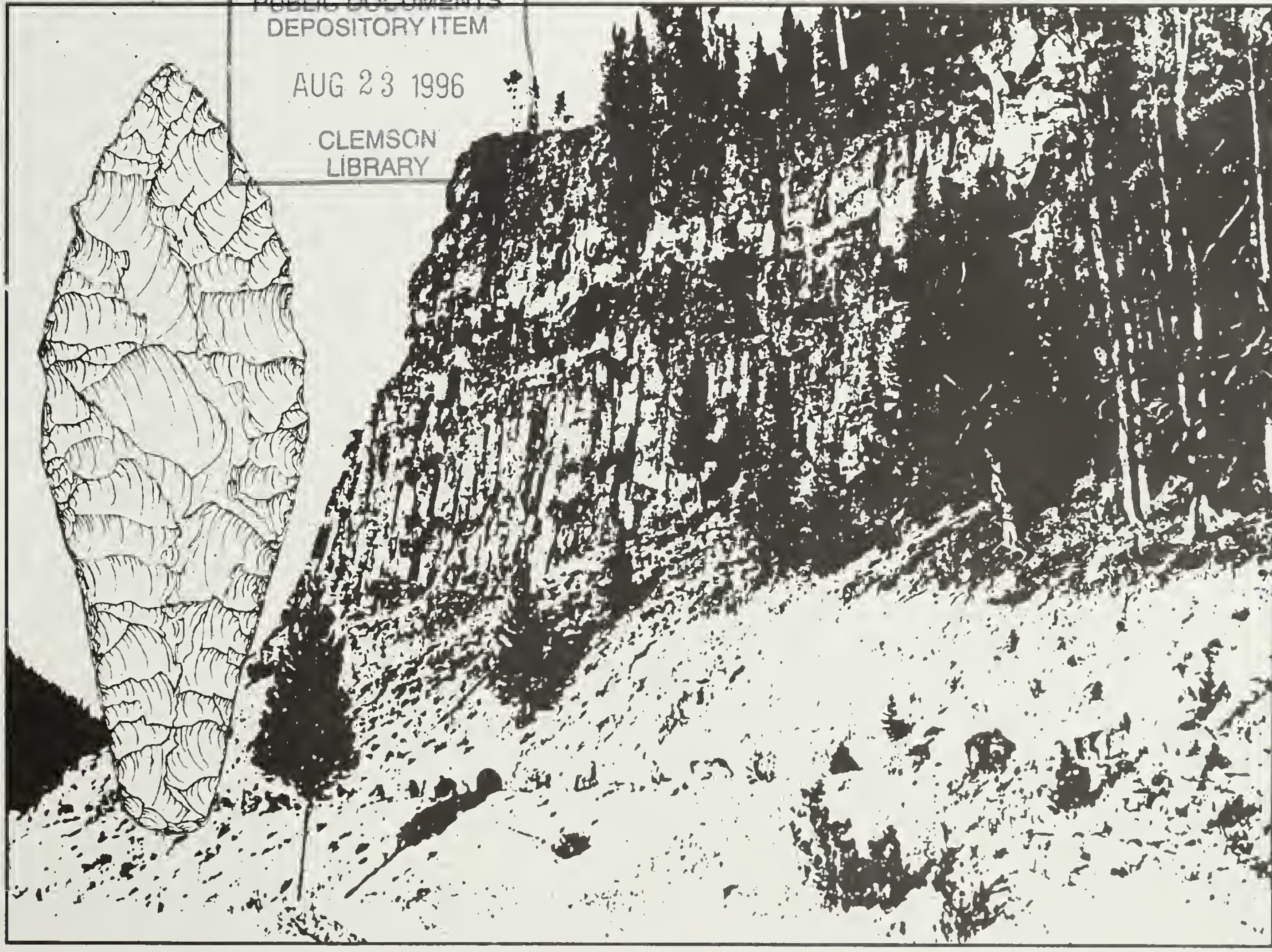
The Obsidian Cliff Plateau Prehistoric Lithic Source, Yellowstone National Park, Wyoming

by

Leslie B. Davis, Stephen A. Aaberg, James G. Schmitt and Ann M. Johnson



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n archaeological reconnaissance of the Obsidian Cliff plateau in Yellowstone National Park as conducted in 1989, the spring following the Wolf Creek fire of 1988 which burned over 90 ercent of the plateau. This first archaeological survey of this renowned geological eature and prehistorically quarried landscape was designed to provide data in support of a ational Historic Landmark nomination by the National Park Service.

ontana State University archaeologists located and described 59 specific quarry/workshop oci within the 14.5 km^2 plateau, thus documenting intensive, large-scale exploitation of edrock and lag obsidian by generations of hunter-gatherers who mined and surfaced collected vailable obsidian atop the plateau.

ighty geological and archaeological specimens were analyzed by x-ray fluorescene to stablish a diagnostic trace-element signature for this parent obsidian source. An dditional 77 archaeological obsidian specimens from sites in Montana were analyzed to test or the presence of obsidian from the Obsidian Cliff plateau or other Rocky Mountain ources.

ulturally diagnostic obsidian artifacts manufactured from Obsidian Cliff plateau obsidian ndicate that obsidian was used at many sites within the Central and Northern Rocky Mountain nd Northwestern Plains regions over more than 10,000 years. Such utilization, for tilitarian and ritual purposes, extended north into Canada, south into Colorado, west into ashington, and as far east as the Ohio River valley, the latter utilized by Hopewell eoples during the first centuries A.D.

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SELECTIONS from the DIVISION OF CULTURAL RESOURCES

No. 6 Rocky Mountain Region

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FOREWORD

Yellowstone National Park is the world's first National Park and one of the Crown Jewels in the U. S. National Park System. The premier archaeological resource in Yellowstone is the Obsidian Cliff prehistoric obsidian quarry. Although Obsidian Cliff, as a geological and an archaeological phenomenon, has been recognized for more than a century, few data are available about the physiographic makeup of the Obsidian Cliff plateau flow, the distribution and intensity of prehistoric mining, the elemental chemistry of the obsidian, and the temporal and spatial distribution of Obsidian Cliff plateau obsidian in the North American archaeological record. This report is a major step in providing that information. So I take great pleasure in making this report on Obsidian Cliff (48YE433) available to the scientific community and the public.

John E. Cook
Regional Director
Rocky Mountain Region

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U. S. Administration. NPS-D539, March, 1995.

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The 1989 archaeological reconnaissance of the Obsidian Cliff plateau in Yellowstone National Park by Montana State University (MSU) was directed and administered by Leslie B. Davis. The project was supervised in the field by archaeologist Stephen A. Aaberg (Bozeman, MT) who was assisted by Kevin Kooistra (Bozeman, MT) and Steven W. Armstrong (Helena, MT), Montana State University Anthropology majors, and by volunteer B. J. Earle (Buffalo, WY).

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Prints of photographs of Obsidian Cliff taken at various times by photographer F. Jay Haynes during the 19th and 20th centuries were generously provided from the Haynes Foundation Collection by the Montana Historical Society (MHS) photoarchive in Helena for reproduction herein.

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The Haskett projectile point figured on the cover was fashioned from Obsidian Cliff plateau obsidian and illustrated by Troy C. Helmick (Townsend, MT). Bud Morris (Ennis, MT) found this point along Grayling Creek north of West Yellowstone in Gallatin County, Montana and loaned it to the Museum of the Rockies for study.

Leslie B. Davis
Principal Investigator
1995

DEDICATION

To Aubrey L. Haines, for his contributions toward improving the public understanding of Yellowstone National Park archaeology and prehistory.

ABSTRACT

The Obsidian Cliff plateau is famous as a long-suspected source of archaeological obsidian found east of the Rocky Mountains in North America. While it is one of a number of glassy rhyolite flows within the Yellowstone rhyolite plateau, the Obsidian Cliff plateau is set apart by the intensity and duration over which it was exploited when compared to any other Central Rocky Mountain obsidian source and most other North American quarries. Early Native Americans were selecting and using Obsidian Cliff plateau obsidian for toolmaking by at least 11,000 years ago. Preferential use of this source continued into latest prehistoric times.

The National Park Service contracted with Montana State University in 1988 to obtain technical data to support the development of a National Historic Landmark nomination for the Obsidian Cliff plateau. Because little was known regarding the spatial extent, structural complexity, accessibility of exposed quarry features, prehistoric obsidian procurement practices, and the trace element composition and geochemical variability of Obsidian Cliff plateau obsidian, an archaeological study was planned for summer 1988. Before fieldwork could begin, however, the Obsidian Cliff plateau flow was burned by the Wolf Lake Fire. The resulting extensive burnoff of heavy ground cover provided an opportunity to assess effects of fire on prehistoric archaeological features and artifacts as well as on exposed geological obsidian. The 1989 archaeological survey recorded 59 prehistoric obsidian procurement loci, including quarries, within the Obsidian Cliff flow plateau; the plateau is considered to be a single extensively quarried lithic procurement site (48YE433). The quarry features vary in form and scale, ranging from single ovoid pits to multiple, overlapping/interlocking pits that occupy large surfaces (up to 250 m in length). Additionally, there are winding, linear trench and pitted quarries forced into bedrock outcrops and lag deposits of obsidian.

Obsidian Cliff occupies a unique position in national and regional human prehistory as a singularly important source of lithic material for early Native Americans of interior western and midwestern regions of North America. No other single lithic material, including Knife River flint in western North Dakota and alibates in Texas, can claim equal popularity.

Fire adversely affected the physical environment and modified the cultural landscape (artifacts and context) at each of the 59 archaeological loci on the Obsidian Cliff plateau. Alteration was greatest at those loci burned intensely by very hot fire. Modification of surface obsidian artifacts at intensely burned loci was variable, but, in certain cases, substantial. Archaeological bone and organics on or close to the surface at intensely burned loci would likely have been severely damaged or consumed by fire much as ungulate skeletal remains were burned. Exposed archaeological and geological obsidian was commonly heat-fractured and shattered. Oxidized surfaces

on a great number of obsidian artifacts at many burned loci resulted from intense heating; oxidation appeared as a bright silver rind and as the subtle dulling of rock surfaces. Such heating and oxidation of obsidian may prohibit, or complicate, the successful application of such technical studies as hydration dating and compositional analysis.

The 1989 archaeological reconnaissance of the Obsidian Cliff plateau yielded several products useful for research and management: (1) a map of specific archaeological obsidian procurement loci; (2) an extensive literature review; (3) a selective compilation of Obsidian Cliff plateau flow geological and archaeological geochemistries from Montana archaeological sites, and comparable data for other archaeological obsidian specimens from interior western North American obsidian sources; and (4) a draft National Historic Landmark Nomination.

The salient qualities of the Obsidian Cliff plateau for Landmark designation are: (1) the parent obsidian has a spatially restricted natural occurrence, which is expressed primarily in bedrock and also in secondary (locally redeposited) context; (2) this obsidian can be positively identified by nondestructive instrumental means wherever found; and (3) this obsidian was used over a long period of time and over considerable space. Peoples repre-sentative of different traditions and ethnicities selected and used Obsidian Cliff obsidian for a variety of utilitarian and nonutilitarian purposes.

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Chapter 1

OBSIDIAN CLIFF PLATEAU RESEARCH DOMAINS AND CURRENT STATUS

by Leslie B. Davis

Description and Human Utilization

The topographic feature known as Obsidian Cliff is part of a rhyolite flow located north of the Yellowstone caldera within the Rhyolite Plateau (Boyd 1961; Christiansen and Blank 1972) (Figure 1).

The first published description, by W. H. Holmes, conveys his impression of Obsidian Cliff as a remarkable natural feature and a bountiful source of lithic raw material for early native peoples:

> Considerable deposits of obsidian and obsidian porphyries had been observed in the national park previous to our visit in the summer of 1878, but no satisfactory exposures of the glassy varieties had been found. In October I had occasion to make examinations of a locality particularly rich in them, situated in the north-western part of the park, near the head of Obsidian or Alum creek, a tributary of the middle fork of Gardiner's river. The crumbling trachytes of this part of the park give, in general, a rounded and monotonous character to the topography. The slopes of the valleys are gentle excepting at points where the glassy rocks predominate.
>
> In ascending Obsidian creek, by way of the newly-cut wagon road which connects Mammoth Hot Springs with the Geyser Basins, we pass first through broad meadows and parked forest. Farther on the valley narrows up and the timber becomes extremely dense. At a point about twelve miles above the junction of the creek with the main stream, there is a narrow gateway known as Obsidian canon, through which the road and creek pass. From the east side of the valley a low promontory extends forward to the creek and breaks off in an abrupt nearly vertical wall, in which the obsidian rocks are exposed. The road approaches the canon along the west side of the valley, and crosses to the east side at the lower end of the canon; in order to avoid the swampy ground that borders the stream it has been carried across the steep debris slopes of the obsidian cliffs. For half a mile it is paved with glassy fragments and lined by huge angular masses of black and banded obsidian rock. From the upper border of the debris slope the vertical cliffs rise to the height of nearly two hundred feet. The lower half is composed of a heavy bed of black obsidian which exhibits some very fine pentagonal columns, somewhat irregularly arranged and frequently distorted, but with perfectly cut faces that glisten in the sunlight. The upper portion of the wall is composed of a much more obscurely columnar mass of impure spherulitic obsidian, the rude faces of the columns being often as much as ten or twelve feet across. To the right and left the columnar

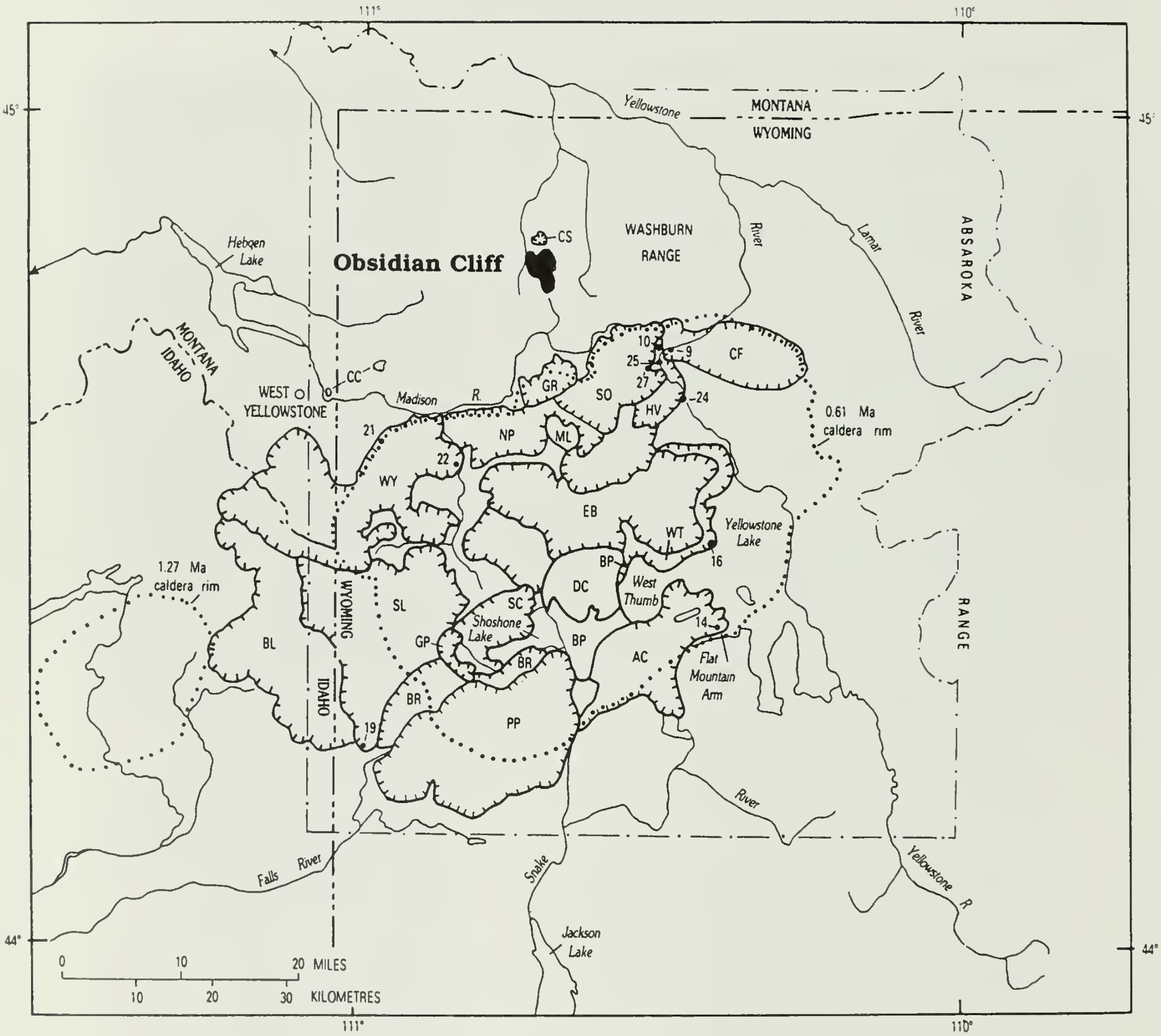

Figure 1. Geological map of Yellowstone National Park and vicinity showing locations and extent of rhyolite lava flows, including the Obsidian Cliff flow (after Richmond 1986: Figure 2).

character becomes less marked, both in the upper and lower part of the cliff, and farther out seems to be entirely lost, the glassy rocks grading into the gray sanidine trachytes and obsidian porphyries of the surrounding hills.

Extending upward from the edge of the promontory in a moderately gentle slope are four or five hundred feet of obsidian strata that exhibit some most interesting characters. There is no heavy mass of pure glassy rock, but a succession of irregular layers of a dozen or more varieties of spherulitic obsidian, obsidian porphyries and breccias. The colors of these rocks are exceedingly varied, the prevailing blacks giving way to reds, browns, greens and the richest possible marblings and mottlings.

One of the most striking characteristics of these rocks are the spherulitic concretions which occur to a greater or less extent in all the varieties. These bodies seem to prevail in the ashy-like bands or layers which, in the more compact mass toward the base, are frequently contorted, giving the rock the appearance of a banded and contorted gneiss. The ashy-appearing layers are probably composed of the same material as the concretions, since when we split the rock with the bands, the surfaces of the gray bands next the glassy layers are simply a connected or coalescent series of nodes or hemispheres which have the usual appearance of the more isolated concretions. Where the concretions are scattered throughout the glassy mass, they are globular or composed of a cluster of globes. They have, in most cases, a distinctly radiated structure, with not infrequently concentric layers near the surface. The interior is gray or pinkish-gray, and the surfaces, pinkish or flesh colored.

In the coarsely columnar part of the wall the spherulites are often a foot or more in diameter and appear much flattened and distorted. It is probable that these irregular forms are produced by the coalescence of a large number of smaller ones, as there are apparently many centers of radiation. Large beds of the rock seem to be made up almost wholly of the concretions, and where decomposed, a mass of coarsely cellular or honey-combed obsidian remains. The brecciated beds consist of an ashy matrix in which are imbedded angular fragments of every variety of the brilliantly-colored spherulitic and ordinary obsidians.

The collection of hand specimens made at this place is very complete, numbering upwards of three hundred. Their examination by specialists in petrography will doubtless develop many new and interesting features, as no equally rich deposit of similar rocks has heretofore been brought to their notice in this country (Holmes 1879:248,250).

Holmes continued:

It occurred to me, while making examinations at this point, that the various Indian tribes of the neighboring valleys had probably visited this locality for the purpose of procuring material for arrow-

> points and other implements. A finer mine could hardly be imagined, for inexhaustible supplies of the choicest obsidian, in flakes and fragments of most convenient shapes, cover the surface of the country for miles around (Holmes 1879:250).

Philetus W. Norris, the first superintendent of Yellowstone National Park, was similarly impressed by the glassy prominence, its extent, and the quality of the obsidian obtained there by early Native Americans:

> ...for two miles in distance and many hundred feet in height, literally towering vertical pillars of glistening black, yellow, and mottled or banded obsidian, basaltic columns in form, but volcanic glass in fact-- ever for the aborigines a vast weapon and implement quarry, of obsidian of a quality unequalled and a quantity elsewhere unknown (Norris 1879:982).

The nationwide fame of Obsidian Cliff may be attributable to some extent to Chittenden, who caused to be set to print a memorable tall tale concocted by mountain man, trapper, and Indian fighter Jim Bridger:

> Coming one day in sight of a magnificent elk, he took careful aim at the unsuspecting animal and fired. To his great amazement, the elk not only was not wounded, but seemed not even to have heard the report of the rifle. Bridger drew considerably nearer and gave the elk the benefit of his most deliberate aim; but with the same result as before. A third and fourth effort met with a similar fate. Utterly exasperated, he seized his rifle by the barrel, resolved to use it as a club since it had failed as a firearm. He rushed madly toward the elk, but suddenly crashed into an immovable vertical wall which proved to be a mountain of perfectly transparent glass, on the farther side of which, still in peaceful security, the elk was quietly grazing. Stranger still, the mountain was not only of pure glass, but was a perfect telescopic lens, and, whereas, the elk seemed but a few hundred yards off, it was in reality twenty-five miles away (Chittenden 1895:49-50)!

Previous Research

Obsidian Cliff is located in the Middle Rocky Mountains of northwestern Wyoming. It (Figure 2) is a geologically distinctive, scenically attractive prominence that dominates a dissected, heavily forested montane landscape overlooking Beaver Lake and Obsidian Creek valley to the west (Figure 3). The Obsidian Cliff Kiosk (which is listed on the National Register of Historic Places), is located about 100 m (330 ft) to the northwest across the highway from the cliff. The kiosk describes local geological history and interprets use of Obsidian Cliff by North American prehistoric peoples to park visitors.

Obsidian Cliff (48YE433) and the associated flow plateau in Yellowstone National Park, northwestern Wyoming, constitutes a unique natural and cultural resource. It is perhaps the single prehistoric lithic source most subject to

Figure 2. F. Jay Haynes 1899 photo of Obsidian Cliff viewed across Beaver Lake (H-3940; MHS Photo).

Figure 3. Southwest view of Beaver Lake and the Obsidian Creek valley from Obsidian Cliff (MSU Photo).

myth fabrication of any quarry in North America. For more than a century, it was believed to be the fabled source of obsidian everywhere east of the Rockies, from the Ohio River Valley and Hopewell Cult to the plains of southern Canada. Recent efforts to instrumentally characterize obsidian for sourcing purposes have replaced this speculation with data (Griffin 1965; Griffin and Gordus 1967; Frison et al. 1968; Griffin et al. 1969; Gordus et al. 1971; Wright et al. 1980; Wright 1982; Cannon 1993; Cannon and Hughes 1993, 1994). Persistent efforts to utilize obsidian's tendency to absorb moisture in molecular amounts from its environs (hydrate) at rates that can be equated with the calendrical time scale have focused additional research interest on obsidian as an exceptionally valued and sought after lithic material.

Because obsidian can be chemically fingerprinted and its human use dated within acceptable temporal limits, this raw material has stimulated a generation of research into petrogenesis by geologists and elemental composition of obsidian by geochemists that is unprecedented for other archaeological lithic material. Such successful studies are providing technical details and data with which archaeologically derived formulations concerning antiquity of use, cultural affiliation of users, functional use patterns, and conjecture regarding such interesting and important matters can be tested. One example is social and economic interactions between and among human prehistoric populations on regional and interregional scales. The directional movement of obsidian users can be inferred from the exotic obsidian that users deposited far from the imported obsidian's source.

While prehistoric peoples did collect and modify obsidian cobbles contained in deposits overlying the flow, they nevertheless quarried substantial quantities of bedrock obsidian (weathered and non-weathered sources) to resupply depleted stocks of raw obsidian for tool production for their own use and for trade.

The Obsidian Cliff plateau lithic source area has been regarded as a nationally prominent prehistoric quarry since its recognition and description late in the 19th century (Norris 1879; Holmes 1879, 1903, 1910, 1918; Chittenden 1895). It was thought to have provided obsidian to prehistoric human groups located at great distance to the east, even beyond the Mississippi River.

Both professional and amateur archaeologists have visited this famed quarry site over the years. Some climbed the difficult talus slope to the cliff edge to stand on its surface and scan the ground for obsidian artifacts. Despite frequent expressions of intellectual interest by archaeologists, authorized archaeological examination of the Obsidian Cliff plateau was not initiated until 1986.

Early Midwestern antiquarians suspected that Obsidian Cliff (= the Obsidian Cliff plateau) was the source for prehistoric obsidian found in archaeological contexts east of the Rocky Mountains as far away as the Ohio River valley (cf. Squier and Davis 1848; Mills 1907; Moorehead 1922; Shetrone 1926, 1930; Kramer 1951; and see Griffin 1965 for a detailed historical appraisal of thinking during that era). Obsidian found at sites in Idaho (Spinden 1908; Gruhn 1961) and sites in the southern Canadian Rockies and Plains (Wormington and Forbis 1965) was also attributed to Obsidian Cliff. Those and other reasoned propositions regarding the source of archaeologically deposited obsidian had gone largely untested until recently when the necessary scientific technologies became available.

The first fieldwork was performed by Montana State University (Missoula) in 1958 and 1959. Those reports mention Obsidian Cliff: journal articles (Hoffman 1958, 1959), a master's thesis (Hoffman 1961), and an uncirculated report (Taylor et al. 1964). No work was undertaken on the Obsidian Cliff plateau itself at that time. They did not understand the extent of flow utilization, but believed that it had not occurred on the cliff face/western rim:

> The glacial till, like so much of northern Yellowstone Park, is studded with glacial obsidian pebbles. Based on our observations in Yellowstone Park we suggest that such glacial boulders were a great source of obsidian for prehistoric toolmakers, and these erratics were used probably as much or more than the *ledges of columnar obsidian* [emphasis ours] (Taylor et al. 1964:77).

A natural declivity formed by a gas bubble vent in the cliff face, which is interiorly glassy, was enlarged by prehistoric obsidian miners. However, there is little indication elsewhere on the cliff face that obsidian was extracted from those difficult-to-scale, nearly vertical exposures.

Moreover, a member of the survey group, J. J. Hoffman, concluded that it was unlikely that Obsidian Cliff had contributed significantly to the obsidian utilized by early peoples who frequented the Yellowstone area. He thought that the importance of this singular source had been exaggerated because of the spectacular shining ledge of glass (Hoffman 1961). Taylor et al. (1964) concluded, however, that, "it would be unrealistic for us not to recognize this [Obsidian Cliff] as an important quarry."

The 1958 survey crew had difficulty determining the full extent of Obsidian Cliff and in deciding whether the whole rhyolite flow should be considered one site or several. They elected to give the cliff and adjacent exposures a single site number (48YE433). Even so, they thought that that decision might be somewhat unrealistic given that the entire flow is a single geologic feature (Taylor et al. 1964).

The archaeology and prehistory of Yellowstone National Park are understood in but a preliminary way since the area has only been selectively surficially surveyed (Hoffman 1961; Taylor et al. 1964). More recent, small-scale, local surveys and excavations prompted by park development have been conducted. Reports are largely unpublished and sporadically available, with some noteworthy exceptions. Reports of excavations are available for a human interment at Fishing Bridge (Condon 1949; Wright et al. 1982; Cannon et al. 1994) and Intermountain ceramics at Yellowstone Lake (Hoffman 1959), as are studies of Yellowstone Indian trails (Replogle 1956; Haines 1962, 1964) and the Lava Creek wickiups (Shippee 1971; Kidwell 1969). Haines (1963, 1965) reported Paleoindian artifacts at high-elevation locations near the park, as well as a 5,000-year-old campsite at Rigler Bluff in the upper Yellowstone Valley (Haines 1966).

Chronology

A regional chronological framework is broadly applicable for ordering events and developments which characterize much of park prehistory. Wright et al. (1980), Wright (1982), and Wright and Chaya (1985) have discussed several problems with the chronological framework that impose constraints on understanding park prehistory. Those critical data deficiencies can be remedied by sustained, problem-oriented, multidisciplinary investigation.

Cultural chronological questions pertinent to the park and the Obsidian Cliff plateau were addressed previously via research into the archaeological application of obsidian hydration dating (cf. Davis 1966b, 1970, 1972a,b, 1986; Wright 1982; Wright and Chaya 1985; Wright et al. 1990) and the geochemical analysis and characterization of archaeological obsidian believed or known (Michels 1981a) to have originated in the park (cf. Griffin 1965; Griffin and Gordus 1967; Griffin et al. 1969; Frison et al. 1968; Davis 1986; Anderson et al. 1986; Baugh and Nelson 1988; Cannon 1993; Cannon and Hughes 1993, 1994; Hughes, various). Ongoing instrumental analyses will increasingly enhance appreciation of cultural dynamics involved in the episodic prehistoric human exploitation of Obsidian Cliff plateau obsidian.

Given the paucity of excavated, clearly stratified archaeological contexts in the park, it is prudent to apply Mulloy's (1958) historical outline, taking into some account those of Reeves (1969, 1983), Frison (1991), Wright (1982), Wright and Chaya (1985), Bender and Wright (1988), Reeve (1989), Greiser (1984), and Davis et al. (1988a, 1989a). A chronological framework constructed from multiple sources is provided in Table 1.

Subsistence Patterns

Archaeological surveys and a few excavations in the upper Yellowstone Valley have provided useful predictive perspectives on park prehistory, documenting to some extent the intermittent occupation of this semi-arid conduit into and out of the park proper (cf. Brackett 1893; Brown 1932; Arthur 1962, 1966a, 1966b, 1968; Haines 1966; Lahren 1968, 1970, 1971, 1976; Davis et al. n.d.b; Jerde 1987).

Subsistence practices are reflected in bison jumps (escarpments with or without associated drive lines of piled stones), other game drives (bighorn sheep and/or deer), flaked stone and ground

Table 1. A Regional Archaeological Sequence Applicable to the Prehistory of the Yellowstone National Park Area.

Late Prehistoric Period (ca. 1,700 to 200 B.P.)
- Intermountain Tradition (500 to 200 B.P.)
- Old Women's/Late Plains Phase (800 to 200 B.P.)
- Avonlea Phase (1,700 to 1,000 B.P.)
- Besant Phase (1,600 to 1,100 B.P.)

Middle Prehistoric (Archaic) Period (ca. 7,500 to 1,700 B.P.)
- Pelican Lake Phase (3,000 to 1,700 B.P.)
- Hanna Phase (3,500 to 3,000 B.P.)
- McKean Complex (4,500 to 3,500 B.P.)
- Oxbow Complex (5,500 to 4,500 B.P.)
- Mummy Cave Complex (Bitterroot) (7,500 to 5,500 B.P.)

Early Prehistoric (Paleoindian) Period (ca. 11,500 to 7,500 B.P.)
- Lusk Complex (8,500 to 7,500 B.P.)
- Pryor Stemmed/Lovell Constricted Complexes (8,000 to 7,500 B.P.)
- Hardinger Complex (8,000 to 8,600 B.P.)
- Alder Complex (9,500 to 9,300 B.P.)
- Alberta/Cody Complex (9,500 to 8,500 B.P.)
- Agate Basin/Hell Gap Complexes (10,500 to 9,500 B.P.)
- Folsom/Midland Complex (11,000 to 10,500 B.P.)
- Goshen Complex (10,800 to 10,300 B.P.)
- Clovis Complex (11,200 to 10,900 B.P.)

---

stone implements, and utilized bone from animals found in campsites associated with or discrete from kill sites. From his experiences during earliest park history, Norris (1879, 1881, 1882) was acquainted with most of the above prehistoric manifestations.

The periodic utilization of large, medium, and small mammals, which characterizes a mixed-game food procurement pattern for the upper Yellowstone Valley, was probably comparable overall to that followed in the park.

There is as yet little direct archaeological evidence for plant gathering and utilization (Reeve 1986). Recent excavations by Cannon and Phillips (1993) introduced utilized plant remains into the prehistoric resource use record.

Settlement Patterns

Local prehistoric human settlement manifestations include conical timbered lodges (wickiups), stone circles (tipi rings), and campsites.

Ethnographically, the park occupies a unique position in this region: it was the only location where identifiable native foot nomads (non-horse using peoples) were observed in historic residence (excepting only the horse-mounted Shoshoni contacted by Lewis and Clark in southwestern Montana in 1805). Bands of Shoshonean-speaking hunter-gatherers, which may have been descendants from the only archaeologically visible ethnic culture in the Central Rockies, the Intermountain Tradition, resided in the park for hundreds of years and into early historic times (Hultkrantz 1954, 1957).

In 1835, trapper Osborne Russell chanced upon some Shoshonean-speaking Sheepeaters while visiting the Lamar River Valley. They found:

> ...a few Snake Indians comprising six men, seven women and eight or ten children who were the only inhabitants of this lonely and secluded spot. They were all neatly clothed in dressed deer and sheepskins of the best quality and seemed to be perfectly happy. They were rather surprised at our approach and retreated to the heights where they might have a view of us without apprehending any danger, but having persuaded them of our pacific intentions we succeeded in getting them to encamp with us. Their personal property consisted of one old butcher knife, nearly worn to the back, two shattered fuses which had long since become useless for want of ammunition, a small stone pot and about 30 dogs on which they carried their skins, clothing, provisions, etc. on their hunting excursions. They were well armed with bows and arrows pointed with obsidian (Russell 1955:26-27).

Such persistent obsidian utilization by local Indians into historic times bespeaks a tradition of obsidian use.

Archaeological attempts to link wickiups, obsidian sidenotched arrowpoints, tubular steatite pipes and steatite vessels, and earthenware ceramics (Intermountain Ware) to Proto-

Shoshonean, or even historic native, populations adapted to forested environments in the Central Rockies continue (cf. Wedel 1951; Mulloy 1958; Kehoe 1959; Marceau 1982; Jerde 1987; Davis et al. 1993).

Also associated with park human prehistory are unresolved questions concerning (1) the possible northward expansion of horse-mounted Shoshoneans (cf. Malouf 1968; Hultkrantz 1968; Wright 1978) and (2) arguments by Hultkrantz (1954, 1979) that native occupation of Yellowstone National Park thermal areas was constrained by the Indians' fear of geysers. Norris appears to have earlier laid some foundation for the fear supposition:

> Owing to the isolation of the park, deep amid snowy mountains, and the superstitious awe of the roaring cataracts, sulphur pools, and spouting geysers over the surrounding pagan Indians, they seldom visit it, and only a few harmless Sheep-eater hermits, armed with bows and arrows, ever resided there, and even they now vanished (Norris 1878:842).

