

The Present Status of Obsidian Source Identification in Anatolia and the Near East

Abstract

A survey of obsidian occurrences as possible sources for the prehistoric trade was carried out in the Tertiary and Quaternary volcanism of Anatolia and Armenia. Over 25 obsidian occurrences from Turkey and from the Armenian SSR are characterized by chemical multi-element analysis. Major emphasis was placed on utilizing standard chemical methods which are applied in many laboratories in order to guarantee a maximum reproducibility of results.

It is shown that discriminant function analysis with sets of chemical elements can unambiguously separate these obsidian sources and can trace the provenance of archaeological material. Also, selected element combinations have a high capacity for discrimination of sources and for correlation. The Ca-Fe relationship for major elements and Rb-Sr combined with Zr-Ba plots for trace elements are used in this paper as examples for characterizing all known sources. On the basis of this general characterization, microprobe analysis on minimum sample amounts is a useful and rapid tool for source fingerprinting of archaeological samples, e.g. in the Ca-Fe space. Additional elements for correlation are obtained by non-destructive, semi-quantitative X-ray fluorescence scans using the peak intensities of the most significant elements.

INTRODUCTION

Obsidian has been widely used in prehistoric civilizations of the Mediterranean area. Renfrew and co-workers (Renfrew *et al.*, 1965, 1966, 1968 ; Cann and Renfrew, 1964 ; Dixon *et al.*, 1968) have carried out the pioneering and now classical studies for correlation of obsidian artifacts with natural sources.

A distinct number of Neogene and Quaternary volcanic provinces have erupted obsidian in the form of lava flows, volcanic domes or as blocks in the pyroclastic products of explosive volcanic eruptions. Two observations make the characterization and correlation of obsidian a case example for provenance studies of prehistoric material technology. These are the limited number of natural obsidian occurrences, and the fact that obsidian from one given volcanic event prove to be distinctly homogeneous in most of its physical and chemical characteristics. This observation is generally confirmed in all obsidian correlation studies. The possible effects of secondary variation due to recrystallization, alteration, or hydration have been discussed by Jezek and Noble (1978) and Zielinski *et al.* (1977).

In addition, it has been shown that obsidians from different sources exhibit enough variation in physical and chemical parameters to allow their characterization, discrimination and correlation. The obsidian literature is full of different approaches to find the most efficient parameters for these purposes.

MEDITERRANEAN OBSIDIAN SOURCES

In the Mediterranean area obsidian occurrences are mainly known in the Italian sector, in the Aegean and in Anatolia. In Italy the sources are Lipari, Pantelleria, Palmarola and Sardinia (Cornaggia *et al.*, 1963 ; Cann and Renfrew, 1964 ; Keller, 1970 ; Hallam *et al.*, 1976 ; Francaviglia, 1984 ; Herold, 1986). With Milos, Yali and Antiparos all Aegean sources can also be considered rather fully known and explored (Renfrew *et al.*, 1965 ; Wagner *et al.*, 1976 ; Mosheim, 1984 ; Francaviglia, 1984).

In contrast, the volcanic provinces of Anatolia and the adjacent areas are not yet explored to the same certainty that all important natural obsidian occurrences are known. Nevertheless, the work by Renfrew *et al.* (1966, 1968) has set the frame and was complemented by studies of Wright and Gordus (1969), Fornaseri *et al.* (1977) and Blackman (1984). Obsidian occurrences and their prehistoric use are mainly documented from Cappadocia in Central Anatolia and from the area north of Lake Van in the East. Major source names are Acigöl and Çiftlik for Cappadocia, Bingöl and Nemrut Dağ volcano in the East. A « Kars » provenance plays a somehow enigmatic role since introduced by Renfrew *et al.* (1966), but has not been defined by any volcanological survey. There are plenty of obsidian occurrences on the territory of the Armenian SSR (Karapetian, 1969 ; Komarov *et al.*, 1972 ; Wagner *et al.*, 1976). These should have contributed significantly to the obsidian use and obsidian trade in the Neolithic. A first step towards a systematic consideration of these Armenian sources is part of this paper.

METHODS OF OBSIDIAN CHARACTERIZATION

A number of techniques and parameters have been tried for obsidian source correlations. These include physical parameters such as color, optical transparency and refractive index. Magnetic properties (McDougall *et al.*, 1983) and thermoluminescence (Huntley and Bailey, 1978) have also proved helpful for specific purposes of distinction. However, modern chemical analysis can determine simultaneously a large number of elements providing the frame of an efficient multi-parameter discrimination. There is a considerable amount of discussion which of the chemical methodology is most suitable for characterization of obsidian sources and for tracing the origin of archaeological material. As a result of all previous obsidian studies it has been stated that individual obsidian sources, in terms of eruptive units, are in general exceedingly homogeneous. The classical studies of Renfrew *et al.* (1966, 1968) used optical emission spectroscopy (OES) and obtained a general subdivision into groups which is still in use. However, it is also clear from the data of Renfrew *et al.* (1966) that OES analysis shows analytical variations for several critical elements of a factor of 2 or 3 for one individual source, far beyond the natural variation.

Neutron activation analysis (NAA) has been introduced in obsidian provenance studies as a powerful method for discrimination, and with the additional advantage of the possibility for non-destructive sample preparation (Gordus *et al.*, 1968 ; Aspinall *et al.*, 1972 ; Hallam *et al.*, 1976). In our view the only shortcoming of NAA is the more restricted availability of the method and the relatively complex technology making analysis expensive and time-consuming compared with other methods of modern multi-element analysis. Moreover, NAA does not provide the basic chemical information of major and minor elements commonly used in petrology. In the case of non-destructive sample preparation the NAA data are not directly comparable with quantitative data from other geochemical methods.

Even more specialized methods have been tried for obsidian source determinations. Nelson *et al.* (1977) and Duerden *et al.* (1980) have used proton-induced X-ray and Gamma-ray analysis (PIXE-PIGME) for simultaneous multi-element analysis, and Gale (1981) has proposed the use of strontium isotopes for distinction of obsidians from the Mediterranean. The exact age of eruption would certainly be one of the best one-parameter discriminants and this birthdate-approach has been tried for Anatolian obsidians by Durrani *et al.* (1971) with the fission track method. However, there is no positive perspective that age determinations for correlation purposes will ever be easily obtainable and precise enough to be used in a general way for the discrimination of obsidian sources. Fission track dating is, however, of potential help in given complicated cases (e.g. Komarov *et al.*, 1972 ; Wagner *et al.*, 1976).

For the chemical characterization one would ideally require a simultaneous multi-element determination with a method which is easily reproduced, available in most laboratories, low cost and rapid, and non-destructive. The method should analyse, and prefer for correlation, chemical elements which are determined with several standard methods with similar accuracy to give the maximum comparability between different labs.

Contrary to a general tendency to rely preferentially on the more sophisticated modern analytical methods, it was shown in a series of papers (Francaviglia, 1984 ; Stevenson *et al.*, 1971 ; Mosheim, 1984 ; Herold, 1986) that most sources can be discriminated by utilizing the standard major elements as analyzed routinely e.g. with XRF. Gale (1981) proposed the use of mass-spectroscopically determined isotopic ratios of $^{87}\text{Sr}/^{86}\text{Sr}$. However, it is incidently obvious from this same paper that the simple use of Sr and Rb concentrations gives similar conclusions, both elements being determined much easier with several standard methods including X-ray fluorescence (XRF), atomic absorption spectroscopy (AAS) or ICP-spectroscopy.

Major elements can be analyzed with the electron microprobe and in using standardized energy-dispersive equipment, the simultaneous analysis of the major elements is very rapid and inexpensive. Merrick and Brown (1984) have applied microprobe analysis successfully to the characterization of peralkaline obsidians from Kenya. Microprobe analysis is non-destructive in the sense that the analyzed sample-mount remains available for inter-laboratory exchange. The mounted and polished sample splinters can be smaller than 1 mm and thus, this method is often applicable even for precious archaeological materials. Once a source is strictly defined, for instance by a full X-ray fluorescence analysis, routine check of large sample numbers can be done at the microprobe. This is the basic approach of this paper.

A completely non-destructive method is the surface analysis of archaeological samples. If the surface of obsidian objects is clean and unaltered several methods can be applied. For correlation problems in the Western Mediterranean and in the Aegean we have used successfully the relative XRF peak-intensities for the elements Rb, Sr, Zr, Nb and Y (Keller, 1987). These elements can be scanned very rapidly in the 2Θ -range of $20\text{-}28^\circ$ (using a Rh tube and a LiF analyzing crystal). The artifact is placed directly in the sample-holder of the XRF-spectrometer. As an example for this technique a XRF scan for $K\alpha$ and $K\beta$ lines for the elements Rb, Sr, Zr, Nb and Y is given in Fig. 11 for the two new Galata sources Yağlar and Sakaeli. Seifried (1990) has checked the correlation of available artifacts from Central Anatolia with success using this technique.

A similar approach based on relative XRF peak-intensities has been used by Nelson *et al.* (1977), Fornaseri *et al.* (1977) and Herold (1986). Fornaseri *et al.* (1977) plotted the relative intensities for Zr, Rb and Y in a triangular diagram and obtained a good separation for several Anatolian sources.

The drawback of XRF scanning is the fact that no absolute quantitative concentrations are obtained, and it is impossible to use such diagrams with data obtained in other laboratories or under different analytical conditions. It is always necessary to use samples from the considered geological sources for reference and comparison under the same analytical conditions.

OBSIDIAN OCCURRENCES IN ANATOLIAN VOLCANISM

Western Anatolia

No natural obsidian occurrences were known from areas west of the Cappadocian sources, i.e. west of the Aksaray-Nevşehir-Niğde triangle (Renfrew *et al.*, 1968). However F.-J. Eckhard, D. Jung and one of the authors (Keller *et al.*, 1976) have detected two obsidian complexes in the Neogene volcanic area of Kizilçahamam (or of Galata) N and NW of Ankara. These areas have been revisited by Seifried (1990).

The *Yağlar-group* consists of several domes and possible short obsidian flows between the villages of Yağlar, Keşmelik and Berçinçatak. This area is situated immediately north of the highway Ankara-Istanbul, about 20 km northwest of Kizilçahamam (Fig. 1). Although there is some compositional variation between different volcanic units of this area, all samples can be treated as one group for which we use the name of Yağlar. *Sakaeli* is the second of these new Western Anatolian sources. Outcrops of perlite and obsidian are found along the road Orta-Kurşunlu, 3-4 km N of Sakaeli.

