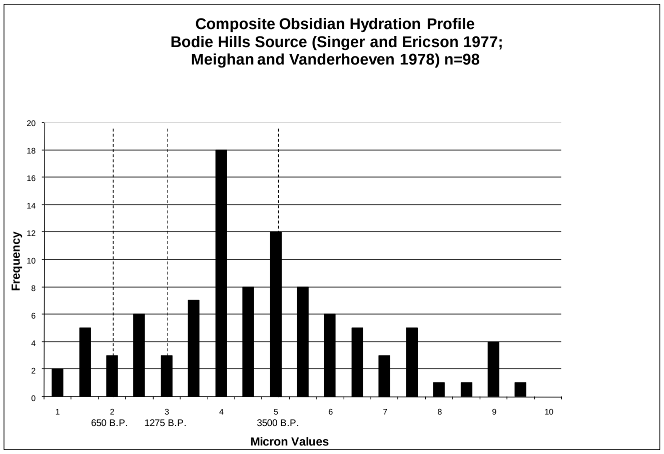


Figure 27.

Discussion

This study has focused on assessing affects at 13 backhoe pit location within the greater Bodie Hills obsidian source. It was determined that the pits were located within the greater Bodie Hills Obsidian Source or District within the cobble flow element of the source. As a whole the Bodie Hills Obsidian Source/District was determined by this study to be eligible for listing on the NRHP due to its significant data potential to answer questions important to this and future studies. As such, a finer grained analyses of questions pertinent to the use of obsidian hydration as a dating method were evaluated. At the outset a number of research objectives and questions were outlined, some of which can be addressed as a result of this investigation.

A) **Spatial and structural integrity of archaeological deposits at the pit locations:** As a result of this investigation, and those conducted previously (Halford 2000; Goebel et al. 2008), it has been determined that archaeological deposits within the cobble flow zone are mainly surface manifestations (0-15 cm below the surface), situated on argillic soil substrates that are Pleistocene in origin and that predate human use of the area. It is difficult to assess the horizontal movement of artifacts, but certainly some displacement has occurred since deposition. This said, the general site structure and human behaviour revealed by the reduction trajectory is still extant.

B) **Chronology:** While only one temporally diagnostic artifact was found, obsidian hydration analyses provide temporal control for the study area. In general, it has been learned that 11 of the 13 pit locations have a mean hydration value that indicates Early Archaic activity was prevalent. This is supported by the various hydration curves presented and analyzed, especially when adjusting for EHT. The chronological use patterns of the cobble flow area are similar to those found in previous studies (Halford 2000; Goebel et al. 2008) where Early Archaic/Paleoindian use dominates the profile.

C) **Activities (Subsistence, exchange, technology):** The artifact assemblage and flaked stone frequency distribution indicate that hard hammerstone, primay reduction of obsidian cobbles was the main activity that occurred at all of the project sites. The lack of formal bifaces in the collection indicates that material was carried offsite at an early stage of reduction. This may be a factor of the general symmetrically biconvex nature of the obsidian cobbles found in the flow, which allows for removal of cortical flakes creating a symmetrical early stage biface form. Also of interest, is that in surveys of the larger cobble flow area it was noted that unifacial biface technology was a dominant form of biface production technology utilized, with these forms of bifaces being prevalent within the flow and source areas.

   No subsistence data could be gleaned from this study. Exchange is predicted to have followed a continnum from early Holocene curation of items to production for exchange beginning in the Newberry period and dropping off in the late Haiwee and Marana periods. This is addressed further below, but as shown above the production curve does not follow the pattern generally seen, of a Newberry period zenith, with instead more emphasis of use of the cobble flow deposits in the Early Archaic/Paleoindian periods.

D) **Models of Production and Acquisition: Depopulation; Embedded production;Technological production changes; Collapse of inter-regional exchange:** As detailed previously, King et al. (nd) have recently evaluated the various hypotheses or explanatory models for the purported peak and collapse of obsidian production. The sudden decline of quarry production at roughly 1100 BP has been likened by King et al. (nd) to a “crash”. They concluded that inter-regional, Trans-Sierran, exchange is the most plausible explanation for the increase in obsidian production during the Newberry Period. They also concluded that the movement of obsidians over such long distances and the collapse of this system created the abrupt decline in production in the Late Period that we see in the hydration record. King et al. (nd:14) argue “that it was the rise of sedentism and logistical organization that helped fuel inter-regional exchange, as well as a variety of other non-subsistence pursuits, during the Late Archaic Period”.

As previously discussed the data from this and past studies of the Bodie Hills cobble flow deposits show a marked variation from the bell shape curve which shows a peak at roughly 2500 B.P. and abrupt decline around 1000 B.P. Instead more bimodality and certainly a negatively skewed curved are shown by the cobble flow datasets, indicating more Early Archaic production and use than previously understood or accepted. The data from this study supports the findings of Halford (2000, 2001) and Goebel et al. (2008), showing prevalent production in the early periods. Following on this one can posit that quarry use followed varying trajectories over time with embedded production (Jones et al. 2003; Ramos 2000) being most prevalent in Early Archaic strategies. As subsistence and mobility patterns moved towards more logistical and sedentary systems during the Newberry Period the need for trade systems would have become more necessary to maintain material and subsistence capabilities and wealth. Trade would have been a viable coping strategy as territorial conscription increased, causing a concomitant decrease in access to previously accessible resources or resource patches. The apparent abrupt collapse in inter-regional exchange suggests that socio-economic factors and territoriality played heavily in the abandonment of obsidian as a source of currency.

Conclusions

The most intriguing result of the composite investigations of the Bodie Hills Cobble Flow Deposits are the bimodal and negatively skewed production curves. This trend is juxtaposed with other regional quarry data which generally show a zenith of production use from 3,000 to 1,000 B.P. under a normally distributed curve. The data from this study suggest that secondary deposits were important tool stone production areas, especially during the Early Archaic period. A similar pattern was noted by Gilreath and Hildebrandt (1997), although not emphasized, within the secondary, “lag” deposits of the Coso Volcanic field. From the perspective of Optimal Foraging Theory it can be hypothesized that the cobble flow area was used during the Early Archaic/Paleoindian periods by opportunistic groups or individuals who embedded exploitation of a cost effective tool stone source into subsistence pursuits. Due to the abundance, size and quality of material there was no cost benefit for acquiring raw material from the primary sources.

As a result of this study the 53 acre Bodie Hills West (BHW) source, recorded by the author in 2000, is introduced (Figure 4). The 2132 acre cobble flow deposits were mapped during the 2007 and 2008 field seasons. Also, the 30 acre Bodie Hills North (BHN) source was located and recorded in 2008. Eleven cobble exposures were recorded between the main and BHW sources (Figure 4). The sum total of these efforts has added over 2215 acres (8.96 km^2) of viable quarrying material to the previously 1462 acre main source are recorded by Singer and Ericson in 1977, expanding the Bodie Hills obsidian source to over 3677 acres (14.9 km^2). With this addition of acreage of useable and desirable material it is better understood why Bodie was such a sought after obsidian through the Holocene, with distributions into the Central Valley of California and the western Great Basin/Nevada (Jones et al. 2003; King et al. nd).

This study reveals that the use and production profile of the Bodie Hills obsidian source is much more complex than that portrayed by Singer and Ericson's 1977 study. The data from this study provide further support for the findings of Halford (2000, 2001) and Goebel et al. (2008). Early Holocene use is prevalent and not just casual as suggested by the Singer and Ericson hydration profile (Figures 23-27). The intensity of Early period use of the project area, the reduction trajectories evident, and the available raw material used, all suggest that obsidian procurement was focused on tool kit rejuvenation devoted mainly to early stage biface production. The generally smaller size of raw material found and the lack of any well finished biface fragments (often found at primary quarry locations) suggests that production for trade was not the impetus for exploitation of the cobble flow deposits. Instead it appears they were used over time by opportunistic individuals or groups who exploited a relatively convenient tool stone source. The apparent focus of quarrying at the main Bodie Hills source area during the Newberry period (Singer and Ericson 1977), and not at the cobble flow deposits, may be a result of the exhaustion of the secondary deposits by earlier users and the lack of raw material sizes desirable for the production of trade items.

Management Considerations

During this investigation 64 proposed backhoe pit locations were surveyed for cultural resources. No cultural resource values were recorded in the 10 Coleville pit locations. Of the 54 locations proposed in the Bodie Hills area, 23 pits had no associated cultural resources, 5 pits were relocated to avoid cultural resource values, 13 pits are located within the Dry Lakes Plateau National Register District (DLP), 13 pits were found to be within the Bodie Hills obsidian quarry/cobble flow area and 1 pit was dropped due to wildlife concerns.

None of the pits on the DLP were within sites and only one was excavated during project implementation. Phase II controlled excavations and surface collections were undertaken at the 13 pits (pits 4, 5, 12-18, and 37-40) found within the "greater Bodie Hills obsidian quarry" (CA-MNO-4527) on both the west and east flanks of the main and BHW sources. These pits could not be avoided by project activities due to the ground coverage of cobble flow and quarry reduction materials, which extend over an 8.96 km^2 (2215 acre) area.

A no adverse effect determination was rendered for the pits within the DLP National Register District and subsequently only one pit was sampled on the Plateau during soil analyses. A no adverse effect determination was also rendered for the 13 pits within the Bodies Hills obsidian flow following test excavations. Subsequently, only 8 of these pits were sampled for the soils analyses for a cumulative impact of less than .0039 acre (< .000176%) within the 2215 acre cobble flow complex. Any impacts were fully mitigated by the methods and findings of this investigation and there was no adverse effect to cultural resources as a result of the proposed undertaking.

References

Adam, David P.

1967 Late Pleistocene and Recent palynology in the central Sierra Nevada, California. In *Quaternary paleoecology*, E. J. Cushing and H. E. Wright editors. pp.275-302. New Haven, Yale University Press.

Aikens, C. Melvin

1983 Environmental Archaeology in the Western United States. In *Late-Quaternary Environments of the United States, Volume 2 The Holocene*, edited by H. E. Wright Jr, pp. 239-251. University of Minnesota Press, Minneapolis.

Al-Rawi, Y. T.

1970 Cenozoic history of the northern part of Mono Basin, California and Nevada. Ph.D. Dissertation, University of California, Berkeley.

Antevs, Ernst

1948 Climatic Changes and Pre-White Man. In The Great Basin with Emphasis on Glacial and postglacial Times. Biological Series 19(7):168-191, *University of Utah Bulletin* 38(20). Salt Lake City.

1955 Geologic-Climatic Dating In The West. *American Antiquity* 20(4):317-355.

Basgall, M.E.

1983 Archaeology of the Forest Service Forty Site (CA-MNO-529), Mono County, California. Department of Anthropology, University of California, Davis, and Far Western Anthropological Research Group, Inc.. Submitted to USDA Forest Service, (Contract No. 52-9JC9-1-79), Bishop, California.

1988 The Archaeology of CA-MNO-679: A Pre-Archaic Site in Long Valley Caldera, Mono County, California. In *Early Human Occupation in Far Western North America: The Clovis-Archaic Interface*, edited by Judith A. Willig, C. Melvin Aikens, and John L. Fagan. Nevada State Museum Anthropological Papers 21:103-120.

1989 Obsidian Acquisition and Use in Prehistoric Central- Eastern California: A Preliminary Assessment. In Current Directions in California Obsidian Studies, edited by R.E. Hughes, pp.111-126. University of California Archaeological Research Facility Contributions 48. Berkeley.

1990 Hydration Dating of Coso Obsidian: problems and Prospects. Paper presented at the 24th meeting of the Society for California Archaeology, Foster City.

1998 Phase II Evaluation Of Archaeological Site CA-MNO-1977 On The Little Walker River, Mono County, California. *ARC Technical Report 98-5*. Prepared for Caltrans, District 6.

Basgall, Mark E., and Mark A. Giambastiani
1995 Prehistoric Use Of A Marginal Environment: Continuity and Change in Occupation of the Volcanic Tablelands, Mono and Inyo Counties, California. C*enter for Archaeological Research at Davis* 12. University of California, Davis.

Basgall, Marl E. and M. C. Hall
2000 Morphological and Temporal Variation in Bifurcate-Stemmed Dart Paoints of the Western Great Basin. *Journal of California and Great Basin Anthropology* 22(2):237-276.

Basgall, Mark E., and Kelly R. McGuire
1988 The Archaeology of CA-INY-30, Prehistoric Culture Change in the Southern Owens Valley, California. On File California Department of Transportation, Bishop.

Basgall, Mark E. and J.R. Richman
1998 Transportation Enhancement Activities Project: Archaeological Roadside Inventory Report for Caltrans District 09, Inyo and Mono Counties, California. *ARC Technical Report 98-10*. Submitted to Caltrans, Sacramento, California.

Baumhoff, Martin A., and Robert F. Heizer
1965 Postglacial Climate And Archaeology In The Desert West. In *The Quaternary of the United States*, edited by H.E. Wright, Jr and David G. Frey, pp. 697-707. Princeton University Press, Princeton, New Jersey.

Betancourt, Julio L., Thomas R. Van Devender, and Paul S. Martin
1990 *Packrat Middens: The Last 40,000 Years of Biotic Change.* The University of Arizona Press, Tucson.

Bettinger, Robert L.
1975 The Surface Archaeology of Owens Valley, Eastern California: Prehistoric Man-Land Relationships in the Great Basin. Ph.D. Dissertation, University of California, Riverside.

1977a Aboriginal Human Ecology in Owens Valley: Prehistoric Change in the Great Basin. *American Antiquity* 42(1):3-17.

1977b The Surface Archaeology of the Long Valley Caldera, Mono County, California. *University of California Archaeological Research Unit Monograph* 1. Univ. of California, Riverside.

1978 Alternate Adaptive Strategies in the Prehistoric Great Basin. *Journal of Anthropological Research* 34:27-45.

1980 Obsidian Hydration Dates for Owens Valley Settlement Categories. *Journal of California and Great Basin Anthropology* 2(2):286-292.

1982 Archaeology East of the Range of Light: *Monographs in California and Great Basin Anthropology* 1.

1989 The Archaeology Of Pinyon House, Two Eagles, And Crater Middens: Three Residential Sites In Owens Valley, Eastern California. *Anthropological Papers of the American Museum of Natural History Museum of Natural History.*

1991a Aboriginal Occupation at High Altitude: Alpine Villages in the White Mountains of California. *American Anthropologist* 93:656-679.

1991b *Hunter-Gatherers: Archaeological and Evolutionary Theory*. Plenum Press, New York.

1993 Doing Great Basin Archaeology Recently: Coping With Variability. *Journal of Archaeological Research* 1(1):43-66.

Bettinger, Robert L., and Martin A. Baumhoff
1982 The Numic Spread: Great Basin Cultures in Competition. *American Antiquity* 47(3):485-503.