That view seems questionable today given the obviously long-term presence of culturally diverse traditional peoples during the 10,000-year duration of park prehistory. Artifacts recovered in geyser areas and large number of sites within in park suggest repeated occupation over time.

In any case, it seems likely that the occupation of the park was seasonally intermittent and included appearances, at one time or another, by peoples of all prehistoric hunter-gatherer cultural entities (complexes, phases, traditions) recognized for the Northwestern Plains and Central and Northern Rockies. Great Basin and Columbia Plateau human prehistoric populations also interacted with and influenced interior montane groups, and periodic contacts were probably made with Plains groups.

Stone Tool Production/Utilization

That nearly 400 generations of Stone Age hunter-gatherers traversed and occupied the Northern Rocky Mountains and contiguous areas is strongly indicated. Their dependence upon quality flakable stone for essential tool production is undeniable. Yet, for all of the knowledge that such conclusions usually portend, very little is understood about prehistoric stone acquisition and redistribution behavior. It is axiomatic that stone procurement, utilization, and redistribution behavior should be conceptualized as a continuum of events in time and space that can be reconstructed through the interpretation of tangible remains.

Traditionally, much of archaeological endeavor has been restricted to the modeling of lithic reduction strategies and the characterization of cultural complex or phase-specific stoneworking behavior, some of that at a microtechnological level. The dynamics of lithic selection and extractive behaviors, as integral startup phases of the lithic use continuum, are still poorly understood.

Research Domains and Status

It is important that prehistoric lithic procurement activities enacted at the Obsidian Cliff plateau and its outlying archaeological environs be considered within a larger (regional and inter-regional) perspective of lithic procurement and utilization. Other important lithic raw materials included porcelanite (Fredlund 1976; Clark 1985), variously available cherts (e.g. Herbort 1981; Davis 1981, 1982a; Reeves 1994), Knife River flint (Clayton et al. 1970; Loendorf et al. 1984; Ahler 1986; Ahler and Christensen 1983; Ahler and Vannest 1985; Gregg 1987), Tongue River silicified sediment (Keyser and Fagan 1987), Spanish Diggings quartzite (Dorsey 1900; Duguid and Bedish 1968; Reher 1991). Others such as Avon chert were more spatially circumscribed in distribution (Fields 1983; Cameron 1984). While technical analyses and studies of archaeological lithics are uneven and often preliminary, such considerations are essential to evaluating the integral role played by Yellowstone obsidian in North American Stone Age or Upper Paleolithic prehistory.

Present Condition

Human Intrusions

Obsidian Cliff, as observed from the paved road that traverses its western toe, still strongly resembles its early appearance, as can be seen from late 19th century and early 20th century photography (Figures 2, 4, and 5). Erosional processes over the past century have had little effect. The fire of 1988 evidently did not adversely alter the appearance or condition of the cliff face nor is it possible to detect adverse effects of previous wild fires.

A narrow road was constructed across the toe of the slope below the cliff in 1878 under the direction of Superintendent P. W. Norris:

> Obsidian there rises like basalt in vertical columns many hundreds of feet high, and countless huge masses had fallen from this utterly impassable mountain into the hissing hot-spring margin of an equally impassable lake, without either Indian or game trail over the glistering fragments of nature's glass, sure to severely lacerate. As this glass barricade sloped from some 200 or 360 feet high against the cliff at an angle of some 45 [degrees] to the lake, we--with the slivered fragments of timber thrown from the height--with huge fires, heated and expanded, and then, men well screened by blankets held by others, by dashing cold water, suddenly cooled and fractured the large masses [of obsidian]. Then with huge levers, steel bars, sledge, pick, and shovels, and severe laceration of at least the hands and faces of every member of the party, we rolled, slid, crushed, and shoveled one-fourth of a mile of good wagon road midway along the slope [see Figure 5]; it being so far as I am aware, the only road of native glass upon the continent (Norris 1879:980).

The prehistorically modified condition of Obsidian Cliff was later further altered by historic human activities, including the collecting and removal of potentially informative artifacts:

Figure 4. F. Jay Haynes 1884 photograph of Obsidian Cliff looking north down the Norris road (H-1464; MHS Photo).

Figure 5. F. Jay Haynes 1884 photograph of the roadway past Obsidian Cliff, or "Glass Mountain," showing the extent of toe slope disturbance and the state of landscape preservation of the cliff face at that time (H-1463; MHS Photo).

> ....chips, flakes, arrowheads, and other Indian tools and weapons have been found by all recent tourists and explorers.... (Norris 1879:982).

Similarly, Chittenden (1895) remarked that, "many fine arrowheads have been picked up by explorers [at Obsidian Cliff]." Also, Hoffman (1961) reports that park concessionaires collected and sold "arrowheads" prior to establishment of Yellowstone National Park in 1872. That observation runs counter, on its face, to the fact that Superintendent Norris was adamant about all archaeological "specimens" going to the Smithsonian (Norris 1882:751).

The archaeological features interpreted as lithic procurement and workshop loci, which collectively comprise the obsidian concentration on the western edge of the cliff margin, have thus been subjected to attrition by artifact and obsidian collectors for decades. The talus slope and workshop debris below the cliff have also been pilfered unrelentingly. However, the forbidding nature of steep, densely forested, and dissected slopes and abrupt precipices of the plateau itself have combined to limit artifact scavenging to the roadside. That certain of the most remote loci (those farthest removed from the easily accessed northwestern edge) display a range of artifacts, preforms, and other detritus typical of workshops adjacent to quarry pits is an indication of their pristine nature. The high degree of contextual integrity of buried features thus contributes to site significance and ensures its potential to yield information important to an in-depth and broader understanding of the roles that this key prehistoric quarry played in the lives of early Native Americans.

For an understanding of the Native American use of what is now Yellowstone National Park in historic times, readers are advised to read works by Replogle (1956), Haines (1977), and Janetski (1987).

Fire Effects

The evaluation of site formation/deformation processes is an intregal aspect of current archaeological research. Forest fires have periodically altered surface-exposed, geological and artifactual obsidian and associated quarry and workshop features in both dramatic and subtle ways. The forfeiture of opportunities to date heat-crazed, surficial archaeological obsidian by the hydration technique can only be mitigated by the fact that unknown, but obviously substantial, amounts of obsidian debris exist within unaffected subsurficial archaeological contexts on the plateau.

Chapter 2

OBSIDIAN CLIFF PLATEAU GEOLOGY AND PETROGRAPHY

by James G. Schmitt

Volcanism

The Obsidian Cliff flow plateau is located within the Yellowstone rhyolite plateau, an extensive and complex volcanic feature in northwestern Wyoming within the Northern Rocky Mountain physiographic province (Figure 6). This geologically remarkable area has been studied intermittently with varying technical intensity since initial reporting by Holmes (1879) and Iddings (1888, 1899) later. Rocky Mountain tectonics and related problems (cf. Hague et al. 1899; Boyd 1961; Hamilton 1963; and others), volcanism (Christiansen and Blank 1972; Christiansen 1989), glaciation (Richmond and Hamilton 1960; Pierce et al. 1976; Richmond 1986; Pierce 1979; Sturchio et al. 1994; and others), and geochronology (Friedman and Clark 1963; Friedman 1968a,b; Friedman et al. 1973; Friedman and Obradovich 1981; Friedman et al. 1994; Obradovich 1992) have been major research interests.

Iddings' detailed description of the Obsidian Cliff setting is classic:

> Obsidian Cliff is at the northern end of Beaver Lake in Yellowstone National Park, about eleven miles south of Mammoth Hot Springs. It forms the eastern wall of a narrow cut in the plateau country through which Obsidian Creek flows at an elevation of 7,400 feet. The cliff extends for half a mile, rising from one hundred and fifty to two hundred feet above the creek and falling away gradually to the north; the upper half is a vertical face of rock, the lower portion a talus slope of the same material. Back of the cliff to the east the country rises in a series of rude benches to about four hundred feet above Beaver Lake; at this level, a little south of Obsidian Cliff, the edge of the plateau forms a small cliff fifty feet high, above a long, steep slope east of the lake. From here the top of the plateau rises in hillocks and basins eastward to an altitude of about eight thousand feet above sea-level. On the opposite side of Beaver Lake and Obsidian Creek abrupt hills slope up to the plateau country west. The whole region in this vicinity is thickly timbered with a small growth of pines.
>
> The cliff presents a partial section of a surface flow of obsidian which poured down an ancient slope of rhyolite from the plateau lying to the east. The underlying rhyolite has a purplish-gray color and is readily distinguished from the black obsidian, as well as from lithoidal portions of the obsidian flow, by the abundance of porphyritic crystals of quartz and feldspar which fill the older rock, the latter flow being entirely free from them. The older rhyolite is not exposed beneath the obsidian along the creek, but is first met with in the edge of the timber south of the

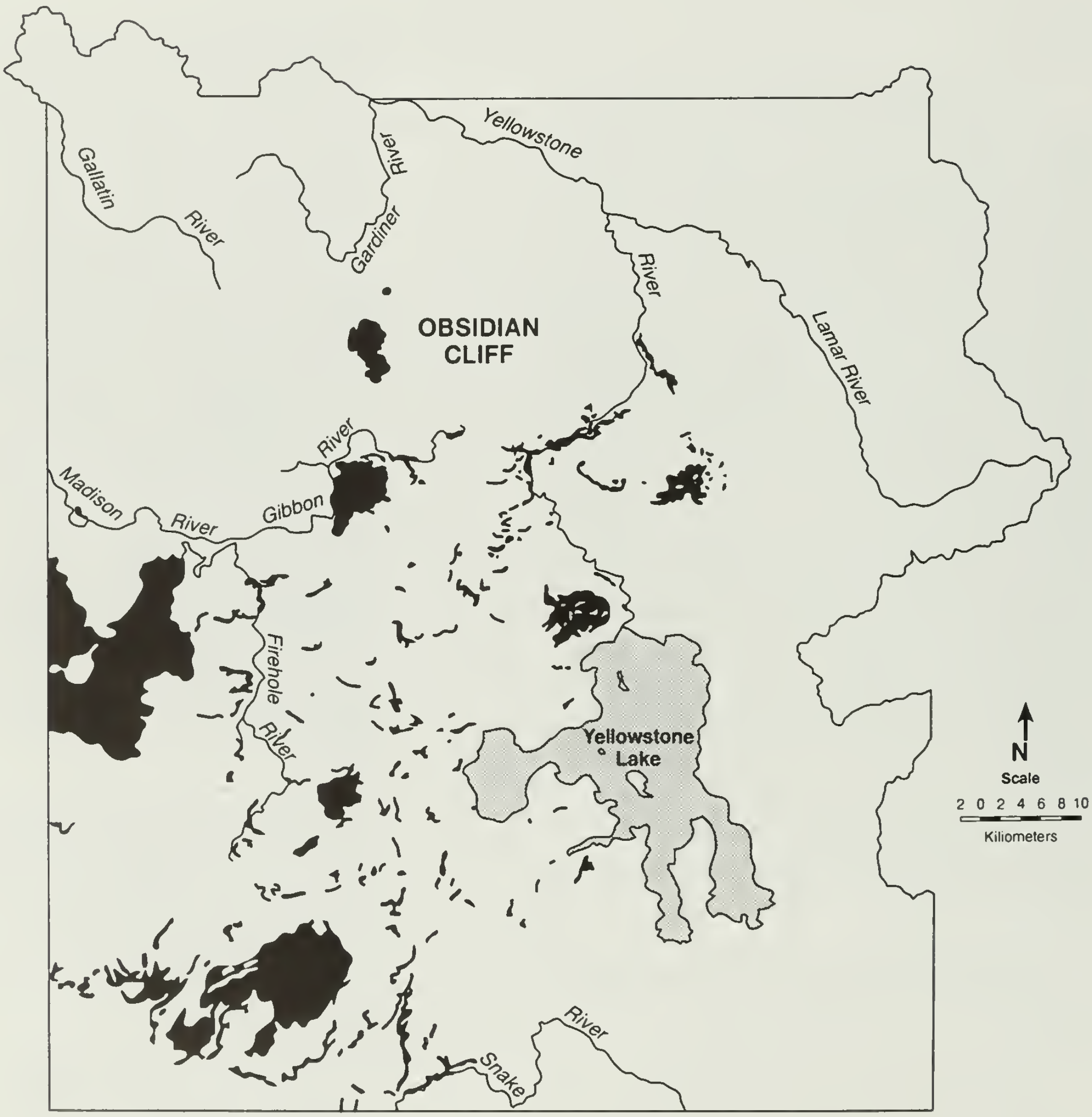

Figure 6. The Obsidian Cliff flow location, and outcrops of Quaternary rhyolite that potentially contain obsidian, within the Yellowstone rhyolite plateau of northwestern Wyoming (by Schmitt after United States Geological Survey maps [1972a,b]).

> end of the cliff, where a narrow drainage channel has cut into the slope.
>
> This rhyolite rises higher to the south and forms the long slope east of Beaver Lake, above which is the low cliff already mentioned. This cliff is of obsidian, which is exposed in a vertical section of more than fifty feet. Following the obsidian back from the face of this cliff up the hummocky surface it becomes filled with gas cavities and passes into banded, pumiceous rock and finally into light-gray pumice. This covers the surface of the plateau for two and a half miles eastward to the valley of Solfatara Creek, which drains into the Gibbon River; here, again, the lava flow is exposed in a cliff the lower portion of which is black and red obsidian. Toward the south the obsidian flow extends for a mile beyond the Lake of the Woods, and northward across the east and west drainage, which cuts off the higher portion of the plateau, a distance of some five miles (Iddings 1888:255-256).

The rhyolite plateau consists of flows and welded tuff, with associated rhyolite domes, basalt, and rhyolite-basalt sequences. The two main geological units are the Yellowstone tuff, that is exposed over 1,560 km^2 (600 mi^2) within Yellowstone National Park, and the younger Plateau flows. These younger flows cover 2,600 km^2 (1,000 mi^2) on the Madison, Central, and Pitchstone plateaus. Individual flows range up to 300 m (1,000 ft) in thickness and cover areas of at least 260 km^2 (100 mi^2). Exposed portions of these flows consist primarily of banded obsidian (mostly black and red/brown, but including a broad color and textural range), perlite, and breccias (Boyd 1961).

The Yellowstone Plateau is one of the largest Quaternary siliceous volcanic fields on earth (Hildreth et al. 1984). The Quaternary geological history of the Yellowstone Plateau is one of repeated caldera collapse and coeval eruption of rhyolitic ash-flows. During each cycle of eruption, large volumes of rhyolite and lesser amounts of basalt were erupted (Eaton et al. 1975). Catastrophic caldera collapse has taken place during three periods over the past two million years.

The first period of caldera formation in the Yellowstone region occurred approximately two million years ago, forming a caldera that extended from Island Park, Idaho, 30 km (20 mi) west of Yellowstone National Park, eastward as far as the central part of the park. The two million year old Huckleberry Ridge Tuff was erupted during this phase. A second period of caldera collapse took place in the Island Park caldera approximately 1.3 million years ago and was accompanied by eruption of the Mesa Falls Tuff. Finally, the Yellowstone caldera collapsed approximately 600,000 years ago and was accompanied by eruption of the Lava Creek Tuff (Figure 3). All of these eruptions yielded extensive ash-fall deposits that blanketed much of western and central North America (Hildreth et al. 1984).

Since the most recent collapse of the Yellowstone caldera 600,000 years ago, the caldera and surrounding area have been the site of eruption of rhyolite lava flows from ring fractures associated with the edges of the caldera. Many of these highly viscous lava flows were confined to the caldera; however, extracaldera flows associated with faults outside the caldera also erupted. Post-caldera rhyolite flow eruption has occurred in two phases: 1) an early phase during a period of about 350,000 years after caldera collapse and 2) a younger phase that began approximately 150,000 years ago. The youngest rhyolite lava flows of the Yellowstone region were likely erupted during this phase between 180,000 and 70,000 years ago (Christiansen and Blank 1972).

Boyd (1961) and Christiansen and Blank (1972) grouped all of the post-caldera rhyolite lava flows into the Plateau Rhyolite. The Roaring Mountain Member of the Plateau Rhyolite was defined as a series of four rhyolite flows that exist north of the Yellowstone caldera. One of these is the Obsidian Cliff flow, which is approximately 183±.003 thousand years old (Obradovich 1992), which comprises the topographic feature known as Obsidian Cliff. The Obsidian Cliff flow covers an area of approximately 14.5 km^2 (5.6 mi^2) and has an approximate exposed thickness of 30 m (98.4 ft).

The Obsidian Cliff flow was erupted on the plateau of welded tuff and basalt east of Obsidian Cliff (Hague et al. 1899) where it spilled into a canyon, displacing the stream. The stream re-established its course by eroding between the flow and the welded tuff in the west wall of the canyon, exposing the Obsidian Cliff section. The rhyolite in the 60 m (200 ft) high cliff is glassy except for the development of spherulites and lithophysae. The rhyolite here, unlike the bulk of the Plateau Rhyolite flows, is non-porphyritic. However, its composition is within the range of other Yellowstone rhyolites (Hamilton 1963).

In most areas, the Plateau Rhyolite flows are covered by glacial drift, but the original surfaces of the flows have been preserved locally without having been glaciated. No exposures have been found where flows of the Plateau Rhyolite group overlie glacial deposits (Boyd 1961). Richmond (1986) has demonstrated that the flow comprising the northwest corner of the Madison Plateau overlies Bull Lake moraines southwest of West Yellowstone. The Yellowstone rhyolites are regarded as Quaternary rather than Tertiary in age, as was once believed (Richmond and Hamilton 1960).

Obsidian Cliff occurs within one of four rhyolite flows included in the Roaring Mountain Member of the Plateau Rhyolite (Boyd 1961; Christiansen and Blank 1972). The Obsidian Cliff flow filled a pre-existing valley, rapidly chilling against the old valley wall. That valley wall, because it was exhumed by Obsidian Creek, is now exposed as west-facing Obsidian Cliff. Most of the top of the Obsidian Cliff flow is covered by a thin mantle of rubble in a loose, fine-grained matrix (Pierce 1973), mostly derived from the frost weathering of local bedrock. However, the presence of Paleozoic quartzite, Quaternary basalt, and igneous erratics within the mantle suggests glacial transport and deposition, probably during one of the Pinedale ice advances between 47,000 and 15,000 years ago (Sturchio et al. 1994).

Obsidian Petrogenesis and Properties

Obsidian is a massive to layered, typically black, but somewhat brown, red, green, or white rock composed of volcanic glass, an amorphous solid with a liquid atomic structure that forms as a result of the extremely rapid cooling of molten material (melt). This glass lacks a crystalline atomic structure because rapid cooling at the earth's surface does not provide enough time for the silicon and oxygen atoms in the molten material (melt) to organize themselves into the highly ordered crystalline structure characteristic of minerals (Best 1982:231). Although obsidian is sensibly solid, it is, in reality, viscous liquid.

Volcanic glass is metastable at the earth's surface (Best 1982:241). The lack of a crystalline structure and the resultant amorphous form represents a thermodynamically higher energy state. At the earth's surface, it begins to devitrify; during this process, a lower and thermodynamically more stable energy state is attained. Devitrification occurs as the atoms in the glass rearrange themselves into a solid crystalline structure. When carried to completion, a piece of devitrified obsidian will be composed entirely of small quartz, feldspar, and other silicate minerals, with little evidence of the former existence of glassy material. This transformation of volcanic glass to more stable crystalline material explains why most examples of volcanic glass are no older than Cenozoic in age (Best 1982:241).

Another important process which alters volcanic glass at the earth's surface is hydration, the absorption of water into glass on the exposed surfaces of weathered obsidian (Ross and Smith 1955; Friedman and Smith 1958; Friedman et al. 1966). Water absorption contributes to an increase in density, expansion, and cracking of the outer portion of the glass surface, causing this hydrated layer to become mechanically strained. Consequent cracking away of the thin outer hydrated layer from the nonhydrated obsidian substrate results in the development of nests of concentric curved fractures. These fractures, combined with the internal reflectance of light, which imparts a lustrous pearly gray color to the obsidian surface, constitute perlitic fabric (Best 1982:65). Black non-hydrated obsidian usually contains less than one weight percent intrinsic water that is likely magmatic in origin. Conversely, hydrated layers exhibiting perlitic fabric commonly contain up to 10 weight percent water that is absorbed into the glass at low temperatures under atmospheric conditions (Best 1982:65). However, the gentle heating of perlitic glass cannot drive off much of this absorbed water. The difference between the refractive indices of the hydrated and nonhydrated portions of obsidian and the increased birefringence due to mechanical strain enable the hydrated layer to be observed easily with a petrographic microscope (Friedman and Smith 1960).

Geology and Petrography

Friedman and Smith (1960) determined that hydration occurs under normal atmospheric conditions and that the rate of hydration is a function of temperature and chemical composition of the obsidian. Thus, if the temperature at which hydration occurred and glass composition are known, a determination of the age of the weathered surface of the obsidian sample can be made by measuring the thickness of the hydration layer. This method of obsidian hydration rim dating has proven useful in archaeological and geological studies (e.g., Friedman and Clark 1963; Friedman 1968a,b; Michels and Bebrich 1971; Friedman et al. 1963, 1970, 1973; Michels 1973; Friedman and Long 1976; Michels and Tsong 1980; Friedman and Obradovich 1981; Adams 1990; Adams and Locke 1992).

When volcanic ash remains in contact with natural waters at the earth's surface, the metastable nature of the glass results in the relatively rapid chemical alteration of glass to a potentially wide variety of products. These processes of chemical alteration especially affect glass shards contained in volcanic ash deposited in lakes or ponds (Surdam and Boles 1979). In freshwater settings, volcanic glass reacts with water to form smectite, a mixed-layer clay mineral (Mathisen 1984). The surfaces of volcanic glass particles develop clay mineral rims which progressively thicken as glass is consumed inward by this reaction.

The Obsidian Cliff flow consists primarily of glassy rhyolite with minor development of vesicles (gas pockets filled with vapor-phase mineral precipitates) and lithophysae (areas of devitrification) and possesses well-developed columnar jointing, an unusual feature for rhyolite flows. Columnar jointing is best developed in that part of the Obsidian Cliff flow that has a massive structure with poorly developed flow-banding and no lithophysae (Boyd 1961); phenocrysts are absent from the flow.

Of this columnar structure at Obsidian Cliff, Iddings commented:

> Obsidian Cliff is especially remarkable for the development of prismatic columns, which form the southern end of the mass... Columnar structure is well developed in the rhyolites of the Yellowstone Park. Instances of its occurrence in obsidian, however, are exceedingly rare, and in the obsidian flow under consideration it is confined to a small area, several hundred feet in extent, in that portion which poured into the old channel and acquired a greater thickness than that of the main flow (Iddings 1888:257) [see Figures 7 and 8].

Glaciation and Deglaciation

Large ice caps covered much of the Yellowstone Plateau repeatedly during the Pleistocene. Periods of glaciation include the pre-Bull Lake, Bull Lake, and Pinedale glaciations. Evidence of pre-Bull Lake (ca. 375,000 B.P.) and Bull Lake (ca. 160,000 to 130,000 B.P.) glacial advances in the Yellowstone region is sparse due to subsequent Pinedale glaciation. Pinedale glacial history (ca. 70,000 to 12,000 B.P.) consists of the formation of ice caps on the northern Absaroka Range, the

Figure 7. View of the columnar structure at the southern end of Obsidian Cliff (from Iddings 1888: Plate IX).

Figure 8. A closeup view of the columnar structures ("Obsidian Columns") at Cliff (from Iddings 1888: Plate X).

Gallatin and Washburn Ranges, and the Yellowstone Plateau (Pierce 1973, 1979). The culmination of Pinedale glaciation resulted in the coverage of almost every topographic feature in the region by the Yellowstone ice cap.

As indicated by abundant ice-sculpted scours and ridges developed on top of the Obsidian Cliff flow plateau, the area was covered by ice during much of the Pinedale glaciation. The Obsidian Cliff area was apparently located near the junction of ice flowing to the north from the Gallatin Range and southwestward from the Beartooth Plateau (Pierce 1979). Cordilleran ice in this area of convergence attained thicknesses as great as 1,000 m (3,280 ft). As such, it is likely that the Obsidian Cliff plateau was beneath ice during Pinedale recessional phases, as well as during glacial advances.

The Obsidian Cliff was apparently freed of Pinedale glacial ice prior to 14,000 B.P., according to radiocarbon dates (Whitlock 1993). Friedman et al. (1994), by measuring hydration thickness, determined that most of the cracks noted in obsidian at Obsidian Cliff, which measured approximately 8 microns in thickness, were attributable to pressure imparted by overlying Pinedale-age glaciers ca. 10,000 B.P. Other cracks with hydration thicknesses of about 15 microns were referred to pressure from Bull Lake ice (Pierce et al. 1976; Friedman et al. 1994).

In the final analysis, it is the fact that the Obsidian Cliff plateau was ice free and accessible to prehistoric peoples searching for quarriable obsidian before 14,500 B.P. (Sturchio et al. 1994) which is most important here. While no archaeological evidence of such antiquity has been developed in this part of North America, time and additional work could place humans on this plateau shortly thereafter.

Chapter 3

RESULTS OF THE 1989 ARCHAEOLOGICAL RECONNAISSANCE

by Stephen A. Aaberg

Background

Beginning in 1986, on-site inspections were made by archaeologists Davis, Johnson, and Elizabeth Hadly and Yellowstone National Park geologist Wayne Hamilton into the forest and terrain of the Obsidian Cliff plateau. Those initial selective surveys provided firsthand familiarity with the extent and scope of archaeological features on the plateau (Johnson 1986). Discoveries made during those visitations led to a systematic surface reconnaissance by Montana State University in 1989. The Wolf Lake Fire in 1988 burned over about 90 percent of the Obsidian Cliff plateau, in the process consuming much of the accumulated surface duff and eliminating much of the lodgepole pine overstory. That substantial clearance of visual obstructions facilitated surface inspection and the location of archaeological features and detritus.

Reconnaissance Strategy

The 1989 archaeological survey of Obsidian Cliff was undertaken as a means of obtaining data necessary for preparing a National Historic Landmark nomination (Davis et al 1992). Since systematic survey of the Obsidian Cliff plateau had not been previously accomplished, data regarding quarry feature and workshop occurrences across the obsidian flow were not available. Therefore, reconnaissance was necessary to determine whether specific areas should be nominated and/or included in the boundaries of the registered property or whether the entire Obsidian Cliff flow plateau should be nominated as the geoculturally defined landmark entity. The reconnaissance was not designed as a comprehensive survey. It was intended to locate the most salient archaeological features resulting from the prehistoric human procurement of volcanic glass on and within the Obsidian Cliff plateau.

The Montana State University survey crew met with National Park Service archaeologist Ann Johnson at Obsidian Cliff on May 30, 1989. At that time, Johnson, Davis, and crew members made an initial visit to the flow area and decided on a general survey strategy. Johnson requested that as much of the main flow of Obsidian Cliff be surveyed as time allowed. What was referred to as the Solfatara Creek lobe of the flow was not included in that original survey area. If time permitted, the National Park Service wanted the Crystal Springs vitrophyre flow, just north of Obsidian Cliff, also inspected. It was later determined that the Solfatara Creek lobe is part of the Obsidian Cliff flow and that it contained substantial evidence of prehistoric quarrying activity. The addition of the sizeable Solfatara Creek lobe to the survey area made it impossible to investigate the Crystal Springs ignimbrite flow, and it also forced a reduction in survey intensity for parts of the Obsidian Cliff flow.

Archaeological Reconnaissance

The boundaries of the Obsidian Cliff flow are roughly defined by Obsidian Lake and Horseshoe Hill to the north, Obsidian Creek to the west, Solfatara Creek and the Horseshoe Hill geothermal area on the east, and Lake-of-the-Woods and the stream which flows out of it on the south. Approximately 10 km^2 (69%) of the flow was inspected closely during the 1989 survey, excluding snow-covered terrain and locales which revealed no suggestion of major quarrying activity.

A flexible, transect-type of foot reconnaissance was employed during the Obsidian Cliff plateau surface reconnaissance. Spacing of the transects varied in response to terrain characteristics, but was always less than 100 m (300 ft). A crew of four conducted the survey for all but two days when crew size was reduced to three. Transects were generally oriented along particular landforms (i.e., drainages, ridges, flow top, flow periphery), but occasionally were directionally oriented (particularly across the top of the flow where specific landmarks were lacking). The edges of the obsidian flow, including the slopes of a major interior drainage which dissects the northwest portion of the flow, were most intensively surveyed. In these areas, the toe, middle, and top of edge slopes were inspected. The top of the Obsidian Cliff flow was less intensively surveyed because, early in the survey, it became obvious that the density of obsidian-procurement sites in that area did not compare with that noted for the edge areas.

Time constraints did not permit examination of the top of the Solfatara Creek lobe, except for the extreme edge. The Solfatara Creek lobe is that part of the flow which occurs south and southeast of the geological topographic feature identified on the United States Geological Survey contour map as "The Landmark." The periphery of the entire Obsidian Creek flow, including the Solfatara Creek lobe, was investigated. Since snow in depths up to 75 cm (29.5 in) covered the extreme northeast edge of the flow, including the slopes, that area was not surveyed.

Located Cultural Resources

Archaeological surface reconnaissance identified 59 (Appendices A, B, and C) prehistoric loci, i.e., spatially discrete locations that presented evidence of prehistoric human activity associated with obsidian procurement. Few of these were previously known to National Park Service archaeologists. Surficial and subsurficial procurement activity loci, along with workshop and occasional campsite loci, are the most prominent archaeological manifestations (Figures 9-13).

The boundaries of those cultural loci were determined and locations were recorded on the United States Geological Survey 7.5' series, Obsidian Cliff Quadrangle topographic map. Some loci extend for hundreds of meters and contain dozens of quarry features. It was not practical, given the priority of getting as much of the flow area surveyed as possible, to map each feature and activity area within each locus. Areal coverage for each locus was estimated (Appendix C). Samples of geological and artifactual

Figure 9. One of the linear trench-like obsidian quarry features recorded at Locus 27, looking south (MSU Photo).

Figure 10. A series of contiguous quarry pits that formed a linear depression in a hillside at Locus 14 (MSU Photo).

Figure 11. A single large quarry entry into obsidian bedrock at Locus 33, looking southwest (MSU Photo).

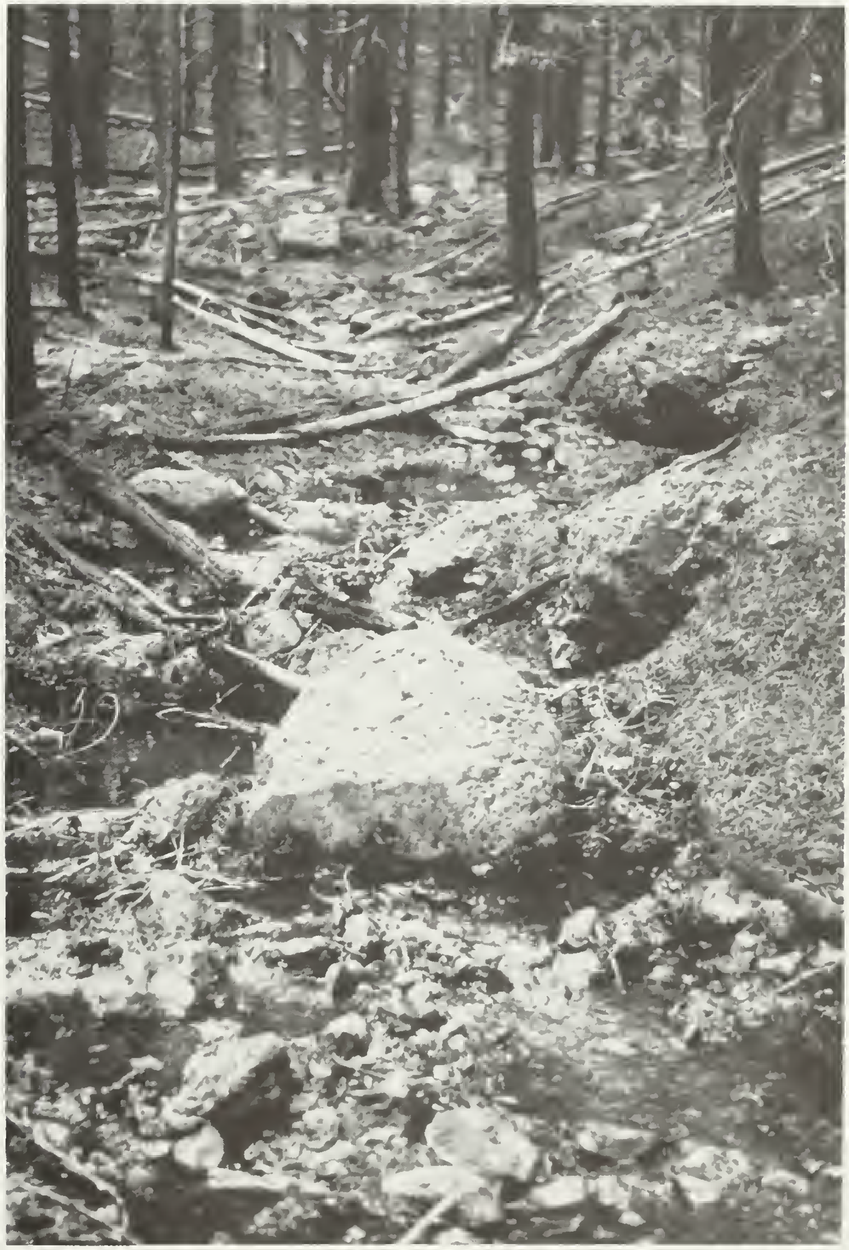

Figure 12. A post-fire view west of a small intermittent creek that drained the Obsidian Cliff plateau, exposing geologic and prehistorically utilized obsidian (MSU Photo).

Figure 13. Deeply eroded bedrock obsidian exposure in vicinity of wind-thrown trees and burned forest cover at Locus 55 (MSU Photo).

obsidian were collected from most loci to facilitate later analysis, such as assessing fire damage and trace element analysis. The loci were photographed and field notes were made for each cultural and physical setting.

Those prehistoric activity loci were associated with obsidian extraction and removal (loci positions are cross referenced in Appendices A-C).

