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FISSION-TRACK DATING OF ARMENIAN AND GEORGIAN OBSIDIANS: CHARACTERISATION OF POTENTIAL SOURCES OF RAW MATERIAL AND PROVENANCE STUDIES OF NUMEROUS ARTEFACTS FROM PREHISTORIC SITES

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Report on the research activities developed by the fission-track group of Pisa for the INTAS research project entitled "Geographic Information System for Armenian Archaeological Sites from the Palaeolithic to the 4th Century AD", 1999 – 2001

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1. Introduction

The spontaneous nuclear fission of ^{238}U occurs at a constant rate during time. Each fission event produces in the solid in which it takes place a damaged region – a trail ~ 10 ÷ 20 μm long – named 'latent track' that can be revealed by chemical etching and observed under a microscope. The number of fission-tracks accumulated during geological times in a mineral or natural glass is proportional to its U-content as well as to the time elapsed since it formed. Therefore, the fission-track (FT) dating method consists in the determination of the fraction of ^{238}U atoms which experienced the spontaneous fission. An irradiation with thermal neutrons in a nuclear reactor produces the induced fission of the ^{235}U isotope. The number of induced tracks formed during irradiation is proportional to the unknown U-content. In practice, a FT age determination consists in the estimate of two track areal densities – the spontaneous and the induced track densities – through counting procedures (an exhaustive description of the FT method and of its applications is given by Wagner and Van den haute, 1992).

As U-content and age are peculiar quantities of each sample, the spontaneous and induced track areal densities are also peculiar of each sample.

The identification of the provenance of obsidian prehistoric artefacts using the FT analysis is based upon the assumption that they maintain memory of the characteristics of the outcrop which they originated from. In other words, in principle an artefact should show FT parameters – such as track densities and age – identical to those of a geological sample one can collect today from its source. Comparison of these parameters on artefacts and potential natural sources of raw material should allow provenance identification, provided that track densities and age are efficient discriminative factors. Since late sixties - early seventies it has been shown that these favourable circumstances commonly verify (Suzuki, 1969; Durrani *et al*., 1971; Arias Radi *et al*., 1972; Bigazzi and Bonadonna, 1973) and that the FT analysis might be an efficient method for obsidian provenance studies. Application in various geographic areas of earth such as Japan (Suzuki, 1969), Europe (Arias Radi *et al*., 1972; Arias *et al*., 1986; Bigazzi *et al*., 1990), Latin America (Miller and Wagner, 1981; Bigazzi *et al*., 1992), the Near East (Bigazzi *et al*., 1993a, 1993b, 1994) proved the potentiality of this method.

Among the several approaches used for characterisation and discrimination of volcanic glass, the chemical composition by major element and/or trace element analysis appears the most popular technique for correlation of artefacts with natural sources. However, as FT dating is based on different parameters, this method turned to be an efficient complementary technique specially in case of dubious source identification, as proved by several examples (see for instance Keller *et al*, 1996a).

In the Near East large amounts of obsidian were erupted since late Oligocene – early Miocene. Recent studies gave a significant contribution to a better knowledge of characteristics of obsidian-bearing volcanics located in Anatolia (see, for instance, the recent book edited by Cauvin *et al.* 1998). Application of the FT analysis to potential natural sources of raw material and to artefacts from archaeological sites of this region yielded new insights on circulation of obsidian during prehistory (Bigazzi *et al*., 1993a, 1994, 1998).

Although in late 90's knowledge of geochronology of Anatolian obsidians could not be considered exhaustive, significant progress had been made. On the contrary, the stage of knowledge of Transcaucasian obsidians was quite poor: geochronological data were available only for a restricted number of occurrences. Moreover, most of them dated back to early seventies. For these reasons a FT study of these glasses was included in the 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". This study, carried out by the FT group of the Institute of Geochronology and Isotope Geochemistry of C.N.R., Pisa, was devoted to fill up numerous blanks of the data-set concerning characteristics and prehistoric use of Transacucasian obsidians. Numerous obsidians were dated using the FT method, in order to (1) enhance knowledge of geochronology of the volcanism of the region and (2) characterise these glasses for discrimination of potential sources of raw materials for tool-making. In a second phase, numerous artefacts from several sites located in various sectors of Armenia were analysed in order to identify their provenance.

The present report illustrates the activity developed by the FT group of Pisa, in co-operation with the Department of General Chemistry of the University of Pavia, during 1999 – 2001, in the frame of the INTAS research project mentioned above. Geological settings of the studied volcanics as well as geological and archaeological implications of the obtained results are not presented here. These subjects will be discussed with the French and Armenian archaeologists and geologists involved in the INTAS project.

2. Peculiarities of fission-track dating of glass

The FT dating method is based on the assumption that the 'fossil' tracks accumulated during geological times are stored undisturbed in a sample. Actually, thermal stability of tracks in some materials is rather poor: specially in glass a certain degree of annealing of the damage produced by the ^{238}U spontaneous fission frequently takes place also at ambient temperatures. Partially annealed tracks are revealed with reduced efficiency in comparison with the ^{235}U induced tracks, which are 'fresh' tracks artificially produced. Therefore, fossil tracks commonly show a certain reduction of the mean size D_S (the mean major axis of the etch-pit). A D_S/D_I mean size ratio < 1 (where subscript I denotes induced tracks that are assumed as reference undisturbed tracks) indicates reduced etching efficiency of spontaneous tracks and a corresponding decrease of the areal spontaneous track density and, consequently, of the age which is determined through the spontaneous to induced track density ratio. The less the D_S/D_I ratio is, the more the FT age is reduced.

Therefore, a FT age on glass is commonly a 'minimum' age (called 'apparent' age), unless a technique for correcting thermally lowered ages is applied. Storzer and Wagner (1969) and Storzer and Poupeau (1973) proposed the “size-correction method” and the “plateau method”, respectively.

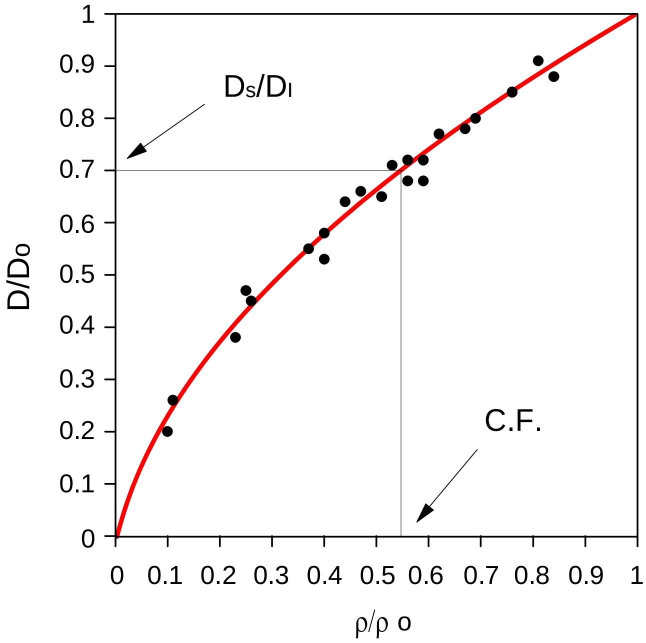

Fig. 1. Size-correction curve for the Mt. Arci obsidian, Sardinia (Italy). Thermal treatments at temperatures between 200°C and 350°C were used in order to produce a variable amount of artificial annealing of the induced tracks. By the spontaneous to induced track-size ratio, D_S/D_I, it was deduced a correction factor (C.F.): the 'true' age of the sample is obtained by dividing the apparent age by this factor (0.54, in this case).

The first technique is based on estimate of track density loss by track-size measurements. Thermal treatments of varying intensity, obtained changing duration and temperature, are imposed to several splits of an irradiated sample in order to produce variable amounts of track-annealing. For each split the D/D_0 (ratio between the mean size of partially annealed and undisturbed tracks) and ρ/ρ_0 (ratio between areal density of partially annealed and undisturbed tracks) ratios are measured. The D/D_0, ρ/ρ_0 points obtained in this way allow to draw out an experimental curve named “correction curve” which represents the relationship between track-size reduction and corresponding track areal density decreasing (Fig. 1). Using this curve, the value in the ρ/ρ_0 axis corresponding to the D_S/D_I ratio determined in the sample represents an estimate of the age reduction due to the spontaneous tracks partial annealing.

The plateau method consists in re-establishing by laboratory thermal treatments an identical etching efficiency of spontaneous and induced tracks. This technique is based on the experimental evidence that partially annealed tracks are progressively more resistant to further annealing. If increasing intensity heating steps (changing duration and/or temperature) are applied to two aliquots (one of them irradiated with neutrons) of a sample affected by partial annealing of spontaneous tracks, its age progressively increases up to a plateau (Fig. 2). The plateau is reached when the amount of natural plus artificial annealing of spontaneous tracks ≈ the amount of artificial annealing of induced tracks. In the plateau region $D_S/D_I = 1$. Commonly, a unique thermal treatment is imposed. The achievement of the plateau condition – an identical revelation efficiency of spontaneous and induced tracks – is verified by track-size measurements: D_S/D_I must by ~1.

Experimental evidence indicates that these techniques produce equivalent results and that corrected FT ages on glass are commonly reliable formation ages (Arias *et al.*, 1981; Naeser *et al.*, 1981; Storzer and Wagner, 1982; Westgate, 1989). Nevertheless, the plateau method is commonly preferred, specially for its higher precision.

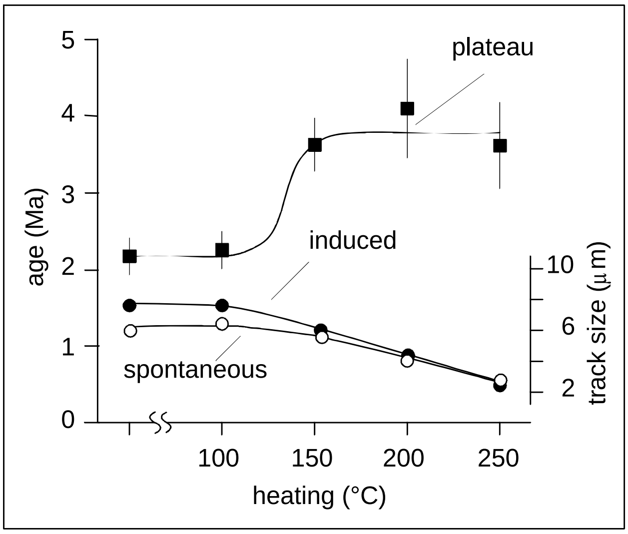

Fig. 2. Plateau fission-track age determination on an obsidian from Sarikamis, eastern Anatolia. Each experimental point represents a determination made after cumulative thermal treatments of two hours at the temperatures indicated in abscissa. For example, the first point on the left refers to the natural sample, whereas the last on the right corresponds to determinations made on the sample after a thermal treatment of 2 h at 100°C + 2 h at 150°C + 2 h at 200°C + 2 h at 250°C. The induced track-sizes (as well as areal density) reduce more quickly than the spontaneous track-sizes (and density). In the plateau region the spontaneous to induced track-size ratio is ~ 1.

Although, due to track partial annealing glass presents more difficulties than minerals for dating, it is an important material: glass is the only datable phase of many tephra (Walter, 1989). Application of FT dating to natural glass proved to be a significant tool for tephrochronological (Westgate, 1989) as well as for chrono-stratigraphical studies in volcanic areas, also in case of just few thousand years old volcanics (Bigazzi and Bonadonna, 1973; Bigazzi *et al*. 1993b).

3. Samples studied during the development of the INTAS research project

Following the literature regarding Armenian obsidians (Karapetyan, 1968, 1969, 1972, Karapetyan *et al.*, 2001; Keller *et al.*, 1996b; Komarov *et al.*, 1972), 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. Because of 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 formation of a series of impressive dome-shaped volcanoes. 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. 3). 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).

