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BLACK LIMESTONE USED IN ANTIQUITY: RECOGNIZING THE LIMESTONE OF TEOS*

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This paper documents the petrographic and isotopic characteristics of some black limestones that were exploited in antiquity near the ancient site of Teos in Ionia (south-western Anatolia, Turkey). The best-quality black limestone of Teos is represented by a series of step-cut-shaped blocks situated north of the Seferihisar–Sığacık road, destined to be exported and used for architectural elements. The techniques used to study these blocks allow possible identification of the origin of Teos in ancient black stone artefacts. Nevertheless, petrographic and geochemical investigation on some black limestones that outcrop in the area near Teos has not firmly identified the quarry fronts from which these blocks were quarried away, but it supports the known hypothesis that Teian black limestones were found and quarried in conjunction with the Africano marble.

KEYWORDS: TEOS, BLACK LIMESTONE, STABLE ISOTOPES, PETROGRAPHY

INTRODUCTION

Black limestones were used in antiquity often in conjunction with coloured stones for architectonic elements, and even more widespread for inlays in *scutulata* pavements and tesserae in mosaics. Brilli *et al*. (2010) reviewed many of the quarries exploited for this material in various parts of the Mediterranean basin, focusing on ancient quarries that were supposedly more widely exported and spread throughout the Roman Empire, reaching Rome itself; they were mainly located in the Roman proconsular Africa (the modern Tunisia and Algeria territories) and the Greek island of Chios. Numerous quarries were exploited for black limestone in various parts of the Mediterranean basin. Other examples were from the area of the Mani peninsula, around Cape Tainaron, and from southern/central Peloponnesus (e.g., Vitina and Dolianà) in Greece (Bruno and Pallante 2002; Lazzarini 2007). Furthermore, a similar black limestone was quarried in Italy, close to Rome, from the Tolfa district (the so-called Palombino), probably related to the Lapis Niger of the Roman Forum (Fornaseri *et al*. 1995; Brilli *et al*. 2010; Lapuente *et al*. 2012). However, most of them were likely used on a local scale, especially because of the poor quality of the stone. Exploitation of many of these quarries started in very early periods, generally reaching the maximum extraction phase during the Roman Empire (Lazzarini 2007).

In general, the provenance of black limestone of unknown artefacts is difficult to determine on an autoptic basis because such materials resemble each other so closely. The sedimentary nature of the stone is not always easy to assess, petrographic analysis often being the only means of preventing confusion with black marbles. Since most black marbles are characterized by low-

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grade metamorphism, they are often macroscopically similar to black limestones. Furthermore, the exposed surfaces of all these limestones tend to turn from black to grey because of the relentless oxidation of the organic, carbonaceous matter responsible for the original colour. Consequently, it is very difficult to determine the provenance of black limestones used in sculptures, capitals, columns and bases, which therefore makes it necessary to adopt specific analyses to characterize them.

Following the work of Brilli *et al*. (2010) on black limestones, a further important black limestone was exploited and exported in antiquity: the black stone of Teos. It was likely quarried during Roman Imperial times, especially in the second century AD (Fant 1987; Pensabene and Lazzarini 1998; Borghini 2001), close to the ancient city of Teos in Ionia (south-western Anatolia, Turkey) (Fig. 1). The black stone of Teos was exploited in concurrence with the famous and widely traded *marmor luculleum*, alias Africano (Pensabene and Lazzarini 1998; Kadıoğlu 2016; Adak and Kadıoğlu 2017). Geologically speaking, Africano marble is not a real marble: it is a carbonatic *breccia* made of white/pinkish clasts mixed in a black-brown-reddish matrix. Ballance (1966) first hypothesized that the Africano marble and black limestone of Teos likely were quarried in an open pit, now filled with water to form a small lake (Fig. 2, a). Its Turkish name is now Karagöl, which means black lake; it is about 130 m in diameter with steep banks uniformly covered with a layer of debris of heterogeneous gravel of black limestone and Africano marble (Fig. 2, b). On the south-western side of the small lake there is an aligned series of step-cut-shaped blocks and columns of both grey/black limestone and Africano marble (Fig. 2, c–d).