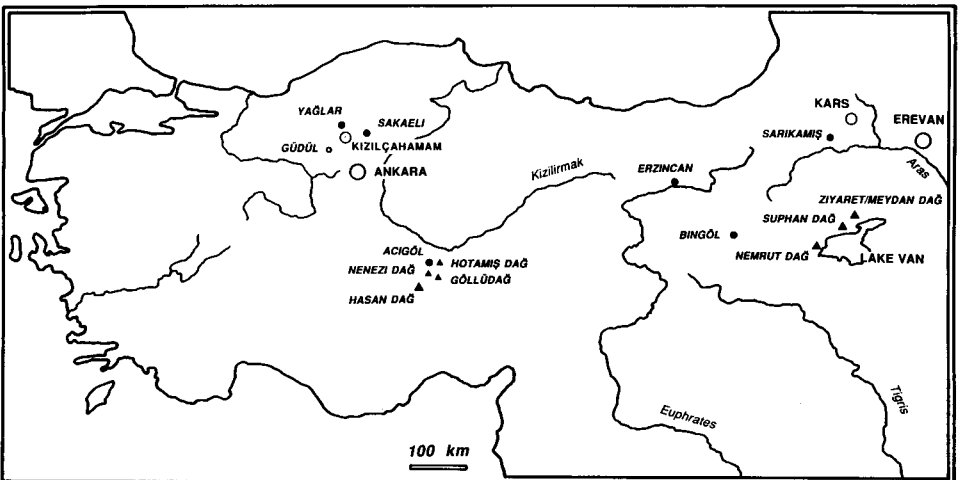


Fig. 1. Locality map for geological obsidian occurrences in the Neogene to Quaternary volcanism of Anatolia. Detailed maps for Central Anatolian and Armenian sources in Figs. 2 and 3.

In the area of both obsidian sources in the volcanic area of Kizilçahamam, or Galata province, worked obsidian has been seen.

A surprising result was obtained for a dozen worked obsidian chips which have been found in the fields near Güdül, about 40 km SW of Kizilçahamam. These were surface findings together with plenty of flakes and blades of chert. It was of obvious interest with which of the two nearby new Galatian sources the obsidian artifacts could be correlated. The analytical results to be reported below showed that these obsidian chips were of homogeneous composition, but different from all other Anatolian sources analyzed in this study. Therefore a third source in this area must be postulated which we will call for the moment « *Galata-X* ».

Central Anatolia

Cappadocia is the classical study area for Anatolian obsidians. Site names are basically Acigöl and Çiftlik (Renfrew *et al.*, 1966, 1968 ; Gale, 1981 ; Fornaseri *et al.*, 1977). Fornaseri *et al.* (1977) have reviewed the previously described sources. But there are several more localities in the area between Aksaray, Nevşehir and Niğde (Fig. 2). Batum (1975) has given a detailed volcanological map of this area. We have distinguished the following occurrences.

Acigöl-crater is a maar-like explosion crater immediately east of Acigöl township, south of the Aksaray-Nevşehir road. Obsidian occurs in pyroclastic levels of the crater rim. Identical obsidian is found on the slopes of the adjacent rhyolitic dome of Göldağ (also called Günneydağ, and not to be confused with Göllüdağ near Çiftlik). Crater formation and extrusion of the Göldağ dome are volcanologically related events, but it is not obvious from the field relationships whether Göldağ itself is a source or carries only strewn blocks from the maar deposit. Samples from both localities are included under *Acigöl-crater*. It must be emphasized that most earlier « Acigöl »-samples come from other sources in the larger area east of the settlement of Acigöl. We retain the name only for the occurrences around Acigöl maar-lake itself. Blackman (1984) refers to a Korudağ sample in the Hebrew University collection, but Batum (1975) describes only rhyolitic vitrophyres from Korudağ south of Acigöl-Göldağ and we have no obsidian sample from this locality.

Kalecitepe is a volcanic dome immediately east of Acigöl village on the north of the Acigöl-Nevşehir road (Sassano, 1964 ; Batum, 1975). Obsidian blocks, including worked obsidian, have been found on this hill. It will be shown that Acigöl-crater and Kalecitepe sources are genetically linked by strong chemical affinities. Both sources (or sub-sources) can however be distinguished by some trace element variations. *Acigöl group* will mean both sources together.

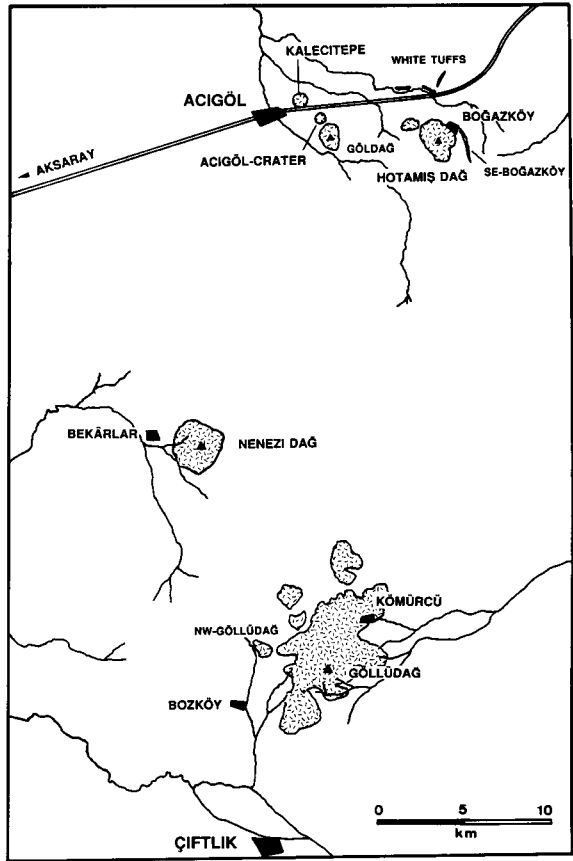


Fig. 2. The Central Anatolian (Cappadocian) source localities between Acigöl and Çiftlik. Topography and outline of obsidian-bearing rhyolite complexes, after Batum (1975).

Hotamis Dağ (also named *Koçatepe*) is the large obsidian dome near Boğazköy. This source is described in some detail in Renfrew *et al.* (1968) and Batum (1975). The obsidian of the dome breaks in a more irregular fashion compared to the other sources which suggests that prehistoric use preferred possibly other qualities.

More obsidian occurrences are found in a circle around *Hotamis Dağ* dome (Pasquaré, 1968 ; Batum, 1975). These occur intercalated with and covered by white pumice tuffs and are older than the dome, and might represent a caldera-like depression around that dome. Two obsidian varieties have been found and named according to their occurrences « SE-Boğazköy » and « White Tuffs North of *Hotamis Dağ* » (Fig. 2).

White Tuffs North of Hotamis Dağ (WTHD). This locality is north of the Acigöl-Nevşehir road immediately opposite the *Hotamis Dağ* dome. It is very likely that most earlier « Acigöl » samples refer to this locality. Renfrew *et al.* (1966) and Fornaseri *et al.* (1977) describe the « Acigöl » source as 8 km east of Acigöl and on the north side of the road. This corresponds to our WTHD source area.

SE-Boğazköy refers to samples collected in a similar mode of occurrence as the WTHD, but about 1 km SSE of Boğazköy. They form again a distinct chemical group.

Renfrew *et al.* (1966) introduced a possible source from NW of Nevşehir from the two localities Kulaklikepez and Karniyarikkepez. Both mountains figure on the map of Pasquaré (1968), but with slightly different localization than given by Renfrew *et al.* (1966, p. 39). Seifried (1990) has revisited these places and has collected small obsidian lumps, together with worked obsidian coming from different Cappadocian sources. Analyses of the unworked pieces allow them to be included in the WTHD group. However, these samples do not fall into the low-Ba field where Renfrew *et al.* (1966, p. 34) place their Kulaklikepez sample. Although a presumed Kulaklikepez/Karniyarikkepez source seems of minor archaeological importance, it must be stated that this group is geologically not yet defined. This question remains open and we have included one analyzed sample from the Kepez-group in our WTHD group.

Nenezi Dağ is a new obsidian source in Central Anatolia (Batum, 1975). It forms an isolated rhyolitic dome rising about 500 meters above the surrounding area, half distance between Acigöl and Çiftlik, east of the village of Bekârlar (Fig. 2). Blackman (1984) also mentions Nenezi Dağ reference specimens from the Hebrew university collection. Although the archaeological importance of this source was long not recognized (but see Yellin and Perlman, 1982), much of the worked obsidian collected as surface findings from the area of Göstük near Aksaray and from Çatal Hüyük proved to come from this source (Table 5).

The Göllüdağ Group comprises obsidian sources which were often named after the nearby township of Çiftlik. Renfrew *et al.* (1966) have demonstrated the wide distribution of this obsidian by prehistoric trade. Göllüdağ is a complex rhyolitic volcano of Quaternary age (Batum, 1975 ; Wagner *et al.*, 1976). Obsidian has been extruded from several centers and at different times. The source with major archaeological interest is on the eastern side of the Göllüdağ near *Kömürcü*. Fornaseri *et al.* (1977) and Seifried (1990) have identified two other distinct sources called here *Bozköy* and *Göllüdağ-NW*. All these sources represent different extrusions from Göllüdağ which can be distinguished geochemically, but form a genetically coherent group with systematic geochemical variation in the form of an evolutionary trend.

Hasan Dağ, the Quaternary stratovolcano near Aksaray, is another obsidian source in Central Anatolia, but no artifacts have been correlated with this source (Renfrew *et al.*, 1966). A detailed volcanological survey of the whole volcano is still lacking but obsidian occurs as blocks in a widespread pyroclastic formation. Samples of Renfrew *et al.* (1966) and of this study come from the area of Karakapu (or Kapu) on the southern flank of the volcano.

Eastern Anatolia

There are still many open problems with obsidian sources in Eastern Anatolia and the adjacent areas. Renfrew *et al.* (1966) have analyzed reference specimens from the British Museum collection with the rather vague geographical designations « Kars », « Bayazit » and « Erevan ».

In addition the sources of Nemrut Dağ and Bingöl are known in the obsidian literature.

The problem of the « Kars » locality is not resolved yet. According to Renfrew *et al.* (1966) the « Kars » sample is similar to obsidians from east of Acigöl (Cappadocia) and therefore grouped together under Renfrews « group 1 e-f ». To date there is still no geological description available for such a Kars source. Reference to obsidian in the Kars area is found in the Explanatory Notes of the geological map of Kars (Erentöz and Ketin, 1974) where obsidian blocks are described from Upper Pleistocene obsidian tuffs of the Kars Plateau. For the present study obsidian samples from the Kars province were available from the area south and west of Sarikamiş. Three samples come from the road between Karakurt, on the Aras river, and Sarikamiş. The obsidian occurrences are near the village of Meşcitli. The volcanic formations of this area have not been surveyed in detail for more obsidian sources. The fourth sample was provided by H. Baş from west of Sarikamiş. It is shown that these four samples are chemically similar, but form two distinguishable groups mainly because of different Ba contents. These groups are termed *Sarikamiş 1* and *Sarikamiş 2*. Apparently these sources are not identical with the « Kars » composition of Renfrew *et al.* (1966) and Gale (1981).

