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Provenance Studies of Middle Eastern Obsidian from Sites in Highland Iran

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Exchange of obsidian from a limited number of sources to most archaeological sites in the Middle East can be documented from the early Neolithic through the Bronze Age. Thus, precise provenance determinations for obsidian artifacts can provide important information concerning contacts among regions and clues to the nature of the exchange itself. Three regions, each with several discrete sources, have been identified as major suppliers of obsidian. Extensive sampling and chemical analysis of sources in Central Anatolia and the Greek Islands provide excellent coverage of these regions. The sources in the Eastern Turkish–Soviet Armenian region are, however, much less well known. The analysis, by instrumental neutron activation, of samples from three sources in this region and four sources in the Central Anatolian region are reported. The source data are compared with the analyses of artifacts from the important highland Iranian sites of Tal-e Malyan and Tepe Yahya. The methods of provenance identification and the implications for exchange in obsidian at these two sites are discussed.

THE EXCHANGE OF OBSIDIAN from a limited number of possible sources to most archaeological sites in the Middle East can be documented from the early Neolithic through the Bronze Age. Precise source provenance determinations for the obsidian artifacts can, therefore, provide important information concerning the nature and organization of exchange in obsidian, as well as in other goods moving in the same network, throughout this long period of cultural development. Obsidian is particularly well suited for use in the study of long-range exchange in the Middle East, for although the obsidian artifacts are widely distributed archaeologically, the geological occurrences are restricted to a relatively

few sources located in geographically circumscribed regions. Moreover, obsidian (at least for the Middle Eastern sources so far examined) appears to be homogeneous within a given flow; precise chemical analysis shows significant elemental concentration differences among the flows, which allow differentiation with a high degree of certainty. The well-established and growing body of literature on obsidian analysis and exchange theory for the Middle East additionally provides a large data base which may be drawn upon to match sources and artifacts to test exchange models.

Users of chemical analysis to characterize obsidian and monitor long-range exchange have concentrated primarily on the earliest time periods from Neolithic to about 3500 B.C. It is, however, after about 3500 B.C. that state polities arose in the Middle East; such developments are postulated to have influenced and in turn have been influenced by long-distance exchange systems of the day. The use of exchanged items as a monitor to trace the direction and perhaps even the volume of exchange during this pivotal period is then of great interest to those attempting to assess the relationship between long-distance exchange and state development.

This investigation focuses on obsidian reaching two highland Iranian sites during the time period from roughly 3500 to 1800 B.C. Geological source samples from two major source regions in Western Asia were used to characterize possible sources of the artifacts.

Archaeological Sites and Obsidian Artifacts

Obsidian from two sites in highland Iran, Tal-e Malyan and Tepe Yahya, forms the basis of this investigation. The obsidian artifacts from these two sites were excavated from deposits dating from about 4500 B.C. to A.D. 400. It is, however, the period from 3500 to 1800 B.C., corresponding to the Middle Uruk through the Ur III to Isin Larsa periods in Mesopotamia (*1,2*), that is of primary concern.

The site of Tal-e Malyan (Figure 1), located in the Kur River Basin in Fars Province in southwestern Iran, was excavated by William Summer of Ohio State University. The first major occupation at Malyan occurred during the Banesh Phase (3400–2800 B.C.). The site reached its peak in size and population during the Kafteri Phase (2100–1800 B.C.), occupying about 200 hectares. During the subsequent Qaleh/Middle Elamite Phase (1600–1000 B.C.), Malyan declined, and it was abandoned sometime after 1000 B.C. (*3*). Confirmed as the ancient city of Anshan (*4*), co-capital with the lowland city of Susa of the Elamite polity, Malyan actively participated in a far-flung exchange system including lowland Elam and the Mesopotamian cities.

The site of Tepe Yahya, located in the Soghun Valley in south-

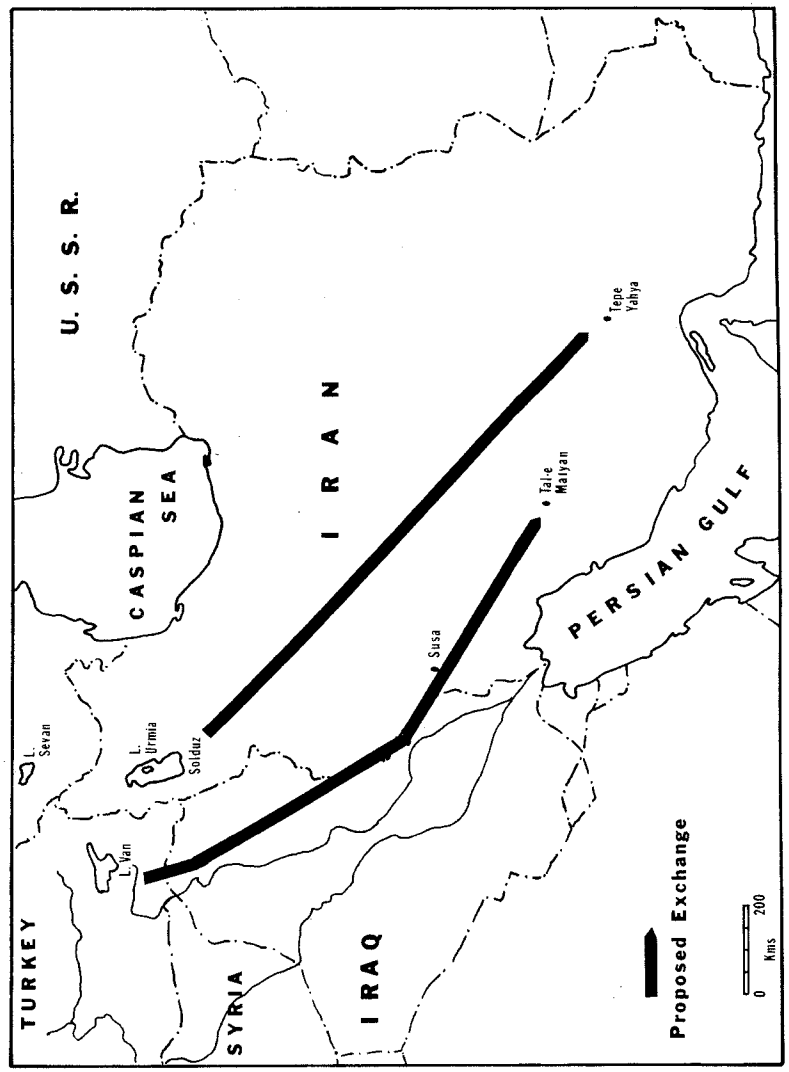

Figure 1. Location of archaeological sites.

central Iran, was excavated by C. C. Lamberg-Karlovsky of Harvard University. About 3 hectares in area, Tepe Yahya was occupied from the mid fifth to early second millenia B.C. (*5*). A site of manufacture of chlorite bowls, Tepe Yahya shows evidence for exchange links with Mesopotamia to the east and has been postulated to have had ties with the Harrapian civilization in the Indus Valley to the west (*6,7*). Protoelamite tablets found at Tepe Yahya indicate the site's inclusion in the Elamite sphere of influence. It therefore seems likely that exchange links should exist between Tal-e Malyan and Tepe Yahya and between them and lowland Elam and Mesopotamia that might be monitored using obsidian provenance information.

Forty-seven obsidian objects, totaling 107 g, have been recovered from excavation at Tal-e Malyan. Two general categories of object may be defined based on function: utilitarian items—tools (mostly blades), cores, and debris; and luxury items—ground and polished bowls, bead/rings, and cylinders. The presence of spent cores and core trimming debris indicates that the blades were struck from the cores at the site rather than arriving as finished products. The manufacturing technology for the obsidian blades is identical to that used to make chert and jasper blades found in abundance and made of local material. The luxury items, ground and polished objects, may well have arrived at Tal-e Malyan as finished products. Although a ground stone industry was present at the site, only relatively soft stone materials such as talc, chlorite, marble, and limestone appear to have been worked. Obsidian, a much harder and more brittle material, would have required different working techniques. Large blocks of obsidian would also have had to be transported over great distances (~1500 km) to supply the raw material. It is likely that the luxury items and the raw material for the utilitarian items were being exchanged in terms of function rather than material type. As such, these two categories of object may have been included in different aspects of the exchange system.

Eleven obsidian objects from Tepe Yahya, composing about one-half of the excavated obsidian, were analyzed. The obsidian was an unsorted sample from two seasons of excavation, and is taken to be representative of the entire collection. All the Tepe Yahya obsidian, seven blades and four flakes, are of the utilitarian type. No obsidian luxury items were reported.

In addition to the Tal-e Malyan and Tepe Yahya artifacts, objects from two other archaeological sites were included in the analysis. The two selected pieces from earlier periods at Ali Kosh and Choga Safid were included to attempt to correlate the samples in this investigation with those analyzed by Renfrew and coworkers (*8–10*) by optical emission spectroscopy.

Geological Source Samples

Two geographically separate regions in Western Asia contain obsidian sources that might have contributed obsidian to archaeological sites in highland Iran. The smaller of the two regions, the Central Anatolian region, is located in central Turkey to the east and southeast of Lake Tuz (Figure 2). The second and by far the greater in area, the Eastern Turkish–Armenian S.S.R. region (ET–ASSR), encompasses most of eastern Turkey and Soviet Armenia stretching from Lake Van in the south to Lake Sevan in the north.

Thirteen samples from three general collection areas within the Central Anatolian region were available for analysis. The three areas, Hotmis Dağ, Göllü Dağ, and Hasan Dağ, are shown in Figure 2. Eight samples were collected from four localities in the area around Hotmis Dağ, three from three localities in the Göllü Dağ area, and two from the Hasan Dağ area.

Thirty-two samples from three general collection areas in the ET–ASSR region were available. Fifteen samples were collected from several localities at Nemrut Dağ on the southwestern shore of Lake Van; 10 samples were from several localities at Suphan Dağ on the northwestern shore of Lake Van; and 6 samples were from a source between the city of Razdan and the northwestern tip of Lake Sevan in the Armenian S.S.R. (Figure 2). A single sample from the Isle of Giali in the Aegean source region was also analyzed.

All of the source samples, except for the Lake Sevan material, were collected by Richard A. Watson of Washington University and Ibrahim T. Cakmak. This field work was facilitated by Saadettin Alpan, Director-General of the Maden Tetkik Arama Enstitutu, and funded by the National Science Foundation through support of the Turkish Prehistoric Project under the direction of Robert J. Braidwood and Halet Cambel. The Lake Sevan samples were provided by J. Allen of Dumbarton Oaks.

Methodology

The elemental analysis of the artifacts and geological source samples was performed by using instrumental neutron activation analysis at the National Bureau of Standards Reactor in Gaithersburg, Md. The geological samples and artifacts were prepared in the same manner. After cleaning in an ultrasonic bath and several washings alternately with distilled water and ethanol, the samples were dried at 105 °C, were wrapped in several thicknesses of clean polyethylene sheeting, and several small chips were struck off with an alumina pestle. The chips were further reduced to medium sand size, rewashed, dried, and about 100 mg was weighed into clean 0.5-mL polyethylene microcentrifuge tubes. About 95-mg replicates of the multielement standard, NBS SRM 1633–coal flyash, and two check standards were also encapsulated in microcentrifuge tubes.

