ANCIENT ‘BLACK’ DECORATIVE STONES AND THE
EPHESIAN ORIGIN OF SCULPTURAL BIGIO ANTICO*

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Isotopic, EPR and petrographic studies aimed at establishing the provenance of sculptural
bigio antico are reported, including 18 possible quarry sites and 21 ancient sculptures. The
results demonstrate that the Belevi quarry, north-east of Ephesos, above the more famous
white marble quarry, was the major source of this marble. Nineteen artefacts belong to Belevi,
whereas the precise origin of the remaining two is unknown, but must probably be found
within the same area. The peculiar distribution of δ13C values both for Belevi and artefacts
was crucial for inferring the correct provenance, subsequently confirmed by additional
analytical and petrographic data.

KEYWORDS: BIGIO ANTICO, BIGIO MORATO, NERO ANTICO, BELEVI, SCULPTURE,
PROVENANCE, ISOTOPES

INTRODUCTION

The aim of the present work is to present new data on the provenance of a ‘black’ carbonate rock1
much used in Roman times and commonly known as bigio antico. The study continues recent
work that identified Göktepe, south of Aphrodisias, as the main source of supply of another dark
grey to black stone, bigio morato, that was used in antiquity to manufacture much prized, high-

The term bigio antico identifies several medium- to coarse-grained grey stones exhibiting
different colour shades, from light grey to almost black, and, often, mottling effects and fossil
relicts (Borghini 1997, 158–9). The definition matches closely the appearance of a ‘black’ stone
commonly used in Roman antiquity for the manufacture of columns and other architectural
elements.

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1Ancient bigio marbles include a variety of colour shades almost encompassing the entire greyscale. For this reason, the word ‘black’,
conventionally used when referring to these stones, is shown in quote marks.
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In turn, the same definition fits several *bigio* varieties, among which the *bigio antico* quarried near Moria on the island of Lesbos is considered to be, on macroscopic and archaeometric bases, the most important architectural variety used in antiquity (Leka and Zachos 2015).

Turning to sculptural *bigio antico*, however, it must be noted that this stone, apart from the similar colour hue, differs considerably from Lesbian and other architectural varieties. It exhibits, in fact, a distinctly finer crystal grain, that barely exceeds 1 mm, and a much more regular texture that implies much better working properties and makes it perfectly suitable for carving statues. In this sense, *bigio antico* and *bigio morato* are rather similar stones, the main difference being the crystal grain size, which is distinctly finer in the latter, although sharp boundaries are difficult to draw. The good working properties of both materials lent them to be used mostly for sculpture, producing artefacts that were prized for being reminiscent of polished (*bigio morato*) or patinated (*bigio antico*) bronze statues depending on the crystal grain size, which causes the stones to shine differently upon polishing (Attanasio et al. 2009).

Following the above arguments, it is obvious that the provenance problem posed by sculptural *bigio antico* is difficult to solve without taking into account both stones and, in general, the whole panorama of ancient ‘black’ stones, which also includes a third variety discussed below and known as *nero antico*. The appearance of this latter does not differ significantly from *bigio morato*. It is generally a very compact material, exhibiting an even finer crystal grain and mediocre working properties that make it hardly suitable for sculpture. *Nero antico* was used mostly for architectural decoration, small decorative artefacts and polychrome floor decoration (Borghini 1997, 254–5).

Despite much recent work, several problems concerning ‘black’ stones are still unclear and include uncertain provenances and terminological ambiguities, as well as different geological interpretations that have affected marble studies. Now, the study of sculptural *bigio antico* provides a better understanding of the relationships existing among the different varieties and indicates that rather different materials are incongruously grouped under the common term *bigio antico*. The entire problem can be reconsidered, providing a slightly different and, hopefully, clearer approach.

It may seem pointless to try to explain and rationalize an old nomenclature based simply on the appearance of the stone. The problem, however, is that this is the standard nomenclature used in the archaeological and art-historical literature. It is important, therefore, that current names are precisely defined and related to their geological properties. Only in this way can traditional terms be used properly without giving rise to confusion and misunderstandings.

### TERMINOLOGY, GEOLOGICAL NATURE AND USE

Table 1 summarizes different terminologies currently used for ancient ‘black’ stones together with relevant geological properties, uses and selected sources of supply. The traditional nomenclature (Corsi 1845, 107–8) distinguishes three varieties called *nero antico*, *bigio morato* and *bigio antico*. On the basis of colour and grain size, Corsi considered *nero antico* and *bigio morato* to be quite similar to one another and different from *bigio antico*. He argued that the two former stones are both homogeneously dark-coloured materials, exhibiting fine to very fine crystal grain that is responsible for their typical metal-like shine. This type of classification, however, is somewhat confusing, as proven by the fact that Corsi himself identified as *bigio antico* two Dacian prisoners (Palazzo dei Conservatori, Rome) now known to be Göktepe *bigio morato* (Attanasio et al. 2009, 334–5).
More recently, a different, geologically based, classification was proposed (Pensabene and Lazzarini 1998; Lazzarini 2013). Nero antico is used as the general name for all Roman ‘black’ stones and includes two sub-categories, bigio antico and bigio morato, defined as crystalline marbles and purely sedimentary limestones, respectively. However, although nero antico is, actually, a pure limestone, the other two varieties do not belong clearly to any of the two limiting categories. They have variously been defined as low to very low metamorphic marbles or heavily diagenetized crystalline limestones (Lazzarini et al. 1999; Lapuente et al. 2012; Leka and Zachos 2015). The different terminologies express, in fact, the same basic concept: these are in all cases intermediate materials somewhere along the process leading from limestones to marbles. The grain size and texture, which were crucial for determining macroscopic appearance and use, depend on several factors such as temperature, pressure and the duration of the process undergone by the stones, the effect of static-dynamic recrystallization and the properties of the protoliths.