Erzincan is a new obsidian locality from the area SE of this city (Baş, 1979). Only one sample from a place called Keşisdağı was available for analysis. We have no indication yet as to possible archaeological importance of this source.

Two important eastern Anatolian sources are *Bingöl* and *Nemrut Dağ* (Renfrew *et al.*, 1966, 1968 ; Dixon *et al.*, 1968 ; Fornaseri *et al.*, 1977). These sites are distinguished from all other Anatolian and Armenian occurrences by their peralkaline chemical affinity. Peralkalinity is defined by molecular proportion of the total alkalis over aluminium greater than unity, which means that these obsidians are characterized by high alkalis and low aluminium. Peralkaline obsidians, in this case Bingöl and Nemrut, are also characterized by high total Fe and low Al_2O_3 , and in the trace elements by very low Sr and Ba, and the highest Zr contents. Peralkaline obsidians are thus very easily distinguished from the calc-alkaline groups. It is important to note that in the Near East only Bingöl and Nemrut are peralkaline. If peralkaline obsidian artifacts are found in Anatolia and the Near East they

have to be considered a priori either Bingöl or Nemrut. However, if indications for obsidian sources in Jordania or Syria become confirmed (see e.g. Francaviglia, 1990), these are expected to be peralkaline and this would change the simple pattern. In the Western Mediterranean Pantelleria is peralkaline and similarly all African obsidians from Tibesti, Yemen, Ethiopia and Kenya belong to this group (Francaviglia, 1990).

Our emphasis is focused on distinguishing the bulk of the obsidian sources in the Near East which are calc-alkaline. In several of our plots Bingöl and Nemrut are omitted so as not to stretch the scale of the diagrams, e.g. because of the high Fe_2O_3 or Zr contents. Bingöl and Nemrut samples have been separated from each other on the basis of Na and Mn contents by Wright and Gordus (1969). It must be emphasized however, that Nemrut shows a wide evolutionary variation in the compositions of its different obsidian flows, with specific samples being very similar to Bingöl.

Two new Lake Van sources have been introduced in the obsidian correlation literature by Fornaseri *et al.* (1977). The samples stem from the geological work in that area by Innocenti *et al.* (1976, 1980), where detailed descriptions and geological maps are given. The obsidians come from two major volcanic structures north of Lake Van and are named *Suphan Dağ* and *Ziyaret*. The obsidian flow near Ziyaret belongs to the large Meydan volcano north of Erciş (Innocenti *et al.*, 1980). It will be shown that this Meydan/Ziyaret source is a possibility for the « Bayezid/3a » obsidians of Renfrew *et al.* (1968) and Wright and Gordus (1969). This would then mean that the locality designation for the British Museum handspecimen « Bayezid » is not used for the town Bayezid (today Doğubayezid), but for a larger district of this name.

Blackman (1984) refers to obsidian samples in the Hebrew University collection from a *Zarnaki Tepe* source north of Lake Van. This corresponds possibly with the Ziyaret/Meydan Dag source but this correlation is not yet confirmed.

OBSIDIAN IN THE ARMENIAN SSR

A number of obsidian occurrences occur in the Neogene and Quaternary volcanism on the territory of the Armenian Republic (Karapetian, 1969 ; Mkrtchian, 1971). In fission track studies several of these occurrences were dated (Komarov *et al.*, 1972 ; Wagner *et al.*, 1976). Very few samples have entered the archaeological obsidian source discussion. Renfrew *et al.* (1966) refer to one specimen from the British Museum collection with the designation « Erevan ». Also Fornaseri *et al.* (1977) have used Armenian obsidians with the designation « Erevan » as reference material without further specification.

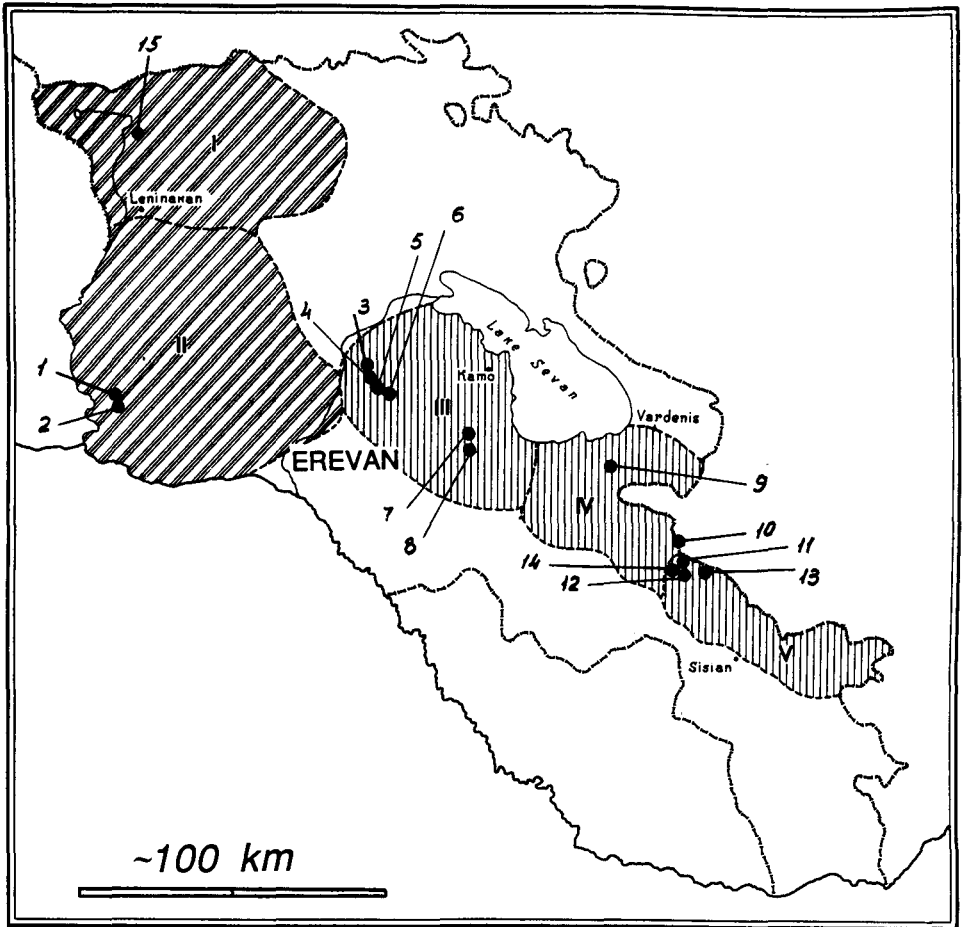


Fig. 3. Schematic map of obsidian occurrences in Armenia. After Karapetian (1969), compilation courtesy of R. Djrbashian, Erevan.

I-V Volcanic Highlands/Massifs :

I - Ketchuk ; II - Aragatz ; III - Geham ; IV - Vardenis-Vaik ; V - Sjunic.

1-15 Rhyolitic centers with obsidian occurrences : (sampled localities)

1. Mets Arteni ; 2. Pokr Arteni ; 3. Alaphars ; 4. Fontan ; 5. Gutansar , 6. Atis (Hatis) ; 7. Spitaksar ; 8. Gechasar ; 9. Choraphor ; 10. Pokr Satanacar ; 11. Mets Satanacar ; 12. Sevkar ; 13. Mitchnek Satanacar ; 14. Bazenk ; 15. Amasia obsidian occurrences.

Three volcanic complexes seem to be the major sources : Gutansar, Atis and Arteni. These are described in Mkrtchian (1971). All known Armenian obsidian occurrences, a total number of 15 are shown on Fig. 3.

Arteni : We have analyzed three different obsidian samples from Arteni complex, which show that Arteni is a heterogeneous source. Several obsidian flows are known from Mets Arteni and Pokr Arteni and perlite-obsidian tuffs

from Brusok (see map in Mkrтчian, 1971), all of which are not yet explored and covered by samples. Artifacts have been collected by us (JK) at Mt. Irind in the east of Arteni which testify to the prehistoric use of Arteni obsidian.

Gutansar is a complex rhyolite volcano on the road from Erevan to the Sevan Lake. This is a large, but compositionally homogeneous source.

From *Atis*, *Spitaksar*, *Sevkar* and *Bazenk* only one sample respectively was available for analysis. Fig. 3 shows their location in respect to a total of 15 different obsidian occurrences in Armenia in 6 geographical groups. The number of occurrences which have not yet been analyzed is pointing out that the potential contribution of these sources has not yet been fully explored.

RESULTS OF CHEMICAL DISCRIMINATION

X-ray fluorescence analysis

Our first goal was to provide the necessary basic geochemical characterization for all known natural sources of obsidian in the Near East. We preferred standard methods of geochemistry for maximum reproducibility.

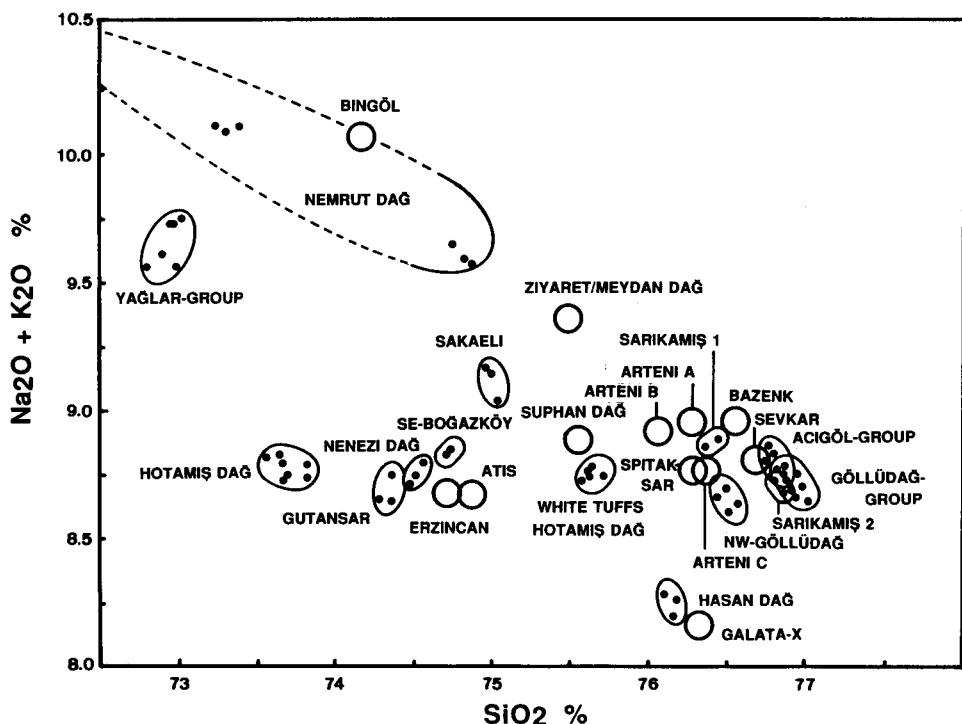


Fig. 4. Total alkalis versus Silica (TAS-) diagram for all analyzed obsidians from geological sources in Anatolia and Armenia. XRF-data from Tables 1-3. Heavier circles indicate sources which are defined so far by one analysis only. Included in this diagram is Galata-X, a postulated source derived from artifacts from Güdül (Table 4, n° 4.1).

