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Archaeometric aspects of white and coloured marbles used in antiquity: the state of the art

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ABSTRACT. — As is well known, the identification of the quarry of ancient marble artefacts is of the utmost interest to archaeologists and art historians. Scholars of different disciplines have been trying for more than a century such an identification by means of a unique laboratory analysis without positive results. To-date the best probabilities of success are obtained by combining together two or more analytical techniques. The paper presents a short history of the important studies, namely those regarding the most frequently used combinations, with particular reference to the petrographic examination of a thin section and the determination of the C & O stable isotopic ratios on the same sample. Such a combination takes advantage of the best existing database for the marbles most commonly used in antiquity. Of these are reported the essential information on their quarries, periods of use and specific bibliography, together with the MGS (Maximum Grain Size) and isotopic diagrams useful for their identification.

RIASSUNTO. — Come è noto, l'identificazione della cava di manufatti marmorei antichi riveste un grande interesse archeologico e storico-artistico. Da oltre un secolo si tenta di raggiungerla con indagini di laboratorio le più varie, senza peraltro essere giunti a risultati univoci impiegando una sola metodologia. Attualmente le più alte probabilità di successo si raggiungono combinando due o più tecniche analitiche. Nell'articolo si presenta una breve storia degli studi, e vengono considerate le tecniche e le combinazioni più usate, in particolare quella dell'esame petrografico di sezioni sottili e l'analisi degli isotopi stabili del C e dell'O che si avvantaggia della più completa banca dati di riferimento esistente per i marmi più importanti usati in antico. Di quest'ultimi, oltre ad alcune essenziali informazioni circa le località di cava, i periodi di uso e la bibliografia specifica più recente, si riportano i diagrammi dell'MGS (Maximum Grain Size) e isotopici più utili per la loro identificazione.

KEY WORDS: *ancient white and coloured marbles, quarries, archaeometric identification, state of the art.*

INTRODUCTION

The first scholar to take an interest in the problem of identifying marbles of Mediterranean origin that were used in ancient times, for the purposes of art history as well as archaeology, was Winkelmann, as far back as the end of the XVIII century. His interest was taken up by whole generations of scholars but

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it was not until a hundred years later that R. Lepsius (Lepsius, 1890) developed the first scientifically correct approach, one that can unreservedly be defined as archaeometric in the strict modern sense of the term.

What follows is a rapid historical overview of archaeometric studies applied to true marbles, white, grey and coloured, dwelling more on the methods currently most frequently used to solve the «problem of the provenance» of marble artefacts and focusing in particular on the methodology followed by the author in the study of many ancient marble monuments and objects, including those at Ostia, examined in the framework of what is certainly the most extensive archaeometric survey so far to have been undertaken.

Marbles in the proper sense of the word, that is pure carbonatic (calcitic and/or dolomitic) rocks with a carbonate content that is usually well in excess of 95% – they are crystalline, they may be white or grey or red or green and they will have been produced by contact or regional metamorphism – are quite common throughout the Mediterranean area. Many of them were used in antiquity, both in pre- and early-historical periods (late Neolithic – Cycladic civilizations) and also in the Greek and Roman and later times, when the quantity of marble employed and the quality of the workmanship often reached remarkable levels. In the case of some marbles we know when they were used for the first time and we have information from various sources that enables us to build up at least a partial picture of their distribution and how they were traded and transported. In most cases however, we really know very little, mainly because of the fundamental difficulty of identifying marbles reliably when they are found as original structural or decorative elements of ancient buildings or in sculptures, or when they are re-used in Mediaeval or Renaissance monuments (e.g. in Rome and Venice).

It is of great importance to archaeologists that the identification of marbles should be based on scientific data: sculptures of uncertain attribution can be ascribed to a specific artist or «atelier» or area of production; monuments (*latu sensu*) that are properly dated can in turn tell us when certain quarries were being worked and hence the demand for the marbles concerned; the identification of marbles forming part of sunken cargoes enables ancient trade routes to be reconstructed; location of the quarry from which a damaged marble came makes it possible to find sound material for the purpose of restorations, replacements, copies, etc..

So far the many studies that have set out to determine the provenance of marbles used in antiquity have led to results which are partial and not always satisfactory from a scientific point of view, especially when identification was based on macroscopic examination, on visual evidence such as the colour, brilliance or grain of the stone. Such identifications almost always turn out to be wrong (Renfrew and Springer Peacy, 1968), essentially because it is often found that samples of marble from the same quarry have different autoptic properties while others from different quarries, sometimes a long way from each other, are identical.