Fire Effects on Plateau Obsidian

Site formation (and site deformation) studies are presently integral aspects of evaluating archaeological site integrity and condition. Their utility is reflected in the attention paid to assessing the importance of exposure opportunities created by fire and evaluating forest and prairie fire effects on the archaeological record (e.g. Kelly and Mayberry 1980; Scott and Fox 1987; Traylor et al. 1990; Trembour 1990; Bennett and Kunzmann 1985; Cannon 1989, 1990b, 1993; Ayers 1989; Connor et al. 1989; Johnson and Lippincott 1989; Johnson et al. 1988, 1991; Eininger 1989; Lintz 1989; Saylor et al. 1989; Picha et al. 1991; Seabloom et al. 1991; Connor and Cannon 1991; Cannon and Phillips 1993; Wettstaed 1993). Estimation of fire effects on surficial geological features and archaeological features and artifacts on the Obsidian Cliff plateau was grounded in that research.

May 24, 1988, when lightning struck a tree in the Lamar Valley, marked the onset of what became the worst fire season in the history of Yellowstone National Park. Fires eventually affected about one half of the acreage in the park. On July 22, 1988, the North Fork Fire started. That fire eventually burned 507,550 acres (206,000 ha), most of it in the park (Wuerthner 1988). The eastern reach of the North Fork Fire, which was renamed the Wolf Lake Fire, burned unevenly over much of the obsidian exposed on the Obsidian Cliff plateau.

As was the case with most of the 1988 fires in Yellowstone, the Wolf Lake Fire burned with variable intensity and affected the landscape to varying extents within the burn area. It has been estimated that, of approximately one million acres (400,000 ha) of land affected by the Yellowstone fires, less than half was actually "touched by flames." About half of those were only lightly burned.

The archaeological survey of the Obsidian Cliff plateau, initiated May 30, 1989, and completed June 8, 1989, observed a mosaic-type burn pattern over much of the obsidian flow area. Based on field observations made during survey, it was estimated that approximately 65 percent of the flow area surveyed was burned intensely by both canopy and understory fires. The area between the topographic feature known as The Landmark and the north end of the flow near Beaver Lake was most intensely burned. The surface of the flow there in particular appears to have burned so hot that much of the ground cover was incinerated. Ghost profiles of large "vaporized" deadfall trees and limbs on the ground testified to the intensity of the burn. The extreme north edge of the flow was largely untouched by fires. A relatively large lobe of the obsidian flow southeast of The Landmark, which is bounded by Solfatara Creek on the south side, was variably burned. Large portions of this lobe were unburned, while other areas were only burned lightly or moderately. Localized hot burns were noted only occasionally on this Solfatara Creek lobe. Generally, fire movement was more capricious on the slopes of the flow and in the drainages that cut down through them and was more predictable and widespread in its effect on the flow surface. Still, many intensely burned areas occurred on the slopes of the flow, particularly in the west-central and east-central sub-localities.

It was not possible to distinguish the effects of previous fires. It has been estimated that major fires in higher elevation areas occur every 200 to 400 years, an interval much greater than for the more frequent fires in lower elevation forests (Taylor 1974; Arno 1980; Romme 1982). According to Millspaugh and Whitlock (1994), intervals between fires on the Central Plateau of Yellowstone National Park have varied from 30 to 100 years during the early Holocene to 150 to 300 year intervals during the late Holocene.

Lodgepole forests in Yellowstone National Park are dominant between 7,800 and 8,200 ft (2,365 and 2,485 m) elevation (Arno 1980). The highest elevation of the Obsidian Cliff plateau is 8,315 ft (2,520 m), which occurs on the flow surface where elevation averages about 8,200 ft (2,485 m) for the main lobe and about 7,800 ft (2,360 m) for the Solfatara lobe. The lowest sector of the Obsidian Cliff plateau occurs at the base of the flow slope near the Obsidian Cliff Kiosk at an elevation of 7,400 ft (2,240 m). The entire Obsidian Cliff plateau area is characterized as higher elevation lodgepole forest.

Significant fires on the scale of those in 1988 had not occurred since park establishment in 1872. Prior to 1988, the worst fire year in the park was in 1940 when 20,700 acres (8,000 ha) burned (Taylor 1974). No fires are known historically for the Obsidian Cliff plateau locality. Nearest fires were the 276-acre (110 ha) Grizzly Lake Fire of 1942 and the Indian Creek Fire (85 acres; 35 ha) of 1960. After the natural burn policy was implemented in 1972, the 30+ acre (12+ ha) Arrow Fire occurred between Obsidian Cliff and Roaring Mountain on the west side of the highway, and another fire of 20 acres (8.5 ha) occurred at Grizzly Lake (Despain and Sellers 1977). Both areas burned during the relatively active fire season of 1976.

A fire scar analysis of forest in the Little Firehole River drainage suggests that 15 fires have occurred in that part of the park since A.D. 1600 (Romme 1982). Seven of those fires were "major fires" that exceeded 10 acres (4 ha) in size, with the most destructive fires occurring in the mid- to late 1700s.

Following destruction of lodgepole forests by fire, and dependent on soil conditions, the numbers and varieties of plant and animal species gradually increase for 25 to 30 years because ground cover increases and provides more diversified habitat (Taylor 1974). After 40 to 50 years, the lodgepole canopy closes, reducing the number of plant ground cover, bird, and mammal species. Once the canopy closes, the forest will remain stable for 300 or more years. Shade-loving understory species such as Engelman spruce and subalpine fir will become established in mature lodgepole forests and, if fire is excluded for a very long time, those species may actually replace the lodgepole.

The presence of large-diameter lodgepole pine with a sub-canopy of subalpine fir and spruce on the extreme northern, unburned edge of the obsidian flow and on the Solfatara Creek lobe suggests that portions of the flow supported a very old lodgepole pine climax community. Another area to the northwest of a topographic low, "the dimple," a hydrothermal feature (Wayne Hamilton, personal communication to Ann Johnson, 1994), was heavily burned, but contained small-diameter, "dog-hair thick" lodgepole pine. It is likely, then, that not all parts of the Obsidian Cliff plateau flow were covered by forest of the same age. It is quite possible that this plateau had not been extensively burned since the 1700s, and conceivably since even earlier. Smaller ignitions have probably burned since that time, but the absence of accumulated ground cover fuels likely prevented rapid and widespread movement of conflagrations over much of the Obsidian Cliff plateau.

Of the 59 recorded archaeological feature loci, 100 percent of the surface of 24 (1-4, 12, 17, 21-23, 28-29, 34, 41-47, 50-51, 54-55, 57) were intensely burned in 1988 (see Appendix B); for present purposes, an intense fire is regarded as one that completely consumed organics in the soil, ground cover, understory, and forest canopy. Two loci (5, 7) were burned moderately over 100 percent of their surface; moderate fires involved ground cover and understory with little or no canopy involvement. Eleven archaeological loci (6, 8-9, 18, 20, 30, 32, 38, 56, 58-59) were lightly burned over 100 percent of their surface. Light fires involved only ground cover. Only three archaeological loci (37, 40, 49) were untouched or unburned by the 1988 fires. Six loci (10, 14, 16, 24, 39, 52) involved lightly burned areas and unburned areas. Four loci (11, 26, 33, 36) had moderately and intensely burned portions. Two loci (13, 31) incorporated intensely and lightly burned areas and unburned areas. Four loci (15, 19, 25, 35) included both lightly and intensely burned areas. One locus (27) contained lightly, moderately, and intensely burned areas. Part of Locus 48 was intensely burned and part was unburned. Locus 53 displayed both lightly and moderately burned areas.

The fire that swept over the Obsidian Cliff plateau affected the physical and biotic environments and deformed the archaeological context and artifacts differentially across these 59 loci. Damage was greatest at those loci that were burned intensely, where ground cover, understory, and canopy involvement contributed to very hot fires. At those loci, the archaeological landscape was denuded of vegetation and the topographic setting became subject to erosion. Fluvial erosion was already evident at some intensely burned loci where runoff had produced both sheet erosion and had induced gullying (Figures 12-13). Such disturbances of context were likely minimal in overall adverse effect, but they did occur following the loss of protective duff, ground cover, and understory.

Erosion was substantial in some areas during the first year following the fire. Significant mass wasting in the form of a landslide, for example, occurred .4-.8 km (.25-.5 mi) south of Obsidian Cliff. Flakes and obsidian debris were scooped up with a front-end loader and disposed of at the Indian Creek pit. Fortunately, since obsidian from the Indian Creek pit (glacially moved cobbles) is identical chemically to that from Obsidian Cliff, obsidian from different sources was not mixed as a consequence of mechanical relocation. Maintenance personnel climbed the hillsides to emplace tree barriers to hold back debris flows and slow erosion.

The single most important factor that altered both the physical and archaeological environments, observed at intensely burned loci, was the wind throwing of burned trees. Wind throwing, the toppling of trees by winds, is a phenomenon that can occur in living as well as dead forests. However, in burned, dead forests (where roots and other soil organics were destroyed by fire, thus forfeiting support, and where rot and insect consumption accelerate the felling of trees), this phenomenon poses a destructive problem. In intensely burned areas, where root damage and destruction were considerable, wind-thrown trees often had pulled up large quantities of soil and rock contained within their root masses. Some charred, fallen trees at various intensely burned archaeological loci contained several cubic meters of material in their root masses. The root holes formed by toppled, uprooted trees were as much as 1.5 m (5 ft) deep. Disturbance and disruption of site stratigraphy and associated artifacts were observed and dislocation is predictable in other situations as well. Cannon points out (personal communication to Leslie Davis, 1994) that live tree throws, because of their larger root ball, cause more damage than dead tree throws.

Although fire damage to artifacts located in intensely burned loci was variable, damage was substantial in some instances. Modern bear and wapiti bones observed at several localities in heavily burned areas were partially consumed by fire, while other bones were extensively charred. Archaeological bone on or close to the surface at those intensely burned cultural loci would unquestionably have been destroyed or severely damaged by fire. Contamination of organic samples of cultural origin at all burned cultural loci (whether lightly or intensely burned) might be an adverse effect, although more deeply buried cultural organics would likely be unaffected.

Direct damage to surficial obsidian artifacts was more apparent and generally greater in intensely burned areas, but artifacts from loci in other affected areas were also damaged. Obsidian artifacts at moderately and lightly burned loci also occasionally exhibited structural damage when found in association with a localized, hotly burned limb, stump, or tree. Heat-fractured obsidian bifaces were noted at several locations, while heat-fractured lithic reduction debris was common at most loci in intensely burned areas. Exfoliated or disintegrated "bombs" of geological obsidian nodules were common in hot burn areas. Heat- and dehydration-induced exfoliation were common on cores and reduction flakes. The potlidding of specimen surfaces also occurred, but was less common than fracturing.

Fire-induced oxidation was apparent on the surface of a great number of obsidian artifacts at many of the burned loci. Oxidation ranged from a bright silver rind to a subtle dulling of the rock surface. While the adverse effects of heating and oxidation on the scientific utility of obsidian artifacts and geological specimens (like hydration research and compositional analyses) are not entirely understood, it is suspected that fire-caused alterations may prohibit or compromise the outcomes of certain technical studies. The percentage of fire-fractured obsidian artifacts at most loci was low, but oxidation did affect a large proportion of the artifacts exposed at the surface.

This post-fire study thus established that much of the obsidian debris on the flow surface away from procurement localities is naturally occurring rather than products of lithic extraction and modification; all was extensively fractured. A few examples of exfoliated archaeological and natural "bombs" were collected for study.

From the perspective of conducting an archaeological survey in heavily forested, duff-covered, mountainous terrain, the 1988 fires significantly enhanced both the short- and long-range visibility of cultural features and associated debris. A pre-fire foot reconnaissance of this densely forested, high-relief plateau was severely hampered by nearly impassable deadfalls on steep, needle-covered, slippery slopes. Visibility through much of the forest was restricted to only a few meters by densely clustered lodgepole pine. That complication was exacerbated by the severe variability in surface relief. No single landform surface could be viewed in its entirety for surface anomalies attributable to prehistoric quarrying and obsidian knapping activity from any distance. Localized obsidian-strewn geological and archaeological surfaces were also obscured by a heavy carpet of duff over much of the forested landscape.

Numerous archaeological features and debris were exposed as a result of fire, increasing site exposure and the possibility of attrition by collectors. The three archaeological loci found in unburned areas were much less evident and therefore considerably more difficult to recognize. Duff and ground cover in those unburned areas obscured not only quarry features, but obsidian artifactual debris as well. In the intensely and moderately burned areas, exposed artifacts and features are presently visible from some distance. Discrete activity areas, marked by distinctive piles of reduction debris and quarry blanks that seemed to represent the full range of quarry technology, became visible in many areas devoid of ground cover or understory. While those areas will be more susceptible to vandalism until ground cover is re-established, archaeologists will, for a time, have an unprecedented opportunity to observe the surficial effects and consequences of quarry formation, lithic extraction, initial reduction technology, and discard.

Chapter 4

CULTURAL UTILIZATION AND REDISTRIBUTION OF OBSIDIAN CLIFF PLATEAU OBSIDIAN

by Leslie B. Davis

The Archaeological Importance of Quarries

Scientific interest in studying and understanding prehistoric human behavior involved in the procurement of lithic resources is of long standing in the Americas. From an early fascination with North American quarries, by (Holmes [1918], Fowke [1928], Bryan [1950], Shaeffer [1958], Shepherd [1980], and many others), increasingly sophisticated lithic sourcing-oriented archaeological studies are now in vogue. Excavations have been conducted at a few quarries in the Northern Plains (Ahler 1977, 1986; Ahler and Christensen 1983) and Northern Rocky Mountains (Davis 1982a). Also, archaeologists and geologists are studying prehistorically utilized lithics with an interest in matching source and archaeologically deposited samples (cf. Clayton et al. 1970; Fredlund 1976; Herbort 1981; Davis 1981; Fields 1983; Cameron 1984; Butler and May 1984; Vehik 1985, 1986, 1988; Francis 1980, 1983).

Archaeological enthusiasm for studying prehistorically quarried bedrock and secondary (lag) deposits accelerated in the 1970s and 1980s in the United States and Canada. For various reasons, archaeologists had been loathe to tackle the study of quarries, preferring to study workshops, lithic technology, and artifacts. The enormous volume of waste flakes, the great scale of some quarries, and the expected lack of datable materials have discouraged quarry excavations. Recognition that the geological source of archaeologically distinctive lithics is singularly important for understanding prehistoric preference, use, and redistribution of key lithics in time and space is now common, (cf. Earle and Ericson 1977; Fry 1980; Ericson and Earle 1982; Ericson and Purdy 1984; Baugh and Nelson 1988; White and Holen 1991; Baugh and Ericson 1994). An appreciation of scale and intensity of procurement activities, especially in bedrock extraction types of quarries produced by underground mining, has resulted.

Of particular relevance to the Obsidian Cliff plateau source are large-scale archaeological investigations performed at specific obsidian sources such as the Alaskan obsidian source Batza Tena (Clark and Clark 1993) and the Mt. Edziza obsidian source in British Columbia (Fladmark 1984). Also, efforts to study utilized obsidian on archaeological culture area (cf. the Great Basin [Hughes 1984] and California [Hughes 1994d] and regional (cf. Northwestern Plains [Davis 1972a,b]) scales reflect the large areal scope of obsidian source exploitation and exchange during prehistory.

Geochemistry of Obsidian Cliff Plateau Source Samples and Artifacts

Eighty geological and archaeological obsidian specimens recovered from the surface of prehistoric quarry features and quarry/workshop loci on the Obsidian Cliff plateau were analyzed by x-ray fluorescence to measure geochemical variability within that flow (see Appendix D). Laboratory procedures and methods and results of analysis are reported by Hughes (1990b):

> Laboratory investigations were performed on a Spectrace™ 5000 (Tracor X-ray) energy dispersive x-ray fluorescence spectrometer equipped with rhodium (Rh) x-ray tube, a 50 kV x-ray generator, with microprocessor controlled pulse processor (amplifier) and bias/protection module, a 100 mHz analog to digital converter (ADC) with automated energy calibration, and a Si(Li) solid state detector with 150 eV resolution (FWHM) at 5.9 keV in a 30 mm^2 area. The x-ray tube was operated at 35.0 kV, .30 mA, using a .127 mm Rh primary beam filter in an air path at 200 seconds lifetime to generate x-ray intensity data for the trace elements zinc (Zn Kα), gallium (Ga Kα), rubidium (Rb Kα), strontium (Sr Kα), yttrium (Y Kα), zirconium Zr Kα), and niobium (Nb Kα). X-ray intensities were converted to concentration estimates employing a least-square calibration line established for each element from analysis of up to 26 international rock standards certified by lines established for each element from analysis of up to 26 international rock standards certified by the U.S. Geological Survey, the U.S. National Institute of Standards and Technology (formerly National Bureau of Standards), the Geological Survey of Japan, and the Centre de Recherches Petrographiques et Geochimiques (France). Data processing for all analytical subroutines is executed by a Hewlett Packard Vetra™ microcomputer, with operating software and analytical results stored on a Hewlett Packard 20 megabyte fixed disk. Further details pertaining to x-ray tube operating conditions and calibration appear in Hughes (1988a).
>
> Trace element measurements on the xrf data tables are expressed in quantitative units (i.e., parts per million [ppm] by weight), and matches between unknowns and known obsidian chemical groups were made on the basis of correspondences (at the 2-sigma level) in diagnostic trace element concentration values (in this case, ppm values for Rb, Sr, Y, Zr, and Nb) that appear in Anderson and others (1986), Hughes (1984), Hughes and Nelson (1987), Nelson (1984), and Jack and Carmichael (1969). Artifact-to-obsidian source (geochemical type) correspondences were considered reliable if diagnostic mean measurements for artifacts fell within 2 standard deviations of mean values for source standards. The term "diagnostic" is used here to specify those trace elements that are well-measured by x-ray fluorescence, and whose concentrations show low intra-source variability and marked variability across sources. Diagnostic elements, then, are those whose concentration values allow one to draw the clearest

geochemical distinctions between sources (Hughes 1990a). Although Zn and Ga ppm concentrations also were measured and reported for each specimen, they are not considered "diagnostic" because they do not usually vary significantly across obsidian sources (see Hughes 1982, 1984). This is particularly true of Ga, which occurs in concentrations between 10-30 ppm in nearly all parent obsidians in the study area. Zn ppm values are infrequently diagnostic; they are always high in Zr-rich, Sr-poor, peralkaline volcanic glasses, but otherwise they do not often vary significantly between sources.

The trace element composition measurements presented in Table 1 are reported to the nearest ppm to reflect the resolution capabilities of non-destructive energy dispersive x-ray fluorescence spectrometry. The resolution limits of the present x-ray fluorescence instrument for the determination of Zn is about 3 ppm; for Rb about 5 ppm; for Sr about 3 ppm; Y about 2 ppm; Zr about 4 ppm; and for Nb about 3 ppm. When counting and fitting error uncertainty estimates (the "±" value in the table) for a sample are greater than calibration-imposed limits of resolution (e.g. the 6 ppm value for Rb in specimen 15 which slightly exceeds the 5 ppm detection limit value), the larger number is preferred as a more conservative, robust reflection of elemental composition and measurement error due to variations in sample size, surface, and x-ray reflection geometry (see Hughes 1988a).

Inspection of the data in Table 1 indicates that, as might be anticipated on the basis of proximity, all specimens match the trace element profile of Obsidian Cliff volcanic glass. The quantitative data in the tables are in excellent agreement with published values on Obsidian Cliff source standards (see Anderson et al. 1986: Table 4, source 30; Nelson 1984: 49, Table 5, source 40; Jack and Carmichael 1969: Table 1, sample Cam 147).

The geochemical integrity of the Obsidian Cliff plateau source is clearly reflected in the limited variation demonstrated by analysis of the geological and archaeological specimens collected during the 1989 survey. To further illustrate integrity of the Obsidian Cliff plateau x-ray fluorescence signature, Hughes transformed the tabled data into bivariate scatter diagrams that display the clustering of zirconium vs. rubidium (Figure 14), yttrium vs. niobium (Figure 15), and yttrium vs. zirconium (Figure 16). These element combinations were graphed by Hughes because those particular pairings provide the best elemental discrimination among parent obsidians in the Northern Rockies.

The baseline importance of empirically establishing the range of geochemical variability within single geological sources (intrasource variability) has been argued and demonstrated by Hughes (1994d) for the Casa Diablo area in California. Presently, the Obsidian Cliff plateau geochemical profile is well defined by reference to accumulated at-the-source x-ray fluorescence data (Appendix D),

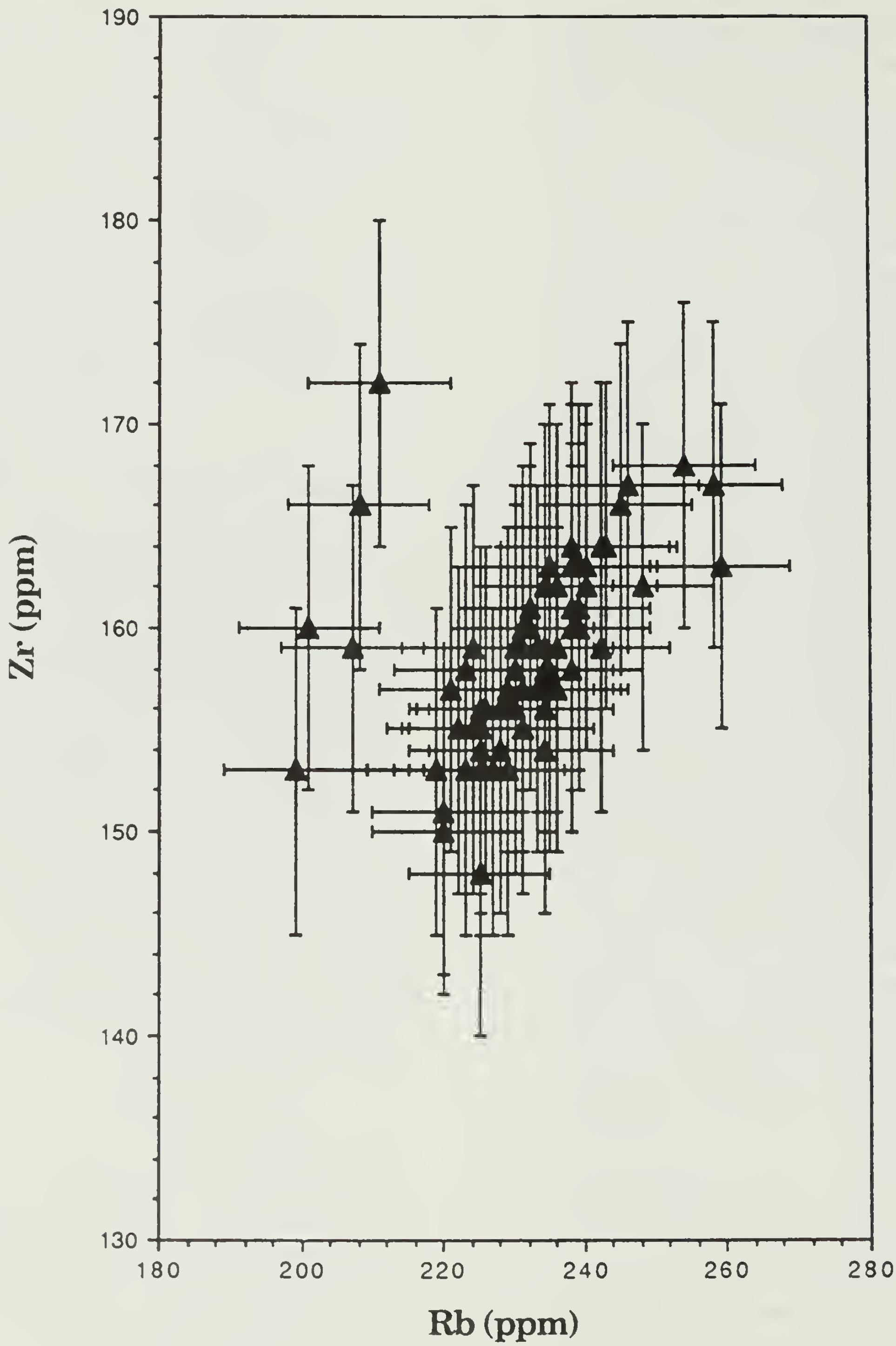

Figure 14. Zirconium vs. rubidium concentration for 80 Obsidian Cliff plateau geological and archaeological samples recovered in 1989 (see Appendix D).

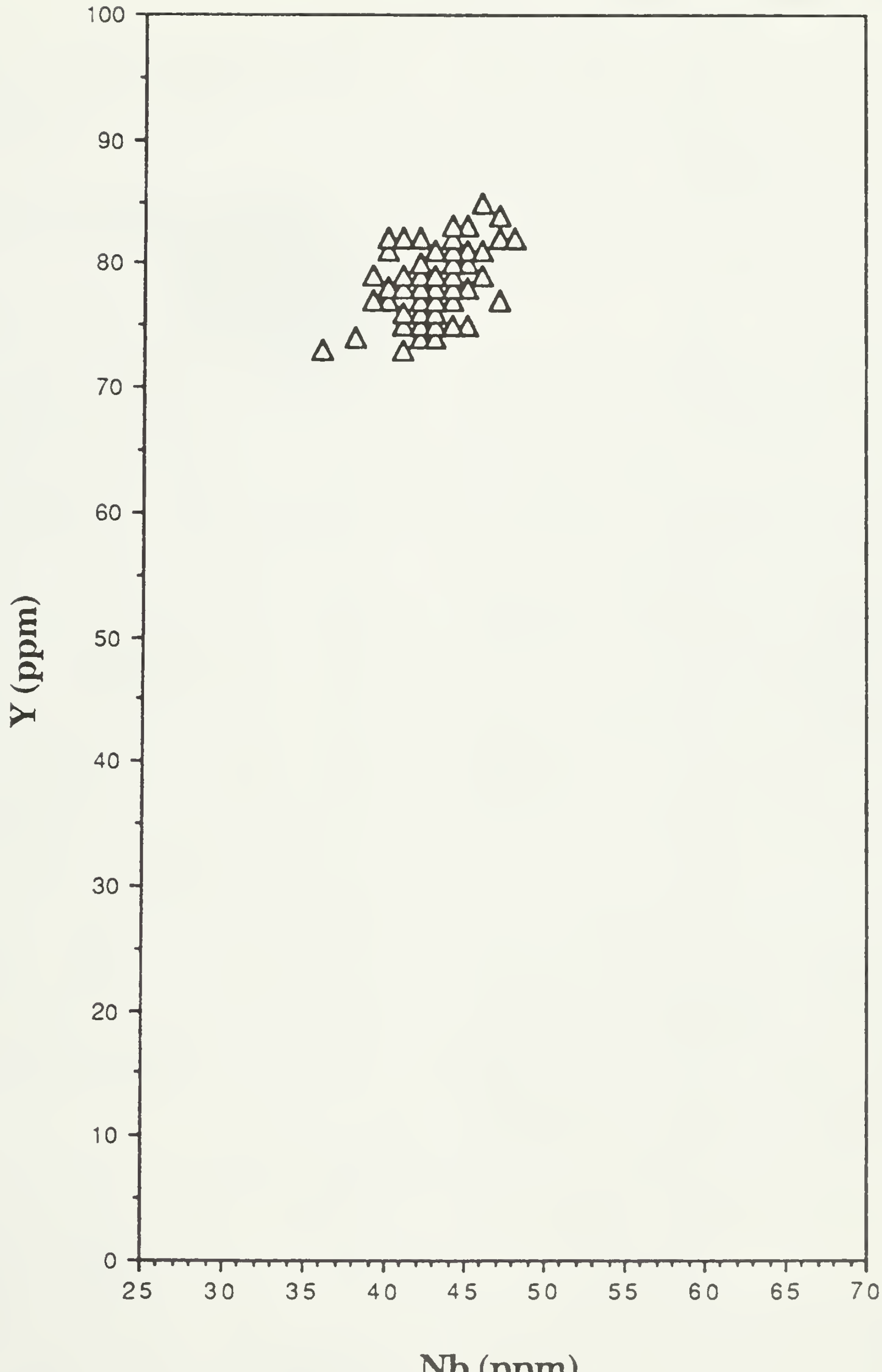

Figure 15. Yttrium vs. niobium concentration for 80 Obsidian Cliff plateau geological and archaeological samples recovered in 1989 (Appendix D).

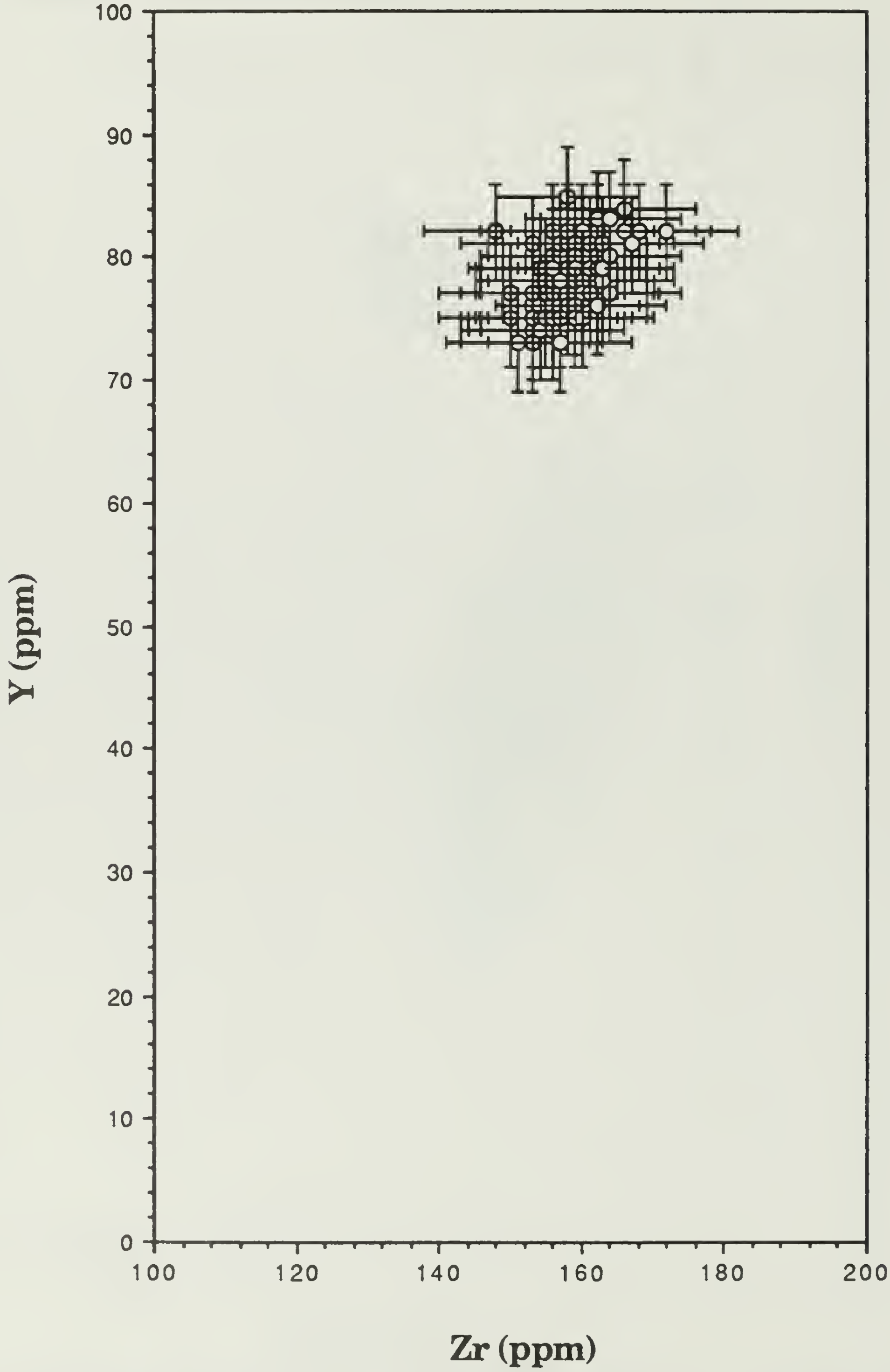

Figure 16. Yttrium vs. zirconium concentration for 80 Obsidian Cliff plateau geological and archaeological samples recovered in 1989 (Appendix D).

neutron activation analysis data (Appendix G), and atomic absorption spectroscopic data (Appendix H).

Prehistoric Use and Redistribution

The first trace element or bulk element compositional analysis obtained for obsidian from the Obsidian Cliff plateau was published in 1968 (Frison et al. 1968). That determination was made by neutron activation analysis. Other applications of regional interest followed (e.g. Gordus et al. 1971; Davis 1972a: see Appendix F). Since then, other instrumental techniques, such as x-ray fluorescence, particle-induced x-ray analysis (pixe) (Nielson et al. 1976; Ferguson et al. 1977), and atomic absorption spectroscopy, have been brought into routine problem solving use by archaeologists. Data production has proliferated. Unfortunately, many of those data are reported in the gray literature or in institutional and regional journals where they are not readily accessible to researchers. Few recently published reports summarize previously accumulated compositional data.

The application of instrumental trace and bulk element geochemistry techniques enables the objective tracing of archaeological specimens to known geological source matches. It can now be demonstrated, for instance, that obsidian from the Obsidian Cliff plateau was exported and imported and utilized for ceremonial purposes by peoples of the Midwestern Hopewell Interaction Sphere, mostly in the Ohio River Valley, during the Middle Woodland period, ca. 2950-1550 B.P. (cf. Frison et al. 1968; Griffin et al. 1969; Hatch et al. 1990). Thus, Yellow-stone obsidian was a valued commodity imported by Hopewellians for specialized ritual use and disposal at mortuary sites.

The present effort assembles and presents geochemistries that bear on the prehistoric use of Obsidian Cliff plateau obsidian. This compilation is inevitably noncomprehensive in view of the recent acceptance by archaeologists of geochemistries as essential descriptive data for sourcing and interpretive purposes. The obsidian geochemistries are summarized here as tabulations organized by the respective applied instrumental techniques: nondestructive x-ray fluorescence (Appendices D, E, and F), neutron activation (Appendix G), and atomic absorption spectroscopy (Appendix H).