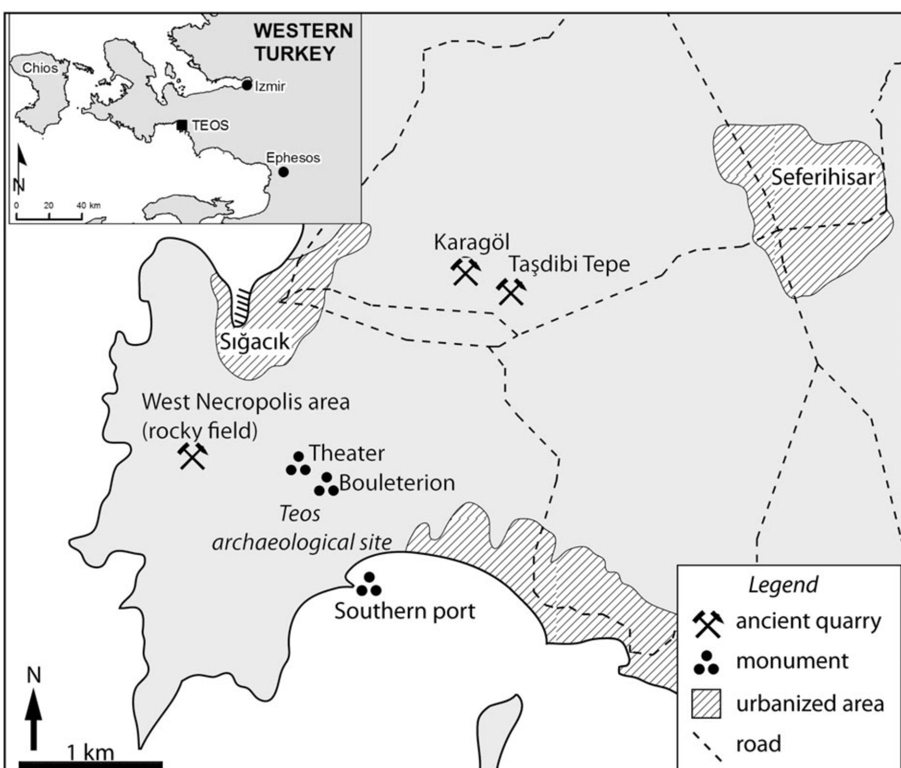

Figure 1 *Sampling locations in Western Turkey.*

Figure 2 *Field photographs of the sampling locations: (a) Karagöl; (b) coarse gravel around the shores of Karagöl lake —Africano and black limestone fragments are evident; (c, d) blocks of black limestone and Africano marble at Karagöl; (e) typical step-cut-shaped block of black limestone at Karagöl; (f) signs of pick marks on a block in the rocky field at the West Necropolis; (g) Taşdibi Tepe; and (h) detail of ancient quarrying at Taşdibi Tepe. [Colour figure can be viewed at wileyonlinelibrary.com]*

These were probably unfinished elements intended for export. Similar shaped blocks of Africano and black limestone were found at Porto (Ostia), where the blocks of stones and marbles transported to Rome by sea were stored (Pensabene and Lazzarini 1998, Pensabene 2014).

Actually, black stones were likely quarried from several exploitation sites around Teos. The best quality of these black stones is represented by the blocks exposed near Karagöl, which were destined for the export market. To date, no studies have undertaken the scientific recognition of this grey-black limestone, with the exception of Pensabene and Lazzarini (1998) who started a preliminary investigation on what they called the *bigio morato* from Teos. Bruno and Pallante (2002) and Attanasio *et al*. (2017) reported little isolated isotopic data for black Teian limestone.

The quarry from which the stone of the blocks from Karagöl was exploited was never really found. Ballance (1966) contends that the exploitation front was dug as a pit at Karagöl; however, this is impossible to confirm as this front would be under several metres of water as well as under an undefinable layer of loose debris, which uniformly covers the banks and bottom floor of the lake. In order to assess the quarry's provenance, a scientific investigation is required on the grey blocks to compare the results from these blocks and possible quarry fronts.

This study describes the scientific features, in particular petrography and carbon and oxygen stable isotopes, of the black limestone of the blocks of Karagöl. This will integrate the database of Brilli *et al*. (2010) on black limestones used in antiquity so that it will be possible to recognize this type of black limestone in monumental areas in Rome and elsewhere. Furthermore, some black stone outcrops in the area around Teos, where it was possible ancient quarrying activity occurred, were also sampled and similarly studied. This further investigation may have the twofold purpose of determining the quarry provenance of the black stone of the blocks around the Karagöl and contributing to understanding of the procurement strategies of building materials of the ancient city of Teos.