Major and minor element concentrations were analyzed by X-ray fluorescence and are given in Tables 1-3. Seifried (1990) has listed additional trace elements for these samples which complement the characterization (e.g. Cu, Zn, Pb, Hf, Ga, La, Th, U). However, for simplicity and clarity we have here restricted our consideration to the most significant and analytically best constrained elements as given in the tables.

The analytical procedure used standard techniques with Li-borate fusions for major elements including a first set of trace elements. The amount of powdered sample for this preparation is 1 gram. In special cases this sample amount can be reduced to 0.5 g. Pressed powder pills were prepared from 4 g of sample for the whole set of trace elements, including those already analyzed together with the majors. Thus, the dominant characterization is achieved in the routine procedure with 1 gram of powdered sample. X-ray fluorescence analysis was carried out with an automatized, sequentially working spectrometer (Philips PW 1450). All oxides are reported on a water-free basis, with the major elements normalized to 100 %. Fe is given as Fe_2O_3 total.

The SiO_2 variation of all obsidians reported is between 72.5 to 77.5 wt%. The geochemical range is shown in the conventional TAS-diagram of Fig. 4. It becomes obvious from the data set that a combination of silica variation with any other major element or combination of elements (e.g. SiO_2 vs alkalis, SiO_2 vs Al_2O_3 , SiO_2 vs $\text{Na}_2\text{O}/\text{K}_2\text{O}$) is often capable of unambiguously discriminating between given sources. In Fig. 5 CaO versus

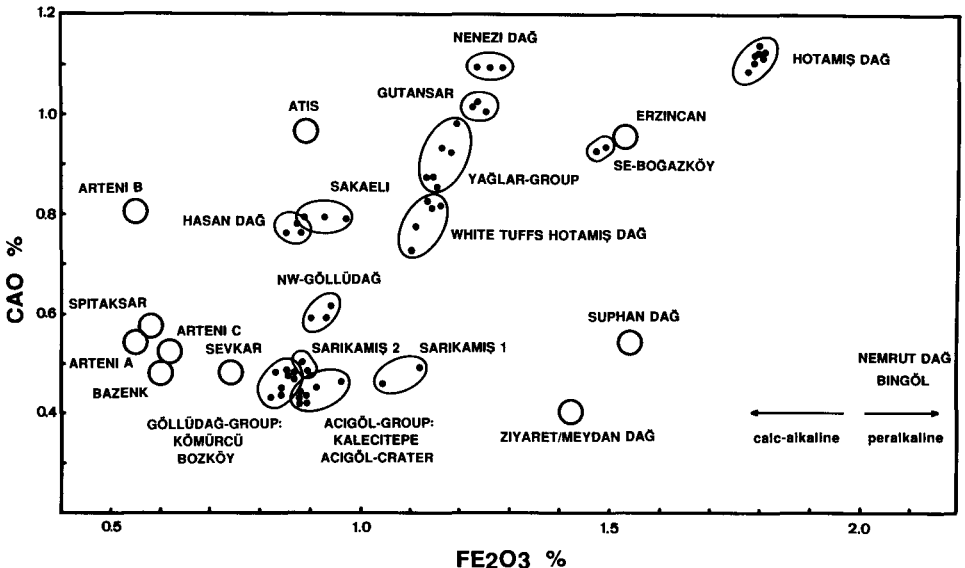


Fig. 5. Calcium concentration (as CaO) versus total iron concentration (as Fe_2O_3) of analyzed obsidian sources. Peralkaline compositions of Bingöl and Nemrut plot outside this diagram due to distinctly higher Fe-contents. Galata-X would plot in the Sakaeli field from which it is clearly discriminated by alkali content and Na/K ratio.

TABLE 1. — X-RAY FLUORESCENCE ANALYSES FOR MAJOR AND TRACE ELEMENTS OF ANATOLIAN CALC-ALKALINE OBSIDIAN SOURCES
(Major elements in wt %, trace elements in ppm)

	Yağlar-Group						Sakaeli			Acigöl-Crater			
	1	1	1	1	1	1	2	2	2	3	3	3	3
SiO ₂	72.97	72.98	72.90	72.99	72.80	73.02	74.96	75.04	75.00	76.85	76.77	76.73	76.76
TiO ₂	0.19	0.19	0.20	0.20	0.20	0.18	0.13	0.13	0.13	0.03	0.03	0.03	0.03
Al ₂ O ₃	14.90	14.88	14.98	14.94	15.03	14.81	13.87	13.90	13.74	12.98	12.98	12.99	12.96
Fe ₂ O ₃	1.14	1.13	1.16	1.18	1.19	1.15	0.88	0.93	0.97	0.88	0.88	0.88	0.89
MnO	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07
MgO	0.13	0.14	0.14	0.13	0.16	0.18	0.11	0.09	0.15	0.00	0.00	0.00	0.00
CaO	0.87	0.87	0.93	0.92	0.98	0.85	0.79	0.79	0.79	0.42	0.43	0.44	0.43
Na ₂ O	5.12	5.09	5.13	5.07	5.19	5.12	4.27	4.12	4.30	4.42	4.46	4.53	4.49
K ₂ O	4.60	4.63	4.47	4.48	4.36	4.62	4.90	4.92	4.85	4.35	4.36	4.33	4.36
P ₂ O ₅	0.02	0.03	0.03	0.03	0.03	0.01	0.03	0.02	0.01	0.00	0.02	0.00	0.01
Rb	153	155	148	148	142	151	164	163	162	267	258	264	263
Sr	122	122	132	132	145	120	108	108	107	3	4	3	4
Ba	443	440	442	434	440	496	482	494	527	2	0	0	1
Y	12	12	12	12	12	11	14	14	13	36	36	37	36
Nb	29	28	28	27	27	28	22	22	21	31	30	30	30
Zr	192	193	195	195	204	194	128	128	127	83	87	85	89

	Acigöl-Crater			Acigöl-Kalecitepe		Hotamış Dağ						
	3	3	3	4	4	5	5	5	5	5	5	5
SiO ₂	76.83	76.79	76.80	76.73	76.76	73.69	73.66	73.56	73.82	73.67	73.65	73.82
TiO ₂	0.03	0.03	0.03	0.04	0.04	0.14	0.13	0.13	0.13	0.14	0.14	0.13
Al ₂ O ₃	12.98	12.98	12.98	13.00	12.92	14.27	14.23	14.30	14.17	14.29	14.16	14.12
Fe ₂ O ₃	0.89	0.89	0.88	0.91	0.96	1.80	1.79	1.80	1.79	1.81	1.81	1.78
MnO	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07
MgO	0.00	0.00	0.07	0.00	0.00	0.12	0.20	0.21	0.14	0.14	0.21	0.19
CaO	0.42	0.42	0.42	0.45	0.46	1.13	1.10	1.11	1.11	1.12	1.11	1.08
Na ₂ O	4.42	4.46	4.41	4.40	4.38	4.59	4.68	4.70	4.56	4.57	4.67	4.60
K ₂ O	4.35	4.36	4.34	4.39	4.41	4.15	4.11	4.11	4.17	4.15	4.15	4.18
P ₂ O ₅	0.01	0.00	0.00	0.01	0.00	0.04	0.03	0.03	0.04	0.04	0.03	0.03
Rb	257	258	269	245	236	154	155	155	154	154	152	153
Sr	4	4	5	5	5	107	110	110	106	108	107	97
Ba	1	1	7	8	5	443	449	449	436	452	491	472
Y	36	36	37	33	32	25	25	25	25	26	24	24
Nb	29	29	31	27	26	17	18	17	17	17	17	16
Zr	86	86	82	88	87	192	196	194	192	197	196	190

TABLE 1 (continued)

	White Tuffs Hotamiş Dağ					SE Boğazköy		Nenezi Dağ		
	6	6	6	6	6	7	7	8	8	8
SiO ₂	75.63	75.64	75.64	75.71	75.58	74.74	74.71	74.51	74.48	74.57
TiO ₂	0.08	0.08	0.08	0.08	0.09	0.10	0.10	0.13	0.13	0.13
Al ₂ O ₃	13.45	13.39	13.42	13.43	13.50	13.74	13.82	13.98	14.02	13.91
Fe ₂ O ₃	1.14	1.16	1.13	1.10	1.11	1.49	1.47	1.24	1.28	1.26
MnO	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07
MgO	0.07	0.07	0.07	0.14	0.15	0.08	0.08	0.21	0.19	0.17
CaO	0.81	0.81	0.82	0.72	0.77	0.93	0.92	1.09	1.09	1.09
Na ₂ O	4.26	4.11	4.29	4.23	4.26	4.44	4.46	4.40	4.34	4.43
K ₂ O	4.48	4.66	4.47	4.51	4.46	4.40	4.36	4.34	4.37	4.36
P ₂ O ₅	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.01
Rb	176	175	177	178	178	166	166	159	160	159
Sr	65	65	66	65	66	79	80	99	98	98
Ba	304	313	316	301	322	394	386	542	542	592
Y	24	24	24	23	23	25	24	20	20	19
Nb	16	17	17	25	17	17	17	16	16	16
Zr	114	114	118	118	109	154	152	137	135	138

	Göllüdağ-Kömürcü				Göllüdağ-Bozköy				Göllüdağ-NW			
	9	9	9	9	10	10	10	10	11	11	11	11
SiO ₂	76.87	76.98	76.87	76.83	77.02	76.90	76.95	76.94	76.44	76.52	76.49	76.57
TiO ₂	0.06	0.07	0.07	0.07	0.05	0.05	0.06	0.05	0.08	0.08	0.07	0.07
Al ₂ O ₃	12.88	12.83	12.83	12.86	12.85	12.87	12.80	12.95	13.08	13.08	13.06	13.08
Fe ₂ O ₃	0.85	0.87	0.86	0.87	0.84	0.84	0.88	0.82	0.94	0.94	0.93	0.90
MnO	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06
MgO	0.08	0.00	0.03	0.09	0.07	0.07	0.00	0.09	0.12	0.09	0.10	0.10
CaO	0.48	0.48	0.48	0.47	0.44	0.45	0.47	0.43	0.61	0.61	0.59	0.59
Na ₂ O	4.15	4.14	4.24	4.18	4.20	4.26	4.20	4.23	4.25	4.16	4.27	4.21
K ₂ O	4.56	4.56	4.54	4.57	4.45	4.48	4.55	4.43	4.41	4.44	4.42	4.42
P ₂ O ₅	0.01	0.01	0.02	0.00	0.01	0.01	0.02	0.00	0.01	0.02	0.01	0.00
Rb	183	180	179	180	194	193	192	191	163	162	163	164
Sr	15	15	15	17	12	13	12	13	44	41	42	42
Ba	148	171	175	170	68	69	75	68	480	455	429	426
Y	22	21	22	21	23	22	23	23	19	20	20	19
Nb	20	19	20	19	21	21	21	21	17	17	16	17
Zr	75	77	77	77	72	73	74	74	80	84	80	83

