ACTIVATION ANALYSIS IDENTIFICATION
OF THE GEOLOGIC ORIGINS OF
PREHISTORIC OBSIDIAN ARTIFACTS

MASTER

Adon A. Gordus Department of Chemistry
James B. Griffin Museum of Anthropology
Gary A. Wright Museum of Anthropology^a

The University of Michigan
Ann Arbor, Michigan 48104

Abstract

The elemental composition of obsidian samples was determined using neutron activation analysis. The geologic origins of prehistoric obsidian artifacts were identified by matching the Na, Mn, La, Sm, Sc, Fe, and Rb contents of the artifacts with that of obsidian from geologic sources. Discussed here are studies of obsidian recovered from the 2000 year-old Hopewell sites in the Midwestern United States and from archaeological sites in the Near East that date to the period 7500 to 3500 B.C.

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^a Present address: Dept. of Anthropology, Case-Western Reserve University, Cleveland, Ohio 44106

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Introduction

A fundamental problem in the study of prehistoric trade routes and cultural contacts is the unambiguous identification of the sources of the raw materials used in the construction of the archaeological artifacts. For example, when Squier and Davis reported in 1848 that they found obsidian artifacts in the 2000-year old Ohio Hopewell burial mounds (1) they asked: "Whence was this singular product obtained?" The nearest geologic sources are 1,500 miles to the west. During the past 120 years Alaska, the Pacific Coast of the United States, Yellowstone National Park, New Mexico, Central Mesoamerica, and Peru were each suggested as the possible origin of the Hopewellian obsidian.

Described in this paper are analytical studies we have performed which permit us to identify the geologic origin of an obsidian artifact. Based on these analyses, we are able to answer questions such as the one posed by Squier and Davis. But we also obtain information on the variation in the utilization of different obsidian sources during prehistoric times and, hence, are able to describe the changes that occurred in the obsidian trade patterns. Lastly, the analytical data have a value in themselves in that information related to the geochemistry of obsidian is also obtained.

Obsidian is an ideal material to study in determining prehistoric trade routes. Being a volcanic material, only a limited number of geologic sources exist and need be examined. Since obsidian is formed by rapid cooling, the composition of obsidian in a single flow is relatively uniform (2), unlike flint, for example, which is a sedimentary material. The construction of an obsidian artifact does not alter the composition of the geologic material; ceramic or metallic artifacts, on the other hand, are

frequently made of mixtures of various raw materials. Lastly, except possibly for a very thin surface layer, the composition of the obsidian artifact is unaltered by centuries of weathering during which time it lay buried; it is a hard, non-porous material and, unlike pottery, resistant to the penetration of groundwater. Only by heating obsidian to high temperatures is it possible to alter the mineral; the glassy structure is destroyed and much of the water released, resulting in a porous matrix. Among the 1,000 obsidian artifacts we have analysed, only one appeared as though it had been subjected to excessive heat; the analytical data for this sample deviated markedly from the data for all other obsidian samples.

In recent years there has been an increased interest in the determination of the geologic origins of obsidian artifacts. The problem was first rigorously approached by Cann and Renfrew (3). After an intensive examination of a number of characteristics of the appearance of obsidian samples from different flows (e.g. color, translucency, etc.), they concluded that individual obsidian flows could not be characterized on the basis of appearance alone (4). The most unambiguous identification, they found, was achieved by considering the elemental composition, which they determined by emission spectroscopy.

Stross has examined various North American obsidian samples using both X-ray fluorescence analysis (5) and neutron activation analysis (6). On a more limited scale, Green, Brooks, and Reeves, using emission spectroscopy, have analysed obsidian from seven New Zealand sources (7) and Parks and Tieh, using X-ray fluorescence, have analysed obsidian from three regions in California (8).

Described in this paper are studies we have performed during the past three years, using neutron activation analysis as a means

of determining the elemental composition of obsidian samples. Both prehistoric obsidian artifact and geologic quarry-site obsidian samples from throughout the world are represented in the 2,800 individual samples we have analysed.

Method of Analysis

There are a number of reasons why we chose to use neutron activation analysis in these studies: (a) If necessary, the sensitivity of the method would permit us to work with samples as small as a mg. or less. (b) The analysis is non-destructive. (c) In some cases, the analysis procedure can be automated. (d) Samples can be reanalysed by re-irradiating the samples after the original activity decays. (e) The sensitivity of detection of elements is dependent upon nuclear properties. Thus, certain common elements such as oxygen, hydrogen, carbon, and nitrogen are not easily activated. It is usually the elements that are readily activated, many of which may be present only in trace quantities, which frequently provide the greatest amount of information.

Given in Table I are the gamma-ray radioactivity levels that would be observed if 10 mg. of a typical obsidian sample were irradiated for one minute in a thermal neutron flux of 10^{12} neutrons $\times$ cm $^{-2}$ $\times$ sec $^{-1}$. Most geologic samples of obsidian contain almost the same amounts of the major elements: O, Si, Al, K. The sodium content may vary by a factor of two between sources, but the other elements that are present in smaller concentrations frequently exhibit an even larger variation between sources. For example, we have found manganese to differ by over a factor of 10 (i.e. 1000%) between some geologic sources (2). On the other hand, the variation in the elemental composition of obsidian for each geologic flow appears to be less than 40% (2).