THE BLACK LIMESTONE OF TEOS: THE QUARRIES

Karagöl

The blocks of black limestone at Teos were first noted and reported from the eighteenth century onwards by many travellers (Pococke 1743–1745; Chandler 1775; Hamilton 1842; Texier 1862; Bequignon and Laumonier 1925), who were attracted by their elaborate step-cut shape (Fig. 2, e). They reported this material as grey marble with the distinctive features of shape and numerous inscriptions, which could provide relevant information about the exact extraction provenance or destination. The actual disposition of these blocks is the result of a reset of the area in recent times, presumably for agricultural purposes. Such works brought to light new blocks and covered up some of the old ones described by previous explorers (Fant 1987, 1989; Kadıoğlu 2016; Adak and Kadıoğlu 2017). None of these old travellers considered the hypothesis that the lake was the ancient site of quarry excavation. Ballance (1966) thought that this was due to the overwhelming interest in the marked blocks that diverted the interest of the travellers from the ancient pit quarry, which is, according to him, also the main front for extraction of Africano marble. Pensabene and Lazzarini (1998) reported that the black stone was quarried away from the same *locus* of Africano as both likely outcropped alternately upon digging or the former outcropped when the latter was exhausted (Fant 1987).

However there is no trace of ancient quarrying of either the black stone or the Africano in close proximity of Karagöl, or visible through the water of the lake itself.

At present there is no evidence of where the step-cut-shaped blocks of the *bigio morato* of Karagöl were really quarried; it was the variety of local black limestone that was appreciated most, since it was the only black Teian stone almost surely exported. A similar block with an inscription was found partially submerged in seawater near the pier of the Ottoman port of Sığacık (and similarly shaped blocks of Africano and black limestone were found at Porto, close to Ostia). The hypothesis of Ballance (1966) is still the most valid, that is, those blocks were likely quarried in conjunction with Africano marble in the pit now filled with water and forming the lake.

The scientific characterization of this stone, useful for its recognition in ancient artefacts, is still missing, unless one considers the brief description of Pensabene and Lazzarini (1998) who reported some petrographic features and isotopes from just one sample.

Taşdibi Tepe

In the surroundings of Teos there are some ancient quarry areas of black limestone, which outcrops almost everywhere. Some were easily discovered because evident ancient quarrying marks are still visible. The most obvious, as well as the largest, ancient quarry area is that located on a rocky hill called Taşdibi Tepe, situated to the north of the Seferihisar–Sığacık road, about 3 km from Seferihisar (Fig. 2, g–h). Already recognized by Ballance (1966), it was recently described by Bruno *et al*. (2012) and more extensively by Adak and Kadıoğlu (2017). Several ancient fronts are recognizable in spite of modern blasting and lime burning all around the hill. The modern activity of quarrying has even brought to light larger fronts than was previously thought possible on the western side. The stone is a dark grey carbonate rock, sometimes streaked with white veins constituted of large or very large crystals. It is possible to consider that it was used for ordinary building work of all periods at Teos, as reported by Ballance (1966); he also suggested that *bigio antico* and *bigio morato* (as the black marble and limestone are traditionally called) frequently occur in Italy, usually as columns; they are macroscopically identical with darker and lighter forms of this Teian marble, even if the possibility of other sources of supply of course is not precluded. The hypothesis of exportation of this stone, however, has still to be demonstrated scientifically.

West Necropolis area

Other black carbonate rocks outcrop and rise isolated and dispersed in the plain north or north-west of Karagöl. Some may not be visible because of destruction due to the recent neighbouring urban expansion of Sığacık. It is probable that around the ancient city of Teos there were quarrying activities because some extraction marks were found to the north and west of the city where the Necropolis of Teos extends (Fig. 2, f). It is believed that this area was quarried mainly to provide the materials for building the Hellenistic wall of Teos and the pier of the southern port (Kadıoğlu 2016; Polat and Tamsu Selli 2016; Adak and Kadıoğlu 2017).

Other quarry sites near Teos

Located on the east face of the valley running south-west towards Sığacık, and north-west of Karagöl, there is a 100 m-long ancient quarry front of an ordinary grey marble, also mentioned by Ballance (1966). The district north of Karagöl could be another possible extraction area now occupied by large active exploitation where different types of rocks are quarried. Near Turgut, a small locality north of Teos, Adak and Kadıoğlu (2017) describe an ancient quarry (Kesikkaya) where an Africano-like marble was mainly exploited. They reported the presence of one step-cut-shaped block of grey stone near the quarry front, deducing that the two types could be quarried in conjunction. This quarry was exploited by the open-pit mining technique, but a survey of the quarry fronts is difficult because of dense vegetation cover and water, which fills the quarry bottom in wintertime.

