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Chronological and chemical approaches to obsidians from Bakla Tepe and Liman Tepe, Western Anatolia

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ABSTRACT

In this study, the provenance of 42 obsidians from the Chalcolithic and Early Bronze Age levels of two settlements – Bakla Tepe and Liman Tepe – located on the Aegean coast of Anatolia were investigated with an interdisciplinary approach using fission-track (FT) dating, Instrumental Neutron Activation Analysis (INAA) and Epithermal Neutron Activation Analysis (ENAA). Some artefacts showed FT ages of a few thousand years. Apparent FT ages of the remaining samples are distributed over a wide range, from 0.53 ± 0.03 to 1.43 ± 0.20 Ma. After application of the size-correction method, most artefacts were distributed in a homogeneous group characterized by FT ages varying from 1.48 ± 0.47 to 1.80 ± 0.20 Ma, with a mean value of 1.65 ± 0.05 Ma and low induced track density corresponding to low U content. The remaining 3 samples showed relatively high induced track densities. One of them has an apparent age of 0.53 ± 0.03 Ma and a size-corrected age of 1.02 ± 0.07 Ma. The probable potential sources for the studied samples were identified as the island of Melos in the Aegean, and the central Anatolian sources – particularly the Göllüdağ complex – through comparison of the FT data. INAA and ENAA studies have been carried out on 34 artefacts at the TRIGA Mark II research reactor of the University of Pavia. The identification of the sources was attained through cluster analysis of the chemical data. These results agree fully with those obtained by FT dating: most artefacts originated from the Melos–Dhemenegaki flow, and only 3 samples from central Anatolia. The current study provides a contribution to a better understanding of the circulation of obsidians in Anatolia.

1. Introduction

Our ancestors used obsidian for tool making from the Palaeolithic period (Moutsiou, 2012). This volcanic glass is one of few materials which can be used for tracing ancient exchange networks and cultural interactions. It is an ideal material for provenance studies since its chemical and physical properties can be used for characterization of potential natural sources in distinct volcanic fields. In recent decades, international research projects have been designed to enhance knowledge of the obsidians of the Near East and Aegean and their circulation during prehistoric periods. A significant data-set is now available on the sources in the Mediterranean and adjacent regions, and on the distribution of obsidians in various settlements over a wide age range - from the Mesolithic up to the Early Iron Age (Bigazzi et al., 1995, Tykot, 1996; Bigazzi et al., 1998a,b; Badalian et al., 2001; Chataigner et al., 2003; Oddone et al., 1997; Yeğingil et al., 2002, Arias et al. 2006; Carter and Shackley, 2007; Carter and Kilikoglou, 2007; Carter, 2009; Milić, 2014; Milić, 2016; Ortega et al., 2014; Ortega et al., 2016; Ibãñez et al., 2016; Tsampiri, 2018). Nevertheless, knowledge of the Near Eastern sources cannot yet be considered exhaustive, especially in Anatolia. Some of the present authors have shown that an interdisciplinary approach using techniques based on different parameters – fission-track (FT) dating and instrumental neutron activation analysis (INAA) – is an efficient tool for identification of the provenance of artefacts, especially in the case of ambiguous source identifications and/or in the case of areas where knowledge of potential natural sources is incomplete (Oddone et al., 2003a and references therein).

Obsidian is recorded in differing amounts at every settlement due to

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Fig. 1. Map showing location of the Bakla Tepe and Liman Tepe settlements studied in this work. Obsidian-bearing volcanics of the Aegean (Melos, Antiparos and Yali/Giali) and Anatolia (Acıgöl and Göllüdağ) related to the research are also shown (Map prepared by Dr. Ümit Gündoğan).

differences in their maritime connectivity, cultural background, local habitat and external influences. There is evidence for obsidian acquisition in the Aegean from three sources, Melos (Nychia and Dhemenegaki), Yali/Giali and central Anatolia/Cappadocia (Göllüdağ and Nenezi). These sources must have played important roles, although mediated through both culture and acquisition processes and so were probably tied directly into the exchange systems linking the Cyclades, western Anatolia and central Anatolia.

Western Anatolia lay, at the closest point, 150–200 km from Melos island and more than 500 km from the central Anatolian sources. The diversity of obsidian in this region offers a good opportunity for understanding different patterns of circulation, exchange and consumption that were active simultaneously. The presence of at least three obsidian varieties in considerable quantities further underlines this belief.

The earliest use in the Aegean of obsidian identified as coming from Melos has been traced back to Upper Palaeolithic levels at Franchthi cave in the Argolid (Peloponnese) (Jacobsen, 1969; Aspinall et al., 1972). The presence of both Melian and central Anatolian obsidian from the Neolithic period in the İzmir Region revealed that both obsidian sources were used in western Anatolia, at least from the Neolithic period onwards (the first half of the 7th millennium BC and the beginning of the 6th millennium BC) (Herling et al., 2008: 55; Milić, 2014; Horejs et al., 2015: 305, 307; Horejs, 2016). The earliest use of obsidian from Melos in the İzmir Region is documented at Ulucak Höyük VI and Çukuriçi Höyük XIII (Çilingiroğlu et al., 2012: 149; Çilingiroğlu and Çakırlar 2013: 23; Horejs et al. 2015: 305; Horejs, 2016). During the Late Neolithic period (at the end of the 7th millennium BC) Melian obsidian usage is attested at the site of Araptepe (Liechter, 2002: 164), Dedecik/Heybeli Tepe (Lichter and Meriç, 2007: 385-6; Herling et al., 2008: 55; Lichter and Meriç 2012: 134), Ege Gübre (Sağlamtimur 2012: 200; Erbil 2015: 27; Milič 2014: 288), Ulucak Höyük (Çilingiroğlu et al., 2012: 148; Milič, 2014: 288), Yeşilova Höyük (Milič, 2014: 288), Kömür Burnu (Çilingiroğlu and Dinçer, 2018: 34) and Çukuriçi Höyük (Horejs, 2012: 120-121; Milič, 2014: 288). Among these sites, at Çukuriçi Höyük, Melian obsidian reached up to 89% of the chipped stone artefacts during the Late Neolithic (Horejs et al., 2015: 305). The use of Melian obsidian at Çukuriçi Höyük continued until the end of the Early Bronze Age (Bergner et al., 2009; Galik and Horejs, 2011: 88-89; Knitter et al., 2012: 362). Apart from Melian obsidian, central Anatolian obsidian (Göllüdağ, Nenezi and Acıgöl) was also used both in western Anatolia and the Aegean islands from the end of the seventh millennium BC (Carter and Kilikoglou, 2007; Bergner et al., 2009: 7). However, central Anatolian obsidians were attested in the Neolithic layers only at Çukuriçi Höyük and Ege Gübre (Sağlamtimur, 2012: 200; Erbil, 2015: 27, 31). This evidence reflects some of the earliest contacts between the İzmir Region, the Cyclades and central Anatolia during the Neolithic Period.

Obsidian use increases in the region during the Chalcolithic period. Both Melian and central Anatolian obsidians were used during this period. The Early Bronze Age data from western Anatolian sites provides clear evidence for the variant forms and ways that obsidian was circulated throughout the Aegean. As in the Neolithic and Chalcolithic periods, there is an uneven distribution of the resource, with a selected range of coastal sites acting as nodal points in long-distance exchange networks. During the first half of the 3rd Millennium BC, there seem to be a sharp increase in the use of Melian obsidian in western Anatolia. By the beginning of the second half of the Millennium however, there is growing evidence (macroscopic studies) for the use of central Anatolian sources as well. At both sites of Bakla Tepe and Liman Tepe the use of obsidian is evidenced from the earliest periods of occupation onwards (i.e. 5th Millennium BC for Liman Tepe and 4th Millennium BC for Bakla Tepe) (Kolankaya-Bostancı, 2004: 164-182, 183-186). An interdisciplinary approach is used in this study to analyse obsidian artefacts from the Chalcolithic and Early Bronze Age levels of the two settlements of Bakla Tepe and Liman Tepe in the İzmir Region (western Anatolia), in order to identify their provenance and put forth a better understanding of exchange networks around the Aegean and Anatolian cultural spheres during these periods.

2. Potential natural sources of obsidian around the aegean and anatolia

There are various obsidian-bearing volcanics around the Aegean and Anatolia. Three sources in the Aegean islands are located at Melos, Antiparos and Yali/Giali (Fig. 1). In Anatolia, obsidian-bearing volcanics cover large areas. Whereas in western Anatolia there are no known obsidian sources for tool making, potential sources are present in northern, central and eastern Anatolia. Since the pioneering work of Renfrew et al. (1966), Anatolian obsidians have been studied by several authors (Balkan-Atlı et al., 1999; Balkan-Atlı and der Aprahamian, 1998; Conolly, 2003; Carter et al., 2006). Descriptions and maps showing the location and stratigraphical relationships of the studied obsidian occurrences of the Near East are reported in various review articles (Ercan et al., 1996; Bigazzi et al., 1998a,b; Poidevin, 1998).

Northern Anatolia – Two sources recognized in the Galata massif at Yağlar and Sakaeli, northwest and north of Ankara (Keller and Seifried, 1990), were the westernmost archaeologically important obsidians of Anatolia.

Central Anatolia – The main sources located in Cappadocia, in the Aksaray-Nevşehir-Niğde triangle, are the large caldera along the Acıgöl-Nevşehir road (Acıgöl obsidians) and the Göllüdağ and Nenezidağ volcanic complexes (commonly referred to as Çiftlik obsidians, after the name of the town located few kilometres south of these volcanoes) (Bigazzi et al., 1993b; Poidevin, 1998). Minor occurrences are also recognized on the slopes of the Hasandağ volcano, south west of Çiftlik.

Eastern Anatolia – Obsidians are recognized in large volcanic areas in eastern Anatolia. Classical sources, introduced since the 1960s (Renfrew et al., 1966), are Kars, Bingöl, Sarıkamış, Erzincan, Nemrutdağ, Süphandağ, and Meydandağ. Other sources more recently studied are Erzurum, Pasinler, Muş, Tendürek and İkizdere (see Poidevin, 1998; Ercan et al., 1996, with references).

In western Anatolia, Schliemann quoted F. Calvert as having located a source near Medje on the road from Assos to Ayvacık (Schliemann, 1880: 247). In addition to this, Mellaart discovered an obsidian source at Düvertepe which is situated between Balıkesir and Kütahya (Mellaart, 1957: 79). These obsidians are not suitable for flaking. In 1964 Phillipson visited Foça (north of İzmir) and found another obsidian source. The small deposits of Kütahya, Kalavbalık valley near Eskişehir and Foça are not well known and samples collected today from these deposits appear unsuitable for tool making; therefore prehistoric exploitation of these obsidians appears unlikely (Ercan et al., 1996: 506).

In summary, there is no valuable obsidian source in western Anatolia. Due to this, western Anatolian communities had to find more readily useable obsidian sources in order to make their implements. Hence, various obsidian sources were used by prehistoric inhabitants of the region, and the use of each of these sources changed through time.

The FT and INAA data-set on geological obsidians considered in this work is available from Bigazzi et al., (1986), Arias et al., (2006) for Aegean obsidians, and from Bigazzi et al., (1993a, 1998, 1994), Oddone et al. (1997) and Yeğingil et al., (2002) for Anatolian obsidians.