Bettinger, Robert L., Michael G. Delacorte, and Robert Jackson
1984 Visual Sourcing of Central Eastern California Obsidians. In *Contributions Of The University Of California Archaeological Research Facility: Obsidian Studies in the Great Basin*, 45, edited by Richard E. Hughes, pp. 63-78. University of California, Berkeley.

Bettinger Robert L., and R. E. Taylor
1974 Suggested Revisions in Archaeological Sequences of the Great Basin in Interior Southern California. *Nevada Archeological Survey Research Papers* 5:1-26. Reno.

Bieling, David G.
1992 Perspectives On Behavior Gained From Lithic Analysis And Archaeological Investigations Near Bridgeport, Mono County, California. M. A. Thesis, Sonoma State University.

Billeb, Emil W.
1968 *Mining Camp Days*. Berkeley: Howell-North Books.

Binford, Lewis R.
1980 Willow Smoke And Dogs Tails: Hunter-Gatherer Settlement Systems And Archaeological Site Formation. *American Antiquity* 45(1):4-20.

1982 The Archeology of Place. *Journal of Anthropological Archaeology* 1(1):5-31.

1983 *In Pursuit of the Past: Decoding The Archaeological Record*. Thames & Hudson, New York, New York.

Bouey, Paul D., and Mark E. Basgall
1984 Trans-Sierran Exchange In Prehistoric California: The Concept Of Economic Articulation. In *Contributions Of The University Of California Archaeological Research Facility: Obsidian Studies in the Great Basin*, 45, edited by Richard E. Hughes, pp.135-172. University of California, Berkeley.

Burton, Jeffrey F.
1987 Cultural resources of Conway Ranch, Mono Basin, California. *Trans-Sierran Archaeological Research Contributions to Trans-Sierran Archaeology*

1995 Archaeological Excavations At Two Sites Near Bridgeport, Mono County, California. *Trans-Sierran Archaeological Research Contributions to Trans-Sierran Archaeology* No. 40.

Busby, Colin I., John M. Findlay and James C. Bard
1979 A Cultural Resource Overview of the Bureau of Land Management Coleville, Bodie, Benton, and Owens Valley Planning Units, California. *Bureau of Land Management Cultural Resources Publications, Anthropology-History*. Bakersfield District, California.

Cain, Ella M.
1956 *The Story of Bodie*. San Francisco: Fearon Publishers.

Butler, B. Robert
1972 The Holocene In The Desert West And Its Cultural Significance. In *Great Basin Cultural Ecology: A Symposium*, edited by Don D. Fowler, pp. 5-12. Desert Research Institute Publications in the Social Sciences 6. Reno.

Callahan, E.
1979 The Basis of Biface Knapping in the Eastern Fluted Point Tradition: A Manual for Flintknappers and Lithic Analysts. *Archaeology of Eastern North America* 7(1).

Camboia, Daniel A.
2000 Field Summary Report: Archaeological Survey of 640 Acres of the Bodie Hills, Mono County, California. Archaeological Research Center, California State University, Sacramento, California. On file at the BLM, Bishop Field Office.

Chesterman, C.W., M.L. Silberman, and C.H. Gray, Jr.
1969 Geology and geochronology of the Bodie mining district, Mono County, California. *Geologic Society of America Abstracts* 1(3):10-11.

Crabtree, Don E.
1972 An Introduction to Flintworking. *Occasional Papers of the Idaho State University Museum* 28. Pocatello.

Cronquist, Arthur, Arthur H. Holmgren, Noel H. Holmgren, and James L. Reveal
1972 *Intermountain Flora, Vascular Plants of the Intermountain West, U.S.A.* Volume 1. Hafner Publishing Company, Inc., New York and London.

Curry, R. R.
1971 Holocene climatic and glacial history of the central Sierra Nevada, California. *Geological Society of America* Special Paper 123.

Currey, Donald R., and Steven R. James
1982 Paleoenvironments Of The Northeastern Great Basin And Northeastern Basin Rim Region: A Review Of Geological And Biological Evidence. In *Man and Environment in the Great*

Basin, edited by David B. Madsen and James F. O'Connell, pp. 27-52. SAA Papers No. 2. Society of American Archaeology, Washington, D.C.

Davis, Emma Lou
1962 Hunter-gatherers of Mono Lake. *Masterkey* 36(1):23-28.

1963 The Desert Culture of the Western Great Basin: A Lifeway of Seasonal Transhumance. *American Antiquity* 29(2):202-212.

1964 An Archaeological Survey of the Mono Lake Basin and Excavations of Two Rockshelters, Mono County, California. *Annual Reports of the University of California Archaeological Survey Reports* 51. Berkeley.

1965 An Ethnography of the Kuzedika Paiute of Mono Lake, Mono County, California. *Miscellaneous Paper 8, University of Utah Anthropological Papers* 2:53-75.

Delacorte, Michael G.
1999 The Changing Role Of Riverine Environments In The Prehistory Of The Central-Western Great Basin: Data Recovery Excavations At Six Prehistoric Sites In Owens Valley, California.. Far Western Anthropological Research. Submitted to Caltrans, District 9, Bishop, California.

Delacorte, M.G., M.C. Hall and M.E. Basgall
1995 Final Report on the Evaluation of Twelve Archaeological Sites in the Southern Owens Valley, Inyo County, California. California Department of Transportation, Bishop.

Elston, Robert G.
1982 Good Times, Hard Times: Prehistoric Culture Change In The Western Great Basin. In *Man and Environment in the Great Basin*, edited by David B. Madsen and James F. O'Connell, pp. 186-206. SAA Papers No. 2. Society of American Archaeology, Washington, D.C.

1986 Prehistory of the Western Area. In *Handbook of North American Indians, Great Basin*, Vol. 11, edited by Warren L. d'Azevedo, pp. 135-148. Smithsonian Institution. Washington, D.C.

Elston, Robert G. and Cameron Covington
1977 An Intensive Archeological Investigation Of Bridgeport Indian Reservation 40 Acre Housing Sites, Final Report. *Nevada Archeological Survey Northern Division*, University of Nevada Reno.

Elston and Zeier
1984 The Sugarloaf Obsidian Quarry. *Naval Weapons Center Administrative Publication 33*, China Lake, California.

Ericson, J.E.
1982 Production for Obsidian Exchange in California. In *Contexts for Prehistoric Change*, edited by J.E. Ericson and T.K. Earle, pp. 129-148. Academic Press New York.

Ericson, J. E. and T.K. Earle, editors
1982 *Contexts for Prehistoric Change*. Academic Press New York.

Fagan, John L.
1995 Introduction to Stone Tool Technologies: An Archaeological Perspective for Making and Analyzing Stone Tools and Debitage. USDI Bureau of Land Management, Lithic Technology Workshop.

Ferguson, C. W.
1968 Bristlecone Pine: Science and Esthetics. *Science* 159(3817):839-846.

Flenniken, J. J., and P. J. Wilke
1989 Typology, Technology, and Chronology of Great Basin Dart Points. *American Anthropologist* 91:149-158.

Fly, Claude L., and Associates
1981 Bodie-Coleville Order 3 Soil Survey For Bureau Of Land Management. On file at the BLM, Bishop Resource Area, CA.

Fowler, Catherine S.
1986 Subsistence. In *Handbook of North American Indians, Great Basin*, Vol. 11, edited by Warren L. d'Azevedo, pp. 66-97. Smithsonian Institution. Washington, D.C.

Fowler, Catherine S., and Don D. Fowler
1990 A History of Wetlands Anthropology in the Great Basin. In *Wetland Adaptations in the Great Basin*, edited by Joel C. Janetski and David B. Madsen, pp. 5-16. Museum of Peoples and Cultures, Occasional Papers 1. Brigham Young University.

Fowler, Catherine S. and Sven Liljeblad
1986 Northern Paiute. *In Handbook of North American Indians, Great Basin*, Vol. 11, edited by Warren L. d'Azevedo, pp. 435-465. Smithsonian Institution. Washington, D.C.

Fowler, Don D.
1966 Great Basin Social Organization. In The Current Status of Anthropological Research In the Great Basin: 1964, pp.57-73. *University of Nevada Desert Research Institute Publications in the Social Sciences* 1. Reno.

Fredrickson, David A.
1991 Archaeological Evaluation of CA-MNO-2456, -2488, and -564, near Bridgeport, Mono County, California. Anthropological Studies Center, Sonoma State University Academic Foundation, Inc. On file at California Department of Transportation District 9, Bishop, CA.

Giambastiani, Mark A.
2004 Prehistoric Obsidian Use on the Volcanic Tableland and its Implications for Settlement patterns and Technological Change in the Western Great Basin. Unpublished Ph.D. dissertation, University of California Davis.

Gilbert, C. M., M. N. Christensen, Y. T. Al-Rawi, and K. R. Lajoie
1968 Structural and volcanic history of Mono Basin California-Nevada. *Geological Society of America Memoirs* 116:275-329.

Gilreath Amy J.
1995 Archaeological Evaluations of Thirteen Sites for the Ash Creek Project, Inyo County, California. Far Western Anthropological Group. On file Caltrans District 9, Bishop, California.

Gilreath, Amy J. and William R. Hildebrandt
1997 Prehistoric Use of the Coso Volcanic Field. *Contributions of the University of California Archaeological Research Facility* 56. Berkeley.

Goebel, Ted, Brant Ivey and Ken Adams
2008 Data-Recovery of CA-MNO-3126 for the Bridgeport Indian Colony 40-Acre Land Sale. Prepared for the United States Department of the Interior, BLM, Bishop Field Office, Bishop, California. Cultural Resource Project: CA-170-00-10. On file at the BLM Bishop Field Office.

Graumlich, Lisa J.
1993 A 1000-Year Record of Temperature and Precipitation in the Sierra Nevada. *Quaternary Research* 39:249-255.

Graybill, D. A., M. R. Rose, and F. L. Nials
1994 Tree-rings and climate: Implications for Great Basin paleoenvironmental studies. In *Proceedings of the fifth Annual International High-Level Radioactive Waste Management Conference and Exposition*, pp. 2569-2573. Las Vegas, NV.

Grayson, Donald K.
1993 *The Desert's Past: A Natural Prehistory of the Great Basin*. Smithsonian Institution Press, Washington and London.

Halford, F. Kirk
1997 Cultural Resource Inventory And Subsurface Testing Report, For the Bridgeport Landfill Disposal: Report CA-017-97-20. U.S. Department of Interior, Bureau of Land Management, Bishop Field Office. Report on file at the Eastern Information Center, Riverside, CA and BLM, Bishop, CA.

1998a Archaeology and Environment on the Dry Lakes Plateau, Bodie Hills, California: Hunter-Gatherer Coping Strategies for Holocene Environmental Variability. Unpublished Masters Thesis, University of Nevada, Reno.

1998b A Cultural Prehistory of the Travertine Hot Springs Area of Critical Environmental Concern, Bridgeport, California. Report CA-017-99-02. U.S. Department of Interior, Bureau of Land Management, Bishop Field Office. Report on file at the Eastern Information Center, Riverside, CA and BLM, Bishop, CA.

2000 Evaluation of CA-MNO-3125/H and CA-MNO-3126 for the Bridgeport Indian Colony 40 Acre Land Sale. Cultural Resource Project: CA-170-00-10. Report on file in the Bureau of Land Management, Bishop Field Office, Bishop, California.

2001 New Evidence for Acquisition and Production of Bodie Hills Obsidian. *Society for California Archaeology Newsletter* 35(1):32-37.

Hall, M.C.
1980 Surface Archaeology of the Bodie Hills Geothermal Area, Mono County, California. United States Department of the Interior, Bureau of Land Management, Bakersfield District.

1983 Late Holocene Hunter-gatherers and Volcanism in the Long Valley-Mono Basin Region: Prehistoric Culture Change in the Eastern Sierra Nevada. Unpublished Ph.D. Dissertation in Anthropology, University of California, Riverside.

1984 Obsidian, Paleoeconomy, and Volcanism in the Eastern Sierra Nevada. Paper presented at the 19th Biennial Meeting of the Great Basin Anthropological Conference, Boise, Idaho.

1989 The OXBOW Archaeological Incident: Investigations at Twenty-three Locations between Owens Valley, Eastern California, and Walker Basin, Southwestern Nevada. Report on file, Oxbow Geothermal Company, Reno, Nevada.

Hall, M.C., and M.E. Basgall
1994 Casa Diablo Obsidian in California and Great Basin Prehistory. Paper presented at the 24th Great Basin Anthropological Conference, Elko, Nevada.

Hall, M. C. and, R. J. Jackson
1989 Obsidian Hydration Rates in California. In *Contributions Of The University Of California Archaeological Research Facility: Current Directions in California Obsidian Studies* 48, edited by Richard E. Hughes, pp. 31-58. University of California, Berkeley

Hall, Raymond E., and Keith R. Kelson
1959 *The Mammals of North America, Volumes 1 and 2*. The Ronald Press Company, New York.

Hardesty, Donald L., Steven F. Mehls, and Priscilla E. Mecham with Mary Rusco
1991 A Class III Cultural Resources Inventory of the 493 Acre Bodie Study Area, Mono County, California. Western Cultural Resource Management.

Harper, K. T. and G. M. Alder
1972 Paleoclimatic Inferences Concerning The Last 10,000 Years From A Resampling Of Danger Cave, Utah. In *Great Basin Cultural Ecology: A Symposium,* edited by Don D. Fowler, pp. 13-23. Desert Research Institute Publications in the Social Sciences 8. Reno.

Harrington, M. R.
1957 A Pinto Site at Little Lake, California. Southwest Museum Papers No. 17. Los Angeles

Heizer, Robert F., and L. K. Napton
1970 Archaeology and the Great Basin Subsistence Regime as Seen from Lovelock Cave, Nevada. *Contributions of the University of California Archaeological Research Facility* 10. Berkeley.

Hemphill, Martha and Peter E. Wigand
1995 A Detailed 2,000-Year Late Holocene Pollen Record From Lower Pahranagat Lake, Southern Nevada, USA.. In *Climate Change in the Four Corners and Adjacent Regions: Implications for Environmental Restoration and Land Use-Planning,* W.J. Waugh editor, pp. 41-50.

Hester, Thomas R.
1973 Chronological Ordering of Great Basin Prehistory. *Contributions of the University of California Archaeological Research Facility* 17. University of California, Berkeley.

Hickman, James C. (editor)
1993 *The Jepson Manual: Higher Plants of California*. University of California Press, Berkeley.

Hughes, Richard E. (editor)
1984 *Contributions Of The University Of California Archaeological Research Facility, Number 45: Obsidian Studies in the Great Basin*. Department of Anthropology, University of California, Berkeley.

1989 *Contributions Of The University Of California Archaeological Research Facility, Number* 48: *Current Directions In California Obsidian Studies*. Department of Anthropology, University of California, Berkeley.

Jackson, Robert J.
1984 Current Problems in Obsidian Hydration Analysis. In *Contributions Of The University Of California Archaeological Research Facility, Number 45: Obsidian Studies in the Great Basin*, edited by R. Hughes, pp. 103-116. Department of Anthropology, University of California, Berkeley.