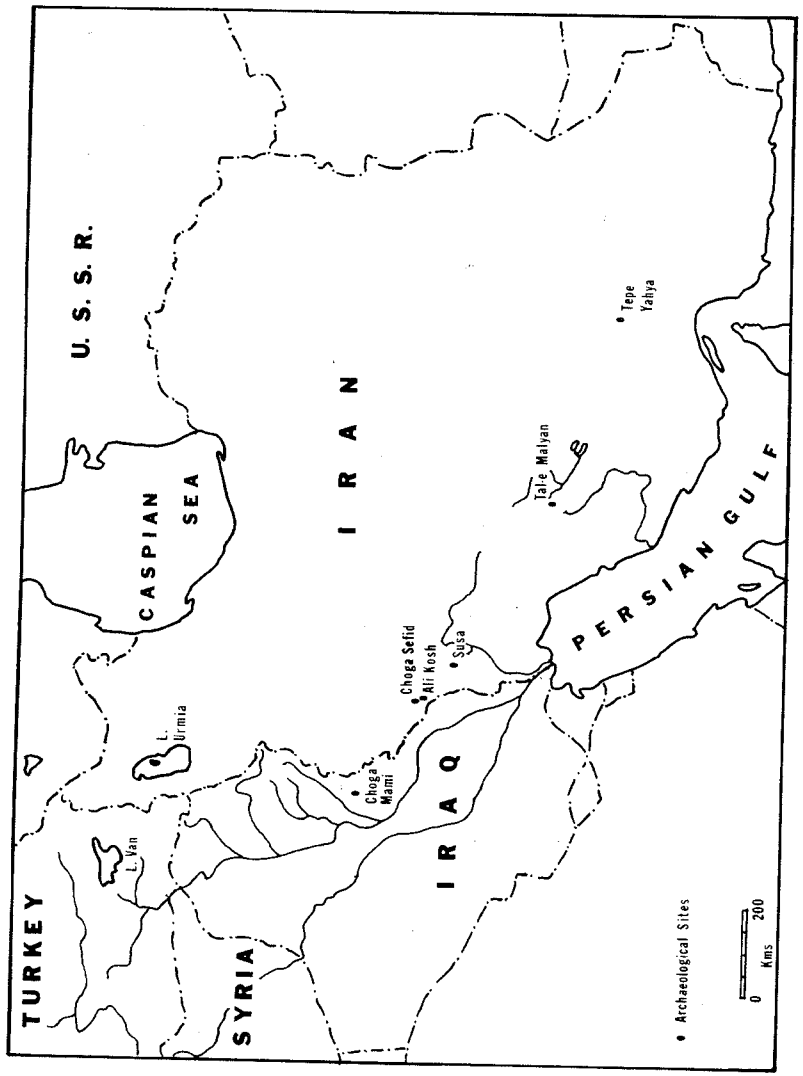

Figure 2. Geological source locations.

Samples and standards were irradiated for 8 h at a flux of 5×10^{13} n/cm^2/s. Following a 6-day decay, the samples were counted for 2 h each using an intrinsic germanium detector (FWHM at 1333 ^{60}Co of 1.71 keV), and data were collected on an 8192-channel MCA. Data processing included corrections for pulse pileup and peak interferences. Samples were then allowed to decay for 30 days post-irradiation and were recounted for 4 h using the same system. Table I presents a summary of the elements sought and quantified.

Elemental concentration data for 19 elements were then used as input in a hierarchical aggregative clustering program (Table I). The clusters, presented as dendrograms plotted as a function of dissimilarity, were produced by "nearest neighbor" distance calculations on a mean character difference matrix (*11*). This method of data analysis is quite useful in sorting, grouping, and displaying

Table I. Experimental Parameters

Elements	*Nuclide Analyzed*	*Gamma Ray Energy (keV)*	*Count*	*Concentration in SRM 1633*
Na[a]	Na-24	1369	1	0.32%
K	K-42	1525	1	1.61%
Ca	Sc-47	159	1	4.70%
Sc[a]	Sc-46	889	2	27.0 ppm
Cr	Cr-51	320	2	131 ppm
Fe[a]	Fe-58	1099 and 1292	2	6.20%
Co	Co-60	1173 and 1333	2	41.5 ppm
Zn[a]	Zn-65	1115	2	213 ppm
As[a]	As-76	559	1	61.0 ppm
Br	Br-82	554	1	8.6 ppm
Rb[a]	Rb-86	1077	2	125 ppm
Sb	Sb-122	564	1	6.9 ppm
Sb[a]	Sb-124	1690	2	6.9 ppm
Cs[a]	Cs-134	796	2	8.6 ppm
Ba	Ba-131	496	1,2	2700 ppm
La[a]	La-140	1596	1	82.0 ppm
Ce[a]	Ce-141	145	2	146 ppm
Nd[a]	Nd-147	91	1,2	64.0 ppm
Sm[a]	Sm-153	103	1	12.9 ppm
Eu[a]	Eu-152	1408	2	2.5 ppm
Gd[a]	Gd-153	103	2	11.2 ppm
Tb	Tb-160	298	2	1.9 ppm
Yb	Yb-169	177	2	6.4 ppm
Yb[a]	Yb-175	396	1	6.4 ppm
Lu[a]	Lu-177	208	1	1.0 ppm
Hf[a]	Hf-181	482	2	7.9 ppm
Ta[a]	Ta-182	1221	2	1.8 ppm
Th[a]	Pa-233	312	2	24.8 ppm
U[a]	Np-239	106	1	11.6 ppm

[a] Elements used in cluster.

quantities of sample data with large numbers of variables per sample. Cluster analysis is not, however, a statistical test, and the clusters formed by this technique must be further tested for statistical significance and geological and archaeological consistency.

Cluster Analysis of Source Samples

When the chemical concentration data from the geological source material were subjected to cluster analysis, several discrete clusters of geologically consistent samples were formed. The dendrogram in Figure 3 shows that the peralkaline obsidian from Nemrut Dağ is easily distinguished from the calc-alkaline to subalkaline obsidians from all the other sources. Finer-scale examination of the dendrogram reveals that all of the source areas sampled can be readily distinguished from one another, although obsidian samples from some source areas are clustered into more than a single group.

The three ET–ASSR source areas—Nemrut Dağ, Suphan Dağ, and Lake Sevan—are each composed of at least two chemically distinguishable groups (Appendix A), probably representing different eruptive events at the respective sources. The source group labeled Nemrut I in Figure 3 and Appendix A is quite homogeneous, with elemental dispersions of 4% or less. The Nemrut II source group is somewhat less homogeneous, particularly for scandium (28%), iron (11%), and europium (27%), and may consist of obsidian from more than one eruptive event. Two source samples from Nemrut Dağ (XNO522 and 525) do not cluster tightly with either Nemrut source group and may represent additional flows at Nemrut Dağ. Altinli (*12*) reported as many as 20 identifiable lava flows from Nemrut Dağ, indicating the likelihood of multiple obsidian occurrences that might be chemically distinguishable.

The Suphan Dağ source samples also cluster into two separate source groups. Chemically these two groups show much greater differences than did the Nemrut Dağ groups (Appendix A). The group designated Suphan I is less homogeneous than is the Suphan II group, and the former group may contain samples from more than one obsidian flow. Five of the six Lake Sevan source samples formed a homogeneous group, designated Sevan I in Figure 3. However, the sixth sample clustered closely with neither the Sevan I group nor with any other source sample. Based on its distinctive composition, this single sample has been tentatively given a separate source group assignment, Sevan II (Svn II in Figure 3).

The Central Anatolian region source samples present an equally intricate picture. The three Göllü Dağ area samples, plus two archaeological samples (XEO540 and 541) from the immediate area, formed a single group of chemically consistent composition. The Hasan Dağ source samples (Hsn in Figure 3) also cluster closely in a readily recognizable

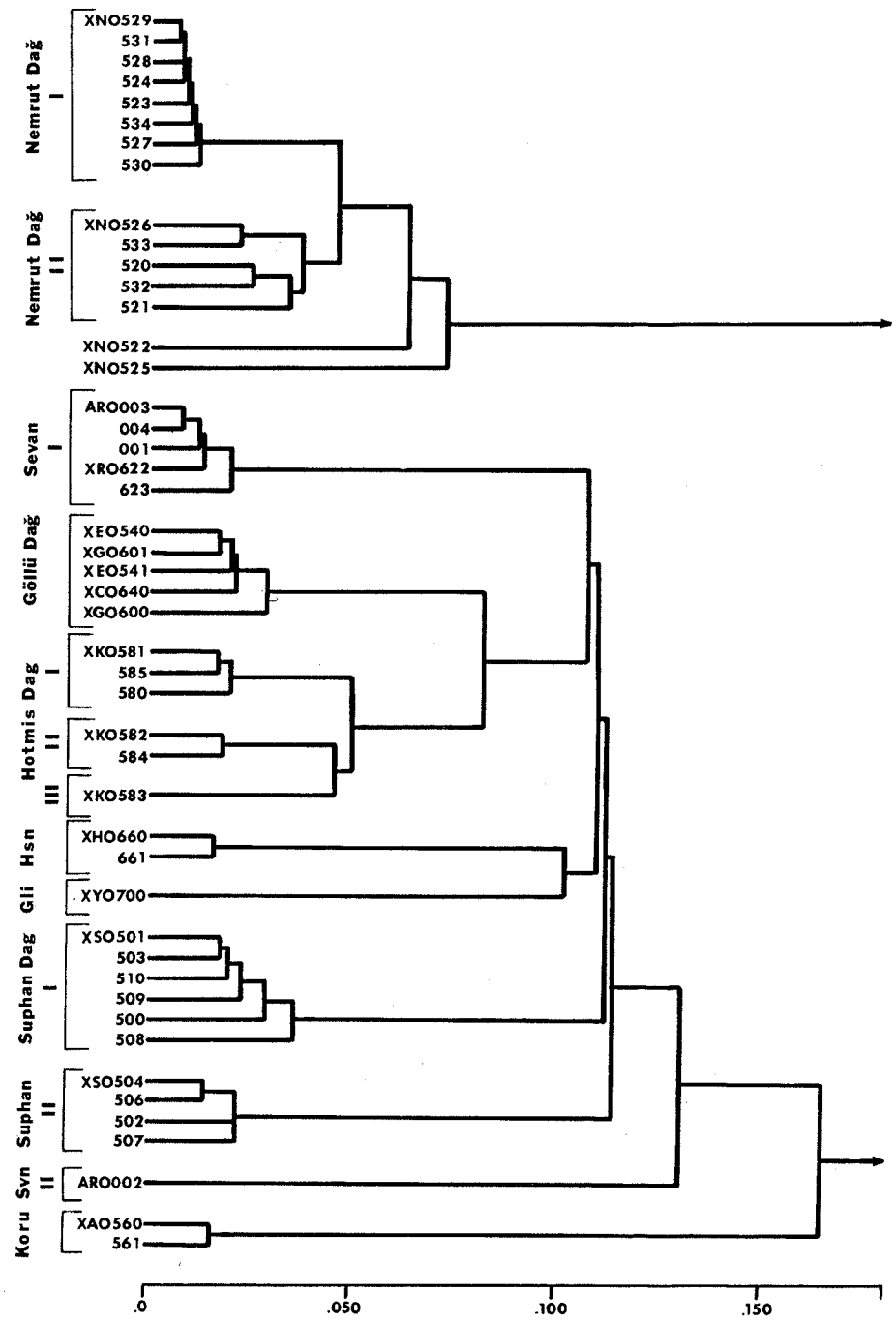

Figure 3. Clustering of source samples.

group. The eight Hotmis Dağ area samples, however, showed more complexity. Two samples clustered closely and were isolated from all other obsidian samples (this group is designated Koru in Figure 3). The remaining five Hotmis Dağ samples formed a loose but distinguishable cluster that may readily be subdivided into three groups, Hotmis I, II, and III. These groups most probably represent different eruptive events at Hotmis Dağ; the Koru group appears to be a separate source.