Seventy-seven excavated and surface-collected archaeological specimens recovered from archaeological proveniences in Montana (Figure 17, Appendix E) were selected for x-ray fluorescence analysis by National Park Service and Montana State University archaeologists to locate instances of Obsidian Cliff plateau obsidian utilization in spatially wide-ranging archaeological contexts.

Temporal and cultural parameters were known in many of those instances. This specific application was designed as a small-scale, known-provenience study as a test of prior postulations of culturally differentiated prehistoric obsidian use for the Central Rocky Mountains, Northwes-

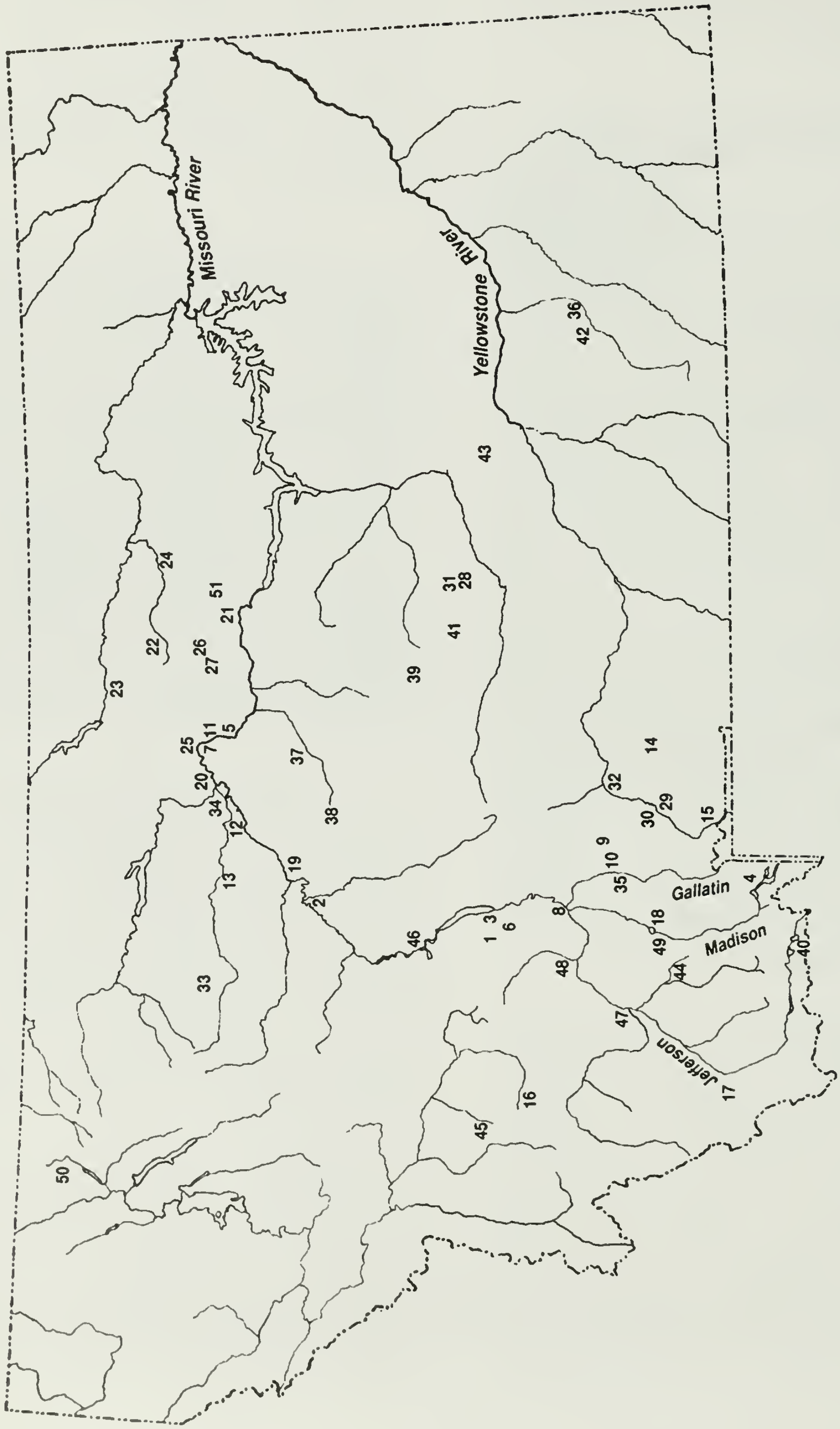

Figure 17. Archaeological sites and find locations in Montana from which obsidian trace element data are presented in Appendices E and G.

1. Indian Creek
2. Cascade/Ulm
3. Canyon Ferry
4. Grayling Creek
5. Lost Terrace
6. Salt Springs
7. Thompson Bottom
8. Schmitt
9. King (24GA214)
10. Antonsen
11. Hoffer
12. Carters Ferry
13. Crawford Ranch
14. Jarrett
15. Corwin Springs
16. California Creek
17. South Everson Creek
18. Jordan Creek
19. Highwood Kill
20. Tunis/Loma
21. Keaster
22. Timber Ridge
23. Wahkpa Chu'gn
24. Three Buttes
25. Dunes
26. Birdtail Ranch
27. Cabin Coulee
28. Stark-Lewis
29. Hardy-Kistner
30. Carbella
31. Stark
32. Myers-Hindman
33. Corey Ranch
34. Somerfeld
35. 24MA557
36. Cooley
37. Sande
38. Square Butte
39. Crystal Lake
40. 24BE1233
41. Garfield Ranch
42. 24RB1164
43. 24YL1208
44. Barton Gulch
45. Flint Creek Valley
46. Bowman Spring
47. Steel's Pass
48. Sheep Rock Spring
49. Varney Bridge
50. Glacier National Park
51. King (24BH2886)

tern Plains, and Wyoming Basin (Davis 1972a,b; see Table 1). The resulting source attributions were somewhat unexpected: this sample did include obsidian obtained from the Obsidian Cliff plateau, but was dominated by obsidian from geological sources in Idaho:

> It is obvious .... that this sample contains considerable source diversity, with obsidian of the Bear Gulch, Idaho, geo-chemical type represented in greater frequency than Obsidian Cliff. Other Idaho obsidians also were identified in the sample; specifically, Timber Butte (n=5) and Big Southern Butte (n=1). Specimen 671 [Appendix E: Corwin Springs, Pelican Lake complex] has unique values which do not match any of the samples in the Hughes reference collection, but the Rb, Sr, Y Zr, Nb, and Ba elemental concentration estimates generated for samples 2050 [Appendix E: Barton Gulch, Alder complex] and 2058 [Appendix E: South Everson, Pelican Lake complex] indicate that both of them represent the same geochemical variety of obsidian. Both of these samples were analyzed a third time to generate titanium, manganese, and total iron compositions. The values obtained (Sample 2050: Ti = 1301 ppm; Mn = 374 $\pm$ 23 ppm; Fe_2O_3T = 1.05 $\pm$ .09%; Sample 2058: Ti = 1253 $\pm$ 28 ppm, Mn = 404 $\pm$ 23 ppm; Fe_2O_3T = 2.04 $\pm$ .09%) are in close agreement with geological obsidian from the Pack Saddle source, Teton County, Idaho (Nelson 1984:48, source 39). Although I have no geologic samples from the Pack Saddle occurrence in my possession, the correspondence between the quantitative data and those reported for the source by Nelson support assigning these samples to the Pack Saddle geochemical type.
>
> The quantitative data in these five tables can be compared directly with those presented for Obsidian Cliff (see Anderson et al. 1986: Table 4, source 30; Nelson 1984:49, Table 5, source 49; Jack and Carmichael 1969: Table 1, sample Cam 147; Hughes 1990b: Figure 1-3) and Bear Gulch (Hughes and Nelson 1987: Table 1) source standards (Hughes 1990c).

Those 77 specimens from Montana sites are identified in Appendix E by reference to Hughes (1990c). Those specimens were selected from contexts for which radiocarbon ages and/or typologically crossdated obsidian projectile points or ceramics were useful for establishing temporal control. This research tactic, which is prerequisite for reconstructing differential source exploitation patterns, is illustrated, for example, in Friedman and Smith (1960), Evans and Meggers (1960), Davis (1972a,b), Cannon (1993), and Cannon and Hughes (1993, 1994). An additional 193 obsidian x-ray fluorescence geochemistries from Montana archaeological sites and localities, with little or no associated cultural-chronological controls, are also incorporated in Appendix E. The tabulated raw data do not necessarily appear in the referenced reports and publications, which are provided to define the associated archaeological contexts.

Appendix F presents x-ray fluorescence geochemistries from sites in Yellowstone National Park and North Dakota. These data provide local and more distant archaeological comparisons from which the occurrence of nearby and exported Obsidian Cliff Plateau obsidian can be assessed in general terms.

Appendix G displays neutron activation data developed for archaeological samples (Davis 1972a) from southern Alberta, Saskatchewan, and Manitoba (12 locations, n = 24 specimens); northern Montana (8 sites; n = 19); central and southern Montana (4 sites; n = 17); southern Montana Montane (2 sites; n = 31); and northern Wyoming (1 site; n = 50). The relative occurrence of Obsidian Cliff plateau obsidian, associated with progressive distance from the source, is evident by inspection of those data.

Appendix H presents selected major element geochemistries for specimens from quarry sources in Wyoming (Cougar Creek, Crystal Spring, Obsidian Cliff, Teton Pass, Parker Peak, Jackson Lake), Montana, and North Dakota, principally for the purpose of pointing out the differing source geochemistries and the distributional differentials related to archaeological obsidian referred to the Obsidian Cliff plateau.

The implications of these data await a variety of analyses which involve time and cultural variables not yet controlled. The inference of use and distribution modalities is an approach of fundamental importance to understanding human behavior, from the acquisition of raw material through the final disposition of obsidian artifacts.

The Human Redistribution of Geological Obsidians

It is clear that Obsidian Cliff plateau obsidian was not the only obsidian used by prehistoric peoples in this region. Obsidian obtained from the Bear Gulch source (or Camas/Dry Creek [Michels 1983]) in the Centennial Mountains of southwestern Idaho was also used by prehistoric peoples at a number of Montana sites, sometimes exclusively or in combination with Obsidian Cliff plateau obsidian, and even with obsidian from still other sources in Idaho and Wyoming (Figure 18) (Appendix E). The spatially diffuse occurrence of Bear Gulch obsidian as lag deposits in the Centennial Mountains of Idaho, and southwestern Montana weakens interpretive utility of that source location definition. The bedrock obsidian obtained from the Obsidian Cliff plateau is more informative because of its spatial circumscription.

The only obsidian Clovis point known from Montana was found by Otho Mack in 1959 when the basement for the Gardiner Post Office was being excavated just north of the park (Arthur 1966a; Haines 1977). While photographs of this artifact are available, its present location is unknown. It has not been analyzed. An obsidian Folsom point recovered in the Bridger-Teton National Forest of Wyoming was sourced to the Obsidian Cliff plateau (Cannon 1993). The only sourced obsidian Folsom point from

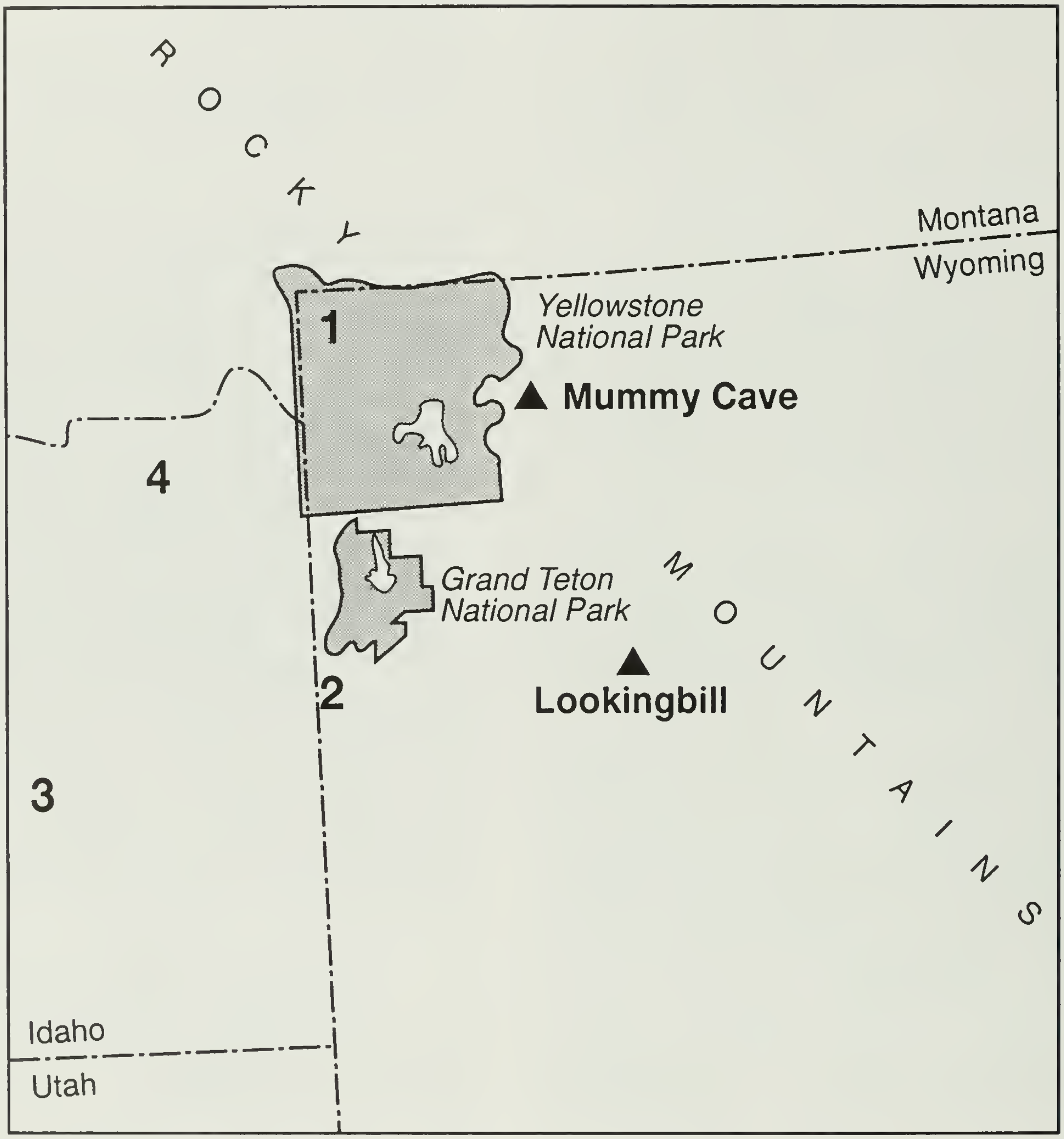

Figure 18. Locations of major archaeological obsidian source localities in Wyoming and Idaho (adapted from Cannon 1993) and the Lookingbill (48FR308) and Mummy Cave (48PA201) sites in northwestern Wyoming: 1, Obsidian Cliff plateau; 2, Teton Pass; 3, American Falls; 4, Bear Gulch.

Canyon Ferry Reservoir (Davis and Helmick 1982) (Figure 17, Appendix F) in west-central Montana, was made from Bear Gulch obsidian. Obsidian artifactsfrom a deeply buried Hell Gap component at the Indian Creek site (Davis 1986) (Figure 18, Appendix E) were found to be split equally between the Obsidian Cliff plateau and Bear Gulch sources. A Haskett point (Butler 1965, 1967), found in Montana north of West Yellowstone on Grayling Creek, was sourced to the Obsidian Cliff plateau flow (Figure 18, Appendix E). An Alberta point collected in Glacier National Park was sourced to Bear Gulch (Hughes 1992b) (Figure 18, Appendix F).

Cannon and Hughes (1994), reporting x-ray fluorescence data derived from 473 obsidian artifacts (104 of them projectile points) recovered from Yellowstone National Park, recognize 15 different geological sources of which four are provisional. For their Terminal Pleistocene-Early Holocene (10,000-7,000 B.P.) projectile points, 54.29 percent were from Obsidian Cliff, 20 percent from Bear Gulch, 8.57 from Teton Pass 2, and 17.76 percent from six other sources. The Middle Holocene (6,500-3,000 B.P.) points distributed as follows: Obsidian Cliff, 85.71 percent; Bear Gulch, 9.52 percent; and Teton Pass 1, 4.76 percent. The Late Holocene (3,000-100 B.P.) points were sourced to Obsidian Cliff (70.83%), Bear Gulch (14.58%), Teton Pass 2 (2.08%), Teton Pass 1 (6.25%), and other Idaho sources (6.25%). The interpretive significance of these numbers, percentages, and indicated source diversity over time and space remains to be explained.

The differential archaeological redistribution of Obsidian Cliff plateau obsidian during later prehistoric times relative to that from the Bear Gulch source can be appraised analytically by reference to 144 neutron activation data sets obtained from 26 archaeological sites and find locations in subareas of the Northwestern Plains (Davis 1972a,b) (Appendix G). Source determinations were made for obsidian from Obsidian Cliff (OC), FMY (now recognized as Bear Gulch [Hughes and Nelson 1987]), Teton Pass (TP), and Unknown (UK). Overall, 54 percent of those specimens are attributed to Obsidian Cliff, with 33 percent to Bear Gulch.

Subarea differentials were evident when geographic distinctions were analyzed. In the northern extremity of the study area (Southern Alberta Montane and Southern Canadian Plains-Alberta), Obsidian Cliff obsidian accounts for only 6.4 percent of Obsidian Cliff obsidian for the region, while Bear Gulch obsidian accounts for 33 percent of all Bear Gulch obsidian. Likewise, 84.5 percent of all Obsidian Cliff plateau obsidian and 40 percent of all Bear Gulch obsidian occurred in the southern subareas (Central/Southern Montana Plains, Southern Montana Montane, and Northern Wyoming Basin). These patterned occurrence differences, when inspected north to south, suggest that the respective obsidians were use relocated and/or exchanged via different routes. Further archaeological site-specific research will enable the complex-by-complex, phase-by-phase determination of obsidian source-specific preferences.

Prehistoric Utilization and Redistribution

Bear Gulch obsidian appears to predominate in the Intermountain area while obsidian from Obsidian Cliff dominates on the Northwestern Plains. The co-occurrence of Bear Gulch obsidian in quantities secondary to that from the Obsidian Cliff plateau in Hopewell sites (observed by Griffin et al. [1969], with respect to occurrences of Yellowstone 150 and 90 Group obsidians based on neutron activation data from Hopewell sites and elucidated by Hughes and Nelson (1987), Hatch et al. (1990), Hughes (1992a), reinforces the inferred multi-source procurement pattern. Such a pattern was previously recognized for the Central and Northern Rockies and Northwestern Plains (Davis 1972a,b).

Research has not yet established the extent to which particular lava flows recognized within the Yellowstone rhyolite plateau are geochemically discrete. Richmond (1986) mapped numerous individual flows (Figure 3). Schmitt's map (Figure 6) locates seven major and more numerous minor, potentially obsidian-bearing, spatially segregated volcanic localities that might have presented obsidian procurement opportunities. Anderson et al. (1986: Figure 2) identify 18 specific obsidian sources in addition to the Obsidian Cliff plateau within the Yellowstone rhyolite plateau. Several potentially "parent" obsidian sources in and near the park have been geochemically distinguished by trace element analysis (cf. Frison et al. 1968; Jack and Carmichael 1969; Sappington 1981b; Nelson 1984; Michels 1981a,b; Anderson et al. 1986; Kunselman 1994).

Collections research by Cannon (1993) and Cannon and Hughes (1993), which involved the x-ray fluorescence analysis of obsidian projectile points in the Yellowstone Museum collection, determined that a Hell Gap and a late Paleoindian point of indeterminate type had been fashioned from Bear Gulch obsidian. Paleoindians are known to have been highly mobile. They traversed considerable territories during annual subsistence and seasonal raw material reprovisioning rounds and participated in materials exchange relationships. Some who entered the Yellowstone National Park area from the northwest brought Bear Gulch obsidian with them, losing and/or discarding some while replenishing their lithic raw material supplies with obsidian at the Obsidian Cliff plateau. Reconstructing past seasonal rounds and movements of people is a complex process, but a topic of great interpretive potential.

While the pattern is not entirely predictable, it does appear that the use of Idaho obsidians dominated obsidian selection and use in southwest Montana. There may have been a pathway (or pathways) from the Centennial Mountains of Idaho and Montana down the Beaverhead River to the Jefferson River in the Missouri River headwaters (see Figure 18).

The low relative frequency of Obsidian Cliff plateau obsidian (26.3%) at an archaeological site in the southern Absaroka Mountains of northwestern Wyoming 165 km (103 mi) from Obsidian Cliff, the Helen Lookingbill site

(48FR308) (Figure 18), was reported by Kunselman (1994). X-ray fluorescence determined that 55.5 percent were derived from the Bear Gulch source located in the Centennial Mountains of Idaho about 215 km (135 mi) to the northwest. The remainder originated from the Fish Creek/Teton Pass and Fish Creek sources south of Yellowstone National Park in Wyoming.

In addition, obsidian from the Obsidian Cliff plateau was used for utilitarian purposes in the Upper Mississippi valley, including 75 percent of the obsidian analyzed from Middle Woodland and Late Prehistoric Period non-ritual sites in central Iowa (Anderson et al. 1986; Hughes and Nelson 1987). Two-thirds of the obsidian analyzed from sites in the Northeastern Plains of North Dakota originated at the Obsidian Cliff plateau, where it was used by Late Plains Archaic, Middle Woodland, and Early Plains Village Period peoples (Baugh and Nelson 1988). Obsidian Cliff plateau obsidian occurs in Middle Woodland mortuary and non-mortuary sites in Ohio, Illinois, Wisconsin, Michigan, and Ontario (Griffin et al. 1969). A single obsidian specimen recovered from the Trowbridge site, a Kansas Hopewell site, was sourced to Obsidian Cliff (Hughes 1995). A significant fraction of southern Canadian Plains and Canadian Rockies (Davis 1972a,b; Godfrey-Smith and Magne 1988) archaeological obsidian originated at the Obsidian Cliff plateau and probably other Yellowstone sources. Many the obsidian artifacts analyzed from sites in the Montana Plains and Rockies and in the Wyoming Basin (Davis 1972a,b) (cf. Frison et al. 1968 and Griffin et al. 1969) also derived from Yellowstone obsidian sources.

Limited quantities of Yellowstone obsidian were also transported west for use at sites in Idaho where reliance on obsidian from multiple local sources was patterned (Sappington 1984); obsidian from Idaho sources also occurs as artifacts within Yellowstone National Park (Cannon 1993). Southward, Obsidian Cliff plateau obsidian was found in south-western Wyoming (Connor 1986) and in northwestern Colorado (Truesdale 1993).

Figure 19 illustrates the exportation-importation vectors that describe the outflow of obsidian from the Obsidian Cliff plateau and Bear Gulch sources in various directions during prehistoric times.

Multiple sources on an even more geologically diverse scale are suggested by the analysis of 13 obsidian specimens drawn from four sites in the Flint Creek Valley of western Montana (Flint and Sappington 1982) (Figure 17). No obsidian from the Obsidian Cliff plateau was present, even though six geologically different sources were identified: 45 percent from north-western Wyoming: Grassy Lake Reservoir just south of Yellowstone National Park, 323 km (200 mi) east of the Flint Creek Valley (30%), and 15 percent from the Kepler Cascades south of Yellowstone National Park, 282 km (175 mi) east of the Flint Creek Valley; while others were obtained from northeastern Oregon (24%) and Idaho (31%), Camas Prairie and Timber Butte (see Sappington 1984). Timber Butte

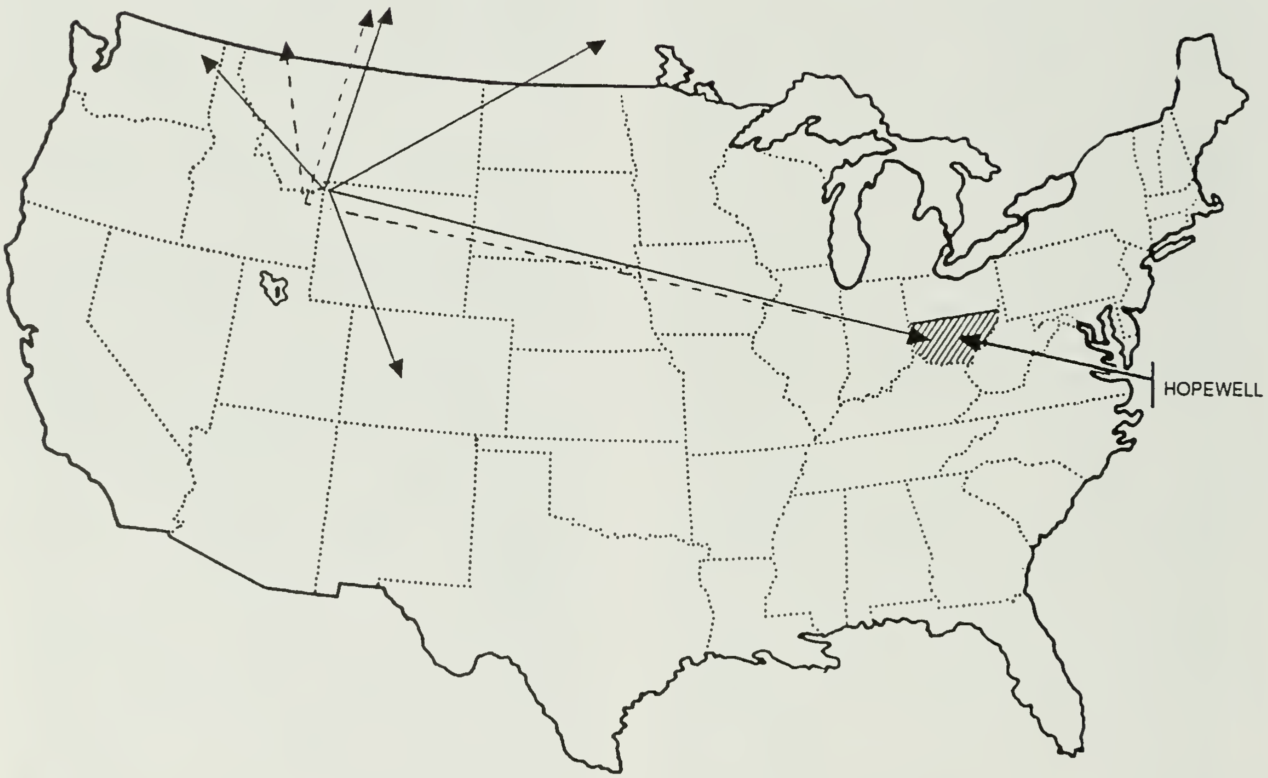

Figure 19. Geological parent obsidian sources and archaeological destinations/vectors for Obsidian Cliff (solid line) plateau and Bear Gulch (dashed lines) obsidians.

obsidian was also found at Kutenai Falls on the Kootenai River in northwestern Montana (Flint and Sappington 1982; Sappington 1988b). However, there is reason to believe that many of the source attributions are highly suspect, for technical reasons discussed by Hughes (1984).

Multiple sources were also indicated for 33 obsidian items recovered from three sites in the Calispell Valley of northeastern Washington (Sappington 1988a). Six specimens from two sites were attributed by x-ray fluorescence to Obsidian Cliff, while the other 27 originated from sources in Idaho and Oregon. Northeastern Washington is the farthest destination for Obsidian Cliff plateau obsidian yet reported to the northwest, over a distance of about 550 km (250 mi). For these source attributions, see also Hughes (1984).

To the north, in Canada, obsidian from the Obsidian Cliff plateau was reported from southern Alberta and Saskatchewan (Appendix G), while Bear Gulch was reported from southern Alberta and Manitoba (Appendix G) (Davis 1972a). An x-ray fluorescence study of 40 obsidian artifacts from north-central and east-central Alberta (Godfrey-Smith 1988) identified eight distinct geochemical types. Twenty of the artifacts were attributed to six known obsidian sources in British Columbia, along the Snake River, in Yellowstone National Park (Obsidian Cliff), and in Oregon. Another x-ray fluorescence study, of seven archaeological obsidian samples from five prehistoric sites in Banff and Jasper national parks in southwestern Alberta (James 1986), identified British Columbia and Yellowstone National Park sources. Two samples from Banff National Park were attributed to Yellowstone National Park, Wyoming. These three studies indicate that Yellowstone obsidian was used and/or traded northward more than 225 km (500 mi) during prehistoric times.

Given expanded research with respect to Obsidian Cliff plateau obsidian, it will be possible to develop an impression of obsidian utilization similar in kind to that proposed for the Pacific Northwest:

> Overall, the archaeological evidence indicates that trade in obsidian has been part of the aboriginal culture pattern in British Columbia for a least the last 9,500 years. Obsidian, because of its non-perishable nature, is the only indicator of trade available over this entire span, but is considered to be an example of trade that took place in many commodities. The obsidian trade increased gradually between 9500 and 6000 B.P., and then leveled off later in later periods. This distribution indicates the presence of considerable indirect cultural interaction and information flow throughout the Pacific Northwest from at least 4000 B.P. onward (Carlson 1994:360-361).

Ohio Hopewell And Obsidian Cliff: A Special Case

W. H. Holmes' fascination with Yellowstone National Park obsidian persisted for at least three decades. He was a visionary who drew broad geographic and ethnological connections and speculated about complex questions:

> With respect to the origin of the great numbers of obsidian implements found in the Hopewell mounds, it may be well to note that there is no trace of Mexican characters in the pottery of these mounds; besides, the general trend of the group of wares [pottery] here associated is from Chillicothe towards the northwest, suggesting the upper Missouri region or the valley of the Columbia as the source of the obsidian. The significance of this observation is emphasized by the discovery of fragments of *rouletted ware* [italics ours] in the Yellowstone National Park, where great beds of obsidian are found (Holmes 1910).

He also speculated about the manner by which obsidian was transferred over great distances:

> The obsidian product was widely distributed from the mining centers, but in accounting for stray bits and occasional implements of obsidian found in the Mississippi Valley it is necessary to assume that the ancient peoples visit distant parts or that it came by trade from afar. It is quite reasonable to suppose that fragments of this material may have been carried by flood and ice from the great deposits in the Rocky Mountains of *Montana* [italics ours], far down the Yellowstone and Missouri Rivers, to be lodged in the banks and bars of the rivers in what are now Dakota, Minnesota, and even Illinois and Missouri (Holmes 1903).

With time, however, Holmes changed his mind about the origin of some of the obsidian found in Ohio Hopewell:

> The most remarkable instance known of the wide distribution from the quarry source of obsidian artifacts is that of a deposit of knives in an Ohio mound. Hundreds of carefully chipped blades of medium and large size...were obtained from a burial mound in Ross County, the nearest source of supply being the Yellowstone country, upward of 1500 miles away. It is, however, regarded as probable that these implements, on account of their remarkable forms, were derived from the [obsidian] mines of Mexico, still more distant, rather than from any northern source (Holmes 1919:227).

The long-distance transfer of quantities of once-suspected Rocky Mountain obsidian to Hopewell sites for mortuary purposes is well attested:

> Adjacent to the burial was a large deposit of several hundred pounds of obsidian or volcanic glass. Encircling the burial and accompanying phenomena was a border of boulders. The obsidian was in fragments, chunks, and chips, clearly the raw material used in fashioning obsidian knives and ceremonial spear- and arrowpoints....The nearest source of obsidian supply was known to be the Rocky Mountains, and the question had been mooted whether these artifacts had been manufactured by the Hopewell artisans, or had been produced

> ready-made from far Western tribes. Here, at last, was the answer. Many of the fragments of the raw material displayed bruised and battered edges, the result of its being carried pickaback halfway across the continent from the far-distant source of supply. It seems logical to suppose that the burial in this mound was that of the master flint-chipper of the community and that the material of his craft had been buried with him as a tribute to his important office (Shetrone 1930).

While such particulars are intriguing and of considerable interest, the transfer of obsidian from the Obsidian Cliff plateau to prehistoric peoples far distant from the source, into the Ohio Valley (and elsewhere), is no longer a matter for conjecture.

The mechanisms by which obsidian was translocated from the Obsidian Cliff plateau source to geographically distant destinations are not known. Overland transport along trails or over water are usually suggested. That the Yellowstone River would have been the gateway or passageway is likely, with continuation via one or more exchange events to a down-stream corridor (or corridors) leading to the Mississippi. Obsidian may have been traded, "utilizing a generalized regional exchange system involving trading partners" (Anderson et al. 1986). To date, materials exchanged or traded for the obsidian which are known to be diagnostic for Hopewell, i.e., Snyders points and Havana Ware, have not been found in the Yellowstone drainage, on the Obsidian Cliff plateau, or in the vicinity (Holmes 1903 to the contrary). That void may reflect the transfer of obsidian from the source eastward by indigenous peoples who quarried it and transferred it to middlemen.

Or Hopewellian traders went to the quarries and, in a single procurement event, acquired sufficient obsidian to meet their needs (Griffin 1965). In any case, the considerable cost incurred and energy expended in a process that involved interaction on both intra-regional and interregional scales were very likely inspired by ideological as well as utilitarian motives (cf. Brose 1978, 1990). The 300 kg (660 lbs) of obsidian found cached at the Hopewell site, for example, attests to the importance, value, and energy involved in moving this high-density raw material over distances, in this case over more than 680 km (1500 mi).

It remains that obsidian outcrops in Yellowstone National Park did provide the majority of the obsidian which met Hopewellians' special needs. The single source, or single-acquisition event, hypothesis, as applied to Hopewell, requires replacement in view of the fact that Hopewell obsidian was imported from multiple sources. That fact necessitates adopting a model which provides for multiple independent procurement events. Accordingly, "evidence for multiple source locations for Hopewellian obsidian would support a model of a more gradual or sporadic appearance of obsidian in the Midwest, either through down-the-line trade or repeated procurement expeditions, and over a longer span of time" (Hatch et al. 1990). The timing of procurement at the sources and of transfer to use destinations is critical to a developing models sufficient to explain such processes. More attention must be paid to developing time-controlled obsidian use vectors upon which such models can be firmly constructed and made testable.

Chapter 5

NATIONAL HISTORIC LANDMARK CONSIDERATIONS

by Leslie B. Davis

Landmark Boundary

The boundary for the Obsidian Cliff National Historic Landmark was determined by extensive reconnaissance and an inventory of archaeological features on the plateau. Those features and associated prehistoric debris are distributed extensively across the Obsidian Cliff rhyolite plateau. The defined Landmark perimeter thus corresponds closely to the topographic limits of the plateau formed by that volcanic flow.