1985 An Archaeological Survey of the Wet, Antelope, Railroad, and Ford Timber Sale Compartments in the Inyo National Forest, Final Report, with Contributions by Robert L. Bettinger. Far Western Anthropological Research Group, Inc. Davis.

Jackson, Robert J., Michael Boynton, William Olsen and Richard Weaver
1988 California Archaeological Resource Identification and Acquisition Program: Sparse Lithic Scatters. Sacramento: Office of Historic Preservation.

Jackson, Thomas L.
1984 A Reassessment of Obsidian Production Analyses for the Bodie Hills and Casa Diablo Quarry Areas. In *Contributions Of The University Of California Archaeological Research Facility: Obsidian Studies in the Great Basin* 45, edited by Richard E. Hughes, pp.117-134. University of California, Berkeley.

Jennings, J.D.
1957 Danger Cave. *University of Utah Anthropological Papers* 27.

Jennings, Jesse D., and Edward Norbeck
1955 Great Basin Prehistory: A Review. *American Antiquity* 21(1):1-11.

Jennings, Steven A., and Deborah L. Elliot-Fisk
1993 Packrat Midden Evidence of Late Quaternary Vegetation Change in the White Mountains, California-Nevada. *Quaternary Research* 39: 214-221.\

Jones, G. T., C. Beck, E.E. Jones and R.E. Hughes
2003 Lithic Source Use and Paleoarchaic foraging territories in the Great Basin. America Antiquity 68(1):5-38.

Koenig, James B.
1963 Walker Lake Sheet. Olaf P. Jenkins edition. United States Divisions of Mines and Geology.

Kelly, Robert L.
1988 The Three Sides Of A Biface. *America Antiquity* 53(4):717-734.

1995 *The Foraging Spectrum: Diversity In Hunter-Gatherer Lifeways*. Smithsonian Institution Press, Washington.

King, J., W. R. Hildebrandt and Jeffrey Rosenthal
nd *Trans Sierran Movement of Bodie Hills Obsidian*. Manuscript in preparation for publication. Far West

Kleinhampl, F. J., W. E. Davis, M. L. Silberman, C. W. Chesterman, R. H. Chapman, and C. H. Gray
1975 Aeromagnetic and limited gravity studies and generalized geology of the Bodie Hills region, Nevada and California. U.S. Geologic Survey Bulletin 1384.

Kobori, Larry S., Colin I. Busby, James C. Bard, and John M. Findlay
1980 A Class II Cultural Resources Inventory Of The Bureau Of Land Management's Bodie And Colville Planning Units, California. Basin Research Associates, Inc. for the U.S. Department of Interior, Bureau of Land Management, Bakersfield District Office.

Koehler, Peter A., and R. Scott Anderson
1995 Thirty Thousand Years of Vegetation Change in the Alabama Hills, Owens Valley, California. *Quaternary Research* 43:238-248.

Kutzbach, John E., and Peter J. Guetter
1986 The Influence of Changing Orbital Parameters and Surface Boundary Conditions on Climate Simulations for the Past 18,000 Years. *Journal Of The Atmospheric Sciences* 43(16):1726-1759.

LaMarche, Valmore C. Jr.
1973 Holocene Climatic Variations Inferred from Treeline Fluctuations in the White Mountains, California. *Quaternary Research* 3:632-660.

1974 Paleoclimatic Inferences from Long Tree-Ring Records. *Science* 183(4129):1043-1048.

Lanning, E. P.
1963 Archaeology of the Rose Spring Site, Iny-372. *Berkeley: University of California Publications in American Archaeology and Ethnology* 49(3):237-336.

Lee, R.
1969 Chemical Temperature Integration. *Journal of Applied Meteorology* 8:423-430.

Liljeblad, Sven, and Catherine S. Fowler
1986 Owens Valley Paiute. In *Handbook of North American Indians, Great Basin,* Vol. 11, edited by Warren L. d'Azevedo, pp. 412-434. Smithsonian Institution. Washington, DC.

Lindstrom, Susan
1990 Submerged Tree Stumps as Indicators of Mid-Holocene Aridity in the Lake Tahoe Basin. *Journal of California and Great Basin Anthropology* 12(2):146-147.

Madsen, David B.
2002 Great Basin Peples and Late Quaternary Aquatic History. In *Great Basin Aquatic Systems History,* edited by Robert Herschler, David B, Madsen and Donald R. Currey, pp. 387-405. Smithsonian Contributions to the Earth Sciences (33), Washington, D.C.

Madsen, David B., and James F. O'Connell (editors)
1982 *Man and Environment in the Great Basin*. Society for American Archaeology Papers 2. Washington.

Madsen, David B., and David Rhode (editors)
1994 *Across the West: Human Population Movement and the Expansion of the Numa*. University of Utah Press. Salt Lake City.

Major, Jack
1977 California climate in relation to vegetation. In *Terrestrial Vegetation of California*, edited by Michael G. Barbour and Jack Major, pp.11-74. John Wiley and Sons, New York.

Mallery, Garrick
1886 Pictographs of the American Indians: A Preliminary Paper. In *4th Annual Report of the Bureau of American Ethnology* for the Years 1882-1883:3-256. Washington.

Mehringer, Peter J.
1986 Prehistoric Environments, edited by Warren L. D'Azevedo, pp. 31-50. *Handbook of North American Indians,* vol. 11, William G. Sturtevant, general editor. Smithsonian Institution, Washington, D.C.

1996 Columbia River Basin Ecosystems: Late Quaternary Environments. Prepared for the *Eastside Ecosystem Management Project* (USFS and BLM) Walla Walla, Washington.

Mehringer, Peter J., and J. C. Sheppard
1978 Holocene history of Little Lake, Mojave Desert, California. In The Ancient Californians: Rancholabrean Hunters of the Mojave Lakes Country, E. L. Davis editor, pp. 153-176. *Natural History Museum of Los Angeles County, Science Series* 29. Los Angeles, California.

Mehringer, Peter J., and Peter E. Wigand
1990 Comparison of Late Holocene Environments from Woodrat Middens and Pollen: Diamond Craters, Oregon. In *Packrat Middens: The Last 40,000 Years of Biotic Change,* edited by Betancourt, Julio L., Thomas R. Van Devender and Paul S. Martin, pp. 294-325. The University of Arizona Press, Tucson.

Meighan, Clement W.
1955 Notes on the Archaeology of Mono County, California. *Reports of the University of California Archaeological Survey* 28:6-28.

Meltzer, David J.
1995 Modeling The Prehistoric Response To Altithermal Climates On The Southern High Plains. *In Ancient Peoples and Landscapes,* edited by Eileen Johnson, pp. 349-368. Museum of Texas Tech University, Lubbock, Texas.

Messick, Tim C.
1982 Flora and Phytogeography of the Bodie Hills of Mono County, California and Mineral County, Nevada, USA. MA Thesis: Humboldt State University.

Michels, Joseph W.
1982a The Hydration Rate For Casa Diablo Obsidian At Archaeological Sites In The Mammoth Junction Area Of Mono County, California. MOHLAB Technical Report No. 6. 118 Smithfield Street, State College, PA 16801.

1982b The Hydration Rate For Bodie Hills Obsidian At Archaeological Sites In The Oakland Area Of California. MOHLAB Technical Report No. 13. 118 Smithfield Street, State College, PA 16801.

Miller, Wick R.
1986 Numic Languages. In *Handbook of North American Indians, Great Basin,* Vol. 11, edited by Warren L. d'Azevedo, pp. 98-106. Smithsonian Institution. Washington, DC.

Miller, Richard F., and Peter E. Wigand
1994 Holocene Changes in Semiarid Pinyon-Juniper Woodlands: Response to climate, fire, and human activities in the US Great Basin. *BioScience* 44(7):465-474.

Mills, Thomas J.
2003 Cultural Adaptations at CA-MNO-3114/H: An Historic Native American Site Near Bridgeport, Mono County, California. Unpublished Masters Thesis, California State University, Sacramento, California.

Moratto, Michael J.
1984 *California Archaeology*, *New World Archaeological Record*. Academic Press, Orlando.

Nelson, Clemens A., Clarence A. Hall, Jr., and W.G. Ernst
1991 Geologic History of the White-Inyo Range. In *Natural History of the White Inyo-Range Eastern California*, edited by Clarence A. Hall, Jr., pp. 42-74. University of California Press, Berkeley.

Nowak, Cheryl L., Robert S. Nowak, Robin J. Tausch, and Peter E. Wigand
1994a A 30000 year record of vegetation dynamics at a semi-arid locale in the Great Basin. *Journal of Vegetation Science* 5:579-590.

Nowak, Cheryl L., Robert S. Nowak, Robin J. Tausch and Peter E. Wigand
1994b Tree And Shrub Dynamics In Northwestern Great Basin Woodland And Shrub Steppe During The Late-Pleistocene And Holocene. *American Journal of Botany* 81(3):265-277.

O'Connell James F., Kevin T. Jones, and Steven R. Simms
1982 Some Thoughts on Prehistoric Archaeology in the Great Basin. *In Man and Environment in the Great Basin*, edited by David B. Madsen and James F. O'Connell, pp. 53-75. SAA Papers No. 2. Society of American Archaeology, Washington, D.C.

O'Connell James F., and David B. Madsen
1982 Man and Environment in the Great Basin: An Introduction. *In Man and Environment in the Great Basin*, edited by David B. Madsen and James F. O'Connell, pp. 53-75. SAA Papers No. 2. Society of American Archaeology, Washington, D.C.

Ramos, Brian A.
2000 Prehistoric Use of the Truman/Queen Obsidian Quarry, Eastern California and Western Nevada: Technological Organization and Adaptation in the Western Great Basin. Ph.D. dissertation, Department of Anthropology, University of California–Davis.

Reynolds, Linda A.
1992 A Programmatic Treatment Plan For Prehistoric Obsidian Quarries On The Inyo National Forest, California And Nevada. On file at the Inyo National Forest, Bishop, California.

1996 In The Dwelling of a Great Spirit: The Prehistory of the Pinon-Juniper of the Inyo-White Mountain Range, Eastern California. Unpublished Ph.D. Dissertation in Anthropology, University of Nevada, Reno.

Rogers, A. K.
2007a Effective Hydration Temperature of Obsidian: A Diffusion-Theory Analysis of Time-Dependent Hydration Rates. *Journal of Archaeological Science.* 34:656-665.

2007b *Scaling of Temperature Data for EHT Computation: A Study of Desert Sites*. Maturango Museum Working Manuscript #19, Rev A, dated 13 June 2007.

2008a *Scaling of Temperature Data for EHT Computation: A Study of Desert Sites near Bodie, California.* Maturango Museum Working Manuscript #41, dated 6 March 2008, Rev A. MS on file, Maturango Museum, Ridgecrest, CA.

2008b Preliminary Analysis Of Obsidian Hydration from sites near Bridgeport, California Maturango Museum Working Manuscript #43, dated 11 March 2008. MS on file, Maturango Museum, Ridgecrest, CA.

2008c A Reassessment of Obsidian Hydration Ages of Projectile Point Types from the Coso Volcanic Field. *Pacific Coast Archaeological Society Quarterly*.

Rondeau, Michael F.

1992 The Archaeology of the Kelley Site. A Phase II Report for the Archaeological Excavations of CA-Tuo-2642, for the East Sonora Bypass Project, Toulumne County, California. Report on file at the California Department of Transportation, Sacramento.

Rosenthal, J. S.

2006 The Prehistory of the Sonora Region: Archaeological and Geoarchaeological Investigations for the Stage I of the East Sonora Bypass Project, State Route 108, Tuolumne County, California. Draft Report submitted to California Department of Transportation, District 10, Stockton.

Rosenthal, J. S., and K. McGuire

2004 *Middle Holocene Adaptations in the Central Sierra Nevada Foothills: Data Recovery Excavations at the Black Creek Site, CA-CAL-789.* Far Western Anthropological Research Group, Inc., Davis, California. Submitted to California Department of Transportation, District 06, Fresno.

Rosenthal, Jeffrey S. and Sharon A. Waechter

2002 Results of Phase-II Test Excavations at CA-ELD-616/H near Cool, Western El Dorado County. Prepared for Caltrans District 03, Marysville, California.

Rusco, Mary

1991 A Class III Cultural Resource Inventory For The Bodie Project: Prehistoric Resources. Western Cultural Resource Management, Inc. Prepared for Bodie Consolidated Mining Company, Bridgeport, California.

Silberman, M.L., and C.W. Chesterman

1972 K-Ar age of volcanism and mineralization, Bodie mining district and Bodie volcanic field, Mono County, California. *Isochron/West* 3:13-22.

Simms, Steven R.

1983 The Effects of Grinding Stone Reuse on the Archaeological Record of the Eastern Great Basin. *Journal of California and Great Basin Anthropology* 5:98-102.

1987 Behavioral Ecology and Hunter-Gatherer Foraging: An Example from The Great Basin. *BAR International Series* 381. Oxford, England.

Singer, Clay A., and Jonathon E. Ericson

1977 Quarry Analysis At Bodie Hills, Mono County, California: A Case Study. In *Exchange System In Prehistory*, edited by Timothy K. Earle and Jonathon E. Ericson, pp. 171-187. Academic Press, New York.

Skinner, Craig E.

1978 Obsidian Studies in Oregon: An Introduction to Obsidian and An Investigation of Selected Methods of Obsidian Characterization Utilizing Obsidian Collected from Prehistoric Quarry Sites in Oregon. Unpublished Master's Project, Interdisciplinary Studies, University of Oregon, Eugene.

1987 Lithic Database Project: Software Documentation. Unpublished manuscript in possession of the author.

Skinner, Craig E. and Jennifer J. Thatcher

1999 X-Ray Flourescence Analysis and Obsidian Hydration Rim Measurement of Artifact Obsidian from the Wedertz Collection, California. Northwest Research Obsidian Studies Laboratory Report 99-31. On file at the BLM, Bishop Field Office, Bishop, California.

2000 X-Ray Flourescence Analysis and Obsidian Hydration Analysis of Artifact Obsidian from CA-MNO-3125/H, The Bridgeport Indian Colony Land Transfer: CA-170-00-10, Mono County California. Northwest Research Obsidian Studies Laboratory Report 2000-31 . On file at the BLM, Bishop Field Office, Bishop, California.

Smith, Andrew T.

1979 High Local Species Richness Of Mammals At Bodie, California. *The Southwestern Naturalist* 24(3):527-556.

Spaulding, W. G.

1985 Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South Central Nevada. *U.S. Geological Survey Professional Paper* 1329.

Stevenson, C., J. Carpenter, and B. Scheetz

1989 Recent Advances in the Experimental Determination and Application of Obsidian Hydration Rates. *Archaeometry* 31.

Stine, Scott

1990 Late Holocene Fluctuations of Mono Lake, eastern California. *Palaeogeography, Palaeoclimatology, Palaeoecology* 78:333-381.