TABLE 1 (continued)

	Hasan Dağ			Erzincan	Sarikamiş 1		Sarikamiş 2		Suphan	Ziyaret
	12	12	12	13	14	14	15	15	16	17
SiO ₂	76.16	76.18	76.10	74.71	76.36	76.44	76.82	76.94	75.55	75.48
TiO ₂	0.11	0.12	0.11	0.07	0.13	0.13	0.09	0.10	0.08	0.08
Al ₂ O ₃	13.62	13.56	13.60	13.86	12.92	12.73	12.82	12.77	13.28	13.15
Fe ₂ O ₃	0.88	0.87	0.85	1.53	1.04	1.12	0.89	0.87	1.54	1.42
MnO	0.05	0.05	0.06	0.05	0.03	0.03	0.06	0.04	0.04	0.07
MgO	0.19	0.14	0.20	0.13	0.18	0.17	0.14	0.10	0.08	0.04
CaO	0.76	0.78	0.76	0.95	0.46	0.49	0.47	0.50	0.54	0.40
Na ₂ O	4.50	4.46	4.51	4.33	4.13	4.11	4.20	4.13	4.17	5.03
K ₂ O	3.70	3.80	3.77	4.34	4.73	4.78	4.51	4.53	4.71	4.32
P ₂ O ₅	0.03	0.04	0.04	0.03	0.02	0.00	0.00	0.02	0.02	0.00
Rb	114	114	116	124	141	140	128	124	144	193
Sr	96	93	95	112	19	21	24	29	21	21
Ba	827	856	829	419	244	281	497	566	414	44
Y	17	17	17	13	28	28	22	25	n.a.	51
Nb	12	11	11	15	13	13	10	10	n.a.	30
Zr	75	78	75	133	135	136	135	142	107	237

TABLE 2. — CHEMICAL ANALYSES OF OBSIDIAN SAMPLES FROM THE ARMENIAN SSR

	Arteni			Atis	Gutansar			Spitak-sar	Bazenk	Sevkar
	18A	18B	18C	19	20	20	20	21	22	23
SiO ₂	76.27	76.05	76.34	74.86	74.36	74.37	74.29	76.31	76.54	76.68
TiO ₂	0.07	0.07	0.10	0.11	0.18	0.19	0.18	0.07	0.07	0.10
Al ₂ O ₃	13.44	13.41	13.42	14.19	14.19	14.08	14.21	13.51	13.17	13.02
Fe ₂ O ₃	0.55	0.55	0.62	0.89	1.22	1.25	1.23	0.58	0.60	0.74
MnO	0.11	0.14	0.07	0.06	0.08	0.09	0.09	0.08	0.07	0.06
MgO	0.07	0.06	0.15	0.24	0.28	0.24	0.29	0.12	0.12	0.12
CaO	0.54	0.80	0.52	0.96	1.01	1.00	1.02	0.57	0.48	0.48
Na ₂ O	4.56	4.55	4.21	4.50	4.51	4.59	4.53	4.38	4.61	4.19
K ₂ O	4.39	4.36	4.55	4.16	4.13	4.15	4.12	4.38	4.34	4.61
P ₂ O ₅	0.00	0.01	0.02	0.03	0.04	0.04	0.04	0.00	0.00	0.00
Rb	140	140	116	106	137	135	134	200	184	169
Sr	12	33	35	112	126	125	126	13	8	19
Ba	51	133	338	516	430	451	430	16	5	45
Y	33	37	25	18	23	24	24	24	10	12
Nb	38	41	28	20	35	36	35	73	35	32
Zr	62	60	59	91	170	170	169	64	91	99

TABLE 3. — THE PERALKALINE SOURCES NEMRUT DAĞ AND BİNGÖL, LAKE VAN AREA

	Nemrut Dağ									Bingöl
	24	24	24	24	24	24	24	24	24	25
SiO ₂	74.74	74.75	74.83	71.04	74.87	71.36	73.24	73.30	73.39	74.16
TiO ₂	0.14	0.15	0.14	0.38	0.17	0.38	0.22	0.22	0.26	0.21
Al ₂ O ₃	12.65	12.69	12.79	10.33	12.45	9.66	12.31	12.27	11.29	10.83
Fe ₂ O ₃	2.29	2.30	2.18	6.89	2.43	7.22	3.64	3.65	4.51	4.40
MnO	0.06	0.06	0.05	0.18	0.06	0.19	0.08	0.08	0.11	0.08
MgO	0.00	0.04	0.05	0.05	0.08	0.00	0.02	0.02	0.02	0.04
CaO	0.28	0.35	0.36	0.38	0.37	0.32	0.37	0.37	0.31	0.22
Na ₂ O	5.24	5.03	4.99	6.29	5.01	6.48	5.48	5.47	5.61	5.71
K ₂ O	4.60	4.61	4.59	4.44	4.55	4.38	4.62	4.61	4.49	4.35
P ₂ O ₅	0.00	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.00
Rb	201	216	214	230	231	248	250	249	252	229
Sr	1	1	1	3	1	1	1	0	1	2
Ba	15	29	39	1	36	3	43	32	15	2
Y	105	114	115	152	116	164	120	117	140	137
Nb	62	71	67	90	74	101	83	79	88	61
Zr	705	612	559	1287	671	1489	1070	1061	1197	1273

total Fe (expressed as Fe₂O₃) is used to demonstrate the discrimination between all known sources in the Near East. There is little overlap in this diagram, but sources falling close together (close to the analytical uncertainty) can be separated by additional elements.

The diagram of Fig. 5 was selected by the consideration, that both elements Ca and Fe are also satisfactorily analyzed with the energy-dispersive microprobe (EDS).

Discriminant function analysis with all major element of the X-ray analysis can underline the distinctions which are already seen by binary element combinations.

For the trace elements we have tried to follow those earlier authors who used simple element plots. Renfrew *et al.* (1966) based many of their conclusions on Ba-Zr variation and Gale (1981) showed that Rb-Sr variation is very significant. As a matter of fact, these four trace elements can unambiguously discriminate between all 25 Anatolian and Armenian sources, whether in the combination of two binary plots (Fig. 6 and 7) or by a discriminant function analysis including these elements (Fig. 8). It should be mentioned that the group distinction in the Ba versus Zr diagram of

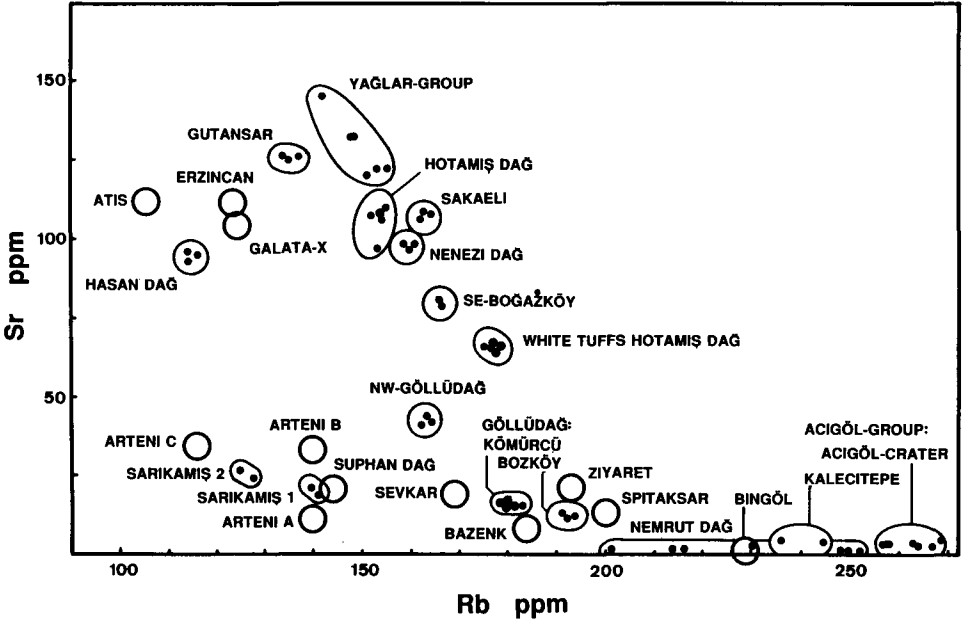


Fig. 6. Strontium concentration versus rubidium concentration for all geological sources (Tables 1-3). Best two-element discrimination. This diagram distinguishes between the chemically very similar Göllüdağ- and Acigöl-subgroups. The Rb-Sr variation of the Hotamis Dağ - Boğazköy - WTHD-trend, within the three Göllüdağ subgroups, and in the Acigölgroupleflects lines of geochemical evolutions within individual comagmatic complexes.

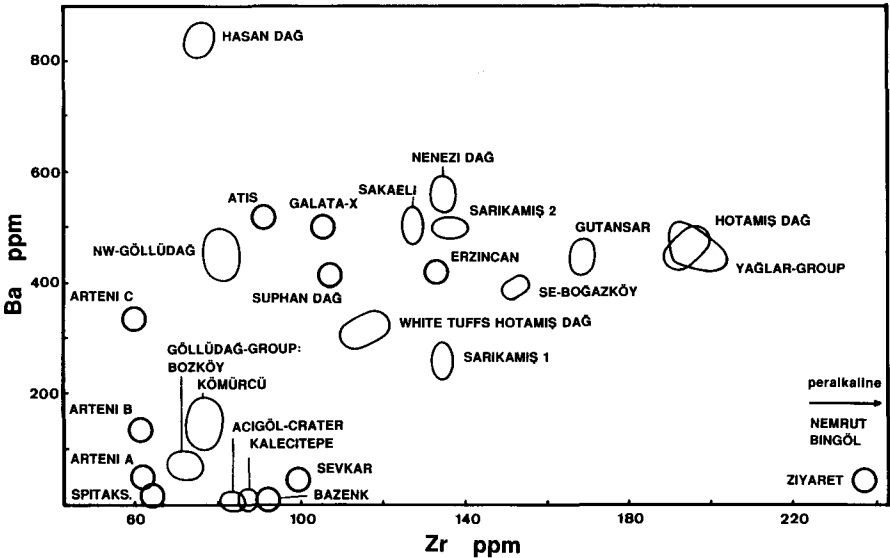


Fig. 7. Barium versus zirconium concentration. Efficient discrimination complementing Ca-Fe and Rb-Sr; e.g. Galata-X is clearly separated from otherwise similar Hasan Dağ; the two Sarikamis compositions are discriminated, and Ziyaret (or Meydan Dağ) plots in a field far from all other sources (due to small sample amount available, Zr value for Ziyaret has a larger error and should be red as 230-300 ppm).