More reliable are identifications based on the mineralogical and petrographic study of thin sections (Herz and Pritchett 1953, Herz 1955, Weiss 1954, Renfrew and Springer Peacy 1968, Young and Ashmole 1968); some of these are often difficult and time-consuming to perform however (e.g. petrotectonic examinations), and they cannot always cope with the sometimes considerable local variability in mineralogical (e.g. with the contents of dolomite) and petrographic (e.g. granulometric) characteristics of pure marbles, even though pure marbles are among the most homogeneous mono-mineralic rocks known.

Better results have been achieved by geochemical studies of the trace elements present in marble samples taken from ancient quarries. For example, certain Anatolian marbles can be distinguished from their Attic counterparts on the basis of sodium and manganese content (Rybach and Nissen 1964), but this criterion cannot be used to discriminate between Attic marbles and those from the Cyclades.

Another problem is that in the case of both Na and Mn there are often considerable quantitative variations in different samples from the same quarry or in different parts of a single sample. This can be explained by the presence of concentrations of these elements in minerals other than calcite, e.g. epidotes and micas, the distribution of which in the structure of the marble may be quite casual. This makes the identification of marble considerably more difficult in cases where just one small sample is available. A more recent study (L. Conforto *et al.* 1975), which examined only marbles of Anatolian and Italian origin and determined their contents in terms of eight trace elements (K, Fe, Mn, Si, Ba, Al, Sr and Ti), has given partial results, similar to those of the preceding technique, and has thus enabled us to characterize certain quarries with respect to others.

But ultimately, the limits of a method of identification that is based on the determination of oligo-elements lie in the fact that their interval of variation is frequently the same for samples from different petrographic regions.

The approach based on measurement of the isotopic ratios of carbon and oxygen has looked interesting and promising ever since its first appearance: it enabled Craig and Craig (1972) to distinguish Greek marbles from Attica from their counterparts in the Cyclades and L. Manfra *et al.* (1975) to distinguish between marble from various localities in Asia Minor. Despite the growth of the isotopic data bank (Herz, 1988), however, it became increasingly clear that neither autoptic observation nor petrographic and geochemical studies alone would enable conclusive identification of the most famous marbles used in antiquity, while a combination of methods seemed more promising. The first proposal came from Renfrew and Springer-Peacy, who suggested combining a cathode-luminescence study with a petrographic study of thin sections. In actual fact the two authors did not develop these techniques and it was only later, in the 1990s, that the cathodomicrofacies (infra) of several marbles were defined.

Another early pluridisciplinary contribution involving a combination of petrographic characteristics (average grain size, type of crystal shape and structure, semi-quantitative assessment of accessory minerals) and the determination of the Calcium/Strontium ratio was proposed by Lazzarini *et al.* in 1980 (1980a). This geochemical ratio was considered especially important in pure marbles for various reasons. Strontium is an isomorphous element of calcium, which it can replace by up to 4% in aragonite (this strontium-rich aragonite has been given the name mossotite), while it rarely exceeds 1% in calcite (Chilingar *et al.* 1967). Most of the marbles in this study are the product of the metamorphism of organogenic limestones or in any case contain the remains of fossil organisms, as was also shown by petrographic studies of the marbles of Attica (Marinos, 1948) and the island of Lesbos (Lazzarini *et al.*, 1999). Now, the protective shell or skeleton of many organisms is made of aragonite, the preference for this polymorphous form of CaCO3 rather than calcite being regulated by temperature. Temperature also controls the Ca/Sr ratio, which remains unaltered in marbles (metamorphism being an essentially isochemical process) so this datum can be useful in estimating the thermic level reached by these rocks. Soviet scholars (Vinogradov *et al.*, 1952) showed that the Ca/Sr ratio is higher in carbonatic rocks the closer they are to the Precambrian; a further scientific reason why its determination in marbles is of interest. It has been observed, in fact, that strontium levels vary considerably in some of the most important marbles of antiquity and this has led to the identification of numerous artefacts (Lazzarini *et al.*, 1980b; Lazzarini *et al.*, 1988).