1994 Extreme and Persistent Drought in California and Patagonia during Medieval time. *Nature* 369:546-549.

Steward, Julian H.

1929 Petroglyphs of California and Adjoining States. University of California Publications in *American Archaeology and Ethnology* 24(2):47-238. Berkeley.

1933 Ethnography of The Owens Valley Paiute. *University of California Publications in American Archaeology and Ethnology* 33(3):233-350. Berkeley.

1938 Basin-Plateau Aboriginal Sociopolitical Groups. *Bureau of American Ethnology Bulletin* 120. Washington. (Reprinted: University of Utah Press, Salt Lake City, 970.)

1955 *Theory of Culture Change*. University of Illinois Press, Urbana.

Tausch, Robin J., Peter E. Wigand, and J. Wayne Burkhardt
1993 Viewpoint: Plant community thresholds, multiple steady states, and multiple successional pathways: legacy of the Quaternary? *Journal of Range Management* 46(5):439-447.

Tausch, R.J., N.E. West, and A.A. Nabi
1981 Tree Age and Dominance Patterns in the Great Basin Pinyon-Juniper Woodlands. *Journal of Range Management* 34(4):259-264.

Thomas, David H.
1981 How to Classify the Projectile Points from Monitor Valley, Nevada. *Journal of California and Great Basin Anthropology* 3(1):7-43.

1990 On Some Research Strategies for Understanding the Wetlands. In *Wetland Adaptations in the Great Basin*, edited by Joel C. Janetski and David B. Madsen, pp. 277-284. Museum of Peoples and Cultures, Occasional Papers 1. Brigham Young University.

Thompson, Robert S.
1990 Late Quaternary Vegetation and Climate in the Great Basin. In *Packrat Middens: The Last 40,000 Years of Biotic Change*, edited by Julio L. Betancourt, Thomas R. Van Devender and Paul S. Martin, pp. 200-239. The University of Arizona Press, Tucson.

Tidwell, William D. , Samuel R. Rushforth, and Danile Simper
1972 Evolution of Floras In The Intermountain Region. In *Intermountain Flora, Vascular Plants of the Intermountain West, U.S.A.*, Volume 1, edited by Arthur Cronquist, A. H. Holmgren, N. H. Holmgren, and J. L. reveal, pp.19-39. Hafner Publishing Company, Inc., New York.

Tremaine, K. J.
1991 A Relative Dating Approach for Bodie Hills and Casa Diablo Obsidian Derived from Accelerated Hydration Experiments. In *Archaeological Evaluation of CA-MNO-2456, 2458, and 564, near Bridgeport, Mono County, California*: Appendix E. On file at California Department of Transportation District 9, Bishop, California.

Van Devender, Thomas R., Robert S. Thompson, and Julio L. Betancourt
1987 Vegetation history of the deserts of southwestern North America; The nature and timing of the Late Wisconsin-Holocene transition. In *North America and adjacent oceans during the last deglaciation*, edited by W.F. Ruddiman and H.E. Wright, pp. 323-352. Boulder, Colorado, Geological Society of America, The Geology of North America, v. K-3.

Wedertz, Frank S.
1969 *Bodie 1859-1900.* Chalfant Press. Bishop, California.

Weide, David L.

1976 The Altithermal As An Archaeological "Non-Problem". In The Great Basin, edited by Robert Elston, pp. 174-184. *Holocene Environmental Change in the Great Basin, Nevada Archeological Survey, Research Paper No. 6*. Reno.

Wharton, R.A., P.E. Wigand, M.R. Rose, R.L. Reinhardt, D.A. Mouat, H.E. Klieforth, N.L. Ingraham, J.O. Davis, C.A. Fox, and J.T. Ball

1990 The North American Great Basin: A sensitive Indicator of Climatic Change. In *Plant Biology of the Basin and Range,* edited by C.B. Osmond, L.F. Pielka, and G.M. Hidy, pp. 323-360. Springer Verlag, New York.

Wigand, Peter E.

1995 Stable Isotopic Analyses In Paleoclimatic Reconstruction. In *Climate Change in the Four Corners and Adjacent Regions: Implications for Environmental Restoration and Land Use-Planning,* edited by W.J. Waugh, pp. 27-38.

1997 A Late-Holocene Pollen Record from Lower Pahranagat Lake, Southern Nevada, USA: High Resolution Paleoclimatic Records and Analysis of Environmental Responses to Climate Change. In *Proceedings of the Thirteenth Annual Pacific Climate (PACLIM) Workshop,* Technical report 53, edited by C.M. Isaacs and V.L. Tharp, pp. 63-77. Asilomar, CA.

Wigand, Peter E., Martha Hemphill, and Sikha (Manna) Patra

1994 Late Holocene Climate Derived From Vegetation History and Plant Cellulose Stable Isotope Records From The Great Basin of Western North America. Paper Presented at the 5th Annual International High-Level Radioactive Waste Management Conference and Exposition. Las Vegas, Nevada.

Wigand, Peter E., Martha Hemphill, Saxon E. Sharpe, and Sikha (Manna) Patra

1995 Great Basin Semi-Arid Woodland Dynamics During the Late Quaternary. In *Climate Change in the Four Corners and Adjacent Regions: Implications for Environmental Restoration and Land Use- Planning,* W.J. Waugh editor, pp. 51-69.

Wigand, Peter E., and Cheryl L. Nowak

1979 Dynamics of Northwest Nevada Plant Communities During the Last 30,000 Years. In *The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains,* White *Mountain Research Station Symposium Volume 4,* edited by Clarence Hall, Victoria Doyle-Jones and Barbara Widawski.

Wilke, Philip J. and Harvey W. Lawton

1976 The Expedition of Capt. J.W. Davidson from Fort Tejon to the Owens Valley in 1859. *Ballena Press Publications in Archaeology, Ethnology, and History* 8. Socorro, N.M.

Willig, Judith A., C. Mevlin Aikens, and John L. Fagan (editors)

1988 Early Human Occupation in Far Western North America: The Clovis-Archaic Interface. *Nevada State Museum Anthropological Papers* 21.

Woodward, Arthur

1967 Indian Trade Goods. *Portland, Oregon Archeological Society Publication* 2:4-15.

Yellen, J.E.
1977 Long Term Hunter-Gatherer Adaptation to Desert Environments: A Biogeographical Perspective. *World Archaeology* 8:262-274.

York, Andrew and W.G. Spaulding
1995 Late Holocene Environment And Culture In The Central Mojave Desert. Paper presented at the 29th Annual Meeting of the Society of California Archaeology, April 1995, Eureka, CA.

Zeanah, David W., Michael G. Delacorte, and Mark E. Basgall
2000 Aberdeen-Blackrock Extended Pahse I and Phase II Research Design For Test Excavations At 21 Archaeological Sites Along Highway 395 Inyo County, California. Archaeological Research Center, California State University, Sacramento. Prepared for Caltrans District 6, Fresno, California.

APPENDIX A:

OBSISIAN HYDRATION ANALYSES

Appendix

Results of Obsidian Hydration Analysis

Table A-1. Obsidian Hydration Results and Sample Provenience: Bodie Hills/NRCS Project, Mono County, California

Site	Specimen No.	Catalog No.	Unit	Depth (cm)	Artifact Type[A]	Artifact Source	Hydration Rims		Comments[B]
							Rim 1	Rim 2	
CA-170-0708	1	0708-P4-1	P4	Surface	DEB	No Source Determined	4.4 ± 0.1	NM ± NM	--
CA-170-0708	2	0708-P4-2	P4	Surface	DEB	No Source Determined	11.1 ± 0.1	NM ± NM	PAT, DFV
CA-170-0708	3	0708-P4-3	P4	Surface	DEB	No Source Determined	3.2 ± 0.1	NM ± NM	--
CA-170-0708	4	0708-P4-4	P4	Surface	DEB	No Source Determined	3.1 ± 0.1	10.2 ± 0.1	PAT, DFV, small rim on BRE
CA-170-0708	5	0708-P4-47	P4	0-10	DEB	No Source Determined	5.0 ± 0.0	NM ± NM	--
CA-170-0708	6	0708-P4-48	P4	0-10	DEB	No Source Determined	NA ± NA	NM ± NM	UNR
CA-170-0708	7	0708-P4-49	P4	0-10	DEB	No Source Determined	5.4 ± 0.1	NM ± NM	--
CA-170-0708	8	0708-P4-50	P4	0-10	DEB	No Source Determined	3.8 ± 0.1	NM ± NM	Same rim on BRE
CA-170-0708	9	0708-P4-66	P4	10-20	DEB	No Source Determined	7.3 ± 0.1	NM ± NM	--
CA-170-0708	10	0708-P4-67	P4	10-20	DEB	No Source Determined	4.5 ± 0.1	NM ± NM	--
CA-170-0708	11	0708-P4-68	P4	10-20	DEB	No Source Determined	NA ± NA	NM ± NM	UNR
CA-170-0708	12	0708-P4-69	P4	10-20	DEB	No Source Determined	8.1 ± 0.1	NM ± NM	--
CA-170-0708	13	0708-P5-70	P4	Surface	DEB	No Source Determined	8.9 ± 0.0	NM ± NM	--
CA-170-0708	14	0708-P5-71	P4	Surface	DEB	No Source Determined	8.7 ± 0.1	NM ± NM	--
CA-170-0708	15	0708-P5-72	P5	Surface	DEB	No Source Determined	8.0 ± 0.1	NM ± NM	--
CA-170-0708	16	0708-P5-73	P5	0-10	DEB	No Source Determined	13.2 ± 0.1	NM ± NM	DFV, HV
CA-170-0708	17	0708-P5-74	P5	0-10	DEB	No Source Determined	NA ± NA	NM ± NM	UNR
CA-170-0708	18	0708-P5-75	P5	0-10	DEB	No Source Determined	NA ± NA	NM ± NM	NVH
CA-170-0708	19	0708-P12-76	P12	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	REC; UNR
CA-170-0708	20	0708-P12-77	P12	Surface	DEB	No Source Determined	4.5 ± 0.1	NM ± NM	--
CA-170-0708	21	0708-P12-78	P12	Surface	DEB	No Source Determined	2.8 ± 0.1	7.5 ± 0.1	Small rim on ventral margin
CA-170-0708	22	0708-P12-79	P12	Surface	DEB	No Source Determined	4.5 ± 0.1	NM ± NM	--
CA-170-0708	23	0708-P12-80	P12	Surface	DEB	No Source Determined	4.6 ± 0.1	NM ± NM	DFV
CA-170-0708	24	0708-P12-91	P12	0-10	DEB	No Source Determined	5.8 ± 0.1	NM ± NM	--

[A] DEB = Debitage; PPT = Projectile Point

[B] See text for explanation of comment abbreviations
NA = Not Available; NM = Not Measured; * = Small sample

Table A-1. Obsidian Hydration Results and Sample Provenience: Bodie Hills/NRCS Project, Mono County, California

Site	Specimen No.	Catalog No.	Unit	Depth (cm)	Artifact Type[A]	Artifact Source	Hydration Rims		Comments[B]
							Rim 1	Rim 2	
CA-170-0708	25	0708-P12-92	P12	0-10	DEB	No Source Determined	6.4 ± 0.1	NM ± NM	REC
CA-170-0708	26	0708-P12-93	P12	0-10	DEB	No Source Determined	5.9 ± 0.1	NM ± NM	DFV
CA-170-0708	27	0708-P12-94	P12	0-10	DEB	No Source Determined	3.7 ± 0.1	7.7 ± 0.1	Small rim on BRE
CA-170-0708	28	0708-P12-95	P12	0-10	DEB	No Source Determined	4.6 ± 0.1	NM ± NM	--
CA-170-0708	29	0708-P13-97	P13	Surface	DEB	No Source Determined	5.9 ± 0.1	NM ± NM	--
CA-170-0708	30	0708-P13-98	P13	Surface	DEB	No Source Determined	3.0 ± 0.1	NM ± NM	--
CA-170-0708	31	0708-P13-99	P13	Surface	DEB	No Source Determined	2.1 ± 0.1	NM ± NM	--
CA-170-0708	32	0708-P13-100	P13	Surface	DEB	No Source Determined	1.9 ± 0.0	NM ± NM	Possibly burnt
CA-170-0708	33	0708-P13-101	P13	Surface	DEB	No Source Determined	5.1 ± 0.1	NM ± NM	--
CA-170-0708	34	0708-P13-102	P13	Surface	DEB	No Source Determined	3.4 ± 0.1	NM ± NM	--
CA-170-0708	35	0708-P13-103	P13	Surface	DEB	No Source Determined	2.9 ± 0.1	NM ± NM	REC; DFV
CA-170-0708	36	0708-P13-104	P13	Surface	DEB	No Source Determined	5.1 ± 0.1	NM ± NM	--
CA-170-0708	37	0708-P13-105	P13	Surface	DEB	No Source Determined	3.1 ± 0.1	NM ± NM	--
CA-170-0708	38	0708-P13-106	P13	Surface	DEB	No Source Determined	3.1 ± 0.1	NM ± NM	REC
CA-170-0708	39	0708-P14-108	P14	Surface	DEB	No Source Determined	8.4 ± 0.1	NM ± NM	DFV
CA-170-0708	40	0708-P14-109	P14	Surface	DEB	No Source Determined	5.1 ± 0.1	NM ± NM	--
CA-170-0708	41	0708-P14-110	P14	Surface	DEB	No Source Determined	7.1 ± 0.1	NM ± NM	--
CA-170-0708	42	0708-P14-111	P14	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	REC; UNR
CA-170-0708	43	0708-P14-112	P14	Surface	DEB	No Source Determined	7.6 ± 0.1	NM ± NM	--
CA-170-0708	44	0708-P14-132	P14	0-10	DEB	No Source Determined	5.2 ± 0.1	NM ± NM	--
CA-170-0708	45	0708-P14-133	P14	0-10	DEB	No Source Determined	6.8 ± 0.1	NM ± NM	DFV
CA-170-0708	46	0708-P14-135	P14	0-10	DEB	No Source Determined	NA ± NA	NM ± NM	REC; UNR (appears burnt)
CA-170-0708	47	0708-P14-136	P14	0-10	DEB	No Source Determined	4.3 ± 0.1	NM ± NM	--
CA-170-0708	48	0708-P14-137	P14	10-20	DEB	No Source Determined	7.5 ± 0.1	NM ± NM	DFV

[A] DEB = Debitage; PPT = Projectile Point

[B] See text for explanation of comment abbreviations

NA = Not Available; NM = Not Measured; * = Small sample

Northwest Research Obsidian Studies Laboratory

Table A-1. Obsidian Hydration Results and Sample Provenience: Bodie Hills/NRCS Project, Mono County, California