Fig. 3. Schematic map showing the distribution of rhyolite-obsidian dome-shaped volcanoes in Armenia and location of occurrences studied in this work. (I): Kechut Volcanic Region, (II): Aragats Volcanic Region, (III): Gegham Volcanic Region, (IV): Vardenis Volcanic Region, (V): Sunik Volcanic Region and (VI) Kapan Volcanic Region. 1 – 23: Sites studied for obsidian provenance identification.
1: Keti, 2: Horom, 3: Shirakavan, 4: Landjik, 5: Akhourian, 6: Tsakhkahovit, 7: Kuchak, 8: Gegharot, 9: Fioletovo, 10: Djoghaz, 11: Chkalovka, 12: Teghut, 13: Aratashen, 14: Mokhrablur, 15: Argishtikhinili, 16: Sardarabad, 17: Dvin, 18: Aygevan, 19: Mtnadzor, 20: Karchaghbiur, 21: Karkarer, 22: Zorakar, 23: Sisian.

3.1. geological samples

A first set of geological samples was selected during the visit of one of us (G.B.) at Clermont-Ferrand. These glasses, collected during a French-Armenian campaign in the Aragats, Gegham, Chorapor and Sunik volcanic regions, in the Damlik Volcanic Complex of the Tsakhkunjats Ridge and in the Palaeo-Araxe river terraces I, II and III, are listed in Table 1.

A second set of obsidians, also listed in Table 1, consisted of 9 samples that were supplied later by the colleagues of the Institute of Geological Sciences, National Academy of Sciences, Yerevan, Armenia. These obsidians had been collected from the Paravani Volcanic Complex, Georgia (7 samples), and from the Damlik Volcanic Complex at Coch – Scharbach and Kamakar. Finally, two further samples were collected during the visit of one of us (G.B.) at Yerevan from the Gutansar Volcanic Complex (Avazan) and from the Atis volcano (Atis Chapelle) in the Ghegam Volcanic Region.

Other obsidians, not represented in Table 1, had been recognised also in the north-western corner of Armenia, in the Kechut Volcanic Region. In a previous study (Oddone *et al.*, 2000) also glasses from two occurrences located in this region – Agvorik and Sizavet – had been analysed: their characteristics can be compared with those of the sample-set subject of the present study. Therefore, the geological samples to be used to produce a reference data-set for provenance studies of obsidian artefacts was quite exhaustive.

Fig. 4. Obsidian artefacts collected at Aratashen.

3.2. Artefacts

All artefacts analysed in this study, collected in 23 Armenian sites whose location is shown in Fig. 3, were supplied by the colleagues of the Institute of Archaeology and Ethnography, National Academy of Sciences, Yerevan, Armenia. Further samples were collected by one of us (G.B.) as surface findings in the Neolithic site of Aratashen (Fig. 4), at the beginning of the excavation carried out in the frame of the INTAS project. All these samples are listed in Table 2. Some samples from river fluvial deposits were also analysed.

Table 1. Georgian and Armenian obsidian samples selected for fission-track dating

Paravani Volcanic Complex		
Paravani	1	Quarry on the S flank of the Chikiani volcano.
	3	Near the top of the volcano.
	4	NE flank of the volcano, midway of the slope.
	5	Quarry on the E flank, in correspondence of sample 4.
	7	SE flank of the volcano.
	9	W flank, at low elevation on the slope overlooking lake Paravani.
	10	N flank, on the big flow with N – NE trend.
Aragats Volcanic Region		
Pokr Arteni	Ar P 9	Pokr Arteni. The oldest unit, SE of the volcano.
	Ar P 4	Pokr Arteni. The unit near the top of the volcano.
Mets Arteni	Ar M 3	Mets Arteni.
Satani Daar	Ar Sa 1	Satani Daar (NE of Mets Arteni).
Aragats Flow	Art 3bis A	Aragats flow, the big flow with a SW trend.
	Art 3 A	Another occurrence very close to the previous one.
Damlik Volcanic Complex – Tsakhkunjats Ridge		
Ttudzhur	Tou 1	Ttudzhur. A dyke on the southern flank.
	Tou 7	Ttudzhur. A flow of the lower part of the dome.
Arzakan	Arz 1	Obsidian pebbles from river bank, near the village of Arzakan.
Damlik	Dam	Damlik. East of Aparan. North Tsakhkunjats Ridge.
Coch - Scharbach		
Kamakar		
North Gegham Volcanic Region		
Alapars	Ala 3, Ala 4	These two samples are from the same flow.
Fontan	Font Av	(Aval = downstream). The same as Gutansar ?
	Font Au 3	(Autoroute). Could be an older flow.
Gutansar	Gut 1	Gutansar, SW flank of the volcano (the same as Djraber).
	Kap E 2	S flank of the Gutansar volcano.
	Gi 1	On the same side as Gutansar, near the village of Gyumush.
	Gi 2	The other side of the Razdan river.
	Avazan	Near Gi1 and Gi2, near the top of the hill.
Atis	Zer W Sup 2	Group 1, U ~ 8 ppm.
	Atis Chapelle	Near Zer W Sup 2
	Agu W Sup 3	Group 2, U ~ 9 ppm.
	Xian Xian	Blocks in pyroclastic deposits.
South Gegham Volcanic Region		
Spitaksar	Spi 4	On the top, the youngest obsidian.
Geghasar	Geg 5	(N ?) flank of the dome.
	Geg 3c	Lowest part of the flow.
	Geg 4c	Stratigraphically over Geg 3c.
	Geg 7bis a	To the south (near the top).
	Geg 6a	A small flow near the top.
Vardenis Volcanic Region		
Choraphor	Cho 4a	Upper part of the volcano, the top of the dome.
Sunik Volcanic Region		
Mets Satanakar	Sata 2b	Main flow. SE flank of the volcano.
	Sata 4b	South (or SE) dependence of the main flow ?
Sevkar Footplains	Se p 3b	Sevkar footplain, 3rd dyke.
	Se p 5a	Sevkar footplain, 5th dyke.
Mets Sevkar	Se m 2a	Mets Sevkar. The major flow.
Bazenk	Baz 3	SE flank of the volcano ?
Blocks in the old terraces of the Araxe river		
Sardarabad	I	The youngest terrace.
Argishtikhinili	II (W)	Intermediate age terrace (West).
	III (E)	The oldest terrace (East).

Table 2. Archaeological samples or pebbles from river deposits analysed in this study

Site	Age	N.	Notes
1. Keti. S. slope of Shirak range.	1 – EBA 2 – EIA	3 7	Surface samples from topographically. distinguished EBA and EIA settlements.
2. Horom. NW slope of the Aragats massif at 1600m.	1 – South Hill, LBA 2 – North Hill (A), EIA 3 – North Hill (B), EIA	2 3 7	Unworked pebbles (geological samples?). From the cultural deposits of the settlement. (S) From the cultural deposits of the settlement. (S)
3. Shirakavan. East bank of the Akhourian river.	EBA	8	Pebbles from the territory of the archaeological site.
4. Landjik. Western foothills of the Aragats massif.	EBA	4	Surface findings from the EBA settlement territory.
5. Akhourian. East bank of the river in front of the ancient town of Ani.		3	Pebbles from the upper (VII°) terrace.
6. Tsakhkahovit. N. flank of the Aragats massif.	EBA LBA	4 3	(S) (S)
7. Kuchak II. E. of the Aragats massif, Kasakh river valley.	BA	1	Surface finding from the BA settlement.
8. Gegharot. S. flank of the Pambak range	EBA	3	(S)
9. Fioletovo. N. slope of the Pambak range, NW of Lake Sevan.	EBA III	4	(S)
10. Djoghaz. Near the border Armenia/Georgia/Azerbaydzhan.	EBA	6	Surface findings.
11. Chkalovka. NW coast of Lake Sevan.	Grave 2. EBA	2	(S)
12. Teghut. Ararat valley, the lower basin of the Kasakh river valley.	Chalcolithic	2	(S)
13. Aratashen. Ararat valley, the lower basin of the Kasakh river valley.	A B – Neolithic	2 9	From river bank. Surface findings.
14. Mokhrablur. Ararat valley, the lower basin of the Kasakh river valley.	EBA	2	(S)
15. Argishtikhinili. Ararat valley.		2 2	W – Pebbles from Palaeo-Araxe river terrace II. E – Pebbles from Palaeo-Araxe river terrace III.
16. Sardarabad. Ararat river valley.	 Neolithic/Chalcolithic	3 1	Pebbles from Palaeo-Araxe river terrace I. From the geological trench section.
17. Dvin. Ararat valley.	EBA	3	(S)
18. Aygevan. Ararat valley.	EBA	6	(S)
19. Mtnadzor. S. coast of Lake Sevan.	LBA – EIA	7	Surface findings.
20. Karchaghbiur. SE coast of lake Sevan.		1	
21. Karkarer. Sunik plateau.	Mesolithic/Neolithic	6	(S)
22. Zorakar. Vorotan river valley.	Megalithic locality, BA	4	
23. Sisian. Vorotan river valley.	I. Grave 2. MBA III II. Grave 3. MBA II	4 2	(S) (S)

EBA: Early Bronze Age; LBA: Late Bronze Age; BA: Bronze Age; EIA: Early Iron Age; MBA: Middle Bronze Age; N.: number of samples; (S): in stratigraphy.

4. Methodologies

From each obsidian sample it was separated one split for irradiation with thermal neutrons. Irradiation was performed in the Lazy Susan (Cd ratio 6.5 for Au and 48 for Co) Triga Mark II nuclear reactor of the University of Pavia. The neutron fluence was determined using the standard glass NRM IRMM-540 recently prepared by the Institute for Reference Materials and Measurements, on behalf of the European Commission. For each fluence determination, between 2600 and 3750 tracks were counted on a muscovite external detector sandwiched with the glass during irradiation.

After irradiation, two splits from each sample (for spontaneous and induced track counting) were mounted in epoxy resin and polished with diamond paste or spray with decreasing granulometry (down to 0.25 μm). The plateau method was routinely applied to the geological samples. The two splits chosen for mounting were previously heated for 4 hours at 200°C or 220°C. Tracks were revealed by chemical etching with 20% HF at 40°C. To optimise the counting procedure, etching duration (commonly, 120 s) was adjusted in order to obtain mean induced track sizes of around 6.5 μm. Tracks were counted under a Leica Orthoplan microscope at a magnification of 500 x using a grid. Track-sizes were measured with a Leica Microvid equipment at 1000 x. At least 100 tracks, when available, were measured for each D_S or D_I determination.

Some samples showed a significant number of bubbles of various shapes or damaged areas in which tracks could not be observed. In such a case the areal track density determination presents a further difficulty, because the real surface useful for counting is lower than the mere area of a field of view multiplied by their number and needs to be estimated. The grid itself can be used for this purpose, however the counting procedure would become much more time-consuming. In this work the alternative method called "point-counting technique", introduced by Fleischer *et al*. (1965) for pumice, commonly used for samples made up of a population of glass shards from tephra beds (Naeser *et al*., 1982; 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 will be a virtual track density expressed as Y/X, where Y is the number of tracks and X is the number of points on glass. This technique introduces an additional error that can not be ignored. Bigazzi and Galbraith (1999) have shown that this additional error can be estimated assuming that the number of points on glass will have a binomial distribution with success probability equal to the fraction of surface useful for counting. In this way, the additional relative error is given by $((1-X/n)/X)^{1/2}$, where n is the number of fields of view. This error of X is anything but negligible when X is not large enough. There is a weakness of the point-counting technique. Whereas it will be easy to reduce this error for spontaneous tracks, specially in case of low densities, as accumulation of an adequate number of counted tracks will require a large number of fields of view to analyse, the time saved using the point-counting technique will be at least partially counterbalanced by a larger time needed to produce a X large enough for the induced tracks. These can be easily counted by a traditional procedure, as their density is commonly large and the counting procedure can be performed using a reduced part of the grid as unit area. A solution to this problem is to adopt a mixed procedure, where the point-counting technique is used only for spontaneous tracks. Sandhu *et al.* (1993) had proposed that the real track density could be estimated by the virtual density Y/X. X/n is an estimate of the proportion of surface that is glass, thus $(X/n) \times n \times a = X \times a$ (where a is the area of a field of view) is an estimate of the total area of glass analysed. Bigazzi (1999) has shown that this assumption is reliable, therefore areal track densities determined using the point counting-technique and by a traditional population of counts on unit areas are comparable, and a mixed procedure turns to be accurate.