Significance

The Obsidian Cliff National Historic Landmark will occupy a unique position in national prehistory as a singularly important source of lithic materials for the early American Indians of interior western North America. Significant on a continental level in the area of indigenous American populations, the Obsidian Cliff plateau is recognized as an exceptionally well-preserved, heavily utilized lithic source that served the utilitarian imperatives and ceremonial requirements of early native peoples over a large area of North America for more than 11,000 years.

Under the National Historic Landmark thematic framework (National Park Service 1987), the Obsidian Cliff plateau lithic source is important for its association with Theme I, Cultural Developments: Indigenous American Populations; subtheme I.A. The Earliest Inhabitants, and the following facets:

Facet I.A.1., **The Early Peopling of North America**, is pertinent to Obsidian Cliff because the earliest acknowledged technocomplex in western north American (Early Prehistoric period [Mulloy 1958], or Paleoindian Period [Frison 1991], Clovis [11,500-11,000 B.P.]), evidently did utilize local obsidian (Arthur 1966b). The Yellowstone Rhyolite Plateau was freed from Cordilleran ice by the end of the Pinedale glaciation more than14,000 B.P. (Whitlock 1993), which enabled access to and exploitation of bedrock obsidian by Early Prehistoric period peoples who reached that area south of the northern ice sheets via the Rocky Mountain trench or Rocky Mountain front and foothills routes. Thus, any possible "Pre-Clovis" precursors who might have frequented the plateau prior to 11,500 B.P. would have found the Obsidian Cliff plateau accessible.

Facet I.A.11., **Archaic Adaptations of the Plains**, is pertinent to the Obsidian Cliff plateau because all of the Middle Prehistoric period, or Plains Archaic period, archaeological entities known for the Northwestern Plains and Central and Northern Rockies acquired or otherwise obtained obsidian from the Obsidian Cliff plateau during the 7,500-1,700 B.P. time period.

Facet I.A.21., **The Big Game Hunters**, of subtheme I.A., Post-Archaic and Pre-Contact Developments, is pertinent to the Obsidian Cliff plateau because some of the technocomplexes distinguished within the Early Prehistoric period within the Northwestern Plains and Rocky Mountains used obsidian from the Obsidian Cliff plateau from 700 to 200 B.P. That use was particularly heavy during the Late Plains or Old Women's phase (700 to 200 B.P.).

Facet I.B.10., **Plains Hunters and Gatherers**, of subtheme I.B., Post-Archaic and Pre-Contact Developments, subsumes all of the prehistoric cultures that utilized the Obsidian Cliff plateau, as enumerated under I.A.1., I.A.11, and I.A.21. above, because hunting and gathering was the stable generalized subsistence strategy that characterized adaptations throughout Northwestern Plains and Rocky Mountain prehistory. Topical facets I.C.2., Prehistoric Technology, and I.C.8., Prehistoric Economics/Trade, sub-theme I.C., Prehistoric Archaeology, are applicable to the Obsidian Cliff plateau since the procurement of lithic raw material, lithic tool production, and associated industrial activities predominated at that location and because surplus obsidian was a valued economic and ceremonial commodity that figured in prehistoric trade networks.

Historic Context

The Obsidian Cliff plateau is nationally significant on several levels. First, it is recognized by archaeologists as an outstanding example of a prehistoric quarry, with associated processing stations and possible occupation sites. (Many prehistoric occupation sites that demonstrate obsidian reduction activities are known from around the Obsidian Cliff plateau, but are outside the proposed Landmark boundary.) Within this volcanic flow are numerous quarries that amply testify to the suitability and utility of local obsidian for artifact production. Obsidian from this source was highly prized by others and extensively traded. The Obsidian Cliff plateau possesses exceptional qualities that illustrate and are useful for interpreting the cultural heritage of the United States. It offers superlative opportunities for scientific study and it retains a high degree of integrity of location, setting, feeling, and association.

Beginning nearly 12,000 years ago, this obsidian was deposited in archaeological sites from the Central Rockies across the Great Plains into the Midwest, into the Columbia Plateau, and possibly the Great Basin. Obsidian mined from bedrock on the Obsidian Cliff plateau and also collected as redeposited cobbles from the overlying glacial till was utilized differentially by occupying hunter-gatherer groups throughout regional prehistory, from the initial Early Prehistoric period Clovis complex (11,500-11,000 B.P.) to the end of the Late Prehistoric period (ca. 200 B.P.) (Davis 1972a,b). Only systematic, sustained excavation can establish which specific prehistoric human groups actually mined rather than surface collected obsidian from this lithic source area, as well as when and where on the plateau each group worked. The degree of reliance on Obsidian Cliff plateau obsidian varied with cultural affiliation, both temporally and spatially, in response to diverse static and dynamic natural and traditional factors that were operational at different times in different places.

The following discussion provides a qualitative and nominally quantitative, replicable technical baseline for describing and thereby differentiating obsidian utilization patterns characteristic for each regional prehistoric culture (Davis 1972a) (Table 2). The archaeological affiliation for obsidian use was inferred by matching hydration ages, for prehistoric obsidian samples taken from 134 sites throughout the Northwestern Plains and Northern Rockies, with the proposed temporal span for each archaeological entity, as established by radiocarbon dating. The respective archaeological cultures in this region are recognized on the basis of diagnostic projectile points associated with and therefore typical for each. The derived differential obsidian use preferences reflect variations within the developed data base, which may or may not be representative of the underlying archaeological realities. The low percentage of the artifacts attributed to the Early Prehistoric period is partly a function of small sample size (Davis 1972a). It was assumed, in the absence of source data (Davis 1972a) that the Yellowstone rhyolite plateau was the only or predominant source of the obsidian sample analyzed in that study. The instrumental analysis of archaeological obsidian from 27 (20%) of those sites attributed 91 percent of the obsidian to sources within the Yellowstone rhyolite plateau: 56 percent from Obsidian Cliff, 32 percent from the FMY/Willow Park/ Canyon Junction source, and 3 percent from Teton Pass; 9 percent were not attributed to a specific geological source (Davis 1972a).

The most notable intervals of intensified obsidian use in the Northwestern Plains and Northern Rocky Mountains occurred during the Late Middle Period Pelican Lake (18.3%) and terminal Late Period Old Women's (32.5%) phases (Davis and Zeier 1978). Increased population, expanded mobility and territoriality, and the development and operation of wide-ranging obsidian trade networks may account for that heightened obsidian utilization. It is perhaps significant that Obsidian Cliff plateau obsidian reached Hopewellians late in the Pelican Lake phase, ca. 1870-1770 B.P. when obsidian use was so prominent and widespread in the Rockies and contiguous Northwestern Plains region (Davis 1972a,b).

All of the regional prehistoric societies that occupied the Obsidian Cliff plateau area were hunter-gatherers. However, the various societies to which the obsidian was traded varied substantially in subsistence, settlement, sociopolitical and ceremonial organization, and complexity over time and space. The Obsidian Cliff plateau was, as an imbedded, specialized resource extraction site, a constant (if seasonally accessible) element in highly varying product procurement/distribution systems.

The persistent reliance on and dispersal through space of obsidian from the Obsidian Cliff plateau exceeded that

Table 2. Proportionate Usage of Obsidian From the Obsidian Cliff Plateau Quarries Per Archaeological Culture (Technocomplex/Phase) in Time and Space Within the Northern Rockies and Northwestern Plains Regions (Davis 1972a,b).

Period	Time	Culture*	Percent of Obsidian Sample Per Culture	Total % Obsidian/Period
Early Prehistoric	11,500-7,500 BP	Pre-Clovis	2.07	
		Clovis	.56	
		Folsom-Midland	.21	
		Agate Basin-Hell Gap	.83	
		Alberta-Cody	2.21	
		Lusk-Fredrick	2.84	
				8.7
Middle Prehistoric	7,500-1,700 BP	Mummy Cave	8.08	
		Oxbow	4.42	
		McKean	8.07	
		Hanna	6.36	
		Pelican Lake	18.26	
				45.0
Late Prehistoric	1,700-200	Besant-Avonlea	7.80	
		Old Women's	32.60	
				40.4
Historic	post-200 BP	Historic	5.90	
				5.9

*After Reeves (1969).

for any other of the widely distributed lithic materials utilized in the Central and Northern Rockies and Northwestern Plains. Obsidian from the Obsidian Cliff plateau source has been identified over a distance of 910 km (2000 mi) west to east and 364 km (850 mi) south to north. Lag obsidian from the Bear Gulch source in southeastern Idaho (Figure 18) (Michels 1983; Hughes and Nelson 1987; Hatch et al. 1990; Hughes 1992a) appears to have been used in Yellowstone National Park (Cannon 1993; Cannon and Hughes 1993, 1994) and that obsidian was also exchanged over considerable distance to cultures far to the east in Ohio. However, no other single lithic material, including the widely used Knife River flint of western North Dakota (Loendorf et al. 1984; Ahler 1986; Gregg 1987) or Alibates, can claim such popularity as Obsidian Cliff obsidian on a comparable scale in time and space. Ahler (1986) guessed, "that perhaps only obsidian from Yellowstone Park in Wyoming is more widely distributed than KRF in the continent." Other archaeo-logically significant lithics recognized in the region (for example, porcelanite [Fredlund 1976; Clark 1985], Spanish Diggings quartzite [Dorsey 1900; Duguid and Bedish 1968; Reher 1991], and Avon chert [Fields 1983; Cameron 1984]) are more spatially circumscribed in natural occurrence, and were not used as continuously over time and in space as Obsidian Cliff plateau obsidian.

The advantageous qualities of the Obsidian Cliff plateau, as a lithic source eligible for Landmark designation, are: (1) the parent obsidian has a spatially restricted natural occurrence and is expressed principally in bedrock as well as secondary (locally redeposited) context; (2) the obsidian can be positively identified using nondestructive instrumental means; and (3) this obsidian was used over a long period of time and over considerable space by peoples representing different traditions and ethnicities. Each one of these attributes, taken singly, can be replicated at other lithic source areas; however, few other sources, if any, share them all. This assertion is illustrated by reference to alibates agatized dolomite, Florence-A chert, catlinite, and Knife River flint. Alibates has a 3-4 km^2 (1-1.5 mi^2) source area, and Florence-A is restricted to bedrock ledge occurrences along the Arkansas River drainage in Oklahoma and Kansas. The Knife River flint quarries occupy more than 10,000 acres (4,000 ha) (Ahler 1986). However, each of those raw materials is also available in stream and glacial gravels (Ahler 1986; Gregg 1987; Vehik 1986; Swenson 1986) over large areas.

Knife River flint is most similar to obsidian from the Obsidian Cliff plateau in its duration of use and spatial redistribution; however, look-a-like lithics and Knife River flint may be found in gravels throughout the Dakotas, southern Manitoba, and Minnesota (Gregg 1987).

Alibates, too, is widely distributed throughout the Southern Plains, New Mexico, and the Southern Rockies. Unlike Obsidian Cliff plateau obsidian, alibates was prevelant during early Prehistoric times. However it later fell in disfavor and use was consistently low prior to the Antelope Creek settlement at the quarries in the Late Prehistoric period (Lintz 1984). While large artifacts can be linked to quarries, because that is the only place where sufficiently large cobbles or stock would be found, there is often no reliable way to determine the source of smaller artifacts found at distance. Also, small pieces of alibates may not have the characteristic color and banding that allow this material to be identified in the hand. Baldy Hill Jasper is an alabites look-alike. For Florence-A, the peak use was during the Late Prehistoric period in the Southern Plains (Vehik 1986). Similarly, most of the prehistoric use of catlinite dates from the last 500 years (Howell 1940; Sigstad 1972; Gunderson 1991).

Obsidian Cliff plateau obsidian (as are other geologically discrete obsidians) are identifiable by relatively inexpensive, nondestructive analytic techniques. That is generally not true for cherts. A few cherts are visually distinctive, but they are not restricted in natural occurrence nor do they share major chemistries (Luedtke and Meyers 1984) or have long, intensive use histories. Because most cherts, catlinite (Howell 1940; Gundersen and Tiffany 1986; Gundersen 1991; Howell 1940), and Knife River flint (Ahler 1986) have "look-a-likes," as does alibates, source identification can be problematic. For cherts, sourcing often depends upon neutron activation, a destructive, expensive analytic technique that requires a large number of samples for source characterization (Luedtke and Meyers 1984). Thus, in general, sourcing problems exist for most non-obsidian lithic resources. Therefore, they cannot be definitively identified visually or geochemically.

Obsidian Cliff plateau and associated obsidian-use sites are also relatively free of historic disturbance because they have been in federal protective ownership for more than 120 years. That is not the case at many other major quarries and their associated processing and campsites. Many lithic source locations were utilized only long enough to obtain raw material. Material was then removed to camps in off-quarry areas for further processing which varied in the extent to which further reduction was carried out. Those camps are typically in nearby stream valleys where floodplains and terraces have been extensively developed and adversely affected by recent intrusions (roads, power lines, collecting, plowing). As a result, while the quarries may have been protected (possibly because they were located in rough terrain or lacked sufficient soil), the surrounding associated campsites and processing areas have often been disturbed and some even eliminated.

Other source areas have been farmed, ranched, and/or variously developed with the resulting destruction of quarry features and displacement and breakage of lithic debris by vehicle traffic. Animals milling about in the confined area such as a corral or pasture have the same effects. Those kinds of disturbances have adversely affected most major quarries and their associated processing and campsites because they are in private or mixed ownership or have only recently gained protected status. For instance, Alibates became a National Monument in 1965. Most major chert quarry sites in Montana, other than the California Creek quarries (24DL6) (which are listed on the National Register of Historic Places and are located on State-owned property [Davis et al. 1988b]), occur on private land and are unprotected. Some chert quarry sites in limestone have been destroyed by limestone quarrying and still others, such as the Three Waters Quarries at the Schmitt site (Davis 1982a), are threatened with commercial consumption in the long term. Other examples are Flint Ridge and the Knife River quarries which extend over many landownerships. Much of the Knife River quarry/workshop area has been cultivated (Ahler 1986), while the integrity of the Flint Ridge quarry/workshops has been severely impacted by historic quarrying and farming (Yerkes et al. 1988). Also, while the detrimental effects of indiscriminant surface collecting, and sometimes the potholing of quarry depressions to collect artifacts, are difficult to assess. Those processes have seriously diminished the public values of many of the larger scale prehistoric quarry sites.

Furthermore, in the case of the Obsidian Cliff plateau, where the societies occupying the source area were hunter-gatherers throughout prehistory, the prehistoric societies to which the material was traded varied substantially in subsistence, settlement, sociopolitical and ceremonial organization, and thereby complexity over time and space. The Obsidian Cliff plateau was, in essence, one constant element in a raw material procurement and distribution system that involved a variety of cultures over time. That unique circumstance is understood as a consequence of the analytical potential of obsidian, namely, through geochemistry for sourcing and hydration age analysis for chronometric dating.

Potential To Yield Significant Information

Although Obsidian Cliff is commonly identified in the archaeological literature as a major obsidian source, the source itself had never been studied in detail. Data-based reconstructions of multiple aspects of obsidian procurement, including quantity of obsidian extracted, quarrying intensity, technological attributes of discarded artifact detritus, and quarry feature morphology and preservation, and, in effect, site formation and deformation, are not now possible. The lack of such basic investigations has misled some to conclude that insufficient obsidian was extracted from the Obsidian Cliff plateau quarries to have supplied obsidian for redistribution out onto the Plains, Prairies, and elsewhere east of the Central Rockies of Wyoming (cf. Hoffman 1961).

Subsurface investigation of the quarry features and surrounding workshops would reveal attributes central to understanding prehistoric knowledge of bedrock geology and mining techniques. The presently unknown depth and scale of quarried features and debitage deposits in workshops disallows estimation of labor commitment, temporal intervals, duration of mining, and other factors of importance in understanding lithic procurement behavior patterns among diverse prehistoric peoples. Such knowledge would enable construction of a mining event sequence, use chronology, and inferences regarding quarrying technology and orientation. The extraction and production of surplus obsidian intended for long-distance use, transfer, and trade are basic problems that can be addressed through investigations at the Obsidian Cliff plateau obsidian source.

The systematic excavation of archaeological loci within the Obsidian Cliff National Historic Landmark has the potential to yield important information (National Register of Historic Places Criterion D) regarding the use history of this key lithic resource area throughout interior western North American prehistory and regarding the broader problem of intercultural transactions or diffusion processes involved in the exportation of obsidian to distant users.

Association With Events That Have Contributed Significantly to Broad Patterns of Our History

It is probable that obsidian from the Obsidian Cliff plateau of Wyoming, imported by Hopewell people of Ohio, figured in the definitive demonstration of obsidian dating (Friedman and Smith 1960; Evans and Meggers 1960). At that time, of course, techniques for sourcing parent obsidian had not been applied to that archaeological problem.

Obsidian collected from the Obsidian Cliff plateau thus played an important role in the development and application of geochemical analyses to archaeological materials for problem solving. In the late 1950s and the early 1960s, the obsidian hydration dating technique was introduced by geochemists to archaeologists as a promising new chronometric method (Friedman and Smith 1959, 1960; Evans and Meggers 1960). In the mid-1960s, interest in determining the source(s) of obsidian found in Hopewell sites led to collaborations among archaeologists and physicists, chemists, and geologists (Frison et al. 1968). Obsidian hydration dating is now widely applied within obsidian-providing geocultural areas of the world, to solving geological (Friedman et al. 1973; Pierce et al. 1976; Adams 1990; Adams and Locke 1992) as well as archaeological dating challenges (Davis 1966b, 1972a,b, 1986; Frison 1974; Davis and Zeier 1978; Nelson 1984; Wright and Chaya 1985; Wright et al. 1990; Hughes, various; and numerous others). This association with events that have made significant contributions to the broad patterns of our history qualifies under National Register Criterion A.

Elucidation of prehistoric obsidian trade and other intercultural connections (Anderson et al. 1986; Hughes and Nelson 1987; Baugh and Nelson 1988) depends upon the ability of the analyst to attribute the obsidian to specific geological sources. This desire has contributed to the evolution of applied geochemical analytical techniques such as neutron activation, atomic absorption spectroscopy, and particle-induced x-ray emission analysis. Recent studies of the enduring Ohio Hopewell obsidian problem have combined and integrated hydration and compositional analyses (Hatch et al. 1990; Hughes 1992a).

Following the successful application of bulk and trace element techniques to obsidian, elemental analysis ("finger-printing") has been applied to other archaeological stone materials such as galena, catlinite, turquoise, copper, and chert. Such instrumental analyses are now routinely applied in American archaeological problem solving (Rapp 1985).

Ongoing research into the factors that influence the rate at which obsidian hydrates (effects of atmospheric temperature, soil temperature and humidity, and geochemistry) and the validity of artificially induced rates of hydration will yield results essential to understanding Obsidian Cliff plateau quarrying history (cf. Ross and Smith 1955; Friedman and Smith 1960; Weaver and Stross 1965; Friedman et al. 1963, 1966, 1970, 1994; Michels and Bebrich 1971; Michels 1973; Friedman 1976; Taylor 1976; Friedman and Long 1976a,b; Laursen and Lanford 1978; Michels and Tsong 1980; Michels et al. 1983; Friedman and Trembour 1978, 1983; Trembour and Freidman 1984a,b; Trembour et al. 1986; Stevenson et al. 1989; Ericson 1988; Stevenson et al. 1987, 1989.

It is clear that obsidian from the Obsidian Cliff plateau played an important role in the development and application of obsidian hydration dating (Friedman and Smith 1960) and in the geochemical fingerprinting of obsidians, both of which techniques are currently accepted and applied to archaeological obsidians worldwide.

Summary

The intermittent yet long-term temporal, multicultural utilization of obsidian from the Obsidian Cliff plateau, as a basic industrial, economic, and exported commodity throughout the 11,500-year-long regional prehistoric culture sequence, establishes the Obsidian Cliff plateau lithic source as significant. The Obsidian Cliff plateau is of exceptional importance for understanding the dynamics of prehistoric hunter-gatherer lithic procurement, production, utilization, and trade/exchange systems and patterns in western interior North America and interregionally.

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Appendix A. Summary Data For Obsidian Cliff Plateau Quarry/Workshop Loci: Landform, Elevation, Distance to Water, Exposure, and View.

Appendix A. Summary Data For Obsidian Cliff Plateau Quarry/Workshop Loci: Landform, Elevation, Distance to Water, Exposure, and View.

Locus	Landform	Elevation (a.m.s.l.) (ft/m)	Nearest Water/Source	Exposure	View
1	plateau top	7950/2423	600 m/Obsidian Creek	all directions	limited
2	plateau top	7970/2429	700 m/Obsidian Creek	all directions	good
3	obsidian flow/ plateau top	8000/2438	800 m west/Obsidian Creek	all directions	good
4	low ridges atop flow	8010/2441	200 m east/glacial kettle pond	all directions	forest obscures
5	slope near drainage	7980/2432	350 m east/glacial kettle lake	northeast	fair (100-200 m)
6	slope on drainage head near flow top	7910/2411	450 m southeast/glacial kettle lake	northeast	obscured by forest (100-200 m north-northeast)
7	drainage slope	7780/2371	75 m east/perennial spring-fed stream	east-northeast	obscured by forest (100 m east)
8	drainage slope	7680/2341	150 m east/spring-fed stream	northeast	limited in all directions
9	ridgetop	7650/2332	225 m east/spring-fed stream	ridgetop, all directions	obscured by forest
10	slope	7700/2347	adjacent/stream	southwest	100 m southwest; obscured by forest and slopes
11	slope	7650/2332	350 m west/Obsidian Creek	west	distant to west; limited by forest in other directions
12	slope	7900/2408	500 m west/Beaver Lake/Obsidian Creek	west	distant to west; obscured by forest
13	slope	7850/2393	350 m west/Beaver Lake/Obsidian Creek	southwest	distant to southwest; obscured by forest and slope
14	slope	7850/2393	350 m southwest/ spring-fed creek	southwest	distant to southwest; limited by forest and slopes

15	slope and plateau rim	7900/2408	250 m southwest/ spring-fed stream	south-southwest	distant to southwest; obscured by forest and slopes
16	flow/plateau top	8000/2438	350 m northeast/ glacial kettle lake	all directions	limited by forest
17	flow/plateau top	7980/2432	400 m southeast/ glacial kettle lake	all directions	obscured by forest
18	slope/bench	7700/2347	250 m west/ Obsidian Creek	west	distant to west; obscured by forest and slopes
19	slope	7890/2405	400 m northwest/ spring-fed stream	southwest	limited by forest
20	slope	8000/2438	525 m west/spring-fed stream	southwest	200 m west; obscured by forest otherwise
21	flow/plateau top	8180/2493	1 km west/spring-fed stream	all directions	limited by forest and glacial
22	slope	8130/2478	550 m east/ permanent unnamed lake	northeast	200 m east; obscured by forest and slopes
23	ridge and slope	8170/2490	300 m south/glacial kettle lake	south and west	limited by forest and slope in all directions
24	slope and bench	8100/2469	400 m west/spring-fed stream	south and west	obscured by forest
25	slope	7900/2408	275 m west/spring-fed stream	west	limited by forest and slope
26	slope	7900/2408	75 m west/spring-fed stream	west	150 m west and south; obscured by forest and slopes
27	talus slopes, cliffs and benches	8000/2438	150 m west/spring-fed stream	west	100-200 m west; obscured by forest and slope
28	flow/plateau top and drainage slope	8050/2454	150 m south/spring	south	limited by forest and slope
29	flow top and drainage slope	8100/2469	275 m southwest/ spring	south	obscured by forest

30	plateau edge and slope	7960/2426	200 m south-southwest/spring	southwest	400 m southwest; obscured by forest and slope
31	slopes and ridges	7920/2414	250 m southwest/ spring	south	200-300 m south; obscured by forest and slope
32	slope	7950/2423	375 m west/spring-fed stream	west	200 m west; obscured by forest and slope
33	draw slopes and flow plateau top	8030/2448	450 m northwest/ Obsidian Creek	northwest	200 m northwest
34	draw slope and flow/plateau top	8120/2475	100 m south/spring	southeast	100 m south-southwest
35	ridges and slopes	7900/2408	375 m south/stream	south	200 m south; obscured by forest and slopes otherwise
36	draw slope	7900/2408	adjacent/stream	south	obscured by forest and slopes
37	slope	7820/2384	200 m south/stream	south	250 m south; obscured by forest otherwise
38	slope	7820/2384	100 m south/stream	south	100 m southwest; obscured by forest and slopes
39	slope	7730/2356	100 m west/stream	west	200 m west; obscured by forest and slopes otherwise
40	slope	7710/2350	100 m west/stream	west	250 m west; obscured by forest and slopes otherwise
41	ridge-slope	8010/2441	275 m southwest/ spring-fed stream	west	150 m west; obscured by forest and slopes
42	drainage slope	8040/2451	400 m west/spring-fed stream	west	200 m west; obscured by forest and slopes
43	plateau/flow top	8160/2487	100 m west/glacial kettle pond	all directions	limited by forest and glacial hills

44	plateau top	8130/2478	400 m south-southeast/spring-fed stream	southeast	400 m southeast
45	drainage slope	8100/2469	300 m south-southeast/spring-fed stream	south	200-300 m southeast; obscured by forest and slopes
46	slope	8000/2438	200 m south/spring	southwest	200 m south and southwest; obscured by forest and slopes
47	slope	7950/2423	100 m southwest/ spring-fed stream	southwest	150 m southwest; obscured by forest and slope
48	alluvial fan and valley bottom	7950/2423	150 m southeast/ stream	southeast	100 m east-southeast; obscured by forest and slopes
49	slope and valley bottom	7950/2423	100 m northeast/ stream	east	good to the east, northeast, and southeast
50	slopes and flow/plateau top	8150/2484	275 m southeast/ spring	south-easterly	200 m east and southeast
51	slope	7950/2423	150 m east/stream	east	200 m east and southeast
52	slope and flow/plateau top	7900/2423	75 m southwest/ glacial kettle pond	south-easterly	75 m southeast; obscured by forest and slopes
53	slopes	7750/2362	150 m east/ Solfatara Creek	east	150 m east; obscured by forest and slope
54	slope	7740/2359	225 m east/ Solfatara Creek	east	250 m east and southeast
55	slope	7700/2347	200 m southeast/ Solfatara Creek	southeast	distant to the east, south, and southeast
56	slopes and ridges	7680/2341	adjacent/stream	southeast	distant to the east and north
57	slope	7720/2353	200 m east/stream	southeast	distant to southeast; obscured by forest and slope

58	slope	7670/2338	300 m south/ Solfatara Creek	south	400 m south; obscured by slope and forest
59	slope	7680/2341	100 m southwest/ stream	southwest	100 m southwest; obscured by forest and slope

Appendix B. Summary Data For Obsidian Cliff Plateau Quarry/Workshop Loci: Vegetation Cover, Soils, Gemorphology, Surface Involved, and Surface Visibility.

Appendix B. Summary Data For Obsidian Cliff Plateau Quarry/Workshop Loci: Vegetation Cover, Soils, Gemorphology, Surface Involved, and Surface Visibility.

Locus	Vegetation Cover	Soils	Geomorphology	Surface Involved (sq/m)	Surface Visibility
1	lodgepole pine	weathered glacial till	glacially weathered subangular, subrounded to rounded nodules	150	100% burned
2	lodgepole pine	glacial till	glacial origin on the flow top rounded and abraded cobbles	1500	100% burned
3	lodgepole pine	glacial till	weathered glaciation created low ridges formed of till on top	50	100% burned
4	lodgepole pine	glacial till	obsidian flow/plateau	400	100% burned
5	lodgepole pine	glacial till	weathered, glaciated deposits	50	100% burned
6	understory and canopy	colluvium and glacial till	glacial till or colluvium with reworked till	5	lightly burned
7	some ground cover, understory and canopy	colluvium and glacial till	weathered till and colluvium	75	moderately burned
8	understory and canopy	colluvium and glacial till	weathered till and colluvial deposits	5	lightly burned
9	understory and canopy	colluvium and glacial till	weathered till and colluvium	2	lightly burned
10	lodgepole pine	colluvium	bedrock exposed	25,000	lightly burned
11	lodgepole pine	colluvium and regolith	weathered bedrock outcrops	50	burned moderately
12	lodgepole pine	regolith	weathered regolith	500	burned intensely
13	lodgepole pine	colluvium and regolith	weathered deposits	50,000	intensely burned
14	lodgepole pine	colluvium and regolith	weathered deposits	1500	lightly burned
15	lodgepole pine	colluvium, regolith, and bedrock	obsidian outcrops	250	intensely burned

Locus	Vegetation Cover	Soils	Geomorphology	Surface Involved (sq/m)	Surface Visibility
16	lodgepole pine	glacial till	glacial till with rounded rhyolite and obsidian	75	lightly burned
17	lodgepole pine	glacial till	weathered glacial till	250	100% burned
18	lodgepole pine	colluvium	weathered rhyolite and obsidian	25	lightly burned
19	lodgepole pine	colluvium	weathered subrounded and subangular obsidian nodules	6000	moderately burned
20	lodgepole pine	colluvium	weathered	2625	lightly burned
21	lodgepole pine	glacial till	weathered glacial till	500	100% burned
22	lodgepole pine	glacial till and colluvium	weathered bedrock	450	100% burned
23	lodgepole pine	glacial till and colluvium	weathered glacial till and colluvium	500	100% burned
24	lodgepole pine	glacial till and colluvium	glacial till and colluvium	7000	lightly burned
25	lodgepole pine	colluvium	weathered bedrock	10,375	intensely burned
26	rocky talus slopes with some lodgepole pine	weathered colluvium	cultural and natural obsidian	22,500	intensely burned
27	lodgepole pine	weathered bedrock, colluvium and glacial till	major obsidian flow, weathered deposits in till and colluvium	70,000	moderately burned
28	lodgepole pine	glacial till, colluvium	weathered	7500	100% burned
29	lodgepole pine	glacial till and colluvium	weathered bedrock	250	100% burned
30	lodgepole pine	glacial till and weathered bedrock	glacial till and weathered bedrock	350	lightly burned
31	lodgepole pine	glacial till	weathered bedrock	26,250	lightly burned
32	lodgepole pine	bedrock and talus	weathered bedrock and colluvium	25,000	lightly burned

Locus	Vegetation Cover	Soils	Geomorphology	Surface Involved (sq/m)	Surface Visibility
33	lodgepole pine	colluvium and glacial till	weathered bedrock	20,000	moderately burned
34	lodgepole pine	colluvium and glacial till	bedrock and colluvium	3300	100% burned
35	lodgepole pine	colluvium and glacial till	bedrock and colluvium	2000	lightly burned
36	lodgepole pine	colluvium, glacial till	weathered bedrock	500	partly burned
37	lodgepole pine	slopewash and colluvium	weathered bedrock	400	unburned
38	lodgepole pine	colluvium	colluvial deposit	1000	lightly burned
39	lodgepole pine	colluvium	colluvial deposit	3000	lightly burned
40	lodgepole pine	colluvium	colluvial deposit	300	unburned
41	lodgepole pine	colluvium	weathered bedrock or colluvial deposit	5	100% burned
42	lodgepole pine	colluvium and glacial till	obsidian and rhyolite bedrock	225	100% burned
43	lodgepole pine	glacial till	weathered bedrock	5	100% burned
44	lodgepole pine	glacial till, colluvium and weathered bedrock	weathered bedrock or talus deposits	22,000	100% burned
45	lodgepole pine	colluvium	obsidian and rhyolite bedrock	700	100% burned
46	lodgepole pine	talus and weathered bedrock	obsidian and rhyolite	250	100% burned
47	lodgepole pine	talus, weathered bedrock	obsidian and rhyolite bedrock	30,000	100% burned
48	lodgepole pine	alluvial gravels	alluvial fan of obsidian and rhyolite	20,000	intensely burned
49	lodgepole pine	colluvium and alluvium	mineral deposits associated with past geothermal activity	150,000	unburned

Locus	Vegetation Cover	Soils	Geomorphology	Surface Involved (sq/m)	Surface Visibility
50	lodgepole pine	colluvium, glacial till	obsidian and rhyolite bedrock	20,000	intensely burned
51	lodgepole pine	slopewash and weathered bedrock	bedrock and weathered bedrock	40,000	100% burned
52	lodgepole pine	colluvium, glacial till	weathered colluvium and glacial till	30,000	lightly burned
53	lodgepole pine	colluvium and weathered bedrock	obsidian and rhyolite bedrock	22,500	lightly burned
54	lodgepole pine	colluvium	obsidian and rhyolite bedrock	7000	100% burned
55	lodgepole pine	colluvium, alluvial gravels	weathered bedrock and talus, fluvial deposits	22,500	100% burned
56	lodgepole pine	colluvial	obsidian and rhyolite bedrock	1000	lightly burned
57	lodgepole pine	colluvium	obsidian and rhyolite bedrock	7500	100% burned
58	lodgepole pine	colluvium	obsidian and rhyolite bedrock	50	lightly burned
59	lodgepole pine	colluvium	obsidian and rhyolite bedrock	7500	lightly burned

Appendix C. Summary Data For Obsidian Cliff Plateau Quarry/Workshop Loci: Archaeological Features, Obsidian Quality, and Artifacts Observed.

Appendix C. Summary Data For Obsidian Cliff Plateau Quarry/Workshop Loci: Archaeological Features, Obsidian Quality, and Artifacts Observed.