Finally about 40 km to the east of Teos, Türk *et al*. (1988) reported the presence of an ancient extraction district where inferior grades of both grey limestone and Africano marble were certainly quarried in antiquity.

MATERIALS AND METHODS

During a sampling campaign in 2009, 22 samples were collected from the step-cut-shaped blocks of black limestone, which were located along a raising dirt road next to the south-west lakeside of Karagöl.

More recently, a new sampling campaign was conducted in 2014 in some quarry areas from where these black blocks could have been quarried: 74 samples were collected from the rocky hill of Taşdibi Tepe and 16 samples from the rocky field to the west of the Teos archaeological site, where the Necropolis is situated (Fig. 1). It is impossible to have samples from the floor of Karagöl lake and there are no outcrops in close proximity. Some fragments (eight samples) of Africano marble were collected from the debris that covers the lake bottom in order to analyse the black matrix.

The black limestone of the quarry area of Beyler was surveyed but not documented in this study. This area is rich in many different coloured stones, even *breccia* that may resemble the Africano. The grey limestone of Beyler has macroscopic characteristics (colour and sedimentary structures) that make this stone quite different from the Teos black limestone of the blocks near Karagöl. Also, the limestone from the 100 m-long quarry front north of Karagöl seems to be macroscopically different from that of the blocks of Karagöl and, at first glance, of lower quality. They may be the subjects of further study.

The samples were analysed for their mineralogical composition on a Philips PW1840 diffractometer (CuKa/Ni: 40 kV and 20 mA) in the diffractometry laboratory at the Earth Science Department, Sapienza University, Rome.

A selection of samples from each group was cut into thin sections for petrographic and mineralogical study under a polarizing microscope. Thin sections were cut and polished in the thin sections laboratory at the Earth Science Department. Textures, fabrics, crystal boundary shapes and grain size features were observed, providing descriptive parameters for the characterization of the types of carbonate of this study (Dunham 1962; Friedman 1965; Wright 1992).

The whole set of samples was powdered for oxygen and carbon isotopes analysis. Oxygen and carbon isotopes were determined on calcium carbonate samples by isotope ratio mass spectrometry. A Thermo Gasbench II automatic preparation device was used for phosphoric acid digestion at 72 °C and CO_2 purification; a Finnigan Delta Plus mass spectrometer measured the carbon and oxygen isotopes ratios of CO_2, expressed in the usual delta notation, which represents the relative deviation in parts per thousand of the heavy/light isotope ratio of the samples from that of a reference standard. The international standard used was V-PDB (Vienna, Pee Dee Belemnite) for both oxygen and carbon isotopes, and analytical precision was better than 0.1‰ for both carbon and oxygen. Isotope measurements were carried out at the IGAG-CNR (Istituto di Geologia Ambientale e Geoingegneria - Consiglio Nazionale delle Ricerche) laboratory of mass spectrometry.

RESULTS

X-ray diffraction (XRD) analyses revealed a mineralogical composition exclusively made of calcite; a few cases showed a small amount of quartz. The presence of dolomite was not observed.

Petrography

Thin-section observation allows for a description to be made of the petrographic aspects and classification of the stones. The petrographic features of the various lithotypes are summarized in Table 1. The black stones of the Karagöl blocks (Fig. 3, a–b) and Taşdibi Tepe (Fig. 3, c–d) appear to have lost their original carbonate texture; the micritic matrix suffered from progressive and subsequent stages of diagenetic recrystallization into microspar and then into sparite in a process of aggrading neomorphism. No fossils or fossil ghosts are present. It is possible to have grains with linear dimensions larger than 4–5 mm and wide areas with very fine crystals, which sometimes fade to marginal micritic plagues. The boundaries of the grains of larger dimensions are irregularly shaped, embayed and never straight. They are intensely and pervasively polisintetic twinned, sometimes strained. Black carbonaceous matter permeates the rock and gives the black appearance. The inter- and intra-granular dispersion of this matter contributes to making the borders of the grains indistinctive. Some stylolitic sutures are visibly filled with brownish fine stripes of insoluble minerals (clay and oxides). Veins of concentration of secondary calcite and hematizated dolomite of brownish colour (nicol//; Fig. 3, a, c) are present as a consequence of the recrystallization process of micrite into sparry calcite. Both the black stone of the Karagöl blocks and Taşdibi Tepe can be classified as crystalline carbonate according to Dunham (1962). This classification was expanded and revised by Wright (1992). Basically, the black stones show very similar petrographic characters that insinuate that carbonate rocks would be the same.