Renfrew *et al.* (1965, 1966) was not used for our data. The reason is that this diagram is based on the semiquantitative OES data and it is not possible to use it with the analytical data obtained for instance by X-ray fluorescence. Moreover, the majority of the analyzed 25 sources would plot in a narrow field straddling the boundary between group 1e-f and group 1g of Renfrew *et al.* (1966). This is also due to the logarithmic scale of the key diagram of Renfrew and coworkers. Figures 4 to 7 all use linear scales.

Microprobe analysis

Based on the observation that major elements can provide a satisfactory discrimination for most correlation cases an attempt was undertaken to compare the X-ray data with microprobe results. Merrick and Brown (1984) have used the microprobe successfully for artifact correlations in Kenya.

The advantage of microprobe analysis is the fact that only minute

TABLE 4. — ANALYSES OF MAJOR AND TRACE ELEMENTS OF THE POSSIBLE SOURCE GALATA-X DERIVED FROM ARTIFACTS AT GÜDÜL, NW OF ANKARA

- 1 Artifact Güdül 1, XRF analysis.
 - 2 dto, reproducibility test, second preparation.
 - 3 Same artifact, microprobe (measurements of three points).
 - 4 Average and range of microprobe analyses of 8 obsidian fragments from Güdül (samples Güdül 1-8).
- bd = below detection

	1	2	3	4	range	
SiO ₂	76.30	76.26	76.72	76.57	76.10	— 76.73
TiO ₂	0.12	0.12	0.18	0.19	0.13	— 0.24
Al ₂ O ₃	13.33	13.33	13.30	13.43	13.33	— 13.55
Fe ₂ O ₃	0.89	0.89	0.90	0.84	0.70	— 0.95
MnO	0.05	0.05	bd	bd	—	—
MgO	0.17	0.17	bd	bd	—	—
CaO	0.80	0.83	0.81	0.85	0.79	— 0.89
Na ₂ O	4.42	4.46	4.22	4.24	4.04	— 4.28
K ₂ O	3.80	3.78	3.84	3.87	3.78	— 3.93
P ₂ O ₅	0.04	0.04	bd	bd	—	—
Rb	123					
Sr	105					
Ba	510					
Zr	106					

sample amounts are required. For the present study fragments of about 1 mm in diameter were used, however the size can be reduced as only spots of $20 \times 20 \mu\text{m}$ are analyzed. Homogeneity is tested by analyzing 3-4 spots on every sample. All reported single analyses (Tables 4-6) are averages of 3-4 spot analyses. The equipment used is a Cambridge scanning electron microscope with an attached Li-drifted silicon detector. Counting time for the simultaneous energy-dispersive analysis of the major elements is 100 sec. The detection limit is 0.1-0.2 wt% depending on the mass of the element. In the frame of obsidian composition this means that TiO_2 , MnO , MgO and P_2O_5 are not analyzable with reliable results. The application of the $\text{CaO-Fe}_2\text{O}_3$ plot of Fig. 5 yielded consistent results which were complemented by SiO_2 , Al_2O_3 , Na_2O and K_2O comparisons. Results of microprobe analyses are compared in Tables 4 to 6 with the X-ray fluorescence data on the same specimen.

TABLE 5. — ANALYSES OF ANATOLIAN OBSIDIAN ARTIFACTS AND COMPARISON WITH THE NENEZI DAĞ SOURCE

- 1 Nenezi Dağ source, average of 3 XRF analyses (compare Table 1).
 - 2 Microprobe analysis for major elements, Nenezi source obsidian.
 - 3 Artifact Göstük-1, XRF.
 - 4 Artifact Göstük-1, microprobe.
 - 5 Artifact Göstük-8, XRF.
 - 6 Artifact Göstük-8, microprobe.
 - 7 Artifact Çatal Hüyük-1, XRF.
 - 8 Artifact Çatal Hüyük-1, microprobe.
- bd = below detection.

	1	2	3	4	5	6	7	8
SiO_2	74.52	75.26	74.71	75.19	74.77	75.33	74.73	74.80
TiO_2	0.13	0.19	0.13	0.21	0.13	0.16	0.13	0.22
Al_2O_3	13.97	13.90	13.74	13.78	13.76	13.86	13.76	13.77
Fe_2O_3	1.26	1.19	1.27	1.21	1.26	1.14	1.28	1.28
MnO	0.07	bd	0.07	bd	0.07	bd	0.07	bd
MgO	0.19	bd	0.19	bd	0.18	bd	0.17	bd
CaO	1.09	1.15	1.10	1.13	1.07	1.08	1.07	1.10
Na_2O	4.39	4.24	4.46	4.41	4.37	4.29	4.34	4.45
K_2O	4.36	4.47	4.41	4.33	4.39	4.24	4.34	4.31
P_2O_5	0.02	bd	0.03	bd	0.03	bd	0.02	bd
Rb	159		163		164		161	
Sr	98		98		99		97	
Ba	559		563		536		559	
Zr	137		133		135		134	

TABLE 6. — CHEMICAL ANALYSES OF OBSIDIAN ARTIFACTS CORRELATED WITH THE GÖLLÜDAĞ-KÖMÜRCÜ SOURCE OF CENTRAL ANATOLIA

- 1 Average Kömürcü composition from Table 1, XRF.
- 2 Kömürcü geological sample, microprobe.
- 3 Artifact Karapınar-7, XRF.
- 4 Artifact Karapınar-7, microprobe.
- 5 Artifact Göstük-8R, microprobe.
- 6 Artifact Çatal Hüyük-8, microprobe.

	1	2	3	4	5	6
SiO ₂	76.89	77.46	77.16	77.25	77.49	77.16
TiO ₂	0.07	bd	0.07	bd	bd	bd
Al ₂ O ₃	12.85	12.73	12.69	12.76	12.56	12.67
Fe ₂ O ₃	0.86	0.71	0.86	0.76	0.80	0.85
MnO	0.06	bd	0.06	bd	bd	bd
MgO	0.06	bd	0.07	bd	bd	bd
CaO	0.48	0.55	0.46	0.52	0.48	0.51
Na ₂ O	4.15	3.90	4.03	3.96	3.98	4.00
K ₂ O	4.59	4.60	4.55	4.54	4.50	4.54
P ₂ O ₅	0.00	bd	0.01	bd	bd	bd
Rb	180		184			
Sr	16		21			
Ba	166		181			
Zr	75		70			

DISCRIMINANT FUNCTION ANALYSIS

Our data set consisting of 77 XRF analyses of major and minor elements (Tables 1-3), and the geographic groups by defined volcanic occurrences provide the frame for the application of discriminant function analysis. This was carried out with the statistics program SPSS-X (Schubö and Uehlinger, 1984). Discriminant function analysis was able to separate all groups with a 100 % correlation. Several element combinations were tested : (1) all major and trace elements, (2) only these major elements which can be analyzed with sufficient accuracy by microprobe analysis, and (3) the four trace elements Rb, Sr, Ba, Zr, which have been used in this paper and also by earlier authors (Renfrew *et al.*, 1965 ; Dixon *et al.*, 1968 ; Gale, 1981) as best discriminating single elements.

Examples with major elements and the trace elements Rb, Sr, Ba, Zr, and with only 5 major elements are reported. Figure 8 gives the result of discriminant analysis with 9 major and trace elements. The program

suppressed consideration of SiO_2 for the definition of the functions because of its restricted variation.

The functions obtained are as follows :

$$F 1 = \text{Al}_2\text{O}_3 \times 2.5798 + \text{Fe}_2\text{O}_3 \times 3.3050 - \text{CaO} \times 27.2182 - \text{Na}_2\text{O} \times 0.3202 + \text{K}_2\text{O} \times 11.5648 + \text{Rb} \times 0.0361 + \text{Sr} \times 0.4043 + \text{Ba} \times 0.0361 - \text{Zr} \times 0.00847 - 106.676.$$

$$F 2 = \text{Al}_2\text{O}_3 \times (-1.7577) - \text{Fe}_2\text{O}_3 \times 1.5929 - \text{CaO} \times 7.7609 + \text{Na}_2\text{O} \times 13.8431 + \text{K}_2\text{O} \times 23.5965 + \text{Rb} \times 0.1740 + \text{Sr} \times 0.3158 - \text{Ba} \times 0.03397 - \text{Zr} \times 0.02152 - 169.9069.$$

$$F 3 = \text{Al}_2\text{O}_3 \times 0.9403 + \text{Fe}_2\text{O}_3 \times 0.7443 - \text{CaO} \times 43.8825 - \text{Na}_2\text{O} \times 3.4704 + \text{K}_2\text{O} \times 10.4176 - \text{Rb} \times 0.0801 + \text{Sr} \times 1.652 + \text{Ba} \times 0.00184 + \text{Zr} \times 0.0104 - 11.8295.$$

The combination of several functions can effectively separate all natural obsidian sources in the Near East (Fig. 8 a, b). However, it must be emphasized that an appreciable number of sources is still defined by only one sample which influences the results of the statistical treatment.

The discriminant analysis using only major elements obtained the following functions F-1, F-2, F-3.

$$F 1 = \text{Al}_2\text{O}_3 \times 1.1888 - \text{Fe}_2\text{O}_3 \times 0.7334 + \text{CaO} \times 38.7809 + \text{Na}_2\text{O} \times 5.4220 + \text{K}_2\text{O} \times 3.8697 - 82.5969.$$

$$F 2 = \text{Al}_2\text{O}_3 \times 4.9045 - \text{Fe}_2\text{O}_3 \times 0.1433 - \text{CaO} \times 10.477 + \text{Na}_2\text{O} \times 12.8767 + \text{K}_2\text{O} \times 11.1594 - 166.4059.$$

$$F 3 = \text{Al}_2\text{O}_3 \times 2.7531 + \text{Fe}_2\text{O}_3 \times 0.0948 - \text{CaO} \times 12.9094 + \text{Na}_2\text{O} \times 2.8571 - \text{K}_2\text{O} \times 18.7776 + 41.6254.$$

All elements considered in these functions can satisfactorily be analyzed with the energy-dispersive microprobe. This has been done for geological samples from the individual sources and for a number of artifacts and worked obsidian available from different areas of our volcanic field studies.