The problem is nicely illustrated by the Gökştepe marble site, which shows that different materials, from marbles to crystalline limestones exhibiting different textures, can be present in the same area where the degree of metamorphism was necessarily the same. The degree of order–disorder of the organic impurities present in the black Gökştepe marbles, as measured by Raman spectroscopy, indicates a metamorphic temperature of about 300°C, which is slightly
lower than the value reported for Carrara. Thus these rocks can be called ‘marbles’ in a petrographic sense, as shown by the extremely pure, white Göktepe marble, which exhibits a well-crystallized, polygonal texture with a homeoblastic metamorphic fabric, with calcite crystal grain sizes of approximately 0.3 mm. On the other hand, the black Göktepe variety, often found side by side with the white marble, is extremely fine-grained and still exhibits some sedimentary structure, such as traces of fossil fragments (Fig. 1). It is clear that, besides temperature, pressure and time, the properties of the protolith, and particularly the level and pattern of impurities that are present in the black Göktepe marble, play a crucial role in determining the systematic textural and grain-size difference between the two varieties. It is a general observation, in fact, that a certain amount of organic or silicate impurities in the original limestone may hinder or even block early recrystallization. Furthermore, it is obvious that different sedimentological types of limestone (e.g., lumachella, porous, fossiliferous, fine-grained micritic etc.) will result in different textural types even under the same physical conditions.

In conclusion, it can be stated that, apart from the purely sedimentary nero antico, other ancient ‘black’ stones—that is, bigio morato and bigio antico—are all geologically related materials that, owing to the precise degree of low-grade metamorphism and protolith differences, exhibit a variety of grain sizes and textures that are responsible for their aspect and use.

Figure 1  The macro- and microscopic appearance of the white to black marble transition at Göktepe: (a) a raw quarry block; (b) a polished quarry sample; (c, d) thin sections showing the transition from white to black marble using (c) plane- and (d) cross-polarized light. The microphotographs are 7 mm wide. Under identical metamorphic conditions, grain size and texture are strongly affected by different properties of the protoliths. A very big fossil relict is visible in the right upper corner of images (c) and (d).
The bigio of Lesbos and other similar varieties show a highly irregular texture that alternates crystalline limestones with layers of light grey laminated calcareous dolomites. A typical mortar fabric is present and includes elongated aggregates of calcite crystals up to 10 mm. The stone was satisfactory and widespread for architecture, but not suitable for sculpture. On the other hand, the Göktepe bigio morato and the sculptural bigio antico of unknown provenance, ranging from fine to medium grain size, exhibit much more regular textures, are slightly heteroblastic and sometimes show schistosity. On this basis, it is suggested that the traditional Corsi classification should be slightly modified and improved by splitting the bigio antico category into two varieties that differ in their texture and use and are called architectural and sculptural bigio antico, respectively. The latter is closely related to bigio morato in that both materials are well suited for sculptural work and were used predominantly for this purpose. Turning to provenance, it should be recalled that in antiquity the marbles used for sculpture were carefully chosen based on high material quality and the reputation of the sculptors used to work them. These criteria seem to contradict the opinion that high-quality ‘black’ marbles used for sculpture might originate unconcernedly from a variety of different sites. The results obtained with bigio morato have already proven that it was produced mostly at Göktepe (Attanasio et al. 2009). Similarly, this study will demonstrate that a single quarry site was by far the main source of the sculptural bigio antico used in antiquity.

SOURCES OF SUPPLY

Apart from few notable exceptions—limited, in fact, to Lesbos and Göktepe—the provenance of ancient ‘black’ artefacts is generally unknown. Detailed analyses are often missing and even quarry studies, when available, are usually not accompanied by analytical identification of archaeological artefacts. Most frequently, only identification of the marble variety (bigio antico, bigio morato or nero antico) is reported and even in this case the results are often doubtful (De Nuccio and Ungaro 2002, 299–301, cat. no. 2; Gasparri 2009, 36–9, cat. nos. 11–12).