The single Aegean region sample from Giali is easily distinguished from the sources in both the Central Anatolian region and the ET–ASSR region. It has been placed in a separate group designated Gli in Figure 3.

The picture that emerges from the cluster analysis and direct comparison of concentration data is complex, but promising. Although several of the source areas consist of multiple occurrences of obsidian, all the source areas sampled have readily distinguishable source-specific compositions. At least 13 chemical groups from 7 collection areas can be identified (Table II). The collection areas of Suphan Dağ, Nemrut Dağ, Lake Sevan, and Hotmis Dağ each consist of two or more groups of distinct chemical composition. The presence of multiple chemical groups from what have been taken as single source areas points up the need for extensive and careful source sampling to avoid confusion in artifact source assignment.

Comparison with Previous Work

There is a large and growing literature on Middle Eastern obsidian studies that contains elemental data from the analysis of many hundreds of samples. Some effort is needed to reconcile the disparate terminology used to classify sources of both known and unknown provenance. The task is made difficult by the use of different analytical techniques of varying precision, the selection of different element sets in analysis and reporting, and the use of different secondary standards to quantify the concentration data.

The earliest work, by Renfrew and coworkers (*8–10*) using optical emission spectroscopic analysis, reported concentrations for 15 elements. The Ba/Zr ratios were the primary discrimination technique. Wright (*13*), Wright and Gordas (*14*), and Mahdavi and Bovington (*15*) used instrumental neutron activation analysis (INAA) as the analytical technique and Na/Mn ratios to make source discriminations. Work done at the University of Bradford by Warren, Aspinall, and their students (*16–19*) used INAA in reporting 16 elements. Plots of 1/Sc (Cs + Ra + Rb/100 + (Th + La + Ce)/10) vs. %Fe/Sc were used as the primary discrimination technique (*16*). Yellin and Perlman (*20–23*) at Hebrew University used high-precision INAA and based source discrimination on an element-by-element comparison of group means and root–mean–square deviations.

Table II. Geological Source Groups

Source Groups	*Hebrew Univ.*	*Bradford Univ.*	*Renfrew et al.*	*Location*
		Central Anatolian Obsidian Sources		
1. Göllü	GLD	B1	2b (ÇIFTLIK)	Göllü Dağ
2. Hotmis I	HTMS-C	B5	1e–f (ACIGOL)	Hotmis Dağ
3. Hotmis II	HTMS-A	B5	1e–f	Hotmis Dağ
4. Hotmis III	HTMS-B	B5	1e–f	Hotmis Dağ
5. Koru	KRUD	—	—	Koru Dağ
6. Hasan	—	—	1h	Hasan Dağ
7. —	NNZD	—	—	Nenezi Dağ
8. —	—	—	4f	Kulaklikepez
		Eastern Turkish–Armenian S.S.R. Obsidian Sources		
1. Nemrut I	NMRD 1	G1	4c	Nemrut Dağ
2. Nemrut II	NMRD 2 (?)	—	—	Nemrut Dağ
3. Nemrut III	—	—	—	Nemrut Dağ
4. Nemrut IV (?)	—	—	—	Nemrut Dağ
5. Suphan I	—	—	—	Suphan Dağ
6. Suphan II	—	—	—	Suphan Dağ
7. Sevan I	—	—	—	Lake Sevan
8. Sevan II	—	—	—	Lake Sevan
9. —	ZNKT	B4 (?)	3a (?)	Zarnaki Tepe
10. —	—	G2	4c	Bingöl Dağ
		Sources of Unknown Provenance		
1. —	—	B2	1g	?

Direct correlation with the analysis done by optical emission spectroscopy and the early INAA work was not possible. However, correlations could be made with Hebrew University and the University of Bradford data. Because different standards were used at these two laboratories and in this investigation to quantify the elements, a set of correlation factors had to be calculated to convert the data to a comparable form. This task was done by intercomparison of the standards (*24,25*). When the converted group means of the Hebrew University and University of Bradford data were clustered with the means of the groups determined in this investigation, as shown in Figure 4, there was good correspondence for the groups from source areas known to be the same. The Göllü source group clustered closely with both the GLD (Göllü Dağ) source group of Hebrew University and the B1 (Çiftlik) source group of Bradford. The Koru source group likewise clustered with the KRUD (Koru Dağ) source group of Hebrew University and the three Hotmis

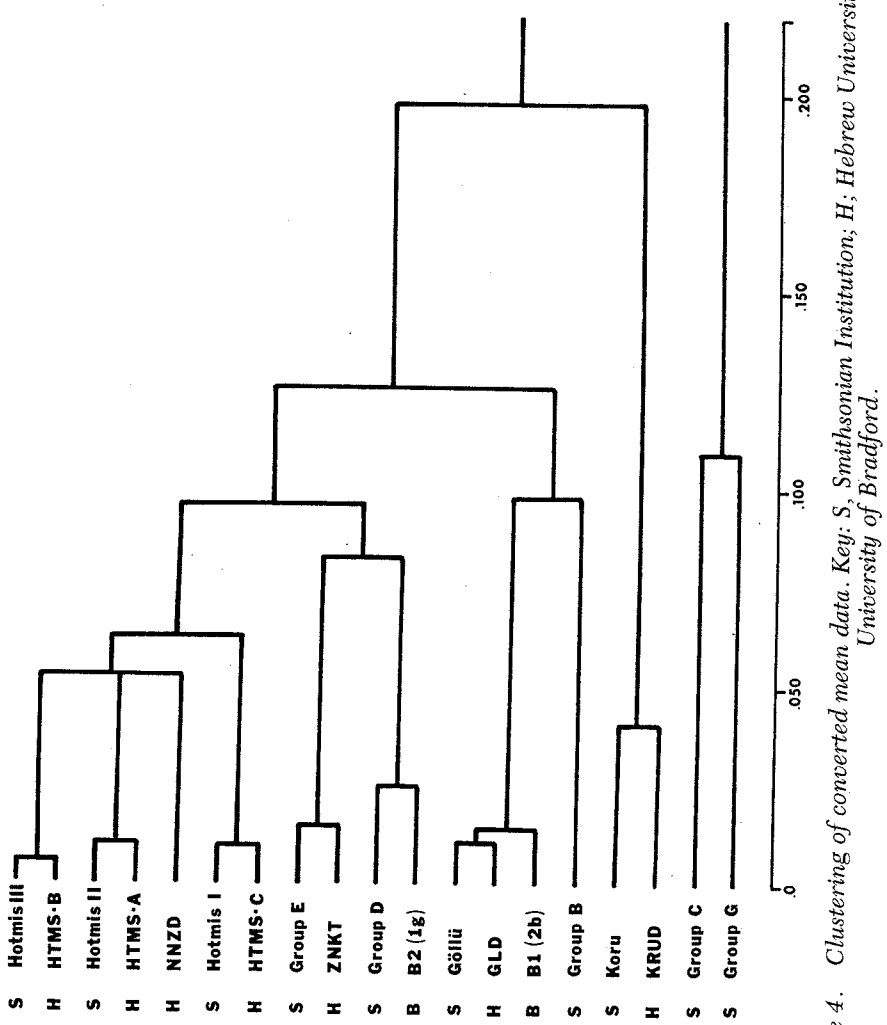

Figure 4. Clustering of converted mean data. Key: S, Smithsonian Institution; H; Hebrew University; B; University of Bradford.

source groups each clustered with one of the HTMS (Hotmis Dağ) source groups of Hebrew University. The close clustering of the converted source-group means from the same source area demonstrates the ability to use analytical data generated in other laboratories in the identification of artifact sources in this investigation. This fact is important because several known geological source groups that were not available for analysis in this investigation and artifact groups of unknown provenance from other archaeological sites have been analyzed at Hebrew University and the University of Bradford. The geological sources include the Nenezi Dağ source northwest of Göllü Dağ in the Central Anatolian region and the important Zarnaki Tepe source north of Lake Van in the ET–ASSR region; both were analyzed at Hebrew University. One of the artifact groups of unknown provenance, Bradford's B2 group, has been identified with the Renfrew et al. (*10*) 1g source. Table II presents a summary of the geological source groups outlined in this investigation and a correlation with the sources reported by the other investigators.

Archaeological Artifacts and Source Assignments

The elemental concentration data from the analysis of the artifacts from the highland Iranian sites of Tal-e Malyan and Tepe Yahya were subjected to the same cluster analysis as the geological source samples. Figure 5 shows that three major clusters were formed, representing significant geochemical differences. Each of these major clusters could be divided into two or more groups of distinctive chemical composition. The first major cluster contained artifact groups A and A′, which appear to be closely related; the second major cluster contained artifact groups C and G; and the third major cluster contained groups E, D, F, and B. In all, eight artifact groups were identified, and each contained at least two samples. The elemental concentration data, presented in Appendix B, demonstrate the validity of these groups as chemically distinct entities.

When the geological source samples and the artifact groups were clustered together, as shown in Figure 6, three close matches between source and artifact group were observed. Group A artifacts and the Nemrut Dağ I source samples formed a single very tight cluster at a low level of dissimilarity. Although none of the artifacts clustered with the Nemrut Dağ II source, the two artifacts of Group A′ formed a cluster with one of the Nemrut Dağ source outliers (XNO525 in Figure 3). This source sample and associated artifacts, now termed Nemrut Dağ III source group, demonstrate the need for a large and comprehensive sample of source material. Artifact Group F and the Sevan I source also formed a tight cluster at low levels of dissimilarity. Table III shows the close agreement, for selected elements, between the artifact group and the