3. Bakla tepe and liman tepe – Archaeological context

3.1. Bakla Tepe

Bakla Tepe is situated at the northern entrance to the former village of Bulgurca in the Menderes district, south of İzmir. The site is now submerged under the waters of the Tahtalı Dam (Erkanal, 1999a, 1999b, 2008; Erkanal and Özkan, 1997, 1998, 1999, 2000; Erkanal and Şahoğlu, 2012; Gündoğan et al., 2019; Şahoğlu, 2008a,b, 2016; Şahoğlu and Tuncel, 2014; Tuğcu, 2019a).

The excavations revealed remains of Late Chalcolithic, Early Bronze Age, Late Bronze Age, Roman and Early Byzantine periods. The Late Chalcolithic settlement at Bakla Tepe covers an area of c. 300 m in diameter and is one of the largest settlements of this period in the entire Aegean area. The excavations revealed an open settlement with wattle-and-daub architecture consisting of grilled plan, apsidal and round structures (Erkanal and Özkan, 1999). Late Chalcolithic layers also contained many infant burials, mainly in big jars buried under the floors of the houses. This period of the settlement can be dated to the second half of the 4th millennium BC (Şahoğlu and Tuncel, 2014).

The Early Bronze Age layers were located on the summit of the mound as well as on its eastern and south-eastern slopes. The Early Bronze Age 1 settlement on the mound has two phases and is contemporary with Liman Tepe VI and Troy I (see Kolankaya – Bostancı, 2006 for an account of obsidian finds from the site). The settlement plan consists of long rectangular buildings (Gündoğan et al., 2019). The extramural cemetery of this settlement was also investigated on the eastern slope of the mound (Şahoğlu, 2016). This cemetery consisted of simple pit, pithos and cist graves cut into the Late Chalcolithic settlement. Finds from the settlement and the cemetery reflect a local western Anatolian character with strong maritime connections with the Aegean (Şahoğlu, 2016).

The Early Bronze Age 2/3 cemetery which was uncovered on the south-eastern slope of the mound is important for the chronological correlations of the Aegean and Anatolia (Şahoğlu, 2016). The Early Bronze Age cemeteries are important as they display links with central Anatolia, mainland Greece and the Cycladic Islands in terms of their burial types and finds.

3.2. Liman Tepe

Liman Tepe is situated in the Urla district of İzmir. The site is located on a promontory on the northern coast of Urla Peninsula. The site has been continuously inhabited from the Neolithic times through to the present day (Erkanal and Erkanal, 1983; Erkanal and Günel, 1996, 1997; for the EBA chronology of Liman Tepe, cf. Şahoğlu, 2005b: Fig. 2).

The Neolithic period is represented through a handful of probable stray finds. Although the Chalcolithic period was investigated in a limited area, it yielded spectacular finds such as pattern burnished pottery, figurines, obsidian arrowheads and marble vessels reflecting strong links especially with the Cyclades (Tuncel and Şahoğlu, 2017). The following EB 1 period reflects a settlement consisting of insulae of row houses, surrounded with a strong fortification wall. During this period Liman Tepe reveals extensive maritime connections, especially with the Cyclades. The strong fortification system with horseshoe shaped bastion dating to the beginning of the Early Bronze Age 2 and the "central monumental structure" of the Late Early Bronze Age 2 demonstrate the existence of a powerful and well-organised settlement at Liman Tepe during this period (Erkanal, 1996, 1999c, 2001; Şahoğlu, 2005a, 2005b). The Early Bronze Age 3 period could only be investigated in a limited area and provided scant architectural features.

4. Obsidian industries of bakla tepe and liman tepe

The chipped stone industry from Bakla Tepe and Liman Tepe uses both chert and obsidian. Chert dominated the lithic industries of these sites in the İzmir Region during the Chalcolithic and Early Bronze 1. However, there is a tendency of increase in the use of obsidian, from the Late Chalcolithic to the later phases of the Early Bronze 2 period. The proportion of obsidian in Early Bronze 1, in comparison to the Late Chalcolithic, increased from 25% to 46% in Bakla Tepe, and to 54% in Liman Tepe (Kolankaya-Bostancı, 2006: 166-167). Later in the Early Bronze 2, the proportion of obsidian increased to 70% in Liman Tepe. The proportions of obsidian types are listed in Table 1.

The obsidian artefacts from Bakla Tepe and Liman Tepe provide data that can produce insights into the exchange and usage of obsidian

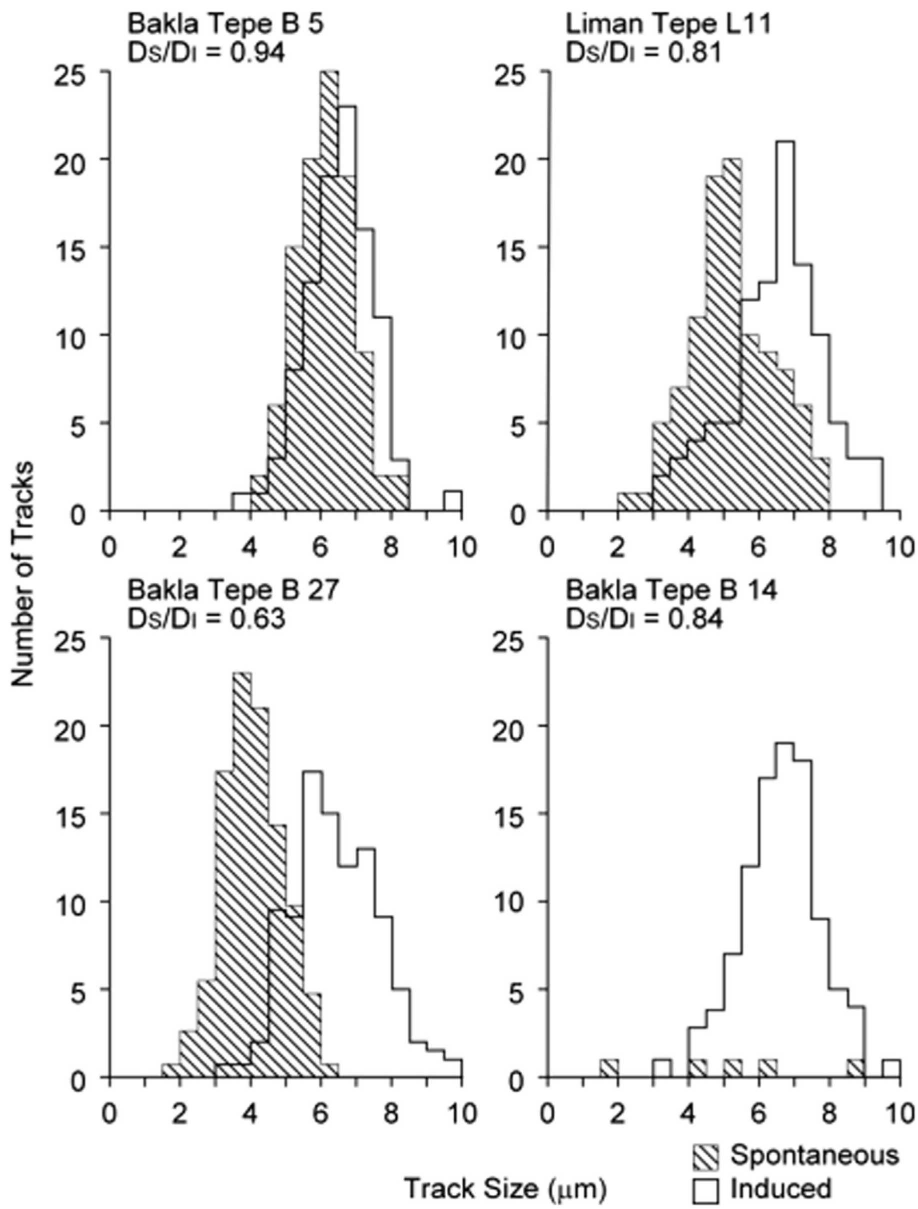

Fig. 2. Obsidian artefacts show different reduction of the mean sizes of the spontaneous tracks compared to those of the induced tracks (assumed as reference undisturbed tracks) according to differential annealing experienced during geological times, from rather negligible (B 5), medium (BL 11) up to rather intense (B 27). Artefact B 14 showed only very few tracks. Following the common interpretation this artefact experienced a heating event during its usage, which erased pre-existing tracks. However, its age also agrees with the ages of the youngest obsidians of the Acıgöl caldera, according to the attribution made by INAA.

in western Anatolia within its wider Aegean and Anatolian context. Analysis of Late Chalcolithic and Early Bronze Age artefacts from these two sites demonstrates that obsidian use was proportionally lower than in the Cyclades and southern Greece where obsidian was dominant in chipped stone tool assemblages. In the İzmir Region, obsidian penetration is similar to that of other parts of the eastern Aegean. On the other hand, the increase in the proportion of obsidian from the Late Chalcolithic to the later phases of the Early Bronze 2 period indicates an expanding trade system and implies technological and economic adjustments.

At Bakla Tepe, both Melian and central Anatolian obsidians were used for making tools during all periods. On the other hand, Melian obsidian usage is more common than central Anatolian sources. Macroscopic analysis revealed that the quantity of central Anatolian obsidian declined during the Early Bronze Age in contrast to the Late Chalcolithic (Kolankaya-Bostancı, 2006: 154-155, 167). It seems that, in the wider İzmir Region, central Anatolian obsidian was imported more in the Late Chalcolithic phases and less in the Early Bronze Age 1 and early 2, but by the later phases of the Early Bronze Age 2 period there was a sharp increase in using central Anatolian obsidian again

Table 1
The macroscopic analysis of obsidian types in Bakla Tepe and Liman Tepe from Late Chalcolithic to Early Bronze Age 2 period.

	Bakla Tepe Late Chalcolithic	*Bakla Tepe* Early Bronze Age 1	*Liman Tepe* Early Bronze Age 1	*Liman Tepe* Early Bronze Age 2
Melian	73%	86%	77%	53%
Central Anatolian	27%	14%	23%	47%

Table 2
Fission-track analysis of artefacts from Bakla Tepe and Liman Tepe settlements.

