



An international research project on Armenian archaeological sites: fission-track dating of obsidians

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Abstract

In the Mediterranean and adjacent regions, the Caucasus is one of the less studied areas in relation to provenance studies of prehistoric obsidian artefacts. In the frame of an international INTAS research project, an extensive surveying and sampling campaign was carried out in the numerous obsidian bearing volcanic complexes of Armenia. 33 obsidian samples were analysed using the fission-track dating method in order to characterise the potential sources of the numerous artefacts found in prehistoric sites. Ages cluster into five groups—Upper Neopleistocene Q_{III}, Middle Neopleistocene Q_{II}, Lower Neopleistocene Q_I, Lower Eopleistocene Q_{EI} and Lower Pliocene N₃¹ groups. This research represents a significant contribution to a better knowledge of chronology of Armenian volcanism for which only few data were available. The resulting data-set appears to be a solid base for future provenance studies. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Fission-track (FT) dating of glass plays an important part in geochronology. Glass is present in many volcanic rocks, and it is the only datable phase of many tephra. The FT method proved to be a significant tool for tephrochronological (Westgate, 1989) as well as for geochronological studies in volcanic areas, also in the case of just few thousand years old volcanics (Bigazzi and Bonadonna, 1973; Bigazzi et al., 1993). Since the early 1970s the FT method was applied in provenance studies of prehistoric obsidian artefacts in the Mediterranean and adjacent regions (Durrani et al., 1971; Bigazzi and Bonadonna, 1973). During the last decade, application of this technique in Anatolia gave a solid contribution to a better knowledge of the potential sources of

obsidian tools and of circulation of this natural glass in that region during prehistoric times (Bigazzi et al., 1993, 1994).

The adjacent Armenian volcanic upland mainly belongs to the classic type of young Late Pliocene-Quaternary volcanism. It is this volcanism that was responsible for the recent mountainous volcanic relief. These mountains became the natural environment for Armenians. In this connection, any new data about the volcanic activity in the Late Pleistocene–Holocene, archaeological and early historical times are of interest. Numerous volcanoes erupted obsidians during the Pliocene and Pleistocene, and excavations of prehistoric sites yielded a lot of obsidian artefacts. Knowledge of the characteristics of these glasses and of their circulation during prehistoric times is quite poor.

Recently, an INTAS (the International Association for the Promotion of Co-operation with Scientists from the New Independent States of the former Soviet Union) project entitled “Geographic Information System for Armenian Archaeological Sites from the Palaeolithic to the 4th Century AD”,

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was devoted to fill up numerous blanks of the data-set concerning the characteristics and the prehistoric use of Armenian obsidians. Numerous obsidians were dated using the FT method, in order to (1) improve the knowledge on the chronology of the volcanism of the region and (2) discriminate these glasses as potential sources of raw materials for tool-making.

2. Obsidian bearing volcanics in Armenia, previous age determinations

In Armenia intense volcanic activity determined by complex late-collision geodynamic setting occurred in three phases, in the Middle Miocene, Upper Miocene–Lower Pliocene and Pleistocene (Karapetyan, 1972; Karapetyan et al., 2001). Due to the character and scale of the eruptions and the good preservation of volcanic edifices, the rhyolites of the third phase are of primary interest. It is this late volcanism that led to the formation of a series of dome-shaped volcanoes, with a complex structure in which obsidians play a significant role (Karapetyan, 1969). The following sequence of eruptions has been established: (1) explosive pyroclastic deposits; (2) rhyolitic obsidian lava flows of diverse inner structure; and (3) obsidian domes, extrusions, and at the final stage, spines of rhyolites and rhyodacites (Karapetyan, 1968).

Six main volcanic regions, distributed in a wide area extending over more than 300 km from the Turkish border (NW) to the Azerbaydzhanian border (SE), have been recognised (Fig. 1) (Keller et al., 1996). We shortly describe here these volcanics and report on the available geochronological data. A publication on the geological settings of the Armenian obsidian bearing volcanics is in preparation. A review on these volcanics is given in the recent book on the geology, characteristics and prehistoric use of obsidians in the Near East edited by Cauvin et al. (1998). Exact location of samples analysed in this study is available from authors (Fig. 2).

2.1. Kechut volcanic region

In the northwestern corner of Armenia, occurrences of obsidian bearing volcanics have been mentioned from Amasia. They consist of volcanoclastic deposits produced by multiple eruptions, covering an area of some tens of square kilometers. Eruption centres are not well defined. Oddone et al. (2000) determined FT ages between 1.04 ± 0.10 and 1.13 ± 0.11 Ma on obsidians from this region. No samples were collected for this study.

