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Research Article

Archaeometric Study of the White Marbles from the Archaeological Site of S. Omobono (Rome - Italy)

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ABSTRACT

This work represents the first archaeometric study carried out on white marble artefacts coming from several areas of the archaeological site of S. Omobono, located in a central area of Rome (Italy). The study was performed on a total of nineteen marble items, sampled from several areas of the site, by combining different laboratory techniques – including optical microscopy (OM), X-ray powder diffraction (XRPD), Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) and Isotope Ratio Mass Spectrometry (IRMS) of C and O – with the aim to characterise them and to determine their provenance. The minero-petrographic features observed, together with the C and O stable isotopes ratios recorded, the evaluation of the Sr and Mn contents, and the XRD refinement of the calcite unit-cell parameters, allowed us to prove that the marbles used in the S. Omobono site mainly come from the Apuan Alps basin (Carrara) and, in few cases, from continental (Mt. Penteli) and insular (Paros-Lakkoi or Thasos-Aliki district) Greek quarries.

Keywords: Archaeometry, White Marbles, Provenance, Optical Microscopy, Isotopic Analysis.

INTRODUCTION

The archaeological site of S. Omobono is located in the centre of Rome (Italy), between the Campidoglio and the Tiber River (Figure 1a). It was casually discovered in 1937 during the construction of a new building, in a period of extensive revitalisation of the area around the river harbour, traditionally called Forum Boarium (Terrenato et al., 2012). After this fortuitous discovery, a campaign of archaeological investigations began, which brought to light a vast sacred structural complex (Figure 1b). Originally, the area was characterised by the archaic temple of Mater Matuta built in two phases (Colonna, 1991), the first one dated back to the Servio Tullio age (578-534 BC), and the second one to the age of Tarquinius Superbus (534-509 BC). At the end of 6th century BC this temple was destroyed. At the beginning of the following century, the level of the area was artificially raised for the construction of a great podium, on which twin temples, devoted respectively to the gods of Fortuna and Mater Matuta, were set (Figure 1b), orientated approximately on an N-S axis (Pisani Sartorio, 1989). In the centuries these two temples were destroyed and rebuilt several times.

Currently, the remains of the temple of Fortuna are the only visible in the area, since the cell of the Mater Matuta temple was reused and transformed (probably during the 6th century AD) into a Christian church, restored in the Middle Ages and dedicated in 1575 to S. Omobono (Pisani Sartorio, 1989), which gives the name to the sacred area (Figure 1c).