Sample	Box Number	ρ_S [cm^{-2}]	N_S	ρ_I [cm^{-2}]	N_I	$p(\chi^2)$ %	D_S/D_I	App. Age (± 1σ) [Ma]	Corr.Age (± 1σ) [Ma]	Source
Bakla Tepe										
B 2	30,032	970	55	110,200	548	64	0.70	0.808 ± 0.114	1.50 ± 0.23	Melos
B 5	16,511	1540	59	95,500	1077	97	0.94	1.43 ± 0.20	1.58 ± 0.22	Melos
B 6	27,020	1340	57	94,000	552	4	0.85	1.31 ± 0.18	1.70 ± 0.25	Melos
B 7	16,369	–	–	92,300	455	37	–	–	–	Dark
B 8	27,189	–	–	101,700	627	86	–	–	–	Dark
B 10	30,076	1490	94	112,000	839	63	0.83	1.22 ± 0.13	1.67 ± 0.20	Melos
B 11	27,174	–	–	99,800	492	80	–	–	–	Arch.
B 13	26,041	–	–	96,600	524	68	–	–	–	Dark
B 14	16,609	24.8	8	268,900	1246	10	0.63	0.0085 ± 0.0030	0.019 ± 0.009	Arch.
B 15	28,045	12.3	2	104,700	516	82		0.0108 ± 0.0076		Arch.
B 17	22,321			85,000	524	91	–	–	–	Arch.
B 18	16,604	1156	57	94,100	587	40	0.82	1.13 ± 0.16	1.60 ± 0.23	Melos
B 19	16,992	1910	369	330,900	1118	99	0.68	0.530 ± 0.032	1.02 ± 0.07	G.D.
B 20	16,177	14.5	5	108,700	536	51	–	0.0122 ± 0.0055	–	Arch.
B 21	16,652	–	–	110,500	327	–	–	–	–	Dark
B 23	16,656	1109	41	116,300	1158	88	0.68	0.875 ± 0.139	1.72 ± 0.30	Melos
B 25	28,032	1188	41	101,900	1005	65	0.78	1.08 ± 0.17	1.65 ± 0.29	Melos
B 26	16,130	1321	57	104,900	576	98	0.82	1.16 ± 0.16	1.64 ± 0.24	Melos
B 27	16,114	859	127	110,200	1369	< 1	0.63	0.715 ± 0.068	1.61 ± 0.17	Melos
B 28	16,128	–	–	104,600	465	98	–	–	–	Dark
B 29	26,086	1379	68	98,500	566	71	0.84	1.29 ± 0.17	1.74 ± 0.25	Melos
B 30	27,265	1518	128	120,500	1053	71	0.80	1.16 ± 0.11	1.70 ± 0.18	Melos
B 31	26,055	–	–	102,800	102	18	–	–	–	Dark
B 32	28,183	1217	15	94,400	237	80	0.79	1.18 ± 0.31	1.78 ± 0.66	Melos
B 33	28,220	947	45	117,300	1370	48	0.62	0.742 ± 0.112	1.69 ± 0.30	Melos
B 34	30,058	1420	70	115,800	578	99	0.81	1,13 ± 0.14	1.61 ± 0.20	Melos
B 35	27,283	1332	43	112,000	1380	9	0.78	1.11 ± 0.17	1.77 ± 0.28	Melos
B 36	27,292	–	–	91,800	500	32	–	–	–	Dark
B40d	26,057	1,438	39	118,200	1165	85	0.82	1.13 ± 0.18	1.57 ± 0.28	Melos
Liman Tepe										
L 1	28147/5	–	–	101,000	498	6	–	–	–	Dark
L 2	27294/1	–	–	92,300	455	86	–	–	–	Dark
L 3	28199/8	1250	102	125,900	627	61	0.72	0.911 ± 0.097	1.63 ± 0.19	Melos
L 4	27206/4	–	–	97,600	481	36	–	–	–	Dark
L 5	8338/2	939	25	98,800	541	62	0.72	0.873 ± 0.178	1.53 ± 0.33	Melos
L 6	28162/2	1453	101	115,600	1154	6	0.77	1.15 ± 0.12	1.80 ± 0.21	Melos
L 7	27181/3	–	–	87,600	216	19	–	–	–	Dark
L 8	8344/1	1324	62	107,600	671	49	0.85	1.13 ± 0.15	1.49 ± 0.21	Melos
L 9	8382/5	1440	110	102,300	1052	72	0.83	1.26 ± 0.13	1.72 ± 0.19	Melos
L 10	28254/6	–	–	86,200	320	11	–	–	–	Dark
L 11	27245/1	1450	224	112,600	1321	36	0.81	1.18 ± 0.09	1.69 ± 0.16	Melos
L 12	7372/4	930	11	93,200	464	92	0.76	0.916 ± 0.279	1.48 ± 0.47	Melos
L 13	27321/1	14.6	3	307,000	1067	98	–	0.0044 ± 0.0025	–	Arch.

$\rho_S(\rho_I)$: spontaneous (induced) track density; N_S (N_I): spontaneous (induced) track counted; $p(\chi^2)$: probability of obtaining χ^2 value testing induced track counts against a Poisson distribution; D_S/D_I: spontaneous to induced track-size ratio; App. Age: apparent age; Corr. Age.: size-corrected age. 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 $1.85 \times 10^{15}\ cm^{-2}$.

(Kolankaya-Bostancı, 2006: 144). There is a general decline in usage of Melian obsidian by the end of the Early Bronze 2 period. This situation can be related to changes through time in socio-political and economic relationships within and between societies participating in the procurement system.

In terms of technology, Bakla Tepe and Liman Tepe obsidian assemblages reflect nearly all phases of the reduction sequences represented by cores, debris, blanks and tools. The quantity of core preparation elements justifies the conclusion that most of the obsidian blades were produced on the sites, at least during the Early Bronze 1 period.

The lithic assemblages at these sites were dominated by end products. Considering the low numbers of cores, it can be suggested that, during the Late Chalcolithic and Early Bronze Age, obsidian was partially worked at both Bakla Tepe and Liman Tepe. Non-cortical debris indicates obsidian was brought to site as decorticated cores. Cores were shaped on the site after they had been decorticated elsewhere. The data from Bakla Tepe and Liman Tepe have demonstrated that there were no changes in the morphology and proportion of various tool types from the Late Chalcolithic till the end of the Early Bronze 2 period. Furthermore, the flow of obsidian into these sites seems to have been continuous from the Late Chalcolithic to the end of Early Bronze Age 2, and there was also no change in knapping techniques throughout these periods.

In the earlier phases of the Early Bronze Age at Bakla Tepe, the production activities were carried out in the open spaces between the buildings and the fortification system (Gündoğan et al., 2019: 1103–1104). An obsidian workshop was recognized outside the citadel during the later phase of the settlement (Kolankaya-Bostancı, 2006: 222-224).

On the other hand in Liman Tepe, obsidian flaking was done in the buildings, which are characterized as “workshop houses” where both production and domestic activities took place (Erkanal et al., 2004: 167; Erkanal and Şahoğlu, 2016; Kouka, 2009).

At these two sites the production and use of obsidian implements are spatially interwoven with a range of domestic activities. Bakla Tepe and Liman Tepe Early Bronze Age communities need obsidian for special purpose tools as unretouched cutting implements. The most common artefact types in the obsidian assemblage from Bakla Tepe and Liman Tepe are the prismatic blade and bladelets. These pieces were

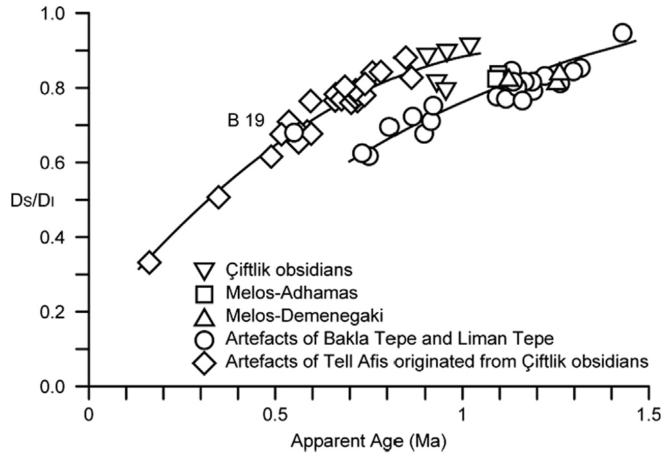

Fig. 3. Diagram apparent age – spontaneous to induced track size ratio of artefacts from Bakla Tepe and Liman Tepe and of the Melos and Göllüdağ obsidians. Artefacts from the Tell Afis settlement (Syria) identified as originating from the Göllüdağ obsidians (Bigazzi et al., 2003b, 2007) are also included.

employed in domestic activities such as food preparation, craft working or even reaping the cereals, rather than in ceremonial or ritual activities.

5. Analytical techniques and results

Since the early applications of the FT dating, some authors (Suzuki, 1969; Durrani et al., 1971; Arias-Radi et al., 1972) have shown that this may be an efficient technique to discriminate between the potential natural sources and to correlate the obsidian artefacts with them. Applying this in different geographic areas proved the potential of this method, based on comparison of the FT parameters (Bigazzi and Radi, 1998; Bigazzi et al., 1990, 1992, 19931, 1994, Badalian et al., 2001. In this work, FT dating was applied to 42 artefacts.

Among the various analytical methods based on the study of the physical and chemical properties of the glass that have been tested for provenance studies of obsidian artefacts, chemical characterization using major, minor and trace elements is nowadays the most widely diffused technique. Different analytical approaches, such as X-ray fluorescence, instrumental neutron activation analysis or inductively coupled plasma mass spectrometry, can also be used. In this study, the instrumental neutron activation analysis (INAA) introduced by Gordus et al. (1968) and Aspinall et al. (1972) was applied to 34 artefacts. INAA is a very sensitive technique suitable for the determination of many chemical elements.

Table 3
Major (as oxide,%), minor and trace (μg/g) element contents in archaeological obsidians.