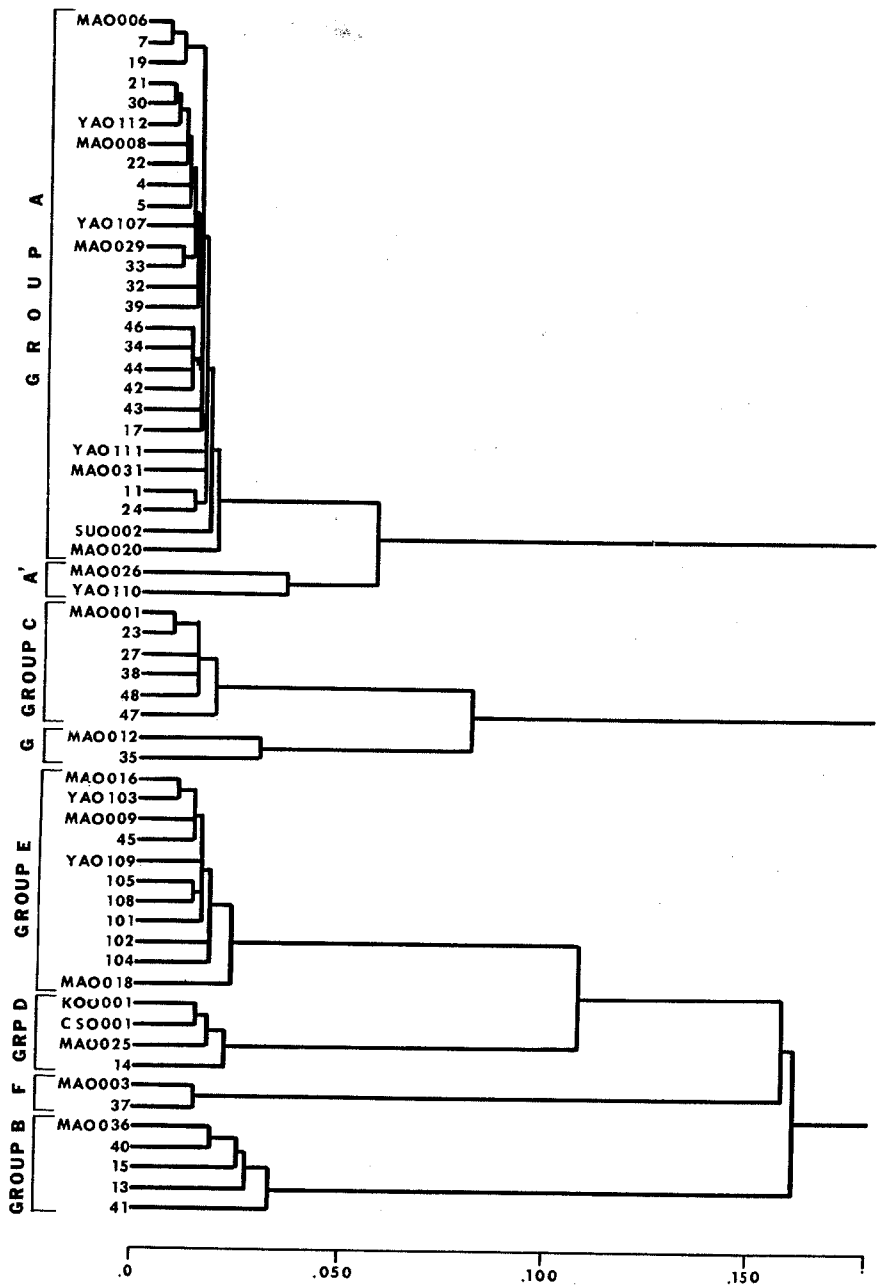

Figure 5. Clustering of archaeological artifact samples. Key: MAO, Tal-e Malyan; YAO, Tepe Yahya; SUO, Susa; KOO, All Kosh; CSO, Choga Safid.

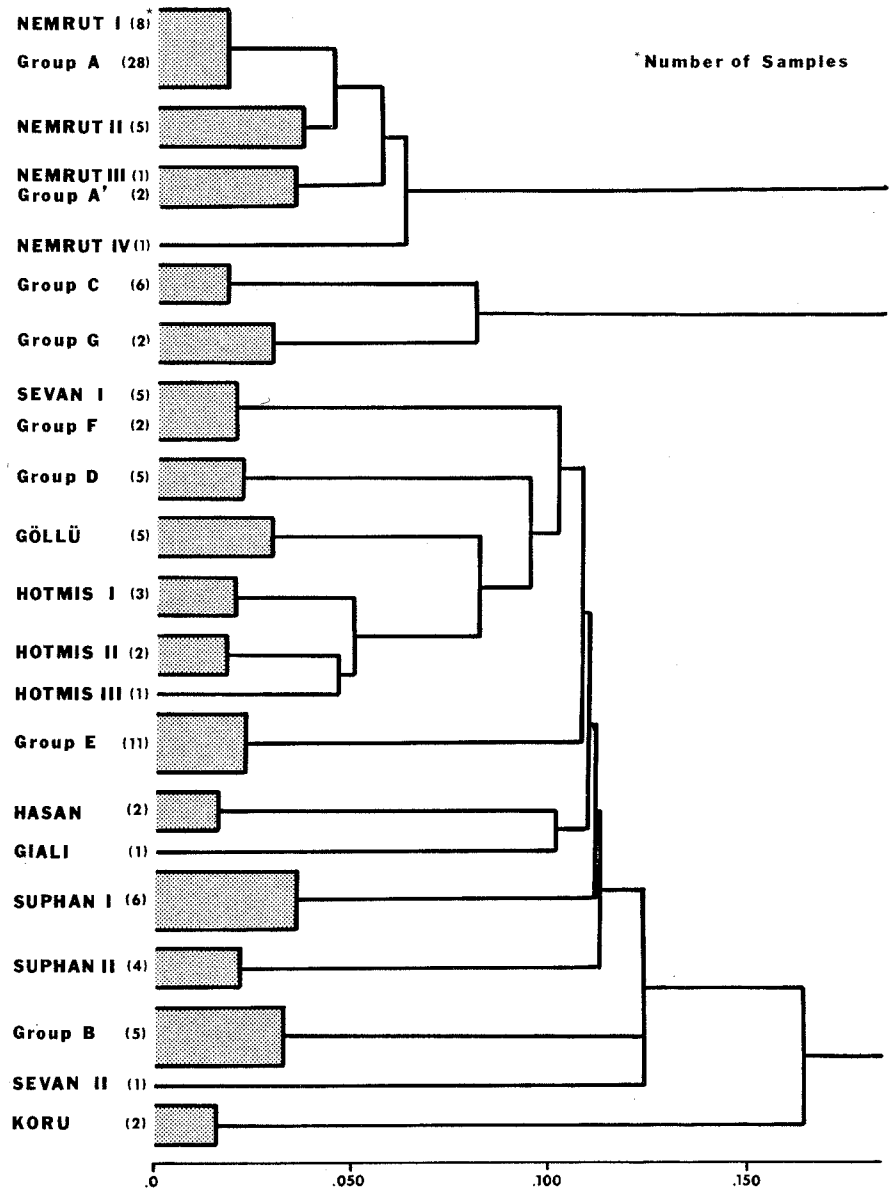

Figure 6. Clustering of geological source and archaeological artifact samples.

Table III. Comparison of Selected Elemental Concentrations Among Artifact Groups and Source Groups

Elements	*Nemrut I*	*Group A*	*Sevan I*	*Group F*
Na (%)	3.83 ±0.03	3.89 ±0.07	3.49 ±0.05	3.45
Sc (ppm)	0.187±0.005	0.193±0.010	2.99 ±0.03	2.95
Fe (%)	2.04 ±0.02	2.03 ±0.05	0.796±0.011	0.802
Rb (ppm)	235 ±5	229 ±9	147 ±6	145
La (ppm)	100 ±0.5	103 ±2	35.7 ±0.4	35.4
Sm (ppm)	19.1 ±0.3	19.2 ±0.7	3.02 ±0.04	3.00
Eu (ppm)	0.423±0.011	0.419±0.028	0.491±0.026	0.488
Th (ppm)	26.7 ±0.6	26.8 ±0.9	17.8 ±0.3	17.3

assigned source group. None of the remaining 5 artifact groups was clustered with any of the remaining 10 source groups.

The unassigned artifact-group means were then clustered with the converted means for the geological source from Nenezi Dağ and Zarnaki Tepe and artifact group B2 (1g) of unknown provenance. Figure 4 shows that none of the unassigned artifact groups clustered with the Central Anatolian source at Nenezi Dağ (NNZD). However, artifact Group E did form a very tight cluster with the Zarnaki Tepe source group (ZNKT) located in the ET–ASSR region, and artifact Group D clustered closely with Bradford's B2 (1g) artifact group of unknown provenance. As was shown earlier in this chapter, the agreement of the converted data among the three laboratories is excellent and lends credence to the contention that Group E artifacts originated at Zarnaki Tepe and that Groups D and B2 of Bradford are the same group. Group D artifacts included the samples from Ali Kosh and Choga Safid (KOO and CSO in Figure 5). Renfrew (*26*) found only Nemrut Dağ and source group 1g obsidian at these two sites, lending additional credence to the contention that artifact Group D obsidian is Renfrew's 1g obsidian.

Two important conclusions can be drawn from the source–artifact group assignments. First, none of the artifact groups originated at any of the known and analyzed Central Anatolian sources. As the analyzed sources from this region include the major sources (Göllü and Hotmis Dağ), it seems highly unlikely that new occurrences of obsidian will be discovered in this region that will prove to be the sources of the artifact groups of unknown provenance. Although central Anatolian obsidian has been found in very rare occurrences in lowland Mesopotamia (*10,19*), it does not appear to have penetrated into the Iranian highlands. The ET–ASSR region seems to be the origin of all obsidian from Tal-e Malyan and Tepe Yahya. Second, none of the artifact groups appears to originate from Suphan Dağ, a multiple source area only 60 km north of the important source at Nemrut Dağ. Much of the Suphan Dağ obsidian contains large 2–4-mm plagioclase phenocrysts and is unsuitable for flaking; however, some of the Suphan Dağ material is of good quality. It is at present unclear why this material was not exploited.

Archaeological Implications

The source assignments, tabulated in Table IV, show that obsidian from eight chemically distinct sources reached Tal-e Malyan during all phases of occupation of the site. During a roughly comparable period of time, Tepe Yahya was receiving obsidian from three of these eight sources. At Tal-e Malyan, more than half of the artifacts were from the Nemrut Dağ I and III sources. The remaining artifacts were fairly evenly distributed among the other six source groups. Three artifacts, two from Nemrut Dağ and one from Group G, were surface finds of unknown provenance, and three additional artifacts, one each from Nemrut Dağ III, Zarnaki Tepe, and Group C, were from Qaleh/Middle Elamite context dating

Table IV. Artifact-to-Source Assignments at Tal-e Malyan and Tepe Yahya

Tal-e Malyan

Source Group	*Banesh 3400–2800* B.C.	*Kafteri 2100–1800* B.C.	*Qaleh/M.E. 1600–1000* B.C.	*Unknown*	*All-Phase Total*
Nemrut I	15 (88%)	7 (29%)	0	2	24
Nemrut II	0	0	1	0	1
Zarnaki	1 (6%)	2 (8%)	1	0	4
Sevan I	0	2 (8%)	0	0	2
Group D (1g)	1 (6%)	2 (8%)	0	0	3
Group B	0	5 (21%)	0	0	5
Group C	0	4 (17%)	1	1	6
Group G	0	2 (8%)	0	0	2
Total	17	24	3	3	47

Tepe Yahya

Source Group	*VI 4500–4000* B.C.	*VA-IVB 3600–2600* B.C.	*Late/ Unknown*	*All-Phase Total*
Nemrut I	0	0	3	3
Nemrut III	0	0	1	1
Zarnaki	1	6	0	7
Total	1	6	4	11

from 1600 to 1000 B.C. Forty-one artifacts were from Banesh and Kafteri contexts and will be discussed at length later in this chapter. At Tepe Yahya, only about a third of the obsidian originated at Nemrut Dağ with both Nemrut Dağ I and III sources represented. Artifacts from these two sources were all from very late contexts or were surface finds of unknown provenance. All Tepe Yahya obsidian artifacts with firm archaeological provenance information, dating from 4500 to 2600 B.C., were assigned to the Zarnaki Tepe source, a relatively minor source at Tal-e Malyan.

When obsidian source assignments for comparable time periods, the Banesh Phase (3400–2800 B.C.) at Tal-e Malyan and periods VA to IVB (3600–2600 B.C.) at Tepe Yahya, are compared (Table IV), both sites show a heavy reliance on a single obsidian source. At Tal-e Malyan, the Nemrut Dağ I source contributes 88% of the obsidian; two other sources, Zarnaki Tepe and Group D (1g), contribute 6% each. At Tepe Yahya, however, the Zarnaki Tepe source contributes 100% of the analyzed obsidian.