The thin sections of the samples collected in the rocky field of the West Necropolis (Fig. 3, e–f) show a diagenized crystalline carbonate. The recrystallization appears to be more intense than it was in the previous limestones; here, larger crystals are more abundant and can reach up to 5–7 mm of linear dimension. Their boundaries are irregularly shaped, embayed and indistinct when they border micritic areas also because carbonaceous black matter permeates the rock. They are intensely and pervasively polisintetic twinned. All around plagues of microsparitic, rarely micritic, calcite are dispersed. Also these samples show brownish veins of calcite and dolomite crystals.

Table 1 reports descriptive terms for crystalline carbonate texture and fabrics which refer to the shape of mineral crystals and the type of crystal faces at crystal boundaries, and to the size and mutual relation of crystals respectively, using the terminology developed by Friedman (1965). All the samples of the three groups above described are characterized by an anhedral texture, the absence of crystal facing bounding the mineral grains, and inequigranular xenotopic and porphyrotopic fabrics, that is, closely packed anhedral crystal with mostly irregular intercrystalline boundaries and larger crystals enclosed in a fine-grained matrix.

The black matrix of the Africano marble (Fig. 3, g–h) is made of microsparitic or micritic calcite, frequently interrupted by less-than-millimetric-wide veins filled with blocky calcite and subordinately quartz and feldspar minerals. Micrite areas are characterized by irregularly distributed, mud-supported peloid and intraclast granules. Texture is anisotropic due to the irregular distribution of grains and sparitic areas. Stylolitic structures of insoluble residues are also present. Clasts of calcite of millimetric dimension or blocky calcite cement may be present with straight, neat boundaries. This limestone can be classified as a wakestone-mudstone, which locally becomes microsparitic crystalline carbonate.

Isotopes

Figure 4 shows all the results of the isotope analysis; summary statistics are reported in Table 1 (the whole data set is included in the supplemental data online). Stable isotope data allow a reliable discrimination among the different quarry sites in the area around Teos.

Table 1 *Summary of the petrographic and isotopic features of the samples analysed in the present study*

	Grain size, maximum (mm)	Grain boundaries	Mineralogy	General fabric	Crystallization texture	Crystallization fabric	Classification	$\delta^{13}C$ (mean, minimum, maximum)	$\delta^{18}O$ (mean, minimum, maximum)
Taşdibi Tepe									
$N_1 = 8$ $N_2 = 74$	3–4	Curved, embayed	Calcite (quartz at trace level)	Micritic, microsparitic	Anhedral	Inequigranular xenotopic porphyrotopic	Crystalline carbonate	2.79 2.04 3.68	−6.18 −8.23 −4.29
Karagöl blocks									
$N_1 = 6$ $N_2 = 22$	5–6	Curved, embayed	Calcite (quartz at trace level)	Micritic, microsparitic	Anhedral	Inequigranular xenotopic porphyrotopic	Crystalline carbonate	2.61 1.08 3.21	−11.33 −11.80 −10.62
Rocky field West Necropolis									
$N_1 = 5$ $N_2 = 16$	4–6	Curved, embayed	Calcite (quartz at trace level)	Micritic, microsparitic	Anhedral	Inequigranular xenotopic porphyrotopic	Crystalline carbonate	5.56 4.90 6.01	−8.41 −9.20 −7.58
Africano matrix									
		Grain types		Fabric	Texture				
$N_1 = 4$ $N_2 = 8$	< 0.5	Intra-clasts, peloids	Calcite (quartz, plagioclase at trace level)	Micritic, microsparitic	Anisotropic, mud-supported		Mudstone-wakestone-crystalline carbonate	2.69 2.19 3.01	−9.81 −11.08 −8.23

Note: Descriptive parameters for crystalline carbonates are according to Friedman (1965); the classification is according to Wright (1992). N_1 and N_2 represent the number of samples used for petrographic thin-section observation and for isotope analysis respectively.