The data of Table I, therefore, suggest one type of neutron activation analysis that can be performed: samples irradiated in a high-flux beam of neutrons can be analysed two hours after the irradiation and more than 99% of the observed activity will be due only to ^{24}Na and ^{56}Mn . Therefore, the analysis of these irradiated samples was relatively simple and it was possible to automate some steps in the analysis procedure.

If, instead, a typical obsidian sample was irradiated for 24 hours in a thermal neutron flux of 10^{13} neutrons $\times$ cm $^{-2}$ $\times$ sec $^{-1}$, then various gamma-ray activities, including those listed in Table II, would be observed. If the sample was

analysed 16 days after the irradiation it would be possible to detect at least 10-15 different isotopes.

Our analysis procedure includes both a series of short-term (32 sec.) and a long-term (24 hour) irradiation of obsidian.

Short-Term Irradiation

Obsidian samples of 30 mg. average weight were individually sealed in polyethylene tubing. 90 samples and 10 $\text{NaNO}_3\text{-MnCO}_3$ chemical standards were packaged in two polyethylene "rabbits" (Fig. 1) and each irradiated for 32 sec. at a neutron flux of 2×10^{12} neutrons $\times \text{cm}^{-2} \times \text{sec}^{-1}$ in a pneumatic-tube facility of The University of Michigan nuclear reactor.

The irradiated samples were analysed automatically by taking a one-minute count every 2 hr., 25 min. for a total of ten counts per sample. A NaI(Tl) scintillation detector was coupled to a single-channel analyser and only the 0.76-0.93 MeV radiation, which includes the principal ^{56}Mn peak, was recorded. Since more than 99% of the detected radioactivity was due to ^{24}Na (15.0 hr) and ^{56}Mn (2.58 hr) it was possible, by computer analysis, to resolve these composite decay data into the two decay components (Fig. 2). Using the data obtained from the chemical standards, the computer then calculated the sodium and manganese contents of the obsidian. This irradiation and computer analysis procedure is described in detail elsewhere (9).

Since the induced activity was almost completely decayed in a week to ten days, it was possible to re-irradiate the samples and obtain replicate Na-Mn analyses of the same samples. Usually four or five such determinations were made for each sample. Typically, the standard deviations of the mean for the replicate Na and Mn assays are within about $\pm 5\%$ of the mean.

Separate irradiations of aluminum and iron samples indicated that negligible ^{24}Na and ^{56}Mn interference activities were produced by high-energy neutron reactions.

The sodium and manganese content analyses permitted grouping the artifacts according to the % Na, % Mn, and the ratio: % Na/% Mn. Comparison of these data with geologic-source samples of obsidian provided a means of eliminating most sources as possible quarry sites.

Long-Term Irradiation

In order to identify which of the few sources having % Na and % Mn contents identical with an artifact was the true source it was necessary to determine the percentage of additional elements. The obsidian samples and chemical standards were irradiated for 24 hours at a neutron flux of 2×10^{13} neutrons $\times \text{cm}^{-2} \times \text{sec}^{-1}$.

Besides the production of radioactive Al, Na, and Mn, detectable amounts of the longer-lived isotopes ^{140}La , ^{59}Fe , ^{46}Sc , ^{86}Rb , and ^{153}Sm , as well as about ten other species,

also were produced. Analysis for these elements was performed by pulse-height gamma-ray spectrometry with a 10 cc. Ge(Li) detector having a full-width at half-maximum of 4 keV. Typical gamma-ray spectra are shown in Fig. 3. Data from these analyses are valid to about $\pm 20\%$.

Since Cs, Ta, Tb, Ir, and Ba were not included in the chemical standards, we have reported data for these elements (and Sc where it is used in a ratio) as radioactivity ratios, corrected for decay to the end of the irradiation.

Elemental Identification of Obsidian

In order to determine the geologic source of an obsidian artifact, it was necessary first to ascertain if each separate obsidian flow could be uniquely characterized by its elemental composition. This was found to be the case (2, 10-12). Elements that have been particularly useful in differentiating between geologic sources include Mn, Sc, La, and Sm.

Samples from almost 100 obsidian flows throughout the world have been analysed. Presented here, for purposes of illustration, are data based on samples from a single geographical locality: Yellowstone and Teton National Parks.

One of the major geographical areas of vulcanism having obsidian flows in the Rocky Mountain chain is the region of Yellowstone and Teton National Parks and an exact count of the separate obsidian flows in this area has not been made. From the reports of Iddings (13)

and Boyd (14) we have been able to itemize more than 20 "exposures" in Yellowstone. This does not include the region of the canyon of the Yellowstone River for which we were not able to obtain data. The United States Geological Survey is conducting a new survey in Yellowstone Park, which includes the remapping of many of the obsidian flows, and Dr. B. Christiansen of the USGS will submit samples to us.