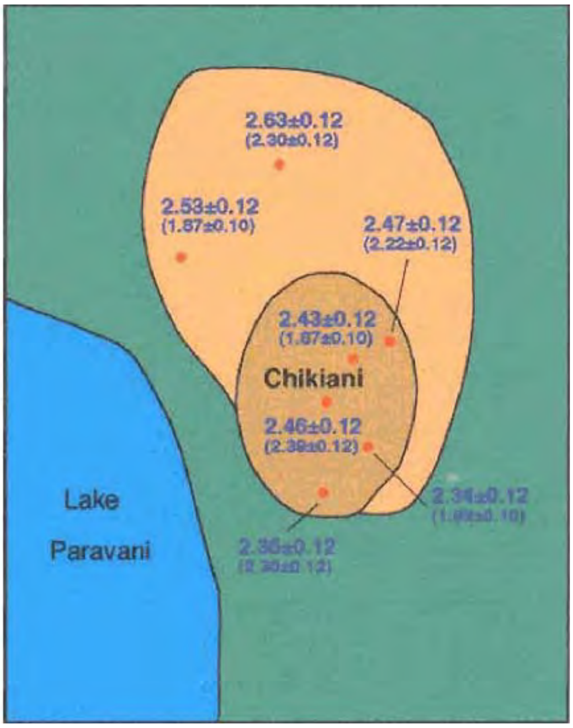

Fig. 5. Apparent (in brakets) and plateau ages of the obsidian occurrences of the Paravani Volcanic Complex studied in this work.

5. Age determinations of geological samples

Results of FT age determinations on the geological samples of the first set are summarised in Table 3a (apparent ages) and Table 3b (plateau ages).

Error of age is propagation of the errors of the spontaneous and induced track densities. To facilitate comparison of data regarding different samples, the error of the neutron fluence, between around 2.2 % and 2.4 %, has been omitted. For $p(\chi^2)$ values > 5 % the Poisson relative error $(1 - N)^{1/2}$, where N is N_S or N_I, was used. In case of $p(\chi^2)$ values < 5 %, it was used the standard error of the track counts. The point-counting technique was applied for 6 samples (Ala 3, apparent age and plateau age, Ala 4, Gi 1, Font Au 3, Gut 1, Kap E 2, plateau ages). For these samples the additional error introduced by this technique was considered. In this case the fraction of surface useful for counting was quite large (between 85 % and 95 %), and the error became rather negligible (between around 1 % and around 1.5 %).

The D_S/D_I ratio values have an error of about 2 %, excepted for sample Zer W Sup 2 (2.8 %, apparent age, and 3.0 %, plateau age) due to the low number of measured sizes.

Some samples turned to be very difficult to analyse due to darkness of glass and/or presence of numerous microlites that made an arduous task unambiguous identification of fission tracks. These are sample Gi 2 (only the induced track density was determined in Table 3a. The plateau method was not applied), Zer W Sup 2 (track counting was performed only in restricted areas)

Table 3a. Fission-track dating of Armenian obsidians (apparent ages)

Obsidian Occurrence	Sample	ρ_S [cm^{-2}]	N_S	ρ_I [cm^{-2}]	N_I	p (χ^2) %	D_S/D_I	Age (± 1σ) [Ma]
Aragats Volcanic Region								
Pokr Arteni	Ar P 9	2,090	317	202,700	1,109	92	0.71	0.774 ± 0.049
	Ar P 4	1,550	134	188,000	1,095	89	0.69	0.617 ± 0.056
Mets Arteni	Ar M 3	3,700	514	280,700	1,232	79	0.87	0.988 ± 0.052
Satani Daar	Ar Sa 1	2,650	317	212,800	1,123	18	0.78	0.933 ± 0.059
Aragats Flow	Art 3bis A	2,990	324	212,600	1,245	56	0.87	1.06 ± 0.07
	Art 3 A	2,790	322	178,300	1,046	48	0.89	1.17 ± 0.08
Damlik Volcanic Complex								
Ttudzhur	Tou 1	16,000	753	343,200	1,245	81	0.85	3.51 ± 0.16
	Tou 7	18,000	651	375,000	1,362	97	0.89	3.61 ± 0.17
Arzakan	Arz 1	10,500	527	284,900	1,095	99	0.78	2.76 ± 0.15
Damlik	Dam	12,300	708	220,100	1,343	35	0.96	4.18 ± 0.19
North Gegham Volcanic Region								
Alapars	Ala 3	958	215	256,000	1,113	92	0.98	0.281 ± 0.021
	Ala 4	1,340	217	322,200	1,168	58	0.93	0.311 ± 0.023
Fontan	Font Av	1,080	234	308,900	1,343	1	0.92	0.262 ± 0.019
	Font Au 3	983	213	281,100	1,222	64	0.96	0.262 ± 0.019
Gutansar	Gut 1	1,060	153	283,300	1,232	7	0.98	0.281 ± 0.024
	Kap E 2	797	118	254,100	1,104	21	0.98	0.235 ± 0.023
	Gi 1	1,020	129	284,300	618	53	0.93	0.268 ± 0.026
	Gi 2			184,900	534	26		
Atis	Zer W Sup 2	541	32	177,900	1,082	< 1	0.93	0.228 ± 0.042
	Agu W Sup 3	974	211	228,800	1,327	71	0.97	0.319 ± 0.024
	Xian Xian	1,600	248	306,000	1,235	61	0.97	0.394 ± 0.027
South Gegham Volcanic Region								
Spitaksar	Spi 4	464	134	369,700	1,069	49	0.83	0.094 ± 0.009
Geghasar	Geg 5	230	68	456,800	1,320	82	0.92	0.038 ± 0.005
	Geg 3c	285	103	418,300	1,088	49	0.88	0.051 ± 0.005
	Geg 4c	400	180	463,100	1,168	88	1.00	0.065 ± 0.005
	Geg 7bis a	443	144	442,400	1,151	92	0.97	0.075 ± 0.007
	Geg 6a	299	108	449,800	1,170	4	0.90	0.050 ± 0.005
Vardenis Volcanic Region								
Choraphor	Cho 4a	8,750	574	524,100	1,152	24	0.88	1.25 ± 0.06
Sunik Volcanic Region								
Mets Satanakar	Sata 2b	1,610	239	343,000	1,244	22	0.88	0.353 ± 0.025
	Sata 4b	2,020	313	320,000	1,395	48	0.87	0.473 ± 0.030
Sevkar Footplains	Se p 3b	1,880	240	372,700	1,157	71	0.86	0.379 ± 0.027
	Se p 5a	1,670	241	318,500	1,387	78	0.78	0.393 ± 0.027
Mets Sevkar	Se m 2a	1,980	358	346,600	1,208	50	0.85	0.429 ± 0.026
Bazenk	Baz 3	1,980	338	349,300	1,268	77	0.81	0.424 ± 0.026
Palaeo Araxe River Terraces								
Sardarabad	I	5,200	171	238,200	703	38	0.69	1.64 ± 0.14
Argishtikhinili	II (W)	5,060	365	152,800	684	21	0.86	2.48 ± 0.16
	III (E)	3,130	113	116,500	122	92	0.81	1.95 ± 0.20

ρ_S (ρ_I): spontaneous (induced) track density; N_S (N_I): spontaneous (induced) track counted; p(χ^2): probability of obtaining χ^2 value testing induced track counts against a Poisson distribution; D_S/D_I: spontaneous to induced track-size ratio. Parameters used for age calculation: $\lambda = 1.55125 \times 10^{-10}$ a^{-1}; $\lambda_F = 8.46 \times 10^{-17}$ a^{-1}; $\sigma = 5.802 \times 10^{-22}$ cm^2; $^{238}U/^{235}U = 137.88$. The neutron fluence, referred to NRM IRMM-540 standard glass, was 1.51×10^{15} cm^{-2}.

Table 3b. Fission-track dating of Armenian obsidians (plateau ages)

Obsidian Occurrence	Sample	ρ_S [cm^{-2}]	N_S	ρ_I [cm^{-2}]	N_I	p (χ^2) %	D_S/D_I	Age (± 1σ) [Ma]
Aragats Volcanic Region								
Pokr Arteni	Ar P 9	2,560	369	146,300	1,075	48	1.01	1.31 ± 0.08
	Ar P 4	1,660	152	106,900	627	91	1.00	1.17 ± 0.11
Mets Arteni	Ar M 3	3,150	353	175,400	1,289	17	1.01	1.35 ± 0.08
Satani Daar	Ar Sa 1	2,380	344	138,800	1,019	66	0.99	1.29 ± 0.08
Aragats Flow	Art 3bis A	2,250	415	138,900	1,019	86	1.01	1.22 ± 0.07
	Art 3 A	3,010	326	163,900	1,205	< 1	0.99	1.38 ± 0.09
Damlik Volcanic Complex								
Ttudzhur	Tou 1	13,020	694	267,500	1,228	77	0.99	4.49 ±0.21
	Tou 7	13,020	694	282,000	1,291	60	0.99	4.26 ± 0.20
Arzakan	Arz 1	9,670	384	162,700	1,045	54	1.02	4.46 ± 0.27
Damlik	Dam	13,700	791	225,000	1,723	7	1.03	4.56 ± 0.20
North Gegham Volcanic Region								
Alapars	Ala 3	514	123	135,700	590	83	1.04	0.284 ± 0.028
	Ala 4	813	196	196,000	1,137	71	1.02	0.311 ± 0.024
Fontan	Font Av	918	232	217,100	1,259	79	1.00	0.317 ± 0.023
	Font Au 3	807	208	204,900	1,188	87	0.99	0.296 ± 0.022
Gutansar	Gut 1	950	120	220,800	1,153	61	1.02	0.323 ± 0.030
	Kap E 2	626	104	187,300	1,004	3	0.98	0.251 ± 0.026
	Gi 1	888	118	214,100	621	92	1.01	0.311 ± 0.031
Atis	Zer W Sup 2	481	45	114,200	530	25	1.04	0.316 ± 0.049
	Agu W Sup 3	985	249	216,800	1,258	36	1.02	0.341 ± 0.024
	Xian Xian	1,230	271	231,600	1,076	48	1.00	0.399 ± 0.027
South Gegham Volcanic Region								
Spitaksar	Spi 4	381	110	238,800	1,036	27	0.97	0.120 ± 0.012
Geghasar	Geg 5	205	111	364,900	1,107	76	1.00	0.042 ± 0.004
	Geg 3c	291	131	351,400	1,013	98	1.00	0.062 ± 0.006
	Geg 4c	391	218	451,600	1,139	26	1.01	0.065 ± 0.005
	Geg 7bis a	492	142	451,600	1,175	75	0.99	0.082 ± 0.007
	Geg 6a	235	127	338,400	1,219	30	0.99	0.052 ± 0.005
Vardenis Volcanic Region								
Choraphor	Cho 4a	8,450	427	414,000	1,098	93	1.01	1.53 ± 0.09
Sunik Volcanic Region								
Mets Satanakar	Sata 2b	1,590	229	273,800	1,193	62	1.02	0.434 ± 0.031
	Sata 4b	1,540	172	206,000	899	52	1.00	0.560 ± 0.047
Sevkar Footplains	Se p 3b	1,550	364	215,900	1,256	95	0.99	0.539 ± 0.032
	Se p 5a	1,860	315	227,500	1,325	80	1.01	0.612 ± 0.039
Mets Sevkar	Se m 2a	1,270	297	180,700	1,051	71	1.03	0.525 ± 0.035
Bazenk	Baz 3	1,250	233	172,000	1,251	22	1.01	0.563 ± 0.040
Palaeo Araxe River Terraces								
Sardarabad	I	3,850	125	107,000	256	98	0.99	2.70 ± 0.29
Argishtikhinili	II (W)	4,430	120	113,500	681	49	0.97	2.93 ± 0.29
	III (E)	3,000	119	78,900	473	90	0.99	2.85 ± 0.29

Samples were mounted after a thermal treatment of 4 h at 200°C or 220°C. See also footnote to Table 3a.

and the 3 samples from the Palaeo-Araxe river terraces (also in this case track counting was performed only in restricted areas, however the number of counted spontaneous tracks is more satisfactory due to their higher areal density).