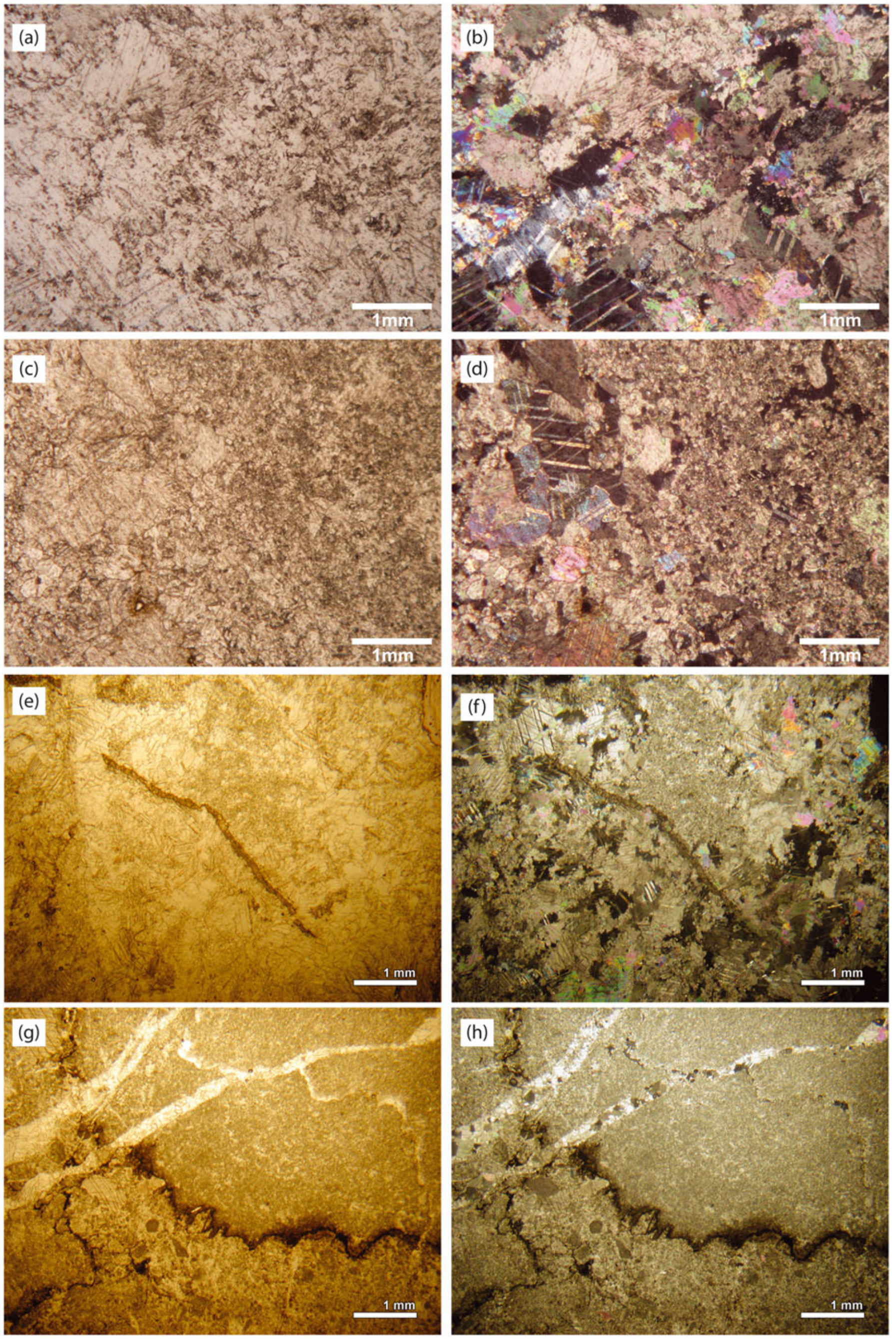

Figure 3 *Microphotographs of thin sections: (a, b) blocks of black limestone at Karagöl; (c, d) black limestone at Taşdibi Tepe; (e, f) black limestone in the rocky field at the West Necropolis; and (g, h) black matrix of the Africano marble. Left side, parallel nicols; right side, crossed nicols. [Colour figure can be viewed at wileyonlinelibrary.com]*

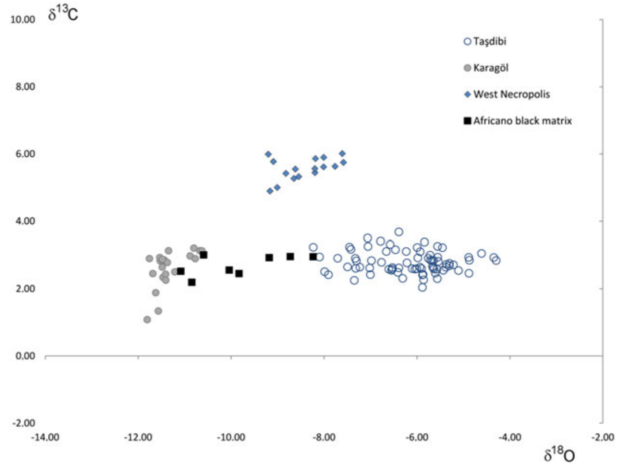

Figure 4 *Carbon and oxygen isotope distribution of the black limestone samples in this study. Isotope data are given as ‰ with respect to the specific international standard, V-PDB. [Colour figure can be viewed at wileyonlinelibrary.com]*