Traditionally, bigio antico is considered to come from Lesbos as well as from other sites mostly on the Aegean coast of Asia Minor and nearby islands such as Rhodes, Kos, Teos, Miletos, Ephesos and others (Gnoli 1988, 179–80). The city quarries of Aphrodisias were also suggested as a possible source (Lazzarini et al. 2002), although there is little evidence of systematic excavation. Other possible sites continue to be proposed, although once again archaeometric support is often missing. They include Langada, Aghios Petros and Cape Tainaron in the Peloponnesos and Belevi, Iznik and others in Asia Minor. The marbles of Iznik have been studied in some detail (Yavuz et al. 2012) but turned out, apparently, to be only for local use. The grey marbles present in large amounts at Carrara (bardiglio), Afyon (bigio and Kaplan Postu), Mt Hymettos and Mt Penteli (Goette et al. 1999) are generally not considered to be true bigi antichi because of their fine grain size. In dealing with the relatively fine-grained bigio antico used for sculpture, however, excluding them a priori is difficult.

Turning to bigio morato, it has been already pointed out that Göktepe was the most important source of the sculptural variety used in antiquity. Alternative sources appear to be irrelevant or simply non-existent. This is the case for the famous ‘black’ quarries of Cape Tainaron mentioned by Pliny (NH 36, 29, 43) and still considered in the art-historical literature as the main source of ancient bigio morato (Borghini 1997, 160). It is now known that only two small, hardly relevant quarries of bigio antico exist at Cape Tainaron, without any trace of bigio morato (Bruno and Pallante 2002).
Nero antico is also present at Göktepe and was used mostly for the production of small to medium-sized columns. Alternative sources are in Tunisia, at Gebel Aziz, Gebel Oust, Ain el Ksir near Chemtou and elsewhere (Brilli et al. 2010), or in southern Peloponnesos, where small outcrops of local relevance have been discovered (Bruno and Pallante 2002).

THE QUARRY DATABASE

The 18 marble sites considered in this work are listed in Table 2, where their most relevant properties are summarized. Complete analytical data are given as online supplementary material. Recalling that the sculptures tested (Table 3) are medium- to fine-grained, distinctly coarser bigio marbles could have been neglected. Since, however, MGS is only one among several analytical variables, it was decided to use as extensive a database as possible. Therefore, all sites known to produce bigio antico were included, regardless of their grain size. Sites that supplied only limited amounts of bigio and are famous for the production of other marbles are also present. This is the case of the Kara Göl quarry near Teos, which was the source of africano, and of Latomi at Chios, where the marble called portasanta was quarried. The underlying hypothesis is that the bigio variety present in these quarries was exploited as a minor side product.

Following the arguments discussed above, the main production site of bigio morato, which is Göktepe, was included and this led to add other fine-grained bigio marbles produced at Carrara and Afyon, even if there are no indications that they were ever used for sculpture.

Other sites, however, are absent. They are the neri antichi from Tunisia and Peloponnesos, which exhibit uniquely fine crystal grain and very high EPR intensity (Brilli et al. 2010) and would be easily ruled out by statistical analysis. The grey marbles from Mt Hymettos and Mt Penteli in Attica and from Aphrodisias in Caria are also absent. In these cases, detailed data sets are not available, but known data including isotopes and other properties demonstrate that provenance of the archaeological artefacts from these sites can be safely excluded. A final question concerns the possible existence of unknown quarries. As already noted, bigio antico marbles are relatively common and the problem of undiscovered sources cannot be ignored, as shown by the discovery of the Iznik quarries (Yavuz et al. 2012).

Even if the database established in this way is probably not exhaustive, from another point of view it is almost certainly redundant. Several locations proposed as possible sources are historically unknown, exhibit little evidence of ancient work and are, in any case, of limited size. Their exploitation, if any, took place almost certainly on a strictly local scale. In the present state of uncertainty, however, it is difficult to rule them out a priori. Sites such as Kirkoy near Aphrodisias (Long 2012, 171) or Langada and Aghios Petros in the Peloponnesos (Lazzarini 2013) were included not as likely sources, but simply to verify their hypothetical use in antiquity. Similarly, Cape Tainaron was included mostly for its dubious fame due to Pliny. Actually, the two bigio antico quarries of Cape Tainaron are quite small and seem to be hardly relevant.

The last bigio area to be considered is located around Ephesos and includes the bigio antico quarry at Belevi and others. Since, however, this bigio variety plays a crucial role in this study, the site is described separately in the next section.

BELEVI AND OTHER EPHESIAN BIGIO ANTICO MARBLES

At Ephesos, as at Afyon and elsewhere, the white marble beds are frequently overlain by thick layers of bigio marble. The grey layer can be quite deep, as shown by the Panayir mountain, located immediately east of the ancient city (34.94152°N, 27.35198°E), which is entirely formed
Table 2  Grey marble quarries selected to establish the provenance of the bigio sculptures, listed in order of increasing grain size. Average and total range values (min.–max.) are given. Isotopic and EPR variables are given as ‰ or % referring to specific standards (Pee Dee Belemnite for isotopes and Dolomite N368 BCS for EPR). MGS is given in mm and colour in %, using an 8-bit scale, where black = 0 and white = 255. The strontium data, measured by atomic absorption spectroscopy following Prochaska (2013), are in parts per million (ppm). Groups 10a and 12a include Belevi and Kuşini Tepe samples reclassified according to their different δ¹³C values.