Bakla Tepe

Sample	B2	B5	B6	B8	B10	B11	B14
SiO_2	66.96 ± 0.08	66.94 ± 0.09	66.95 ± 0.07	66.97 ± 0.07	66.96 ± 0.09	66.95 ± 0.02	75.38 ± 0.02
TiO_2	0.181 ± 0.008	0.189 ± 0.004	0.186 ± 0.002	0.182 ± 0.004	0.184 ± 0.003	0.185 ± 0.003	0.063 ± 0.005
Al_2O_3	14.04 ± 0.04	14.03 ± 0.03	14.08 ± 0.04	14.05 ± 0.02	14.02 ± 0.03	14.06 ± 0.03	13.03 ± 0.02
Fe_2O_3	1.333 ± 0.003	1.344 ± 0.006	1.341 ± 0.002	1.342 ± 0.004	1.341 ± 0.008	1.342 ± 0.002	1.001 ± 0.006
MnO	0.0777 ± 0.0006	0.0775 ± 0.0005	0.0776 ± 0.0007	0.0778 ± 0.0003	0.0776 ± 0.0008	0.0779 ± 0.0003	0.086 ± 0.007
MgO	0.197 ± 0.006	0.197 ± 0.005	0.198 ± 0.003	0.197 ± 0.004	0.196 ± 0.003	0.198 ± 0.002	0.050 ± 0.004
CaO	1.083 ± 0.004	1.092 ± 0.005	1.083 ± 0.006	1.086 ± 0.005	1.086 ± 0.004	1.085 ± 0.002	0.42 ± 0.03
Na_2O	3.32 ± 0.06	3.34 ± 0.07	3.35 ± 0.08	3.33 ± 0.03	3.34 ± 0.04	3.34 ± 0.06	3.99 ± 0.04
K_2O	2.58 ± 0.08	2.52 ± 0.04	2.51 ± 0.02	2.54 ± 0.04	2.56 ± 0.03	2.52 ± 0.02	4.80 ± 0.05
Sc	1.86 ± 0.03	1.85 ± 0.04	1.84 ± 0.04	1.86 ± 0.05	1.84 ± 0.04	1.87 ± 0.09	1.12 ± 0.04
Cr	0.824 ± 0.006	0.826 ± 0.006	0.828 ± 0.008	0.829 ± 0.002	0.826 ± 0.003	0.827 ± 0.002	2.78 ± 0.04
Co	1.129 ± 0.003	1.099 ± 0.002	1.095 ± 0.009	1.108 ± 0.002	1.108 ± 0.005	1.103 ± 0.008	3.29 ± 0.05
Zn	33.8 ± 0.8	35.7 ± 0.5	35.5 ± 0.2	35.0 ± 0.4	35.8 ± 0.7	35.2 ± 0.3	45.3 ± 0.2
Ni	3.9 ± 0.6	3.7 ± 0.4	3.2 ± 0.7	3.8 ± 0.4	3.6 ± 0.3	3.5 ± 0.2	4.1 ± 0.4
Ga	5.68 ± 0.02	5.70 ± 0.03	5.54 ± 0.09	5.64 ± 0.05	5.61 ± 0.07	5.60 ± 0.03	21.03 ± 0.04
As	2.40 ± 0.05	2.41 ± 0.07	2.40 ± 0.06	2.40 ± 0.07	2.42 ± 0.05	2.43 ± 0.03	1.90 ± 0.01
Se	1.47 ± 0.02	1.46 ± 0.02	1.42 ± 0.01	1.44 ± 0.05	1.47 ± 0.04	1.47 ± 0.02	1.23 ± 0.06
Rb	113.3 ± 0.1	116.8 ± 0.8	116.7 ± 0.5	108.9 ± 0.7	107.9 ± 0.7	112.0 ± 0.5	238.0 ± 0.2
Sr	100.0 ± 0.2	99.9 ± 0.3	100.1 ± 0.7	101.0 ± 0.9	102.0 ± 0.7	100.3 ± 0.6	3.89 ± 0.04
Y	15.89 ± 0.05	15.90 ± 0.06	15.53 ± 0.06	15.88 ± 0.02	15.80 ± 0.02	15.78 ± 0.04	34.03 ± 0.09
Zr	120.45 ± 0.04	120.57 ± 0.03	120.75 ± 0.05	120.59 ± 0.09	120.44 ± 0.02	120.65 ± 0.07	86.10 ± 0.04
Nb	10.1 ± 0.3	10.2 ± 0.3	10.6 ± 0.4	10.1 ± 0.5	10.4 ± 0.4	10.8 ± 0.2	32.9 ± 0.3
Sb	0.125 ± 0.009	0.127 ± 0.001	0.126 ± 0.005	0.126 ± 0.002	0.127 ± 0.007	0.128 ± 0.009	0.569 ± 0.007
Cs	2.94 ± 0.08	2.96 ± 0.03	2.98 ± 0.04	2.96 ± 0.04	2.97 ± 0.08	2.96 ± 0.05	14.1 ± 0.4
Ba	547.4 ± 0.3	547.6 ± 0.8	546.9 ± 0.8	547.5 ± 0.4	547.3 ± 0.3	547.1 ± 0.2	9.5 ± 0.3
La	24.64 ± 0.05	24.76 ± 0.07	24.59 ± 0.06	24.66 ± 0.09	24.66 ± 0.07	24.64 ± 0.04	17.6 ± 0.2
Ce	33.77 ± 0.06	34.36 ± 0.03	34.49 ± 0.05	34.21 ± 0.04	34.21 ± 0.03	34.32 ± 0.06	27.8 ± 0.2
Nd	14.73 ± 0.07	14.79 ± 0.03	14.82 ± 0.03	14.78 ± 0.05	14.78 ± 0.04	14.80 ± 0.02	20.6 ± 0.4
Sm	3.54 ± 0.09	3.80 ± 0.07	3.83 ± 0.02	3.06 ± 0.06	3.16 ± 0.05	3.36 ± 0.03	3.73 ± 0.05
Eu	0.404 ± 0.005	0.419 ± 0.006	0.417 ± 0.006	0.415 ± 0.009	0.414 ± 0.007	0.416 ± 0.003	0.04 ± 0.002
Gd	4.09 ± 0.05	3.94 ± 0.03	3.93 ± 0.06	3.92 ± 0.03	3.97 ± 0.08	3.97 ± 0.04	5.98 ± 0.04
Tb	0.680 ± 0.006	0.679 ± 0.008	0.684 ± 0.004	0.687 ± 0.003	0.681 ± 0.002	0.682 ± 0.002	1.10 ± 0.03
Dy	3.71 ± 0.05	3.72 ± 0.04	3.78 ± 0.06	3.719 ± 0.005	3.712 ± 0.005	3.714 ± 0.004	6.75 ± 0.03
Ho	0.91 ± 0.03	0.90 ± 0.04	0.92 ± 0.04	0.90 ± 0.05	0.91 ± 0.02	0.89 ± 0.04	1.53 ± 0.04
Tm	0.30 ± 0.02	0.31 ± 0.06	0.33 ± 0.03	0.32 ± 0.04	0.31 ± 0.02	0.32 ± 0.06	0.63 ± 0.03
Yb	1.75 ± 0.05	1.74 ± 0.02	1.69 ± 0.06	1.73 ± 0.03	1.75 ± 0.05	1.71 ± 0.02	4.05 ± 0.05
Lu	0.269 ± 0.007	0.268 ± 0.006	0.262 ± 0.003	0.267 ± 0.004	0.266 ± 0.003	0.264 ± 0.006	0.51 ± 0.06
Hf	3.16 ± 0.06	3.20 ± 0.05	3.19 ± 0.03	3.19 ± 0.07	3.18 ± 0.04	3.17 ± 0.03	0.99 ± 0.01
Ta	0.805 ± 0.004	0.803 ± 0.003	0.799 ± 0.006	0.802 ± 0.007	0.800 ± 0.005	0.797 ± 0.004	3.91 ± 0.04
Th	10.72 ± 0.02	10.78 ± 0.03	10.77 ± 0.04	10.77 ± 0.04	10.76 ± 0.03	10.73 ± 0.09	34.04 ± 0.02
U	2.84 ± 0.02	2.89 ± 0.02	2.91 ± 0.05	2.93 ± 0.04	2.88 ± 0.03	2.89 ± 0.02	12.90 ± 0.03

Table 4
Major (as oxide,%), minor and trace (μg/g) element contents in archaeological obsidians.

Bakla Tepe							
Sample	B15	B17	B18	B19	B20	B21	B23
SiO_2	66.94 ± 0.04	66.96 ± 0.07	66.93 ± 0.08	72.53 ± 0.04	66.84 ± 0.02	66.92 ± 0.08	66.96 ± 0.08
TiO_2	0.183 ± 0.002	0.183 ± 0.004	0.183 ± 0.003	0.124 ± 0.008	0.061 ± 0.003	0.184 ± 0.003	0.181 ± 0.002
Al_2O_3	14.07 ± 0.06	14.05 ± 0.02	14.03 ± 0.06	13.71 ± 0.04	13.07 ± 0.04	14.06 ± 0.05	14.03 ± 0.06
Fe_2O_3	1.342 ± 0.003	1.343 ± 0.004	1.341 ± 0.009	1.048 ± 0.005	1.00 ± 0.09	1.342 ± 0.002	1.341 ± 0.002
MnO	0.0774 ± 0.0004	0.0779 ± 0.0003	0.0776 ± 0.0004	0.080 ± 0.005	0.086 ± 0.007	0.0776 ± 0.0003	0.0776 ± 0.0003
MgO	0.193 ± 0.001	0.196 ± 0.002	0.199 ± 0.005	0.080 ± 0.003	0.050 ± 0.004	0.196 ± 0.002	0.197 ± 0.005
CaO	1.085 ± 0.008	1.087 ± 0.002	1.085 ± 0.009	0.582 ± 0.002	0.42 ± 0.03	1.087 ± 0.007	1.086 ± 0.005
Na_2O	3.34 ± 0.03	3.34 ± 0.06	3.36 ± 0.09	4.06 ± 0.05	3.99 ± 0.04	3.36 ± 0.06	3.35 ± 0.05
K_2O	2.53 ± 0.08	2.52 ± 0.02	2.53 ± 0.03	4.98 ± 0.07	4.80 ± 0.05	2.54 ± 0.02	2.56 ± 0.07
Sc	1.84 ± 0.04	1.85 ± 0.03	1.84 ± 0.04	1.62 ± 0.04	1.12 ± 0.03	1.86 ± 0.06	1.84 ± 0.02
Cr	0.826 ± 0.005	0.826 ± 0.002	0.821 ± 0.005	2.88 ± 0.03	2.78 ± 0.04	0.825 ± 0.006	0.827 ± 0.006
Co	1.105 ± 0.004	1.103 ± 0.008	1.105 ± 0.004	1.613 ± 0.007	3.30 ± 0.03	1.103 ± 0.007	1.105 ± 0.006
Zn	35.1 ± 0.4	35.90 ± 0.03	35.1 ± 0.4	35.0 ± 0.2	35.3 ± 0.3	35.2 ± 0.3	35.2 ± 0.3
Ni	3.8 ± 0.1	3.5 ± 0.2	3.6 ± 0.4	5.1 ± 0.4	4.2 ± 0.3	3.5 ± 0.2	3.6 ± 0.1
Ga	5.62 ± 0.03	5.60 ± 0.06	5.62 ± 0.03	22.06 ± 0.07	21.03 ± 0.04	5.74 ± 0.03	5.60 ± 0.06
As	2.49 ± 0.06	2.42 ± 0.03	2.40 ± 0.08	7.49 ± 0.04	1.91 ± 0.02	2.44 ± 0.03	2.40 ± 0.08
Se	1.47 ± 0.01	1.49 ± 0.07	1.48 ± 0.04	0.98 ± 0.06	0.96 ± 0.05	1.45 ± 0.03	1.48 ± 0.03
Rb	110.2 ± 0.2	112.0 ± 0.3	110.2 ± 0.2	175.3 ± 0.9	238.1 ± 0.3	112.0 ± 0.4	112.4 ± 0.5
Sr	100.0 ± 0.3	100.3 ± 0.6	100.9 ± 0.9	72.8 ± 0.4	3.89 ± 0.04	100.3 ± 0.6	100.0 ± 0.6
Y	15.73 ± 0.07	15.68 ± 0.06	15.73 ± 0.07	6.90 ± 0.08	34.03 ± 0.09	15.70 ± 0.03	15.71 ± 0.01
Zr	120.62 ± 0.04	120.65 ± 0.09	120.62 ± 0.04	123.18 ± 0.06	86.10 ± 0.03	120.65 ± 0.09	120.52 ± 0.09
Nb	10.1 ± 0.6	10.1 ± 0.2	10.1 ± 0.6	20.3 ± 0.3	32.9 ± 0.3	10.1 ± 0.2	10.5 ± 0.2
Sb	0.127 ± 0.003	0.127 ± 0.009	0.126 ± 0.003	1.007 ± 0.002	0.569 ± 0.007	0.126 ± 0.007	0.127 ± 0.009
Cs	2.96 ± 0.04	2.97 ± 0.05	2.96 ± 0.04	6.48 ± 0.09	14.10 ± 0.04	2.96 ± 0.05	2.96 ± 0.05
Ba	547.2 ± 0.1	547.1 ± 0.2	547.2 ± 0.1	249.5 ± 0.2	9.5 ± 0.3	547.1 ± 0.2	547.4 ± 0.3
La	24.65 ± 0.02	24.64 ± 0.04	24.61 ± 0.03	41.95 ± 0.09	17.60 ± 0.02	24.65 ± 0.04	24.64 ± 0.06
Ce	34.26 ± 0.08	34.32 ± 0.06	34.26 ± 0.08	54.40 ± 0.06	27.80 ± 0.03	34.31 ± 0.02	34.32 ± 0.05
Nd	14.87 ± 0.09	14.80 ± 0.02	14.79 ± 0.01	44.60 ± 0.09	20.60 ± 0.04	14.72 ± 0.03	14.80 ± 0.02
Sm	3.29 ± 0.02	3.32 ± 0.04	3.29 ± 0.02	2.93 ± 0.06	3.73 ± 0.05	3.36 ± 0.05	3.36 ± 0.04
Eu	0.416 ± 0.003	0.416 ± 0.007	0.415 ± 0.003	0.466 ± 0.003	0.046 ± 0.002	0.417 ± 0.003	0.416 ± 0.004
Gd	3.98 ± 0.07	3.67 ± 0.04	3.76 ± 0.07	4.26 ± 0.02	5.98 ± 0.04	3.69 ± 0.02	3.67 ± 0.04
Tb	0.681 ± 0.001	0.682 ± 0.002	0.681 ± 0.005	0.748 ± 0.002	1.11 ± 0.03	0.681 ± 0.006	0.682 ± 0.002
Dy	3.713 ± 0.002	3.714 ± 0.004	3.732 ± 0.003	4.558 ± 0.003	6.75 ± 0.03	3.713 ± 0.006	3.717 ± 0.004
Ho	0.90 ± 0.04	0.89 ± 0.04	0.90 ± 0.06	1.02 ± 0.03	1.53 ± 0.04	0.88 ± 0.04	0.89 ± 0.04
Tm	0.33 ± 0.04	0.32 ± 0.02	0.33 ± 0.04	0.38 ± 0.09	0.63 ± 0.03	0.33 ± 0.08	0.32 ± 0.02
Yb	1.72 ± 0.05	1.71 ± 0.02	1.73 ± 0.02	2.31 ± 0.06	4.05 ± 0.05	1.72 ± 0.04	1.71 ± 0.04
Lu	0.267 ± 0.003	0.264 ± 0.003	0.265 ± 0.003	0.285 ± 0.004	0.51 ± 0.06	0.265 ± 0.006	0.264 ± 0.003
Hf	3.19 ± 0.01	3.18 ± 0.03	3.19 ± 0.05	3.22 ± 0.03	0.99 ± 0.01	3.19 ± 0.03	3.18 ± 0.02
Ta	0.799 ± 0.002	0.797 ± 0.004	0.796 ± 0.006	1.765 ± 0.004	3.90 ± 0.04	0.798 ± 0.005	0.797 ± 0.004
Th	10.80 ± 0.04	10.76 ± 0.04	10.79 ± 0.04	27.60 ± 0.03	34.00 ± 0.02	10.78 ± 0.04	10.76 ± 0.09
U	2.88 ± 0.08	2.89 ± 0.02	2.84 ± 0.04	7.06 ± 0.06	12.90 ± 0.05	2.91 ± 0.02	2.89 ± 0.07