Another important analytical contribution was made by Cordischi and his co-authors (1983), with the proposal to use electronic spin resonance (ESR) on the traces of Mn in marbles. As the method was applied to an increasing number of marbles, the initial encouraging results were placed in another perspective by the overlapping of representative fields (Lloyd *et al.*, 1985) – the same thing happened subsequently with isotopic analyses and the analyses of the oligoelements – and it was not until a decade later that new improvements and developments were achieved, especially by associating this investigative method with others (infra). Another important proposal involving the application of a combination of analytical, petrographic (including the introduction of MGS – maximum grain size of calcite/dolomite) and geochemical methodologies was made by a large team of Belgian scientists (Moens *et al.*, 1988). Attribution of marble artefacts to their quarries of origin was improved but the method was still not absolutely reliable. Finally, in 1989, Barbin and others (1989) re-proposed the use of cathodoluminescence, with considerably improved equipment and coupled with the petrographic study of the same thin section; this led to the determination of accurate cathodomicrofacies for the main marbles of antiquity. The cathodoluminescence of these stones is linked to the presence of traces of Mn, which enhance it, and of Fe, which reduces it. Calcite features an orange or blue luminescence while that of dolomite is red. The intensity and the distribution of these luminescences add parameters that are sometimes so characteristic that they enable many (not all) kinds of marble, and even different quarries yielding the same marble, to be distinguished from each other: for example, the Parian marble *lychnites* from Stephani has a blue luminescence while that of the same marble from Lakkoi is orange.

Some of these analytical techniques were applied in monographic studies of important marbles, including those from Luni (Herz and Dean, 1986), Thasos (Herz, 1987) and the Cyclades (Germann *et al.*, 1988), all of which still provide substantial help to archaeometric scientists.

In conclusion, until the 1990s the many studies designed to identify the marbles used in antiquity led only to results that were partial and not always satisfactory from a scientific point of view. In addition to what is revealed by the main critical study of the literature produced up to then (Mariottini, 1998), it is clear that the greatest uncertainty was a consequence of the fact that none of the studies had taken into simultaneous consideration all the marble-producing areas of the Mediterranean, only the best-known ones, ignoring others that may have been insignificant for the Greek period but which could well have been significant sources for the Romans, not to mention the many other quarries that have since come to light and added so much to our knowledge of the extraction and use of crystalline marbles in the imperial age.

An important stimulus to scientific investigation over the last two decades has been provided by ASMOSIA (Association for the Study of Marbles and Other Stones in Antiquity) and its members. New methods have been proposed and many new marbles and quarries, both major and minor, have been characterized. One of the most significant new methods to emerge was the first to be entirely non-destructive (i.e. that did not depend on the procurement of a sample), proposed by Careri and his team in 1992; this was based on the use of portable laser equipment that recorded the absorbance/reflecting qualities of quarried marble, a parameter connected essentially to the type of structure, granulometry and composition (presence of carbonaceous/graphite substances) in a given marble. The method achieved good discrimination for some marbles and more or less nil for others: since it proved to be of only partial usefulness right from the beginning, the perhaps mistaken decision was taken not to proceed with development of the methodology. Similar results have been recorded very recently (2004) by Biricotti and Severi using an optical non-destructive methodology. The method is currently being studied and improved.

Considerable interest has been aroused by the determination of the component elements of rare earths (Barbin *et al.*, 1991) carried out with various methods including NAA (Meloni *et al.*, 1995), and the new ICP-MS = Inductively Coupled Plasma-Mass Spectrometry, (Green *et al.*, 2002). Though the same unresolved problems again arise for these trace elements (repeatability of results, their comparability when obtained with different analytical methods, content variability at small and large scale, etc.), we agree with Matthews (1997) and Green *et al.* (2002) that the creation of a data bank for REE would be immensely useful.

Electronic paramagnetic resonance spectroscopy (EPR), the equivalent of ESR, was further developed with the creation of bigger data banks, but when used alone it was still an unreliable way of attributing a marble artefact to its quarry of origin. At first it was coupled with certain petrographic characteristics (Attanasio and Platania, 2002; Polikreti and Maniatis, 2002; Attanasio, 2003) that could be seen with the naked eye, such as MGS, but these were obviously not the most significant or precise; later it was used together with other analytical procedures such as the isotopic technique, and subjected to statistical processing (Attanasio *et al.*, 2002). Statistical processing had already been used in the assessment of chemical data, especially of trace elements, but the availability of more sophisticated equipment (specific software and more powerful computers) now ensures that the results are more significant, although not always reliable.