Site	Specimen No.	Catalog No.	Unit	Depth (cm)	Artifact Type[A]	Artifact Source	Hydration Rims		Comments[B]
							Rim 1	Rim 2	
CA-170-0708	49	0708-P15-138	P15	Surface	DEB	No Source Determined	5.9 ± 0.1	NM ± NM	--
CA-170-0708	50	0708-P15-139	P15	Surface	DEB	No Source Determined	6.8 ± 0.1	NM ± NM	--
CA-170-0708	51	0708-P15-140	P15	Surface	DEB	No Source Determined	7.3 ± 0.1	NM ± NM	--
CA-170-0708	52	0708-P15-141	P15	Surface	DEB	No Source Determined	6.7 ± 0.1	NM ± NM	--
CA-170-0708	53	0708-P15-134	P15	0-10	DEB	No Source Determined	6.5 ± 0.1	NM ± NM	--
CA-170-0708	54	0708-P15-155	P15	0-10	DEB	No Source Determined	6.4 ± 0.1	NM ± NM	--
CA-170-0708	55	0708-P15-156	P15	0-10	DEB	No Source Determined	4.8 ± 0.0	NM ± NM	--
CA-170-0708	56	0708-P15-157	P15	0-10	DEB	No Source Determined	5.5 ± 0.1	NM ± NM	--
CA-170-0708	57	0708-P15-158	P15	0-10	DEB	No Source Determined	6.5 ± 0.1	NM ± NM	--
CA-170-0708	58	0708-P15-159	P15	10-20	DEB	No Source Determined	5.4 ± 0.1	NM ± NM	--
CA-170-0708	59	0708-P16-160	P16	Surface	DEB	No Source Determined	6.8 ± 0.1	NM ± NM	--
CA-170-0708	60	0708-P16-161	P16	Surface	DEB	No Source Determined	4.9 ± 0.1	NM ± NM	--
CA-170-0708	61	0708-P16-162	P16	Surface	DEB	No Source Determined	7.3 ± 0.1	NM ± NM	--
CA-170-0708	62	0708-P16-163	P16	Surface	DEB	No Source Determined	5.8 ± 0.0	NM ± NM	--
CA-170-0708	63	0708-P16-164	P16	Surface	DEB	No Source Determined	6.8 ± 0.1	NM ± NM	--
CA-170-0708	64	0708-P16-165	P16	Surface	DEB	No Source Determined	4.3 ± 0.1	NM ± NM	NVH on BRE
CA-170-0708	65	0708-P16-166	P16	Surface	DEB	No Source Determined	6.1 ± 0.1	NM ± NM	--
CA-170-0708	66	0708-P16-172	P16	10-20	DEB	No Source Determined	4.4 ± 0.1	NM ± NM	--
CA-170-0708	67	0708-P16-173	P16	10-20	DEB	No Source Determined	7.5 ± 0.1	NM ± NM	--
CA-170-0708	68	0708-P16-174	P16	10-20	DEB	No Source Determined	3.9 ± 0.0	6.6 ± 0.1	Small rim on ventral margin
CA-170-0708	69	0708-P17-175	P17	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	REC; UNR (appears burnt)
CA-170-0708	70	0708-P17-176	P17	Surface	DEB	No Source Determined	6.9 ± 0.1	NM ± NM	--
CA-170-0708	71	0708-P17-177	P17	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	WEA, UNR
CA-170-0708	72	0708-P18-178	P18	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	REC; UNR (appears burnt)

[A] DEB = Debitage; PPT = Projectile Point

[B] See text for explanation of comment abbreviations
NA = Not Available; NM = Not Measured; * = Small sample

Northwest Research Obsidian Studies Laboratory

Table A-1. Obsidian Hydration Results and Sample Provenience: Bodie Hills/NRCS Project, Mono County, California

Site	Specimen No.	Catalog No.	Unit	Depth (cm)	Artifact Type[A]	Artifact Source	Hydration Rims: Rim 1	Hydration Rims: Rim 2	Comments[B]
CA-170-0708	73	0708-P18-179	P18	Surface	DEB	No Source Determined	3.3 ± 0.1	9.6 ± 0.1	Small rim on ventral surface
CA-170-0708	74	0708-P18-180	P18	Surface	DEB	No Source Determined	8.0 ± 0.1	NM ± NM	DFV
CA-170-0708	75	0708-P18-181	P18	Surface	DEB	No Source Determined	5.3 ± 0.1	NM ± NM	DFV, PAT
CA-170-0708	76	0708-P18-187	P18	0-10	DEB	No Source Determined	3.7 ± 0.1	NM ± NM	Possibly burnt
CA-170-0708	77	0708-P18-188	P18	0-10	DEB	No Source Determined	4.0 ± 0.1	NM ± NM	--
CA-170-0708	78	0708-P18-189	P18	0-10	DEB	No Source Determined	6.7 ± 0.1	NM ± NM	REC; possibly burnt
CA-170-0708	79	0708-P18-199	P18	10-20	DEB	No Source Determined	2.8 ± 0.1	NM ± NM	--
CA-170-0708	80	0708-P18-200	P18	10-20	DEB	No Source Determined	4.9 ± 0.1	NM ± NM	--
CA-170-0708	81	0708-P18-201	P18	10-20	DEB	No Source Determined	4.6 ± 0.0	NM ± NM	--
CA-170-0708	82	0708-P37-202	P37	Surface	DEB	No Source Determined	6.2 ± 0.1	NM ± NM	DFV, PAT
CA-170-0708	83	0708-P37-203	P37	Surface	DEB	No Source Determined	7.4 ± 0.1	NM ± NM	DFV, PAT
CA-170-0708	84	0708-P37-204	P37	Surface	DEB	No Source Determined	5.6 ± 0.1	NM ± NM	--
CA-170-0708	85	0708-P37-205	P37	Surface	DEB	No Source Determined	6.6 ± 0.1	NM ± NM	--
CA-170-0708	86	0708-P37-206	P37	Surface	DEB	No Source Determined	4.6 ± 0.1	NM ± NM	--
CA-170-0708	87	0708-P37-207	P37	Surface	DEB	No Source Determined	8.8 ± 0.1	NM ± NM	DFV, PAT
CA-170-0708	88	0708-P37-208	P37	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	REC; UNR (appears burnt)
CA-170-0708	89	0708-P37-209	P37	Surface	DEB	No Source Determined	3.3 ± 0.1	NM ± NM	--
CA-170-0708	90	0708-P37-210	P37	Surface	DEB	No Source Determined	3.4 ± 0.1	NM ± NM	--
CA-170-0708	91	0708-P37-212	P37	0-10	DEB	No Source Determined	NA ± NA	NM ± NM	REC
CA-170-0708	92	0708-P38-221	P38	Surface	DEB	No Source Determined	3.8 ± 0.1	15.5 ± 0.1	Large rim on dorsal surface
CA-170-0708	93	0708-P38-222	P38	Surface	DEB	No Source Determined	4.6 ± 0.1	8.1 ± 0.1	Small rim on ventral margin
CA-170-0708	94	0708-P38-223	P38	Surface	DEB	No Source Determined	4.3 ± 0.1	NM ± NM	--
CA-170-0708	95	0708-P38-224	P38	Surface	DEB	No Source Determined	2.9 ± 0.1	NM ± NM	--
CA-170-0708	96	0708-P38-225	P38	Surface	DEB	No Source Determined	5.4 ± 0.1	7.8 ± 0.1	Small rim on dorsal margin

[A] DEB = Debitage; PPT = Projectile Point

[B] See text for explanation of comment abbreviations
NA = Not Available; NM = Not Measured; * = Small sample

Table A-1. Obsidian Hydration Results and Sample Provenience: Bodie Hills/NRCS Project, Mono County, California

							Hydration Rims		
Site	Specimen No.	Catalog No.	Unit	Depth (cm)	Artifact Type[A]	Artifact Source	Rim 1	Rim 2	Comments[B]
CA-170-0708	97	0708-P38-226	P38	0-10	DEB	No Source Determined	5.1 ± 0.1	NM ± NM	--
CA-170-0708	98	0708-P38-227	P38	0-10	DEB	No Source Determined	2.8 ± 0.0	NM ± NM	--
CA-170-0708	99	0708-P38-228	P38	0-10	DEB	No Source Determined	2.7 ± 0.1	NM ± NM	--
CA-170-0708	100	0708-P38-229	P38	0-10	DEB	No Source Determined	5.8 ± 0.1	NM ± NM	--
CA-170-0708	101	0708-P38-230	P38	0-10	DEB	No Source Determined	3.1 ± 0.1	NM ± NM	--
CA-170-0708	102	0708-P39-239	P39	Surface	DEB	No Source Determined	8.1 ± 0.1	NM ± NM	PAT, DFV
CA-170-0708	103	0708-P39-240	P39	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	OPA, UNR
CA-170-0708	104	0708-P39-241	P39	Surface	DEB	No Source Determined	8.9 ± 0.1	NM ± NM	PAT, DFV
CA-170-0708	105	0708-P39-242	P39	Surface	DEB	No Source Determined	3.8 ± 0.0	NM ± NM	--
CA-170-0708	106	0708-P39-243	P39	Surface	DEB	No Source Determined	NA ± NA	NM ± NM	WEA, UNR
CA-170-0708	107	0708-P39-244	P39	Surface	DEB	No Source Determined	7.6 ± 0.1	NM ± NM	--
CA-170-0708	108	0708-P39-245	P39	Surface	DEB	No Source Determined	8.9 ± 0.1	NM ± NM	--
CA-170-0708	109	0708-P39-246	P39	Surface	DEB	No Source Determined	8.3 ± 0.1	NM ± NM	DFV
CA-170-0708	110	0708-P39-255	P39	Surface	DEB	No Source Determined	4.0 ± 0.1	NM ± NM	--
CA-170-0708	111	0708-P39-256	P39	Surface	DEB	No Source Determined	8.0 ± 0.1	NM ± NM	--
CA-170-0708	112	0708-P40-329	P40	Surface	DEB	No Source Determined	8.6 ± 0.1	NM ± NM	--
CA-170-0708	113	0708-P40-330	P40	Surface	DEB	No Source Determined	8.1 ± 0.1	NM ± NM	--
CA-170-0708	114	0708-P40-331	P40	Surface	DEB	No Source Determined	3.8 ± 0.1	NM ± NM	--
CA-170-0708	115	0708-P40-332	P40	Surface	DEB	No Source Determined	5.8 ± 0.1	NM ± NM	BRE is PAT, UNR
CA-170-0708	116	0708-P40-333	P40	Surface	DEB	No Source Determined	3.8 ± 0.1	6.3 ± 0.1	Small rim on BRE
CA-170-0708	117	0708-P40-334	P40	Surface	DEB	No Source Determined	3.5 ± 0.1	NM ± NM	--
CA-170-0708	118	0708-P40-335	P40	Surface	DEB	No Source Determined	4.0 ± 0.1	NM ± NM	Dorsal is WEA, UNR
CA-170-0708	119	0708-P40-336	P40	Surface	DEB	No Source Determined	4.3 ± 0.1	NM ± NM	DFV
CA-170-0708	120	0708-P40-337	P40	Surface	DEB	No Source Determined	3.8 ± 0.1	NM ± NM	--

[A] DEB = Debitage; PPT = Projectile Point

[B] See text for explanation of comment abbreviations

NA = Not Available; NM = Not Measured; * = Small sample

Table A-1. Obsidian Hydration Results and Sample Provenience: Bodie Hills/NRCS Project, Mono County, California

Site	Specimen No.	Catalog No.	Unit	Depth (cm)	Artifact Type[A]	Artifact Source	Hydration Rims		Comments[B]
							Rim 1	Rim 2	
CA-170-0708	121	0708-I-4	ISO	Surface	PPT	No Source Determined	6.5 ± 0.1	NM ± NM	Same rim on BRE
CA-170-0708	122	0708-P37-213	P37	Surface	DEB	No Source Determined	4.9 ± 0.1	NM ± NM	--
CA-170-0708	123	0708-P39-247	P39	0-10	DEB	No Source Determined	6.5 ± 0.1	NM ± NM	--
CA-170-0708	124	0708-P39-248	P39	0-10	DEB	No Source Determined	8.8 ± 0.1	NM ± NM	--
CA-170-0708	125	0708-P39-249	P39	0-10	DEB	No Source Determined	3.1 ± 0.1	4.6 ± 0.1	Small rim on ventral surface
CA-170-0708	126	0708-P39-250	P39	0-10	DEB	No Source Determined	NA ± NA	NM ± NM	WEA, UNR
CA-170-0708	127	0708-P39-251	P39	0-10	DEB	No Source Determined	6.5 ± 0.1	NM ± NM	DFV, PAT
CA-170-0708	128	0708-P39-252	P39	0-10	DEB	No Source Determined	3.1 ± 0.1	NM ± NM	--
CA-170-0708	129	0708-P39-253	P39	0-10	DEB	No Source Determined	4.2 ± 0.1	NM ± NM	--
CA-170-0708	130	0708-P39-254	P39	0-10	DEB	No Source Determined	7.1 ± 0.1	NM ± NM	--
CA-170-0708	131	0708-P38-230	P38	Surface	DEB	No Source Determined	3.1 ± 0.0	6.7 ± 0.1	Small rim on dorsal surface

---

[A] DEB = Debitage; PPT = Projectile Point

[B] See text for explanation of comment abbreviations
NA = Not Available; NM = Not Measured; * = Small sample

Abbreviations and Definitions Used in the Comments Column

All hydration rim measurements are recorded in microns.

BEV - (Beveled). Artifact morphology or cut configuration resulted in a beveled thin section edge.

BRE - (BREak). The thin section cut was made across a broken edge of the artifact. Resulting hydration measurements may reveal when the artifact was broken, relative to its time of manufacture.

DES - (DEStroyed). The artifact or flake was destroyed in the process of thin section preparation. This sometimes occurs during the preparation of extremely small items, such as pressure flakes.

DFV - (Diffusion Front Vague). The diffusion front, or the visual boundary between hydrated and unhydrated portions of the specimen, are poorly defined. This can result in less precise measurements than can be obtained from sharply demarcated diffusion fronts. The technician must often estimate the hydration boundary because a vague diffusion front often appears as a relatively thick, dark line or a gradation in color or brightness between hydrated and unhydrated layers.

DIS - (DIScontinuous). A discontinuous or interrupted hydration rind was observed on the thin section.

HV - (Highly Variable). The hydration rind exhibits variable thickness along continuous surfaces. This variability can occur with very well- defined bands as well as those with irregular or vague diffusion fronts.

IRR - (IRRegular). The surfaces of the thin section (the outer surfaces of the artifact) are uneven and measurement is difficult.

1SO - (1 Surface Only). Hydration was observed on only one surface or side of the thin section.

NOT - (NOT obsidian). Petrographic characteristics of the artifact or obsidian specimen indicate that the specimen is not obsidian.

NVH - (No Visible Hydration). No hydration rind was observed on one or more surfaces of the specimen. This does not mean that hydration is absent, only that hydration was not observed. Hydration rinds smaller than one micron often are not birefringent and thus cannot be seen by optical microscopy. "NVH" may be reported for the manufacture surface of a tool while a hydration measurement is reported for another surface, e.g. a remnant ventral flake surface.