The limestone of Taşdibi Tepe appears to be well grouped between −8.23‰ and − 4.29‰ for oxygen and between 2.04‰ and 3.68‰ for carbon isotopes, while the blocks of the Karagöl black limestone show less dispersion of oxygen isotope data between −11.80‰ and − 10.62‰ and a similar range for carbon between 1.01‰ and 3.21‰. Oxygen isotopes allow an evident separation between the fields of belonging of the two limestones in the scatterplot $\delta^{18}O/\delta^{13}C$ (Fig. 4). Whereas carbon isotopes show values typical of a pristine marine carbonate from which these limestones surely derived before diagenesis, oxygen isotopes underwent a diagenetic process of exchange with water of probable meteoric origin (Faure 1987). The variability of oxygen isotopic compositions was a function of temperature and water/rock ratio (the higher the ratio, the lower the isotopic composition). The isotope data of the samples collected from the rocky field are distinct from the other data especially due to an anomalously high carbon isotopic composition with a mean of 5.56‰ and a very narrow dispersion. Finally, the black matrix of the Africano marble shows a similar carbon composition of Taşdibi and Karagöl black limestones and an oxygen isotopic composition that is intermediate between both (Fig. 4).

DISCUSSION

The petrographic observation on thin sections of the stones sampled at Karagöl, Taşdibi and the West Necropolis of Teos shows that the limestones are all crystalline carbonate, that is, carbonate rocks completely diagenized where the pristine depositional nature and texture were totally obliterated by recrystallization. While the stones of the first two locations are carbonates at a similar stage of diagenesis (indicated by the same texture and grain size characteristics and distribution), the rock of the third site shows a more intense diagenetic process as more abundant larger crystals were developed and more abundant stylolite surfaces and veins were observed.

The isotopes confirm this scenario and attest an isotopic alteration during the diagenesis in a system open to water circulation (Faure 1987). Carbon isotopes of the limestones of Karagöl blocks and Taşdibi rocky hill have the same values and spread, while isotopes of oxygen are clearly (and significantly) different. The difference in the oxygen isotopic composition can be attributed to a difference in their location with respect to an oxygen isotopic alteration front of a water fluid. This implies that the rock of the Karagöl blocks does not come from the Taşdibi rocky hill. Ballance's (1966) suggestion that the lake of Karagöl was a quarry pit from which the blocks were quarried away remains the most probable, but it cannot be corroborated by the present study because no samples could be collected from the bottom of Karagöl lake. Unfortunately there are no outcrops of black limestone in the immediate proximity of the lake, the area being flat and the bedrock being covered with an indefinite soil layer.

Ballance (1966) also suggests that Karagöl was also the extraction site of the well-known Africano. The petrographic investigation attests that the Africano matrix is a calcitic micrite or microsparite; geologically, however, Africano marble is a *breccia*, quite different from the black limestone that characterizes the area. The isotopic analysis may help to confirm the contiguity of the black limestone and Africano when the isotopic alteration shows the same effects in the two lithotypes. Adak and Kadıoğlu (2017) have already showed that the *breccia* of an Africano-like marble was in contact somewhere with black limestone and quarried together in a double column exposed at Sığacık, which is made of the two lithologies. The black matrix of Africano, collected from the debris below the lake's water level, shows isotopic compositions that range from those of the black limestone of Karagöl blocks to those of Taşdibi Tepe. This may allow one to conclude that: (1) the samples of debris of Africano represent a rock body positioned in the middle of the alteration fluid path from Karagöl to Taşdibi; (2) the Africano could have been exploited at different sites in between; and (3) the lake and the area all around in the past could have served for the storage and discharge of quarried material. This could be partially confirmed by Adak and Kadıoğlu's (2017) reporting the presence of Africano debris below the north side of Taşdibi Tepe. This could attest to the existence of a further Africano extraction site below the black limestone.