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<th>δ¹⁸O (‰)</th>
<th>δ¹³C (‰)</th>
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**Table 2 (Continued)**
Table 3  *The 21 bigio sculptures tested in this work, listed in chronological order. Analytical data, provenance results and available chronological information are shown. The relative and absolute probability values (RP and AP) are defined in the text. Units are as in Table 1.*

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<th>$\delta^{13}C$ (%)</th>
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<td>1</td>
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<td>Agnoli (2002, 31–40), Gregarek (1999, 198, cat. no. C294)</td>
<td>0.6</td>
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<td>Ares Borghese type, Florence, Uffizi, inv. 1914.192</td>
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<td>Botti and Romanelli (1951, 116–17, cat. no. 186), Gregarek (1999, 176, cat. no. A34)</td>
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<td>Presumably coeval with the renovation of the theatre sponsored by Matidia Minor Gasparri (2009, 38–9, cat. no. 12), Gregarek (1999, 196, cat. no. C19)</td>
<td>1.3</td>
<td>13</td>
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<td>Isis, Ostia, Archaeological Museum, inv. 18141</td>
<td>Middle to late second century AD</td>
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<th>δ¹³C (%)</th>
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of fine-grained grey marble, usually not included among the bigio antico varieties. The Panayir marble has been actively quarried since Hellenistic times and is therefore present in the database selection, although it was mostly used as a convenient building material for the nearby city (Crouch Troy 2003, 226).

Today, the main visible source of good-quality medium-grained bigio antico in the area is the modern abandoned quarry located above the white marble quarry at Belevi (Fig. S1 (a)). Although modern quarrying at Belevi has cancelled out most ancient traces, some evidence still survives, including a locus where a basin was extracted, scattered traces around the main quarry and a small waste dump (Figs S1 (b) – S1 (d)). A thick layer of bigio marble is also present at Kuşini Tepe, although no evidence of ancient or modern extraction was found.

Belevi and Kuşini Tepe are just examples of the complex outcropping of white and black marbles that occurs in the region, also including large deposits of greco scritto marble near Hasançavuslar (Yavuz et al. 2011; Attanasio et al. 2012). Especially interesting is the area that extends in a south-west–north-east direction from Belevi to Aya Klıkiri, west of Hasançavuslar (Fig. S2). The place is mostly known for the production of greco scritto at Zimparà and near Hasançavuslar (eastern and western districts labelled HCE and HCW, respectively). White marbles, however, are also present and prevail to the north (Göllüce, Aya Klıkiri) and to the south (white Belevi, Kentli Çiftliği). In addition, grey marbles are found in most greco scritto quarries, where the marble becomes more heavily veined and darker in the inner part of the quarries, eventually changing to typical bigio antico. The plateau between HCW1 and Aya Klıkiri (Fig. S2) is dotted with many extraction loci that were opened to exploit small to medium-sized outcrops of white, bigio and greco scritto marbles. Isotopically, samples from this area are split into two rather homogeneous groups, differing distinctly in their $\delta^{13}C$ values. Despite the fact that the quarries are not homogeneous sources of bigio, grey samples from the area are tentatively included in the database (Hasançavuslar A and Hasançavuslar B groups). The hypothesis is that bigio antico production at Ephesos might have extended beyond Belevi, involving a number of nearby quarries that supplied, perhaps occasionally, suitable material for sculptural or architectural use.

THE BIGIO ANTICO SCULPTURES

Coloured marble sculptures, and in particular ‘black’ statues, represent a relatively restricted and yet important phenomenon of Roman art. They have attracted much interest and are the object of numerous studies, including the systematic investigation carried out by Gregarek (1999). Following a tradition that goes back to Egypt and the Greek East, the fashion of coloured sculptures in Rome began under Augustus, peaked under the Flavians and Hadrian, and continued in Antonine and Severan times, slowly fading away in the late second and third centuries, when bigio artefacts are mostly found at provincial sites (Gregarek 2002). The purpose was primarily decorative and the themes were often deities and mythological figures, used to embellish baths and Imperial or elite residences. Independently of the specific material used, dark grey to black sculptures were praised for similar reasons; that is, their decorative appeal and the resemblance to bronze or patinated bronze sculptures. In this sense, they are all part of the same art-historical phenomenon and are often discussed together. This is also due to the fact, repeatedly underscored, that separating some of the above materials clearly is difficult, a problem that considerably complicates the possibility of obtaining information on workshops and production places.

The 21 sculptures investigated in this study (Table 3) nicely exemplify the above problems. Their MGS values, which represent the easiest and most convenient differentiating criterion,
are often intermediate between typical bigio morato and bigio antico values. The barbarian head no. 12, the Perge dancer no. 7, the Demeter no. 13, the Vittoria dei Simmaci no. 18, the river god no. 16 and the mule head no. 3 show MGS values between 0.5 and 0.65 mm, and have often been defined as bigio morato marbles. Other sculptures, such as the Fortuna no. 6 and the Isis no. 10, are distinctly coarser (1.2 and 1.3 mm, respectively). Despite this, they have also been considered as bigio morato artefacts (Gasparri 2009, 36–9, cat. nos. 11–12), showing that grain size is just one of the many elements affecting macroscopic identification. In connection with the art-historical problems mentioned above, it is clear that reliable provenance results are much more informative than uncertain and controversial classifications based on marble type.