OPA - (OPAque). The specimen is too opaque for measurement and cannot be further reduced in thickness.

PAT - (PATinated). This description is usually noted when there is a problem in measuring the thickness of the hydration rind, and refers to the unmagnified surface characteristics of the artifact, possibly indicating the source of the measurement problem. Only extreme patination is normally noted.

REC - (RECut). More than one thin section was prepared from an archaeological specimen. Multiple thin sections are made if preparation quality on the initial specimen is suspect or obviously poor. Additional thin sections may also be prepared if it is perceived that more information concerning an artifact's manufacture or use can be obtained.

UNR - (UNReadable). The optical quality of the hydration rind is so poor that accurate measurement is not possible. Poor thin section preparation is not a cause.

WEA - (WEAthered). The artifact surface appears to be damaged by wind erosion or other mechanical action.

APPENDIX B:

FLAKED AND TOOL STONE CATEGORIES

APPENDIX B

Flaked and Tool Stone Reduction Categories

(after Callahan 1979; Crabtree 1972; Fagan 1995; Jackson 1985; Jackson et al.1988; Rondeau 1992).

Thinning

Primary Decortication: Primary decortication flakes are produced during early stages of core reduction and exhibit greater than 50% cortex on the dorsal surface. Platforms are single faceted, thick and wide and the dorsal scar morphology simple.

Secondary Decortication: This flake type exhibits less than 50% cortex on the dorsal surface and is typically indicative of early and mid stages of reduction. Cortex may be present on late stage reduction flakes, early stage and mid stage biface thinning flakes and finished tools, but is predominantly found on early and mid stages of core or flake blank reduction. Platform and dorsal scar morphology may parallel primary decortication, but more of these flakes can be found in mid and late stages of reduction and may show more complex morphology.

Early Stage Thinning Flake: This reduction stage is defined by percussion flaking subsequent to decortication, often placed in a "catch all" category of interior flakes characterized as such due to the lack of cortex. Dorsal flake scar morphology is simple, exhibiting no more than two previous flake removals. Dorsal scar arrises will tend to run parallel to the lateral margins. Platform preparation may be apparent though platform morphology will be simple. Bulbs of percussion and compression rings are prevalent. This flake type typically represent mid stage core or early biface reduction.

Mid Stage Thinning Flake: These flakes represent the next step in the reduction continuum. They are delineated by the presence of three to four dorsal flake scars and generally are thinner and more symmetrical than early stage flakes and will often exhibit expanding margins. Platform morphology will display a moderate level of complexity, with preparation more distinctly identifiable. Bulbs are prominent, but compression rings become more diffuse. Typically, the flake type is representative of late stage core or early and mid stage biface reduction.

Late Stage Thinning: Characterized by a complex dorsal scar morphology with more than four flake scars. Generally, flake sizes are smaller than mid stage flakes, but are larger than 6mm when percussion is used. Platforms are narrow, thin and complex or multifaceted. The bulb of percussion and compression rings tend to be diffuse. Termination's at this stage are expanding and feathered. Generally, this type is representative of stage 1 to stage 3 biface reduction as defined below.

Biface Thinning: This flake category is an indicator of biface reduction and exhibits platforms bearing remnant flake scars originating from the opposite side of the biface. This is the only attribute by which to distinguish this category from the mid and late stage thinning categories. Early through late stages of biface thinning flakes are identified by this platform attribute. Dorsal scar morphology is predominantly complex. Platforms will be multifaceted and thin, and will often exhibit acute angles. The flakes will tend to be thin and moderately excurvate in cross section and parallel, but predominantly expanding in planar view.

Pressure Flakes: Pressure flakes are defined by the use of direct pressure versus striking the artifact as in percussion. Flake remnants, by definition, tend to be curved and twisted in

longitudinal section with parallel margins. Platforms are angled acutely, isolated and thin and often exhibit grinding or crushing. Bulbs will be large in relation to flake size and dominate the proximal end of the flake. Dorsal scar morphology is generally complex and will exhibit remnant ventral scars or percussion scars from previous biface or unifacial thinning.
Linear Flake: These are blade like flakes defined by their characteristic parallel and subparallel edges, with the length being at least twice as long, or longer, than their width.

Alternate Flakes: Alternate flakes are the byproduct of creating a bifacial, beveled, edge. They are often triangular in cross section, the proximal end being blocky, exhibiting the original square or thick edge.

Broken Flakes: This is a catch all category, including shatter. These flakes exhibit no definitive characteristics. Generally, platforms and terminations are missing.

Cores and Tools

Cores: A core has been defined as the nucleus that remains after the removal of flakes, or an artifact which has been reduced to provide useful flake tools or blanks (Crabtree 1972; Fagan 1995). The analysis of this category is useful for from the standpoint of representing quarrying, procurement, and curation. Cores will tend to be blocky, angular and thick relative to their length and width.

Bifaces: (definitions follow Basgall and Giambastiani 1995; Callahan 1979)
Biface technology may be indicative of behavioral shifts through time. The production, use and trade of bifaces has received a significant amount of attention (Bouey and Basgall 1984; Hall 1983; T. Jackson 1984; Singer and Ericson 1977). Biface production and trade reached its zenith during the Newberry period (Bouey and Basgall 1984) and declined along with intensive quarrying activities during the late period (Haiwee-Marana). Many reasons for this decline have been posited (Bettinger and Baumhoff 1982; Bouey and Basgall 1984; Hall 1983), but more recent evidence suggest a technological shift with the advent of the bow and arrow (Rondeau 1992) in concert with decreasing mobility and trade (Basgall 1989; Basgall and Giambastiani 1995), evident in more recycling of on site and local resources during the late period. The advent of smaller arrow points would have allowed for small flake blank technology to be more efficiently employed on recycled debitage during the late period (Rondeau 1992). In sum, biface analyses can provide important information for understanding land use patterns on the Dry Lakes Plateau and how they tie into the regional picture.

Stage 1: Stage 1 bifaces are thick in section, often with limited symmetry, and display irregular margins characterized by large, early stage, percussion flake removals. Cortex may be prevalent on the remnant dorsal surface if flake blank technology was employed. Byproducts may include secondary decortication, alternate, and early stage thinning flakes.

Stage 2: Stage 2 bifaces are slightly more symmetrical, thinner in section, and have more regularized margin modification. Flake scar morphology becomes increasingly more complex and will be represented by early and mid stage percussion thinning.

Stage 3: Stage 3 bifaces are well shaped and symmetrical with regularized margins and are thin in relation to length and width. Flake scar morphology is complex with many flake removals extending across the midsection. Basgall and Giambastiani (1995:17) have characterized stage 3 bifaces as preforms. For this analysis, preforms are representative of stage 4 bifaces and are evidenced by pressure flaking. Stage 3 bifaces, following Fagan (1995), will be defined as blanks, exhibiting mid and late stage percussion scars.

Stage 4: Stage 4 bifaces are defined as preforms and are characterized by pressure flake removal scars in preparation for the manufacture of projectile points or a useable edge. Thin in section, remnant ventral flake scar morphology becomes increasingly complex and is evidenced by smaller pressure flake removals. Margins will exhibit an acute angle sharp enough to act as a cutting edge. Blades, knives and drills would be placed in this category.

Projectile Points: Projectile points, or Stage 5 Bifaces, are thin (typically <7mm) in section. Remnant ventral flake scar morphology will represent late stage pressure flaking, with closely spaced and parallel arris intervals emanating from the margins to the midsection.

Formed Flake Tools: This artifact category includes unifaces (modified on a single surface, typically plano-convex) and formal scrapers. In plan they are often circular to semi-circular. They are generally separated from edge modified flakes by the more intrusive percussion and pressure flaking patterns (Rondeau 1992) which overlap previous removal scars.

Edge Modified Flake: This category includes artifacts that have been modified along one or more of the lateral margins either through use or pressure retouch. The flake scars are typically short and represent edge modification occurring during use or sharpening for use. Expedient flake tools are represented in this category and are defined by the microscopic flake patterns developed during use. By definition this tool type will exhibit much of the remnant dorsal and ventral surfaces of the flake blank. This category is problematic as a useable field recordation type, due to the taphonomic issues which may influence the identification of this category. Human, animal and geomorphic agents have been shown to cause patterned edge wear (Nielsen 1991; Rondeau 1992). But, this category has been found to be important in late period contexts (Basgall and Giambastiani 1995; Delacorte et al. 1995) and will be recorded for this study with the caveat that various agents may be responsible for creation of these tool types.

APPENDIX C:

ROGERS BODIE HILLS EHT ANALYSES

SCALING OF TEMPERATURE DATA FOR EHT COMPUTATION: A STUDY OF SITES NEAR BODIE, CALIFORNIA

Alexander K. Rogers
Archaeology Curator and Staff Archaeologist

Rev A
6 March 2008

Maturango Museum
Working Manuscript # 41

INTRODUCTION

This paper addresses develops a method for estimation of temperature parameters for EHT computations. The method is based on publicly-available meteorological records, and also includes a recommended step-by-step procedure for applying the method to a practical archaeological case.

Computation of EHT by the method of Rogers (2007a) requires three temperature parameters for the site: annual average temperature (T_a); annual temperature variation (V_a), defined as difference between the July average temperature and the January average temperature; and mean diurnal variation (V_d), defined as the average of the daily temperature ranges for July and January.

Frequently there are no long-term meteorological records for the area of an archaeological site, so the parameters must be scaled from a surrogate site which lies in a similar weather pattern and does have records. Traditionally, scaling has been done for altitude, using the mean adiabatic lapse rate of -1.9ºC/1000 ft altitude change; however, this lapse rate strictly applies only to T_a, so the other variables are still an issue to be addressed by this analysis.

The parameters must be computed from a sufficiently long run of data to be representative of long-term climate. Sensors emplaced at a site do not provide this, so all of the computations discussed here are based on data covering a period of 30 years, in accordance with standard meteorological practice (Cole 1970). All the temperatures used in this study are air temperatures, measured five feet above the ground in an enclosure which shelters the sensor from direct sunlight, again normal meteorological practice.

The analysis follows the method employed by Rogers 2007b.

DATA BASE

The analysis is based on monthly temperature data from the Western Regional Climate Center (WRCC), using the data base from 1971 – 2000. Table 1 summarizes the sites used in the temperature scaling analysis. All are from desert or desert mountain environments near Bodie, California, and are in similar weather patterns.

Table 1. Sites used in the Scaling Analysis.

Station	Alt, ft	Ave Max, deg F	Ave Min, deg F	Annual Ave, deg F	Jul Max, deg F	Jul Min, deg F	Jan Max, deg F	Jan Min, deg F
Hawthorn Apt	4220	69.5	40.6	55.1	93.8	60.3	46.5	23.3
Yerington	4380	68.6	36.2	52.4	91.6	54.3	46.4	20.2
Bridgeport	6440	62.6	24.4	43.5	83.1	40.2	42.8	9.4
Mono Lake	6530	61.4	32.4	46.9	83.4	48.1	39.6	18.6
Bodie	8370	56.4	19.4	37.9	76.3	34.6	40.1	6.1

ANALYSIS

ALTITUDE EFFECTS

The temperature parameters were computed from the data of Table 1. All temperatures were converted to ºC, and the computations made as follows:

$$T_a = \text{annual average temperature} \quad (1)$$

$$V_a = (\text{July max} + \text{July min})/2 - (\text{Jan max} + \text{Jan min})/2 \quad (2)$$

$$V_d = [(\text{July max} - \text{July min}) - (\text{Jan max} - \text{Jan min})]/2 \quad (3)$$

Table 2 summarizes the results.

Table 2. Computed Temperature Parameters.

Station	**Alt, ft**	**Ta, deg C**	**Va, deg C**	**Vd, deg C**
Hawthorn Apt	4220	12.81	13.32	15.75
Yerington	4380	11.33	11.74	17.64
Bridgeport	6440	6.39	6.60	21.19
Mono Lake	6530	8.28	8.57	15.64
Bodie	8370	3.28	4.04	21.03

The next step was to examine the stability of the altitude scaling of the three parameters. Figure 1 shows the scaling of T_a with altitude. The data show a reasonable degree of correlation with the straight-line fit. Note that the slope is -2.2ºC/1000 feet, which is higher than the mean adiabatic lapse rate.

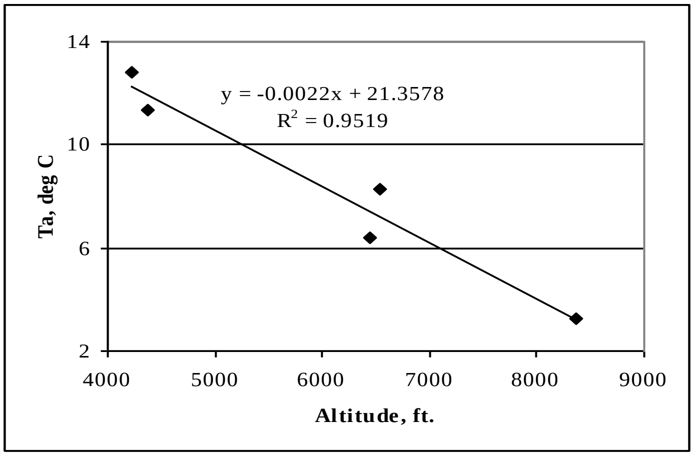


Figure 1. Scaling of annual average temperature (T_a) with altitude.

Figure 2 shows the similar plot for V_a, again exhibiting a relatively tight grouping. Generally differences between measured quantities are less numerically stable then averages because of random fluctuations; in this case the parameter is a difference of averages, and it appears to be fairly stable and predictable.

Finally, Figure 3 shows the scaling for V_d, which can be seen to be very poor. In this case the quantity V_d again represents a difference of measured quantities, so the instability is not unexpected. In addition, the data represent short-term phenomena, which tend to be less stable than long-term. The correlation coefficient is so small that the best strategy is not to scale at all, but to use the mean value of V_d, 18.3ºC, as the best estimate.

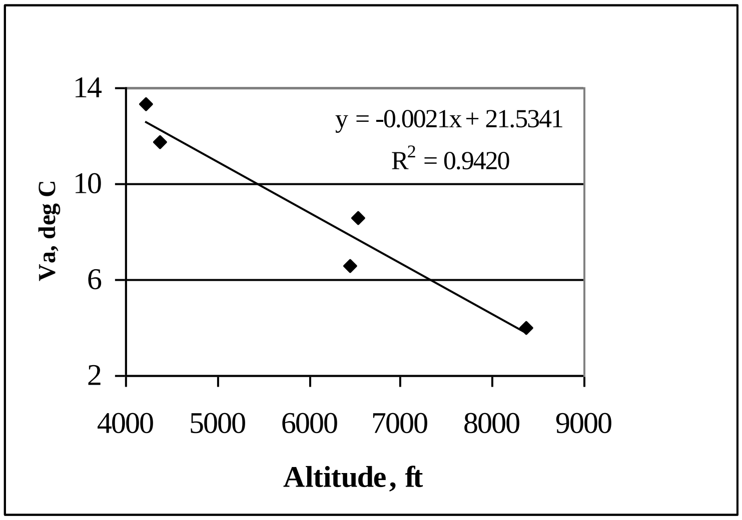


Figure 2. Scaling of annual temperature variation (V_a) with altitude.