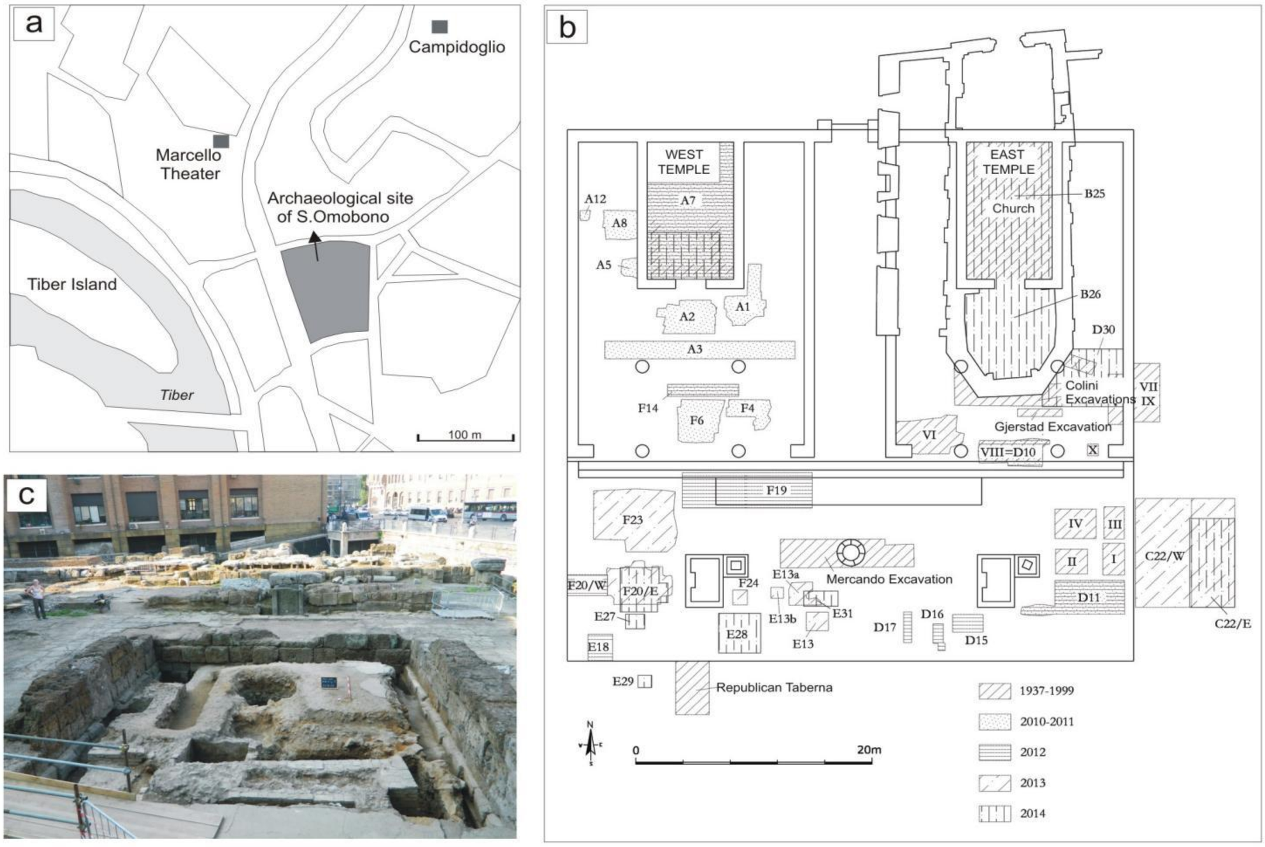

Figure 1. (a) Location of the Archaeological Site of S. Omobono. (b) Map of the Archaeological Site with the Areas Excavated from 1937 to 2014. (c) Current View of the S. Omobono Archaeological Excavations (by Terrenato et al., 2012).

Despite the importance of the archaeological site of S. Omobono and the great value of the natural and artificial materials revealed by the archaeological excavations, the studies conducted on this area are still a few and they are principally focused on archaeological and historical issues (Mura, 1977; Terrenato et al., 2012; Brocato et al., 2012, 2016; Brocato & Terrenato, 2012, Ceci, 2017).

The scientific literature based on the archaeometric study of the materials present in the site is extremely poor (Ammerman et al., 2008; Miriello et al., 2019). The current work represents the first archaeometric study performed on stone materials found in the archaeological area. In particular, its aim is the characterisation and the geographical provenancing of nineteen white marble samples from fragmentary architectural elements collected from different areas of the site, in order to increase the knowledge related both to the stone materials used in the archaeological site and the related commercial trade occurred in an area very close to the river port of the Forum Boarium (Colini, 1980).

As it is well known, due to its excellent technical and physical features, in antiquity the white marble was the material that was most employed for architectural and sculptural purposes since the classical period and, together with pottery, it is found very frequently in the archaeological excavations of important sites. In the last four decades many scholars have focused their attention on the archaeometric study of the ancient marbles. Recent researches have appreciably improved and extended the reference datasets (Attanasio, 2003; Brilli et al., 2005; Attanasio et al., 2006, 2021; Antonelli & Nestola, 2021; Antonelli et al., 2017, 2020; Beltrame and Antonelli, 2022; Beltrame et al., 2020, 2021; Antonelli & Lazzarini, 2013; Prochaska et al., 2018; Taelman et al., 2020, 2021; Wilegosz-Rondolino et al., 2020, 2024) aimed to determine their sources areas or specific quarries and to collect information on the commercial relationships and trade routes. The determination of marble provenance can be conducted by different analytical techniques (Wielgosz-Rondolino et al., 2020; Antonelli & Lazzarini, 2015 and references therein), even if the most frequently adopted procedure (also in this work) is based on minero-petrographic investigations, trace element analysis and carbon and oxygen stable isotope study.