2.2. Aragats volcanic region

In the southwestern part of the Aragats volcanic massif, a large dome complex consisting of three major eruption centres—Mets (big) Arteni, Pokr (small) Arteni and

Satani Daar—produced large amounts of obsidian and perlite in several eruptive episodes. The main flow is the perlitic Aragats flow which covers more than 10 km^2 . Several FT ages are available for these obsidians (1.25 Ma, Komarov et al., 1972, Mets Arteni and 1.36 Ma, Wagner et al., 1976, 1.27 ± 0.09 Ma and 1.20 ± 0.10 Ma, Oddone et al., 2000, Pokr Arteni). Karapetyan (1968) reports K–Ar ages on obsidian ranging from 1 to 1.36 Ma for the Arteni complex rhyolites.

Northeast of the Aragats massif, obsidians occur in the Damlik volcanic complex. FT ages are available only for one of the occurrences (4.30 ± 0.23 Ma and 4.16 ± 0.22 Ma, Oddone et al., 2000). Four samples were collected from these sources.

2.3. Gegham volcanic region

Obsidian occurrences located in the Gegham highland form two groups. At the northwestern foot of the highland, the obsidian bearing volcanics produced by the Alapars, Fontan and Gutansar centres partially overlap and form a complicated structure of rhyolite-perlite lavas, pumice and breccias extending over approximately 35 km^2 , classified as Hrazdan structure. Around 6 km southeast of Mt. Gutansar rises the Atis volcano (2529 m), which during multiple phases of acid volcanism produced large amounts of obsidians, mainly as basal parts or intermittent ledges in rhyolite-perlite flows. Two identical FT ages of 0.31 Ma have been determined by Komarov et al. (1972) and Wagner et al. (1976). Oddone et al. (2000) report FT ages between 0.21 ± 0.02 and 0.32 ± 0.03 Ma for four occurrences of the Gutansar and Alapars volcanoes. For Mt. Atis, Komarov et al. (1972) and Karapetyan (1972) report a K–Ar age on obsidian of 0.65 Ma and a FT age of 0.33 Ma.

The southern part of the Gegham highland is dominated by two large domes, Spitaksar (3560 m) and Geghasar (3446 m). Obsidians occur as basal facies of the dome-related flows and near the top of the Spitaksar dome. Komarov et al. (1972) report a fission-track age of 0.51 Ma for the Spitaksar obsidian. For the Geghasar volcano, no previous data are available. Sixteen samples were collected from the Gegham volcanic region.

2.4. Vardenis volcanic region

In this volcanic area located south of the lake Sevan obsidians occur in the main rhyolitic flow of the Choraphor volcano (2906 m) as lenses and in breccias. A K–Ar age of 1.75 Ma is available for these obsidians (Komarov et al., 1972). One sample was collected from this volcanic region.

2.5. Sunik volcanic region

In the Sunik highlands of south-east Armenia, four volcanoes, Pokr and Mets Satanakar, Sevkar and Basenk which reach an elevation of 3228 m, align along the



Fig. 1. Schematic map showing the distribution of rhyolite-obsidian dome-shaped volcanoes in Armenia. Volcanic regions: Kechut (I), Aragats (II), Gegham (III), Vardenis (IV), Sunik, (V) and Kapan (VI).