The group definitions are shown in Fig. 9 a, b for F-1, F-2 and F-3. The artifact analyses of Tables 4-6 are applied in the diagram of Fig. 10 a, b.

It is obvious, especially from Fig. 10 b, that discriminant function analysis is highly dependent on the comparability of data. The higher scatter in the microprobe determination of alkalis, especially Na_2O , results in much wider fields, whereas XRF-data of artifacts center generally in the respective source fields. It is in the line of this paper to point out, that in such cases the approach of Fig. 10 b — as other methods to transfer the rather lucid direct chemical data into more cryptic formulas — has no great advantage over the simplistic use of e.g. the Ca/Fe relationship of Fig. 5, if needed combined with consideration of additional chemical elements.

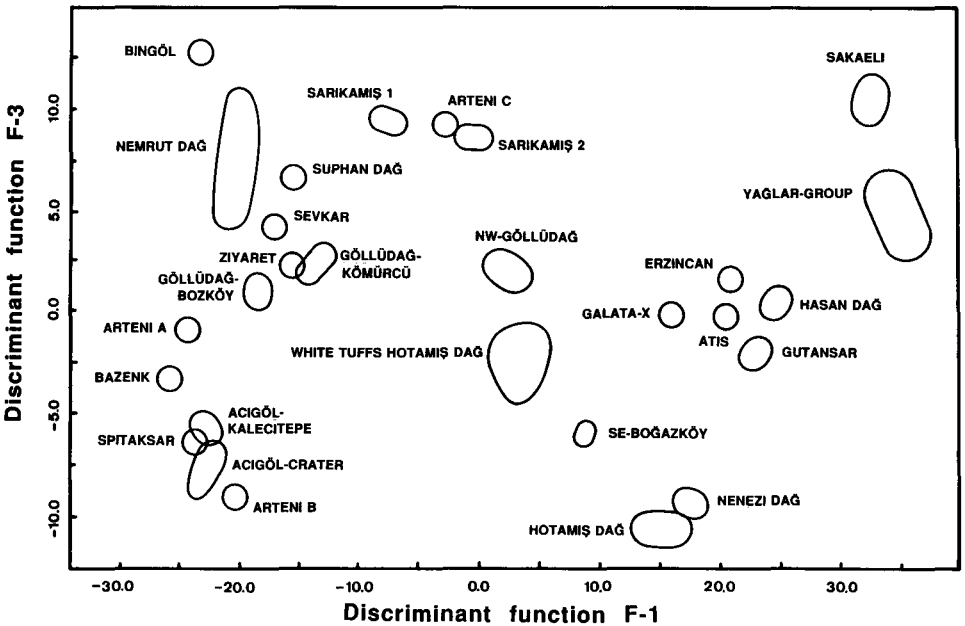
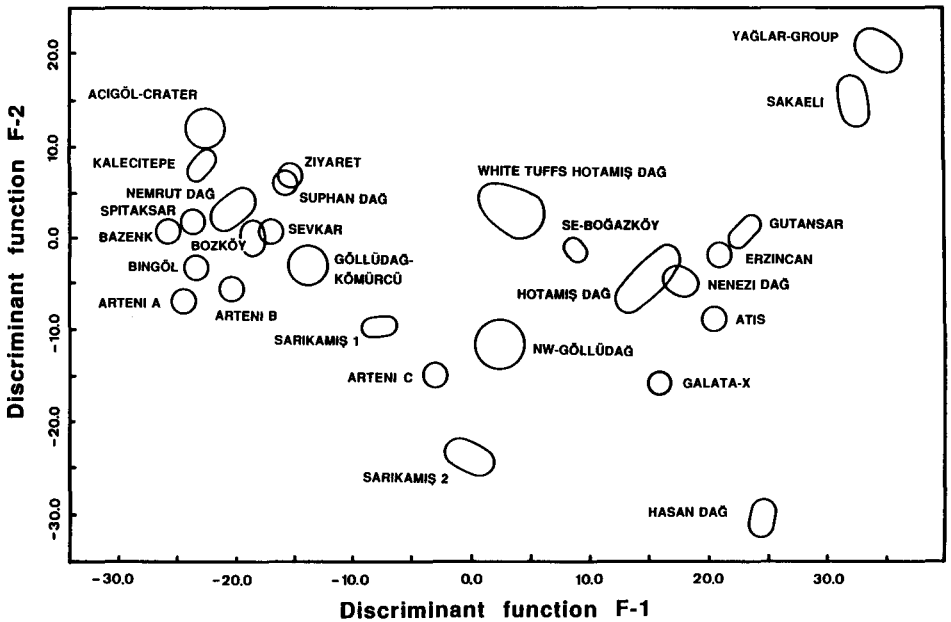


Fig. 8. Discriminant function diagram F1 versus F2 (a) and F1 versus F3 (b) for all geological source samples. This discriminant function analysis considers 9 elements (the major elements Al_2O_3 , Fe_2O_3 , CaO , Na_2O , K_2O and the trace elements Rb, Sr, Ba, Zr). For definition of functions see text.

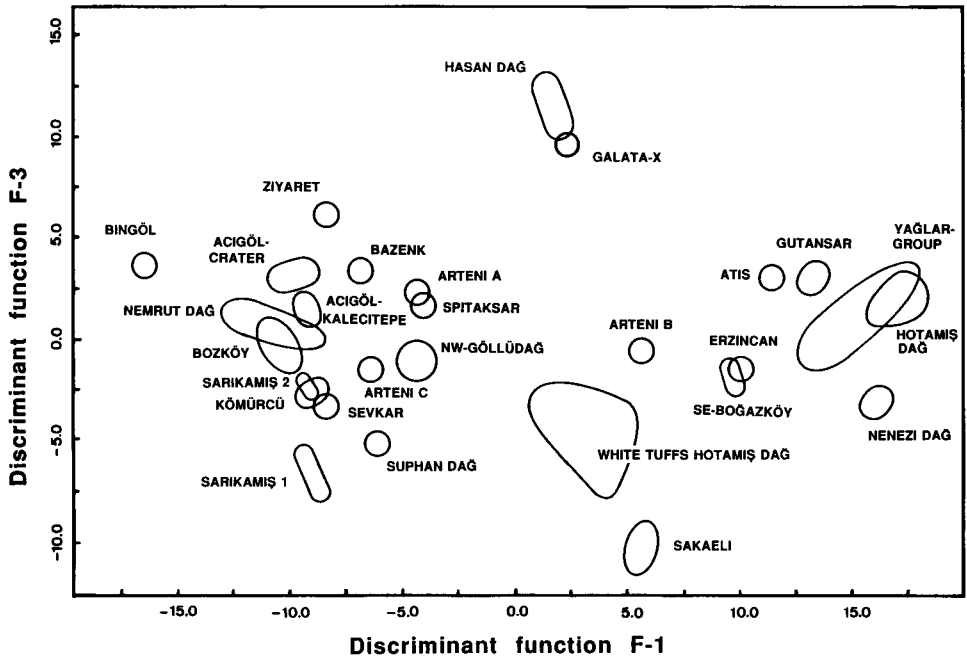
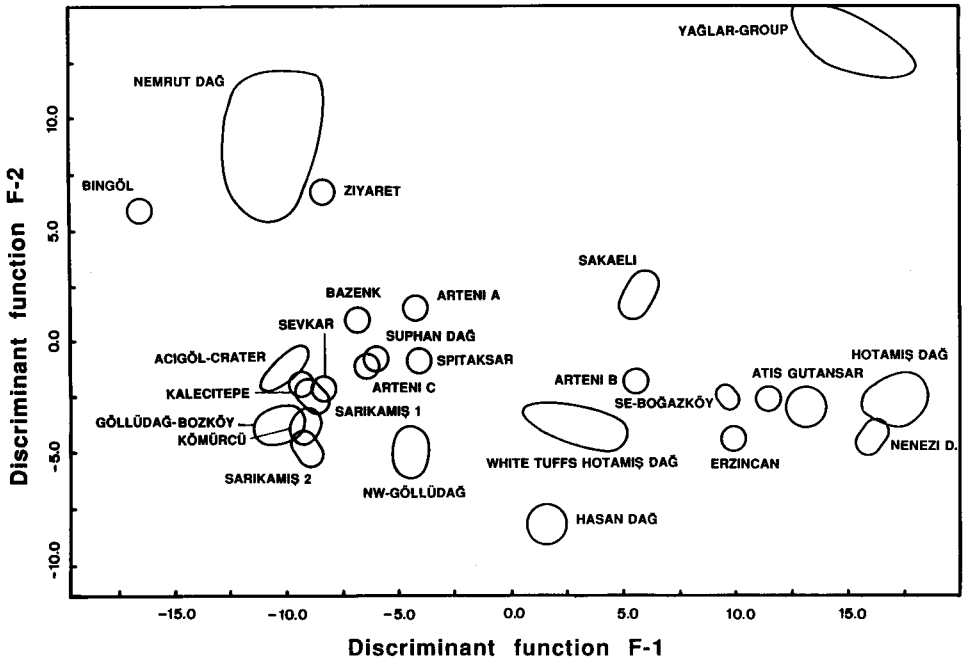


Fig. 9. Discriminant function analysis using only the major elements Al_2O_3 , Fe_2O_3 , CaO , Na_2O , K_2O . (a) F1 versus F2 diagram and (b) F1 versus F3 diagram.