Renfrew and Dixon (27) postulated an exchange network, the Zagros Interaction Zone, that included Nemrut Dağ (4c) obsidian and Group D (1g) obsidian (thought to be located west or southwest of Lake Van), operating along the western flanks of the Zagros Mountains as far south as Ali Kosh and Chogha Sefid on the Deh Luran Plain in 7500–5500 B.C. The proposed mechanism of the obsidian exchange was a reciprocal "down the line" exchange. After an apparent interruption in the flow of obsidian from these sources, the exchange resumed in about 5000 B.C., but with a third source, Group 3 (3a), replacing the 1g source. The redefined interaction zone, called the Tigris–Plateau Zone, now includes highland sites, and the mode of exchange is thought to have changed from reciprocal to central-place directional exchange (27). By 4000–3500 B.C., both Nemrut Dağ I (4c) and Group 3 (3a) had penetrated the southern highlands and are found at Tal-e Bakun, about 10 km from Tal-e Malyan in the same river basin. Renfrew et al. (*10*) and Dixon (28) postulated the Group 3 (3a) source to be located northeast of Lake Van and to have entered the system by way of Lake Urmia (Figure 7).

Epstein (*19*) analyzed obsidian from the lowland site of Choga Mish, dated to ca. 5500–4200 B.C. He found that 1g obsidian had not been replaced by Group 3 (3a) at Choga Mish, but that obsidian from these two sources coexisted with Nemrut Dağ (4c) obsidian. The Nemrut Dağ I (4c) source predominated with 1g, 3a, and possibly three other sources in subsidiary roles.

The source pattern for obsidian reaching Tal-e Malyan in 3400–2800 B.C. appears to have changed little from that reported by Renfrew et al. (*10*) and Epstein (*19*) for earlier lowland sites. Nemrut Dağ I obsidian predominates, with Group D (1g) and Zarnaki Tepe (3a?) present in minor

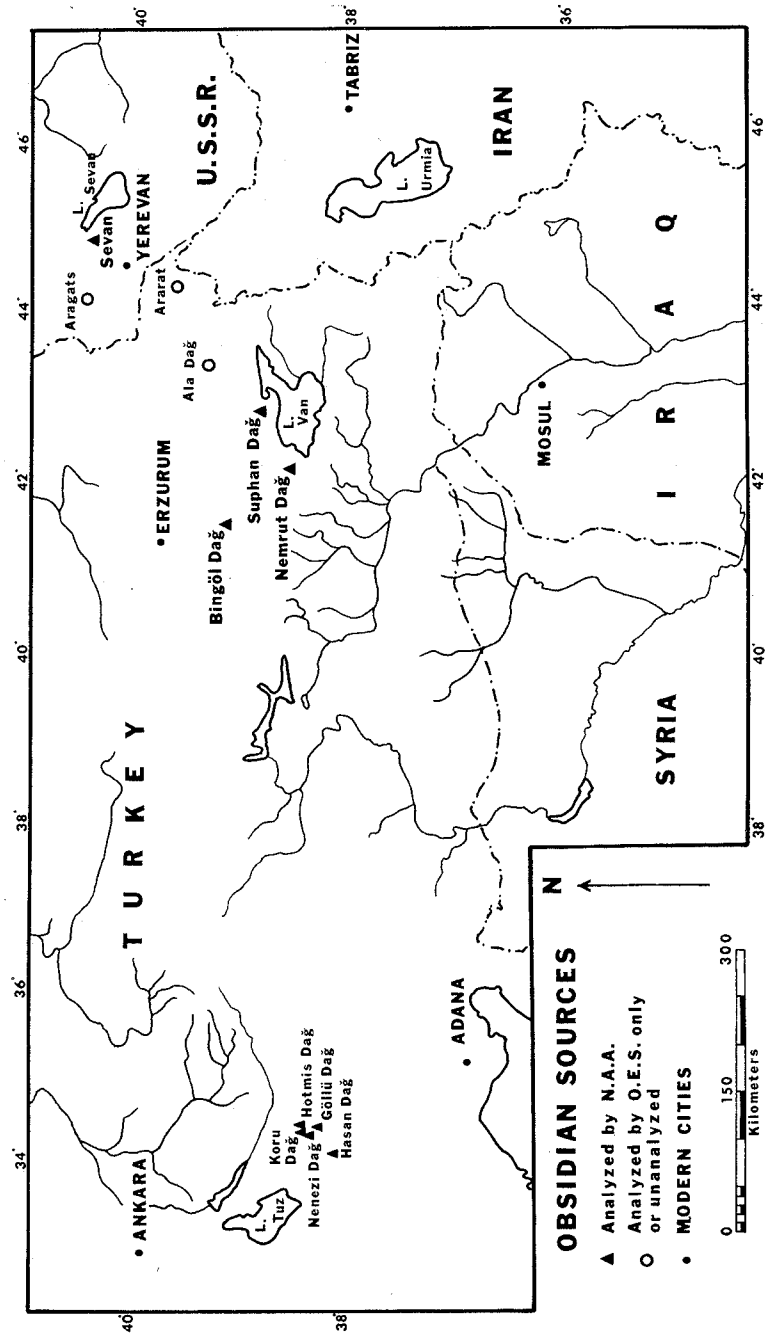

Figure 7. Postulated obsidian exchange routes.

amounts. However, the source pattern for obsidian from Tepe Yahya is quite different. Zarnaki Tepe (3a?) is the sole source of obsidian from good stratagraphic context for the periods from 3600 to 2600 B.C. No Group D (1g) obsidian is present and no Nemrut Dağ obsidian is from good context. Although the presence of Nemrut Dağ obsidian cannot be totally discounted, it would appear to be in a subsidiary role to the Zarnaki Tepe obsidian.

The Tepe Yahya sample is admittedly a small one; however, the distribution pattern argues against the inclusion of Tal-e Malyan and Tepe Yahya in the same obsidian exchange network during the period from 3500 to 2700 B.C. If, as Renfrew suggests, the exchange at this time took place between central places, obsidian moving along the western flanks of the Zagros Mountains should have moved through Susa and Tal-e Malyan before reaching Tepe Yahya (Figure 7). Were this the case, Nemrut Dağ obsidian should also be the predominant source at Tepe Yahya, as it is at Tal-e Malyan. It appears that the obsidian reaching Tepe Yahya may have taken a different route, more directly connected to the Zarnaki Tepe source north of Lake Van. This route could be from the Lake Urmia area, where Renfrew et al. (*10,27*) found Group 3 obsidian to predominate, via the valley systems east of the Zagros Mountains and thus to Tepe Yahya. Information on obsidian from archaeological sites in the valleys of the eastern Zagros is scarce or nonexistent and so this hypothesized exchange must await confirmation.

One-half of the obsidian recovered at Tal-e Malyan was from the Kafteri Phase ca. 2000 B.C., contemporaneous with Ur III in Mesopotamia. Comparison of the source distribution patterns between the earlier Banesh Phase and the later Kafteri Phase shows distinctly different patterns of source utilization. Unfortunately, contemporaneous obsidian artifacts from Tepe Yahya were not available, so these changes could not be monitored in the south central highlands.

During the Kafteri Phase, while the three sources present in the Banesh Phase continue to reach the site, four new sources have been added to the obsidian inventory. Three of these are of unknown provenance (Groups B, C, and G); however, the fourth is from the Sevan I source in the Armenian S.S.R. about 300 km north of Lake Van (Table IV). The distribution of artifacts among the sources also changes dramatically. The Nemrut Dağ I source contribution drops from 88% in the Banesh Phase to 29% in the Kafteri Phase; the contribution of the other sources rises from 12% in the Banesh to 71% in the Kafteri. Two of the sources introduced in the Kafteri Phase, Groups B and C, are 21% and 17%, respectively, of the assemblage. The distribution pattern has changed from heavy reliance on a single source in the Banesh to a more even reliance on at least three sources in the Kafteri.

In addition to these changes, it appears that luxury items made of obsidian were introduced during the Kafteri Phase. Two bowl fragments and a large highly polished bead/ring were recovered. One of the bowl fragments and the bead/ring were made of Nemrut Dağ I obsidian; the other bowl was of Zarnaki Tepe obsidian. If, as hypothesized earlier, these artifacts were not made at Tal-e Malyan, then one or more sites of bowl manufacture should exist, probably near Lake Van.

In summary, four major aspects of obsidian exchange have altered between Banesh and Kafteri times at Tal-e Malyan.

1. The number of sources utilized has increased twofold.
2. The reliance on a single source has been replaced by a more uniform distribution among the sources.
3. The geographical area exploited, which had centered on the Lake Van area, has expanded to include the most northerly known source on Lake Sevan in Soviet Armenia.
4. Luxury items make their appearance during the Kafteri Phase.

These changes argue for significant alterations in either the organization of the exchange, the political alignment in the source region, or both. During the Kafteri Phase, Tal-e Malyan together with Susa occupied an important and influential position as co-capital of Elam and as conduit for raw materials and finished goods moving out of the highlands and into lowland Mesopotamia. The position of importance held by Tal-e Malyan does not, however, explain the changes observed in the obsidian exchange. Although Tal-e Malyan might have been able to command a larger share of the exchange in many other types of goods, its distance from the obsidian sources makes its direct influence over events in the source region unlikely. One must look to developments in Ur III Mesopotamia for factors that effected the observed changes in the obsidian exchange. Expansion of Ur III influence into northern Mesopotamia or strictly local developments in the source region appear to have resulted in increased access to a larger number of obsidian sources. A tighter control over the exchange may be indicated, with the possibility of collection and transshipment locales resulting in the mixing of obsidian from different sources.

Conclusions

This study has demonstrated that precise chemical analysis is a powerful tool for the characterization and provenance determination of Middle Eastern obsidian. Thirteen to 15 chemically distinctive groups were distinguishable in geological source samples collected from eight source

areas. It appears that several of these groups represent different eruptive events at the same volcanic source. The presence of multiple chemical groups at the same volcano points out the need for extensive sampling at each potential source.

Eight chemical groups were identified within the artifact sample. Of these groups, four could be identified with known geological sources; however, the remaining four groups are of unknown provenance and three of the four do not appear to have been previously recognized. Clearly a great deal more field and analytical work needs to be done in the Eastern Turkish–Armenian S.S.R. region before a complete inventory of sources is available.

This investigation also demonstrates the potential of provenance studies to monitor exchange in both obsidian and other goods presumed to be flowing in the same network. There is a tendency to think of exchange as a unified phenomenon, i.e., a single network, organized along a single set of principles for each period of cultural development. Obsidian evidence from Tal-e Malyan and Tepe Yahya shows that exchange must be viewed as a much more complex procedure. Archaeological evidence indicates that these two sites should be linked in the exchange of several types of items. The obsidian source patterns point to the opposite conclusions for obsidian. Although obsidian reaching Tal-e Malyan during the period from 3400 to 2800 B.C. fits well with the central place redistributive model developed by Renfrew et al. (*10*) for the lowlands, Tepe Yahya does not seem to be participating in this obsidian exchange system. Tepe Yahya seems to have received its obsidian through a different system that may have been organized on a similar level, or may be a continuation of the reciprocal down-the-line system from earlier periods.

Coincident with Tal-e Malyan's expansion as a major local and regional power during the Kafteri Phase (2100–1800 B.C.), the level of organization and the scope of the obsidian exchange also appear to have undergone a significant change. The changes in the obsidian exchange system seem to be centered in the source region and possibly in northern Mesopotamia, but similar changes in exchange of other materials were also undoubtedly occurring. Whether long-range exchange was a factor contributing to, or the result of, increased sociopolitical organization in the region cannot be assessed from the study of a single material.

Extension of this study of obsidian into other sites in highland Iran is needed to outline more definitively the exchange routes in effect during the late fourth and early third millenia B.C. Expansion of precise provenance studies to include other types of exchange items is needed to provide the fine-grained information about the direction and nature of exchange not possible with more conventional archaeological techniques. It will, however, be the integration of provenance studies and the more traditional archaeological techniques that will eventually determine the role of long-range exchange in the development of the Middle East.