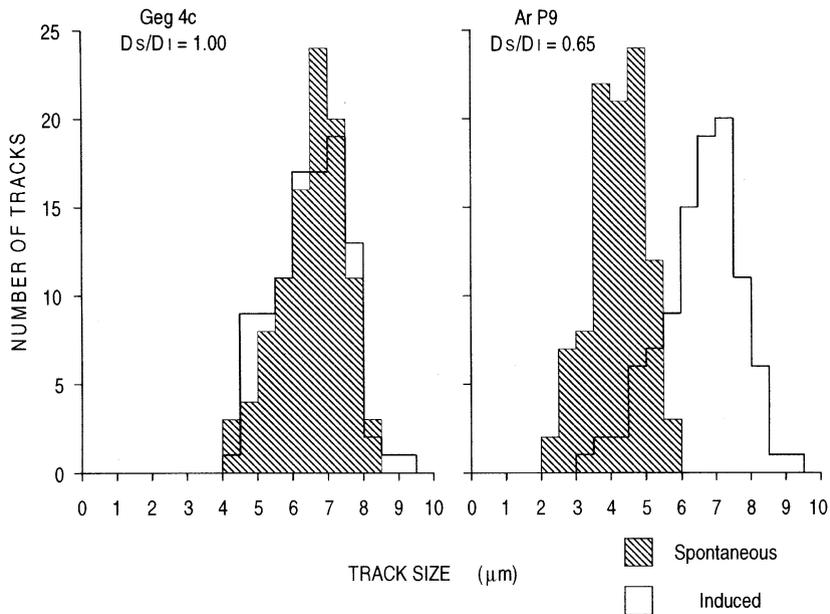


Fig. 2. Armenian obsidians show variable amount of track annealing from negligible (left) to rather significant (right).

Azerbaijani border. Obsidians occur within rhyolitic and perlitic flows in the flanks of the last three volcanoes and in dykes of the Sevkar Footplains. Karapetyan (1972) and Komarov et al. (1972) have determined FT ages of 0.30, 0.51 and 0.64 Ma for the Bazenk, Sevkar Footplains and Mets Satanakar obsidians, respectively, and a K–Ar age of 0.90 Ma for the Sevkar Footplains obsidian. Six samples were collected from this volcanic region.

No obsidian occurrences were found in the Kapan volcanic region.

3. Fission-track analysis

The results of the application of fission-track dating to the 33 samples that were subject of this study are shown in Table 1. The experimental techniques used in this work are described in footnote to Table 1. The plateau technique (Storzer and Poupeau, 1973; Westgate, 1989) for correction of thermally lowered ages was routinely applied (to save space, analytical details regarding plateau age determinations have been omitted in Table 1).

Some samples showed a significant number of bubbles of various shapes or damaged areas in which tracks could not be identified. In such samples the areal track density determination is difficult, because the real surface useful for counting of each field of view has to be estimated, and the counting procedure becomes much more time-consuming. In this work the alternative method called ‘point-counting technique’, proposed for samples made up of a population of glass shards from tephra beds (Westgate, 1989), was applied for the first time to obsidian samples. When the point-counting technique is used, a field of view is coded as 1 only when a reference point (for example, the centre of a grid) falls on an area of glass where a track, if present, would be etched and identified. Otherwise (reference point on epoxy resin or on an area where a track could not be identified) the field of view is coded as 0. The final result is a virtual track density expressed as number of tracks/number of points on glass.

4. Discussion and conclusions

The FT ages group into rather restricted clusters. These are: (1) obsidians from the watershed of the southern part of the Gegham volcanic area, Upper-Neopleistocene age—Q_{III} (Spitaksar, Geghasar), (2) obsidians of Atis, Goutansar, Fontan and Alapars volcanoes, Middle Neopleistocene age—Q_{II}, (3) obsidians of the Sunik volcanic area, Lower Neopleistocene—Q_I (Mets Satanakar, Mets Sevkar, Bazenk), (4) obsidians of the Aragats (Mets Arteni, Pokr Arteni, Satani Daar) and Vardenis (Choraphor) volcanic areas, Lower Eopleistocene—Q_{EI} and (5) obsidians of the Damlik Complex, Lower Pliocene—N₃ (the geological time table recommended by the International Stratigraphic

Commission of the New Independent States is adopted here). These results, in principle, correspond with geological expectations, and provide better constraints to the chronology of Armenian obsidians. To give an example, the obsidians from the Geghasar volcano were considered the youngest of Armenia, however, no analytical data were available.

Agreement with previous FT age determinations, when available, is reasonably good, except some cases. For example, the age of the Spitaksar obsidian determined by Komarov et al. (1972) is significantly older than the age of sample Spi 4 of this work. The available K–Ar ages are substantially older, with the only exception of those regarding the Aragats region.

The present fission-track extensive study confirms that this method is very useful for dating in obsidian-bearing volcanic fields, also in case of very young volcanics difficult to be dated using other techniques. A comparison of plateau ages from the same volcanic area shows that most obsidians were erupted in short time spans. In many cases, ages of different occurrences are reciprocally indistinguishable, considering the experimental errors. To give an example, sample Geg 4c is stratigraphically younger than sample Geg 3c, but this geological evidence was not detected by the fission-track analysis. These results correspond with geological observations which suggest a short duration for the volcanic activity which produced obsidians in each volcanic field.