At this time, we have element composition data for 15 different exposures. They are listed in Tables III and IV. Most of the 15 localities were investigated by Iddings, and the samples from his survey were submitted for analysis by Dr. H. Banks, Smithsonian Institution. Dr. I. Friedman submitted the Teton Pass specimens, and G. A. Wright collected the Canyon Junction samples. The West Thumb and Norris Cut-Off specimens were in the collections of the University of Michigan-Museum of Anthropology. A number of investigators are responsible for the Obsidian Cliff samples. Besides Iddings, they include Dr. E. Wm. Heinrich and Dr. J. B. Griffin. One exposure is represented by only one specimen (No. 528). It was received from the Field Museum of Natural History, Chicago, and was catalogued only as "Yellowstone". Hereafter, it will be referred to as Field Museum Yellowstone (FMY).

In terms of field geology and chemical analysis, Obsidian Cliff is one of the best studied obsidian flows in the world. Samples from this source have % Na/% Mn ratios which are approximately 150. This high ratio is due largely to the extremely low Mn content in this flow; an average of about $2.1 \times 10^{-2}\%$.

Specimens from two exposures in the Norris Basin (at Geyser Creek and on the east wall of Norris Geyser Basin) also have % Na/% Mn ratios of about 150. Based on the analysis data, these exposures appear to belong to the same flow. They may be distinguished from Obsidian Cliff, however, by their lower Sc and La contents (Table III). In addition, the Sc/Cs and Sc/Ta radioactivity ratios for the Norris Basin exposures are about one-half the value of the ratios for Obsidian Cliff.

The FMY sample has a % Na/% Mn ratio of approximately 90 and differs from West Thumb and Buffalo Lake samples on the basis of a higher Sc content. It also has a lower Tb/Cs radioactivity ratio than West Thumb, and a slightly higher Fe content. Buffalo Lake seems to have both higher Na and Mn contents, and certainly a higher Sc/Cs ratio in comparison to West Thumb.

The data of Tables III and IV indicate that the various Yellowstone and Teton exposures may be readily differentiated in terms of their elemental content. In cases where two adjacent exposures appear chemically similar they may in fact be from different exposures of the same flow. Only a more complete mapping of the volcanic features of this region will solve this part of the problem.

In summary, these and other data suggest that obsidian sources can be uniquely characterized on the basis of their elemental composition. One method of visually comparing these data is shown in Fig. 4, where the composition of four North American sources is plotted relative to that of Obsidian Cliff.

We will make use of this type of diagram in discussing the data for Hopewell and Near Eastern obsidian artifacts.

Analysis of Obsidian Artifacts

In our studies of the geologic origins of obsidian artifacts we have concentrated on two major areas: the Middle-Western United States (15) and the Near East (10-12). Data from some of these samples are summarized below. In addition, we have initiated a study of Mesoamerican obsidian and have analysed over 1,000 specimens from that region, but our data are not yet complete enough to permit a full description of the changing pattern of obsidian utilization in this area. This is primarily because we have not yet obtained adequate samples from the large number of potential sources.

Middle Woodland Obsidian

Although elemental analyses of obsidian from various geologic sources, including Yellowstone National Park, had been available since the late 19th century (13), no Hopewellian material had been tested until we began our studies in 1966.

We have tested 87 Hopewell obsidian artifacts for their Na and Mn contents (16) and found that the %Na/%Mn ratios of the samples fell into two groups (17) as seen in Table V. One ranged from 132 to 170; this is our 150 Group. The second ranged from 84 to 101; this is our 90 Group. The differences were due to a consistently lower Mn content in the 150 Group specimens. There were 68 specimens in the former group and 19 in the latter. Both groups contained well-made ceremonial objects (e.g. large projectile points, Fig. 5, and bifacially worked blades), cores, and chipping debris.

A number of samples in each Na-Mn group were tested for additional elements and we found that these additional analyses confirmed the separation into two groups. For example, the 150 Group showed a range in Sc content of 1.3 to $1.8 \times 10^{-4}\%$ whereas the range for the 90 Group was 3.4 to $4.3 \times 10^{-4}\%$. Using gamma-ray spectral data for each sample, we computed various radioactivity ratios for the samples. The Tb/Cs ratio ranged from 7.4 to 9.7 for the 150 Group and 5.0 to 6.3 for the 90 Group. All of the data from the 12 elements studied left no doubt as to the validity of the two groups. Some of these data are given in Table VI and depicted in Fig. 6.

Next, these Hopewell obsidian data were compared with similar data compiled in our laboratory on obsidian flows in Alaska, the Pacific Coast, Yellowstone National Park, New Mexico, and Central Mexico. Our conclusion (15) is that the 150 Group corresponds to Obsidian Cliff in Yellowstone National Park and the 90 Group corresponds to the FMY sample. This correspondence of source and artifact data is clearly seen in Fig. 6. Equally important, the lack of correspondence of the Hopewell obsidian data with other source data is seen when diagrams such as Fig. 4 are compared with Fig. 6.