METHODOLOGY

Nineteen white marble samples (Figure 2 and Table 1) were collected from different areas of the archaeological site of S. Omobono. Most of them belong to architectural elements, except sample MA19 that is a statue fragment. For this last sample it was not possible to provide a hypothetical dating, while for the others their hypothetically historical period is shown in Table 1.

Figure 2. Samples Collected from the Archaeological Site Of S. Omobono. By Sovrintendenza Capitolina Beni Culturali-AFMonAS.

The multi-analytical approach adopted in this study is based on the application of different techniques. Petrographic analysis was performed by polarised light microscopy on thin sections, using a Zeiss petrographic microscope equipped with a Canon PowerShot A640 photo camera. Thin sections were observed to determine the maximum grain-size (MGS) and the boundary shapes of the carbonate crystals, the rock microstructures and fabrics as well as the occurrence and distribution of accessory minerals.

The possible presence of dolomite and other mineralogical phases was verified by X-ray Powder Diffraction analysis (XRPD), using a Bruker D8 Advance X-ray powder diffractometer, with Cu–Kα radiation, operating at 40 kV and 40 mA. Scans were collected in the range of 3–60° (2Θ) with a step interval of 0.02° (2Θ) and a step-counting time of 3 s. The mineralogical phases were identified through the EVA software, by comparison with the 2005 PDF2 reference patterns. The XRPD technique was also used for measuring and refining the calcite unit-cell parameters, as proposed by Antonelli and Nestola (2021).

The trace element content of Sr and Mn was obtained by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) using an equipment Elan DRCe (Perkin Elmer/SCIEX), connected to a New Wave UP213 solid-state Nd-YAG laser probe (213 nm). Ablation was performed with laser beams of 80 μm, with a constant laser repetition rate of 10 Hz and fluency of ~ 20 J cm^{-2}. Calibration was performed using glass reference material NIST 612-50 ppm (Pearce et al., 1997) in conjunction with an internal standardisation applying CaO concentrations (Fryer et al., 1995) from SEM-EDS analyses. Data were processed through GLITTER software.

Stable carbon and oxygen isotope ratios measurements were performed with a Gasbench II preparation line connected on-line to a ThermoFinnigan Five Plus mass spectrometer in a continuous flow mode. Samples were reacted with 100% phosphoric acid at 70 ° C. Reproducibility was verified by replicate analyses of laboratory standards calibrated to NBS19 and LSVEC and is better than ±0.07 ‰ for δ 13C and ±0.04 ‰ for δ 18O.

Table 1. White Marble Samples from S. Omobono Site with Inventory Number, Location, Typology, Supposed Dating and Bibliography

Sample	Inv. Number	Location	Typology	Supposed Dating	Bibliography
MA1	SO 666	Side portico of the Church	Lesena decorated shaft	Trajan age	Toynbee and Ward-Perkins 1950, 15; Mathea-Förtsch 1999, 159 (kat. 168 I), tav. 40, fig. 2, tav. 41
MA2	SO 667	Side portico of the Church	Lesena decorated shaft	Trajan age	Mathea-Förtsch 1999, 159 (kat. 168 II), tav. 40, figs. 3-4
MA3	SO 662	Side portico of the Church	Frieze – Architrave	Late Augustan – Julio-Claudian age	Dal Monte 2020, 168 fig. 20
MA4	SO 733	East side embankment	Frieze – Architrave	Julio-Claudian age	Unpublished
MA5	SO 730	East side embankment	Frieze – Architrave	Julio-Claudian age	Unpublished
MA6	SO 723	East side embankment	Decorated frame	1st century AD, third quarter	Unpublished
MA7	SO 180	Eastern side of the Church	Architrave with three bands	Late Augustan – Julio-Claudian age	Unpublished
MA8	SO 705	Eastern side of the Church	Decorated frame with ceiling	Late Augustan – Julio-Claudian age	Unpublished
MA9	SO 743	Archaeological area	Abacus fragment	Late 1st – early 3rd century AD	Unpublished
MA10	SO 635	Archaeological area	Composite column base	2nd – 3rd century AD	Unpublished
MA11	SO 360	Side portico of the Church	Corinthian capital	Domitian age	Unpublished
MA13	SO 306	Storage under the offices	Frieze with spirals	Late 1st – early 3rd century AD	Unpublished
MA14	SO 939	Storage under the offices	Composite lesena base	1st – 3rd century AD	Unpublished
MA15	SO 241	Storage under the offices	Fragment of frieze with wing	1st century AD	Unpublished
MA16	SO 222	Storage under the offices	Relief with Triton	2nd – 3rd century AD	Unpublished
MA17	SO 217	Storage under the offices	Relief with spirals	2nd century AD	Unpublished
MA18	SO 175a	Storage under the Church	Coffers with rosette	Julio-Claudian age	Unpublished
MA19	SO 146	Storage under the Church	Statue fragment	-	Unpublished
MA20	SO 1288	Storage under the Church	Coffer with rosette	Domitian age	Unpublished