Turning to chronology, it must be noted that the number of sculptures tested is too limited to provide a significant and unbiased panorama, especially considering that the dates of several sculptures, and especially fragmentary artefacts, are highly uncertain. Nevertheless, available chronologies confirm that the use of ‘black’ stones peaked in the second century AD. The largest number of pieces belong to the Antonine period. Other sculptures are dated to different periods of the second century, whereas the number of first-century sculptures is much more limited.

The most surprising chronologies are those of the Vatican deer no. 2 and the Isis Fortuna from Palestrina, no. 1, which have been dated to the first century BC, or even to the late second or early first century BC in the case of the Isis (Agnoli 2002). This latter opinion has certainly been influenced by the sanctuary chronology. Nevertheless, the Hellenistic dating is surprising because the use of bigio marble in this period, if any, was quite limited. On this basis, a different, probably Flavian, chronology has been suggested. Within this frame, the provenance of marble may provide important, though indirect, elements of information bound primarily to the known periods of quarry exploitation.

SAMPLING, EXPERIMENTAL METHODS AND DATA ANALYSIS

Table 3 lists all the artefacts tested and includes analytical data, provenance results and available chronological information. The samples were tiny chips taken from hidden positions or pre-existing fractures. After mechanical cleaning, petrographic and instrumental analyses, including electron paramagnetic resonance (EPR) spectroscopy and stable isotope analysis (δ\(^{13}\)C, δ\(^{18}\)O), were carried out according to experimental procedures and standardization methods described elsewhere (Yavuz et al. 2011).

The provenance of the samples was determined with the aid of a multivariate approach that uses linear discriminant analysis to compare the experimental values of five variables:

- the oxygen isotopic ratio, \(\delta^{18}\)O
- the carbon isotopic ratio, \(\delta^{13}\)C
- the EPR intensity,
- the EPR linewidth, and
- the maximum grain size (MGS),

with related values available for quarry samples. The procedure has been discussed in detail in a number of instances (Yavuz et al. 2011). Here, only definitions of relevant probability parameters are recalled:

- The relative or posterior probability (RP): the probability that the sample belongs to one of the groups in the selection. Low values (<60%) indicate uncertainty among different groups.
- The absolute or typical probability (AP): a distance-dependent parameter measuring the absolute probability that the sample belongs to the chosen group. The 10% threshold
corresponds to samples on the edge of the 90% probability ellipse. Lower values indicate outliers or samples possibly not belonging to any group in the selection.

The assignments are considered valid if the probability values are above the thresholds. In this way, uncertain provenances can easily be identified and the problem of possible unknown bigio quarries (low absolute probability) can be addressed.

**RESULTS AND DISCUSSION**

**Isotopic analyses**

Isotopic data, and in particular the distinctive distribution of $\delta^{13}C$ values, was crucial in unravelling the bigio antico problem. The isotopic graph of Figure 2 (a) shows a number of features that need further discussion. The graph is simplified in that only seven relevant quarries are shown, whereas the remaining 11 sites listed in Table 2 have been ignored because their isotopic

![Isotopic graphs showing selected database quarries and the 21 artefacts tested.](image-url)

Isotopic (a, b) and EPR/MGS (c, d) graphs showing selected database quarries and the 21 artefacts tested. Graphs (b) and (d) are drawn after reclassification of the Belevi and Kuşöni Tepe samples as Ephesos bigio 1 and Ephesos bigio 2, depending on their $\delta^{13}C$ values (see text). Graph (a) shows individual data points for the samples collected at Belevi during two separate campaigns (open circles and squares, respectively).
values are incompatible with the artefacts. Therefore famous locations such as Cape Tainaron, which do not fit the bigio sculptures, are not shown on the graph, whereas a barely known and unlikely source such as Kirköy, near Aphrodisias, is present. The relevance of the Hasançavuslar B group is connected with the provenance of samples no. 6 and no. 10 and will be discussed later.

The most notable feature of the graph is the distinctive isotopic distribution of the sculptures, which are quite homogeneous in terms of $\delta^{18}$O ratios but exhibit clearly discontinuous $\delta^{13}$C values. Apart from samples no. 6, Isis Fortuna inv. 6368, and no. 10, Isis inv. 6370, at very high $\delta^{13}$C and sample no. 5, Ares Borghese inv. 1914.192, at intermediate values, the remaining 18 sculptures are split into two homogeneous groups centred at distinctly different high and low carbon values (averages 3.07 and 0.70‰, respectively).

At first, this result was taken as a clear indication of the existence of two main sources of supply. Inspecting the graph, however, it is difficult to make reasonable guesses. Both the high- and low-carbon groups appear to be marginal with respect to the best known bigio sources, such as Lesbos or the isotopically similar lithos lartios of Rhodes. The Göktepe or Kirköy possibilities are unlikely in terms of grain size and EPR intensity, and are easily ruled out with the help of the graphs of Figures 2 (c) and 2 (d), discussed in the following section.