Archaeologically, the Yellowstone and Teton areas are extremely important because they contain at least two major sources of obsidian utilized by prehistoric Indians, and possibly a third source (18). The Obsidian Cliff and FMY exposures were intensively exploited, and specimens matching these sources have been recovered from archaeological sites ranging from Idaho to the Northern Plains and eastward into the Ohio Valley (19). Thus, there is a distributional link between the Hopewellian sites and the

Yellowstone sources. Obsidian Cliff appears to have been the major source for these areas (19), and, if one can trust the obsidian-hydration dates, was apparently utilized in the Northern Plains for nearly 10,000 years. There also are historical references to historic Indian groups collecting obsidian in Yellowstone National Park, but the quarries are never identified.

Near East

There are two major regions of vulcanism in the Near East which contain obsidian flows, the Nevşehir-Aksaray-Niğde area of Central Anatolia and the Lake Van region of Eastern Turkey. Near Eastern obsidian artifacts were divided into groups (17) according to their elemental composition, using the notation of Renfrew (3, 4). Artifacts of group 1e-f (source: Acigol) and 2b (source: Çiftlik) derive from obsidian sources in Central Anatolia (10) whereas those that form group 3a (source: Bayezid ?), 4c (source: Nemrut-Dağ B), and 1g (source: ?) appear to derive from sources near Lake Van. The location of these sources and the sites from which obsidian artifacts were obtained for testing are shown in Fig. 7. It has become apparent from these studies that a preliminary identification may be made on the basis of the Na content. All of the obsidian samples from Central Anatolian sources have less than 3.8% Na whereas Lake Van source groups have 3.95% Na or more. Other element contents, particularly Mn, Sc, Ba, and Zr provide an unambiguous separation of the various groups (12).

We will discuss here the data for archaeological obsidian artifacts found in two areas: the Zagros-Taurus arc-- Southern Mesopotamia, and the Levant. Although the use of obsidian in the Near East begins prior to 7,500 B.C. and extends later

than 3,500 B.C. we will limit our discussion to that 4,000 year period. This time range roughly defines the appearance of early village farming communities up to the end of the Ubaid Phase.

In Fig. 10, Na and Mn are given for samples from seven prehistoric sites in the Zagros-Taurus arc which pre-date the Hassuna Phase which began about 5,800 B.C. Two major obsidian groups are represented: 4c and 1g. Further tests on additional elements in the samples have confirmed these group designations (11, 12). One sample from Cayönü lies outside the range of either group and appears to derive from a source near the town of Bingöl which is situated between Cayönü and the Nemrut Dağ source (11, 12). The final sample which falls outside the 4c and 1g Na-Mn ranges is from Jarmo. It belongs to an unknown group.

In Fig. 9 are presented Na and Mn data for 11 sites in the same area which date between 5,800 and 3,500 B.C. It is clear that there is a major change in source utilization, with 1g being replaced by 3a. Group 1g is found in the Zagros-Taurus arc--Southern Mesopotamia area during the 5,800-3,500 B.C. time period only at ^rApachiyah where it is in association with both groups 3a and 1g.

The change in obsidian source exploitation by the end of the Hassuna Phase (ca. 5200 B.C.) correlates closely with the initial settlement at the site of Tilki Tepe. This site is located on the eastern shore of Lake Van, near the major Eastern Anatolian obsidian sources. The excavator of the site recovered hundreds of large obsidian blades and more than 20 obsidian cores, one of which weighed more than 25 lbs (20). The site has been functionally interpreted as an obsidian working and trading station due to its proximity to major obsidian sources, the presence of large blades and cores, and the absence of cores on most sites in the sub-area (12).

In the Levant, prior to 7000 B.C., obsidian is known only from Pre-Pottery Neolithic-A sites (PPNA) at Jericho and Nahal Oren. These specimens all appear to derive from Central Anatolia (group 2b) (12).

During the Pre-Pottery Neolithic B period (PPNB) (ca. 7200 to 6250 B.C.), group 2b obsidian is known from Jericho and Beidha. There is an obsidian microblade from Munhata level 6 which seems to belong to group 1e-f, and a blade from level A at El Khiam for which the element data most closely approximate a minor Central Anatolian source (21).

Obsidian from the Lake Van sources first reached the Levant during the PPNB. Group 4c obsidian is known from Beidha, Beisamoun, and Ramad (21).

By 4000 B.C. about one-half of the obsidian in the Levant was from Lake Van sources. Group 1g, for example, did not reach the Levant until it was no longer utilized in the Zagros-Taurus

arc. At one site, Byblos five groups have been identified: 1e-f, 1g, 2b, 3a, and 4c. (120).

These obsidian data may be utilized to examine certain hypotheses about cultural development in the Near East.

Earlier we mentioned that the obsidian data lend some support to the idea that Tilke Tepe was a specialty site for the preparation of obsidian for trade.