FT age determinations on samples of the second set are shown in Table 4 (see also Fig. 5). For sample Coch – Scharbach only the apparent age was determined. The thermal treatment of 4 h at 200°C imposed for the plateau age determination produced alteration of the glass that made impossible track counting. A second attempt, made using a longer time – 64 hours – and a lower temperature – 140°C – also failed. Considering the D_S/D_I ratio value, 0.67, a size-corrected age (see next section regarding archaeological samples) of 4.25 ± 0.40 Ma can be deduced, in agreement with plateau ages of obsidians of the Damlik Volcanic Complex.

Table 4. Fission-track dating of Transcaucasian obsidians

Obsidian Occurrence	Φ ($\times 10^{15}$) [cm^{-2}]	ρ_S [cm^{-2}]	N_S	ρ_I [cm^{-2}]	N_I	p (χ^2) %	D_S/D_I	Age (± 1σ) [Ma]
Paravani Volcanic Complex								
1	2.93	4,800	520	304,500	1,072	88	0.97	2.30 ± 0.12
4h 200°C		4,010	579	249,000	1,096	19	0.99	2.35 ± 0.12
3	2.93	4,680	558	285,900	1,133	54	1.02	2.39 ± 0.12
4h 200°C		4,090	591	242,100	1,493	58	1.03	2.46 ± 0.12
4	2.93	3,680	531	286,300	1,005	43	0.85	1.87 ± 0.10
4h 200°C		3,210	579	192,800	1,132	99	1.03	2.43 ± 0.12
5	2.93	4,210	532	276,400	1,094	49	0.95	2.22 ± 0.12
4h 200°C		3,510	704	207,000	1,216	18	1.01	2.47 ± 0.12
7	2.93	3,490	504	263,600	1,157	74	0.85	1.93 ± 0.10
4h 200°C		3,700	534	230,000	1,351	37	0.98	2.34 ± 0.12
9	2.93	3,870	559	301,100	1,057	51	0.86	1.87 ± 0.10
4h 200°C		3,690	533	212,400	1,248	39	0.99	2.53 ± 0.13
10	2.93	4,330	547	273,800	1,205	43	0.94	2.30 ± 0.12
4h 200°C		3,780	683	209,900	1,234	61	1.03	2.63 ± 0.13
Damlik Volcanic Complex								
Coch - Scharbach	3.04	6,090	349	433,300	949	19	0.67	2.13 ± 0.11
Kamakar	2.93	11,200	525	426,400	1,011	32	0.95	3.82 ± 0.21
4h 200°C		8,510	553	288,500	1,201	96	1.00	4.30 ± 0.22
NorthGegham Volcanic Region								
Atis Chapelle	3.04	862	311	505,500	1,170	64	0.81	0.258 ± 0.016
4h 200°C		769	222	347,400	1,106	8	1.00	0.335 ± 0.025
Avazan	3.04	899	222	483,400	1,119	19	0.97	0.281 ± 0.021
4h 200°C		720	213	374,200	1,191	41	1.02	0.291 ± 0.022

Φ: neutron fluence; 4h 200°C denotes the plateau age determination; age: apparent or plateau age. See also footnote to Table 3a.

The FT plateau ages shown in Tables 3b and 4 distribute in a wide interval and group in rather restricted clusters (only the plateau ages, commonly considered to represent the formation ages of glasses, and the size-corrected age of sample Coch – Scharabach, are considered here).

Following the geological time table recommended by the International Stratigraphical Commission of the New Independent States (Fig. 6), these clusters are:

1. obsidians from the watershed of the southern part of the Ghegam volcanic area, Upper-Neopleistocene age – Q_{III} (Spitaksar, Geghasar).
2. obsidians of Atis, Gutansar, 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}.
5. obsidians of the Paravani Volcanic Complex, Upper Pliocene - N_3^2.
6. obsidians of the Damlik volcanic Complex, Lower Pliocene - N_3^1.
7.

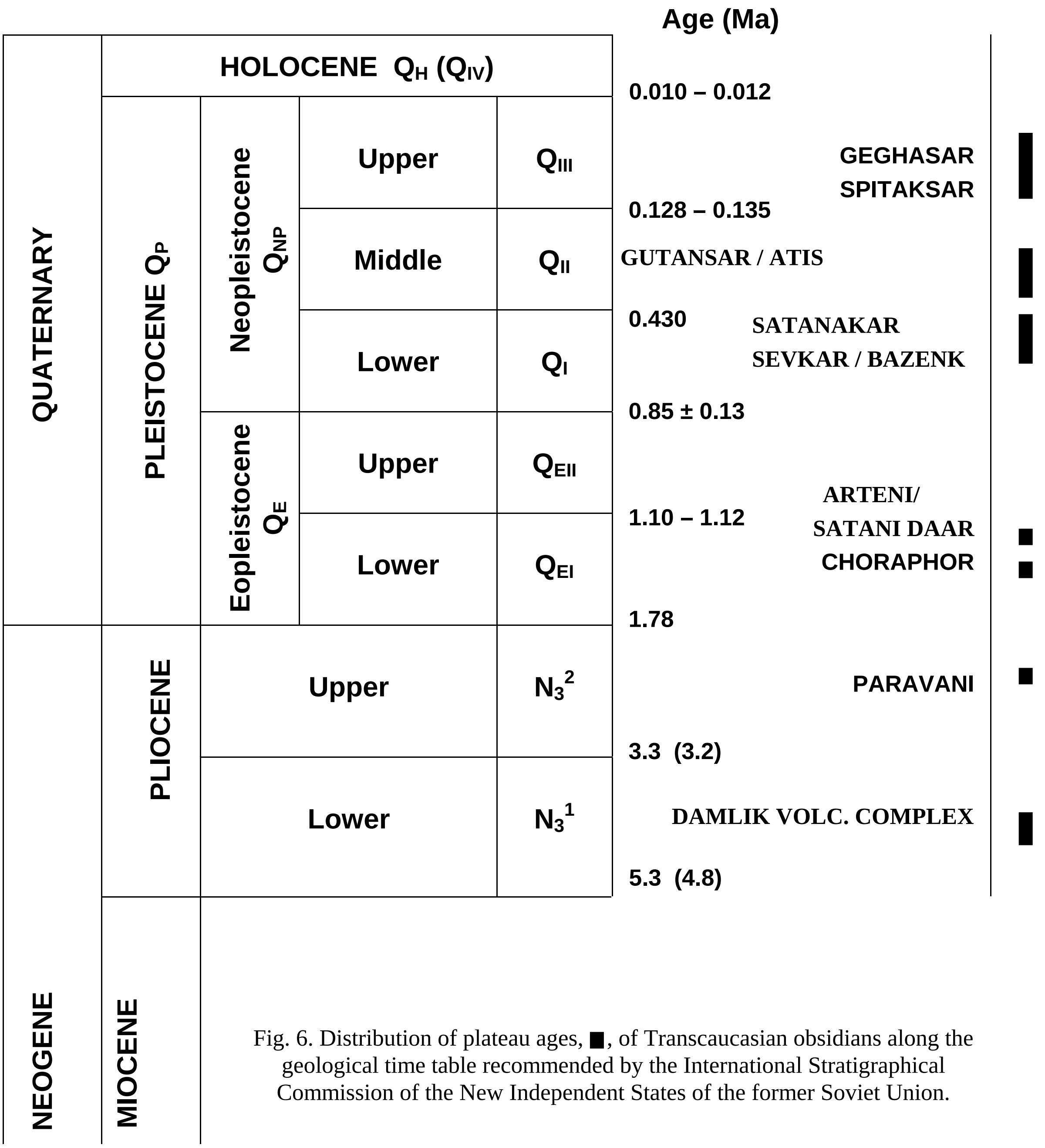

Fig. 6. Distribution of plateau ages, ■, of Transcaucasian obsidians along the geological time table recommended by the International Stratigraphical Commission of the New Independent States of the former Soviet Union.

The obsidian pebbles from the Palaeo-Araxe river terraces, that yielded peculiar FT data that do not recall other obsidians of this work, have not been considered in the classification made above.

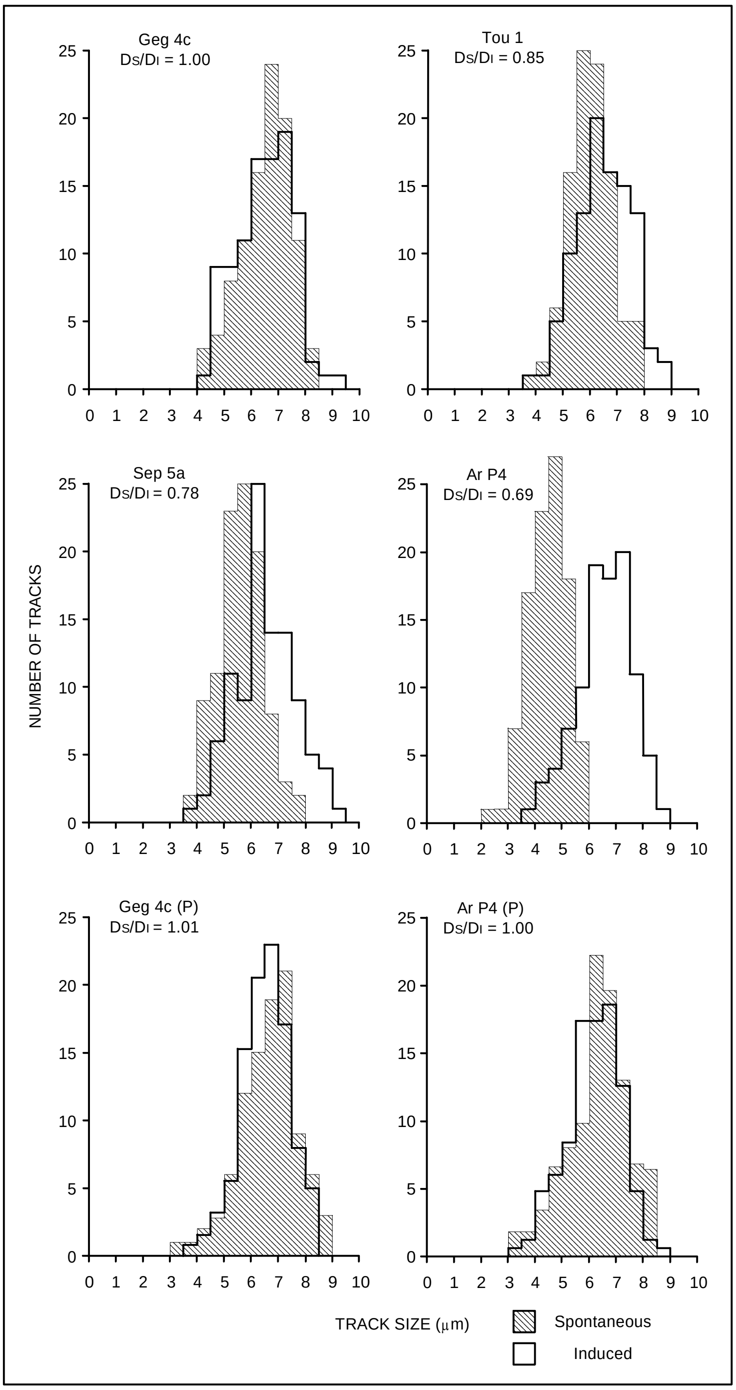

Fig. 7. The spontaneous to induced track-size ratio, D_S/D_I, of Armenian obsidians distributes in a relatively wide interval that indicates from negligible ($D_S/D_I = 1$) to relatively intense ($D_S/D_I = 0.69$) track-annealing. After the thermal treatment imposed for the plateau (P) age determination, D_S/D_I values of about 1 were determined for all samples.