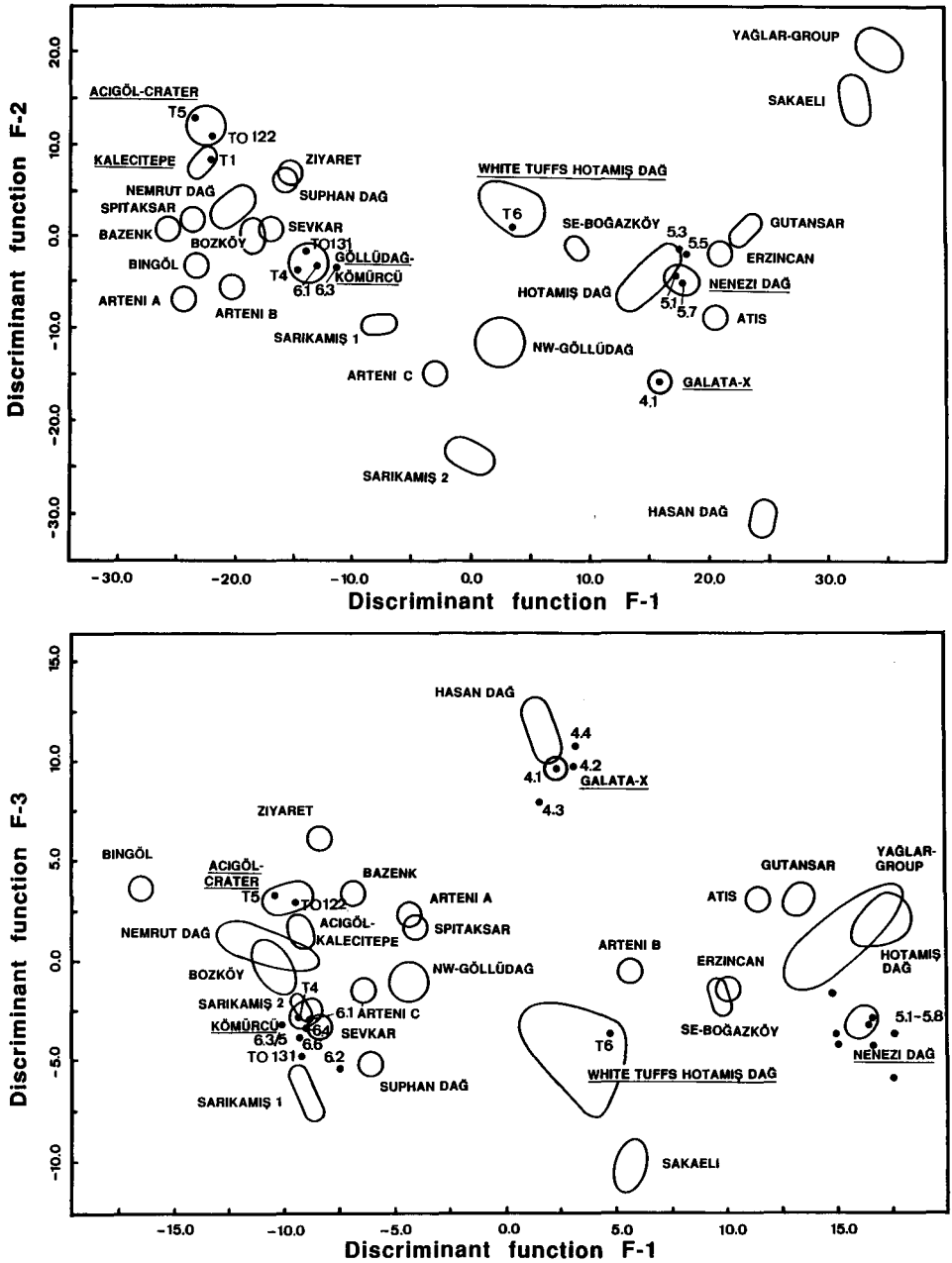


Fig. 10. Application of discrimination diagrams for a correlation test of artifact analyses : (a) F1 vs F2 diagram for 9 elements as in Fig. 8a, and

(b) F1 vs F3 diagram for 5 major elements as in Fig. 9b. Artifact from Tables 4-6, additional samples from Seifried (1990) :

T1 : artifact from Kalecitepe, Kalecitepe source ; T4 : artifact from Acigöl-Göldağ, Kömürçü source ; T5 : artifact from Acigöl-Göldağ, Acigöl-crater source ; T6 : artifact from Kalecitepe, HDWT source ; TO122 : artifact from Kulaklikepez, Acigöl-crater source ; TO133 : artifact from Karakapu/Hasan Dağ, Kömürçü source.

RESULTS FOR DISCRIMINATION AND CORRELATION

This study was primarily designed to provide the basic geochemical data for comparing the natural obsidian occurrences. However, some surface findings of worked obsidian and flakes, or just obsidian fragments in areas of no natural source were available for testing their origin, and hence our correlation scheme.

From Figs. 4 to 7 it can be seen that some sources are characterized even by one single chemical element. Pairs of major element can satisfactorily discriminate between individual sources. Where overlaps exist more parameters may be used. The full chemical information can be drawn from Tables 1-3. Discriminant function analysis can help to utilize the full information of chemical multi-element analysis.

The approach for artifact correlation was threefold: (1) microprobe analyses were carried out to apply the Ca-Fe plot of Fig. 5, or the F-1 versus F-2 diagram of Fig. 9; (2) non-destructive XRF scanning for relative peak intensities of Rb, Sr, Zr, Nb and Y were used to test the obtained correlations (Fig. 11); and (3) selected larger pieces of artifacts or worked obsidian specimens, already analyzed with the microprobe, were partially powdered and 1 g was analyzed by X-ray fluorescence for major elements and simultaneously for Rb, Sr, Zr, and Ba. This further checked the obtained correlation and provided a test for the comparability of the two methods, as given in Tables 4-6.

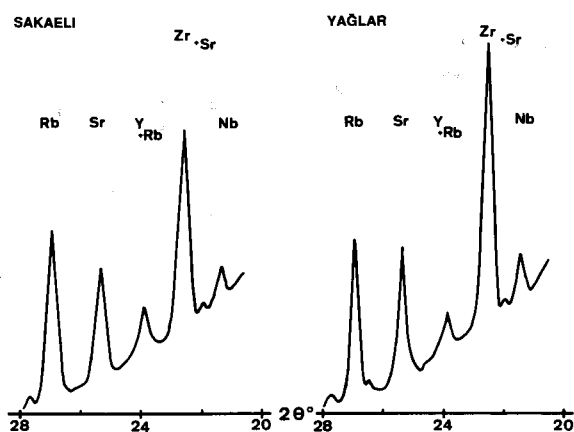


Fig. 11. Example for non-destructive, semi-quantitative XRF-spectrometry scanning. Relative peak intensities are determined for a set of trace elements whose discriminating efficiency revealed from quantitative XRF-analysis. The sources Sakaeli and Yağlar are characterized by the following intensity ratios, normalized to Rb = 100: Rb : Sr : Y : Zr : Nb = 100 : 65 : 27 : 116 : 18 for Sakaeli, 100 : 86 : 24 : 180 : 30 for Yağlar.

In this way samples of prehistoric use or transport have been checked from the following localities: Gūdül NW of Ankara, Gōstük east of Aksaray, Çatal Hüyük near Konya, Kalecitepe and Gōldağ near Acigöl, Karapınar, Karakapu, and Karniyarikkepez. In addition, worked obsidian of local origin was found close to many of the source localities e.g. Kōmürçü,

Kalecitepe, Acigöl-crater, Yağlar, Sakaeli, White Tuffs north of Hotamiş Dağ and also from Arteni in Armenia.

The artifacts from Gūdül (Table 4) have chemical similarities for most elements with Sakaeli and Hasan Dağ. Yet there are enough discriminating features between the Gūdül composition and all other known sources to postulate an unknown source « Galata-X ».

Seven obsidian blades from scattered surface findings over the Quaternary volcanic area of Karapınar (Keller, 1974) are all from Göllüdağ-Kömürcü. This is shown by their Ca-Fe relationship and by the Rb-Sr-Ba-Zr contents (Table 6). The Kömürcü composition, defined by low Ca and Fe, low Ba and Zr, low Sr and high Rb, is quite close to the Acigöl group (Kalecitepe and Acigöl maar). However, the discrimination is clearcut with a precise Ba or Rb analysis, with Na/K ratio, with a single selected oxide like TiO₂, or with discriminant function analysis. Obsidian from the Kömürcü source has also been analyzed from Çatal Hüyük, from Göldağ/Acigöl, from the area of Karakapu south of Hasan Dağ and from Göstük/Aksaray.

From Çatal Hüyük 10 objects were tested. Six proved to be Nenezi Dağ and 4 from Göllüdağ-Kömürcü. In spite of the small statistical basis and the completely random collection this ratio indicates that Nenezi Dağ, which is more than 200 km from Çatal Hüyük, must have been an important source in the Neolithic. It is not completely clear in which correlation Nenezi Dağ artifacts were previously hidden. If plotted in the *logarithmic* Barium-Zirconium diagram of Renfrew *et al.* (1966) Nenezi Dağ is close to the White Tuffs north of Hotamiş Dağ (WTHD-group). However, the chemical data provide a number of highly distinctive parameters (e.g. Table 1, Fig. 5).

From Göstük east of Aksaray 8 artifacts were tested (Tables 5 and 6). Göstük is about 20 km from the new Nenezi Dağ source and 5 of 8 samples came from this source. The remainders are from Göllüdağ-Kömürcü.

Several artifacts from Kalecitepe/Acigöl and from Karniyarikkepez/Nevşehir belong to the WTHD-group. This group comprises most of the earlier « Acigöl-source » samples.

Artifacts from Mt. Irind in Armenia, a volcanic cone roughly 10 km to the East of Arteni are correlated with the big flow of Mets Arteni (Mkrtchian, 1971). Analysis of all collected artifacts is not completed and reference is only made to demonstrate the prehistoric use of this Armenian source.

Renfrew *et al.* (1966, 1968) were able to define several unknown sources in Eastern Anatolia on the basis of group characteristics of archeological samples from a large geographic area in the Near East. Of major importance are the groups named 3a, 3c and 1g. Without having analyzed the reference material of this group distinction it is not possible to propose definitive

sources. It is difficult to compare the OES data used for the group definition with our XRF data. However, mainly on the basis of a high Zr content we propose Ziyaret/Meydan Volcano as the source for the 3a-group. The 3c-group exhibits striking similarities with Basenk, Spitaksar and Sevkar and an Armenian source seems a reasonable assumption. However as stated before, not all Armenian sources have been explored. The same restriction applies to a tentative correlation of the 1g-group of artifacts with the large Gutansar source between Erevan and Lake Sevan. Such a correlation seems possible by comparing the trace element data for Gutansar in Table 2 with the OES data of Renfrew *et al.* (1966). Manganese contents, however, reported for 1g material by Wright and Gordus (1969) would not support the Gutansar correlation. The next steps in obsidian source characterization in the Near East must be the full chemical analysis of the reference materials for these groups, and the continuation of exploration of all Armenian sources. This must also include known Georgian obsidian occurrences (Komarov *et al.*, 1972) and possible Aserbaidjan sources.

CONCLUSIONS

Several new obsidian occurrences in the area of Anatolia and Armenia are described bringing the analyzed sources for the possible prehistoric use of obsidian in the Near East to about 25. Our survey has also shown that one cannot expect that all natural occurrences are known. It is in this sense a review of the state-of-the-art.

Chemical characterization of all sources has been achieved by chemical analysis of major and trace elements. Our preferred approach was to apply the most generally adopted geochemical standard methods for analysis, and to use elements for discrimination which can be accurately determined by several methods and in most geochemical laboratories. Quantitative X-ray fluorescence analysis is the basis of our study. Discriminant function analysis of the natural groups according to volcanic sources yields a perfect distinction between the natural sources. Also selected element pairs such as CaO vs $\text{Fe}_2\text{O}_3\text{T}$, Rb vs Sr, Ba vs Zr have a satisfactory discriminating capacity. Artifacts at our disposal could be unambiguously correlated to known sources. An unknown source, Galata-X, is postulated according to the homogeneous composition of artifacts from Gdl northwest of Ankara.

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