A second example concerns the domestication of wheat and its transferral out of its natural habitat zone to the rest of the Near East. Harlan and Zohary (22) have recently noted that there are two races of wild wheat: one located in the Zagros-Taurus arc and one south of the Syrian Saddle in the Jordan River watershed. Their studies suggest that "the present evidence indicates that most modern tetraploid cultivated wheat stemmed from the race now found in the upper Jordan watershed" (22). The crucial time period for the domestication of wheat and its spread is about 7500 to 6500 B.C. By 6500 B.C. it is known both at Beidha in Jordan and in the Zagros-Taurus arc. Lake Van obsidian is also known in the Levant at Beidha, Beisamoun (in the Jordan watershed), and at Ramad by 6500 B.C.. These obsidian data clearly suggest contact between cultural groups in the Levant and the Zagros-Taurus arc during the crucial time period. The obsidian trade routes thus may have served as paths along which domesticated wheat moved from the Jordan Valley into the rest of the Levant, Central Anatolia, and the Zagros-Taurus arc.

Related Studies

In addition to the extensive studies of obsidian sources, we have also initiated studies of flint, hematite, magnetite, and, in cooperation with Prof. Curt Beck of Vassar College, amber. The preliminary data for flint indicate that Na may be a particularly useful element to use in the identification of sources. Other elements which are activated and easily detected in flint include Mn, Fe, La, Sc, and As. The data from analyses of Mexican magnetite samples indicates that each exposure may be characterized by its Fe, Co, and Sc contents and the presence or absence of a detectable level of Sm.

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Figure Captions

- Fig. 1 Obsidian samples and Na-Mn chemical standards are sealed in polyethylene tubing and packaged in polyethylene "rabbits" prior to irradiating the samples for 32 sec. in the reactor.
- Fig. 2 The composite decay data for an obsidian sample is resolved into its ^{24}Na and ^{56}Mn components.
- Fig. 3 The gamma-ray spectra for obsidian samples indicate the presence of more than 15 radioactive isotopes.
- Fig. 4 Composition of various geologic obsidian samples relative to the average composition of 23 samples from Obsidian Cliff, Yellowstone National Park. Glass Butte, Ore., (5 samples): $\bigcirc$. Cerro de las Navajas, Mex., (10 samples): $\bigcirc$. Vias Mountain, New Mex., (5 samples): $\triangle$. Powder River, Mont., (4 samples): $\blacktriangle$.
- Fig. 5 Ceremonial obsidian blade recovered from a Hopewell burial mound.
- Fig. 6 Composition of Hopewellian obsidian samples relative to the average composition of 23 samples from Obsidian Cliff, Yellowstone National Park. 17 Hopewell samples of the 150 Group: $\bigcirc$. 9 Hopewell samples of the 90 Group: $\bullet$. Data for the FMY sample (No. 528): $\square$.
- Fig. 7 Na and Mn contents of obsidian samples from archaeological sites that date to the Pre-Hassuna Phase.
$\bullet$ = Çayönü	$\square$ = Sarab	$\blacksquare$ = Tamer Khan
$\bigcirc$ = Jarmo	$\triangle$ = Anygerm	∇ = Tell Shemshara
	$\blacktriangle$ = Ali Kosh	
- Fig. 8 Na and Mn contents of obsidian samples from archaeological sites that date to the Hassuna and Post-Hassuna Phases.
$\bullet$ = Banahilk	$\square$ = Matarrah	$\blacksquare$ = Halaf
$\bigcirc$ = Eridu-Ubaid	∇ = Thalathat	$\odot$ = Hassuna
$\blacktriangle$ = Arpachiyah	$\blacktriangledown$ = Tilki Tepe	$\times$ = Yanik Tepe
$\triangle$ = es-Sawwan	$\otimes$ = Tepe Gawra	

Figure Captions, Cont'd.

Fig. 9 Composition of Near Eastern obsidian relative to the average composition of 23 samples from Obsidian Cliff, Yellowstone National Park. 3 samples from Nemrut Dağ-B source (Group 4c): ○. 22 artifacts (Group 4c): ●. 2 samples from Çiftlik source (Group 2b): △. 4 artifacts (Group 2b): ▲. 4 artifacts (Group 3a): □.

Fig. 1

Fig. 2

Fig. 3

CONTENTS RELATIVE TO
OBSIDIAN CLIFF SAMPLES

Fig. 4

CONTENTS RELATIVE TO
OBSIDIAN CLIFF SAMPLES

Fig. 6

CONTENTS RELATIVE TO
OBSIDIAN CLIFF SAMPLES

- 3 Nemrut-Dağ (4c)
- ⊙ 22 Artifacts (4c)
- △ 2 çiftlik (2b)
- △ 4 Artifacts (2b)
- 4 Artifacts (3a)