On the isotopic front, the study of the isotopes of strontium (Pentia *et al.*, 2002) also seems to be a promising methodology, though the high cost of the analyses makes it somewhat problematic for large-scale investigations involving samples from quarries or artefacts.

The last dozen or so years have seen the appearance of some very important studies of single marbles, including those by Asgari and Matthews (1995) on Proconnesian marble, by Bruno *et al.* (2002) on the marbles of Thasos, by Bruno *et al.* (2000) and Herz (2000) on the marbles of Paros, by Lazzarini *et al.* (2002) on Aphrodisian marble, and by Matthews *et al.* (1992), Pike (1999) and Goette *et al.* (1999) on Pentelic marble.

Several new quarries have also been discovered and characterized in recent years including those of the Greek islands of Skyros, Fourni (Lazzarini and Cancelliere, 2000) and Tinos (Lazzarini and Antonelli, 2003), and Microasiatic areas of marble production such as those of Ionia and Caria, including the region of Ephesus (Koller *et al.*, in press), Miletus and Heraklea on the lake Latmos (Peschlow-Bindokat and Germann, 1981).

There is no question but that identification of the provenance of white marbles used in antiquity remains an issue of fundamental interest for archaeologists and art historians and continues to engage scientists of various disciplines. Despite the efforts of mineralogists, petrographers, geochemists, statisticians and physicists, who, as we have seen, have used an extraordinary variety of analytical methods over the last century and more, the problem can still not be considered wholly and satisfactorily resolved: even now there is no non-destructive investigative technique that can quickly and unequivocally establish the provenance of most white marbles.

The analytical methods currently most commonly used, and the most recurrent white marbles

As shown above, the approach most likely to produce reliable results concerning the quarries of provenance of a given marble involves studying the sample with at least two independent analytical methodologies and jointly processing all the data obtained. The two methods now most widely used are undoubtedly the minero-petrographic analysis of thin sections and the isotopic analysis of oxygen and carbon; when used together the methods enable most marbles to be identified, if not with absolute certainty then at least with a fully acceptable degree of reliability. Both techniques require an accurate knowledge of the parameters considered in the marbles of the quarries worked in antiquity; this can only be acquired via the analysis of a large number of samples taken either from these quarries or from artefacts of known attribution. In other words, data banks must be available which are as representative as possible of the mineralogical-petrographic characteristics and the $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios. For the former, observations have been developed on the basis of the classic treatises of petrography and metamorphism (Galwey and Jones, 1963; Kretz, 1966; Spry, 1976); the latter have been expressed respectively as the $\delta^{18}O$ and $\delta^{13}C$ of the various marbles used in Greek and Roman times, as first proposed by the Craigs. As we know, the isotopic composition of oxygen and carbon, as for other elements with a low atomic number, such as H, N, S, Si and Ca, is determined via dedicated mass spectrometry following the methodology introduced by McCrea (1950), and conventionally expressed in terms of the «δ unit», defined as:

$$\delta_{camp} = (R_{camp}/R_{std} - 1) \times 1000$$

where R_{camp} and R_{std} represent the isotopic ratio considered ($^{18}O/^{16}O$ and $^{13}C/^{12}C$ respectively for oxygen and carbon) in the sample and in a suitable reference standard. For the two elements that concern us, the international standard adopted is known by the initials PBB (calcite of the rostrum of a *Belemnitella Americana* of the Pee Dee formation of North Carolina (Craig, 1957).

Recently, Gorgoni *et al.* (2002a) have proposed considerably updated data banks based on hundreds of analyses relative to the minero-petrographic and isotopic characteristics of the marbles from the main quarries active in Greek and Roman times: Paros, Naxos, Thasos and Mount Pentelic in Greece, which had long been the subject of historical research and applied petrography (Papageogakis, 1967), Carrara in Italy (Dolci, 1980), Aphrodisias, Afyon and Marmara in Anatolia, present-day Turkey; the latter two areas were the source of marbles, Docimium and Proconnesium, that were widely used in antiquity (Monna e Pensabene, 1977). We do not yet have enough data to be able to characterize other important classical marbles such as those of Ephesus and other places in the Meander Valley (present-day Menderes), including Tiunta, near Denizli, Stratonicea, Milasa, etc., in Anatolia, and Mani, Vrestena, Dolianà, etc., in Greece. Research on these areas is however ongoing and it may be assumed that the gaps will shortly be filled.