5.1. FT dating

The FT analysis was performed using the standard procedures set at the Institute of Geosciences and Earth Resources of C.N.R., Pisa. One split from each obsidian sample was irradiated in the Lazy Susan (LS) facility (Cadmium Ratio for Gold 6.5 and, for Cobalt, 48) of the TRIGA reactor at Pavia. After mounting in epoxy resin, they were polished to reveal an internal surface, and then etched, in 20% HF at 40 °C for 120 s. Track counting was performed in transmitted light using a Leitz Orthoplan microscope at 500x. Track sizes were measured using Leitz Microvid equipment at 1000x. Results are shown in Table 2.

The analysis with FT was an arduous task since most artefacts were very dark and after mounting and polishing, only some rather restricted areas were adequate for observation under a microscope. For some samples only low precision ages were determined. For a few artefacts, particularly dark ones, only the induced track density was measured (Dark in Table 2). A few other artefacts revealed very low spontaneous track densities and FT ages of a few thousand years, which is very probably due to some thermal events which may have occurred during their usage, and the result of which was full annealing of pre-existing tracks. These ages are commonly referred to as "archaeological" ages (Arch. in Table 2), since they date human activities, instead of the eruption which produced the glass. Thermal stability of fission tracks in glass is rather poor. Most glasses show a certain amount of annealing of the tracks accumulated during geological times. Partially annealed tracks are etched with reduced efficiency in comparison with the "fresh" induced tracks produced by the irradiation with neutrons, which is used in the FT routine for calibrating the unknown U content. Therefore, FT ages of glasses are commonly rejuvenated ages referred to as "apparent" ages. Storzer and Wagner (1969) have shown that track partial annealing in glass can be detected by measuring the mean major axis of track etch pits (track sizes, Fig. 2).

The authors introduced the size-correction method, which allows estimating the formation age through a correction curve, an experimental curve that represents the relationship between track size and track density reduction. Some years later Storzer and Poupeau (Storzer and Poupeau, 1973) proposed the "plateau method", commonly preferred for its higher precision. Considering that for analysis of artefacts in order to identify their provenance, precision is not an important factor, and the small sizes of some of them, the size-correction method was applied in this work, using a correction curve previously determined from annealing experiments of induced tracks on geological samples (Oddone et al., 2003b). The spontaneous to induced track size ratio values of Table 2, between 0.62 and 0.94, indicate that the samples which are the subject of this study suffered variable amount of track annealing, from negligible up to rather intense. Excepting those of a few thousand years, the apparent FT ages of Table 2 are distributed in a wide range of interval, between 0.53 ± 0.03 and 1.43 ± 0.20 Ma.

Table 5
Major (as oxide,%), minor and trace (μg/g) element contents in archaeological obsidians.

Bakla Tepe

Sample	B25	B26	B27	B28	B29	B30	B31
SiO_2	66.95 ± 0.05	66.93 ± 0.04	66.97 ± 0.06	66.94 ± 0.04	66.94 ± 0.03	66.95 ± 0.02	66.97 ± 0.03
TiO_2	0.183 ± 0.004	0.184 ± 0.005	0.183 ± 0.003	0.182 ± 0.003	0.181 ± 0.006	0.183 ± 0.005	0.182 ± 0.002
Al_2O_3	14.04 ± 0.03	14.03 ± 0.09	14.08 ± 0.03	14.09 ± 0.04	13.89 ± 0.04	14.06 ± 0.05	14.03 ± 0.03
Fe_2O_3	1.345 ± 0.003	1.340 ± 0.004	1.342 ± 0.004	1.343 ± 0.001	1.343 ± 0.005	1.339 ± 0.007	1.341 ± 0.003
MnO	0.0776 ± 0.0007	0.0774 ± 0.0002	0.0773 ± 0.0005	0.0779 ± 0.0004	0.0779 ± 0.0003	0.0779 ± 0.0004	0.0776 ± 0.0007
MgO	0.199 ± 0.002	0.196 ± 0.006	0.198 ± 0.002	0.196 ± 0.006	0.197 ± 0.002	0.195 ± 0.007	0.197 ± 0.004
CaO	1.087 ± 0.003	1.086 ± 0.007	1.088 ± 0.003	1.095 ± 0.003	1.090 ± 0.003	1.085 ± 0.003	1.085 ± 0.002
Na_2O	3.43 ± 0.07	3.39 ± 0.03	3.37 ± 0.03	3.41 ± 0.03	3.45 ± 0.03	3.35 ± 0.03	3.34 ± 0.07
K_2O	2.53 ± 0.07	2.53 ± 0.03	2.52 ± 0.01	2.54 ± 0.09	2.59 ± 0.09	2.57 ± 0.09	2.53 ± 0.03
Sc	1.84 ± 0.09	1.86 ± 0.03	1.82 ± 0.01	1.87 ± 0.03	1.87 ± 0.06	1.89 ± 0.04	1.84 ± 0.08
Cr	0.821 ± 0.003	0.826 ± 0.008	0.824 ± 0.005	0.862 ± 0.008	0.872 ± 0.009	0.827 ± 0.005	0.826 ± 0.007
Co	1.106 ± 0.009	1.107 ± 0.002	1.101 ± 0.004	1.105 ± 0.009	1.105 ± 0.008	1.108 ± 0.007	1.104 ± 0.002
Zn	35.1 ± 0.5	35.0 ± 0.4	35.3 ± 0.3	35.2 ± 0.5	34.8 ± 0.6	35.1 ± 0.5	35.1 ± 0.3
Ni	3.8 ± 0.2	3.6 ± 0.4	3.5 ± 0.2	3.8 ± 0.3	3.0 ± 0.2	3.5 ± 0.7	3.5 ± 0.3
Ga	5.63 ± 0.05	5.68 ± 0.06	5.62 ± 0.05	5.69 ± 0.03	5.72 ± 0.07	5.71 ± 0.05	5.61 ± 0.02
As	2.49 ± 0.03	2.42 ± 0.05	2.43 ± 0.03	2.39 ± 0.05	2.32 ± 0.08	2.30 ± 0.02	2.40 ± 0.09
Se	1.48 ± 0.02	1.47 ± 0.06	1.45 ± 0.02	1.48 ± 0.06	1.42 ± 0.07	1.46 ± 0.07	1.46 ± 0.06
Rb	111.9 ± 0.7	109.9 ± 0.6	111.2 ± 0.4	110.8 ± 0.8	111.6 ± 0.5	112.6 ± 0.6	110.9 ± 0.3
Sr	100.6 ± 0.5	100.9 ± 0.2	100.1 ± 0.5	100.8 ± 0.4	104.0 ± 0.3	100.8 ± 0.9	100.3 ± 0.3
Y	15.74 ± 0.03	15.76 ± 0.07	15.72 ± 0.01	15.66 ± 0.07	15.78 ± 0.06	15.64 ± 0.09	15.71 ± 0.03
Zr	120.61 ± 0.08	121.60 ± 0.06	120.64 ± 0.06	123.73 ± 0.04	124.87 ± 0.05	123.71 ± 0.08	124.63 ± 0.06
Nb	10.14 ± 0.09	10.1 ± 0.3	10.2 ± 0.1	10.7 ± 0.3	10.9 ± 0.8	10.7 ± 0.4	10.1 ± 0.8
Sb	0.126 ± 0.006	0.128 ± 0.009	0.12 ± 0.004	0.125 ± 0.003	0.124 ± 0.003	0.125 ± 0.002	0.126 ± 0.003
Cs	2.97 ± 0.07	2.96 ± 0.05	2.97 ± 0.03	2.99 ± 0.05	2.98 ± 0.05	2.92 ± 0.03	2.96 ± 0.03
Ba	547.2 ± 0.2	547.3 ± 0.5	547.2 ± 0.2	549.6 ± 0.9	545.7 ± 0.7	546.7 ± 0.4	547.2 ± 0.3
La	24.65 ± 0.04	24.66 ± 0.09	24.68 ± 0.05	24.65 ± 0.03	24.48 ± 0.07	23.24 ± 0.04	24.64 ± 0.07
Ce	34.25 ± 0.02	34.23 ± 0.06	34.34 ± 0.09	34.00 ± 0.03	33.18 ± 0.08	33.96 ± 0.03	34.28 ± 0.06
Nd	14.79 ± 0.02	14.78 ± 0.04	14.80 ± 0.01	14.95 ± 0.07	14.76 ± 0.05	14.95 ± 0.08	14.79 ± 0.03
Sm	3.37 ± 0.07	3.22 ± 0.05	3.28 ± 0.03	3.40 ± 0.03	3.29 ± 0.02	3.28 ± 0.03	3.26 ± 0.02
Eu	0.414 ± 0.004	0.415 ± 0.005	0.416 ± 0.002	0.440 ± 0.008	0.424 ± 0.004	0.413 ± 0.008	0.415 ± 0.002
Gd	3.77 ± 0.02	3.79 ± 0.02	3.71 ± 0.06	3.71 ± 0.03	3.71 ± 0.07	3.72 ± 0.08	3.72 ± 0.02
Tb	0.681 ± 0.006	0.681 ± 0.007	0.680 ± 0.004	0.678 ± 0.008	0.675 ± 0.005	0.678 ± 0.003	0.681 ± 0.002
Dy	3.713 ± 0.003	3.712 ± 0.002	3.719 ± 0.004	3.718 ± 0.002	3.733 ± 0.007	3.732 ± 0.005	3.713 ± 0.003
Ho	0.90 ± 0.08	0.91 ± 0.03	0.89 ± 0.06	0.90 ± 0.03	0.91 ± 0.02	0.92 ± 0.09	0.89 ± 0.05
Tm	0.33 ± 0.05	0.31 ± 0.01	0.32 ± 0.02	0.38 ± 0.04	0.37 ± 0.07	0.38 ± 0.05	0.32 ± 0.02
Yb	1.72 ± 0.05	1.73 ± 0.07	1.72 ± 0.04	1.78 ± 0.05	1.81 ± 0.02	1.80 ± 0.04	1.72 ± 0.03
Lu	0.265 ± 0.002	0.266 ± 0.009	0.265 ± 0.006	0.263 ± 0.006	0.263 ± 0.009	0.264 ± 0.009	0.265 ± 0.008
Hf	3.19 ± 0.01	3.18 ± 0.09	3.19 ± 0.07	3.17 ± 0.05	3.18 ± 0.07	3.17 ± 0.08	3.18 ± 0.01
Ta	0.799 ± 0.004	0.800 ± 0.003	0.796 ± 0.004	0.794 ± 0.003	0.793 ± 0.003	0.794 ± 0.005	0.798 ± 0.004
Th	10.74 ± 0.02	10.76 ± 0.05	10.77 ± 0.09	10.41 ± 0.05	10.63 ± 0.04	10.41 ± 0.03	10.76 ± 0.06
U	2.88 ± 0.03	2.89 ± 0.04	2.90 ± 0.08	2.89 ± 0.07	2.86 ± 0.06	2.89 ± 0.05	2.89 ± 0.02