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Appendix A

Elemental Concentrations in the Source Samples (Data given as ppm except where noted otherwise. N.D., not determined; n.d., not detected)

Samples	*Na* (%)	*Sc*	*Fe* (%)	*Zn*	*As*	*Br*	*Rb*	*Sb*	*Cs*	*Ba*	*La*	*Ce*	*Nd*	*Sm*	*Eu*	*Gd*	*Yb*	*Lu*	*Hf*	*Ta*	*Th*	*U*
										Nemrut Dağ I	*Source Group*											
XNO523	3.82	.180	2.03	140	22.1	6.34	233	1.23	7.66	112	100	189	92.0	19.1	.421	12.4	13.6	2.01	27.9	3.69	26.3	7.77
XNO524	3.82	.189	2.03	140	22.8	6.27	233	1.34	7.50	75.1	101	189	86.9	19.1	.426	12.1	13.8	2.08	28.1	3.81	26.3	8.11
XNO527	3.82	.190	2.03	145	23.0	5.64	229	1.12	7.45	141	101	188	85.3	18.6	.445	11.4	13.6	2.00	27.9	3.78	26.1	7.78
XNO528	3.87	.196	2.07	152	24.3	7.63	240	1.25	7.89	70	101	192	89.4	19.3	.428	12.1	14.0	2.10	29.4	3.91	27.5	8.37
XNO529	3.86	.187	2.06	140	23.3	6.59	241	1.26	7.68	107	100	190	87.7	19.4	.418	11.4	13.9	2.07	28.9	3.92	27.3	8.25
XNO530	3.83	.184	2.05	142	24.2	6.19	238	1.36	7.78	88.5	99.8		90.7	19.4	.423	10.4	13.8	2.06	28.8	4.01	27.2	8.34
XNO531	3.81	.182	2.05	149	22.2	8.10	239	1.29	7.90	120		189	87.7	19.4	.416	10.9	14.2	2.10	29.0	3.93	27.0	8.63
XNO534	3.78	.185	2.00	139	23.1	6.20	227	(1.48)	7.55	112	99.3	186	87.0	18.8	.406	10.9	13.6	2.02	27.8	3.68	25.9	7.91
Mean	3.83	.187	2.04	143	23.1	6.62	235	1.26	7.68	108	100	189	88.3	19.1	.423	11.5	13.8	2.06	28.5	3.84	26.7	8.15
±1σ	.03	.005	.02	5	.8	.82	5	.08	.17	21	.5	1.5	2.2	.3	.011	.7	.2	.04	.6	.12	.6	.31
										Nemrut Dağ II	*Source Group*											
XNO520	4.26	.214	2.99	161	18.5	5.00	249	.805	8.78	114	115	209	98.6	20.0	.792	14.4	14.6	2.17	28.7	4.46	31.4	9.39
XNO521	4.18	.352	2.49	135	20.9	4.93	243	1.11	9.13	120	110	200	94.7	19.0	.453	12.6	13.7	2.07	28.0	4.22	31.9	9.67
XNO526	4.15	.198	3.19	163	20.6	4.50	268	1.20	9.62	123	121	222	103	20.7	.758	13.4	15.6	2.30	31.3	4.84	33.4	11.4
XNO532	4.33	.241	2.81	147	19.1	5.83	256	.992	8.76	155	110	202	93.3	19.3	.656	11.3	14.1	2.17	28.3	4.40	30.9	9.91
XNO533	4.24	.313	3.25	167	22.1	5.71	260	1.17	9.36	107	119	220	102	21.6	.806	12.3	15.3	2.38	30.9	4.88	33.3	10.6
Mean	4.23	.257	2.93	154	20.2	5.16	255	1.05	9.12	123	115	210	98.2	20.1	.678	12.5	14.6	2.19	29.4	4.55	32.2	10.2
±1σ	.07	.072	.33	14	1.5	.58	10	.19	.38	19	5	10	4.4	1.1	.184	1.2	.8	.15	1.6	.30	1.1	.8
										Nemrut Dağ III	*Source Group*											
XNO525	4.22	.106	3.01	173	33.3	18.8	252	2.42	14.7	175	104	197	92.5	20.7	.670	14.1	15.2	2.22	30.3	4.18	33.1	11.8
										Nemrut Dağ IV	*Source Group*											
XNO522	4.30	.908	3.12	150	18.6	3.87	246	1.43	8.03	135	115	210	96.4	19.3	1.02	12.2	14.1	2.13	28.4	4.25	30.2	8.63
										Suphan Dağ I	*Source Group*											
XSO500	3.31	3.41	.816	32.4	13.6	n.d.	211	1.07	7.68	n.d.	20.5	38.4	16.4	4.49	.140	4.25	3.55	.660	3.64	1.34	14.8	5.55
XSO501	3.06	3.43	.817	26.7	11.6	n.d.	210	1.14	7.72	n.d.	20.7	41.3	17.6	4.35	.173	4.80	3.79	.626	3.34	1.38	15.6	6.83
XSO503	3.05	3.43	.814	24.8	12.6	n.d.	212	1.14	7.81	n.d.	19.4	39.1	15.1	4.14	.152	4.92	3.87	.620	3.26	1.43	14.8	6.99
XSO508	3.09	3.57	.954	39.1	12.0	n.d.	206	1.07	7.88	n.d.	23.9	48.3	17.3	4.88	.145	3.48	4.09	.644	4.06	1.33	17.5	7.27
XSO509	3.06	3.55	.841	37.8	13.2	n.d.	210	1.17	7.95	n.d.	19.0	39.1	17.9	4.27	.148	3.80	3.70	.625	3.35	1.43	15.4	7.17
XSO510	3.05	3.63	.906	26.6	13.0	n.d.	220	1.38	8.00	n.d.	18.1	36.9	13.5	4.10	.144	5.30	3.86	.621	3.26	1.36	14.7	7.09
Mean	3.10	3.50	.856	30.7	12.6	n.d.	211	1.16	7.84	n.d.	20.2	40.4	16.4	4.36	.150	4.38	3.80	.633	3.47	1.38	15.3	6.79
±1σ	.10	.09	.059	6.6	.8	—	5	.11	.13	—	2.0	4.0	1.9	.29	.012	.77	.19	.016	.31	.04	1.1	.79
										Suphan Dağ II	*Source Group*											
XSO502	3.04	2.97	.862	27.5	8.12	n.d.	168	.626	5.13	602	32.3	59.8	22.9	5.00	.402	5.55	3.06	.510	3.79	.812	17.1	4.66
XSO504	3.13	3.09	.910	25.9	8.48	n.d.	177	.608	5.30	577		62.8	22.1	5.28	.433	4.44	3.22	.548	4.42	.893	18.4	4.86
XSO506	3.06	3.00	.886	26.1	8.48	n.d.	158	.602	5.02	573	33.7	61.2	23.9	5.10	.439	4.57	3.19	.528	4.71	.895	17.6	4.87
XSO507	3.02	2.97	.894	36.1	10.0	n.d.	168	.578	5.21	620	33.1	60.0	22.5	4.89	.458	3.71	3.12	.503	3.75	.886	17.3	4.56
Mean	3.06	3.01	.888	28.6	8.74	n.d.	168	.603	5.16	593	33.3	60.9	22.8	5.07	.433	4.52	3.15	.522	4.15	.871	17.6	4.74
±1σ	.05	.06	.020	4.9	.84	—	8	.020	.12	22	.8	1.4	.8	.17	.024	.81	.07	.020	.50	.042	.6	.16

Continued on next page.

Elemental Concentrations in the

Samples	Na (%)	Sc	Fe (%)	Zn	As	Br	Rb	Sb	Cs	Ba
										Lake Sevan I
XRO622	3.43	3.02	.811	40.3	2.18	n.d.	158	.328	5.56	601
XRO623	3.46	3.01	.795	39.6	3.07	n.d.	143	.308	5.07	583
ARO001	3.47	2.96	.779	N.D.	N.D.	n.d.	142	.277	5.22	572
ARO003	3.55	2.98	.802	N.D.	N.D.	n.d.	148	.339	5.11	567
ARO004	3.54	2.96	.794	N.D.	N.D.	n.d.	145	.333	5.32	577
Mean	3.49	2.99	.796	40.0	2.63	n.d.	147	.317	5.26	580
± 1σ	.05	.03	.011	—	—	—	6	.025	.20	13
										Lake Sevan II
ARO002	3.17	2.53	.392	36.9	3.84	n.d.	148	.493	3.69	162
										Göllü Dağ
XGO600	3.16	1.78	.559	23.4	8.07	n.d.	222	1.06	8.37	208
XGO601	3.01	1.70	.554	25.4	7.00	n.d.	208	1.04	7.67	369
XCO640	3.13	1.68	.542	19.4	6.20	n.d.	196	.859	7.30	305
XEO540	3.10	1.72	.569	22.7	7.09	1.84	204	.902	7.75	270
XEO541	3.05	1.69	.560	20.5	6.42	n.d.	199	.821	7.54	285
Mean	3.09	1.71	.557	22.3	6.96	—	206	.936	7.73	287
± 1σ	.06	.04	.010	2.4	.73	—	10	.108	.40	58
										Hasan Dağ
XHO660	3.15	2.05	.580	20.5	6.39	2.31	145	.789	5.11	1004
XHO661	3.39	2.06	.586	21.0	6.03	1.48	144	.784	5.32	981
Mean	3.27	2.05	.583	20.8	6.21	1.90	145	.787	5.22	993
										Koru Dağ
XAO560	3.38	2.07	.568	24.9	11.3	n.d.	298	1.23	14.2	193
XAO561	3.35	2.09	.579	22.6	11.1	n.d.	298	1.35	15.0	157
Mean	3.37	2.08	.574	23.8	11.2	n.d.	298	1.29	14.6	175
										Hotmis Dağ I
XKO580	3.13	1.02	.738	32.8	5.00	2.82	201	.520	8.47	440
XKO581	3.20	1.04	.755	30.1	6.05	3.07	196	.683	8.39	431
XKO585	3.22	1.08	.749	30.5	6.48	2.76	196	.502	8.28	448
Mean	3.18	1.05	.747	31.1	5.84	2.88	198	.568	8.38	440
± 1σ	.05	.03	.009	1.5	.76	.16	3	.100	.05	9
										Hotmis Dağ II
XKO582	3.41	1.30	1.23	41.2	4.67	1.96	171	.637	6.85	550
XKO584	3.48	1.31	1.22		5.63	3.31	176	.613	6.85	572
Mean	3.45	1.31	1.23	41.6	5.15	2.64	174	.625	6.85	561
										Hotmis Dağ III
XKO583	3.14	1.18	.944	34.5	5.07	2.81	194	.561	7.42	477
										Giali
XYO700	2.86	1.56	.667	18.7	9.26	7.14	155	.510	5.23	1032