In the first, more important areas mentioned above, marble was not extracted from just one quarry but from several, which were often some kilometres apart. At Paros, Naxos and Thasos, for example, various extraction sites have been recognized, including one or more quarries yielding marbles with different minero-petrographic and geo-chemical characteristics. To date, four ancient sites have been identified at Paros, all situated in an area of a few square kilometres in the central-northern part of the island. Some of these marbles belong to different geological formations. The sites include:

1. the underground quarries of the Stefani Valley, near the village of Marathi, which until the VI century B.C. yielded a much-prized variety of marble known as *lychnites*, conventionally referred to as «Paros-1» by Moens *et al.* (1988);
2. small and medium size open cast quarries scattered over the area of Lakkoi and especially in the Valley of Chorodaki. The marble from these quarries, referred to as «Paros-2» by Moens *et al.*, (1988), is of excellent quality but differs from the preceding variety, not only because it has different petrographic and isotopic features but also visually (it often has grey patches or areas of foliation);
3. small, mainly open cast quarries to the SE of the Valley of Marathi, from which came a marble with similar characteristics to those of Paros-2, referred to as «Paros-3» by some authors (Germann *et al.*, 1988; Bruno *et al.*, 2000; Gorgoni *et al.*, 2000);
4. a small quarry recently discovered by Karavos near the village of Kostos (Bruno *et al.*, 2000), which contains a relatively small

quantity of dolomitic marble as well as the predominant calcitic variety. The marble from this quarry could be called «Paros-4».

At Naxos too several ancient and modern extraction sites have been identified: the most important ancient sites are those of Apollonas (a vast area in the extreme north of the island characterized by the presence of deposits of coarse grain marble, some of which are very thick) and those of Melanes-Flerià, a hilly area about 15 km to the south-west of Apollonas which is famous for the abandoned remains of many half-finished *kouroi*. Essentially, the marbles from the two sites can be distinguished by means of isotopic analysis (Herz, 1985 and Lazzarini-Turi, unpublished data).

There are many sites that yield the Thasian marble, some of which were already active in the VI century B.C.. There was intensive quarrying on the Alikì promontory on the northern coast of the island, where exploitation continued at least until the VII century A.D.; this large-grain marble, which often featured grey patches and veins, was exported to Italy, Greece and Asia Minor. The quarries at Cape Fanari, about 3 km to the south-east of Limenas, yielded a similar marble to that of Alikì and were worked at more or less the same time. Dolomitic marble of excellent quality was obtained from quarries a few kilometres to the south (at Cape Vathy, Saliara); this was much used in the Archaic period and later in Roman times for statuary and sarcophaghi (Hermann e Newman, 1995; Marc, 1995; Wurch-Kozelj and Kozelj, 1995). The marbles from these sites are referred to respectively as Thasos-2, Thasos-1 and Thasos-3 by Moens *et al.* (1988). Other small quarries such as those located near the Acropolis supplied marble for local use (Herz, 1987).

Several vast extraction sites are known on the island of Marmara; the marbles they yielded had different characteristics but they were generally of medium grain, with grey patches, veins and straight-parallel foliations from organic/graphite substances. Gorgoni *et al.* (1998) distinguish two main varieties, chiefly on the basis of isotopic parameters: one comes from the quarries of Saraylar and Kavala (Proconnesian – 1) and the other from those of Çamlik (Proconnesian – 2).

The salient mineralogical and petrographic characteristics (structure, boundary of the calcite and/or dolomite crystals, significant accessory minerals) of the above-mentioned marbles are summarized in Table 1 (Gorgoni *et al.*, 2002, mod.), while the maximum grain size (MGS) appears in Fig. 1.

It should be noted that these data have a general and not absolute validity (anomalous compositions and characteristics are always possible) and that accessory minerals that are more or less ubiquitous in all marbles – minerals such as quartz, common white-mica (muscovite/phengite), graphite/carbonaceous substances, apatite and ferrous oxides (haematite and limonites) - have not been taken into consideration. Similarly, no account has been taken of the presence of dolomiteis, which very common in almost all marbles (e.g. in Pentelic, Parian from Karavos, Lunense, Proconnesian, Thasian from Alikì, etc.) in various quantity levels, from trace to several per cent (Lazzarini and Mariottini, 1987).

The petrographic data in Table 1 and Fig. 1 are used for comparison with the results of the study of thin sections of ancient marble artefacts; this comparison in turn must be tested against the direct comparison of sections of reference quarry marbles with sections from the artefacts. This latter phase is of the utmost importance in cases of doubtful identification.