Locus	Archaeological Features	Obsidian Quality*	Artifacts Observed
1	trench-like depression 9.5 m long and 4.5 m wide, 0.5 to 1 m deep; with one 1.25 m diameter oval depression 40 m south of trench. Debris forms berm around margins and extends 20 m in all directions	good	cores, blocks, nodules, and reduction debris
2	three 1-1.5 m diameter oval depressions; three smaller oval depressions and large trench-like depression 2.5 m X 1.5 m; and cluster of 6 pits including a 2 m X 1 m trench	good	primary and secondary reduction debris and blocky cores
3	large depression formed by small interconnected pits 5 m X 7 m and 1-1.5 m deep	good	cores and raw material and primary and secondary reduction debris
4	irregularly shaped pits and trenches 20 m X 10 m, about 1.5 m deep	good	blocky cores and raw material and quantities of primary and secondary reduction debris. Two hammerstones formed on round cobbles
5	2 to 3 1 X 1.5 m oval pits 1-1.5 m in diameter and 25-50 cm deep	good	quarry debris in the form of blocky cores and pieces of raw material along with primary and secondary reduction debris
6	single ovoid pit 1 X 1.5 m in diameter and 50 cm deep	good	cores and raw material and primary and secondary reduction debris
7	4 clustered small diameter pits and one small pit nearby	good	blocky cores and raw material and primary and secondary reduction
8	single ovoid pit 1.5 X 2 m and 50 cm deep	good	blocky cores and raw material and reduction debris

Locus	Archaeological Features	Obsidian Quality	Artifacts Observed
9	single ovoid pit 0.5 m in diameter and 30 cm deep	good	raw material and blocky cores and reduction debris
10	maze of trenches and pits 1.75 m deep and 5-25 m in diameter, over a 250 m long distance	good to very good	dense concentration of prepared and unprepared cores, raw material, and primary and secondary reduction flakes
11	two linear adjoining trenches 9 m and 6 m long and 1.5-1.75 m wide, with one pit 1.75 m diameter at end of trench	good	raw material and blocky cores and reduction debris
12	unknown number of subtle pits across an area 25-30 m X 12-15 m, filled with slopewash	good	primary and secondary reduction debris and raw material
13	maze of long trenches and shallow and deep pits 400 m X 125 m	very good	cores, raw material, and reduction debris
14	two trenches 8-9 m long and 2-2.5 m wide, with one 25 m diameter pit; 30 to 40 small 1.5 m diameter pits	good	quarry and reduction debris
15	one 10 m X 6.5 m trench with five irregularly shaped pits	good	quarry and reduction debris
16	one linear weaving trench 35 m long X 1.75 m wide and 1-1.5 m deep	very good	quarry and reduction debris
17	unknown number of small shallow pits	good	quarry debris, flakes, blocky cores, and raw materials
18	one ovoid pit 4 m in diameter and 20-25 cm deep	good	blocky cores, raw material, and reduction debris
19	maze of ovoid pits and a trench	very good	blocky cores, raw material, and quantities of reduction debris
20	stepped or terraced pits over a 75 m X 35 m area	good	reduction flakes, blocky cores, and chunks

Locus	Archaeological Features	Obsidian Quality	Artifacts Observed
21	workshop	good	primary and secondary reduction flakes and interior reduction flakes
22	subtle small ovoid depressions over a 30 m X 15 m area	good	primary and secondary reduction flakes
23	single ovoid pit 2 m in diameter	good	primary and secondary reduction flakes
24	at least 12 and probably more pits and linear trenches occur within a 175 m X 40 m wide area, with depth of 1-1.75 m	good	blocky cores and raw material
25	maze of pits and trenches in 115 X 90 m area	good	block cores, raw material, and reduction debris
26	two pits, one 8 X 4 m, and one 1.15 m in diameter along steep slope	good	quantities of natural and cultural obsidian blocks and cores
27	pits cover a 700 X 100 m area	good	reduction debris, and finished tools in drainage
28	numerous pits (at least 9) and trenches and one hearth and fire-broken rocks	good	quarry and reduction debris, workshop debris, finished tools, and thinning and sharpening flakes
29	one linear trench 8 X 2 m and one 1.5 m diameter pit, with fire-broken rocks nearby	good	workshop debris, including thinning and finishing flakes and fire-broken rocks
30	6-8 small pits 0.5 m deep, covering a 35 m X 10 m wide area	good	blocky cores, raw material, and quarry reduction
31	some pits 15 m in diameter and 2.5 m deep; others are shallow and subtle, within a 350 m X 75 m area	good	blocky cores, raw material, and quarry and reduction debris

Locus	Archaeological Features	Obsidian Quality	Artifacts Observed
32	4 to 5 linear, trench-like depressions; 1 2.5 m X 2 m pit on slope	good	blocky cores, raw material, and primary and secondary reduction debris
33	10 clusters of trenches, pits, and depressions in 200 m X 100 m area	good	blocky cores, raw material, and primary and secondary reduction debris
34	6-10 linear trenches in 59 m X 35 m area	good	quarry and reduction debris and interior reduction thinning and sharpening flakes
35	15 linear trenches in a maze on opposing ridges	good	blocky cores, raw material, and reduction debris
36	2 deep trench-like depressions and single shallow pit	good	blocky cores and raw material and reduction debris
37	3 shallow depressions 1-2 m in diameter and 25-35 cm deep	good	blocky cores and raw material and reduction debris
38	8 deep to shallow linear and ovoid depressions	good	quarry and reduction debris
39	2 linear, trench-like depressions 6-7 m long X 2.5 m wide; 15 pits and trenches 40 m south, 6.5 m to 2.5 m in diameter and 25-75 cm deep	very good	quarry and reduction debris, including interior reduction, thinning, and sharpening flakes
40	5 linear depressions and pits	good	prepared and unprepared cores, bifaces, hammerstone, and interior reduction flakes
41	single pit 2.5 m long X 1.5 m wide and 25 cm deep	good	unprepared cores, raw material, and primary and secondary reduction debris
42	3 irregularly shaped pits at 15 m intervals along steep draw	good	unprepared cores and raw material and reduction debris
43	single trench 2 m long by 1 m wide and 25-30 cm deep	good	unprepared cores and raw material and primary and secondary reduction debris

Locus	Archaeological Features	Obsidian Quality	Artifacts Observed
44	long, deep trench (22 m X 7 m) accompanied by subtle depressions	good	unprepared cores, hammerstone, abrading stones, interior reduction flakes, thinning flakes, and sharpening flakes
45	subtle and shallow infilled depressions	good	unprepared cores and raw material and primary and secondary reduction debris
46	3 large pits 8.5 m long and 2.5 m wide	good	unprepared cores and raw material and primary and secondary reduction flakes
47	no quarry features	good	unprepared cores, raw material, and reduction debris
48	maze of shallow trenches and pits in 80 m X 70 m area	good	reduction flakes, thinning and sharpening flakes, quarry blanks and bifaces, hammerstone, and exotic lithics
49	no quarry features	very good	reduction flakes, interior reduction flakes, thinning flakes, sharpening flakes, quarry blanks and bifaces, hammerstone, and exotic lithics
50	25 pits in 200 m X 100 m area; trenches, pits, and depressions	good	extraction and reduction debris; workshop has many interior reduction flakes, quarry blanks, and bifaces
51	subtle infilled depressions	good	unprepared cores and raw material and primary and secondary reduction flakes
52	15-20 trenches and pits in 400 m X 75 m area	very good	unprepared cores and primary and secondary reduction flakes
53	2 pits	good	unprepared cores and raw material and primary and secondary reduction flakes

Locus	Archaeological Features	Obsidian Quality	Artifacts Observed
54	2 small pits 75 m apart: 2 m X 1 m in diameter	good	unprepared cores and raw material and primary and secondary reduction flakes
55	subtle infilled depressions on slope	good	unprepared cores and raw material and primary and secondary reduction flakes
56	3 to 5 pits 25 to 75 cm in diameter and 20-30 cm deep	good	unprepared cores and raw material, primary and secondary reduction flakes, and thinning flakes
57	single pit 10 m long by 3 m wide	good	unprepared cores and raw material, primary and secondary reduction flakes, and thinning flakes
58	3 to 4 1-m diameter depressions in a 12 m X 4 m area	good	unprepared cores, raw material, and primary and secondary reduction flakes
59	2 clusters: 2 trench-like depressions, one 12 m long X 2.5 m wide and the other 8 m X 2 m, both 75 cm deep. Second is a cluster of pits 30 m X 15 m, with maze of small pits nearby	good	unprepared cores, raw material, and primary and secondary reduction flakes

*The quality distinction as between "good" and "very good" is obviously subjective and not very useful. Numerous varieties of poor grade (from a knapping point of view) obsidian were not sampled since it was the primary and utilized obsidians that were subjected for analysis, first by stoneworkers and later by archaeologists, both differently motivated.

Appendix D. X-Ray Fluorescence Trace Element Chemistries and Source Determinations for Geological and Archaeological Obsidian Specimens Collected During the 1989 Reconnaissance of the Obsidian Cliff Plateau Flow Lithic Source.

Appendix D. X-Ray Fluorescence Trace Element Chemistries and Source Determinations for Geological and Archaeological Obsidian Specimens Collected During the 1989 Reconnaissance of the Obsidian Cliff Plateau Flow Lithic Source.

Specimen Number	Trace Element Concentrations[1] Zn	Ga	Rb	Sr	Y	Zr	Nb	Obsidian Source (Chemical Type)[2]
1	78 ±5	17 ±3	225 ±5	1 ±3	82 ±2	148 ±4	40 ±3	OC
2	75 ±5	17 ±3	223 ±5	2 ±3	77 ±2	153 ±4	43 ±3	OC
3	77 ±5	21 ±3	233 ±5	1 ±3	78 ±2	157 ±4	42 ±3	OC
4	68 ±5	21 ±3	233 ±5	2 ±3	78 ±2	159 ±4	42 ±3	OC
5	72 ±5	19 ±3	228 ±5	0 ±3	75 ±2	154 ±4	42 ±3	OC
6	75 ±5	17 ±3	238 ±5	3 ±3	75 ±2	160 ±4	41 ±3	OC
7	71 ±5	19 ±3	201 ±5	3 ±3	82 ±2	160 ±4	44 ±3	OC
8	77 ±5	22 ±3	230 ±5	2 ±3	76 ±2	158 ±4	42 ±3	OC
9	79 ±5	20 ±3	239 ±5	1 ±3	77 ±2	160 ±4	42 ±3	OC
10	70 ±5	22 ±3	234 ±5	1 ±3	77 ±2	155 ±4	47 ±3	OC
11	79 ±5	21 ±3	235 ±5	2 ±3	81 ±2	158 ±4	43 ±3	OC

Specimen Number	Trace Element Concentrations[1]							Obsidian Source (Chemical Type)[2]
	Zn	Ga	Rb	Sr	Y	Zr	Nb	
12	100 ±6	25 ±3	258 ±5	2 ±3	81 ±2	167 ±4	43 ±3	OC
13	77 ±5	21 ±3	231 ±5	0 ±3	79 ±2	155 ±4	44 ±3	OC
14	75 ±5	20 ±3	239 ±5	1 ±3	81 ±2	161 ±4	45 ±3	OC
15	79 ±6	18 ±4	238 ±6	0 ±3	85 ±2	158 ±4	46 ±4	OC
16	79 ±5	24 ±3	234 ±5	2 ±3	74 ±2	156 ±4	43 ±3	OC
17	70 ±5	19 ±3	230 ±5	1 ±3	78 ±2	159 ±4	44 ±3	OC
18	65 ±5	21 ±3	231 ±5	2 ±3	75 ±2	157 ±4	43 ±3	OC
19	66 ±5	18 ±3	229 ±5	1 ±3	80 ±2	156 ±4	42 ±3	OC
20	74 ±5	21 ±3	230 ±5	1 ±3	76 ±2	156 ±4	45 ±3	OC
21	67 ±6	23 ±3	235 ±5	1 ±3	79 ±2	163 ±4	44 ±3	OC
22	69 ±5	23 ±3	222 ±5	2 ±3	75 ±2	155 ±4	42 ±3	OC
23	72 ±5	21 ±3	234 ±5	1 ±3	81 ±2	159 ±4	44 ±3	OC
24	64 ±5	21 ±3	230 ±5	1 ±3	77 ±2	156 ±4	42 ±3	OC

Specimen Number	Trace Element Concentrations[1] Zn	Ga	Rb	Sr	Y	Zr	Nb	Obsidian Source (Chemical Type)[2]
25	68 ±6	19 ±3	229 ±5	3 ±3	78 ±2	157 ±4	46 ±4	OC
26	74 ±5	17 ±3	220 ±5	1 ±3	73 ±2	151 ±4	41 ±3	OC
27	77 ±5	21 ±3	245 ±5	1 ±3	82 ±2	166 ±4	47 ±3	OC
28	67 ±5	20 ±3	225 ±5	2 ±3	74 ±2	154 ±4	42 ±3	OC
29	65 ±5	25 ±3	236 ±5	2 ±3	80 ±2	159 ±4	42 ±3	OC
30	76 ±5	21 ±3	234 ±5	1 ±3	79 ±2	162 ±4	42 ±3	OC
31	82 ±5	19 ±3	231 ±5	3 ±3	78 ±2	155 ±4	40 ±4	OC
32	67 ±5	22 ±3	238 ±5	2 ±3	82 ±2	160 ±4	41 ±3	OC
33	71 ±5	19 ±3	238 ±5	1 ±3	79 ±2	161 ±4	46 ±3	OC
34	71 ±5	18 ±3	239 ±5	1 ±3	78 ±2	163 ±4	42 ±3	OC
35	69 ±6	17 ±3	234 ±5	4 ±3	79 ±2	154 ±4	42 ±4	OC
36	76 ±5	24 ±3	228 ±5	3 ±3	78 ±2	156 ±4	42 ±3	OC

Specimen Number	Trace Element Concentrations[1]							Obsidian Source (Chemical Type)[2]
	Zn	Ga	Rb	Sr	Y	Zr	Nb	
37	79 ±5	29 ±3	240 ±5	2 ±3	82 ±2	162 ±4	42 ±3	OC
38	71 ±5	19 ±3	236 ±5	2 ±3	80 ±2	157 ±4	45 ±3	OC
39	72 ±5	22 ±3	231 ±5	1 ±3	75 ±2	159 ±4	45 ±3	OC
40	70 ±5	22 ±3	230 ±5	2 ±3	79 ±2	156 ±4	42 ±3	OC
41	67 ±5	24 ±3	219 ±5	1 ±3	73 ±2	153 ±4	36 ±3	OC
42	68 ±5	18 ±3	232 ±5	1 ±3	78 ±2	160 ±4	43 ±3	OC
43	74 ±5	17 ±3	242 ±5	0 ±3	77 ±2	164 ±4	42 ±3	OC
44	71 ±5	20 ±3	229 ±5	0 ±3	81 ±2	157 ±4	44 ±3	OC
45	73 ±5	26 ±3	234 ±5	1 ±3	82 ±2	158 ±4	44 ±3	OC
46	64 ±5	22 ±3	225 ±5	1 ±3	78 ±2	156 ±4	41 ±3	OC
47	69 ±5	20 ±3	230 ±5	2 ±3	77 ±2	159 ±4	43 ±3	OC
48	72 ±5	25 ±3	235 ±5	0 ±3	80 ±2	157 ±4	44 ±3	OC

Specimen Number	Trace Element Concentrations[1]							Obsidian Source (Chemical Type)[2]
	Zn	Ga	Rb	Sr	Y	Zr	Nb	
49	73 ±5	16 ±3	229 ±5	1 ±3	74 ±2	153 ±4	38 ±3	OC
50	82 ±5	24 ±3	246 ±5	0 ±3	82 ±2	167 ±4	46 ±3	OC
51	77 ±5	17 ±3	229 ±5	1 ±3	82 ±2	156 ±4	42 ±3	OC
52	72 ±5	16 ±3	211 ±5	0 ±4	82 ±2	172 ±4	44 ±3	OC
53	76 ±5	22 ±3	259 ±5	3 ±3	81 ±2	163 ±4	46 ±3	OC
54	64 ±5	15 ±3	230 ±5	0 ±3	80 ±2	156 ±4	45 ±3	OC
55	69 ±5	20 ±3	227 ±5	0 ±3	75 ±2	153 ±4	45 ±3	OC
56	67 ±5	19 ±3	232 ±5	2 ±3	79 ±2	161 ±4	39 ±3	OC
57	77 ±5	17 ±3	220 ±5	1 ±3	77 ±2	150 ±4	39 ±3	OC
58	79 ±5	23 ±3	243 ±5	2 ±3	80 ±2	164 ±4	45 ±3	OC
59	64 ±5	25 ±3	223 ±5	1 ±3	79 ±2	158 ±4	44 ±3	OC
60	77 ±5	21 ±3	199 ±5	1 ±3	81 ±2	153 ±4	44 ±3	OC

Specimen Number	Trace Element Concentrations[1] Zn	Ga	Rb	Sr	Y	Zr	Nb	Obsidian Source (Chemical Type)[2]
61	75 ±5	20 ±3	236 ±5	1 ±3	76 ±2	162 ±4	41 ±3	OC
62	76 ±5	18 ±3	229 ±5	1 ±3	76 ±2	156 ±4	41 ±3	OC
63	83 ±5	20 ±3	240 ±5	1 ±3	79 ±2	163 ±4	44 ±3	OC
64	76 ±5	25 ±3	225 ±5	1 ±3	81 ±2	153 ±4	40 ±3	OC
65	65 ±5	18 ±3	220 ±5	1 ±3	75 ±2	150 ±4	44 ±3	OC
66	74 ±5	24 ±3	128 ±5	1 ±3	79 ±2	163 ±4	43 ±3	OC
67	59 ±5	21 ±3	221 ±5	1 ±3	73 ±2	157 ±4	41 ±3	OC
68	70 ±5	20 ±3	231 ±5	2 ±3	75 ±2	160 ±4	43 ±3	OC
69	63 ±6	20 ±3	225 ±5	2 ±3	75 ±2	155 ±4	41 ±3	OC
70	73 ±5	22 ±3	234 ±5	2 ±3	78 ±2	157 ±4	45 ±3	OC
71	73 ±5	17 ±3	226 ±5	1 ±3	79 ±2	156 ±4	39 ±3	OC
72	76 ±5	24 ±3	248 ±5	1 ±3	80 ±2	162 ±4	44 ±3	OC

Specimen Number	Trace Element Concentrations[1]							Obsidian Source (Chemical Type)[2]
	Zn	Ga	Rb	Sr	Y	Zr	Nb	
73	75 ±5	20 ±3	242 ±5	3 ±3	77 ±2	159 ±4	40 ±3	OC
74	85 ±5	19 ±3	248 ±5	1 ±3	83 ±2	162 ±4	45 ±3	OC
75	82 ±5	24 ±3	208 ±5	1 ±3	84 ±2	166 ±4	47 ±3	OC
76	75 ±5	23 ±3	232 ±5	1 ±3	77 ±2	161 ±4	44 ±3	OC
77	63 ±5	17 ±3	224 ±5	0 ±3	78 ±2	159 ±4	43 ±3	OC
78	79 ±5	24 ±3	234 ±5	2 ±3	76 ±2	159 ±4	43 ±3	OC
79	63 ±5	17 ±3	207 ±5	2 ±3	79 ±2	159 ±4	41 ±3	OC
80	73 ±5	21 ±3	254 ±5	1 ±3	82 ±2	168 ±4	48 ±3	OC

Trace element values in parts per million (ppm); ± = pooled estimate (in ppm) of x-ray counting uncertainty and regression fitting error at 200 seconds livetime; all specimens have "OC-89-" catalogue prefixes.

1 Zn = zinc Ga = gallium Rb = rubidium Sr = strontium Y = yytrium Zr = zirconium Nb = niobium

2 OC = Obsidian Cliff plateau

Appendix E. X-Ray Fluorescence Trace Element Chemistries and Source Determinations for Archaeological Obsidian Specimens From Selected Montana Sites.

Appendix E. X-Ray Fluorescence Trace Element Chemistries and Source Determinations for Archaeological Obsidian Specimens From Selected Montana Sites.

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Culturel Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Be	Obsidian Source*	Reference
Antonsen (Hughes 1990c) (24GA660)														
	t-n pt	Lete Pleins	Late	578	54 ±6	21 ±3	179 ±5	36 ±3	45 ±2	292 ±5	57 ±4	744 ±13	BG	Devis and Zeier 1978; Zeier 1983
	Besent pt	Besant	Late	581	62 ±5	13 ±3	177 ±5	41 ±3	47 ±2	297 ±4	57 ±3	707 ±12	BG	
	t-n pt	Late Plains	Late	588	83 ±6	19 ±3	248 ±5	1 ±3	86 ±2	168 ±4	45 ±4	nm.	OC	
	t-n pt	Late Pleins	Late	590	75 ±6	21 ±3	234 ±5	1 ±3	77 ±2	162 ±4	45 ±4	nm.	OC	
	Besent pt	Besant	Late	2088	55 ±5	19 ±3	169 ±5	40 ±3	46 ±2	280 ±4	51 ±3	718 ±12	BG	
	Besent pt	Besent	Late	2089	50 ±5	16 ±3	176 ±5	42 ±3	45 ±2	294 ±4	52 ±3	721 ±12	BG	
	Besant pt	Besant	Late	2090	60 ±6	17 ±3	176 ±5	41 ±3	44 ±2	294 ±5	53 ±4	800 ±12	BG	
	Besent pt	Besant	Late	2091	58 ±5	19 ±3	176 ±5	40 ±3	48 ±2	294 ±4	55 ±3	720 ±12	BG	
	Besent pt	Besant	Late	2092	53 ±5	15 ±3	174 ±5	42 ±3	47 ±2	295 ±4	54 ±3	731 ±12	BG	
	Besent pt	Besant	Late	2093	55 ±5	14 ±3	175 ±5	44 ±3	46 ±2	287 ±4	58 ±3	749 ±12	BG	
	Besant pt	Besant	Late	2094	66 ±5	19 ±3	181 ±5	43 ±3	46 ±2	295 ±4	55 ±3	730 ±12	BG	
	Besant pt	Besent	Late	2095	60 ±5	17 ±3	164 ±5	43 ±3	47 ±2	304 ±4	58 ±3	772 ±12	BG	
	Besant pt	Besant	Late	2026	53 ±5	19 ±3	178 ±5	43 ±3	46 ±2	290 ±4	55 ±3	697 ±12	BG	
	s-n pt	Late Plains	Late	2042	71 ±5	26 ±3	244 ±5	1 ±3	78 ±2	166 ±4	44 ±3	nm.	OC	
	Pelicen Lake pt	Pelican Lake	Middle	2043	63 ±5	20 ±3	170 ±5	41 ±3	49 ±2	288 ±4	52 ±3	731 ±12	BG	
	Besent pt	Besent	Lete	2044	54 ±5	17 ±3	181 ±5	44 ±3	50 ±2	293 ±4	55 ±3	714 ±12	BG	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
Corwin Springs (Hughes 1990c) (24PA195)														
	Pelican Lake pt	Pelican Lake	Middle	671	54 ±5	18 ±3	116 ±5	159 ±3	23 ±2	122 ±4	14 ±3	1219 ±13	UK	Davis 1982b; Davis et al. n.d.b.
	Pelican Lake pt	Pelican Lake	Middle	692	81 ±5	15 ±3	237 ±5	2 ±3	80 ±2	159 ±4	44 ±3	nm.	OC	
Cascade/Ulm (Hughes 1990c) Locality														
	Hell Gap	Hell Gap	Early	2025	73 ±5	18 ±3	234 ±5	2 ±3	76 ±2	152 ±4	45 ±3	nm.	OC	
	Hanna pt	Hanna	Middle	2075	57 ±5	19 ±3	173 ±5	13 ±3	44 ±2	60 ±4	34 ±3	21 ±11	TB	
	Hanna pt	Hanna	Middle	2076	65 ±5	19 ±3	179 ±5	43 ±3	44 ±2	292 ±4	54 ±3	707 ±12	BG	
	Hanna pt	Hanna	Middle	2077	57 ±5	19 ±3	182 ±5	43 ±3	49 ±2	298 ±4	54 ±3	693 ±12	BG	
	Hanna pt	Hanna	Middle	2078	56 ±5	18 ±3	175 ±5	39 ±3	45 ±2	283 ±4	55 ±3	718 ±12	BG	
Jarrett (Hughes 1990c) (24SW651)														
	Bitterroot pt	Mummy Cave	Middle	2027	91 ±5	21 ±3	232 ±5	2 ±3	79 ±2	160 ±4	44 ±3	nm.	OC	Davis 1982b; Aaberg et al. n.d.
	Avonlea pt	Avonlea	Late	2028	96 ±6	20 ±3	252 ±6	1 ±3	85 ±2	169 ±4	41 ±4	nm.	OC	
	t-n pt	Late Plains	Late	2029	93 ±6	17 ±3	238 ±5	3 ±3	81 ±2	163 ±4	48 ±4	nm.	OC	
	Pelican Lake pt	Pelican Lake	Middle	2030	94 ±5	22 ±3	243 ±5	0 ±3	80 ±2	160 ±4	45 ±3	nm.	OC	
	Hanna pt	Hanna	Middle	2031	87 ±5	24 ±3	210 ±5	0 ±3	88 ±2	165 ±4	45 ±3	nm.	OC	
Schmitt (Hughes 1990c) (24BW559)														
	c-t biface	Pelican Lake	Middle	2032	50 ±5	18 ±3	173 ±5	40 ±3	46 ±2	281 ±4	54 ±3	674 ±12	BG	Davis 1982a,b
	c-t biface	Pelican Lake	Middle	2033	57 ±5	17 ±3	164 ±5	37 ±3	45 ±2	273 ±4	50 ±3	636 ±12	BG	
	Pelican Lake pt	Pelican Lake	Middle	2034	80 ±5	19 ±3	231 ±5	3 ±3	77 ±2	155 ±4	42 ±3	nm.	OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
	Pelican Lake pt	Pelican Lake	Middle	2035	82 ±5	18 ±3	204 ±5	3 ±3	83 ±2	164 ±4	46 ±3	nm.	OC	
	Pelican Lake pt	Pelican Lake	Middle	2036	60 ±5	20 ±3	158 ±5	41 ±3	46 ±2	295 ±4	53 ±3	749 ±12	BG	
	Pelican Lake pt	Pelican Lake	Middle	2084	65 ±5	16 ±3	164 ±5	41 ±3	45 ±2	288 ±4	57 ±3	723 ±12	BG	
	Pelican Lake pt	Pelican Lake	Middle	2085	62 ±5	16 ±3	175 ±5	40 ±3	43 ±2	285 ±4	52 ±3	727 ±12	BG	
	Pelican Lake pt	Pelican Lake	Middle	2086	56 ±5	18 ±3	172 ±5	42 ±3	45 ±2	292 ±4	53 ±3	741 ±12	BG	
	Pelican Lake pt	Pelican Lake	Middle	2087	60 ±5	17 ±3	173 ±5	41 ±3	45 ±2	286 ±4	56 ±3	723 ±12	BG	
Salt Springs (Hughes 1990c) (24BW552)														
	s-n pt	Late Plains	Late	2037	97 ±6	13 ±3	175 ±5	41 ±3	47 ±2	289 ±5	58 ±4	753 ±14	BG	Davis et al. n.d.c
	s-n pt	Lake Plains	Late	2038	75 ±6	16 ±3	173 ±5	14 ±3	46 ±2	55 ±4	36 ±4	37 ±12	TB	
	t-n pt	Late Plains	Late	2039	77 ±6	18 ±3	160 ±5	41 ±3	48 ±2	297 ±5	59 ±4	722 ±14	BG	
Thompson Bottom (Hughes 1990c) (24CH425)														
	fl	Late Plains	Late	2040	100 ±8	26 ±4	268 ±6	3 ±3	86 ±3	167 ±5	46 ±4	nm.	OC	Davis 1976, 1982b
	fl	Late Plains	Late	2041	88 ±6	22 ±3	266 ±5	2 ±3	87 ±2	172 ±4	51 ±4	nm.	OC	
	fl	Late Plains	Late	2045	74 ±6	18 ±3	246 ±5	0 ±18	82 ±2	164 ±4	45 ±4	nm.	OC	
	fl	Late Plains	Late	2046	87 ±6	23 ±3	254 ±6	2 ±3	88 ±2	165 ±4	49 ±4	nm.	OC	
	fl	Late Plains	Late	2047	86 ±6	27 ±3	247 ±6	4 ±3	83 ±2	172 ±4	46 ±4	nm.	OC	
Barton Gulch (Hughes 1990c) (24MA171)														
	Ruby Valley pt	Alder	Early	2048	63 ±5	15 ±3	175 ±5	40 ±3	46 ±2	291 ±4	57 ±4	769 ±12	BG	Davis et al. 1988a, 1989a
	ss	Alder	Early	2049	60 ±5	19 ±3	172 ±5	39 ±3	48 ±2	289 ±4	55 ±3	716 ±12	BG	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
	Ruby Valley pt	Alder	Early	2050	79 ±5	21 ±3	170 ±5	15 ±3	73 ±2	339 ±5	55 ±4	966 ±12	PS	
	Ruby Valley pt	Alder	Early	2051	70 ±5	16 ±3	188 ±5	42 ±3	49 ±2	309 ±5	61 ±3	753 ±12	BG	
	Ruby Valley pt	Alder	Early	2052	67 ±5	21 ±3	187 ±5	46 ±3	45 ±2	302 ±4	58 ±3	731 ±12	BG	
	Ruby Valley pt	Alder	Early	2053	61 ±5	13 ±3	176 ±5	41 ±3	48 ±2	298 ±4	59 ±3	743 ±12	BG	
	Ruby Valley pt	Alder	Early	2054	67 ±5	15 ±3	179 ±5	44 ±3	42 ±2	298 ±4	56 ±3	748 ±12	BG	
	(Hughes 1989b)			BG-88A-17	65.5 ±11.3	15.8 ±7.5	185.3 ±5.8	51.3 ±3.1	45.5 ±2.6	323.8 ±5.9	57.5 ±3.7		BG	
				BG-88A-21	67.0 ±9.9	18.2 ±5.7	178.7 ±5.5	45.0 ±3.0	45.2 ±2.4	310.5 ±5.4	58.0 ±3.6		BG	
				BG-88A-40	68.3 ±9.5	15.1 ±6.8	184.4 ±5.6	45.3 ±3.0	39.7 ±2.5	298.9 ±5.4	50.9 ±3.6		BG	
	(Hughes 1989i)			BG 86-2	65.2 ±10.1	17.7 ±6.1	172.1 ±5.5	42.5 ±2.9	38.7 ±2.4	290.3 ±5.2	54.5 ±3.6		BG	
				BG 88-1	78.9 ±9.9	22.1 ±5.5	184.4 ±5.7	47.0 ±3.0	39.9 ±2.9	315.1 ±5.7	55.3 ±3.7		BG	
				BG 88-2	56.9 ±12.2	15.7 ±7.2	180.4 ±5.9	48.6 ±3.1	39.7 ±2.7	288.3 ±5.7	56.0 ±3.8		BG	
				BG 88-3	83.0 ±9.4	19.9 ±5.5	245.1 ±5.9	6.0 ±3.5	70.1 ±2.5	173.3 ±4.6	44.9 ±3.6		OC	
				BG 88-4	64.6 ±8.8	17.3 ±5.4	180.4 ±5.4	48.0 ±2.9	44.3 ±2.4	307.4 ±5.2	59.3 ±3.5		BG	
				BG 88-5	61.5 ±8.7	18.0 ±5.7	179.3 ±5.4	45.4 ±2.9	37.4 ±2.4	293.9 ±5.1	53.9 ±3.5		BG	
				BG 88-6	70.1 ±9.1	18.2 ±5.5	186.7 ±5.6	48.3 ±3.0	41.6 ±2.5	314.5 ±5.4	56.1 ±3.6		BG	
				BG 88-7	73.3 ±8.5	20.5 ±4.6	184.1 ±5.5	49.9 ±2.9	38.8 ±2.4	312.3 ±5.3	58.8 ±3.6		BG	
				BG 88-8	93.0 ±8.0	21.2 ±4.6	254.1 ±5.9	8.4 ±3.0	69.1 ±2.5	177.2 ±4.6	44.3 ±3.5		OC	
				BG 88-9	81.9 ±8.3	27.3 ±4.0	253.2 ±5.9	8.9 ±3.0	68.0 ±2.6	180.7 ±4.6	46.5 ±3.5		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
California Creek (Hughes 1990c) (24DL6)														
	lanceolate	?	Early	2055	58 ±5	18 ±3	180 ±5	42 ±3	46 ±2	295 ±5	54 ±4	732 ±12	BG	Davis et al. 1988b
South Everson (Hughes 1990c) (24BE559)														
	Bitterroot	Mummy Cave	Middle	2056	57 ±5	14 ±3	167 ±5	39 ±3	42 ±2	277 ±4	55 ±3	729 ±12	BG	Davis 1981
	Pelican Lake pt	Pelican Lake	Middle	2057	62 ±5	17 ±3	173 ±5	40 ±3	43 ±2	287 ±4	56 ±3	733 ±12	BG	
	Pelican Lake pt	Pelican Lake	Middle	2058	80 ±5	24 ±3	169 ±5	17 ±3	69 ±2	341 ±4	53 ±3	1014 ±12	PS	
	t-n pt	Late Plains	Late	2059	70 ±6	20 ±4	183 ±5	41 ±3	47 ±2	298 ±5	60 ±4	744 ±13	BG	
	t-n pt	Late Plains	Late	2060	59 ±6	18 ±3	191 ±5	15 ±3	46 ±2	55 ±4	36 ±3	54 ±11	TB	
	Pelican Lake pt	Pelican Lake	Middle	2063	57 ±5	14 ±3	181 ±5	43 ±3	46 ±2	288 ±4	55 ±3	750 ±11	BG	
	t-n pt	Late Plains	Late	2064	65 ±6	20 ±3	181 ±5	41 ±3	43 ±2	293 ±5	54 ±4	709 ±13	BG	
	Oxbow pt	Oxbow	Middle	2065	66 ±5	15 ±3	175 ±5	41 ±3	45 ±2	295 ±4	55 ±3	735 ±12	BG	
	Hanna pt	Hanna	Middle	2066	61 ±5	16 ±3	175 ±5	43 ±3	48 ±2	295 ±4	58 ±3	743 ±12	BG	
	s-n pt	Late Plains	Late	2067	70 ±5	22 ±3	178 ±5	14 ±3	44 ±2	53 ±4	34 ±3	72 ±11	TB	
	s-n pt	Late Plains	Late	2068	267 ±8	29 ±4	305 ±6	1 ±3	227 ±3	306 ±5	295 ±4	nm.	BSB	
Jordan Creek (Hughes 1990c) (24MA126)														
	fl	Avonlea	Late	2061	83 ±8	19 ±5	197 ±6	52 ±3	48 ±2	303 ±5	54 ±4	667 ±17	BG	Davis 1978
	fl	Avonlea	Late	2062	88 ±7	19 ±4	209 ±6	50 ±3	49 ±2	321 ±5	58 ±4	706 ±17	BG	
Crawford Ranch (Hughes 1990c) (24CA451)														
	s-n pt	Late Plains	Late	2069	66 ±6	14 ±4	196 ±5	44 ±3	47 ±2	318 ±5	58 ±4	718 ±14	BG	Davis 1966a