Table I. Radioactivity Formed in a 1.0 minute Irradiation of 10 mg. of Obsidian

Element	Chemical Weight-% ^a	Isotope Formed	Half Life	Gamma-Rays Emitted per Minute	
				End of Irrad.	2 Hours Later
Oxygen	42	¹⁹ O	29.1 sec	2,200	- - -
Silicon	41	³¹ Si	2.6 hr	90	53
Aluminum	7	²⁸ Al	2.3 min	13,000,000	- - -
Potassium	3.4	⁴² K	12.4 hr	4,600	4,100
Sodium	3.0	²⁴ Na	15.0 hr	370,000	336,000
Iron	2.2	⁵⁹ Fe	45.6 day	9	9
Calcium	0.9	⁴⁹ Ca	8.8 min	2,200	- - -
Magnesium	0.3	²⁷ Mg	9.5 min	18,000	3
Titanium	0.16	⁵¹ Ti	5.8 min	1,900	- - -
Hydrogen	0.14	- -	- - -	- - -	- - -
Phosphorus	0.06	³² P	14.3 day	- - -	- - -
Cobalt	0.04	⁶⁰ Co	5.3 year	- - -	- - -
Manganese	0.02	⁵⁶ Mn	2.6 hour	1,600,000	940,000
Carbon	0.01	- -	- - -	- - -	- - -
Antimony	0.003	¹²⁴ Sb	60.4 day	- - -	- - -
Scandium	0.0015	⁴⁶ Sc	83.9 day	30	30
Lanthanum	0.0011	¹⁴⁰ La	40.2 hour	135	130

^a Composition of a typical obsidian sample.

Table II, Radioactivity Formed in a 24 hour Irradiation of 10 mg. of Obsidian

Element	Chemical Weight-% ^a	Isotope Formed	Half Life	Gamma-Rays Emitted per Minute	
				End of Irrad.	16 days later
O, Si, Al, Mg, Ti, Mn	- -	- - -	- - - -	large	- - - - -
Sodium	3.0	²⁴ Na	15.0 hour	520,000,000	60
Iron	2.2	⁵⁹ Fe	45.6 day	130,000	102,000
Zinc	0.06	⁶⁵ Zn	245. day	18,200	18,000
Cobalt	0.04	⁶⁰ Co	5.3 year	5,000	5,000
Rubidium	0.02	⁸⁶ Rb	18.7 day	317,000	175,000
Antimony	0.003	¹²⁴ Sb	60.4 day	50,000	40,500
Cesium	0.003	¹³⁴ Cs	2.1 year	34,000	34,000
Ytterbium	0.003	¹⁷⁵ Yb	4.2 day	560,000	40,000
Scandium	0.002	⁴⁶ Sc	83.9 day	430,000	380,000
Samarium	0.002	¹⁵³ Sm	46.8 hour	2,150,000	7,500
Lanthanum	0.001	¹⁴⁰ La	40.2 hour	190,000	24,000
Hafnium	0.001	¹⁷⁵ Hf	70.0 day	35,000	30,000
Lutecium	0.0001	¹⁷⁷ Lu	66.7 day	180,000	35,000
Iridium	0.000004	¹⁹² Ir	74.2 day	6,500	5,500

^aComposition of a typical obsidian sample.

Table III: Analyses of Yellowstone - Teton Obsidians Analyses

Sample No.	Location	% Na	% Mn x10 ²	% La x10 ²	% Fe	% Rb x10 ²	% Sr x10 ⁴	% Sm x10 ³	% Na % Mn	Sc/Cs	Sc/Ta	Tb/Cs	Ir/Tb	Ir/Sc	Sc/Ba
Y-1	Obsidian Cliff	3.59	2.41	1.2	1.3	2.3	1.8	1.6	149.5						
Y-2	"	3.56	2.24	0.93	1.2	2.1	1.4	1.6	159.5	3.9	8.5	10.1	3.2	9.4	
Y-3	"	3.39	2.24	0.97	1.2	1.8	1.5	1.8	152.4						
Y-4	"	3.22	2.02	0.93	0.97	2.0	1.4	1.8	159.6	2.8	9.7	8.3	3.1	10.2	
Y-5	"	3.35	2.18	1.0	1.3	2.0	1.7	1.8	153.7	3.3	8.2	9.7	3.3	9.5	23.5
Y-6	"	3.26	2.07	1.0	1.1	1.7	1.7	1.7	157.2	2.0			3.1	8.9	
Y-7	"	3.54	2.30	0.93	1.1	2.1	1.4	1.6	154.2	2.7	7.1	7.4	2.7	7.4	17.7
Y-8	"	3.55	2.32	0.98	1.1	2.0	1.3	1.8	153.0	3.3	7.8				
Y-10	"	3.25	2.00	1.0	1.1	2.0	1.5	1.5	162.5	2.8	9.0	7.9	3.3	9.5	
Y-12	"	3.03	2.11	0.92	0.96	1.7	1.4	1.4	143.6						
Y-16	"	3.42	2.22	1.0	1.2	1.8	1.5	1.7	153.7	3.0	7.6	9.2	3.3	9.8	
Y-19	"	3.11	2.13	0.97	1.1	1.8	1.3	1.9	146.1						
21	"	3.20	2.16	1.0	1.1	2.4	1.8	1.4	148.3						
96	"	3.53	2.35	0.93	1.2	2.4	1.3	1.7	150.2	3.1	7.2	9.8	3.3	10.7	
217	"	3.27	2.12	1.2	1.3	2.2	1.5	1.9	159.2	2.2			3.1	8.9	
219	"	3.13	2.03	0.95	1.0	1.8	1.6	1.6	154.2						
235	"	3.45	2.58	1.2	1.1	2.4	1.8	1.4	132.6						
240	"	2.92	1.90	1.2	1.1	2.3	1.6	1.7	153.6						
242	"	3.43	1.97	1.1	1.1	1.9	1.5	1.6	174.1						