The analytical results obtained in this study represent a complex of data which are consistent with those obtained in other regions. The measured D_S/D_I ratio values of Tables 3a and 4, between 1 and 0.69 (see also Fig. 7), 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. See, for example, those of the Aragats Volcanic Region and of the Damlik Volcanic Complex that have D_S/D_I ratios as well as apparent ages distributed in relatively wide intervals. After the thermal treatment imposed for the plateau age determination, the samples from the two complexes distribute in two very narrow intervals. At the same time, the D_S/D_I ratio values, that distribute around 1, indicate that the plateau condition – the same etching efficiency for spontaneous and induced tracks – was attained. These results are well consistent with the experience acquired with the application of the correction techniques of thermally lowered ages of glasses and provide further evidence that the plateau method yields reliable formation ages.

However, it has to be pointed out that data regarding Armenian obsidians contain somewhat new in comparison with those obtained in other areas: it is very remarkable the large number of samples that have D_S/D_I ratio values > 0.9 and apparent and plateau ages that are in agreement within the experimental errors. The track-annealing amount suffered by these glasses is rather negligible. D_S/D_I values ~ 1 had been determined before only in some very young (few thousands years) obsidians.

5.1. Comparison with previous geochronological data and discussion

The already available data-set regarding chronology of Georgian and Armenian obsidians is rather poor (see also Fig. 8). For the Paravani Volcanic Complex, the new plateau ages shown in Table 4 substantially agree with the 2.24 Ma FT age determined by Komarov *et al.* (1972) for an occurrence whose location is unknown to us. Also for the Aragats Volcanic Region, the ages obtained in this study are in close agreement with the FT ages of 1.25 Ma (Mets Arteni) and 1.36 Ma (Pokr Arteni) determined by Komarov *et al*. (1972) and Wagner *et al*. (1976), respectively, as well as with those published for Pokr Arteni – 1.27 ± 0.09 Ma and 1.20 ± 0.10 Ma, FT plateau method – by Oddone *et al*. (2000). These authors had dated also obsidians from the Kechut Volcanic Region. Two samples from the Agvoric occurrence had yielded identical apparent ages of 0.97 ± 0.8 Ma and plateau ages of 1.13 ± 0.11 Ma and 1.07 ± 0.10 Ma. Very similar ages had been obtained on two samples from the Sizavet occurrence – 0.96 ± 0.09 Ma and 0.93 ± 0.08, apparent ages, 1.13 ± 0.11 Ma and 1.04 ± 0.10 Ma, plateau ages.

For the Tsakhkunjats Ridge, the only available ages – 4.30 ± 0.23 Ma and 4.16 ± 0.22 Ma, FT plateau method – refer to an obsidian named Hankavan and are reported in the paper quoted above.

Oddone *et al*. (2000) had dated with the FT plateau method also four obsidians from the North Gegham Volcanic Region: Alapars, 0.21 ± 0.02 Ma, Gutansar, 0.32 ± 0.03 Ma and 0.31 ± 0.03 Ma, Nurnus, 0.27 ± 0.03 Ma, and Gyumush, 0.24 ± 0.03 Ma (we report here the nomenclature given by these authors). Two identical FT ages of 0.31 Ma had been determined by Komarov *et al*. (1972) and Wagner *et al*. (1976). Agreement with the present new ages and the published ones is rather good, excepted for Alapars.

For Mt. Atis, Komarov *et al*. (1972) and Karapetyan (1972) report a K-Ar age of 0.65 Ma and a FT age of 0.33 Ma. This latter age value is in agreement with the ages of some samples from the Atis volcano determined in this study. For a Spitaksar obsidian Karapetyan (1972) reports a FT age of 0.51 Ma, significantly older than the age determined in this study on sample Spi 4. For the Geghasar volcano no previous data are available.

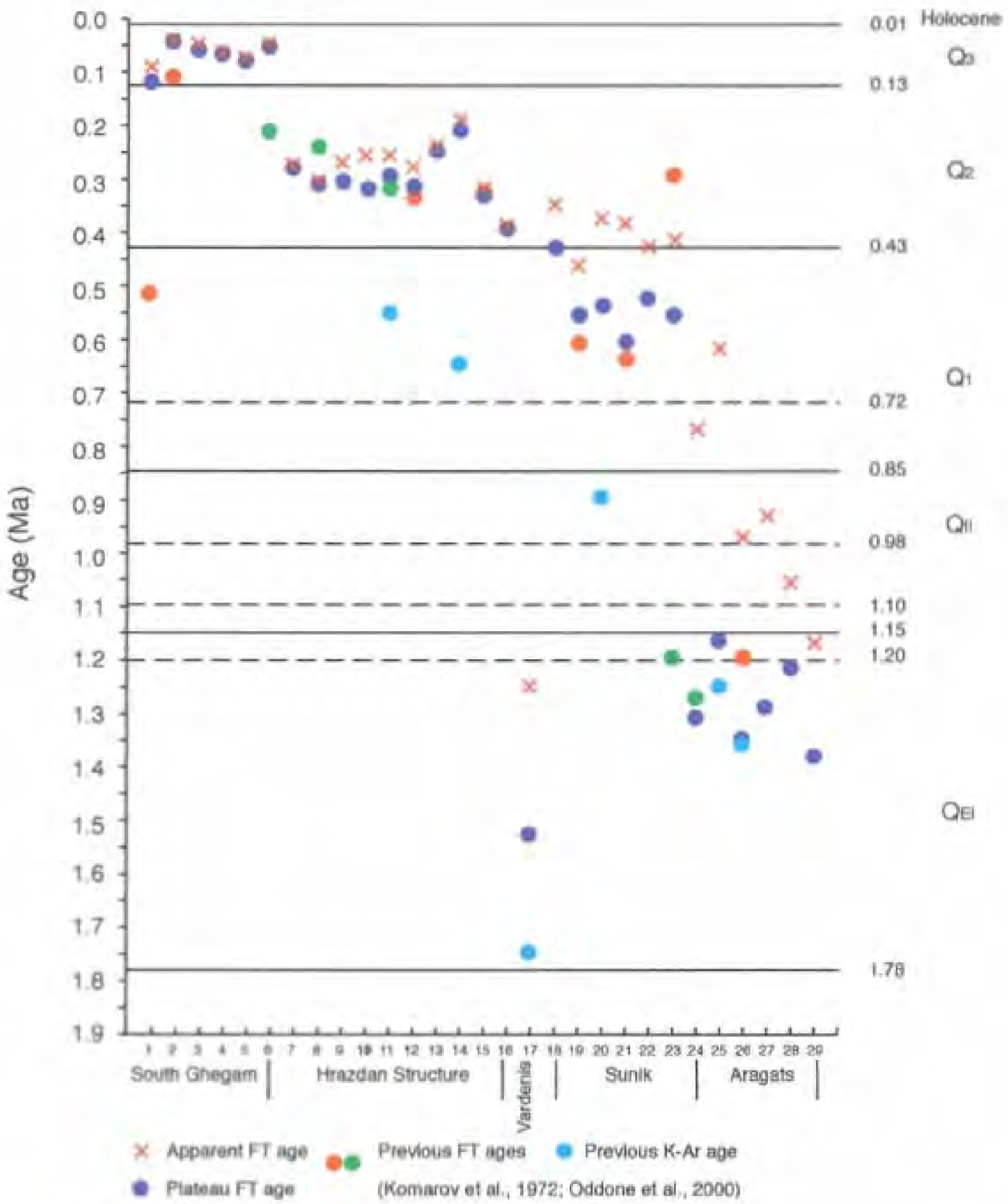

Fig. 8. Comparison of ages determined in this work with published ages.

The FT age of sample Cho 4, the unique obsidian from the Vardenis Volcanic Region studied in this research, is slightly younger than the 1.75 Ma K-Ar age quoted by Komarov *et al*. (1972).

Karapetyan (1972) and Komarov *at al*. (1972) have determined FT ages of 0.30 Ma, 0.51 Ma and 0.64 Ma for the Bazenk, Sevkar Footplains and Mets Satanakar obsidians, respectively, and a K-Ar age of 0.90 Ma for a Sevkar Footplains obsidian.

The obsidian pebbles from the terraces of the Palaeo-Araxe river had been considered in this study in order to identify their provenance. Apparent ages of these samples vary between 1.64 and 2.48 Ma, with D_S/D_I ratio values between 0.69 and 0.86 that indicate differential track-annealing. Plateau ages reciprocally agree and D_S/D_I ratio values are close to 1. The FT parameters of samples I, II (W) and III (E) do not recall those of Armenian occurrences. Palaeogeographical considerations indicate the adjacent area of eastern Anatolia (Turkey) as the very probable source. Obsidians collected few km SW of Kars and at Yaglika, few km S of Digor, had been previously studied by Innocenti *et al*. (1982) and Bigazzi *et al*. (1994). For the Digor obsidians these authors had determined a K-Ar age of 2.7 ± 0.3 Ma and a FT plateau age of 3.00 ± 0.21 Ma, respectively. The FT parameters – age and track densities – of samples I, II (W) and III (E) are very similar to those of the Yaglika – Digor obsidians. Qualitatively, also characteristics of glass – very dark, with many microlites that make difficult track counting – are very similar. The hydrography of the region is consistent with transportation of Yaglika – Digor obsidians to the Araxe river. However, it has to be pointed out that in the old Russian literature presence of an obsidian source area is reported for the region NE of Kars, near the Armenian border (R. Badalaian, personal communication). Characteristics of these glasses are unknown to us.

The present extensive FT 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 Geg4c is stratigraphically younger than sample Geg 3c, but this geological evidence was not detected by the FT analysis. These results correspond with geological observations which suggest a short duration for the volcanic activity which produced obsidians in each volcanic field. For these reasons, the use of the FT ages in this region for detailed chrono-stratigraphical reconstructions appears to have some limitations. The FT dating method yields ages whose precision is limited by the number of spontaneous tracks one can count in a reasonable time span, and it has not enough resolution for discriminating events whose ages differ by a relatively short interval of time.

5.2. Archaeometric significance

Discrimination of the various volcanic areas as potential natural sources of raw materials for tool making during prehistoric times is rather satisfactory, with some exceptions. For example, some samples from Mt. Atis yielded FT data very similar to those of the Gutansar area. Sample Xian Xian (Mt. Atis) has FT parameters similar to those of sample Sata 2b, from the Mets Satanakar volcano (Sunik Volcanic Region).

For the considerations made above, discrimination between occurrences located in the same volcanic field is more problematic. In other words, the results of the analyses of Georgian and Armenian obsidians suggest that FT dating in this region can be an efficient tool to correlate artefacts with given source areas rather than to identify specific occurrences.

Also track densities are an important factor useful for discrimination. To give an example, the Kehcut Volcanic Region obsidians mentioned above have FT ages only slightly younger than those of the Aragats Volcanic Region. However, track densities of obsidians from the first volcanics are significantly lower (by around 50 %). Another example is the very high induced track density of the South Gegham Volcanic Region obsidians, that discriminates them from all other obsidians located in the Near East.