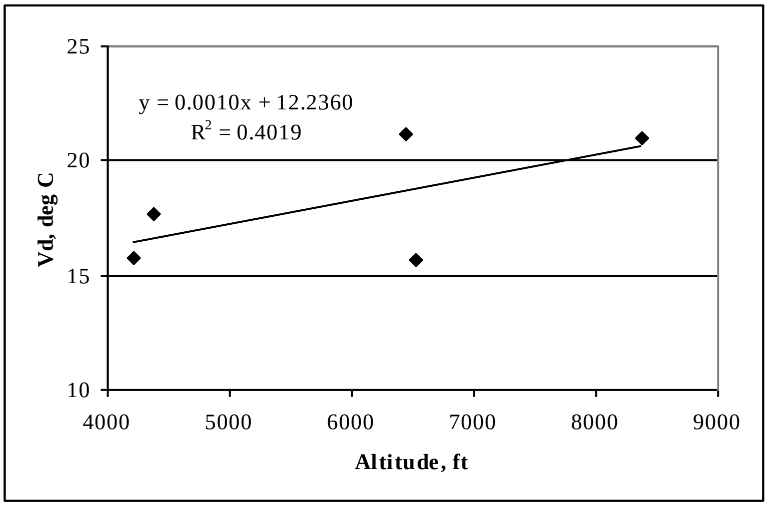


Figure 3. Altitude scaling of diurnal temperature variation (V_d).

CORRELATION BETWEEN T_a AND V_a

Meteorological theory (e.g. Cole 1970) suggests that T_a should scale for altitude by the mean adiabatic lapse rate. This was shown in Figure 1, and Figure 2 shows a similar scaling for V_a. Thus, T_a and V_a should be related, so that knowing T_a should allow predicting V_a. Figure 4 shows a plot of the data from Table 2, demonstrating the strong correlation between T_a and V_a .

This plot shows that V_a can be predicted with considerable accuracy if T_a is known. A separate plot could be developed for other areas (e.g. Rogers 2007b).

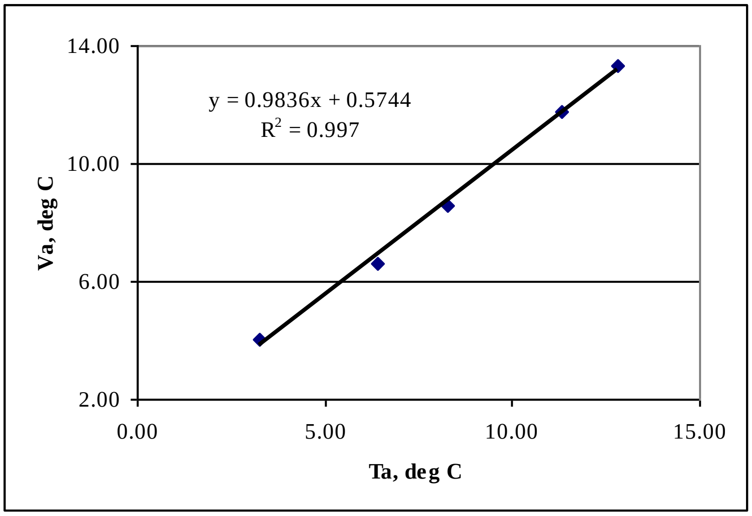


Figure 4. Plot showing correlation between T_a and V_a.

CONCLUSIONS

For conditions in the Bodie region, the annual average temperature was shown to be predicted by the equation

$$T_a = 21.36 - 2.2x \qquad (4)$$

where x is altitude in thousands of feet. The accuracy of this model is 0.84ºC, 1-sigma, for the data set of Table 2.

The annual temperature variation was found to decrease by 1.7ºC/1000 ft. altitude increase, and to be predicted by

$$V_a = 21.53 - 2.1x \qquad (5)$$

with x defined as above. The accuracy of the prediction is 0.91ºC for the data set of Table 2. Furthermore, if T_a is known for a site, V_a is predicted by

$$V_a = 0.57 + 0.98T_a \qquad (6)$$

The accuracy of this predictor is 0.21ºC, for the data set of Table 2.

Finally, the best fit between V_d and altitude is very poor (Figure 3), and, in the absence of other data about a site, the best estimate is 18.3ºC for locations encompassed by the area of the data set of Table 2 (i.e. the western Great Basin and desert mountains, near Bodie). The accuracy of this estimate is 2.73ºC, 1-sigma.

APPLICATION

Few archaeological sites seem to be close to current weather stations (most inconsiderate on the part of the original occupants!), so the climate parameters must be inferred. If the site is located in close proximity to a current weather station, the 30-year climate data from the station can be used to calculate the temperature parameters. Otherwise, a preferable strategy is to compute the parameters from a regional analysis such as this; since the regional analysis includes many sites in similar weather patterns, it is more likely to yield a representative result than extrapolating from a single site would. To apply the equations from this analysis, the following procedure is recommended:

1. Determine the altitude of the archaeological site.
2. Compute T_a for the site, using equation 1.
3. Compute V_a for the site, using equation 2.
4. Use 18.3ºC for V_d.
5. If the artifact in question is buried, multiply V_a and V_d by the following factors prior to computing EHT:

$$V_a = V_{a0}\exp(-0.44z)$$
$$V_d = V_{d0}\exp(-8.5z)$$

where V_{a0} and V_{d0} refer to the results of steps 3 and 4 above, and z is burial depth in meters (Carslaw and Jaeger 1959; also recent measurements by the author)

6. If the site is in a rock shelter –
    a. Use T_a as is.
    b. Multiply V_a by 0.75
    c. Use 5ºC for V_d (Everett-Curran et al. 1991).

Again, a depth correction can be applied for buried artifacts as in step 5 above.

7. Compute the variation parameter Y for each artifact:

$$Y = [V_{a0}\exp(-0.44z)]^2 + [V_{d0}\exp(-8.5z)]^2$$

where z is burial depth in meters. For surface artifacts (z = 0), this becomes

$$Y = V_a^2 + V_d^2$$

8. Now compute EHT

$$EHT = T_a(1 - 3.8\times10^{-5}\, Y) + .0096Y^{0.95}$$

9. The objective of the whole exercise is to be able to adjust the rim values to a common set of temperature conditions, so they can be compared and so that age can be computed. Thus, each rim measurement is multiplied by a rim correction factor R

$$R = \exp[-.06(EHT - EHT_r)]$$

where EHT_r is the EHT of the reference site or locus. Typically it is chosen to match the conditions for which the hydration rate was measured.

REFERENCES CITED

Carslaw, H. S., and J. C. Jaeger

1959 *Conduction of Heat in Solids*, 2nd ed. Oxford: Clarendon Press.

Cole, F. W.

1970 *Introduction to Meteorology*. Wiley: New York.

Everett-Curran, Linda, Richard G. Milo, and Duane Quiatt

1991 Microgeographic Comparisons of Climate Today Afford Inferences Concerning Past Behavior: An Overview of Data and Applications from a Study of Chapin Mesa (Mesa Verde National Park) Climate. In: *Anasazi Symposium 1991*, Art Hutchinson and Jack E. Smith, eds., pp. 109-116. Mesa Verde: Mesa Verde Museum Association.

Rogers, A. K.

2007a Effective Hydration Temperature of Obsidian: A Diffusion-Theory Analysis of Time-Dependent Hydration Rates. *Journal of Archaeological Science.* 34:656-665.

2007b *Scaling of Temperature Data for EHT Computation: A Study of Desert Sites*. Maturango Museum Working Manuscript #19, Rev A, dated 13 June 2007.

PRELIMINARY ANALYSIS OF OBSIDIAN HYDRATION FROM SITES NEAR BRIDGEPORT, CALIFORNIA

Alexander K. Rogers
Archaeology Curator and Staff Archaeologist

11 March 2008

Maturango Museum
Working Manuscript #43

Introduction

This paper analyzes the obsidian hydration data resulting from a series of sites located near Bridgeport, California. All specimens are Bodie Hills obsidian. The analysis corrects rim values for effective hydration temperature and computes age estimates, based on three age equations. No correction for paleoclimatic change is made, due to uncertainty in the age equation for this obsidian source (Rogers 2006a; 2007a; 2007b; 2007c; Rosenthal n.d.).

Theory

Hydration of obsidian has both a physical and a chemical aspect, and is known as a diffusion-reaction process (Doremus 1994, 2000, 2002). All that is known of the physics and chemistry of the process suggests the relationship between age and rim thickness should be quadratic, i.e. of the form

$$t = k\,x^2 \qquad (1)$$

where t is age in calendar years, x is rim thickness in microns, and k is a constant, the hydration coefficient (e.g. Ebert et al. 1991; Zhang et al. 1991; Doremus 2000, 2002; Stevenson et al. 1989, 1998). No other form of functional dependence is currently suggested by theory; Haller argued in 1963, based on the physical chemistry of diffusion, that if any dependence other than quadratic is found, "it is more likely the fault of the experiment rather than any inherent feature of the diffusion process" (Haller 1963:217). When obsidian data are expressed in radiocarbon years before the present (rcybp, by convention referenced to 1950), the quadratic form is still the best fit, giving the smallest overall error in age estimation, but with a different rate constant (Rogers 2006b).

Two age equations were proposed by Rosenthal and Waechter (2002) for Bodie Hills obsidian from high altitude sites:

$$t = 169.39x^2 - 50 \qquad (2a)$$

and

$$t = 101.35x^{2.2175} \qquad (2b)$$

Equation 2a is preferable from the standpoint of physics, since it explicitly preserves the quadratic form of equation 1 (although not described in the Rosenthal and Waechter text, the –50 is apparently to correct the origin to 1950, for rcybp.).

An alternative equation can be derived based on the data of Rosenthal (n.d., Table 32), with modifications. Table 32 gives a series of obsidian-radiocarbon pairings based on projectile point types, and is apparently the basis for equations 2a and 2b; however, a recent reanalysis of the same point types from the Coso volcanic field suggests the dates given by Rosenthal are too young (Rogers 2008c). Table 1 summarizes the age data suggested by Rosenthal and Waechter, and the revised dates from Rogers (2008c). The resulting equation is

$$t = 177x^2 \qquad (2c)$$

The rate constant in equation 2c is computed by a linear best fit between x^2 and t, and is the average of the rate constant computed with t independent and with x^2 independent; this provides an approximation to the optimal solution, which is given by the total least squares algorithm (Rogers 2007b).

Figure 1 compares the ages computed from these three equations. In all cases the rim values are understood to be EHT-corrected rims, referenced to conditions at about 6500 ft altitude in the eastern Sierra.

The hydration coefficient varies with effective hydration temperature, or EHT (e.g. Hull 2001; Ridings 1996; Rogers 2007a; Stevenson et al. 1989, 1998, 2004; Onken 2006), with relative humidity (Friedman et al. 1994; Mazer et al. 1991; Onken 2006), and with structural water concentration in the obsidian (Friedman et al. 1966; Stevenson et al. 1998, 2000; Ambrose and Stevenson 2004; Rogers 2008a).

The analysis reported here controls for EHT by the technique of Rogers (2007a), which specifically accounts for average annual temperature, annual variation, diurnal variation, and burial depth. The equation for EHT is

$$\mathrm{EHT} = T_a\times(1-Y\times3.8\times10^{-5})+.0096\times Y^{0.95} \qquad (3)$$

where T_a is annual average temperature, and the variation factor Y for surface artifacts is defined by

$$Y = V_a^2 + V_d^2 , \qquad (4a)$$

in which V_a is annual temperature variation (July mean minus January mean) and V_d is mean diurnal temperature variation. All temperatures are in degrees C.

For buried artifacts, V_a and V_d represent the temperature variations at the artifact depth, which are related to surface conditions by (Carslaw and Jaeger 1959:81)

$$V_a = V_{a0}\exp(-0.44z) \qquad (4b)$$

and

$$V_d = V_{d0}\exp(-8.5z) \qquad (4c)$$

where V_{a0} and V_{d0} represent surface conditions and z is burial depth in meters.

Once EHT has been computed, the measured rim thickness is multiplied by a rim correction factor (RCF) to adjust the rims to be comparable to conditions at a reference site:

$$\mathrm{RCF} = \exp[-0.06(\mathrm{EHT}-\mathrm{EHT}_r)] \qquad (5)$$

where EHT_r is effective hydration temperature at the reference site. The value of EHT_r is taken to be that of CA-MNO-3125, which is computed below. Correcting the rim to MNO-3126 allows direct comparison of EHT-corrected rim data between the sites. All temperatures are air temperatures with at least 30 years of history, reported by the Western Regional Climate Center.

Onken (2006) has suggested that the temperatures used in equations 3 and 4 ought to be surface temperatures, not the air temperatures reported by meteorological services. However, Rogers (2007d) has shown that EHT *differences* between sites can be computed with either air temperatures or surface temperatures, as long as they are used consistently.

It has been shown that depth correction for EHT is desirable, even in the presence of site turbation (Rogers 2007e), and the depth correction in equation 3 should be based on surface temperatures (here assumed to be approximated by air temperatures). Finally, all the samples were assumed to have been exposed to the same relative humidity.

Since climate has not been stable over the periods of archaeological interest, the effects of resulting temperature changes should be included. West et al (2007) presented a graph of mean temperature fluctuations over the past 18,000 years. Data from this graph have been used to model the effects of climate change on obsidian hydration (Rogers 2007c), computed as a weighted average of effective diffusion rates over time. The maximum paleoclimatic correction is of the order of ±7% of age, and is generally smaller. Rogers (2007c; 2008b) contain details of the computation. However, this correction was not applied here, due to uncertainty in the age equations.

Note that EHT refers to an artifact, not to a site. Artifacts from the same site may have different EHT if their burial depth, or other hydration conditions, were different.

Computational Approach and Results

Temperature parameters were estimated from data for 5 sites in the western Great Basin near Bridgeport, reported by the Western Regional Climate Center Rogers (2007f).
For conditions in the Bridgeport – Bodie region, the annual average temperature was shown to be predicted by the equation

$$T_a = 21.36 - 2.2x \qquad (6)$$

where x is altitude in thousands of feet. The accuracy of this model is 0.84ºC.

The annual temperature variation was found to decrease by 1.7ºC/1000 ft. altitude increase, and to be predicted by

$$V_a = 21.53 - 2.1x \qquad (7)$$

with x defined as above. The accuracy of the prediction is 0.91ºC. Furthermore, if T_a is known for a site, V_a is predicted by

$$V_a = 0.57 + 0.98T_a \qquad (6)$$

The accuracy of this predictor is 0.21ºC.