The single-source hypothesis was reconsidered and it was noted that the $\delta^{13}$C distribution of the sculptures is reminiscent of a similar distribution that is typical of the white Ephesos marbles and that led to the establishment of the well-known groups Ephesos 1 (high carbon, including Kentli Çiftiliği, Ahmetli, Göllüce and other quarries) and Ephesos 2 (low carbon, including Belevi and Kuşini Tepe). Such a grouping, which also includes an Ephesos 3 group corresponding roughly to the quarry of Aya Klirkiri, was recognized long ago by Herz (1985) and was fully confirmed later (Yavuz et al. 2011). The single-source hypothesis was supported by preliminary analyses of the Belevi bigio marble carried out in 2008 on 14 quarry samples (Fig. 2 (a), open circles). The isotopic data, in fact, are clearly distributed into three groups and closely mimic, within a single quarry, the behaviour of the Ephesos white marbles recalled above. At the same time, they seem to fit the archaeological data points rather satisfactorily.

Subsequently, more detailed sampling was carried out at Belevi and bigio samples were collected and analysed at Kuşini Tepe and in many quarries in the area shown in Figure S2. The results of this work can be summarized as follows:

- Thirty-two new Belevi samples, combined with the 14 samples already available, confirm the discontinuous distribution of $\delta^{13}$C but demonstrate that the phenomenon is less sharp than previously suggested. The $\delta^{13}$C values do not show any clear dependence on the exact sampling location within the quarry.
- The bigio marble of Kuşini Tepe is macroscopically similar to the Belevi variety but invariably shows low carbon values. No indication of ancient exploitation was found.
- The bigio samples collected in the area shown in Figure S2 generally differ from the marble of the sculptures by virtue of several properties including coarser grain, higher EPR intensity and more negative oxygen values. This is especially true for Hasançavuslar A, which does not seem to be a possible source for any of the sculptures. At variance with this, Hasançavuslar B is isotopically compatible with the very high $\delta^{13}$C samples no. 6 and no. 10.

Based on the results summarized above and following the approach commonly used for the Ephesos white marbles, the bigio samples from Belevi and Kuşini were reclassified into two groups (Ephesos bigio 1 and Ephesos bigio 2, or EB1 and EB2) depending on their carbon values. The threshold is set at $\delta^{13}$C = 1.65 and the overall properties of the new groups, which replace Belevi and Kuşini Tepe, are shown in the two bottom rows of Table 2 and in Figure 2 (b).

Regrouping the Ephesos *bigio* samples may seem a questionable operation that tries to classify quarry samples so as to fit artefact analyses. The purpose, however, is that of taking into account the strong $\delta^{13}C$ variation shown by quarry and archaeological samples. In this way, more precise classification is possible and the most relevant analytical peculiarity of the *bigio* sculptures is recognized. The same approach is commonly used for several white marble sites in order to obtain improved accuracy in classification. Ephesos is obviously the most pertinent example, but many others are known, such as Paros, Proconnesos and others.

**EPR and grain-size analyses**

The results of Table 3 indicate that the *bigio* artefacts exhibit low to medium EPR intensities (5.3–23.5%) and are generally fine-grained marbles with MGS values below 1.0 mm. Exceptions are samples nos. 6, 10, 17 and 19, which exhibit coarser grain sizes (1.1–1.3 mm) as well as higher $\delta^{13}C$ values. Apart from this, the EPR and grain-size data are relatively homogeneous and do not show any grouping similar to the discontinuity noted for carbon isotopes.

These results, although not especially indicative of a precise provenance, are important because they allow us to rule out some possibilities. Figures 2 (c) and 2 (d) show clearly that both Göktepe and Kirköy are highly unlikely, the former because of its finer grain size, and the latter because of its much more intense EPR spectra (higher manganese concentration). Besides that, the graphs show that all sculpture data points are evenly distributed within the Ephesian field. Even if this cannot be considered a conclusive proof of provenance, it is certainly a quite satisfactory result.

**Statistical provenance**

The above discussion was aimed at understanding, on an intuitive basis, the possible provenance from Belevi of the *bigio* marble of the sculptures and the absence of likely alternatives.

At this point, however, it is necessary to go back to the more quantitative methods provided by statistics. Only in this way can all experimental data be dealt with simultaneously, the entire *bigio* database be taken into account, and uncertain or unknown provenances be identified.

Linear discriminant analysis carried out using five variables ($\delta^{18}O$, $\delta^{13}C$, EPR intensity, EPR linewidth and MGS) and the database of Table 2 including the EB1 and EB2 groups, indicates that the overall rate of success is 77%. In other words, 77% of the database samples are correctly reassigned to their true provenance quarries. The result is not especially high and leaves considerable possibilities for misclassification. This is due to the fact that many sites are taken into account and they often produce marbles with rather similar properties. In spite of this, reliable results can be obtained because the probability parameters allow us to distinguish dependable from uncertain provenances. Low relative probabilities (RP) identify samples that are in doubt between two or more provenances, whereas low absolute probabilities (AP) suggest that the sample is an outlier (an atypical representative of the provenance site) or does not originate from any quarry in the database.