Sample No.	Location	% Na	% Mn x10 ²	% La x10 ²	% Fe	% Rb x10 ²	% Sc x10 ⁴	% Sm x10 ³	% Na % Mn	Sc/Cs	Sc/Ta	Tb/Cs	Ir/Tb	Ir/Sc	Sc/Ba
625	Obsidian Cliff	3.48	2.26	1.1	1.1	2.0	1.5	1.7	154.0						
626	"	3.39	2.23	0.92	1.1	2.1	1.6	1.8	152.4	2.8	7.7	8.4	3.1	9.2	22.8
1343	"	3.08	2.14	0.98	1.3	1.8	1.5	1.5	144.0	3.2	10.0	8.9	3.1	8.7	
1358	"	3.41	2.24	1.2	1.0	2.0	1.8	1.5	152.2	3.4	10.6				
528	Yellow- stone	3.28	3.59	1.6	1.7	1.8	3.8	1.6	90.0	5.6	12.2	5.0	3.5	3.5	
1284	Two Miles West of West Thumb	3.03	3.22	1.4	1.2	1.9	2.5	1.7	94.1	9.5	14.4	11.2	3.6	4.2	
1067	2.6 Miles North of Canyon Junct.	2.63	2.50	0.73	0.89	1.3	4.4	0.93	104.9						
1068	"	2.40	2.18	0.67	1.0	1.1	4.6	0.88	111.4						
1095	"	2.86	2.42	0.74	0.85	0.92	4.3	1.1	118.2						
1097	"	3.18	2.63	0.92	0.99	1.3	4.6	1.3	121.2						
1333	North Side Lake of The Woods	3.68	2.52	1.0	1.3	3.1	1.8	1.7	146.0	2.6	8.2	7.8	3.2	9.5	
1334	Plateau East of Willow Park	2.99	3.44	0.87	2.1	1.7	6.9	1.3	86.9	15.6	49.0	9.0	3.2	2.1	
1335	"	2.81	3.05	0.95	2.3	1.8	7.0	1.4	92.1	15.5	47.5	10.4	3.2	2.0	
1336	"	3.08	3.50	0.79	2.9	1.4	11.0	1.2	88.0	28.1	59.5	9.1	3.2	1.0	

Table III. Continued

Sample No.	Location	% Na	% Mn $\times 10^2$	% La $\times 10^2$	% Fe	% Rb $\times 10^2$	% Sc $\times 10^4$	% Sm $\times 10^3$	% Na % Mn	Sc/Cs	Sc/Ta	Tb/Cs	Ir/Tb	Ir/Sc	Sc/Ba
1337	Bluffs W. of Falls of Boundary Creek	3.17	3.06	1.3	1.3	1.8	3.0	1.6	103.5	6.3	13.7	10.0	3.2	5.0	
1339	W. End of Madison Plateau	3.20	1.50	0.91	1.0	1.6	2.4	1.1	201.3	6.9	20.1	13.1	3.9	6.5	
1340	"	2.93	1.52	0.91	1.1	1.7	2.6	1.1	193.8	7.8	24.2	12.8	3.7	6.7	
1344	Geyser Creek	3.19	2.09	0.72	1.1	2.4	1.1	1.6	152.6	1.6	4.6	8.7	3.1	13.0	
1345	"	3.45	2.41	0.67	1.1	2.6	1.1	1.6	143.1	1.5	5.0	7.4	3.1	12.0	
1346	E. Wall Norris Geyser Basin	3.61	2.35	0.69	1.1	2.3	1.2	1.6	153.6	1.5	5.4	7.8	3.1	11.8	
1347	"	3.52	2.39	0.63				1.5	147.3						
1348	Top of Mount Hancock	3.46	3.52	1.4	0.91	1.6	2.0	1.7	98.3	5.0	12.3	15.5	3.0	6.3	
1349	NE. of Buffalo Lake	3.65	4.23	1.4	1.2	1.7	2.0	1.4	86.2	3.9	9.5				
1350	5 Miles SE. of Kepler's Cascade	3.13	3.09	1.3	1.2	1.6	2.5	1.8	101.3	6.1	11.2	10.9	3.1	5.1	

Table III. Continued.