A large number of Armenian obsidians have D_s/D_1 ratio, values > 0.9 and the apparent and plateau ages are in agreement within experimental errors. Hence, the track annealing is almost negligible in these glasses.

Whereas discrimination of the various volcanic areas as potential natural sources of raw materials for tool making during prehistoric times is rather satisfactory, discrimination between occurrences located in the same volcanic field is more problematic. However, in some cases occurrences with very similar ages can be discriminated using the uranium content. The use of fission-track dating for discriminating Armenian obsidians from those of the numerous potential sources located in Anatolia is more satisfactory. In few cases Armenian and Anatolian obsidians, whose analytical fission-track data are reported by Bigazzi et al. (1993, 1994), might be confused as sources of artefacts. For example, the Aragats Volcanic Region obsidians have fission-track parameters similar to those of some sources located in Cappadocia, in central Anatolia. However, the relatively great distance between these potential sources makes a superimposition of their circulation areas rather unlikely.

The present study confirms the importance of a multidisciplinary approach, using techniques based on different parameters, such as chemical compositional studies and fission-track analysis, for provenance studies of obsidians. Oddone et al. (2000) have shown that some Armenian obsidians that are poorly discriminated by cluster analysis of neutron activation chemical data have significantly different

Table 1
Fission-track dating of Armenian obsidians^a

Obsidian Occurrence	Sample	$\rho_S \times 10^3$ (cm ⁻²)	N_S	$\rho_I \times 10^5$ (cm ⁻²)	N_I	D_S/D_I	A. Age ($\pm 1\sigma$) (Ma)	P. Age ($\pm 1\sigma$) (Ma)	U (ppm)
Aragats volcanic region									
<i>Pokr Arteni</i>	Ar P 9	2.09	317	2.03	1109	0.65	0.77 \pm 0.05	1.31 \pm 0.08	6.0
	Ar P 4	1.55	134	1.88	1095	0.74	0.62 \pm 0.06	1.17 \pm 0.11	5.5
<i>Mets Arteni</i>	Ar M 3	3.38	366	2.61	1143	0.92	0.97 \pm 0.06	1.35 \pm 0.08	7.7
<i>Satani Daar</i>	Ar Sa 1	2.65	317	2.13	1123	0.78	0.93 \pm 0.06	1.29 \pm 0.08	6.3
<i>Aragats Flow</i>	Art 3bis A	2.99	324	2.13	1245	0.87	1.06 \pm 0.07	1.22 \pm 0.08	6.3
	Art 3 A	2.79	322	1.78	1046	0.89	1.17 \pm 0.08	1.38 \pm 0.09	5.3
Damlik volcanic complex									
<i>Ttudzhur</i>	Tou 1	16.0	753	3.43	1245	0.85	3.51 \pm 0.16	4.49 \pm 0.21	10
	Tou 7	18.0	651	3.75	1362	0.89	3.61 \pm 0.17	4.26 \pm 0.20	11
<i>Arzakan</i>	Arz 1	10.5	527	2.85	1095	0.74	2.76 \pm 0.15	4.46 \pm 0.27	8.4
<i>Damlik</i>	Dam	12.3	708	2.20	1343	0.96	4.18 \pm 0.19	4.56 \pm 0.20	6.5
Gegham volcanic region—Hrazdan structure									
<i>Alapars</i>	Ala 3	0.96	215	2.56	1113	0.98	0.28 \pm 0.02	0.28 \pm 0.03	7.6
	Ala 4	1.34	217	3.22	1168	0.93	0.31 \pm 0.02	0.31 \pm 0.02	9.5
<i>Fontan</i>	Font Av	1.08	234	3.09	1343	0.92	0.26 \pm 0.02	0.32 \pm 0.02	9.1
	Font Au 3	0.98	213	2.81	1222	0.96	0.26 \pm 0.02	0.30 \pm 0.02	8.3
<i>Gutansar</i>	Gut 1	1.06	153	2.83	1232	0.98	0.28 \pm 0.02	0.32 \pm 0.03	8.4
	Kap E 2	0.80	118	2.54	1104	0.98	0.24 \pm 0.02	0.25 \pm 0.03	7.5
	Gi 1	1.02	129	2.84	618	0.93	0.27 \pm 0.03	0.31 \pm 0.03	8.4
<i>Atis</i>	Zer W Sup 2	0.41	15	1.66	601	0.97	0.19 \pm 0.05	0.21 \pm 0.04	4.9
	Agu W Sup 3	0.97	211	2.29	1327	0.97	0.32 \pm 0.02	0.34 \pm 0.04	6.7
	Xian Xian	1.60	248	3.06	1235	0.97	0.39 \pm 0.03	0.40 \pm 0.03	9
Gegham volcanic region—southern part									
<i>Spitaksar</i>	Spi 4	0.46	134	3.70	1069	0.83	0.094 \pm 0.009	0.12 \pm 0.01	11
<i>Geghasar</i>	Geg 5	0.23	68	4.57	1320	0.92	0.038 \pm 0.005	0.042 \pm 0.004	13
	Geg 3c	0.29	103	4.18	1088	0.81	0.051 \pm 0.005	0.062 \pm 0.006	12
	Geg 4c	0.40	180	4.63	1168	1.00	0.065 \pm 0.005	0.065 \pm 0.005	14
	Geg 7bis a	0.44	144	4.42	1151	0.97	0.075 \pm 0.007	0.082 \pm 0.007	13
	Geg 6a	0.30	108	4.50	1170	0.90	0.050 \pm 0.005	0.052 \pm 0.005	13
Vardenis volcanic region									
<i>Choraphor</i>	Cho 4a	8.75	574	5.24	1152	0.88	1.25 \pm 0.06	1.53 \pm 0.09	15
Sunik volcanic region									
<i>Mets Satanakar</i>	Sata 2b	1.61	239	3.43	1244	0.88	0.35 \pm 0.02	0.43 \pm 0.03	10
	Sata 4b	2.02	313	3.20	1395	0.87	0.47 \pm 0.03	0.56 \pm 0.05	9.4
<i>Sevkar Footplains</i>	Se p 3b	1.88	240	3.73	1157	0.86	0.38 \pm 0.03	0.54 \pm 0.03	11
	Se p 5a	1.67	241	3.19	1387	0.78	0.39 \pm 0.03	0.61 \pm 0.04	9.4
<i>Mets Sevkar</i>	Se m 2a	1.98	358	3.47	1208	0.78	0.43 \pm 0.03	0.53 \pm 0.03	10
<i>Bazenk</i>	Baz 3	1.98	338	3.49	1268	0.81	0.42 \pm 0.03	0.56 \pm 0.04	10