As regards isotopic data, the increasing number of isotopic analyses of ancient marbles appearing in the literature in recent years testifies to the huge popularity of the technique in archaeometric research. Paradoxically, the large quantity of data available has resulted in an extremely complex overall picture: in a global diagram with coordinates of $\delta^{13}C$ vs. $\delta^{18}O$, which includes all the data available in the literature relating both to samples collected in the various quarries and to those from ancient artefacts of certain provenance, the fields of variability of the two parameters in the extraction areas under consideration overlap considerably and make the use of this

TABLE 1

The minero-petrographic characteristics essential for the microscopic recognition of the important ancient marbles in thin section.

MARBLE	Locality	CRYSTAL BOUNDARIES	TYPE	FABRIC: most frequent features
DOKYMAEN		embayed / sutured	HE/HO	mosaic, with strained crystals
APHRODISIAN		curved / embayed	HE	mosaic, sometimes lineated and stressed
PROCONNESIAN		sutured / embayed	HE	mortar, often with deformed polysinthetic twins
THASIAN	ALIKI'	curved to sutured	HE	mosaic, often lineated and stressed
	VATHY	curved to sutured	HO/HE	mosaic, sometimes with strained crystals
NAXIAN	APOLLONA	Embayed	HE	mosaic, with strongly strained crystals
	MELANES	Embayed	HE	mosaic, sometimes lineated, with strained crystals
PARIAN	LEFKES	curved / embayed	HE	mosaic, sometimes with fine-grained areas and def. twins
	KARAVOS	Embayed	HE/HO	lineated, with coarse stressed crystals
	STEPHANI	Curved	HE/HO	mosaic
PENTELIC		curved / embayed	HO/HE	lineated, sometimes mosaic
LUNENSE		straight / curved	HO	polygonal with triple points, often mosaic

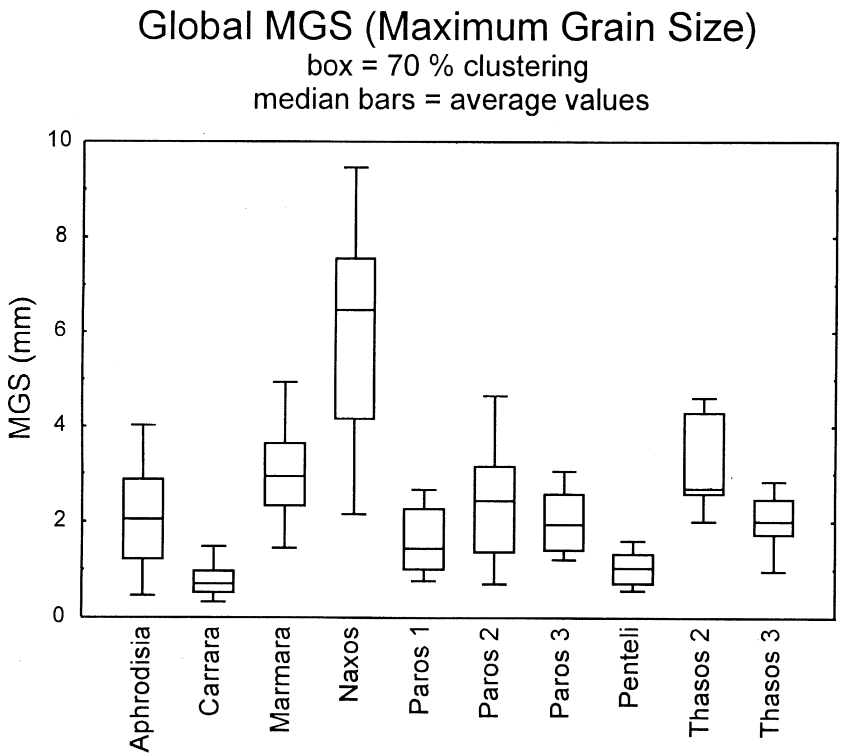

Fig. 1 – MGS of the Main Mediterranean marbles used in antiquity.

investigative method problematic. The problem has been at least partly overcome by taking account of an important parameter that can be obtained from thin section analysis of the sample, i.e. by MGS. On the basis of the average values of this parameter (MGS greater or lesser by 2 mm, which more or less separates the fine-grain marbles from those with a medium-coarse grain), the isotopic characteristics of the marbles from the various sites can be represented by the diagrams of Figs. 2 and 3 (Gorgoni *et al.*, 2002a).