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
	s-n pt	Late Plains	Late	2074	61 ±5	18 ±3	170 ±5	38 ±3	45 ±2	284 ±4	52 ±3	713 ±12	BG	
Highwood Kill (Hughes 1990c) (24CA1002)														
	t-n pt	Late Plains	Late	2070	74 ±6	21 ±3	219 ±5	1 ±3	85 ±2	166 ±4	46 ±4	nm.	OC	
	t-n pt	Late Plains	Late	2071	90 ±6	19 ±4	255 ±6	2 ±3	84 ±2	172 ±4	47 ±4	nm.	OC	
	s-n pt	Late Plains	Late	2072	53 ±5	17 ±3	171 ±5	41 ±3	43 ±2	279 ±4	53 ±3	714 ±13	BG	
	s-n pt	Late Plains	Late	2073	74 ±6	21 ±3	183 ±5	46 ±3	47 ±2	295 ±5	58 ±4	752 ±13	BG	
Carter's Ferry (Hughes 1990c) (24CH1400)														
	Pelican Lake pt	Pelican Lake	Middle	2079	77 ±5	22 ±3	246 ±5	2 ±3	76 ±2	166 ±4	45 ±3	nm.	OC	Shumate 1967
	Pelican Lake pt	Pelican Lake	Middle	2080	55 ±5	15 ±3	172 ±5	39 ±3	45 ±2	282 ±4	53 ±3	711 ±12	BG	
	Pelican Lake pt	Pelican Lake	Middle	2081	62 ±5	18 ±3	188 ±5	44 ±3	47 ±2	300 ±4	56 ±3	754 ±12	BG	
Tunis/Loma (Hughes 1990c) Locality														
	Pelican Lake pt	Pelican Lake	Middle	2082	64 ±5	16 ±3	181 ±5	14 ±3	47 ±2	51 ±4	33 ±3	34 ±11	TB	Shumate 1984
	Pelican Lake pt	Pelican Lake	Middle	2083	57 ±5	14 ±3	178 ±5	42 ±3	45 ±2	286 ±4	54 ±3	725 ±12	BG	
Indian Creek (Hughes 1989b) (24BW626)														
	Hell Gap	Hell Gap	Early	28	71.6 ±+8.6	20.9 ±4.5	235.2 ±5.7	5.8 ±3.4	63.5 ±2.4	165.0 ±4.5	40.6 ±3.5		OC	Davis 1986; Davis and Greiser 1992
	Hell Gap uniface	Hell Gap	Early	1013	81.9 ±8.3	16.9 ±5.3	239.9 ±5.7	7.2 ±3.0	66.2 ±2.5	164.5 ±4.5	43.4 ±3.5		OC	
Canyon Ferry Reservoir (Hughes 1989a,b)														
	Folsom pt	Folsom	Early	2024	57.1 ±9.4	19.4 ±4.7	171.9 ±5.5	46.7 ±2.9	41.7 ±2.4	295.3 ±5.3	54.4 ±3.6		BG	Davis and Helmick 1982
				97	85.5 ±7.7	24.2 ±4.0	238.8 ±5.7	7.8 ±3.0	66.1 ±2.5	169.7 ±4.5	40.5 ±3.5		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
				147	61.3 ±9.5	16.7 ±5.7	174.3 ±5.5	49.4 ±2.9	42.3 ±2.4	299.8 ±5.3	51.1 ±3.6		BG	
				150	67.7 ±8.3	17.2 ±4.9	177.0 ±5.5	49.2 ±2.9	38.8 ±2.4	294.1 ±5.3	53.1 ±3.6		BG	
				157	66.0 ±8.9	20.0 ±4.6	172.3 ±5.5	48.2 ±3.0	39.2 ±2.5	307.7 ±5.4	57.3 ±3.6		BG	
				158	57.0 ±8.7	21.3 ±4.3	170.8 ±5.5	43.5 ±2.9	40.3 ±2.4	302.2 ±5.3	53.4 ±3.5		BG	
				164	57.4 ±9.5	15.0 ±6.3	171.7 ±5.5	46.9 ±3.0	38.3 ±2.5	297.3 ±5.3	52.7 ±3.6		BG	
				165	78.1 ±8.9	17.5 ±5.8	185.1 ±5.6	48.4 ±3.0	43.6 ±2.4	306.1 ±5.5	55.9 ±3.6		BG	
				210	60.1 ±9.9	21.3 ±4.9	175.2 ±5.5	46.8 ±3.0	41.6 ±2.4	305.2 ±5.3	51.5 ±3.6		BG	
				651	45.9 ±11.9	22.0 ±4.7	182.4 ±5.6	47.6 ±3.0	40.9 ±2.5	309.3 ±5.4	54.9 ±3.6		BG	
				1582	69.9 ±10.8	19.6 ±5.4	175.3 ±6.0	56.8 ±3.2	44.3 ±2.7	305.8 ±6.2	56.6 ±3.9		BG	
				1583	80.5 ±8.7	24.9 ±4.4	181.2 ±5.6	50.6 ±3.0	42.0 ±2.5	309.8 ±5.5	49.7 ±3.6		BG	
				1646	47.9 ±11.6	22.4 ±4.7	179.9 ±5.7	45.9 ±3.0	40.9 ±2.5	313.4 ±5.7	52.1 ±3.7		BG	
				1651	66.8 ±10.5	17.7 ±6.3	176.3 ±5.7	46.8 ±3.0	40.4 ±2.6	305.8 ±5.7	52.2 ±3.7		BG	
				1653	72.4 ±9.8	16.6 ±6.7	177.8 ±5.6	49.3 ±3.0	39.2 ±2.5	295.1 ±5.4	62.8 ±3.6		BG	
				2231	73.6 ±8.6	18.6 ±4.9	169.2 ±5.5	46.9 ±3.0	39.6 ±2.5	290.6 ±5.3	53.9 ±3.6		BG	
Square Butte (Hughes 1990e) (24CH395)	s-n pt	Late Plains	Late		86 ±5	20 ±3	264 ±5	2 ±3	86 ±2	183 ±4	46 ±0	0 ±10	OC	Johnson and Armstrong 1990
Sande (Hughes 1990e) (24CH758)	s-n pt	Late Plains	Late		93 ±5	23 ±3	267 ±5	1 ±3	84 ±2	175 ±4	44 ±3	31 ±11	OC	Johnson, personal communication, 1990

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
Hoffer (Hughes 1989c) (24CH669)														
	fl				49.0 ±12.5	24.6 ±5.0	183.0 ±5.7	45.6 ±3.0	40.8 ±2.5	315.5 ±5.7	58.0 ±3.7		BG	Davis et al. 1989b
	fl				56.3 ±11.1	21.2 ±5.1	181.6 ±5.6	47.9 ±3.0	44.6 ±2.5	317.9 ±5.6	56.4 ±3.6		BG	
	fl				73.5 ±9.7	22.2 ±5.0	177.0 ±5.6	47.9 ±3.0	38.1 ±2.5	314.1 ±5.7	55.0 ±3.7		BG	
	fl				58.8 ±9.7	17.0 ±5.4	174.6 ±5.5	45.0 ±3.0	39.0 ±2.4	304.1 ±5.4	57.9 ±3.6		BG	
24MA557														
			Late Late	43	55.2 ±9.0	22.7 ±4.2	183.2 ±5.3	47.7 ±2.9	44.8 ±2.3	318.2 ±5.0	58.0 ±3.4		BG	Deaver and Deaver 1983
			Late Late	56	61.4 ±7.8	18.9 ±4.3	189.2 ±5.3	50.8 ±2.9	42.0 ±.3	319.6 ±5.0	53.7 ±3.4		BG	
			Late Late	147	58.5 ±8.0	16.5 ±4.6	163.6 ±5.3	46.2 ±2.9	36.0 ±2.3	288.7 ±4.9	54.3 ±3.4		BG	
			Late Late	349	71.6 ±9.3	21.7 ±4.8	186.3 ±5.7	47.9 ±3.0	45.2 ±2.5	321.0 ±5.7	61.9 ±3.7		BG	
			Late Late	360	67.4 ±8.4	25.2 ±4.0	180.6 ±5.6	49.5 ±3.0	42.0 ±2.4	305.4 ±5.4	54.9 ±3.6		BG	
			Late Late	364	62.6 ±8.2	20.7 ±4.2	180.0 ±5.4	50.0 ±2.9	42.9 ±2.3	312.5 ±5.1	54.3 ±3.5		BG	
			Late Late	366	84.1 ±7.9	23.1 ±4.3	249.2 ±5.6	6.2 ±3.2	69.5 ±2.4	180.4 ±4.4	44.0 ±3.4		OC	
			Late	400	91.7 ±8.7	24.4 ±4.6	249.9 ±6.1	7.3 ±3.2	66.9 ±2.7	170.8 ±4.7	44.6 ±3.6		OC	
			Early Late		403 ±9.9	76.1 ±4.9	24.0 ±6.0	187.4 ±3.1	50.0 ±2.7	39.0 ±6.1	315.0 ±3.8	59.8	BG	
			Early Late		407 ±9.9	63.9 ±5.5	19.7 ±6.0	204.3 ±3.1	52.1 ±2.7	42.5 ±6.0	314.2 ±3.8	54.8	BG	
			Early Late		421 ±7.7	74.1 ±4.0	23.7 ±5.4	187.4 ±2.9	48.1 ±2.3	40.5 ±5.0	309.5 ±3.4	57.6	BG	
Crystal Lake (24FR1003)														
	fl			FR1003-fl	84.1 ±6.8	22.1 ±3.8	236.0 ±5.6	6.2 ±3.3	68.2 ±2.4	171.5 ±4.4	41.6 ±3.4		OC	Foor 1986

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
	fl			FR1003-f7	93.1 ±8.9	22.8 ±4.5	240.3 ±6.4	6.8 ±3.4	66.5 ±2.8	169.2 ±4.9	42.4 ±3.8		OC	
	fl			FR1003-8	61.2 ±9.4	20.1 ±4.8	181.1 ±5.8	48.7 ±3.1	41.4 ±2.6	330.2 ±6.0	62.2 ±3.8		BG	
24BE1233	fl			1	64.6	17.4	167.2	46.3	36.8	287.4	50.4		BG	Foor and Donahue 1987
	fl			2	56.1	16.6	156.8	42.0	38.0	278.2	50.3		BG	
	fl			3	61.2	16.9	172.6	43.8	40.6	291.4	50.4		BG	
	fl			4	61.9	21.3	165.6	45.8	38.0	296.3	59.1		BG	
	fl			5	62.8	21.3	173.4	50.1	39.5	300.1	50.4		BG	
Garfield Ranch (Hughes 1990h) (24GV117)	Avonlea			117-1	78 ±5	19 ±3	248 ±5	2 ±3	81 ±2	164 ±4	43 ±3		OC	Munson et al. 1990b
	Avonlea			117-2	82 ±6	21 ±3	266 ±5	1 ±3	88 ±2	182 ±4	50 ±4		OC	
	Avonlea			117-3	88 ±5	23 ±3	253 ±5	2 ±3	91 ±2	179 ±4	44 ±3		OC	
	Avonlea			117-4	94 ±6	25 ±3	244 ±6	14 ±3	80 ±2	170 ±4	45 ±4		OC	
				117-5	57 ±5	19 ±3	177 ±5	44 ±3	48 ±2	299 ±4	56 ±3		BG	
24RB1164 (Hughes 1990h)				1164-1	68 ±5	19 ±3	235 ±5	2 ±3	78 ±2	162 ±4	45 ±3		OC	Munson et al. 1990a
				1164-2	100 ±6	25 ±4	250 ±6	1 ±3	83 ±2	172 ±4	50 ±4		OC	
				1164-3	84 ±6	24 ±3	261 ±6	3 ±3	88 ±2	172 ±4	48 ±4		OC	
				1164-4	89 ±6	25 ±3	265 ±6	2 ±3	87 ±2	177 ±4	49 ±4		OC	
				1164-5	83 ±5	29 ±3	254 ±5	1 ±3	87 ±2	178 ±4	47 ±3		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
					Trace Element Concentrations									
				1164-6	64 ±5	19 ±3	174 ±5	46 ±3	47 ±2	293 ±4	58 ±3		BG	
				1164-7	84 ±6	24 ±3	264 ±5	1 ±3	86 ±2	180 ±4	47 ±4		OC	
				1164-8	54 ±5	20 ±3	185 ±5	42 ±3	48 ±2	298 ±4	58 ±3		BG	
				1164-9	98 ±6	21 ±3	259 ±6	1 ±3	84 ±2	178 ±4	46 ±4		OC	
				1164-10	76 ±7	25 ±4	248 ±6	1 ±3	81 ±3	162 ±5	43 ±4		OC	
Cooley (Hughes 1987) (24RB1059)														
	Yonkee/Pelican Middle Lake			1	87.5 ±8.6	22.6 ±4.3	252.3 ±6.3	8.0 ±3.1	70.8 ±2.7	189.2 ±4.9	45.5 ±3.7		OC	Munson 1988
				2	74.2 ±7.3	22.3 ±3.8	242.8 ±5.7	5.0 ±4.1	67.6 ±2.4	176.3 ±4.5	44.4 ±3.5		OC	
				3	109.1 ±9.6	24.3 ±4.8	242.0 ±7.0	8.0 ±3.5	69.0 ±3.2	171.3 ±5.4	37.2 ±4.2		OC	
				4	89.8 ±8.2	26.7 ±4.0	240.6 ±6.2	5.8 ±3.7	66.7 ±2.8	179.2 ±4.9	41.4 ±3.7		OC	
				5	74.8 ±7.7	24.2 ±3.8	241.6 ±5.9	9.2 ±3.0	67.8 ±2.6	172.2 ±4.7	47.3 ±3.6		OC	
				6	79.1 ±6.7	22.6 ±3.5	238.7 ±5.6	6.5 ±3.1	67.0 ±2.4	169.5 ±4.4	44.6 ±3.4		OC	
				7	84.1 ±8.0	19.8 ±4.3	239.9 ±6.1	6.0 ±3.6	66.4 ±2.7	177.4 ±4.8	40.2 ±3.7		OC	
				8	69.7 ±7.5	25.5 ±3.7	181.1 ±5.6	48.0 ±3.0	42.2 ±2.5	315.9 ±5.6	53.9 ±3.6		BG	
				9	69.1 ±7.8	19.8 ±4.0	238.6 ±5.9	9.9 ±2.9	69.0 ±2.6	173.1 ±4.7	44.4 ±3.6		OC	
				10	92.5 ±7.0	22.2 ±3.8	254.2 ±5.9	7.2 ±3.1	67.1 ±2.6	175.3 ±4.6	42.3 ±3.6		OC	
				12	97.1 ±9.4	13.4 ±8.7	242.2 ±7.0	9.2 ±3.3	69.1 ±3.2	178.7 ±5.5	37.7 ±4.1		OC	
				13	76.1 ±7.6	20.8 ±4.0	241.1 ±5.9	6.3 ±3.3	67.4 ±2.6	174.1 ±4.7	43.3 ±3.6		OC	
				14	86.4 ±7.6	22.8 ±4.0	252.3 ±6.1	4.5 ±6.5	65.6 ±2.7	183.2 ±4.8	50.0 ±3.7		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
Bowman Spring (Hughes 1994b) (24LC294)														
	fl			2077	69 ±6	15 ±3	170 ±5	42 ±3	44 ±2	288 ±5	54 ±3		BG	Davis et al. 1996
	fl			2078	59 ±6	24 ±3	178 ±5	44 ±3	47 ±2	290 ±5	56 _3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2075	54 ±6	14 ±4	162 ±4	37 ±3	43 ±2	278 ±5	52 ±3		OC	
	fl			2082	62 ±6	17 ±3	171 ±4	39 ±3	45 ±2	286 ±5	54 ±3		BG	
	fl			2083	61 ±6	17 ±3	173 ±5	39 ±3	43 ±2	275 ±5	46 ±3		BG	
	fl			2085	57 ±6	19 ±3	172 ±5	40 ±3	42 ±2	286 ±5	55 ±3		BG	
	fl			2081	59 ±6	15 ±3	168 ±4	41 ±3	42 ±2	280 ±5	50 ±3		BG	
	fl			2096	51 ±7	18 ±4	174 ±5	39 ±3	43 ±2	289 ±5	53 ±3		BG	
	fl			2095	57 ±7	20 ±4	177 ±5	45 ±3	49 ±2	310 ±5	59 ±4		BG	
	Hanna pt	Hanna	Middle	2097	51 ±7	17 ±4	168 ±5	39 ±3	41 ±2	275 ±5	53 ±4		BG	
	fl			2079	52 ±6	15 ±3	162 ±4	40 ±3	43 ±2	275 ±5	53 ±3		BG	
	fl			2080	58 ±7	17 ±4	178 ±5	40 ±3	44 ±2	291 ±5	57 ±3		BG	
	fl			2084	52 ±7	17 ±4	168 ±5	39 ±3	42 ±2	283 ±5	54 ±3		BG	
	fl			2092	68 ±6	22 ±3	242 ±5	3 ±3	80 ±2	161 ±5	44 ±3		OC	
	fl			2093	80 ±8	21 ±4	255 ±5	3 ±3	87 ±2	161 ±5	47 ±3		OC	
	fl			2091	66 ±6	17 ±3	227 ±5	2 ±3	77 ±2	156 ±5	42 ±3		OC	
	fl			2094	91 ±7	24 ±4	250 ±5	2 ±3	81 ±3	170 ±5	47 ±3		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
	s-n pt	Late Plains	Late	2076	80 ±6	24 ±3	225 ±5	4 ±3	76 ±2	153 ±5	41 ±3		OC	
	fl			2088	64 ±7	21 ±4	190 ±5	46 ±3	46 ±2	298 ±5	57 ±4		BG	
	fl			2089	98 ±7	29 ±4	295 ±5	5 ±3	87 ±2	176 ±5	47 ±3		UK	
	fl			2090	82 ±6	29 ±3	240 ±5	3 ±3	78 ±2	164 ±5	45 ±3		OC	
	fl			2086	67 ±6	15 ±4	190 ±5	46 ±3	49 ±2	306 ±5	59 ±3		BG	
	fl			2087	87 ±7	25 ±4	251 ±5	2 ±3	82 ±3	166 ±5	48 ±3		OC	
Steel's Pass (Hughes 1993, 1994c; Jackson 1991) (24MA565)														
	McKean pt	McKean	Middle	2035	66 ±6	16 ±3	177 ±4	40 ±3	43 ±2	286 ±5	50 ±3		BG	Davis el al. 1993
	Pelican Lake pt	Pelican Lake	Middle	2036	58 ±6	19 ±3	174 ±4	42 ±3	44 ±2	285 ±5	56 ±3		BG	
	Hanna pt	Hanna	Middle	2037	59 ±6	20 ±3	177 ±4	13 ±3	42 ±2	55 ±5	35 ±3		TB	
	Hanna pt	Hanna	Middle	2038	50 ±6	19 ±3	170 ±4	42 ±3	43 ±2	285 ±5	53 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2039	52 ±6	21 ±3	171 ±4	41 ±3	43 ±2	281 ±5	55 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2040	61 ±6	22 ±3	188 ±5	44 ±3	46 ±2	307 ±5	60 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2041	60 ±6	19 ±3	176 ±4	43 ±3	46 ±2	288 ±5	56 ±3		BG	
	Avonlea pt	Avonlea	Late	2042	75 ±7	17 ±4	188 ±5	46 ±3	48 ±2	300 ±5	51 ±4		BG	
	t-n pt	Late Plains	Late	2043	90 ±6	19 ±3	203 ±5	24 ±3	67 ±2	232 ±5	49 ±3		OC	
	Pelican Lake pt	Pelican Lake	Middle	2044	64 ±6	19 ±3	176 ±4	40 ±3	46 ±21	295 ±5	59 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2045	49 ±6	20 ±3	176 ±4	42 ±3	42 ±2	286 ±5	55 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2046	60 ±6	14 ±4	176 ±4	42 ±3	46 ±2	291 ±5	57 ±3		BG	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations								Obsidian Source*	Reference
					Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba		
	Pelican Lake pt	Pelican Lake	Middle	2047	53 ±6	19 ±3	176 ±4	42 ±3	42 ±2	286 ±5	52 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2048	58 ±6	19 ±3	174 ±5	42 ±3	44 ±2	291 ±5	55 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2049	58 ±6	21 ±3	172 ±5	39 ±3	45 ±2	281 ±5	52 ±3		BG	
	t-n pt	Late Plains	Late	2050	67 ±7	20 ±4	187 ±5	44 ±3	48 ±2	302 ±5	62 ±3		BG	
	t-n pt	Late Plains	Late	2051	85 ±7	25 ±3	243 ±5	4 ±3	84 ±2	172 ±5	46 ±3		OC	
	t-n pt	Late Plains	Late	2052	62 ±6	19 ±3	173 ±4	41 ±3	44 ±2	288 ±5	54 ±3		BG	
	Pelican Lake pt	Pelican Lake	Middle	2053	63 ±7	18 ±4	187 ±5	41 ±3	47 ±2	300 ±5	56 ±3		BG	
	fl			2054	91 ±8	17 ±5	211 ±5	52 ±3	47 ±3	317 ±6	55 ±4		BG	
Sheep Rock Spring (Hughes 1994a) (24JF292)														
	fl	Pelican Lake	Middle	2068	59 ±6	20 ±3	169 ±5	42 ±3	47 ±2	285 ±5	56 ±3		BG	Wilson and Davis 1994
	fl	Pelican Lake	Middle	2069	53 ±6	17 ±3	171 ±4	41 ±3	43 ±2	283 ±5	52 ±3		BG	
	fl	Pelican Lake	Middle	2070	70 ±6	18 ±3	193 ±5	46 ±3	50 ±2	305 ±5	58 ±3		BG	
	fl	Pelican Lake	Middle	2071	76 ±7	17 ±4	190 ±5	45 ±3	43 ±2	300 ±5	54 ±3		BG	
	fl	Pelican Lake	Middle	2072	83 ±7	30 ±4	200 ±5	47 ±3	49 ±2	304 ±5	59 ±4		BG	
	fl	Pelican Lake	Middle	2073	73 ±6	14 ±4	198 ±5	47 ±3	49 ±2	301 ±5	55 ±3		BG	
	fl	Pelican Lake	Middle	2074	54 ±5	19 ±3	168 ±4	40 ±3	45 ±2	275 ±5	53 ±3		BG	
Keaster (Hughes 1991) (24PH401)														
	Pelican Lake pt	Pelican Lake	Middle		62 ±6	16 ±3	172 ±4	43 ±3	47 ±2	285 ±5	56 ±3	684 ±14	BG	Davis and Stallcop 1965

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
Varney Bridge (24MA778)														
	pt		Early	2030	84.5 ±3.7	21.4 ±1.8	247.0 ±1.7	6.6 ±5.3	79.1 ±1.3	169.4 ±4.2	46.2 ±1.4		OC	Brumley 1989
	fl			2031	69.1 ±4.2	22.2 ±2.1	191.3 ±1.9	46.5 ±5.3	47.4 ±1.4	300.4 ±4.5	58.0 ±1.7		BG	
	fl			2032	79.7 ±4.4	25.0 ±2.4	202.8 ±2.2	52.6 ±5.5	47.2 ±1.5	311.1 ±4.6	61.0 ±1.8		OC	
	Eden pt	Cody	Early	2033	65.23 ±3.9	20.5 ±1.9	191.6 ±1.7	48.9 ±5.3	45.5 ±1.3	309.1 ±4.4	61.9 ±1.5		BG	
Glacier National Park (Hughes 1992b)														
	pt			5616	69 ±5	19 ±3	183 ±4	40 ±3	46 ±2	279 ±5	55 ±3	715 ±13	BG	Reeves 1995
	Alberta pt	Cody	Early	10625	55 ±5	18 ±3	169 ±4	40 ±3	44 ±2	284 ±5	54 ±3	666 ±13	BG	
	fl			10627	85 ±5	25 ±3	253 ±4	4 ±3	82 ±2	165 ±5	48 ±3	13 ±13	OC	
	fl			12301	55 ±5	23 ±3	180 ±4	41 ±3	46 ±2	291 ±5	53 ±3	715 ±14	BG	
Brown's Pass Campground (Hughes 1994e) (24FH544)														
	rf			2055	71 ±7	23 ±4	185 ±4	45 ±3	51 ±2	307 ±4	64 ±3		BG	
24GL658														
	fl			2056	75 ±6	21 ±3	128 ±4	64 ±3	36 ±2	99 ±4	7 ±2		M	
	fl			2057	77 ±5	20 ±3	128 ±3	66 ±3	32 ±2	102 ±4	8 ±2		M	
Redhorn Pass (24FH535)														
	sf			2058	61 ±6	20 ±4	180 ±4	44 ±3	47 ±2	301 ±4	57 ±2		BG	
Pray Lake (24GL204)														
	shatter			2059	61 ±6	22 ±3	182 ±4	45 ±3	48 ±2	306 ±4	61 ±3		BG	
St. Mary Bridge (24GL203)														
	rf			2060	96 ±7	27 ±4	254 ±4	3 ±3	96 ±2	172 ±4	47 ±3		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
	fl			2061	91 ±8	24 ±4	189 ±4	39 ±3	47 ±2	271 ±5	57 ±3		BG	
Windy Point (24GL200)														
	pt	Lt Paleoindian	Early	2062	70 ±6	24 ±4	182 ±4	43 ±3	47 ±2	304 ±4	58 ±2		BG	
	c			2063	71 ±6	18 ±4	191 ±4	47 ±3	50 ±2	310 ±5	55 ±3		BG	
	c			2064	66 ±6	21 ±3	178 ±4	41 ±3	46 ±2	281 ±4	57 ±2		BG	
	c			2065	57 ±6	14 ±4	175 ±4	46 ±3	48 ±2	301 ±4	57 ±3		BG	
	rf			2066	53 ±6	20 ±3	154 ±4	47 ±3	40 ±2	271 ±4	55 ±2		BG	
	f			2067	68 ±7	24 ±4	196 ±4	46 ±3	47 ±2	301 ±5	60 ±3		BG	
Grayling Creek (Hughes 1994f)														
	Haskett pt	Haskett	Early		81 ±6	22 ±6	235 ±4	2 ±3	80 ±2	165 ±6	45 ±6		OC	
King (24PH2886)														
	fl	post-Pelican Lake	Middle	16178	59 ±7	14 ±4	183 ±5	46 ±3	44 ±2	298 ±5	58 ±4		BG	Brumley et al. 1993
	fl	Pelican Lake	Middle	16179	91 ±6	23 ±3	253 ±5	4 ±3	79 ±2	173 ±5	46 ±3		OC	
	fl	Pelican Lake	Middle	16180	90 ±6	22 ±3	250 ±5	2 ±3	82 ±2	167 ±5	45 ±3		OC	
	fl			16181	91 ±7	22 ±4	242 ±5	5 ±3	82 ±2	161 ±5	40 ±3		OC	
	shatter			16182	80 ±7	23 ±4	250 ±5	5 ±3	79 ±2	159 ±5	43 ±3		OC	
	fl			16183	77 ±6	26 ±3	242 ±5	2 ±3	78 ±2	160 ±5	46 ±3		OC	
	fl	Pelican Lake	Middle	16184	80 ±7	27 ±4	265 ±5	4 ±3	85 ±2	182 ±5	47 ±3		OC	
	fl	Pelican Lake	Middle	16185	63 ±6	21 ±3	222 ±5	4 ±3	74 ±2	156 ±5	43 ±3		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source*	Reference
	fl	Pelican Lake	Middle	16186	106 ±8	22 ±4	272 ±5	4 ±3	86 ±3	180 ±5	44 ±4		OC	
	fl	Besant or Prairie/Plains	Late	16187	99 ±6	28 ±4	274 ±5	4 ±3	84 ±2	175 ±5	47 ±3		OC	
	shatter	Prairie/Plains	Late	16188	83 ±6	20 ±4	256 ±5	5 ±3	78 ±2	175 ±5	45 ±3		OC	
	fl	Besant or Avonlea	Late	16189	91 ±8	23 ±4	286 ±5	6 ±3	82 ±3	169 ±5	45 ±3		OC	
	shatter	Pelican Lake	Middle	16190	130 ±8	26 ±4	281 ±5	5 ±3	77 ±3	156 ±5	43 ±4		OC	
	fl	Pelican Lake	Middle	16191	89 ±7	22 ±4	248 ±5	3 ±3	76 ±3	167 ±5	41 ±3		OC	
	fl	Pelican Lake	Middle	16192	78 ±7	22 ±4	248 ±5	5 ±3	80 ±2	171 ±5	43 ±3		OC	
	fl	Avonlea?	Late	16193	78 ±7	28 ±4	252 ±5	2 ±3	81 ±3	165 ±5	42 ±3		OC	
	shatter		Late	16194	94 ±7	19 ±4	260 ±5	4 ±3	83 ±3	170 ±5	46 ±4		OC	
	shatter	Pelican Lake	Middle	16195	96 ±7	25 ±4	279 ±5	3 ±3	90 ±3	177 ±5	45 ±3		OC	
	shatter	Prairie/Plains	Late	16196	64 ±8	14 ±4	185 ±5	46 ±3	49 ±2	298 ±5	55 ±4		BG	
	shatter			16197	85 ±5	22 ±3	256 ±5	4 ±3	82 ±2	170 ±5	45 ±3		OC	
	shatter			16198	78 ±7	19 ±4	248 ±5	3 ±3	80 ±3	167 ±5	49 ±3		OC	
	fl	Pelican Lake	Middle	16199	85 ±6	28 ±3	251 ±5	4 ±3	79 ±2	161 ±5	45 ±3		OC	
	shatter	Prairie/Plains	Late	16201	72 ±9	20 ±5	189 ±5	42 ±3	53 ±3	311 ±6	63 ±4		BG	
	shatter	Post-Pelican Lake	Middle	16202	53 ±6	22 ±3	177 ±5	42 ±3	47 ±2	294 ±5	58 ±3		BG	
	fl			16203	74 ±6	21 ±3	241 ±5	3 ±3	75 ±2	158 ±5	41 ±3		OC	
	fl	Pelican Lake	Middle	16204	71 ±7	18 ±4	264 ±5	3 ±3	83 ±3	172 ±5	50 ±4		OC	

Site/ Locality	Obsidian Artifact	Cultural Affiliation	Cultural Period	Specimen Number	Trace Element Concentrations								Obsidian Source*	Reference
					Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba		
	fl	Pelican Lake	Middle	16205	72 ±7	23 ±4	240 ±5	5 ±3	82 ±2	171 ±5	42 ±3		OC	
	fl	Pelican Lake	Middle	16206	78 ±7	24 ±3	260 ±5	3 ±3	83 ±2	168 ±5	44 ±3		OC	
	fl	Pelican Lake	Middle	16207	68 ±6	21 ±3	239 ±5	4 ±3	76 ±2	159 ±5	42 ±3		OC	
	shatter	Pelican Lake	Middle	16208	81 ±6	25 ±3	243 ±5	3 ±3	79 ±2	164 ±5	44 ±3		OC	
	shatter			16209	88 ±7	18 ±4	164 ±5	39 ±3	43 ±2	267 ±5	48 ±4		BG	
	fl	Pelican Lake	Middle	16210	79 ±7	19 ±4	233 ±5	4 ±3	74 ±3	156 ±5	42 ±3		OC	
	shatter	Pelican Lake	Middle	16211	74 ±7	19 ±4	244 ±5	6 ±3	80 ±2	176 ±5	47 ±3		OC	
	shatter	Pelican Lake	Middle	16212	70 ±6	20 ±3	242 ±5	4 ±3	75 ±2	164 ±5	42 ±3		OC	
	fl	Pelican Lake	Middle	16213	70 ±6	19 ±3	231 ±5	2 ±3	77 ±2	164 ±5	40 ±3		OC	
	fl	Pelican Lake	Middle	16214	72 ±6	20 ±3	231 ±5	1 ±3	73 ±2	152 ±5	40 ±3		OC	
	shatter	Prairie/Plains	Late	16215	53 ±6	19 ±3	181 ±5	44 ±3	43 ±2	293 ±5	57 ±3		BG	

All trace element values in parts per million (ppm); ± = counting and fitting error uncertainty at 200 and 300 (*) seconds livetime; nm. = not measured.

*Sources:
OC = Obsidian Cliff Plateau, Wyoming
BG = Bear Gulch (Camas/Dry Creek; FMY), Idaho
TB = Timber Butte, Idaho (see Sappington 1981a, 1984a; Michels 1982)
BSB = Big Southern Butte, Idaho (see Sappington 1981a, 1984a; Michels 1982)
JP = Jackass Pass, Wyoming
PS = Pack Saddle, Wyoming
UK = Unknown

Artifact Class:
pt = projectile point
t-n pt= trinotched point
s-n pt = sidenotched point

c-t biface = corner-tanged biface
fl = waste flake
ss = side scraper
c = core
rf = retouched flake

Appendix F. X-Ray Fluorescence Trace Element Data for Obsidian From Archaeological Sites in Yellowstone National Park and North Dakota.

Appendix F. X-Ray Fluorescence Trace Element Data for Obsidian From Archaeological Sites in Yellowstone National Park and North Dakota.