Regarding the effectiveness of the techniques used in this study to recognize the black limestone of the blocks of Karagöl in archaeological artefacts, the oxygen isotopic composition is the parameter that contributes the most. The diagenesis event has altered the limestone up to $-11‰$ on average for $\delta^{18}O$. This allows this stone to have a significantly lower oxygen isotope

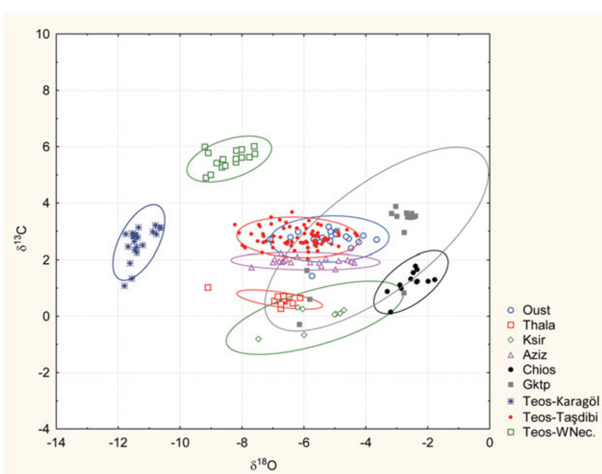

Figure 5 *Carbon and oxygen isotope distribution of the black limestones quarried in antiquity in the Mediterranean area. The quarry sites are those of Djebel Oust, Djebel Aziz and Thala in Tunisia; of Chios in Greece (after Brilli et al. 2010); of Göktepe in Turkey (after Brilli et al. 2018); and of Teos (present study). Confidence ellipses are drawn at 90% probability. [Colour figure can be viewed at wileyonlinelibrary.com]*

ratio than the black limestones quarried in antiquity, investigated thus far in previous studies. Also, the limestone surveyed and sampled in the rocky field of Teos' West Necropolis has an isotopic composition that easily distinguishes it because of an elevated carbon isotopic composition, which is likely due to a difference in the nature of the carbonatic lithotype precursor. Note that this stone could have had local importance, contributing to building the Hellenistic walls and the pier of the southern port of Teos. In Figure 5, a collection of black limestones, used in antiquity and presumably widespread in the Mediterranean area, is reviewed in a $\delta^{18}O/\delta^{13}C$ scatterplot, which evidences the clear separation of the Teos limestone of the blocks situated near Karagöl with respect to the other black limestones. It is difficult to recognize the Taşdibi limestone using the isotopic technique, which falls into the most densely populated region of the isotopic diagram. However, petrographic observation of the thin sections is effective in uniquely characterizing all the Teian limestones in comparison with the black limestone reported in the relevant literature by Brilli *et al*. (2010) and Lazzarini *et al*. (2006), due to their remarkable crystalline fabric.

CONCLUSIONS

This paper examines the petrographic and isotopic characteristics of some black limestones that were exploited near the ancient site of Teos in Ionia (south-western Anatolia, Turkey). Those step-cut-shaped, unfinished stones located around Karagöl lake may represent the black limestone of Teos, which were intended for export. Where these blocks were quarried is not entirely clear. Black limestone outcrops exist all around Teos; however, numerous scholars, supporting the hypothesis of Ballance (1966), consider the stone to have been quarried away, along with the more famous Africano marble, from an open-pit quarry which is now Karagöl lake. Unfortunately, it is impossible to explore the floor of the lake, which is carpeted with a pile of loose debris and is (in the centre) several metres below the water level. The blocks of black limestone near Karagöl, Taşdibi Tepe and a rocky field west of the west wall of Teos archaeological site were surveyed and sampled for petrographic and isotopic investigation. Some samples of the black matrix of Africano marble collected from the debris of Karagöl lake were also studied using the same techniques. Petrographic features of these stones and isotope data allow a unique distinction to be made. This means that none of the black limestone sources examined provided the step-cut-shaped blocks placed near Karagöl, which could be quarried from the bottom of the lake itself. Isotopes allow the confirmation to be made that the black limestone of Karagöl could be quarried in conjunction with Africano marble, which could be continuously in contact with the black stone between the sites of Karagöl and Taşdibi Tepe and exploited in this area.

This study makes it possible to contend that the black Teian limestone destined for export is easily recognizable using isotopic and petrographic techniques and can be satisfactorily applied to assigning the Teos provenance to black archaeological artefacts.

The data presented here furthermore may allow one to determine the provenance of black stone situated at the ancient site of Teos where the use of black stone for monuments was widely adopted.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supporting Information