Table 5. Fission-track parameters of obsidians from Anatolia

Source	App. Age [Ma]	Form. Age [Ma]	ρ_S [cm^{-2}]	ρ_I [cm^{-2}] (x 10^3)	D_S/D_I
Western Anatolia					
Foça	3.9	9.1	13,600	174	0.61
Galatean Massif					
Sakaeli	13.6 - 17.4	20.9 - 22.8	36,900 - 43,800	116 - 143	0.78 - 0.86
Yaglar	17.5	23.5	61,600	175	0.82
Cappadocia					
Çatköy	0.16	0.20	360	115	0.86
Acigöl - Bogazköy	0.11 - 0.13	0.11 - 0.18	240 - 340	110 - 135	0.82 - ~1
Acigöl - Kocadag	0.071	0.077	115	81.1	0.95
Acigöl - Güneydag/Korüdag	0.015 - 0.018	0.019	52 - 55	140 -181	0.73 - 0.92
Çiftlik - Göllüdag	0.92 - 1.0	0.97 - 1.3	1,990 - 2,740	106 -169	0.79 - 0.91
Çiftlik - Nenezidag	0.93	1.18	2,350	126	0.89
Hasandag	0.27	0.39	660	122	0.74
Hasan - Kayirli	1.02	1.47	2,870	141	0.81
Eastern Anatolia					
Kars - Digor	2.4	3.0	4,600	95	0.83
Kars	3.6	4.0	9,650	134	0.87
Sarikamis	2.3 - 3.9	3.5 - 5.0	4,770 - 7,070	87 - 100	0.70 - 0.89
Ikizdere	1.28 - 1.77	1.63 - 1.89	2,420 - 3,200	88.2 - 102	0.80 - 0.92
Pasinler	3.5 - 4.9	6.0 - 6.6	12,100 - 15,000	154 - 179	0.70 - 0.88
Erzurum	5.0 - 5.4	6.8 - 6.9	8,700 - 9,660	85.7 - 88.7	0.80 - 0.82
Bingöl	1.4 - 4.0	4.6	1,790 - 11,200	65.5 - 140	0.68 - 0.93
Mus	1.7 - 1.9	2.6 - 2.7	2,710 - 3,060	69.1 - 88.7	0.78 - 0.82
Nemrutdag	0.024 - 0.035	0.024 - 0.034	65 - 127	140 - 181	0.92 - ~1
Süphandag	0.068	0.068	73	52.8	~1
Meydandag	0.06 - 0.70	0.60 - 0.90	190 - 1,520	114 - 153	0.76 - 0.97

Appa. Age: apparent age. Form. Age: the corrected fission-track age, assumed here as formation age, does not refer to the full range of apparent ages for some eastern Anatolian sources. For example, the plateau age reported for Bingöl was determined for the occurrence named Çavuslar, whose parameters (app. age and track densities) are the upper limit of the range. The induced track density is referred to a standard neutron fluence of 10^{15} cm^{-2}. Detailed analytical data as well as location of obsidian outcrops quoted here have been published by Bigazzi *et al*. (1993b, 1994, 1998). From Oddone *et al*. (2000).

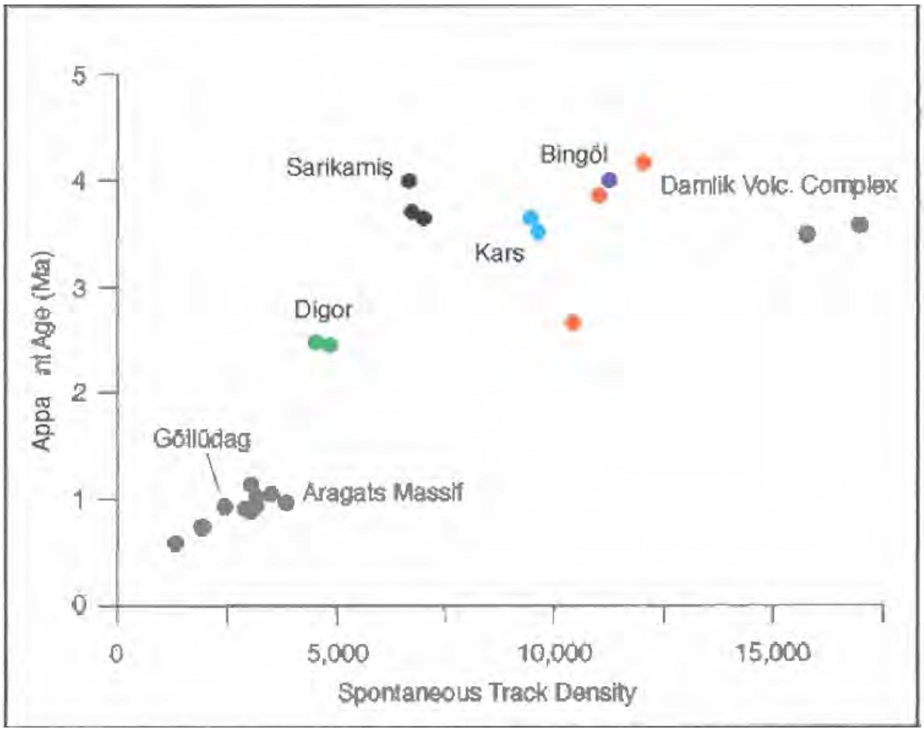

Fig. 9. Spontaneous track density – apparent age diagram for some Anatolian obsidians and those from the Damlik Volcanic Complex and from the Aragats Volcanic Region. One obsidian from the Bingöl source area and those from the Göllüdag massif are not fully discriminated from those of these Armenian volcanic areas.

The performance of FT dating for discrimination of Transcaucasian obsidians from those of the numerous potential sources located in Anatolia is rather satisfactory. FT data regarding these sources are presented in a condensed way in Table 5. In few cases Armenian and Anatolian obsidians might be confused as sources of artefacts (Fig. 9). The Aragats Volcanic Region obsidians have FT parameters similar to those of some sources located in Cappadocia, in central Anatolia. However, the relatively great distance between these potential sources makes rather unlikely superimposition of their circulation areas. Another case is the Çavuslar obsidian of the Bingöl volcanic field of eastern Anatolia, which is surprisingly similar to two obsidians from the Damlik Volcanic Complex of the Tsakhkunjats. However, it has to be pointed out that knowledge of characteristics of obsidians of the Quaternary volcanoes of the north coast of Lake Van, eastern Anatolia, is still incomplete. At the present stage it would be incautious to exclude that some of them might be confused with some Armenian obsidians.

6. Archaeological samples

The results of the analyses of the obsidians – artefacts and some pebbles from fluvial deposits – listed in Table 2 are shown in Table 6. The study of these samples was carried out in order to identify their provenance. Therefore, precision of ages is not important. For this reason the size-correction technique was applied. This choice allowed to waste significant time, considering the large number of samples to be analysed.

Table 6. Fission-track dating of Armenian obsidian artefacts and pebbles from river banks

Site	Φ ($x10^{15}$)	ρ_S	N_S	ρ_I	N_I	$P(\chi^2)$ %	D_S/D_I	A. Age (± 1σ) Ma	C. Age (± 1σ) Ma	Source
Keti E.B.										
1	2.90	3,580	119	250,500	587	99	0.82	2.07 ± 0.21	2.89 ± 0.37	Kars
2	2.90	9,460	512	427,400	757	48	0.81	3.19 ± 0.18	4.60 ± 0.33	D.V.C.
3	2.90	8,030	435	428,300	756	47	0.77	2.71 ± 0.16	4.30 ± 0.33	D.V.C.
Keti E.I.										
1	2.93	810	105	353,000	613	52	0.45	0.335 ± 0.035	1.37 ± 0.15	A.V.R.
2	2.93	5,370	310	313,200	552	34	0.89	2.50 ± 0.18	3.07 ± 0.25	Kars
3	2.93	2,320	239	343,400	599	94	0.81	0.986 ± 0.075	1.42 ± 0.11	A.V.R.
4	2.93	3,490	252	316,200	554	9	0.57	1.61 ± 0.12	4.23 ± 0.39	D.V.C.
5	2.93	2,720	314	314,700	550	98	1.00	1.26 ± 0.09	—	A.V.R.
6	2.93	3,100	112	281,700	329	48	0.73	1.61 ± 0.18	2.77 ± 0.34	Kars
7	2.93	—	—	337,600	585	17	—	—	—	A.V.R.
Horom L.B.										
1	2.93	1,460	47	229,700	267	98	0.49	0.929 ± 0.147	3.20 ± 0.58	Kars
2	2.93	6,750	390	317,600	562	25	0.86	3.10 ± 0.20	3.92 ± 0.28	D.V.C.
Horom E.I.										
A1	2.93	5,370	566	320,400	1,129	35	0.88	2.44 ± 0.13	2.96 ± 0.19	Kars
A2	2.93	4,750	326	310,000	818	30	0.86	2.24 ± 0.15	2.88 ± 0.23	Kars
B1	2.93	2,930	317	383,700	670	29	0.94	1.11 ± 0.09	1.21 ± 0.09	A.V.R.
B2	2.93	2,520	218	360,500	629	85	0.93	1.22 ± 0.10	1.37 ± 0.14	A.V.R.
B3	2.93	2,820	326	335,400	586	58	0.95	1.23 ± 0.09	1.33 ± 0.11	A.V.R.
B4	2.93	2,470	330	427,500	745	20	0.78	0.843 ± 0.056	1.30 ± 0.12	A.V.R.
B5	2.93	3,260	412	392,100	685	70	0.95	1.21 ± 0.08	1.31 ± 0.10	A.V.R.
B6	2.93	886	117	427,100	618	41	1.01	0.300 ± 0.030	—	N.G.V.R.
B7	2.93	434	114	385,100	668	17	0.31	0.166 ± 0.017	1.19 ± 0.15	A.V.R.
		7.3	4				0.92	0.0028 ± 0.0014		
Shirakavan										
1	2.90	8,050	523	355,500	630	96	0.87	3.27 ± 0.19	4.11 ± 0.26	D.V.C.
2	2.90	2.8	1	356,100	617	41	—	0.0011 ± 0.0011	—	A.V.R. ?
3	2.90	2,680	320	386,300	674	66	0.88	1.00 ± 0.07	1.24 ± 0.11	A.V.R.
4	2.90	1,900	48	247,400	288	15	0.60	1.11 ± 0.17	2.70 ± 0.45	Kars
5	2.90	2,480	269	394,600	688	57	0.81	0.909 ± 0.065	1.31 ± 0.13	A.V.R.
6	2.90	2,470	356	406,100	708	86	0.78	0.877 ± 0.057	1.34 ± 0.14	A.V.R.
7	2.90	7,780	562	425,000	750	79	0.76	2.64 ± 0.15	4.30 ± 0.34	D.V.C.
8	2.90	3,010	326	381,300	666	61	0.93	1.14 ± 0.08	1.29 ± 0.11	A.V.R.
Landjik										
1	3.04	554	251	353,200	613	85	0.39	0.237 ± 0.018	1.17 ± 0.11	A.V.R.
		8.8	4				0.92	0.0038 ± 0.0019		
2	3.04	2,450	310	350,200	611	56	0.89	1.06 ± 0.07	1.28 ± 0.13	A.V.R.
3	3.04	2,190	237	389,100	678	71	0.78	0.850 ± 0.064	1.33 ± 0.13	A.V.R.
4	3.04	2,400	347	392,400	680	13	0.83	0.932 ± 0.061	1.29 ± 0.11	A.V.R.
Akhourian										
10a	2.87	4,230	217	300,500	528	42	0.83	2.01 ± 0.16	2.79 ± 0.30	Kars
10b	2.87	3,770	204	286,500	503	20	0.79	1.88 ± 0.16	2.80 ± 0.26	Kars
10c	2.87	3,320	108	239,600	421	49	0.80	1.97 ± 0.21	2.90 ± 0.37	Kars

A. Age (C. Age): apparent (size-corrected) age.
A.V.R.: Aragats Volcanic Region (Arteni Complex); D.V.C.: Damlik Volcanic Complex; N.G.V.R.: North Gegham Volcanic Region (Alapars, Fontan, Gutansar and Atis); S.G.V.R.: South Gegham Volcanic Region (Spitaksar and Geghasar); S.V.R.: Sunik Volcanic Region (Mets Satanakar, Sevkar Complex, Bazenk); Kars: unknown source(s)

of the Kars region.