Cat. Number	Trace Element Concentration Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source (Chemical Type)*
24YE1208	79 ±5	17 ±3	245 ±5	1 ±3	82 ±2	166 ±4	44 ±3	24 ±11	OC
48YE10 (Hughes 1989b)	80.1 ±8.0	24.8 ±4.1	232.4 ±5.7	5.8 ±3.5	66.8 ±2.5	164.3 ±4.5	43.5 ±3.5		OC
48YE357	77.3 ±8.2	25.0 ±4.1	249.5 ±5.7	7.6 ±3.0	69.0 ±2.5	176.6 ±4.5	41.5 ±3.5		OC
Obsidian Lake (48YE356) (Hughes 1990f)	74 ±5	19 ±3	243 ±5	1 ±3	81 ±2	169 ±4	45 ±3	34 ±11	OC
Yellowstone National Park Museum Collection (Hughes 1989e; Cannon and Phillips 1993)									
Sheepeater Ridge (48YE320) 887	93.6 ±9.5	27.3 ±4.8	259.7 ±6.2	7.8 ±3.1	71.8 ±2.7	174.1 ±4.8	47.1 ±3.7		OC (6962 B.P.)
Sheepeater Ridge (48YE320) 910	79.6 ±8.9	17.9 ±5.5	237.7 ±5.8	11.6 ±2.9	63.4 ±2.5	169.9 ±4.6	38.5 ±3.5		OC (6944 B.P.)
48YE371 6512	86.1 ±9.9	26.1 ±4.8	246.9 ±6.4	9.4 ±3.1	66.2 ±2.8	177.2 ±5.0	38.5 ±3.8		OC (Desert S-N)
Lower Geyser Basin 6627	80.0 ±8.9	20.0 ±5.0	247.3 ±5.9	7.6 ±3.1	69.8 ±2.5	175.4 ±4.6	40.8 ±3.5		OC (Bitterroot)
Lower Geyser Basin 6642	59.8 ±9.9	16.6 ±5.7	169.9 ±5.5	45.6 ±3.0	39.7 ±2.5	294.9 ±5.3	48.3 ±3.6		BG (Hell Gap)
48YE302 6671	78.0 ±8.3	17.7 ±5.1	240.9 ±5.7	4.5 ±5.8	71.2 ±2.5	174.5 ±4.5	43.7 ±3.5		OC (Pelican Lake)
Goose Lake 6673	61.0 ±9.3	21.7 ±4.5	182.8 ±5.5	49.4 ±2.9	40.6 ±2.4	306.3 ±5.3	50.6 ±3.5		BG (Pelican Lake)
Old Faithful 6680	50.9 ±10.9	26.3 ±4.9	129.8 ±5.3	75.6 ±3.1	31.0 ±3.1	90.0 ±4.3	15.3 ±3.5		M (LP S-N)
48YE394 6987	95.5 ±8.5	18.5 ±5.4	240.8 ±6.0	7.7 ±3.1	61.1 ±2.6	165.0 ±4.7	44.1 ±3.6		OC (Columbia Valley C-N)
Big Horseshoe Creek 7070	84.6 ±8.8	21.6 ±4.8	236.3 ±5.8	4.7 ±4.9	68.2 ±2.5	178.6 ±4.6	44.3 ±3.5		OC (Late Plains Archaic)
Beach Spring Lagoon 7772	85.5 ±9.3	26.1 ±4.7	236.2 ±5.8	7.2 ±3.1	61.1 ±2.5	165.3 ±4.6	46.3 ±3.5		OC (McKean)
Specimen Ridge 8694	78.1 ±8.3	21.7 ±4.6	235.7 ±5.7	8.6 ±2.9	62.4 ±2.5	172.6 ±4.5	42.2 ±3.5		OC (Oxbow)
24YE344 9468	71.4 ±9.3	25.5 ±4.5	245.6 ±6.0	6.9 ±3.2	66.6 ±2.6	173.7 ±4.7	41.0 ±3.6		OC (Pelican Lake)
Heath Lake Trail 9494	79.1 ±8.4	18.6 ±5.1	246.0 ±5.8	6.8 ±3.1	68.6 ±2.8	173.3 ±4.6	46.0 ±3.5		OC (Agate Basin)
48YE394 10491	81.4 ±8.4	16.6 ±5.4	247.5 ±5.8	6.4 ±3.3	70.7 ±2.5	178.8 ±4.6	43.4 ±3.5		OC (Late Plains Archaic)

Cat. Number	Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Obsidian Source (Chemical Type)*
				Trace Element Concentration					
48YE394									
10498	84.5 ±8.3	22.2 ±4.4	234.2 ±5.7	8.6 ±2.9	65.7 ±2.5	168.9 ±4.5	42.6 ±3.5		OC (McKean)
Fishing Bridge (48YE1)									
10675	91.6 ±10.0	17.5 ±6.9	241.4 ±6.2	5.9 ±3.7	64.3 ±2.8	168.0 ±4.8	32.3 ±3.8		OC (Avonlea)
10676	67.3 ±10.8	16.0 ±7.0	176.5 ±5.8	46.3 ±3.1	40.2 ±2.6	289.1 ±5.7	53.2 ±3.7		BG (Avonlea)
48YE417									
10980	65.1 ±8.9	26.3 ±4.2	174.4 ±5.5	47.6 ±2.9	40.9 ±2.4	293.1 ±5.2	52.2 ±3.5		BG (Late Plains Archaic)
48YE417									
10982	78.2 ±8.7	26.6 ±4.2	233.2 ±5.8	6.0 ±3.4	67.5 ±2.5	168.2 ±4.5	45.1 ±3.5		OC (Late Plains Archaic)
48YE1094	82.0 ±5.0	19.0 ±3.0	178.0 ±5.0	20.0 ±3.0	79.0 ±2.0	188.0 ±4.0	59.0 ±3.0	572.0 ±11.0	OC
48YE507	81.0 ±5.0	24.0 ±3.0	228.0 ±5.0	4.0 ±3.0	89.0 ±2.0	215.0 ±4.0	68.0 ±3.0	103.0 ±11.0	OC
48YE356	74.0 ±5.0	19.0 ±3.0	243.0 ±5.0	1.0 ±3.0	81.0 ±2.0	169.0 ±4.0	45.0 ±3.0	34.0 ±11.0	OC
North Dakota:									
32ME220 (Hughes 1989h; Deaver and Deaver 1990)									
83	81.0 ±7.2	25.7 ±3.7	257.5 ±5.6	7.5 ±3.0	68.0 ±2.4	177.7 ±4.4	41.5 ±3.4		OC
151	90.5 ±7.2	20.3 ±4.1	242.8 ±5.7	6.3 ±3.2	63.7 ±2.4	171.8 ±4.5	41.7 ±3.5		OC
155	83.4 ±7.6	23.5 ±3.9	237.4 ±5.7	7.1 ±3.1	65.7 ±2.4	167.2 ±4.5	40.2 ±3.5		OC
160	80.8 ±9.4	16.8 ±5.9	246.7 ±6.1	5.9 ±3.8	70.3 ±2.7	176.7 ±4.8	50.2 ±3.7		OC
161	106.5 ±9.3	21.3 ±5.1	283.1 ±6.5	7.5 ±3.3	73.2 ±2.8	189.0 ±5.0	40.3 ±3.8		OC
162	90.6 ±7.4	25.3 ±3.8	245.9 ±5.6	7.4 ±3.0	65.7 ±2.4	177.6 ±4.5	42.4 ±3.4		OC
164	94.0 ±7.6	20.2 ±4.5	256.0 ±5.8	7.0 ±3.1	69.0 ±2.5	182.6 ±4.6	44.2 ±3.5		OC
Theodore Roosevelt National Park (Hughes 1989d; Kuehn 1989)									
32BI557	78.1 ±8.8	21.2 ±4.7	256.2 ±5.9	6.0 ±3.4	72.9 ±2.5	178.8 ±4.6	42.9 ±3.5		OC
32BI567a	75.9	19.1	222.5	7.1	65.0	159.2	40.9		OC
32BI567b	83.7 ±10.7	19.7 ±6.1	253.6 ±6.3	8.5 ±3.1	74.9 ±2.8	186.0 ±5.0	50.0 ±3.8		OC
32BI567c	96.5 ±9.8	21.8 ±5.6	266.6 ±6.4	8.5 ±3.1	77.9 ±2.8	179.7 ±4.9	53.2 ±3.7		OC
32BI567d	86.4 ±9.8	24.9 ±5.2	254.3 ±6.3	7.0 ±3.4	72.8 ±2.8	184.5 ±4.9	43.6 ±3.7		OC
THRO-125	61.7 ±10.4	19.0 ±5.5	179.4 ±5.7	49.7 ±3.0	42.4 ±2.5	317.4 ±5.7	61.4 ±3.7		BG

*Source:
OC = Obsidian Cliff, Wyoming
BG = Bear Gulch, Idaho
M = Malad, Idaho

Appendix G. Neutron Activation Trace Element Compositional Data for Archaeological Obsidian From the Northern Rockies and Northwestern Plains (after Davis 1972a).

Appendix G. Neutron Activation Trace Element Compositional Data for Archaeological Obsidian From the Northern Rockies and Northwestern Plains (after Davis 1972a).

Site Location	NWP Specimen Number	NAA Lab Specimen Number	%NA	%Mn	Na/Mn	Indicated Source*
Southern Alberta Montane						
A-2 Wellmans Field	R491	OB-4158	2.932	.018	162.80	OC
A-5 Red Rock Canyon	R509	OB-4159	2.810	.028	101.52	FMY
	R510	OB-4160	2.967	.029	100.88	FMY
	R511	OB-4161	2.822	.028	100.39	FMY
	R902	OB-4162	3.210	.033	97.69	FMY
A-9 DgPl-8	R929	OB-4163	3.009	.031	96.50	FMY
A-10 DgPl-86	R1146	OB-4164	2.866	.031	91.87	FMY
A-11 DgPl-68	R1164	OB-4165	3.023	.031	96.05	FMY
	R1165	OB-4166	3.079	.033	94.16	FMY
Southern Canada Plains						
Alberta:						
B-1 General Locality	R43	OB-962	3.495	.039	90.66	FMY
B-6 Kenney	R84	OB-967	3.280	.038	87.20	FMY
	R85	OB-968	3.140	.021	153.17	OC
	R86	OB-969	3.363	.022	150.13	OC
	R87	OB-965	3.470	.023	150.22	OC
	R88	OB-966	3.570	.039	92.01	FMY
B-20 Little Gem	J1078	OB-4150	2.999	.022	134.06	OC
	J1079	OB-4151	3.103	.031	99.81	FMY
B-21 DJ	J1082	OB-4152	3.087	.031	99.26	FMY
	J1083	OB-4153	3.234	.032	101.09	FMY
	J1084	OB-4154	2.844	.030	95.56	FMY
	J1085	OB-4155	3.003	.031	97.00	FMY
B-22 FX	R41	OB-960	3.650	.024	153.68	OC
Saskatchewan:						
B-29 Chamberlain	L83	OB-964	3.367	.023	146.39	OC
Manitoba:						
B-41 Oak Lake	R42	OB-961	3.270	.035	92.63	FMY
Northern Montana Plains						
C-1 Keaster (24PH401) (Davis and Stallcop 1965)	MR1	OB-839	1.875	.022	86.21	FMY
	MR2a	OB-837	3.410	.039	88.57	FMY
	MR2b	OB-838	3.175	.037	86.98	FMY
C-2 Timber Ridge (24BL101) (Davis 1966a)	MR3	OB-818	3.300	.020	161.53	OC
	MR4	OB-819	3.040	.035	87.61	FMY
C-3 Wahkpa Chu'gn (24HL101) (Davis and Stallcop 1966)	MR10	OB-813	3.247	.037	88.64	FMY

Site Location	NWP Specimen Number	NAA Lab Specimen Number	%NA	%Mn	Na/Mn	Indicated Source*
	MR9	OB-814	3.203	.036	90.15	FMY
	MR698	OB-812	3.327	.039	85.37	FMY
	MR699	OB-811	3.580	.024	151.69	OC
C-4 Three Buttes (24BL104) (Brekke 1970)	MR11	OB-810	3.040	.039	78.35	TP
C-5 Dunes (24CH101) (Davis 1966a, 1976)	MR16	OB-825	3.190	.021	152.99	OC
	MR14	OB-823	3.340	.038	87.21	FMY
	MR13	OB-824	3.185	.036	88.72	FMY
	MR15	OB-826	3.295	.039	80.18	UK
C-13 Birdtail Ranch (24BL102) (Brumley 1990)	MR6	OB-817	3.230	.020	158.33	OC
	MR5	OB-816	3.470	.038	91.63	FMY
C-14 Cabin Coulee (24BL402)	MR12	OB-820	3.380	.022	155.76	OC
C-17 Crawford Ranch (24CA451) (Davis 1966a)	S22	OB-822	3.290	.038	86.58	FMY
	S21	OB-821	3.515	.024	145.25	OC
<u>Central-Southern Montana Plains</u>						
D-1 Cascade Valley	S29	OB-809	3.430	.022	158.80	OC
	S32	OB-831	3.120	.020	159.60	OC
	S26	OB-832	3.575	.025	143.57	OC
	S23	OB-834	3.550	.024	150.47	OC
	S24	OB-833	3.300	.022	151.03	OC
	S31	OB-828	3.290	.037	89.65	FMY
	S27	OB-829	3.430	.038	90.26	FMY
	S25	OB-835	3.410	.040	85.89	FMY
	S421	OB-836	3.455	.038	90.92	FMY
	S1095	OB-845	3.385	.022	153.51	OC
D-3 Carters Ferry (24CH1400) (Shumate 1967)	S30	OB-953	3.350	.037	90.61	FMY
D-11 Stark-Lewis (24GV401) (Feyhl 1972)	C38	OB-957	3.675	.024	155.39	OC
	C39	OB-958	3.610	.023	160.44	OC
	C36	OB-955	3.500	.039	90.67	FMY
	C40	OB-959	3.560	.039	91.66	FMY
	C37	OB-956	3.190	.043	74.53	UK
D-14 Hardy-Kistner (24GA306) (Arthur 1966b)	A52	OB-996	3.123	.020	157.97	OC
<u>Southern Montana Montane</u>						
Yellowstone Valley:						
E-3 Carbella (24PA302) (Arthur 1966b)	A55	OB-997	3.800	.025	154.91	OC

Site Location	Nwp Specimen Number	NAA Lab Specimen Number	%NA	%Mn	Na\Mn	Indicated Source*
	A69	OB-999	3.070	.020	155.83	OC
	A70	OB-1000	3.540	.022	160.91	OC
	A71	OB-1001	3.470	.022	160.28	OC
	A79	OB-1003	3.495	.022	161.06	OC
	A80	OB-1004	3.400	.021	161.90	OC
	A82	OB-1005	3.510	.024	147.79	OC
	A75	OB-1002	3.540	.039	90.77	FMY
Gallatin Valley:						
E-2 King (24GA214) (Arthur 1968)	A46	OB-971	3.457	.023	152.49	OC
	A50	OB-975	3.610	.023	157.99	OC
	A51	OB-976	3.520	.023	151.72	OC
	A54	OB-978	3.327	.021	154.96	OC
	A57	OB-980	3.203	.021	155.48	OC
	A58	OB-981	3.540	.025	144.49	OC
	A59	OB-982	3.390	.023	150.20	OC
	A61	OB-984	2.947	.018	165.56	OC
	A62	OB-985	3.235	.021	156.66	OC
	A63	OB-986	3.123	.020	154.83	OC
	A66	OB-989	3.337	.022	153.28	OC
	A74	OB-993	3.257	.020	164.74	OC
	A78	OB-995	3.350	.021	159.52	OC
	A45	OB-970	3.500	.037	93.58	FMY
	A48	OB-973	3.700	.040	93.20	FMY
	A49	OB-974	3.327	.037	88.96	FMY
	A53	OB-977	3.290	.038	87.40	FMY
	A56	OB-979	3.645	.039	93.10	FMY
	A64	OB-987	3.183	.035	89.99	FMY
	A65	OB-988	3.320	.036	92.04	FMY
	A77	OB-994	3.260	.036	90.48	FMY
	A47	OB-972	3.390	.050	67.33	UK
	A60	OB-983	3.245	.035	92.32	FMY
	A67	OB-990	3.575	.080	44.66	UK
	A71	OB-991	3.205	.031	104.06	FMY
	A72	OB-992	3.190	.026	124.61	UK
Northern Wyoming Basin						
F-1 Mummy Cave (48PA201) (Wedel et al. 1968; McCracken 1978)	H89	OB-1009	3.257	.019	169.90	OC
	H91	OB-1011	3.447	.023	153.20	OC

Site Location	NWP Specimen Number	NAA Lab Specimen Number	%NA	%Mn	Na/Mn	Indicated Source*
	H92	OB-1012	3.653	.023	158.83	OC
	H93	OB-1013	3.200	.022	148.35	OC
	H94	OB-1014	3.357	.021	158.87	OC
	H95	OB-1015	3.550	.022	162.32	OC
	H96	OB-1016	6.483	.041	85.22	FMY
	H97	OB-1017	3.613	.023	160.58	OC
	H98	OB-1018	3.507	.022	157.48	OC
	H99	OB-1019	3.263	.020	164.55	OC
	H100	OB-1020	33.36	.021	158.49	OC
	H101	OB-1021	3.273	.021	158.65	OC
	H102	OB-1022	3.280	.020	161.02	OC
	H103	OB-1023	3.350	.022	151.11	OC
	H104	OB-1024	3.303	.043	76.46	TP
	H105	OB-1025	3.243	.022	145.88	OC
	H106	OB-1026	3.023	.039	77.65	TP
	H177	OB-1780	3.557	.038	93.04	FMY
	H178	OB-1781	3.110	.023	132.91	OC
	H179	OB-1782	3.200	.025	125.98	UK
	H180	OB-1783	3.290	.045	73.77	UK
	H181	OB-1784	3.255	.026	126.65	UK
	H182	OB-1785	3.063	.020	153.53	OC
	H183	OB-1786	2.435	.018	133.42	OC
	H184	OB-1787	3.238	.023	139.57	OC
	H185	OB-1788	3.188	.023	137.99	OC
	H186	OB-1789	3.007	.022	135.45	OC
	H187a	OB-1790	3.019	.037	81.33	UK
	H187b	OB-1791	3.241	.044	73.65	UK
	H187c	OB-1792	3.337	.045	74.19	UK
	H188a	OB-1793	3.311	.024	138.02	OC
	H188b	OB-1794	3.269	.042	77.46	TP
	H188c	OB-1795	3.323	.023	146.52	OC
	H188d	OB-1796	3.429	.043	79.74	TP
	H189a	OB-1797	3.370	.030	110.67	UK
	H189b	OB-1798	3.358	.027	123.77	UK
	H189c	OB-1799	3.228	.024	136.78	OC
	H326	OB-4167	2.958	.019	159.55	OC
	H327	OB-4168	3.028	.020	155.12	OC
	H328	OB-4169	3.137	.020	159.32	OC

Site Location	NWP Specimen Number	NAA Lab Specimen Number	%NA	%Mn	Na/Mn	Indicated Source*
	H329	OB-4170	3.040	.019	159.66	OC
	H330	OB-4171	3.120	.020	158.94	OC
	H331	OB-4172	2.998	.019	155.66	OC
	H332	OB-4173	2.953	.018	163.06	OC
	H333	OB-4174	2.971	.019	160.42	OC
	H334	OB-4175	3.077	.019	157.88	OC
	H335	OB-4176	2.936	.018	162.84	OC
	H336	OB-4177	3.214	.020	162.25	OC
	H337	OB-4178	3.141	.019	166.81	OC
	H338	OB-4179	3.105	.019	164.63	OC

Source:
OC = Obsidian Cliff, Wyoming
FMY = Bear Gulch, Idaho
TP = Teton Pass, Wyoming
UK = Unknown

Appendix H. Atomic Absorption Spectroscopy (Major Element) Data for Archaeological Specimens From Yellowstone National Park, Wyoming, Montana, and North Dakota Sites.

Appendix H. Atomic Absorption Spectroscopy (Major Element) Data for Archaeological Specimens From Yellowstone National Park, Wyoming, Montana, and North Dakota Sites.

	Major Element Composition*					
Specimen No.	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
YELLOWSTONE NATIONAL PARK						
Parker Peak (48YE507)						
471-507-1	3.53	5.21	1.47	0.41	0.05	PP
471-507-2	3.56	5.06	1.44	0.41	0.07	PP
471-507-3	3.55	5.11	1.50	0.39	0.06	PP
Crystal Spring Flow (Michels 1987d)						
425-2	3.85	4.80	1.68	0.81	0.28	CS
425-3	3.82	4.83	1.28	0.40	0.05	CS
425-1	3.87	4.83	1.34	0.42	0.07	CS
48YE380	3.73	4.87	1.21	0.42	0.05	OC
Obsidian Cliff (48YE433) (Michels 1985b)						
307-2-E	3.83	5.02	1.13	0.38	0.04	OC
307-1-D	3.78	4.97	1.19	0.35	0.04	OC
307-1-A	3.79	4.91	1.07	0.36	0.04	OC
307-3-C	3.74	5.16	1.24	0.35	0.04	OC
307-1-G	3.85	4.97	1.13	0.35	0.04	OC
307-1-B	3.85	4.99	1.06	0.34	0.04	OC

Specimen No.	Major Element Composition*					Source**
	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	
307-1-F	3.82	5.00	1.09	0.35	0.04	OC
307-1-H	3.68	5.09	1.12	0.35	0.04	OC
307-2-D	3.75	4.92	1.15	0.39	0.04	OC
307-1-E	3.75	5.00	1.21	0.39	0.04	OC
307-1-C	3.78	5.01	1.20	0.40	0.04	OC
307-2-C	3.82	4.90	1.20	0.38	0.04	OC
307-3-A	3.72	4.92	1.12	0.38	0.04	OC
307-4-D	3.74	4.94	1.18	0.37	0.04	OC
307-2-A	3.74	4.98	1.19	0.37	0.04	OC
307-4-A	3.75	4.92	1.10	0.38	0.04	OC
307-5-A	3.80	4.95	1.19	0.36	0.04	OC
307-6-C	3.75	5.01	1.17	0.36	0.04	OC
307-5-F	3.76	4.97	1.07	0.34	0.04	OC
307-4-B	3.65	5.05	1.12	0.38	0.04	OC
307-5-C	3.77	4.93	1.17	0.38	0.04	OC
307-4-C	3.79	4.89	1.15	0.37	0.04	OC
307-5-B	3.75	4.97	1.14	0.36	0.04	OC
307-6-B	3.76	4.90	1.18	0.36	0.04	OC
307-6-A	3.74	4.89	1.30	0.38	0.04	OC

Specimen No.	Major Element Composition* Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
307-5-E	3.80	4.91	1.13	0.38	0.04	OC
307-5-D	4.07	4.48	1.15	0.37	0.04	OC
307-2-B	3.76	4.88	1.18	0.37	0.04	OC
307-3-B	3.76	4.96	1.25	0.38	0.04	OC
WYOMING						
Teton Pass (Michels 1985b)						
307-6-D	3.91	4.12	1.14	1.17	0.13	TP
MONTANA						
Indian Creek (24BW626) (Michels 1985e)						Davis 1986
330-IC-85-2002	4.02	5.33	1.63	0.62	0.17	C/DC
330-IC-85-2001	3.46	5.44	1.60	0.54	0.13	C/DC
330-IC-85-2000	3.96	5.33	1.51	0.59	0.18	C/DC
330-IC-85-2003	3.47	5.41	1.56	0.51	0.13	C/DC
287-499	4.26	4.92	1.20	--	0.06	OC
287-500	--	4.89	1.16	--	--	OC
287-501	--	4.86	1.14	--	-	OC
287-502	--	4.83	1.08	--	-	OC
287-503	--	5.57	1.42	--	-	C/DC

Specimen No.	Major Element Composition* Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
303-IC-85-2	3.44	5.42	1.70	--	--	C/DC
303-IC-85-1	3.44	5.44	1.62	--	--	C/DC
303-IC-85-4	3.63	5.47	1.76	--	--	C/DC
303-IC-85-9	3.58	5.46	1.65	--	--	C/DC
03-IC-85-8	3.44	5.39	1.60	--	--	C/DC
303-IC-85-5	3.46	5.47	1.61	--	--	C/DC
303-IC-85-3	3.45	5.39	1.71	--	--	C/DC
303-IC-85-6	3.42	5.48	1.80	--	--	C/DC
303-IC-85-7	3.60	5.60	2.08	--	--	C/DC
260-1013	3.74	4.88	1.29	--	--	OC
260-1020	3.54	5.35	2.03	--	--	C/DC
260-28	3.79	4.90	1.34	--	--	OC
260-1019	3.64	5.39	1.89	--	--	C/DC
260-1016	3.57	5.34	1.64	--	--	C/DC
Lost Terrace (24CH68) (Michels 1985e, 1987c)						Davis and Fisher 1988, 1990; Greiser 1988
330-LT-85-2004	--	4.96	1.44	0.48	--	OC
330-LT-85-2005	--	5.04	1.26	0.52	--	OC
330-LT-85-2006	--	4.83	1.32	0.59	--	OC

Specimen No.	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
	Major Element Composition*					
406-LD-2017	3.51	4.86	1.19	0.35	0.04	OC
406-LD-2016	3.83	5.20	1.22	0.61	0.09	OC
406-LD-2012	3.71	5.15	1.38	0.56	0.06	OC
406-LD-2014	3.57	4.85	1.20	0.37	0.03	OC
406-LD-2015	3.23	5.92	0.89	0.44	0.04	UK
Schmitt Chert Mine (24BW559) (Michels 1987b)						Davis 1982a
286-1055	3.78	5.72	1.72	--	--	C/DC
286-1053	3.95	5.68	1.86	--	--	C/DC
286-1061	3.83	5.64	1.73	--	--	C/DC
286-1069	3.97	5.09	1.35	--	--	OC
286-1054	4.42	5.15	1.38	--	--	OC
286-1062	3.84	5.67	1.83	--	--	C/DC
286-1063	3.92	5.72	2.03	--	--	C/DC
286-1056	4.37	5.17	1.35	--	--	OC
286-1057	4.03	5.79	1.95	--	--	C/DC
286-1058	3.92	5.14	1.33	--	--	OC
286-1060	3.77	5.75	1.71	--	--	C/DC
286-1059	3.78	5.75	1.88	--	--	C/DC
286-1065	3.80	5.67	1.74	--	--	C/DC

Specimen No.	Major Element Composition* Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
286-1066	3.74	5.63	1.66	--	--	C/DC
286-1068	3.80	5.67	1.74	--	--	C/DC
286-1064	3.75	5.67	1.99	--	--	C/DC
286-1067	3.82	5.59	1.69	--	--	C/DC
419-5	3.45	5.51	1.59	0.51	0.11	C/DC
419-16A	3.39	5.38	1.61	0.60	0.11	C/DC
419-2C	3.45	5.44	1.62	0.41	0.10	C/DC
419-7A	3.47	5.32	1.55	0.59	0.10	C/DC
419-10	3.56	5.35	1.61	0.56	0.10	C/DC
419-8	3.46	5.42	1.56	0.48	0.11	C/DC
419-13C	3.59	5.43	1.56	0.55	0.13	C/DC
419-8D	3.46	5.59	1.57	0.59	0.10	C/DC
419-21	3.39	5.38	1.56	0.67	0.11	C/DC
419-17	3.44	5.09	1.89	0.46	0.50	UN
419-14	3.47	5.52	1.67	0.64	0.10	C/DC
419-13B	3.47	5.47	1.57	0.69	0.11	C/DC
419-13A	3.53	5.41	1.68	0.64	0.14	C/DC

Specimen No.	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
		Major Element Composition*				
Stark (24ML564) (Michels 1987a, 1987c)						Davis et al. n.d.a
405-2031	3.69	4.92	1.17	0.32	0.04	OC
405-2030	3.58	5.03	1.71	0.42	0.07	BSB
405-2032	3.57	4.80	1.17	0.32	0.06	OC
405-2024	3.50	5.41	1.51	0.64	0.14	C/DC
405-2029	3.66	4.83	1.07	0.24	0.05	OC
405-2025	3.51	5.34	1.68	0.73	0.12	C/DC
405-2026	3.60	5.38	1.78	0.56	0.16	C/DC
Somerfeld (24CA194) (Michels 1986b)						Quigg 1986
332-194-6	3.26	5.36	1.71	0.53	0.13	C/DC
332-194-8	3.43	4.94	1.31	0.31	0.05	OC
332-194-7	3.32	4.90	1.26	0.29	0.05	OC
Corey Ranch (24TT83) (Michels 1986b)						Quigg 1986, 1988
332-83-5	3.19	5.46	1.79	0.54	0.13	C/DC
332-83-6	3.28	5.43	1.78	0.54	0.15	C/DC
332-83-7	3.08	5.88	1.78	0.48	0.16	C/DC
332-83-10	3.14	5.48	1.74	0.58	0.20	C/DC

	Major Element Composition*					
Specimen No.	Na_2O	K_2O	$Fe_2O_2{}^T$	CaO	MgO	Source**
332-83-4	3.06	5.26	1.74	0.52	0.18	C/DC
332-83-11	3.28	4.92	1.40	0.30	--	OC
332-83-8	3.60	5.52	1.96	0.64	--	C/DC
WYOMING						
Jackson Lake (Michels 1986c)						
393-1	3.27	4.93	1.40	0.39	0.06	HC
393-2	3.50	3.89	1.20	1.13	0.09	MR
393-3	3.15	4.99	1.65	0.32	0.03	GLR
Jackson Lake Sites (Michels 1985d,f, 1986d)						Connor 1986
48TE1062						
309-31-245	4.00	3.93	1.18	1.31	0.15	TP
48TE 1071						
309-41-277	3.47	5.16	1.69	0.51	0.13	C/DC
309-41-276	4.09	3.90	1.20	1.34	0.15	TP
309-41-270	3.56	4.63	1.40	0.38	0.05	Teton B
48TE509						
309-48-387	4.16	3.89	1.21	1.36	0.16	TP
309-48-357	3.77	4.80	1.32	0.38	0.05	OC
309-48-347	3.75	4.78	1.39	0.42	0.06	OC

Specimen No.	Major Element Composition* Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
309-48-345	3.76	3.93	1.20	1.29	0.15	TP
309-48-308	3.90	3.96	1.30	1.30	0.15	TP
309-48-319	3.80	3.71	1.35	1.36	0.24	Teton A
309-48-291	3.83	3.82	1.34	1.48	0.24	Teton A
309-48-371	3.71	4.93	1.32	0.37	0.05	OC
309-48-389	3.47	4.97	1.45	0.53	0.09	Teton B
48TE1061						
309-30-231	3.69	3.62	1.56	1.68	0.29	Teton A
309-30-232	4.27	3.93	1.17	1.25	0.16	TP
48TE1039						
309-5-184	3.46	5.32	1.66	0.68	0.14	C/DC
48TE1071						
309-41-270	3.56	4.63	1.40	0.38	0.05	Teton B
48TE1051						
309-20-205	3.71	4.86	1.34	0.28	0.04	OC
309-20-206	3.81	3.93	1.21	1.28	0.21	TP
309-20-207	3.83	3.95	1.25	1.25	0.20	TP
48TE1042						
309-10-188	3.85	3.68	1.69	1.75	0.31	UK A

	Major Element Composition*						
Specimen No.	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO		Source**
48TE1043							
309-12-197	3.97	3.90	1.23	1.34	0.23		TP
309-12-198	3.81	3.62	1.61	1.68	0.30		UK A
48TE1065							
309-34-253	3.85	3.41	1.52	1.60	0.31		UK
48TE1069							
309-38-283	3.78	4.92	1.26	0.29	0.05		OC
48TE1044							
309-13-199	3.76	4.89	1.29	0.25	0.04		OC
48TE1070							
309-40-289	3.52	5.42	1.71	0.51	0.13		C/DC
48TE1056							
309-25-234	4.26	4.00	1.24	1.27	0.19		TP
309-25-235	3.92	3.83	1.40	1.41	0.25	TP	
309-25-235							TP
48TE1054							
309-23-233	4.11	3.47	1.69	1.74	0.30		Teton A
48TE1052							
309-21-223	3.38	5.05	1.42	0.42	0.03		Teton B

Major Element Composition*						
Specimen No.	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
48TE1042						
309-9-187	3.85	3.95	1.16	1.27	0.19	TP
48TE1049						
309-18-204	3.81	3.41	1.54	1.56	0.27	UK A
48TE1059						
309-28-228	4.19	3.79	1.33	1.41	0.36	TP
309-28-227	4.09	3.60	1.48	1.65	0.29	Teton A
48TE1046						
309-15-201	3.72	3.94	1.35	1.23	0.18	TP
48TE1063						
309-32-252	3.86	3.95	1.25	1.27	0.20	TP
309-32-250	4.17	3.65	1.43	1.64	0.27	UK A
48TE1057						
309-26-225	3.87	3.59	1.46	1.69	O.31	Teton A
309-26-226	3.83	3.82	1.33	1.48	0.24	TP
309-26-225						Teton A
48TE1048						
309-17-218	3.79	4.98	1.25	0.38	0.04	OC

	Major Element Composition*					
Specimen No.	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
48TE1060						
309-29-237	4.17	4.01	1.14	1.28	0.19	TP
48TE1047						
309-16-203	3.56	5.42	1.63	0.66	0.14	C/DC
48TE1055						
309-24-224	3.78	3.55	1.51	1.72	0.33	UK A
48TE1038						
309-4-180	3.74	3.65	1.42	1.54	0.27	UK A
48TE1058						
309-27-236	3.80	3.66	1.41	1.70	0.33	UK A
319-12A	3.81	4.92	1.18	0.50	0.08	OC
319-13	3.91	4.94	1.26	0.44	0.04	OC
319-677-2	3.95	4.96	0.57	0.53	0.06	UK
319-17A	3.90	4.97	1.17	0.38	0.04	OC
319-11A	3.80	4.91	1.16	0.39	0.04	OC
319-677-1	3.57	4.79	1.75	0.95	.031	UK
319-9B	3.90	5.07	1.58	0.67	0.12	JP
319-8	3.82	5.04	1.54	0.60	0.06	JP
319-19	3.70	5.02	1.48	0.53	0.07	JP

Major Element Composition*						
Specimen No.	Na_2O	K_2O	$Fe_2O_2^T$	CaO	MgO	Source**
319-10A	3.83	4.90	1.24	0.40	0.03	OC
319-18A	3.83	5.03	1.39	0.56	0.06	JP
319-16A	3.96	4.90	1.26	0.44	0.04	OC
319-14A	3.90	4.93	1.49	0.58	0.06	JP
319-15C	3.91	4.95	1.49	0.82	0.14	JP

*Source:
OC = Obsidian Cliff, Wyoming
TP = Teton Pass, Wyoming
C/DC = Camas/Dry Creek (= Bear Gulch), Idaho
HC = Hominy Creek, Wyoming
MR = McNeeley Ranch, Wyoming
** All values in weight percent (%) composition

GLR = Grassy Lake Reservoir, WY
CS = Crystal Springs, Wyoming
BSB = Big Southern Butte, Idaho
JP = Jackass Pass, Wyoming
UK = Source Unknown

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