RESULTS

Minero-Petrographic Features

The main petrographic features of the investigated marbles are shown in Table 2. Samples MA1, MA6 (Figure 3a), MA13, MA14, MA15, MA16, MA17 and MA18 present mainly a homeoblastic microstructure and a mosaic fabric, often with triple junctions. Samples MA3, MA4, MA11, MA19 and MA20 often display heteroblastic microstructures and foliated to slightly foliated fabrics, also with preferential orientation of the K-mica lepidoblastes (sample MA19; Figure 3b). Fine and very fine-grained areas are visible, respectively, in samples MA3 and MA2, which show micritic patches (Figure 3c). The boundary shapes of the calcite crystals are mostly straight, sometimes curved, i.e. for samples MA1-MA8 and MA11-MA18, and curved to embayed for samples MA9, MA10 (Figure 3d), MA19 and MA20 (Table 2).

As concerns the mineralogical composition (Table 2), the XRPD analysis revealed variable amounts of dolomite in samples MA1, MA2, MA3 (average abundant), MA16, MA17, MA19 and MA20 (traces). The accessory (non carbonate) phases include graphite, quartz, muscovite, plagioclase, apatite, chlorite and ore minerals (often Fe-oxides and pyrite).

Table 2. Minero-Petrographic Features of the Marble Samples [Qtz: quartz; Ms: Muscovite; Gr: Graphite; Ore Min.: Ore Minerals; Pl: Plagioclase; Ap: Apatite; Chl: Chlorite; Dol: Dolomite, Detected by Optical Microscopy and XRPD Analysis; +++ Very Abundant; ++: Abundant; +: Present; ±: Traces. MGS: Maximum Grain Size; HE: Heteroblastic; HO: Homeoblastic]

Sample	Accessory Minerals							Dol	MGS	Calcite Crystals Boundaries	Texture	Fabric
	Qtz	Ms	Gr	Ore min.	Pl	Ap	Chl					
MA1			+++	+				+	0.58	curved, straight	HO/HE	Mosaic, with rare triple points
MA2		±	+++	+				++	0.56	straight, curved ± embayed	HE	Mosaic, with very fine grained areas and micritic patches
MA3			++	+				++	0.72	straight ± curved	HE	Mosaic slightly foliated with fine grained areas
MA4	+	±	+	+	±				0.90	curved	HO/HE	Mosaic slightly foliated
MA5	±		+			±			1.18	curved ± straight	HE	Mosaic
MA6			+						0.68	straight, curved	HO	Mosaic, with some triple junctions
MA7			+						0.75	straight, curved	HE	Mosaic
MA8			++	±					0.60	curved	HO	Mosaic
MA9	+	+	+			±			0.75	curved to embayed	HE	Mosaic
MA10		+	+	+		+			7.20	embayed	HE	Mosaic, with strained crystals
MA11	+		++	+					0.70	curved ± straight	HO/HE	Mosaic, slightly foliated
MA13	++		+		+				0.75	straight ± curved	HO	Mosaic, with rare triple junctions
MA14	±		++						0.76	Straight	HO	Mosaic, with triple junctions, somewhere polygonal
MA15	±		+	±					0.75	straight ± curved	HO	Mosaic, with rare triple junctions
MA16			+	±				+	0.62	straight ± curved	HO	Mosaic, with triple junctions
MA17			+	±	±			+	0.60	straight ± curved	HO	Mosaic, with some triple junctions
MA18			+		±				0.65	straight, curved	HO/HE	Mosaic, with rare triple junctions
MA19	+	+++	++				±	+	0.85	curved ± embayed	HE	Foliated
MA20	+++	++					++	+	0.95	curved ± embayed	HE	Foliated, somewhere tending to mosaic

Considering the values of the maximum grain size (MGS) of the calcite crystals (Table 2 and Figure 4) it is evident that, except sample M10, which shows an MGS of 7,2 mm, all the marble samples are fine-grained (mostly with MGS <1 mm; Table 2 and Figure 4).