Determination of the provenance of red marbles used in Antuqity

The scenario described above also applies, with the same conclusions, at least as far as is currently known, to some coloured marbles, which feature archaeometric problems of provenance entirely similar to those of white marbles. The example of *rosso antico* is instructive: it is a haematitic-marble that has been used ever since the Minoan period and especially in Roman imperial times, when it was given the name *marmor taenarium* because of its origins in the vicinity of Cape Tainaron on the Mani peninsula in the Peloponnese (Greece). Both the evenly coloured variety and the white veined sort due to its wavy scistosity, can easily be mistaken for the analogous types of *cipollino rosso*, called *marmor Iassense* by the Romans because it was quarried near the the town of Iasos (now Kiykislacik, province of Milas, Turkey) in the ancient region of Caria. Both these marbles were used for architectural elements and statuary and it is of considerable

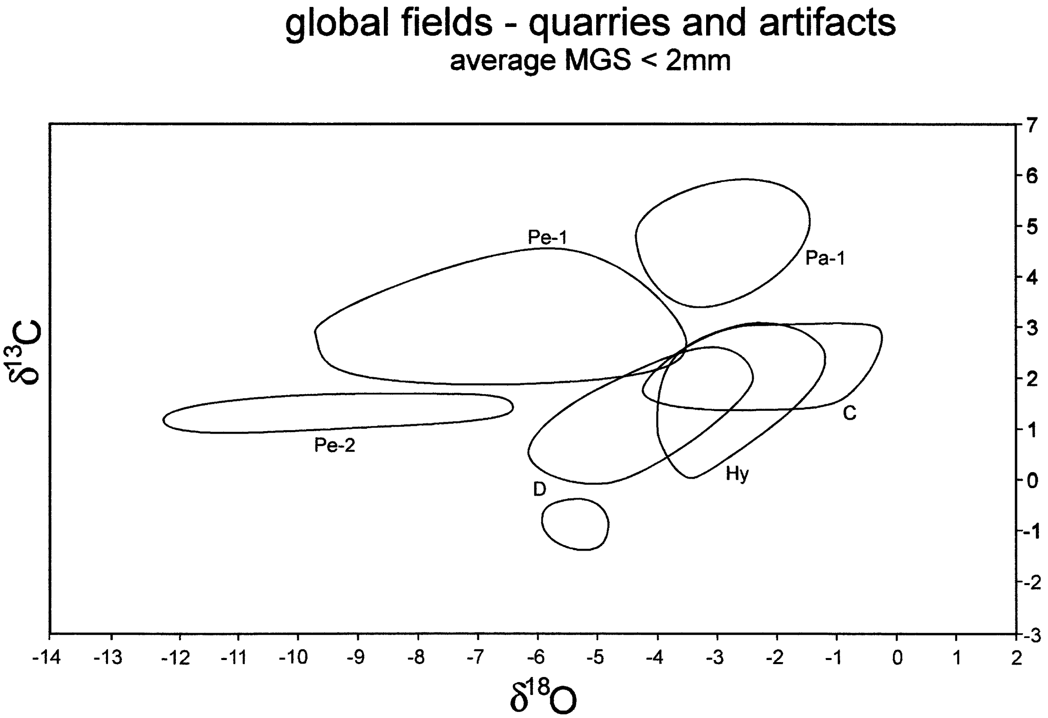

Fig. 2 – Global isotopic diagram (including quarry and artefact data) relating to ancient marbles with MGS < 2mm. C = Lunense; D = Docimaenian; Hy = Hymettian; Pa-1 = Parian lychnites; Pa-3 = Parian from Karavos; Pe-1 e 2 = Pentelic.