Finally, the best fit between V_d and altitude is very poor, and, in the absence of other data about a site, the best estimate is 18.3ºC for locations encompassed by the area of the data set analyzed, i.e. the western Great Basin and desert mountains, near Bridgeport. The accuracy of this estimate is 2.73ºC, 1-sigma.

These equations are for air temperatures. Obsidian on the surface is exposed to surface temperatures, which can be significantly higher than air temperatures in areas devoid of vegetation (Johnson et al. 2002; Rogers 2007d). However, for surfaces which have intermittent foliage coverage, the air temperatures are, on average, a good approximation to surface temperatures. Based on these considerations and an altitude of 6,480 ft above mean sea level (amsl), the temperature parameters for the reference site, CA-MNO-3126, were computed to be as shown in Table 2.

Effective hydration temperature was computed for each specimen based on equations 3 and 4 above, using the temperature data of Table 2, scaled for altitude as necessary. Depth corrections to EHT were made for buried artifacts by equations 4b and 4c. Following this, the rim thickness for each sample was corrected for EHT by equation 5 above, and age estimates were then computed by equations 2a – 2c. The complete data set is attached as an Excel spreadsheet.

Analysis

Figure 2 shows a histogram of the age data per equation 2a from data set 0010, corresponding to CA-MNO-3126. The histograms follow the same general shape, except that the subsurface deposits contain a larger quantity of younger artifacts. Figure 3 shows the same data plotted as a cumulative percentage distribution. A Kolmogorov-Smirnoff test shows that the maximum difference between the two distributions is 0.121, while the threshold for distinguishing the distributions at the 95% confidence level is 0.236 ($N_1 = 41$, $N_2 = 172$). Thus, the two distributions are not distinguishable. Also, there is a total of 31 artifacts (2 surface, 29 subsurface) which yielded ages greater than 12,000 rcybp, which probably should be regarded as anomalous.

The data set 0708 is comprised of data from surface surveys from 13 test units, ranging in altitude from 6500 ft to 8000 ft amsl. The sample sizes from the units range from 1 to 16. Table 3 gives the age statistics for the test units, based on equation 2a (age statistics from the other equations are virtually identical). Figure 4 presents a plot of mean and standard deviations by test unit. The age distributions suggest P12 through P40 may have cultural components. The age indicated for units P4 and P5, however, suggests the hydration rims are primarily geologic in origin, although they could also have been of cultural origin and subsequently altered by fire.

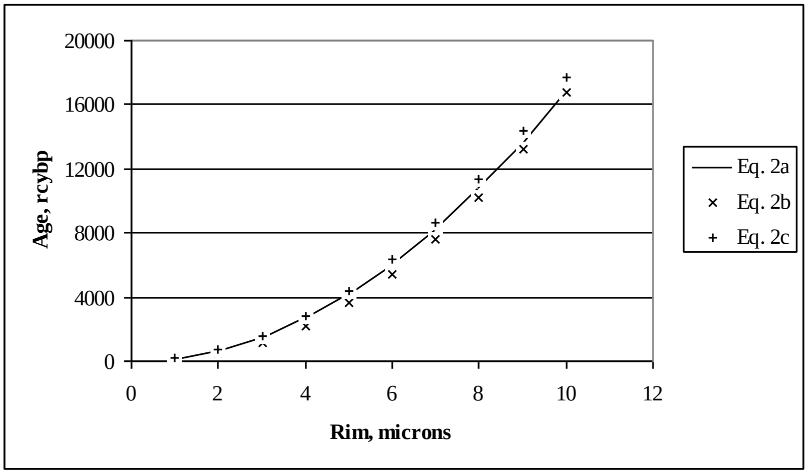


Figure 1. Comparison of Bodie Hills age equations.

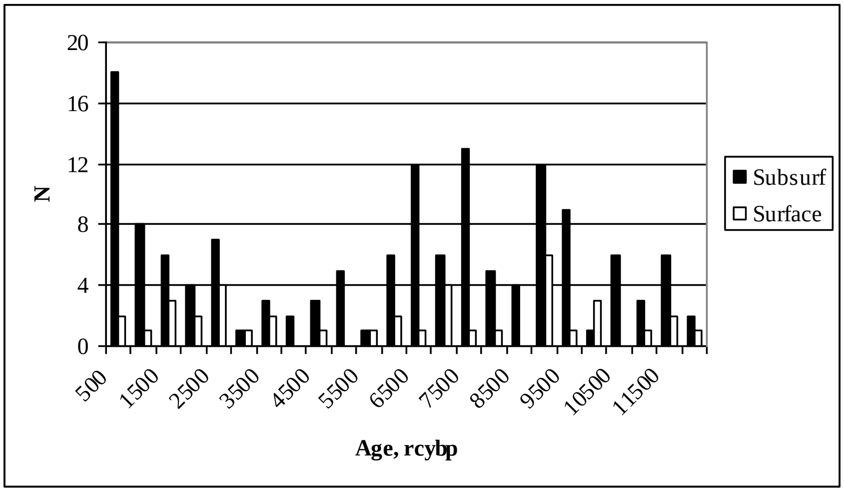


Figure 2. Histogram of obsidian ages from CA-MNO-3126.

Figure 3. Frequency distribution of ages from CA-MNO-3125.

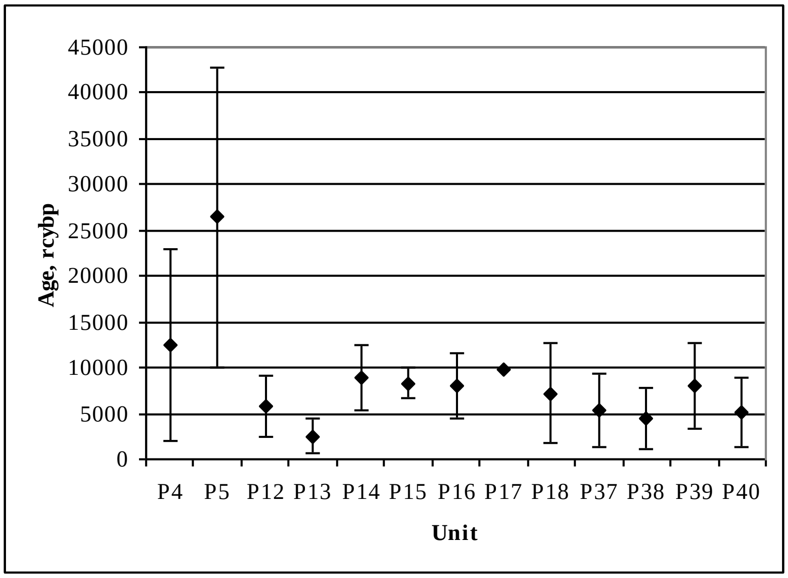


Figure 4. Age means and standard deviations by survey plot for data set 0708.

Table 1. Ages for Bodie Hills obsidian calculations

	Median Age, rcybp		
	Halford 2000, 2001	Revised (Rogers 2008c)	Remarks
DSN	400	526	
Rose Spring/Eastgate	1020	1532	
Elko Series	2270	3242	
Gatecliff	3850	3850	Not present in Coso
Lake Mojave	9000	9060	

Table 2. Temperature parameters for CA-MNO-3125

Parameter	Deg C
Ta	7.10
Va	7.92
Vd	18.30
EHT	9.83

Table 3. Age statistics, 0708 data set; rcybp

Unit	Mean	St Dev	CV	N
P4	12393	10476	0.85	11
P5	26419	16283	0.62	4
P12	5703	3331	0.58	11
P13	2561	1934	0.76	10
P14	8876	3632	0.41	8
P15	8267	1651	0.20	10
P16	7994	3521	0.44	11
P17	9694	-	-	1
P18	7204	5482	0.76	10
P37	5299	3970	0.75	10
P38	4479	3333	0.74	14
P39	8063	4640	0.58	16
P40	5112	3886	0.76	10

References

Ambrose, W. R., and C. M Stevenson
2004 Obsidian Density, Connate Water, and Hydration Dating. *Mediterranean Archaeology and Archaeometry* 4(2):5-16.

Basgall, Mark E.
1990 *Hydration Dating of Coso Obsidian: Problems and Prospects*. Paper presented at the 24th Annual Meeting of the Society for California Archaeology, Foster City.

Carslaw, H. S., and J. C. Jaeger
1959 *Conduction of Heat in Solids*, 2nd ed. Oxford: Clarendon Press.

Doremus, R. H.
1994 *Glass Science,* 2nd. ed. New York: Wiley Interscience.

2000 Diffusion of Water in Rhyolite Glass: Diffusion-reaction Model. *Journal of Non-Crystalline Solids* 261 (1):101-107.

2002 *Diffusion of Reactive Molecules in Solids and Melts*. New York: Wiley Interscience.

Ebert, W. L., R. F. Hoburg, and J. K. Bates
1991 The Sorption of Water on Obsidian and a Nuclear Waste Glass. *Physics and Chemistry of Glasses* 34(4):133-137.

Friedman, Irving, Robert I. Smith, and William D. Long
1966 Hydration of Natural Glass and Formation of Perlite. *Geological Society of America Bulletin* 77:323-328.

Friedman, Irving, Fred W. Trembour, Franklin L. Smith, and George I. Smith
1994 In Obsidian Hydration affected by Relative Humidity? *Quaternary Research* 41(2):185-190.

Gilreath, A. J., and W. R. Hildebrandt
1997 *Prehistoric Use of the Coso Volcanic Field.* No. 56, Contributions of the University of California Archaeological Research Facility. Berkeley.

Haller, W.
1963 Concentration-dependent Diffusion Coefficient of Water in Glass. *Physics and Chemistry of Glasses* 4(6):217-220.

Hull, Kathleen 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* 28:1025-1040.

Johnson, Michael J., Charles J. Mayers, and Brian J. Andraski
2002 *Selected Micrometeorological and Soil-Moisture Data at Amargosa Desert*

Research Site in Nye County near Beatty, Nevada, 1998 – 2000. U.S. Geological Survey Open-File Report 02-348. USGS, Carson City, Nevada. With CD containing meteorological data records.

Mazer, J. J., C. M. Stevenson, W. L. Ebert, and J. K. Bates
1991 The Experimental Hydration of Obsidian as a Function of Relative Humidity and Temperature. *American Antiquity* 56(3):504-513.

Onken, Jill
2006 *Effective Hydration Temperature and Relative Humidity Variation within the Nevada Test and Training Range, Southern Nevada*. Statistical Research Inc. Technical Report 06-50.

Pearson, James L.
1995 *Prehistoric Occupation at Little Lake, Inyo County, California: A definitive Chronology.* Unpublished MA thesis, Department of Anthropology, California State University, Los Angeles.

Ridings, Rosanna
1996 Where in the World Does Obsidian Hydration Dating Work? *American Antiquity* 61(1):136-148.

Rogers, Alexander K.
2006a *An Improved Method for Computing Effective Hydration Temperature of Obsidian*. Society for California Archaeology Newsletter 40(2): 35-41.
2006b *A Model-Based Investigation of Alternative Forms of Time Dependence of the Hydration Front in Obsidian, and its Archaeological Implications.* Maturango Museum Working Manuscript #13, dated 1 November 2006. MS on file, Maturango Museum, Ridgecrest, CA.
2007a Effective Hydration Temperature of Obsidian: A Diffusion-Theory Analysis of Time-Dependent Hydration Rates. *Journal of Archaeological Science* 34:656-665.
2007b An Improved Calculation of Coso Obsidian Hydration Rate, based on Obsidian-Radiocarbon pairings and the Total Least Squares Algorithm. *Pacific Coast Archaeological Society Quarterly*. Submitted.
2007c *How did the Altithermal Affect Obsidian Hydration Rates? A Model-Based Study of the Hydration Process and Paleoclimatic Change.* Paper presented at the second Three-Corners Conference, Las Vegas, NV.
2007d Field Data Validation of an Algorithm for Computing Effective Hydration Temperature of Obsidian. *Journal of Archaeological Science.* In press.
2007e A Tale of Two Gophers: Depth Correction for Obsidian Effective Hydration Temperature in the presence of Site Turbation Effects. *IAOS Newsletter,* Summer 2007.
2007f *Scaling of Temperature Data for EHT Computation: A Study of Desert Sites near Bodie, California.* Maturango Museum Working Manuscript #41, dated 6 March 2008, Rev A. MS on file, Maturango Museum, Ridgecrest, CA.
2008a Obsidian Hydration Dating: Accuracy and Resolution Limitations Imposed by Intrinsic Water Variability. *Journal of Archaeological Science*. In press.

2008b *Theory and Design of a Model for Obsidian Hydration Analysis of Coso Obsidian in Desert Regions*. Maturango Museum Working Manuscript #42, dated 4 March 2008. MS on file, Maturango Museum, Ridgecrest, CA.

2008c A Reassessment of Obsidian Hydration Ages of Projectile Point Types from the Coso Volcanic Field. *Pacific Coast Archaeological Society Quarterly*. Submitted.

Rosenthal, Jeffrey S. and Sharon A. Waechter

2002 *Results of Phase-II Test Excavations at CA-ELD-616/H near Cool, Western El Dorado County*. Report prepared for CalTrans District 03, Marysville, California.

Stevenson, Christopher M., J. Carpenter, and B. E. Scheetz

1989 Obsidian Dating: Recent Advances in the Experimental Determination and Application of Hydration Rates. *Archaeometry* 31(2):1193-1206.

Stevenson, Christopher M., E. Knauss, J. J. Mazer, and J. K. Bates

1993 The Homogeneity of Water Content in Obsidian from the Coso Volcanic Field: Implications for Obsidian Hydration Dating. *Geoarchaeology* 8(5):371-384.

Stevenson, Christopher M., J. J. Mazer, and B. E. Scheetz

1998 Laboratory Obsidian Hydration Rates: Theory, Method, and Application. In: *Archaeological Obsidian Studies: Method and Theory. Advances in Archaeological and Museum Science*, Vol. 3, M. S. Shackley, ed., pp.181-204. New York: Plenum Press.

Stevenson, Christopher M., Mike Gottesman, and Michael Macko

2000 Redefining the Working Assumptions for Obsidian Hydration Dating. *Journal of California and Great Basin Anthropology* 22(2):223-236.

Stevenson, Christopher M., Ihab. M. Abdelrehim, and Steven W. Novak

2004 High Precision Measurement of Obsidian Hydration Layers on Artifacts from the Hopewell Site Using Secondary Ion Mass Spectrometry. *American Antiquity* 69(4):555-568.

West, G. J., W. Woolfenden, J. A. Wanket, and R. S. Anderson

2007 Late Pleistocene and Holocene Environments. In: *California Prehistory: Colonization, Culture, and Complexity*, T. L. Jones and K. A. Klar, eds., pp. 11-34. Altamira Press: Walnut Creek.

Zhang, Y., E. M. Stolper, and G. J. Wasserburg

1991 Diffusion of Water in Rhyolytic Glasses. *Geochimica et Cosmochimica Acta* 55:441-456.

APPENDIX D:

BODIE HILLS OBSIDIAN DISTRICT SITE RECORD