^a ρ_S (ρ_I): spontaneous (induced) track density; N_S (N_I): spontaneous (induced) track counted; D_S/D_I : spontaneous to induced track-size ratio. A. (P.): apparent (plateau) age. U: uranium content deduced by the induced track density. Parameters used for age calculation: $\lambda = 1.55125 \times 10^{-10} \text{ a}^{-1}$; $\lambda_F = 8.46 \times 10^{-17} \text{ a}^{-1}$; $\sigma = 5.802 \times 10^{-22} \text{ cm}^2$; $^{238}\text{U}/^{235}\text{U} = 137.88$. The neutron fluence, referred to the NRM IRMM-540 standard glass (De Corte et al., 1998), was $1.51 \times 10^{15} \text{ cm}^{-2}$. Samples were irradiated in the LS (Cd ratio 6.5 for Au and 48 for Co) facility of the Triga Mark II reactor of the University of Pavia (Italy). Two splits from each sample, for spontaneous and induced (the irradiated one) track counting, were mounted in epoxy resin, polished and etched in 20% HF at 40°C. To optimize the counting procedure, etching duration (commonly 120 s) was adjusted in order to obtain mean induced track sizes of $\sim 6.5 \mu\text{m}$. Tracks were counted using a Leitz Orthoplan microscope at 500 \times . Track-sizes were measured with a Microvid equipment at 1000 \times . Errors of ages are propagation of counting errors. The D_S/D_I values, between 1 and 0.65 (Fig. 2), indicate that these samples suffered variable amount of track annealing, from negligible up to rather significant, also in case of occurrences located in the same volcanic complex. The plateau condition (D_S/D_I values ~ 1) was attained with heating steps of 4 h at 200°C and 4 h at 220°C that determined track-size reduction by up to 35% for the same etching conditions.

ages, so they are easily distinguished by fission-track dating. At the same time, glasses indistinguishable on the base of fission-track data, may have chemical compositions that fully discriminate them (this is the case of the Çavuslar, Bigazzi et al., 1994, eastern Anatolia, and Damlik obsidians, this study).

In conclusion, combination of complementary techniques based on different analytical approaches is potentially an ideal tool for provenance studies of obsidians. Chemical analyses on the sample-set, that was the subject of this work, are in progress.

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