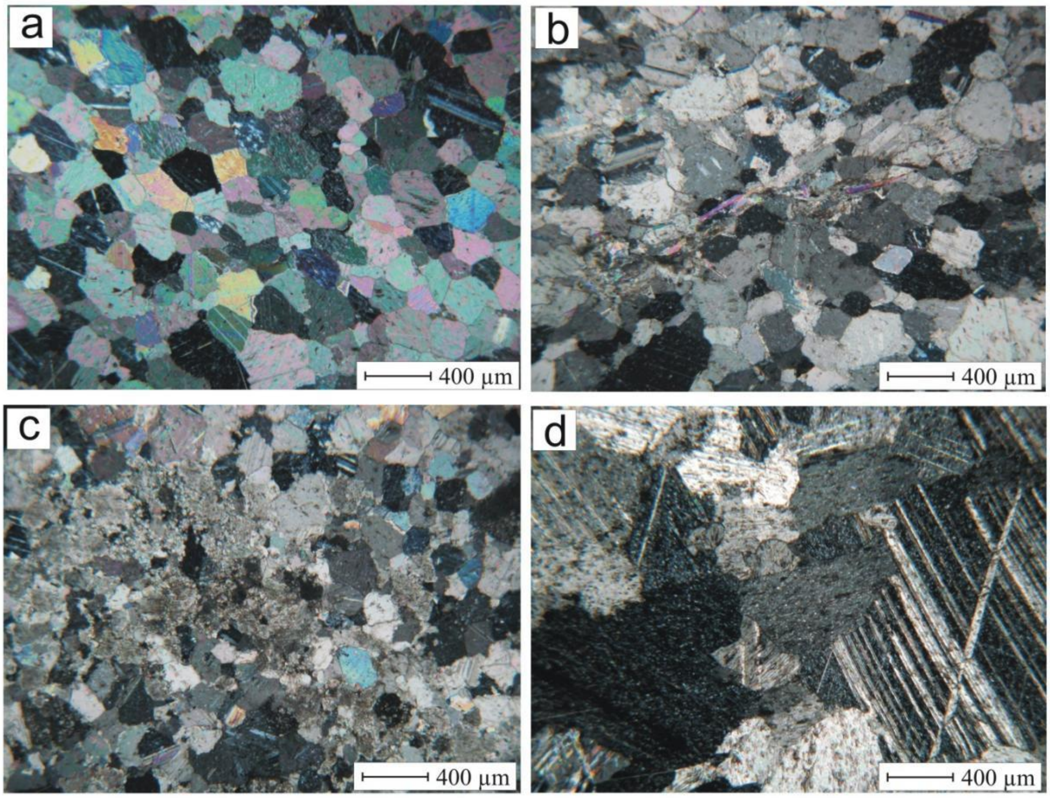

Figure 3. Microphotographs in Thin Section, under Cross-Polarised Light, Showing Textural Features of Some Marble Samples. (a) Sample MA6, Homeoblastic Microstructure and Mosaic Fabric with some Triple Junctions. (b) Sample MA19, Heteroblastic Microstructure and Foliated Fabric; A Preferential Orientation of the K-Mica Lepidoblastes is visible in the Middle of the Image. (c) Sample MA2, Heteroblastic Microstructure and Mosaic Fabric with very Fine-Grained Areas and Micritic Patches. (d) Sample MA10, Heteroblastic Microstructure, Mosaic Fabric with Strained Crystals and Embayed Calcite Crystals Boundaries