After application of the size-correction method, a homogeneous group of 23 samples is characterized by FT ages varying between 1.48 ± 0.47 and 1.80 ± 0.20 Ma, with a mean value of 1.65 ± 0.05 Ma, and low induced track densities corresponding to low U content (around 3 ppm). By comparison of the FT data with the probable potential sources, this group was identified as originating from the obsidians of the island of Melos, which have an identical mean age and similar low induced track densities (Arias et al., 2006). FT dating does not allow distinguishing between obsidians from the two main sources Nychia and Dhemenegaki.

Another sample, B19, presents FT data (induced track density and corrected FT age) compatible with a Göllüdağ (G.D. in Table 2) origin, central Anatolia (Çiftlik obsidians; Bigazzi et al., 1993a). In this case also, FT dating does not fully discriminate the different obsidian occurrences of the Göllüdağ complex. The so-called East- and West-Göllüdağ sources have similar ages (1.15 ± 0.07 and 0.98 ± 0.05 Ma, respectively; Bigazzi et al., 1993a) and track densities. In an apparent age – spontaneous to induced track size ratio diagram, points corresponding to sources and artefacts originating from them distribute along curves typical of samples which suffered differential annealing (Fig. 3). In the upper curve, points corresponding to artefacts from the Tell Afis settlement (Syria) identified as originating from the Çiftlik obsidians have also been reported (Bigazzi et al., 2007).

Samples B15 and B20 present induced track densities similar to that of the main (23 samples) group, but with only two and five spontaneous tracks respectively and thus very young FT apparent ages. As it is considered that these ages are more probably reset ages rather than genuine formation ages (Table 2), a Melian provenance is tentatively proposed.

Another group of 14 samples, again with similar induced track densities as the first group (of 23 samples), but no observable spontaneous track (due to darkness), are also tentatively attributed the same origin.

Sample B14, with a "higher" induced track density and a very young corrected age of 0.019 Ma, might come from the Acigöl area, central Anatolia (Bigazzi et al., 1993a). Finally, obsidian L13, with an induced track density similar to that of B19, but a very low FT age, might have also a Göllüdağ origin, provided that its very young age is due to a recent total track annealing.

5.2. Naa

INAA and ENAA studies have been carried out on 34 artefacts at the TRIGA Mark II research reactor of the University of Pavia. Analyses were performed using the standard techniques adopted in the Radiochemistry Laboratory of the Department of General Chemistry (Oddone et al., 1997). The obsidian samples were ground to a fine powder in an agate mortar. 250 mg from each of them were sealed in

Table 6
Major (as oxide,%), minor and trace (μg/g) element contents in archaeological obsidians.

Bakla Tepe

Sample	B32	B33	B34	B35	B36	B40
SiO_2	66.93 ± 0.05	66.96 ± 0.03	66.94 ± 0.07	66.96 ± 0.03	66.92 ± 0.04	66.94 ± 0.07
TiO_2	0.186 ± 0.006	0.185 ± 0.004	0.183 ± 0.006	0.183 ± 0.006	0.183 ± 0.005	0.185 ± 0.003
Al_2O_3	14.09 ± 0.05	14.03 ± 0.04	14.07 ± 0.05	14.05 ± 0.05	14.07 ± 0.09	13.79 ± 0.06
Fe_2O_3	1.343 ± 0.008	1.335 ± 0.005	1.348 ± 0.002	1.342 ± 0.007	1.343 ± 0.004	1.342 ± 0.005
MnO	0.0773 ± 0.0004	0.0779 ± 0.0003	0.0781 ± 0.0004	0.0780 ± 0.0009	0.0778 ± 0.0004	0.0799 ± 0.0003
MgO	0.197 ± 0.008	0.195 ± 0.002	0.198 ± 0.008	0.196 ± 0.007	0.197 ± 0.006	0.194 ± 0.006
CaO	1.090 ± 0.003	1.089 ± 0.007	1.088 ± 0.003	1.088 ± 0.002	1.090 ± 0.007	1.085 ± 0.007
Na_2O	3.40 ± 0.03	3.46 ± 0.03	3.37 ± 0.02	3.47 ± 0.05	3.43 ± 0.03	3.36 ± 0.03
K_2O	2.57 ± 0.02	2.53 ± 0.09	2.57 ± 0.03	2.57 ± 0.02	2.60 ± 0.03	2.47 ± 0.08
Sc	1.86 ± 0.04	1.87 ± 0.06	1.86 ± 0.05	1.86 ± 0.03	1.87 ± 0.03	1.83 ± 0.06
Cr	0.828 ± 0.009	0.825 ± 0.003	0.824 ± 0.009	0.826 ± 0.003	0.823 ± 0.008	0.828 ± 0.002
Co	1.106 ± 0.003	1.108 ± 0.007	1.109 ± 0.008	1.108 ± 0.008	1.54 ± 0.09	1.643 ± 0.004
Zn	35.2 ± 0.5	35.7 ± 0.6	35.4 ± 0.4	35.2 ± 0.8	34.9 ± 0.6	35.0 ± 0.8
Ni	3.8 ± 0.3	3.4 ± 0.6	3.8 ± 0.2	3.7 ± 0.4	3.8 ± 0.4	2.2 ± 0.6
Ga	5.69 ± 0.08	5.79 ± 0.04	5.50 ± 0.06	15.49 ± 0.02	5.70 ± 0.03	5.20 ± 0.03
As	2.43 ± 0.03	2.39 ± 0.08	2.41 ± 0.02	2.38 ± 0.06	2.30 ± 0.05	2.32 ± 0.02
Se	1.48 ± 0.05	1.46 ± 0.02	1.44 ± 0.08	1.44 ± 0.05	1.44 ± 0.06	1.49 ± 0.07
Rb	112.7 ± 0.4	112.9 ± 0.2	112.1 ± 0.6	113.2 ± 0.8	111.5 ± 0.5	112.0 ± 0.5
Sr	100.8 ± 0.6	109.5 ± 0.4	103.4 ± 0.5	104.4 ± 0.4	100.8 ± 0.2	105.3 ± 0.3
Y	15.64 ± 0.05	15.73 ± 0.08	15.70 ± 0.03	15.63 ± 0.07	15.77 ± 0.07	15.62 ± 0.08
Zr	123.73 ± 0.08	125.30 ± 0.04	124.54 ± 0.02	125.55 ± 0.06	123.73 ± 0.04	124.23 ± 0.09
Nb	10.7 ± 0.7	10.6 ± 0.3	10.4 ± 0.2	10.4 ± 0.4	10.7 ± 0.3	10.73 ± 0.08
Sb	0.215 ± 0.003	0.125 ± 0.003	0.126 ± 0.002	0.124 ± 0.003	0.121 ± 0.002	0.124 ± 0.003
Cs	2.98 ± 0.08	2.94 ± 0.06	2.93 ± 0.07	2.93 ± 0.03	2.94 ± 0.08	2.98 ± 0.04
Ba	549.6 ± 0.6	548.0 ± 0.4	548.4 ± 0.6	547.3 ± 0.2	549.6 ± 0.5	550.13 ± 0.02
La	24.23 ± 0.06	24.35 ± 0.07	25.08 ± 0.06	25.02 ± 0.08	24.23 ± 0.03	24.70 ± 0.08
Ce	34.00 ± 0.03	36.56 ± 0.08	35.05 ± 0.09	34.48 ± 0.03	33.99 ± 0.06	34.00 ± 0.08
Nd	14.95 ± 0.03	14.73 ± 0.04	14.69 ± 0.06	14.51 ± 0.09	14.95 ± 0.04	14.91 ± 0.01
Sm	3.39 ± 0.02	3.29 ± 0.02	3.35 ± 0.03	3.38 ± 0.07	3.37 ± 0.02	3.26 ± 0.03
Eu	0.423 ± 0.009	0.414 ± 0.006	0.430 ± 0.002	0.430 ± 0.008	0.423 ± 0.005	0.350 ± 0.004
Gd	3.73 ± 0.02	3.72 ± 0.08	3.76 ± 0.01	3.76 ± 0.03	3.72 ± 0.09	4.29 ± 0.08
Tb	0.677 ± 0.002	0.681 ± 0.005	0.683 ± 0.009	0.680 ± 0.002	0.677 ± 0.002	0.778 ± 0.001
Dy	3.732 ± 0.006	3.736 ± 0.007	3.787 ± 0.006	3.787 ± 0.004	3.732 ± 0.004	3.749 ± 0.008
Ho	0.86 ± 0.03	0.92 ± 0.02	0.94 ± 0.02	0.95 ± 0.09	1.02 ± 0.03	1.05 ± 0.02
Tm	0.32 ± 0.01	0.34 ± 0.09	0.36 ± 0.06	0.35 ± 0.04	0.38 ± 0.03	0.39 ± 0.01
Yb	1.82 ± 0.02	1.83 ± 0.02	1.86 ± 0.09	1.89 ± 0.06	1.90 ± 0.05	1.93 ± 0.08
Lu	0.263 ± 0.003	0.271 ± 0.008	0.274 ± 0.002	0.275 ± 0.002	0.273 ± 0.003	0.274 ± 0.009
Hf	2.99 ± 0.03	2.92 ± 0.08	2.85 ± 0.01	2.85 ± 0.02	2.75 ± 0.07	2.73 ± 0.05
Ta	0.795 ± 0.006	0.762 ± 0.001	0.760 ± 0.005	0.765 ± 0.007	0.764 ± 0.003	0.761 ± 0.001
Th	10.41 ± 0.01	10.44 ± 0.04	10.31 ± 0.08	11.31 ± 0.07	10.41 ± 0.05	10.78 ± 0.09
U	2.79 ± 0.05	2.73 ± 0.04	2.90 ± 0.05	2.93 ± 0.05	2.89 ± 0.09	2.78 ± 0.06

polyethylene vials. Induced radioactivity was measured by gamma-ray spectrometry using a Ge detector with high purity coupled to a computer-assisted analyzer. A geological standard from the National Institute of Standards and Technology (obsidian rock NIST-SRM 278) and a nitric solution of the analysed elements were irradiated together with the samples as reference standards. Na, Mg, Si, Al, K, Ca, Sc, Ti, Cr, Mn, Fet, Co, Zn, Ni, Ga, As, Se, Rb, Sr, Zr, Nb, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Tm, Yb, Lu, Hf, Ta, Th and U were determined (see Oddone et al., 1997, for nuclear data of the analysed elements). Accuracy was evaluated by comparing determined and certified abundances for the NIST-SRM 278 standard: a general agreement within experimental errors was observed (Oddone et al., 1997; Oddone et al., 2003b; Arias et al., 2006). INAA data of obsidian artefacts from Bakla Tepe and Liman Tepe are shown in Tables 3–7.