The results of Table 3 demonstrate that 19 of the 21 sculptures can be reliably identified as Ephesos *bigio* 1 or Ephesos *bigio* 2 marbles and therefore most probably originate from the Belevi quarry. The absolute probability values are always satisfactory, whereas some relative probabilities are below the 60% threshold. The second most probable provenance, however, is invariably the alternative Ephesos *bigio* group, and therefore no uncertainty on the Ephesian origin of sculptural *bigio* antico.
provenance exists. The statistical results have been verified using the alternative database that includes Belevi and Kuşını Tepe instead of the EB1 and EB2 groups. Using this approach, a few EB1 samples are misclassified as Rhodes. This is the predictable result of ignoring the discontinuous distribution of $\delta^{13}$C values, a point that since the beginning has been identified as crucial for establishing the correct provenance of the bigio sculptures.

The remaining two sculptures, no. 6, Isis Fortuna inv. 6368, and no. 10, Isis inv. 6370, do not seem to fit any bigio quarry in the database, owing to their very high $\delta^{13}$C values. The provenance from Hasançavuslar B that seemed possible on isotopic grounds is not confirmed by EPR and grain-size data (Figs 2 (c) and 2 (d)) and is also statistically unlikely. Although at this stage the precise marble provenance of the two sculptures is unknown, the most likely hypothesis still suggests an unknown quarry in the same area. A possible candidate is quarry HCE4, which is part of Hasançavuslar B and, owing to the presence of very dense vegetation, could not be properly surveyed. The quarry is an enormous pit, approximately 35–40 m deep and more than 150 m in diameter. It produced approximately 600 000 m$^3$ of marble that probably includes not only white and greco scritto varieties but also bigio antico (Bruno et al. 2012). Additional fieldwork is required to solve the problem of the two Isis in Naples. The testing of additional sculptures might also be useful in helping to verify whether the two Isis are just outliers or whether they indicate the existence of another variety of bigio that was used successfully.

**Petrographic results**

Despite the great number of quarries proposed in the past, the provenance of sculptural bigio antico from Ephesos had never been suggested and was certainly unexpected. For this reason it was thought that, although the analytical data seem to be unquestionable, additional evidence based on petrographic information might be useful. Unfortunately, only a few samples were big enough to make the study possible.

Figures 3 (a) and 3 (b) show thin-section microphotographs of the Isis Fortuna of Palestrina and the fragmentary sculpture of Sessa Aurunca, which are low-$\delta^{13}$C samples. In both cases, the images show a medium-grained well-crystallized marble exhibiting some schistosity and slightly heteroblastic texture. The graphitic impurity is evenly distributed at grain boundaries and within the calcite crystals. Accessory minerals are mostly mica, but also plagioclase and quartz. The Belevi quarry sample (Figs 3 (c) and 3 (d)) shows quite similar features. In a petrographic sense, the above-mentioned samples are true metamorphic marbles with completely recrystallized mineral fabric and mature organic substance (graphitic pigment). In contrast to this, the Lesbos and Rhodes quarry samples (Figs 3 (e), 3 (f) and 3 (h)) are closely similar to one another, and are typical fossiliferous limestones with a moderate thermal overprint and recrystallization of the rock in its very initial state. The texture is dominated by large, elongated calcite crystals of the shell fragments of the original limestone, and stylolites and fossil relicts are frequently observed. The samples contain immature organic compounds (greyish brown specks) without showing mature organic substance as graphite, or at least semi-graphite. The most obvious proof that these rocks are still unmetamorphosed limestones is the presence of ‘Rudiste Bivalve’ up to 10 cm that are clearly visible on even surfaces of the Lesbos limestones (Fig. 3 (h)). Other varieties present in the bigio database exhibit various petroographies and include limestones and marbles of various metamorphic degrees, all of which can be easily distinguished from Belevi or the sculptural samples shown in Figure 3, which are the only examples of true metamorphic marbles.
The Belevi provenance based on analytical data seems to be fully confirmed. It should be added, however, that other sculptures exhibit somewhat different petrographies. Thin sections of the Isis in Ostia (Fig. 3 (g)) or the Perge dancer in Antalya (not shown), although different from Lesbos or Rhodes, are not easily associated with Belevi. The former is still a high-carbon sample, but the latter belongs to the low-carbon group and, in general, the two groups do not

Figure 3 Thin sections of quarry and artefact bigio samples under (d) plane- or (all others) cross-polarized light: (a) the Isis Fortuna from Palestrina, no. 1; (b) a fragmentary sculpture (plinth) from Sessa Aurunca, no. 9; (c) a Belevi quarry sample; (d) the same as (c) in plane-polarized light; (e) a Lesbos quarry sample; (f) a Rhodes quarry sample; (g) the Isis from Ostia, no. 11; (h) a Lesbos quarry sample, showing the presence of large calcite crystals. The images are 7 mm wide.