Table 6. (continued)

Site	Φ (x10^{15})	ρ_S	N_S	ρ_I	N_I	P(χ^2) %	D_S/D_I	A. Age (± 1σ) Ma	C. Age (± 1σ) Ma	Source
Tsakhkahovit										
4a	2.87	2,640	314	389,900	907	49	0.81	0.96 ± 0.06	1.39 ± 0.11	A.V.R.
4b	2.87	10,900	550	430,000	764	81	0.90	3.61 ± 0.20	4.35 ± 0.32	D.V.C.
4c	2.87	—	—	435,400	503	15	—	—	—	D.V.C.
3a	2.87	11,200	527	419,000	749	42	0.93	3.80 ± 0.22	4.37 ± 0.35	D.V.C.
3b	2.87	11	5	415,500	480	< 1	—	0.0036 ± 0.0016	—	D.V.C.
3c	2.87	12,400	536	456,200	812	48	0.94	3.87 ± 0.22	4.27 ± 0.28	D.V.C.
3d	2.87	2,730	345	362,600	633	55	0.91	1.07 ± 0.07	1.26 ± 0.10	A.V.R.
Kuchak										
1	2.87	2,250	203	562,200	652	94	0.28	0.571 ± 0.046	4.40 ± 0.39	D.V.C.
		10	9				0.90	0.0026 ± 0.0009	—	
Gegharot										
5a	2.87	11,100	522	375,500	670	47	0.97	4.22 ± 0.25	4.44 ± 0.32	D.V.C.
5b	2.87	9,945	283	341,300	1,013	15	0.92	3.95 ± 0.27	4.57 ± 0.35	D.V.C.
5c	2.87	9,270	328	354,900	631	82	0.93	3.73 ± 0.25	4.24 ± 0.32	D.V.C.
Fioletovo										
1	3.04	726	131	433,300	752	4	0.92	0.253 ± 0.024	0.292 ± 0.033	N.G.V.R.
2	3.04	378	140	709,500	820	38	0.96	0.081 ± 0.007	0.086 ± 0.009	S.G.V.R.
3	3.04	7,730	558	369,100	653	8	0.78	3.17 ± 0.18	4.83 ± 0.38	D.V.C.
Djoghaz										
1	2.90	3,700	427	268,700	708	8	0.88	1.99 ± 0.12	2.45 ± 0.18	Paravani
2	2.90	3,840	554	308.600	812	79	0.82	1.80 ± 0.10	2.51 ± 0.16	Paravani
3	2.90	3.4	1	284,300	739	79	—	0.0017 ± 0.0017	—	Paravani
4	2.90	687	124	293,600	765	71	0.31	0.335 ± 0.033	.2.48 ± 0.37	Paravani
		5.5	4				1.04	0.0027 ± 0.0013		
5	2.90	2,200	317	331,400	867	81	0.57	0.957 ± 0.063	2.52 ± 0.19	Paravani
6	2.90	5,060	455	309,900	907	93	0.95	2.36 ± 0.14	2.56 ± 0.18	Paravani
Chkalovka										
13a	2.87	566	143	773,300	894	62	0.95	0.104 ± 0.094	0.112 ± 0.011	S.G.V.R.
13b	2.87	432	101	764,800	884	38	0.95	0.080 ± 0.008	0.087 ± 0.011	S.G.V.R.
Teghut										
a	2.87	2,560	323	393,900	687	7	0.81	0.93 ± 0.06	1.34 ± 0.12	A.V.R.
b	2.87	3,180	344	421,000	735	93	0.92	1.08 ± 0.07	1.24 ± 0.10	A.V.R.
Aratashen										
A1	2.93	11,500	539	609,400	789	51	0.74	2.75 ± 0.15	4.62 ± 0.37	D.V.C.
A2	2.93	10,100	363	444,200	656	72	0.84	3.30 ± 0.22	4.40 ± 0.41	D.V.C.
B1	2.93	—	—	350,300	607	23	—	—	—	A.V.R.
B2	2.93	45	42	361,200	626	29	0.51	0.018 ± 0.003	—	A.V.R.
		13	12				1.01	0.0052 ± 0.0015	—	
B3	2.93	8.1	5	488,200	846	47	0.91	0.0024 ± 0.0011	—	N.G.V.R.
B4	2.93	948	206	475,200	825	82	0.96	0.291 ± 0.023	0.310 ± 0.031	N.G.V.R.
B5	2.93	2,180	236	379,900	662	78	0.81	0.836 ± 0.063	1.21 ± 0.13	A.V.R.
B6	2.93	5.6	3	328,400	569	86	—	0.0025 ± 0.0014	—	A.V.R.
B7	2.93	2,640	315	339,700	791	36	0.94	1.13 ± 0.09	1.24 ± 0.09	A.V.R.
Mokhrablur										
2a	2.87	1,125	203	432,300	751	2	0.95	0.371 ± 0.029	0.403 ± 0.035	N.G.V.R.
2b	2.87	11,300	531	410,500	731	43	0.95	3.93 ± 0.22	4.23 ± 0.27	D.V.C.

Table 6. (continued)

Site	Φ ($x10^{15}$)	ρ_S	N_S	ρ_I	N_I	$P(\chi^2)$ %	D_S/D_I	A. Age (± 1σ) Ma	C. Age (± 1σ) Ma	Source
Argishtikhinili										
West	2.87	5,090	239	320,000	751	55	0.84	2.27 ± 0.17	3.07 ± 0.31	Kars
East	2.87	5,070	238	263,300	465	53	0.95	2.75 ± 0.22	2.95 ± 0.27	Kars
Sardarabad										
7a	2.87	4,210	38	319,000	560	47	0.77	1.88 ± 0.32	2.99 ± 0.52	Kars
7b	2.87	2,540	221	325,300	524	46	0.95	1.11 ± 0.09	1.20 ± 0.10	A.V.R.
Chalco.	2.87	11	4	491,700	852	39	—	0.0031 ± 0.0016	—	?
Dvin										
1	3.04	776	112	432,700	626	60	0.92	0.259 ± 0.027	0.297 ± 0.036	N.G.V.R.
2	3.04	731	132	384,800	668	49	0.96	0.274 ± 0.026	0.290 ± 0.032	N.G.V.R.
3	3.04	679	103	323,900	750	49	1.01	0.303 ± 0.032	—	N.G.V.R.
Aygevan										
1	3.04	364	131	798,600	923	99	1.00	0.069 ± 0.006	—	S.G.V.R.
2	3.04	986	247	507,400	881	24	1.01	0.294 ± 0.021	—	N.G.V.R.
3	3.04	1,040	336	525,300	1216	64	0.93	0.298 ± 0.018	0.335 ± 0.024	N.G.V.R.
4	3.04	1,061	249	523,500	909	64	0.98	0.307 ± 0.022	—	N.G.V.R.
5	3.04	403	145	830,600	960	2	1.02	0.073 ± 0.007	—	S.G.V.R.
6	3.04	319	158	835,900	966	81	0.87	0.058 ± 0.005	0.073 ± 0.007	S.G.V.R.
Mtnadzor										
1	2.90	126	51	718,900	623	52	0.75	0.025 ± 0.004	0.042 ± 0.007	S.G.V.R.
2	2.90	14	5	766,400	664	9	0.63	0.0026 ± 0.0012	—	S.G.V.R.
3	2.90	11	6	678,900	549	82	0.98	0.0024 ± 0.0010	—	S.G.V.R.
4	2.90	389	217	865,300	1000	97	1.01	0.065 ± 0.05	—	S.G.V.R.
5	2.90	22	6	722,800	501	70	0.67	0.0044 ± 0.0018	—	S.G.V.R.
6	2.90	317	103	702,600	812	64	0.95	0.065 ± 0.007	0.070 ± 0.008	S.G.V.R.
7	2.90	284	115	746,800	863	50	1.01	0.055 ± 0.006	—	S.G.V.R.
Karchaghpiur										
	2.93	1,830	211	545,300	632	74	0.94	0.488 ± 0.039	0.542 ± 0.054	S.V.R.
Karkarer										
1	3.04	1,670	314	597,400	692	40	0.85	0.423 ± 0.029	0.561 ± 0.053	S.V.R.
2	3.04	618	116	592,400	685	71	0.49	0.158 ± 0.016	0.527 ± 0.056	S.V.R.
		39	27				1.02	0.0099 ± 0.0019	—	
3	3.04	1,980	322	587,500	681	50	1.00	0.510 ± 0.034	—	S.V.R.
4	3.04	463	102	587,300	679	67	0.43	0.119 ± 0.012	0.534 ± 0.092	S.V.R.
		18	10				0.86	0.0047 ± 0.0015	—	
5	3.04	1,733	219	577,400	669	42	0.89	0.454 ± 0.035	0.554 ± 0.052	S.V.R.
6	3.04	453	162	573,500	663	13	0.43	0.119 ± 0.010	0.542 ± 0.069	S.V.R.
		14	5				1.00	0.0037 ± 0.0017	—	
Zorakar										
1	2.90	2,010	218	577,100	669	71	0.95	0.504 ± 0.039	0.545 ± 0.052	S.V.R.
2	2.90	2,060	335	563,200	653	53	0.99	0.529 ± 0.036	—	S.V.R.
3	2.90	14	6	553,100	639	49	0.94	0.0038 ± 0.0015	—	S.V.R.
4	2.90	950	120	550,500	637	48	0.65	0.249 ± 0.025	0.519 ± 0.061	S.V.R.
Sisian I										
11a	2.87	2,060	372	528,300	919	37	0.98	0.556 ± 0.034	—	S.V.R.
11b	2.87	1,800	223	497,400	865	38	1.00	0.518 ± 0.039	—	S.V.R.
11c	2.87	1,730	226	536,800	902	24	0.91	0.461 ± 0.034	0.536 ± 0.045	S.V.R.
11d	2.87	1,950	246	547,500	952	57	0.99	0.507 ± 0.036	—	S.V.R.
Sisian II										
12a	2.87	1,990	216	543,900	946	<1	0.99	0.523 ± 0.043	—	S.V.R.
12b	2.87	1,910	242	521,500	907	84	0.96	0.524 ± 0.038	0.557 ± 0.050	S.V.R.

As written before, in principle an artefact should be a replica of a geological sample collected from its source. However, by experience the real situation in provenance studies of obsidian artefacts may be somewhat different from an ideal one. A certain aliquot of samples show FT parameters that do not fit well with those available in the reference data-set regarding the geological samples. Many factors may produce changes of the FT parameters. Due to low thermal stability of fission tracks, the peculiar environmental conditions experienced in the last few thousands of years by an artefacts may have produced an accelerated annealing. Accidental heating processes, due to natural causes or to human activity, may have produced total or partial annealing of pre-existing tracks.

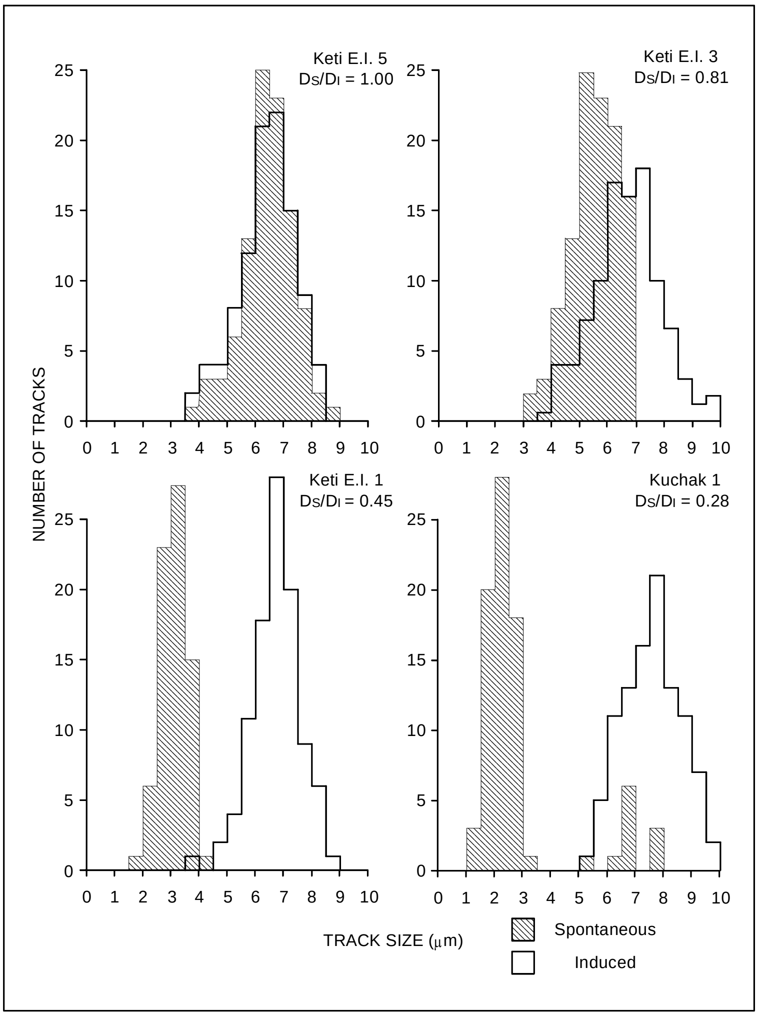

Fig. 10. The spontaneous track-size distribution reveals peculiar thermal histories experienced by artefacts. Three artefacts from the same site show different amount of track annealing, from negligible (Keti E.I. 5) up to significant (Keti E.I. 1). A fourth artefact (Kechut 1) showed a bimodal track-size distribution. This artefact suffered a recent heating event that determined intense annealing of pre-existing tracks (the smaller ones). Tracks formed after this event have normal sizes. Separation of tracks into two families – smaller tracks and larger tracks – allows determination of a 'geological' age as well as of an 'archaeological' age, respectively.