The identification of provenance of archaeological obsidian samples was carried out using PC assisted pattern recognition procedures with the BMDP7 statistical package (Dixon, 2000). These are quite helpful especially when a large database is available. In order to assign some unknown observations to a group with a low error rate, a discriminant analysis program was first applied. A multiple-group analysis finds similarities among the investigated samples. A dimension reduction was applied to the trace element abundances, including the data-set of previously studied Aegean sources (Oddone et al., 1997; Arias et al., 2006). The variables for computing the linear classification function were chosen in a stepwise manner. The Sc, Hf, Ni, Ce and U concentrations were found to have the highest discrimination power.

The results of the compositional analysis for the obsidian artifacts from Bakla Tepe and Liman Tepe are summarized in Fig. 4 which shows the bivariate plots of Cs versus Th, Cs versus Hf, and Rb versus Sr, for the artifacts. The comparison was highly successful with sources for nearly all of the artifacts securely established. Examination of the data found that 35 of the 38 artifacts agreed with the most likely source as suggested to be Melian and mainly from Dhemenegaki flow. Three samples (B14, B19 and B20), with the lowest overall membership probabilities, were found to belong to another source, most probably from central Anatolian Göllüdağ instead of the Melos.

Using these variables, a hierarchical cluster analysis program was also carried out to look for similarity among archaeological obsidian samples and potential sources. The final result of the whole procedure is exemplified by the dendrogram of cluster analysis of Fig. 5. The results from the bivariate plots agree with those obtained from FT dating: most artefacts originated from the Melos–Dhemenegaki flow, and only 3 samples from central Anatolia.

6. Discussion and conclusion

The examples in the literature illustrate that obsidian provenance studies can be very beneficial to archaeologists interested in studying

Table 7
Major (as oxide,%), minor and trace (μg/g) element contents in archaeological obsidians.

Liman Tepe						
Sample	L2	L3	L5	L6	L7	L12
SiO_2	66.93 ± 0.05	66.96 ± 0.04	66.97 ± 0.03	66.95 ± 0.04	66.95 ± 0.08	66.97 ± 0.02
TiO_2	0.186 ± 0.004	0.186 ± 0.003	0.187 ± 0.009	0.184 ± 0.008	0.188 ± 0.009	0.187 ± 0.008
Al_2O_3	13.89 ± 0.05	14.02 ± 0.05	13.99 ± 0.01	13.96 ± 0.03	14.00 ± 0.05	13.97 ± 0.04
Fe_2O_3	1.343 ± 0.009	1.344 ± 0.004	1.344 ± 0.004	1.341 ± 0.005	1.342 ± 0.006	1.341 ± 0.007
MnO	0.0790 ± 0.0003	0.0779 ± 0.0006	0.0782 ± 0.0009	0.0784 ± 0.0003	0.0781 ± 0.0003	0.0783 ± 0.0002
MgO	0.197 ± 0.005	0.195 ± 0.002	0.199 ± 0.008	0.198 ± 0.002	0.198 ± 0.003	0.197 ± 0.002
CaO	1.090 ± 0.002	1.086 ± 0.007	1.086 ± 0.008	1.086 ± 0.004	1.085 ± 0.001	1.083 ± 0.006
Na_2O	3.45 ± 0.02	3.37 ± 0.07	3.39 ± 0.09	3.40 ± 0.01	3.44 ± 0.03	3.40 ± 0.09
K_2O	2.49 ± 0.08	2.46 ± 0.02	2.47 ± 0.03	2.47 ± 0.04	2.46 ± 0.05	2.47 ± 0.04
Sc	1.87 ± 0.05	1.81 ± 0.08	1.82 ± 0.06	1.87 ± 0.09	1.82 ± 0.04	1.83 ± 0.09
Cr	0.827 ± 0.008	0.825 ± 0.009	0.827 ± 0.003	0.824 ± 0.003	0.826 ± 0.004	0.823 ± 0.002
Co	1.468 ± 0.005	1.191 ± 0.004	1.264 ± 0.005	1.311 ± 0.001	1.238 ± 0.006	1.292 ± 0.005
Zn	34.8 ± 0.6	35.6 ± 0.8	34.9 ± 0.9	35.1 ± 0.3	35.7 ± 0.3	36.0 ± 0.3
Ni	3.0 ± 0.2	3.4 ± 0.4	3.3 ± 0.5	3.2 ± 0.6	3.3 ± 0.7	3.2 ± 0.6
Ga	5.19 ± 0.04	5.23 ± 0.06	5.75 ± 0.06	5.12 ± 0.03	5.57 ± 0.03	5.49 ± 0.02
As	2.38 ± 0.08	2.39 ± 0.05	2.37 ± 0.04	2.35 ± 0.03	2.37 ± 0.04	2.36 ± 0.02
Se	1.43 ± 0.02	1.41 ± 0.02	1.44 ± 0.02	1.43 ± 0.02	1.42 ± 0.03	1.43 ± 0.04
Rb	112.1 ± 0.8	113.3 ± 0.3	112.3 ± 0.4	112.6 ± 0.6	112.2 ± 0.2	111.6 ± 0.7
Sr	104.0 ± 0.6	101.2 ± 0.3	103.3 ± 0.3	101.9 ± 0.3	104.1 ± 0.4	101.8 ± 0.3
Y	15.77 ± 0.04	15.44 ± 0.06	15.56 ± 0.02	15.45 ± 0.08	15.85 ± 0.06	15.43 ± 0.05
Zr	124.88 ± 0.09	129.26 ± 0.07	118.10 ± 0.04	117.36 ± 0.08	118.51 ± 0.05	117.67 ± 0.08
Nb	10.94 ± 0.08	11.06 ± 0.04	10.82 ± 0.05	10.29 ± 0.03	10.54 ± 0.07	11.10 ± 0.03
Sb	0.130 ± 0.006	0.123 ± 0.007	0.126 ± 0.008	0.127 ± 0.006	0.125 ± 0.001	0.126 ± 0.009
Cs	2.97 ± 0.04	3.04 ± 0.02	3.48 ± 0.02	3.01 ± 0.02	3.04 ± 0.06	3.21 ± 0.04
Ba	547.58 ± 0.02	545.67 ± 0.05	547.76 ± 0.07	546.42 ± 0.04	544.36 ± 0.07	541.12 ± 0.08
La	24.47 ± 0.05	24.36 ± 0.05	24.13 ± 0.02	23.98 ± 0.08	24.22 ± 0.07	24.05 ± 0.03
Ce	33.92 ± 0.03	34.04 ± 0.04	33.82 ± 0.02	33.66 ± 0.01	33.87 ± 0.06	33.72 ± 0.09
Nd	15.08 ± 0.03	15.03 ± 0.06	15.02 ± 0.02	15.04 ± 0.03	15.14 ± 0.09	15.29 ± 0.09
Sm	3.30 ± 0.02	3.31 ± 0.09	3.30 ± 0.07	3.27 ± 0.02	3.23 ± 0.08	3.27 ± 0.09
Eu	0.353 ± 0.003	0.400 ± 0.004	0.388 ± 0.003	0.379 ± 0.004	0.392 ± 0.009	0.383 ± 0.005
Gd	4.20 ± 0.02	4.18 ± 0.05	3.99 ± 0.02	3.95 ± 0.03	3.89 ± 0.07	3.93 ± 0.03
Tb	0.761 ± 0.005	0.770 ± 0.004	0.771 ± 0.004	0.772 ± 0.005	0.768 ± 0.007	0.772 ± 0.004
Dy	3.742 ± 0.006	3.800 ± 0.003	3.936 ± 0.006	4.000 ± 0.004	3.899 ± 0.003	3.973 ± 0.005
Ho	1.00 ± 0.02	0.99 ± 0.07	0.94 ± 0.06	0.95 ± 0.08	0.93 ± 0.09	0.95 ± 0.08
Tm	0.37 ± 0.05	0.36 ± 0.03	0.34 ± 0.03	0.35 ± 0.04	0.34 ± 0.04	± 0.34 ± 0.04
Yb	2.06 ± 0.02	1.89 ± 0.05	1.89 ± 0.04	1.94 ± 0.01	1.86 ± 0.05	1.92 ± 0.03
Lu	0.273 ± 0.006	0.275 ± 0.003	0.283 ± 0.004	0.288 ± 0.003	0.280 ± 0.004	0.286 ± 0.005
Hf	2.80 ± 0.08	3.01 ± 0.02	3.02 ± 0.02	2.98 ± 0.07	3.05 ± 0.02	3.00 ± 0.08
Ta	0.763 ± 0.009	0.769 ± 0.003	1.025 ± 0.007	1.091 ± 0.004	0.988 ± 0.005	1.064 ± 0.008
Th	10.64 ± 0.08	10.69 ± 0.05	12.47 ± 0.08	12.96 ± 0.06	12.18 ± 0.09	12.75 ± 0.03
U	2.56 ± 0.05	2.73 ± 0.07	3.62 ± 0.09	3.83 ± 0.04	3.50 ± 0.05	3.74 ± 0.04

long-distance interactions between prehistoric humans in the form of trade and exchange. Many interesting questions about the inhabitants of the Aegean coast of Anatolia and their contacts with the peoples living near the obsidian sources can be examined using the data from obsidian provenance studies. The objective of archaeological research on obsidian is to say something about the people who used obsidian and why exploitation or trade patterns changed in antiquity. It is clear that answering such questions depends heavily upon a reliable obsidian source database. The results of this study confirm the potential of an interdisciplinary approach. INAA substantially confirms the results obtained through the FT analysis, including the hypothesis that artefacts which did not allow spontaneous track counting had the same provenance as the other artefacts with mean age 1.65 ± 0.05 Ma attributed to the Melian obsidians. Whereas on the basis of FT data the main obsidian flows of Melos cannot be discriminated, INAA indicate that the artefacts in the present study originated from the Dhemenegaki flow. Only one case is doubtful. Artefact B 20 was attributed, by FT dating based only on the induced track density, to the group originating from Melos, while it was attributed by INAA to the Acıgöl obsidians. However we cannot exclude the possibility that low U content obsidians may be present also in central Anatolia.