Sample No.	Location	% Na	% Mn $\times 10^2$	% La $\times 10^2$	% Fe	% Rb $\times 10^2$	% Sc $\times 10^4$	% Sm $\times 10^3$	% Na % Mn	Sc/Cs	Sc/Ta	Tb/Cs	Ir/Tb	Ir/Sc	Sc/Ba
1352	North Branch Witch Creek	2.75	2.65	1.0	1.5	0.77	3.3	1.2	103.6	8.9	29.9	7.4	2.9	2.5	
1353	"	3.22	3.09	1.1	1.6	0.78	3.8	1.3	104.2	8.3	45.1	7.2	3.0	2.2	
1354	"	2.93	2.67	1.0	1.6	0.95	3.6	1.2	109.7	8.0	33.0	7.5	2.9	2.2	
1355	Pelican Creek	3.52	3.07	1.2	1.2	2.2	2.0	1.7	114.7	3.5	9.4	9.1	3.1	4.6	
1356	"	3.13	3.06	0.91	1.1	1.9	1.7	1.4	102.3	3.2	6.0	9.3	3.1	4.6	
1357	"	3.32	2.92	1.4				2.0	113.7			10.2	2.9		
1700	Teton Pass	3.48	4.60	0.47	1.1	0.93	3.1	0.72	75.7						
1701	"	3.53	4.53	0.50	1.1	0.83	3.0	0.71	77.9						

^d The 1 samples were taken from a 2" x 2" x 1" piece of ossidian from Obsidian Cliff.

Table I : Na and Mn Data for Yellowstone Obsidian Samples
not completely converted in Table 5.

<u>Origin</u>		<u>% Na</u>	<u>% Mn x10²</u>	<u>% Na/% Mn</u>
Obsidian Cliff	N	73	73	73
	Ave.	3.27	2.13	153
	Range	2.92-3.57	1.90-2.60	132-174
Canyon Junction	N	10	10	10
	Ave.	2.92	2.63	110
	Range	2.52-3.18	2.26-2.97	104-121
West Thumb	N	3	3	3
	Ave.	3.07	3.23	95
	Range	3.02-3.16	3.18-3.29	92-99
Norris Cut-Off	N	3	3	3
	Ave.	3.37	3.70	91
	Range	3.22-3.46	3.42-3.93	88-92
Lake-of- The-Woods	N	3	3	3
	Ave.	3.56	2.43	147
	Range	3.45-3.68	2.36-2.52	146-149
Boundary Creek	N	2	2	2
	Ave.	3.20	2.93	109
	Range	3.11-3.22	2.80-3.06	104-115

Table V. Middle-Woodland Obsidian Samples Tested by Neutron
Activation Analysis

Locality	Number of Sites	Number of Samples		
		150 Group	90 Group	Total
Ohio	4	36	11	47
Illinois	19	27	5	32
Indiana	1	--	1	1
Michigan	2	3	--	3
Wisconsin	3	1	2	3
Ontario	1	1	--	1
Totals:	30	68	19	87

Table VI. Analysis of Hopewellian Obsidian Artifacts

Sample No.	Location	% Na	% Mn $\times 10^2$	% La $\times 10^2$	% Fe	% Rb $\times 10^2$	% Sc $\times 10^4$	% Sm $\times 10^3$	% Na % Mn	Sc ^a Cs	Sc ^a Ta	Tb ^a Cs	Ir ^a Tb	Ir ^a Sc
81	Ogden-Fettie site, Ill.	3.35	2.13	0.97	1.1	2.4	1.8	1.9	158	2.8	7.1	8.9	3.4	10.8
85	Damiansville site, Ill.	3.32	1.98	0.99	1.2	2.4	1.8	1.8	168	2.6	7.3	8.0	3.2	10.1
101	Russell-Brown site, Ohio	3.02	2.03	0.95	0.97	1.7	1.4	1.6	149	2.8	6.9	8.7	3.1	9.5
92	Hopewell site, Md. 11, Ohio	3.35	2.25	1.0	1.0	1.9	1.5	b	149					
542	Hopewell site Md. 11, Ohio	3.38	2.22	1.1	1.0	1.7	1.6	1.4	153					
561	Naomikong site, Mich.	3.31	2.33	0.95	1.3	1.9	1.8	1.6	143					
1296	Trempealeau Lakes, Wis.	3.35	2.26	1.0	1.0	1.8	1.8	1.9	148	2.8	7.3	7.7	3.3	9.3
90	Snyders site, Ill.	3.03	3.46	1.6	1.8	1.6	3.6	1.3	88	5.0	11.3	5.0	3.5	3.5
525	Hopewell site Md. 25, Ohio	3.34	4.01	1.3	1.7	2.0	4.3	1.4	83					
1293	Mann site, Ind.	3.19	3.76	1.1	1.6	1.4	3.4	1.3	85	6.5	12.1	6.3	3.7	3.5
1295	Schwert mound group, Wis.	3.25	3.58	1.4	1.6	1.8	3.8	1.3	91	6.7	14.2	6.2	3.5	3.3

^a Data are given as radioactivity ratios.

^b Data not taken.

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