A further problem arises from incomplete knowledge of sources. Also in case of well known areas, the ancient occurrences exploited by our ancestors might be inaccessible nowadays because covered by recent alluvium, totally exhausted or disappeared due to recent human activities. An example is given by the Carpathian region (Bigazzi *et al.*, 1990). Due to sensitiveness of tracks to temperature, samples collected from different points of the same occurrence may show different annealing amounts. For these reasons, track-size measurements are of great moment for artefacts, as the analysis of the spontaneous track-size distribution is an efficient tool for deciphering peculiar thermal histories experienced by artefacts.

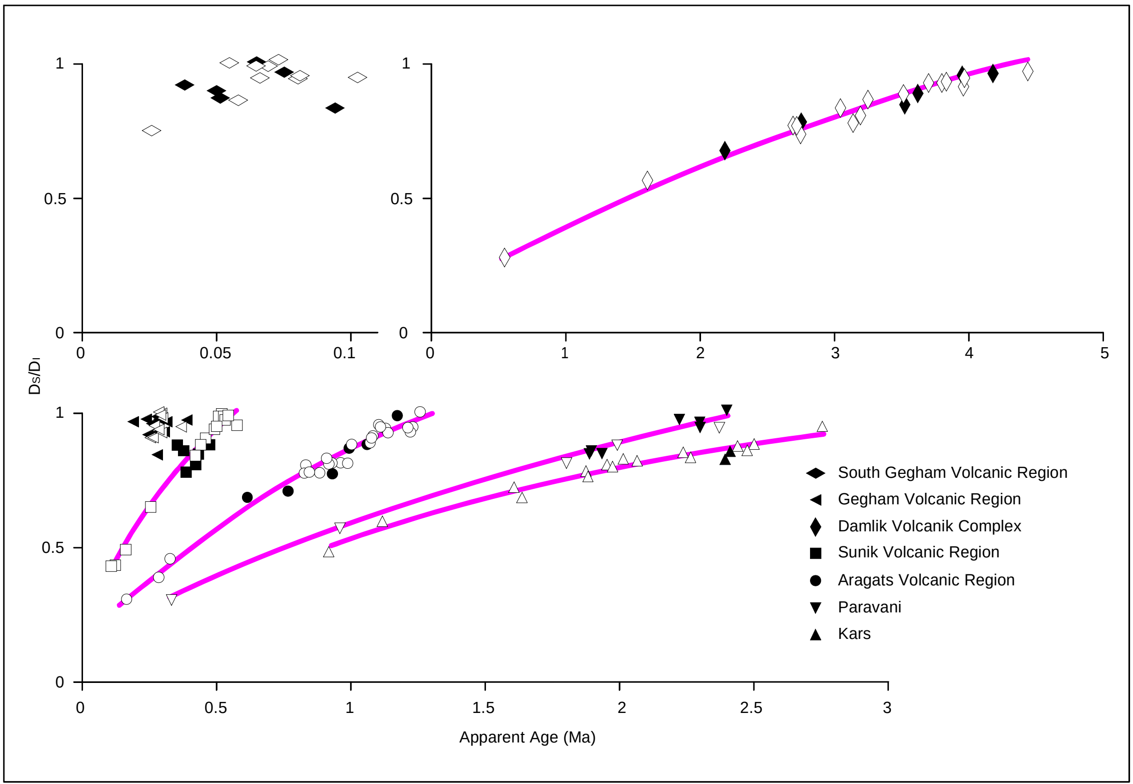

Fig. 11. Geological samples from the various Transcaucasian obsidian-bearing volcanics and artefacts originated from them show variable apparent ages and D_S/D_I ratios according to differential track-annealing suffered by glasses from the same volcanic complexes and to peculiar environmental conditions experienced by artefacts during the last thousands of years. Points corresponding to samples from the older sources distribute along age, D_S/D_I plots typical of glasses affected by variable annealing. Younger glasses – specially those from the South Gegham Volcanic Region – show a higher dispersion: in this case, due to their young age, differences of age are of the same order of the age itself and can be detected by the FT dating method.

Several examples that illustrate the considerations made above are available in the data-set of Table 6 (see also Fig. 10). Two artefacts – Keti E.I. 7 and Tsakhkahovit 4c – did not show spontaneous tracks in the observed surface. This 'zero age' is due to total annealing of spontaneous tracks produced by a recent intense heating process. In other samples – Shirakavan 2, Tsakhkahovit 3b, Djoghaz 2, Aratashen B1, Sardarabad Chalcolithic, Mtnadzor 2, 3 and Zorakar 3 – very low spontaneous track densities were determined, compared with those of the potential natural sources. In these cases, the observed tracks formed after the thermal event that erased pre-existing tracks. Therefore, the age determined for these samples is the age of the heating process. In case of a sample from excavation, it is reasonable to assume that the total annealing of tracks is related to its prehistoric use, so its age, called 'archaeological' age, refers to the corresponding stratigraphical context.

Commonly these archaeological ages are rather insignificant, as they are affected by large experimental errors due to the low number of tracks one can count. However, exist in literature cases in which these ages turned to be very important. In addition, as precision of an age is the more high the more tracks are counted, it is possible to enhance it by analysing larger glass areas. However, counting procedures involving surfaces of several square centimetres are very time consuming. They can be carried out only in very important cases.

Another case considered very rare is exemplified by a surprisingly large number of samples, considering the results obtained in other regions, in Table 6 – Horom E.I. B7, Landjik 1, Kuchak 1 (Fig. 10), Djoghaz 4, Aratashen B2, Karkarer 2, 4 and 6. In this case a thermal event produced a strong partial annealing without a full reset of the FT clock. These samples showed a characteristic bimodal track-size distribution, where pre-existing tracks (the small ones) and tracks accumulated after the event (the larger ones) coexist. Separation of tracks into two populations allows determination of a 'geological' age as well as of an archaeological age. All samples that showed a significant reduction of spontaneous mean track-size – for example Keti E.I. 1 (Fig. 10) – very probably experienced rather an intense heating short event than an accelerated continuous annealing long process due to peculiar environmental conditions. Therefore, these samples also should show bimodal track-size distributions. Actually, absence of larger tracks only means no larger tracks observed in the analysed surface. It does not mean that larger tracks do not exist.

A last case is represented by artefact Aratashen B2. In this case the geological age is meaningless (for this reason the size-correction was not applied). Due to inhomogeneous annealing, the small tracks are present only in some areas whose dimensions are difficult to be determined. Identification of the source area of this artefact, as well as of those samples that showed or no tracks or very few normal size tracks, was made, when possible, on the base of the induced track density.

Many samples showed FT parameters that are in close agreement with those referring to geological samples, whereas some showed larger annealing amounts. In such cases the application of the size-correction method allowed to point to specific sources. In an apparent age – D_S/D_I diagram (Fig. 11), points representing artefacts distribute along typical curves, such as already observed in other regions (Bellot-Gurlet *et al.*, 1999). In some cases, artefacts show annealing amounts very low or negligible, compared with geological samples. This experimental evidence is only apparently a contradiction. As commented above, also samples collected from different points of the same occurrence may show differential annealing.

Some samples are worthy of specific comments. Provenance of sample Shirakavan 2, indicated as A.V.R. ? in Table 6, is somewhat ambiguous. Although the induced track density (as well as characteristics of glass) point to the Aragats Volcanic Region, also some artefacts identified as originated from the Damlik Volcanic Complex have similar track densities. Artefact Mokhrablur 2a showed a FT age which is in close agreement with the age of sample Xian Xian from the Atis volcano. This is the unique artefact originated from the North Gegham Volcanic Region that can be for a certainty correlated with the Atis volcano instead of with the occurrences of the other volcanoes of the same region.

The only case of unidentified provenance (indicated with '?' in Table 6) refers to Sardarabad Chalcolithic. This sample suffered a recent heating event that erased pre-existing tracks and lost memory of its geological age. It was hypothesised on the base of its chemical composition that it might have been originated from the Nemrut volcano located in eastern Anatolia (C. Chataigner, personal communication). Although the induced track density (as well as characteristics of glass) are consistent with that one of a sample from Nemrut previously analysed by us (Bigazzi *et al.*, 1998), we can not state that Nemrut is the unique possible source of this artefact.

In the north western corner of Armenia the source of several samples has been indicated as 'Kars' in Table 6 (see also Fig. 3). These have homogeneous FT parameters which discriminate them from the Armenian obsidians and that are very similar to those of the obsidian pebbles of the Palaeo-Araxe river terraces (Sardarabad I and 7a and Argishtikhinili II (W), West, III (E) and East in Table 3a, 3b and 6). However, natural transportation of Digor obsidians in this area is incompatible with the hydrography of the region. Therefore, a Digor provenance of these samples, specially those collected from the Akhourian river banks, has to be excluded. These obsidians may have been originated from the source(s) located NE of Kars reported in the old Russian literature mentioned above.

7. Conclusions

The present study represents a solid contribution to a better knowledge of geochronology of Transcaucasian obsidians. Several occurrences were dated for the first time. The results obtained in this work confirm the potentiality of the FT method for dating also very young volcanics difficult to be dated using other techniques, such as those of the South Gegham Volcanic Region.

By the archaeometric point of view, the FT method is an efficient tool for discrimination of different potential source areas located in Armenia and Georgia. Discrimination of these sources from those located in Anatolia is rather satisfactory, although some of them have similar FT parameters. Discrimination of different obsidian occurrences produced by the same volcanic complex appears more problematic, due to the short time intervals in which obsidians were erupted. However, the FT data allow a certain degree of discrimination. For example, all samples from the Pokr Arteni volcano analysed in this study and in the previous one by Oddone *et al*. (2000) have ages which are similar to those of the samples collected from other occurrences of the same volcanic complex. However, the amount of partial annealing of spontaneous tracks is significantly higher. For this reason, considering the FT parameters determined on artefacts 'A.V.R.' of Table 6, only for three of them – those that, having an anomalous amount of annealing, have partially lost memory of the characteristics of the source (see also Fig. 11) – a Pokr Arteni provenance can not be excluded. The remaining A.V.R. artefacts very probably originated from the Aragats flow or from the Mets Arteni volcano.

The present study confirms the performance of the FT method for correlation of artefacts with the volcanic complexes potential natural sources of row material. Only in very few cases provenance identification turned to be ambiguous.

Contrary to what found in other sectors, such as Europe where, due to the restricted number of obsidian-bearing volcanics, artefacts from some occurrences were identified at great distances also when significantly nearer sources were present, the diffusion areas of the obsidian studied in this work appear to be related to geographic criteria. For examples, the sites located in south-eastern Armenia yielded only artefacts originated from the Sunik Volcanic Region.

Two potential sources of artefacts – the Kechut Volcanic Region and the Vardenis Volcanic Region obsidians – were not identified in the artefacts analysed in this study. This result indicates that their prehistoric use, if any, should have been rather sporadical.

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