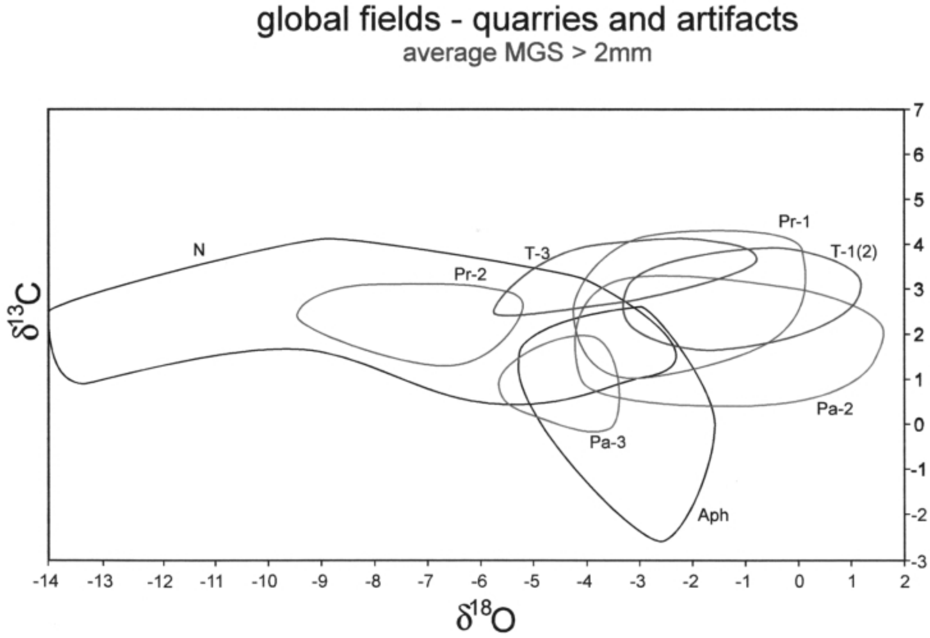

Fig. 3 – Isotopic diagram as in Fig.2, but including marbles with MGS > 2mm. Aph = Aphrodisian; N = Naxian; Pa-2 = Parian from Lefkes; Pr-1 = Proconnesian from Saraylar, Pr-2 = Proconnesian from Çamlik; T-1 = Thasian from Phanari, T-2 = Thasian from Alikì, T-3 = Dolomitic Thasian from Vathy-Saliara.

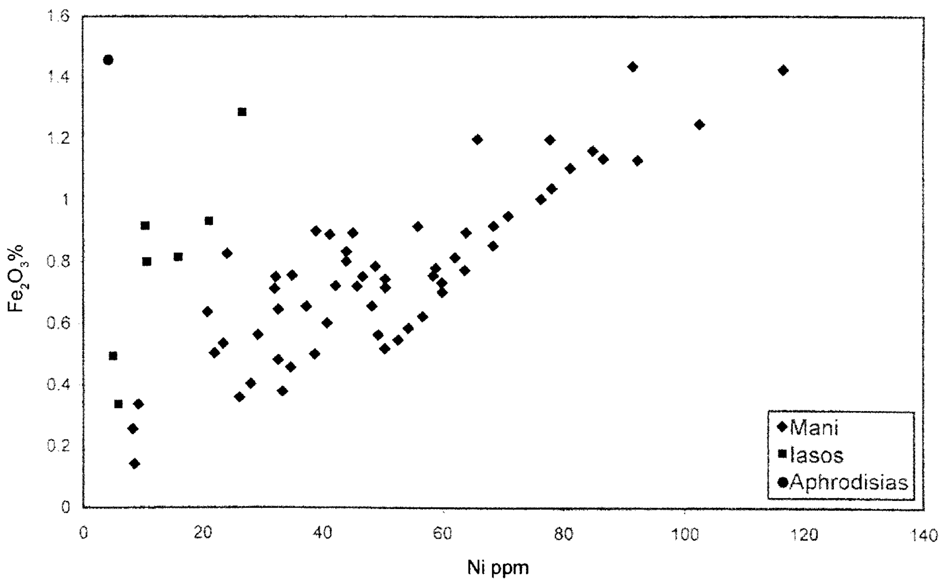

Fig. 4 – General Fe-Ni correlation for the two important red marbles used in antiquity (from Mani and Iasos), to which has been added the much more rare red from Aphrodisias.

importance that they should be distinguishable from each other, especially for Late Antiquity and the Byzantine period. A first distinction based on isotopic analysis and trace elements, which had seemed possible (Gorgoni *et al.*, 1992), was subsequently shown to be inadequate (Lazzarini, in press), thus prompting the need for supplementary chemical and statistical analysis. This supplement takes into consideration a higher number of reference samples, themselves analysed for trace elements, taken from the two ancient quarries. The results of all the analytical series shows that the Fe/Ni relationship (Fig. 4) is of itself sufficient to solve the archaeometric problem (Gorgoni *et al.*, 2002b).

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