Source Samples—*Continued*

La	Ce	Nd	Sm	Eu	Gd	Yb	Lu	Hf	Ta	Th	U
Source Group											
35.9	57.1	18.6	3.03	.508	n.d.	2.76	.403	5.18	3.10	18.3	9.47
35.2	56.4	28.0	3.07	.476	4.02	2.80	.406	4.75	3.10	17.7	9.32
35.4	55.3	18.5	2.98	.469	n.d.	2.69	.402	4.94	3.10	17.7	9.24
36.0	56.0	17.7	3.04	.528	n.d.	2.70	.400	4.93	3.03	17.7	9.40
36.1	55.9	17.4	2.98	.479	n.d.	2.68	.400	4.90	2.98	17.6	9.09
35.7	56.1	20.0	3.02	.491	—	2.73	.402	4.94	3.06	17.8	9.30
.4	.7	4.5	.04	.026	—	.05	.002	.15	.05	.3	.15
Source Group											
17.6	32.4	12.0	2.87	.238	N.D.	3.06	.439	3.40	2.42	14.7	8.19
Source Group											
25.7	45.4	14.8	2.83	.131	N.D.	2.61	.402	3.45	2.37	23.4	9.50
26.7	45.3	13.2	2.93	.148	N.D.	2.40	.372	3.49	2.06	23.0	8.40
26.0	43.4	13.2	2.59	.138	N.D.	2.44	.316	2.86	2.21	22.5	8.07
26.7	45.6	14.1	2.71	.155	N.D.	2.43	.375	3.20	2.13	23.4	8.53
25.9	44.4	15.3	2.91	.133	N.D.	2.43	.359	3.20	2.07	22.8	8.29
26.2	44.8	14.1	2.79	.141	N.D.	2.46	.365	3.24	2.17	23.0	8.56
.5	.9	.9	.14	.010	—	.08	.031	.25	.13	.4	.55
Source Group											
27.2	43.7	12.6	2.34	.418	n.d.	1.39	.280	2.86	1.35	14.3	3.95
27.0	44.6	12.0	2.38	.428	2.54	1.57	.257	2.92	1.40	14.6	4.21
27.1	44.2	12.3	2.36	.423	—	1.48	.269	2.89	1.38	14.5	4.08
Source Group											
15.2	31.8	12.8	3.62	.020	N.D.	4.58	.664	4.46	3.99	38.9	12.8
15.5	32.1	14.0	3.62	n.d.	N.D.	4.64	.652	4.51	3.68	33.8	12.4
15.4	32.0	13.4	3.62	.020	N.D.	4.61	.658	4.49	3.84	35.4	12.6
Source Group											
31.1	50.4	15.5	2.85	.276	N.D.	3.01	.434	4.10	2.25	28.9	8.24
31.7	51.1	16.0	2.90	.272	N.D.	3.00	.446	4.20	2.15	29.1	8.26
31.9	51.2	16.4	2.84	.295	N.D.	3.05	.459	4.32	2.20	30.1	8.33
31.6	51.0	16.0	2.86	.281	N.D.	3.02	.446	4.21	2.20	29.4	8.28
.4	.6	.5	.03	.012	—	.03	.013	.11	.05	.6	.05
Source Group											
37.7	60.6	19.7	3.47	.503	N.D.	3.12	.524	5.62	1.81	25.6	7.09
38.6	61.7	16.9	3.40	.517	3.88	3.10	.479	5.48	1.94	26.2	7.24
38.2	61.2	18.3	3.44	.510	3.88	3.11	.502	5.55	1.88	25.9	7.17
Source Group											
34.5	55.7	19.4	3.15	.386	N.D.	2.96	.507	4.81	1.96	27.1	7.59
Source Group											
42.9	64.5	16.7	2.69	.282	3.10	1.94	.317	3.37	1.57	18.8	5.02

Appendix B

Elemental Concentrations in the Artifact Samples (Data given as ppm except where noted otherwise. N.D., not determined; n.d., not detected)

Samples	*Na* (%)	*Sc*	*Fe* (%)	*Zn*	*As*	*Br*	*Rb*	*Sb*	*Cs*	*Ba*
										Artifact Group A:
MAO002	3.83	.181	1.97	147	N.D.	N.D.	217	1.32	7.32	99.5
MAO004	3.80	.208	2.04	138	24.8	6.45	227	1.42	7.53	83.7
MAO005	3.94	.208	2.09	123	23.9	5.90	224	1.26	7.74	n.d.
MAO006	3.82	.189	1.98	146	23.1	6.30	220	1.42	7.00	82.4
MAO007	3.83	.179	1.96	145	25.1	5.46	220	1.40	7.15	n.d.
MAO008	3.82	.202	2.09	146	23.0	6.88	227	1.23	7.52	n.d.
MAO011	3.89	.204	2.00	N.D.	N.D.	N.D.	226	1.26	7.68	96.5
MAO017	3.91	.192	2.12	N.D.	N.D.	N.D.	232	1.26	7.84	67.4
MAO019	3.84	.201	1.97	143	23.7	6.60	220	1.39	7.14	164
MAO020	3.85	.201	1.97	N.D.	N.D.	N.D.	221	1.17	7.86	79.0
MAO021	3.87	.200	2.08	142	26.2	7.15	224	1.32	7.46	88.9
MAO022	3.96	.190	2.09	148	25.8	7.10	231	1.43	7.57	110
MAO024	3.95	.194	1.99	N.D.	N.D.	N.D.	224	1.34	7.60	78.5
MAO029	3.90	.182	2.04	N.D.	N.D.	N.D.	228	1.41	7.50	81.6
MAO030	3.74	.202	2.08	150	26.8	7.28	229	1.32	7.67	n.d.
MAO031	3.95	.188	2.13	N.D.	N.D.	N.D.	241	1.33	7.01	n.d.
MAO032	3.81	.182	2.04	144	24.9	7.25	228	1.42	7.77	n.d.
MAO033	3.92	.181	2.03	N.D.	N.D.	N.D.	227	1.35	7.55	78.1
MAO034	3.93	.200	2.01	146	26.7	6.84	235	1.36	7.35	111
MAO039	3.98	.187	2.01	149	22.1	5.14	229	1.30	7.83	83.3
MAO042	3.98	.197	2.03	147	23.5	6.13	233	1.39	7.62	139
MAO043	3.96	.179	2.02	157	25.7	6.94	233	1.27	7.71	n.d.
MAO044	3.89	.199	1.98	149	22.9	6.26	238	1.25	7.41	n.d.
MAO046	3.92	.191	1.99	152	22.2	5.57	236	1.56	7.69	n.d.
YAO107	4.02	.203	2.13	152	26.2	6.49	248	1.45	7.86	n.d.
YAO111	3.87	.172	1.96	N.D.	N.D.	N.D.	202	1.46	7.74	57.7
YAO112	3.85	.192	2.07	142	24.0	6.49	236	1.36	7.50	n.d.
SUO002	3.97	.197	2.06	158	24.5	6.97	247	1.33	7.98	n.d.
Mean	3.89	.193	2.03	146	24.5	6.48	229	1.35	7.56	93.8
±1σ	.07	.010	.05	7	1.5	.62	9	.08	.26	26.8
										Artifact Group A':
MAO026	3.97	.128	2.50	167	33.4	16.9	243	2.15	14.0	170
YAO110	4.25	.188	2.83	N.D.	N.D.	N.D.	219	2.14	13.8	86.8
Mean	4.11	.158	2.67	167	33.4	16.9	231	2.15	13.9	128
										Artifact Group B:
MAO013	3.13	1.59	.457	28.3	n.d.	n.d.	169	.181	3.87	173
MAO015	3.22	1.72	.467	32.6	n.d.	n.d.	187	.217	4.36	172
MAO036	3.21	1.69	.461	31.1	n.d.	n.d.	183	.143	4.23	200
MAO040	3.29	1.65	.472	30.0	n.d.	n.d.	184	.154	4.27	172
MAO041	3.31	1.84	.445	25.2	n.d.	n.d.	200	.241	4.87	170
Mean	3.23	1.70	.460	29.3	n.d.	n.d.	184	.184	4.30	177
±1σ	.07	.10	.011	3.1	—	—	11	.045	.37	13

La	*Ce*	*Nd*	*Sm*	*Eu*	*Gd*	*Yb*	*Lu*	*Hf*	*Ta*	*Th*	*U*
Nemrut Dağ I											
99.7	188	81.8	N.D.	.417	21.3	13.5	N.D.	27.1	4.05	26.2	N.D.
103	191	86.5	19.2	.433	18.5	14.2	2.10	27.5	3.74	26.3	8.07
105	195	89.4	19.8	.417	17.4	14.5	2.15	28.3	3.80	26.7	8.62
98.3	189	85.1	18.5	.403	19.4	13.7	2.02	26.3	3.98	25.7	8.22
98.1	188	84.3	18.2	.408	18.2	13.4	2.02	26.3	3.97	25.4	8.11
104	196	92.0	19.8	.421	18.2	14.4	2.10	28.1	3.91	27.1	8.85
101	193	N.D.	N.D.	.422	N.D.	13.9	2.22	23.7	3.96	26.9	N.D.
103	N.D.	N.D.	19.5	.458	N.D.	14.3	2.22	30.8	4.37	28.3	N.D.
98.9	189	79.0	18.8	.420	15.7	13.5	1.99	26.3	3.87	25.6	8.39
102	184	N.D.	20.5	.426	N.D.	13.9	2.22	22.4	3.91	26.7	N.D.
104	195	92.7	19.5	.404	17.5	14.3	2.08	28.0	3.89	29.9	8.49
104	195	94.1	19.7	.427	16.3	14.3	2.12	28.1	4.05	27.0	8.78
103	193	N.D.	N.D.	.379	N.D.	14.3	2.24	21.4	3.81	27.1	N.D.
104	N.D.	N.D.	18.1	.417	N.D.	14.2	2.09	28.0	4.20	26.3	N.D.
104	197	92.2	19.7	.397	15.9	14.4	2.10	28.5	4.09	27.0	8.65
106	N.D.	N.D.	19.9	.491	N.D.	15.0	2.22	29.4	4.41	27.9	N.D.
100	189	86.6	19.0	.369	19.2	14.4	2.10	28.3	3.93	27.1	8.01
104	N.D.	N.D.	18.1	.360	N.D.	14.0	2.09	28.7	4.31	26.5	N.D.
104	192	83.5	18.7	.417	18.1	13.8	2.07	26.7	4.33	26.6	8.01
104	193	83.3	18.6	.440	18.5	13.8	2.10	26.8	4.30	26.7	8.08
103	193	82.8	18.8	.399	15.3	14.7	2.08	26.9	4.25	26.8	6.61
101	190	82.7	19.5	.472	14.3	13.7	2.13	27.4	4.42	27.3	7.88
101	192	78.6	19.1	.406	15.7	13.7	2.05	26.7	4.29	26.3	8.30
101	189	79.3	19.3	.446	16.1	13.9	2.08	27.2	4.38	26.9	8.08
107	199	91.2	20.3	.430	20.1	14.6	2.15	28.8	3.88	27.7	8.87
101	193	N.D.	N.D.	.400	N.D.	14.0	2.01	26.0	4.27	25.3	N.D.
103	193	90.9	19.4	.415	17.5	14.2	2.09	28.0	3.85	26.6	8.48
105	196	85.4	19.0	.451	18.2	14.4	2.07	28.5	4.13	27.2	8.37
103	192	86.1	19.2	.419	17.6	14.1	2.11	27.2	4.08	26.8	8.26
2	3	4.9	.7	.028	1.8	.4	.07	2.0	.21	.9	.50
Nemrut Dağ III											
100	192	84.7	19.4	.566	N.D.	14.4	2.10	27.8	4.07	32.4	11.8
102	197	N.D.	N.D.	.508	N.D.	14.6	2.09	25.4	4.46	29.9	N.D.
101	195	84.7	19.4	.537	N.D.	14.5	2.10	26.6	4.26	31.2	11.8
Unknown Provenance											
38.1	56.4	13.0	1.68	.175	n.d.	1.50	.256	3.80	2.17	31.7	9.64
36.0	54.2	13.8	1.58	.145	n.d.	1.52	.255	3.58	2.24	33.9	10.3
37.6	54.6	12.1	1.60	.158	n.d.	1.57	.248	3.64	2.32	33.7	9.60
40.4	58.6	15.0	1.75	.153	n.d.	1.59	.254	3.68	2.42	33.6	9.88
35.1	50.7	12.2	1.46	.134	n.d.	1.62	.264	3.63	2.53	35.3	10.9
37.4	54.8	13.2	1.61	.152	n.d.	1.56	.255	3.67	2.33	33.6	10.1
2.1	3.0	1.2	.11	.016	—	.05	.006	.08	.14	1.3	.5

Continued on next page.