Recent studies showed that there were major regional and chronological distinctions in the exploitation of Nychia and Dhemenegaki sources. For example in Crete, while Dhemenegaki was the primary source for making chipped stone tools during the Neolithic, Nychia was the primary obsidian source within the Early Bronze Age 1 (Carter, 2008: 225). In western Anatolia, at Çine-Tepecik Höyük it was determined that from the Chalcolithic Period until the end of the Late Bronze Age, obsidian was obtained from Nychia (Kolankaya-Bostancı et al., in press). According to Carter (2008: 225-226), the choice of quarry was related to communities' participation in different exchange/trade networks. This situation shows that Bakla Tepe and Liman Tepe preferred to use Dhemenegaki sources as the primary obsidian source in a different exchange network

A very interesting case is artefact B 14. Considering the large experimental error, its very young age – 0.019 ± 0.009 Ma – was considered to be due to resetting of the FT clock caused by some heating process experienced by the artefact. Considering the attribution made by INAA of this artefact to the youngest obsidians of Acıgöl, actually this age is also consistent with their age (0.015–0.020 Ma, Bigazzi et al., 1993b).

Identification of Aegean obsidian at Bakla Tepe and Liman Tepe had been an expected result, considering the ties of these settlements with the Aegean world. However, the artefacts originating from central Anatolia, although in small amounts, prove the importance of the central Anatolian sources which were also distributed to great distances. The presence of Anatolian obsidian in the İzmir region during the Late Chalcolithic is a phenomenon also mirrored at Aphrodisias

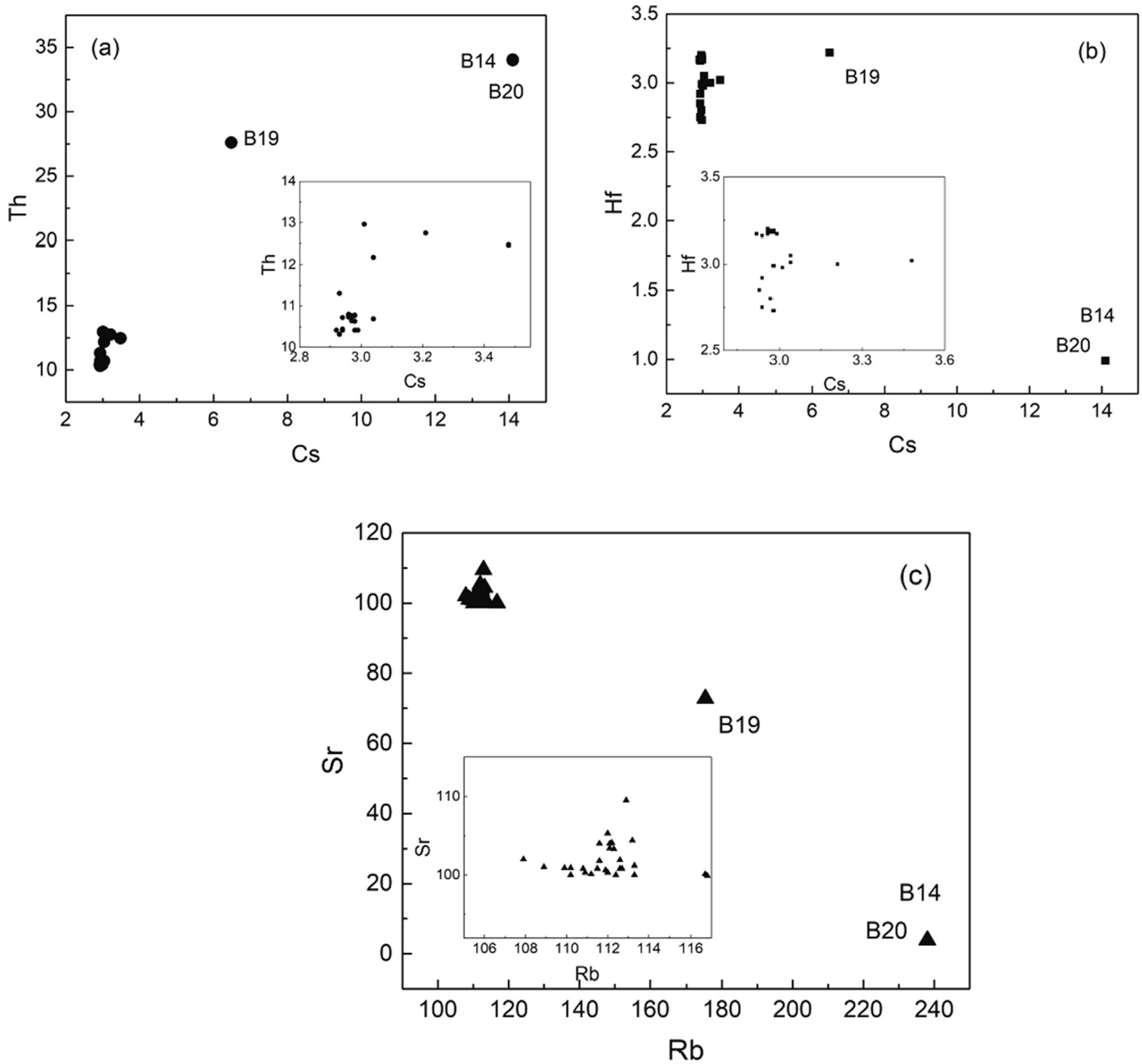

Fig. 4. Bivariate plots of (a) Cs versus Th, (b) Cs versus Hf, and (c) Rb versus Sr, for obsidian sources in Bakla Tepe and Liman Tepe. Data for the artifacts from Melos-Dhemenegaki flow appear as a tight cluster in each of the three plots, and this Melian data is also displayed, at an enlarged scale, in the inset in each of the three plots,

further inland in southwestern Anatolia. Here, 50% of the obsidian encountered is said to have originated from central Anatolian sources (Blackman, 1986: 279-85). Asopos Hill in Laodikeia, which is also in the same region, reflects a similar case with central Anatolian obsidians during the Late Chalcolithic period (Şimşek et al., 2014). Occurrence of Anatolian obsidian in western Anatolia during the Late Chalcolithic is a strong indication of the circulation of raw materials between these areas and deserves a closer look since this connection is currently not visible on any other archaeological material evidence, other than obsidian. The discovery of obsidian assemblages from different sources, central Anatolian and Melian, together in the same context, links Anatolia to the Aegean in extensive and organized exchange systems. While Melian obsidian reflect the overseas contacts with the Cyclades the use of central Anatolian obsidian attests the connections with central Anatolia.

The following Early Bronze 1–2 periods highlight strong maritime connections of western Anatolian coastline especially with the Cyclades. Imported Cycladic pottery and other finds reflect a maritime oriented culture at Bakla Tepe and Liman Tepe. The Central Anatolian connections seem to have been reduced during this period.

By the late Early Bronze 2 period however, a new world order began to emerge connecting far distances, extending from Mesopotamia all the way to the Aegean and beyond (Şahoğlu, 2005b; 2019). This phenomenon, which can be phrased as the Early Bronze Age Anatolian Trade Network, connected central and western Anatolia to each other through distribution of metals, pottery, wine, olive oil and other materials. Not only materials but also technologies and ideas travelled together with the merchants of the time accelerating changes in the quality of life on both ends of this trade network. The re-appearence of Anatolian obsidian in western Anatolia during this period could be linked directly to the Anatolian Trade Network. This precious material must have travelled with the merchants and arrived in the Izmir region – a nodal point in the flow of this extensive trade network.

CRediT authorship contribution statement

Zehra Yeğingil: Conceptualization, Investigation, Writing - original draft, Visualization, Supervision, Project administration. **Massimo Oddone:** Methodology, Formal analysis, Investigation, Writing - original draft, Visualization. **Giulio Bigazzi:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization. **Hayat Erkanal:** Conceptualization,

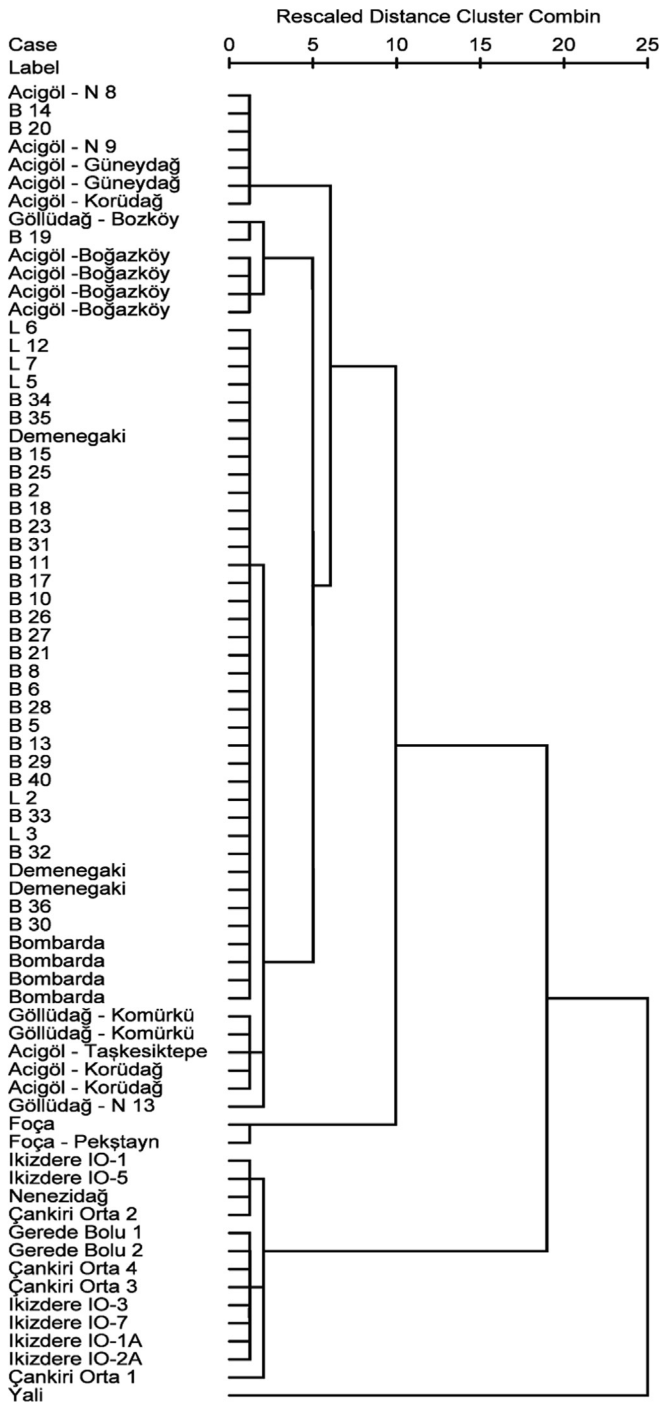

Fig. 5. Dendrogram of cluster analysis of artefacts from the Bakla Tepe and Liman Tepe settlements and potential natural sources obtained using the University of California BMDP7 statistical package (Dixon, 2000).

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