The Belevi provenance based on analytical data seems to be fully confirmed. It should be added, however, that other sculptures exhibit somewhat different petrographies. Thin sections of the Isis in Ostia (Fig. 3 (g)) or the Perge dancer in Antalya (not shown), although different from Lesbos or Rhodes, are not easily associated with Belevi. The former is still a high-carbon sample, but the latter belongs to the low-carbon group and, in general, the two groups do not
exhibit any systematic petrographic difference. In analytical terms, the four sculptures mentioned above are all typical representatives of Ephesian bigio antico and do not differ from the other sculptures tested.

Summing up the petrographic and analytical information, it seems reasonable to assume that additional bigio quarries may exist, besides Belevi, and that they are all found in the same area. This was the logical basis underlying the surveys carried out around Belevi, and that were, however, not entirely successful. Apparently, a satisfactory solution to some details concerning the provenance of sculptural bigio antico still requires additional fieldwork.

CONCLUSIONS

Although some minor aspects of the bigio problem are still unclear, the results of this work demonstrate that the vast majority of ancient bigio sculptures were made using marbles quarried in the Ephesos region, mostly at Belevi and perhaps other nearby quarries. Together with previous Göktepe work, these results provide a general solution for the long-standing problem of the provenance of sculptural ‘black’ marbles, and demonstrate that they came from selected sources apparently renowned for their quality of material and workmanship. These localities are both in Asia Minor, and are Göktepe for bigio morato and Ephesos for bigio antico. If the extraordinary success met by the white marble of Göktepe (early second century onwards) is also taken into account, it seems possible to state that Asiatic marbles, mostly used by Asiatic sculptors, became dominant in the heyday of the Roman Empire and affected technical and stylistic trends.

The provenance of bigio antico from Belevi contributes to expanding the role played by Ephesos as a marble production and trade centre. Besides the well-known quarries of Belevi and Kuşini Tepe, several other white marble quarries have been reported in recent years in the Ephesos area. They include Kentli Çiftliği, Ahmetli, Urfaladığı Tepe, Taşlantepe and others (Yavuz et al. 2011). Although the export of Ephesos white marbles is not well documented and was probably limited, several other varieties or newly discovered quarries producing already known marbles had Ephesos as the main collecting and export centre, and were widely used in the architecture and decoration of the city. Besides bigio antico, they include the greco scritto quarries at Zimparà and Hasançavuslar, the previously unknown africano quarries at Turgut, the breccia quarries near Beyler, the breccia corallina and broccatellone quarries in the Karaburun peninsula and others.

The role of Ephesos bigio antico was probably not limited to the production of sculptural marble. Preliminary unpublished isotopic results obtained on bigio columns and other architectural elements at Ephesos (lower and upper Agoràs), but also in North Africa (Cyrene and Tolmeita), are not in line with Lesbos and reproduce closely the $\delta^{13}C$ distribution typical of Belevi. Although many other architectures that are being tested are unquestionably Lesbian, these results suggest that the bigio marbles of Ephesos were used locally and also along specific export directions for architectural artefacts.

To conclude, we want to stress again the crucial role played in this study by the $\delta^{13}C$ values. The discontinuous distribution of values shown by the sculptural samples was the first and most important clue for suspecting the Belevi provenance that was subsequently verified using additional data. This piece of information was the result of a relatively extensive programme of analyses, and would have been completely missed if the provenance of only one or few sculptures had been attempted. In this case, the marginality of the sculptures with respect to other possible provenances would have not been recognized and many of them would have been misclassified, most probably as Lesbos, which in several cases is roughly compatible and is commonly
The Ephesian origin of sculptural bigio antico considered as the most likely and widespread source of bigio antico marble. The consequence is of general relevance and indicates that the collective properties of a group of related samples are extremely important, and sometimes crucial for obtaining correct results. Particularly when dealing with new or complex problems of provenance, single-item analysis may be risky and extensive testing of related archaeological artefacts should be the rule.

REFERENCES

Corsi, F., 1845, Delle pietre antiche, Puccinelli, Rome.


SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this paper at the publisher’s web-site.

Table S1. Complete analytical results available for the database of gray marbles used to prove-nance the bigio antico sculptures. The selection includes 18 different quarry sites and 576 quarry samples. Some variables (strontium, manganese, dolomite, color) although not used for provenancing for being incomplete or for other reasons provide, nevertheless, relevant information and are included. Isotopic and EPR variables are given in ‰ or % of their standards (Pee Dee Belemnite for isotopes and Dolomite N368 BCS for EPR). Strontium and manganese concentrations are given as parts per million, ppm), dolomite and color as %. The latter is referred to an 8-bit scale where 0 represents black and 255 white.

Figure S1. (a) Overall view of the Belevi bigio quarry; (b)-(c) ancient extraction loci; (d) ancient marble waste.

Figure S2. Map of the quarries surveyed in the Belevi area. Several small to medium quarries are found within the area encircled by the ellipse, where the Hasançavuslar bigio samples were collected. GPS coordinates of the quarries are as follows: Göllüce 38.08710 N, 27.48705 E; Aya Kılık 38.08413 N, 27.51987 E; HCE1 38.07214 N, 27.53968 E; HCE4 38.07189 N, 27.53689 E; HCW1 38.06656 N, 27.49798 E; Zimparà 38.05099 N, 27.47213 E; Kentli Çiftliği 38.04473, 27.45528.