Elemental Concentrations in the

Samples	Na (%)	Sc	Fe (%)	Zn	As	Br	Rb	Sb	Cs	Ba
										Artifact Group C:
MAO001	3.86	.480	1.54	145	1.62	3.29	117	.379	1.30	616
MAO023	3.89	.480	1.58	142	n.d.	4.37	120	.364	1.30	631
MAO027	3.82	.469	1.55	140	n.d.	2.90	108	.347	1.10	636
MAO038	3.84	.483	1.54	138	n.d.	n.d.	117	.423	1.16	671
MAO047	3.93	.482	1.55	143	n.d.	2.58	122	.299	1.44	625
MAO048	3.77	.489	1.59	148	n.d.	3.29	123	.434	1.28	610
Mean	3.85	.480	1.56	143	1.62	3.23	118	.371	1.26	631
± 1σ	.06	.007	.02	4	—	.70	6	.054	.13	21
										Artifact Group D:
MAO014	3.74	2.48	1.33	40.6	6.69	2.23	225	.949	10.5	576
MAO025	3.66	2.13	1.25	37.8	7.28	2.92	226	.994	10.4	487
KOO001	3.52	2.14	1.30	33.1	7.36	n.d.	251	.843	10.5	489
CSO001	3.56	2.16	1.30	39.3	7.67	n.d.	250	.961	10.2	511
Mean	3.62	2.22	1.30	37.6	7.24	2.55	238	.935	10.4	515
± 1σ	.10	.17	.03	3.5	.43	—	15	.070	.1	42
										Artifact Group E:
MAO009	3.78	1.89	.940	60.8	n.d.	n.d.	218	.386	9.09	188
MAO016	3.77	1.90	.941	63.5	n.d.	n.d.	203	.435	8.75	n.d.
MAO018	3.68	1.81	.888	58.5	n.d.	1.13	199	.352	8.39	n.d.
MAO045	3.86	1.86	.943	61.0	n.d.	n.d.	216	.437	9.34	223
YAO101	3.84	1.90	.972	62.6	2.63	n.d.	226	.432	9.51	79.0
YAO102	3.81	1.89	.972	64.6	2.94	n.d.	226	.591	9.40	127
YAO103	3.84	1.88	.956	N.D.	N.D.	N.D.	219	.419	8.61	129
YAO104	3.79	1.93	.988	N.D.	N.D.	N.D.	234	.346	8.96	115
YAO105	4.02	1.83	.943	62.5	2.36	n.d.	205	.454	9.01	286
YAO108	3.73	1.85	.944	N.D.	N.D.	N.D.	212	.459	8.58	105
YAO109	3.79	1.86	.948	62.7	2.11	n.d.	228	.403	9.44	199
Mean	3.81	1.87	.949	62.0	2.49	1.13	217	.429	9.01	161
± 1σ	.09	.03	.026	1.9	.38	—	11	.066	.39	67
										Artifact Group F:
MAO003	3.44	2.98	.795	37.3	2.20	n.d.	140	.370	4.71	567
MAO037	3.46	2.89	.810	38.8	n.d.	n.d.	150	.363	4.66	536
Mean	3.45	2.94	.802	38.1	2.20	n.d.	145	.367	4.69	552
										Artifact Group G:
MAO012	3.53	1.47	102	n.d.	4.90	113	.440	1.63	699	111
MAO035	3.77	1.49	108	n.d.	5.39	122	.459	1.23	702	116
Mean	3.65	1.48	105	n.d.	5.14	117	.449	1.42	700	113

Artifact Samples—*Continued*

La	Ce	Nd	Sm	Eu	Gd	Yb	Lu	Hf	Ta	Th	U
Unknown Provenance											
83.7	164	72.9	17.5	2.28	19.7	10.8	1.53	21.1	7.66	15.9	4.00
84.6	165	72.5	17.9	2.28	16.3	10.9	1.52	20.8	7.74	16.2	4.48
82.9	163	73.9	17.7	2.19	14.3	10.9	1.52	21.3	7.74	16.0	4.33
85.4	163	71.8	17.4	2.38	N.D.	10.9	1.57	20.9	8.23	16.3	3.77
84.2	163	69.7	18.2	2.32	N.D.	10.9	1.51	20.0	8.33	16.3	3.84
86.2	166	73.3	18.1	2.38	N.D.	11.0	1.56	21.1	8.38	16.8	3.40
84.5	164	72.3	17.8	2.30	16.6	10.9	1.54	20.9	8.01	16.2	3.95
1.2	1	1.5	.3	.07	2.9	.1	.02	.5	.34	.3	.42
Unknown Provenance (1g)											
42.8	72.8	24.9	4.61	.485	N.D.	3.68	.552	8.33	1.64	27.8	9.20
41.6	71.2	24.9	4.33	.396	N.D.	3.60	.529	7.96	1.69	28.1	9.40
42.9	71.1	24.5	4.51	.415	6.09	3.39	.604	8.21	1.44	28.9	9.44
42.6	70.5	26.2	4.48	.425	5.05	3.40	.546	8.22	1.50	28.8	9.49
42.5	71.4	25.1	4.48	.429	5.55	3.52	.557	8.18	1.56	28.4	9.38
.6	1.0	.7	.12	.039	—	.15	.033	.16	.12	.5	.15
Zarnaki Tepe Source Group											
35.2	70.1	29.9	6.73	.386	6.90	5.96	.934	8.46	2.28	25.3	8.74
35.5	70.0	31.4	7.24	.406	7.37	5.97	.949	8.45	2.45	24.2	8.65
33.1	67.0	29.4	6.82	.342	6.23	5.98	.927	8.14	2.21	23.4	7.94
35.2	69.6	30.3	7.22	.363	7.01	6.21	.993	8.43	2.61	25.1	8.67
35.8	71.1	33.7	7.65	.368	10.7	6.47	1.03	8.99	2.29	25.9	9.25
36.0	71.0	31.2	7.60	.337	7.17	6.60	.995	8.94	2.36	25.7	9.06
35.4	N.D.	N.D.	N.D.	.407	N.D.	5.72	.925	8.52	2.51	24.8	N.D.
34.4	N.D.	N.D.	N.D.	.361	N.D.	5.91	.959	8.82	2.48	25.7	N.D.
35.7	69.1	32.0	7.07	.333	7.05	6.13	.935	8.73	2.22	24.9	8.21
35.3	N.D.	N.D.	N.D.	.336	N.D.	5.61	.911	8.37	2.41	24.5	N.D.
35.8	69.8	32.9	7.52	.324	9.02	6.47	.999	9.08	2.44	25.3	9.00
35.2	69.7	31.3	7.22	.360	7.57	6.09	.960	8.63	2.39	25.0	8.65
.8	1.3	1.5	.36	.029	1.44	.32	.039	.30	.13	.7	.46
Lake Sevan I Source Group											
34.6	56.1	17.0	3.00	.457	5.34	2.80	.398	4.73	2.93	17.4	8.83
36.2	56.6	18.6	3.00	.518	N.D.	2.76	.371	4.72	3.11	17.1	8.44
35.4	56.4	17.8	3.00	.488	5.34	2.78	.385	4.73	3.03	17.3	8.64
Unknown Provenance											
111	203	81.4	16.8	1.80	13.8	8.92	1.25	14.2	7.42	18.2	4.92
116	203	80.1	17.3	1.88	n.d.	9.11	1.39	14.0	7.99	18.8	3.78
113	203	80.7	17.0	1.84	13.8	9.02	1.32	14.1	7.70	18.5	4.31

Literature Cited

1. Johnson, G. A. "Local Exchange and Early State Development in Southwestern Iran"; Anthropological Papers No. 38; Univ. Mich.: Ann Arbor, Mich., 1973.
2. Ehrich, R. W. "Chronology in Old World Archaeology"; Univ. Chicago Press: Chicago, Ill., 1965.
3. Sumner, W. M. *Iran* **1976,** *14.*
4. Reiner, E. *Iran* **1974,** *12.*
5. Lamberg-Karlovsky, C. C. *Iran* **1972,** *10,* 89–100.
6. Lamberg-Karlovsky, C. C. In "Ancient Civilization and Trade"; Sablott, J.A.; Lamberg-Karlovsky, C. C., Eds.; Univ. N.M. Press: Santa Fe, 1975.
7. Kohl, P. L. *Current Anthropology,* **1978,** *19.*
8. Cann, J. R.; Renfrew, C. "The Characterization of Obsidian and Its Application to the Mediterranean Region"; *Proc. Prehistor. Soc.* 30, **1964.**
9. Renfrew, C.; Dixon, J. E.; Cann, J. R. "Obsidian and Early Cultural Contact in the Near East"; *Proc. Prehistor. Soc.* 32, **1964.**
10. Renfrew, C.; Dixon, J. E.; and Cann, J. R. "Further Analysis of Near Eastern Obsidian"; *Proc. Prehistor. Soc.* 34, **1968.**
11. Bieber, A. M.; Brooks, D. W.; Harbottle, G.; Sayre, E. J. *Archaeometry* **1976,** *18*(1).
12. Altinli, I. E. "Explanatory Text of the Geological Map of Turkey"; Van. Maden Tetkik ve Arama Enstitutu Vajinlarindan: Ankata, 1964.
13. Wright, G. A. "Obsidian Analysis and Prehistoric Near Eastern Trade: 7500 to 3500 B.C."; Anthropological Papers No. 37; Univ. Mich.: Ann Arbor, Mich., 1969.
14. Wright, G. A.; Gordas, A. A. *Isr. Explor. J.* **1969,** *19.*
15. Mahdavi, A.; Bovington, C. *Iran* **1972,** *10.*
16. Aspinall, A.; Feather, S. W.; Renfrew, C. *Nature* **1972,** *237.*
17. McDaniels, J.; Warren, S. E.; Moore, A. M. T. *Int. Symp. Archaeom. Archaeolog. Prospection;* Edinburgh, **1976.**
18. McDaniels, J. M.A. Thesis, University of Bradford, 1976.
19. Epstein, S. M. M.A. Thesis, University of Bradford, 1977.
20. Perlman, I.; Yellin, J. HUAL 1 preprint, 1977, unpublished.
21. Yellin, J.; Perlman, I. SI–NBS Obsidian Workshop, Gaithersburg, Md., 1978.
22. Perlman, I.; Yellin, J. *Isr. Explor. J.* **1980,** *30.*
23. Yellin, J.; Perlman, I. *Rev. Archaeometrie* **1982,** *111.*
24. Blackman, M. J. *Symp. Archaeom. Archaeolog. Prospection,* Brookhaven National Laboratory, 1981.
25. Blackman, M. J., in preparation.
26. Renfrew, C. "Studies in the Archaeological History of the Deh Luran Plain"; Memoirs of the Museum of Anthropology No. 9; Univ. Mich., Ann Arbor, Mich., 1977.
27. Renfrew, C.; Dixon, J. E. In "Problems in Economic and Social Archaeology"; Sieveleing, G. deG.; Longworth, I. H.; Wilson, K. E., Eds.; Westview: Boulder, Colo., 1977.
28. Dixon, J. E. In "Advances in Obsidian Glass Studies"; Taylor, R.E., Ed.; Noyes: Park Ridge, N.J., 1977.

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