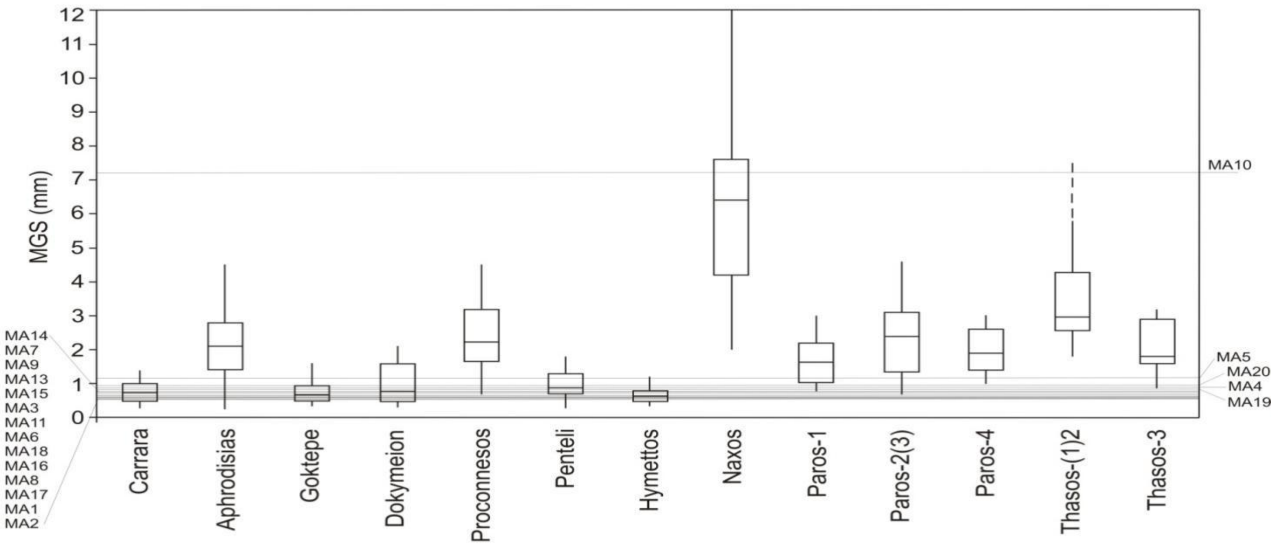

Figure 4. MGS Values of the Marble here Analysed Compared with the MGS Ranges of the Major Historical White Marbles of the Mediterranean Basin (Antonelli and Lazzarini, 2015).

Geochemical Composition and Isotopic Analysis

The Mn and Sr contents (obtained by LA-ICP-MS) are expressed in ppm and listed in Table 3 together with the isotopic signatures of δ 13C ‰ and δ 18O ‰ (obtained by mass spectrometry) of all the analysed samples.

The Sr content is generally lower than 150-170 ppm for all the samples with the exception of MA10 in which 245 ppm were recorded. As for the Mn values, they vary from 17 ppm (sample MA10) to 115 ppm (sample MA19) with a clear predominance of contents below 45-50 ppm.

The carbon and oxygen isotopic data (δ 13C and δ 18O) are plotted into two distinct bivariate isotopic diagrams (Antonelli and Lazzarini, 2015) related to fine grained marbles (Figure 5a) and to medium-coarse marbles (Figure 5b).

Table 3. Geochemical Features of the Marble Samples with their Most Probable Provenance

Sample	^{13}C (PDB)	^{18}O (PDB)	Sr (ppm)	Mn (ppm)	Most Probable Provenance
MA1	2.60	-2.10	124	45	Carrara
MA2	2.80	-1.90	106	89	Carrara
MA3	2.30	-3.30	136	66	Carrara
MA4	2.40	-1.80	142	51	Carrara
MA5	2.40	-2.10	156	37	Carrara
MA6	2.30	-1.70	170	19	Carrara
MA7	2.40	-1.80	145	27	Carrara
MA8	2.30	-1.30	138	29	Carrara
MA9	2.90	-7.10	129	106	Pentelic
MA10	3.10	-0.90	245	17	Thasos -Alikì or Proconnesos, Saraylar)
MA11	2.40	-2.00	130	19	Carrara
MA13	2.30	-1.60	152	23	Carrara
MA14	2.40	-1.50	127	21	Carrara
MA15	2.30	-1.60	131	19	Carrara
MA16	2.30	-1.70	126	23	Carrara
MA17	2.20	-1.70	126	22	Carrara
MA18	2.20	-1.90	133	19	Carrara
MA19	3.10	-5.60	149	115	Pentelic
MA20	2.80	-4.10	137	82	Pentelic

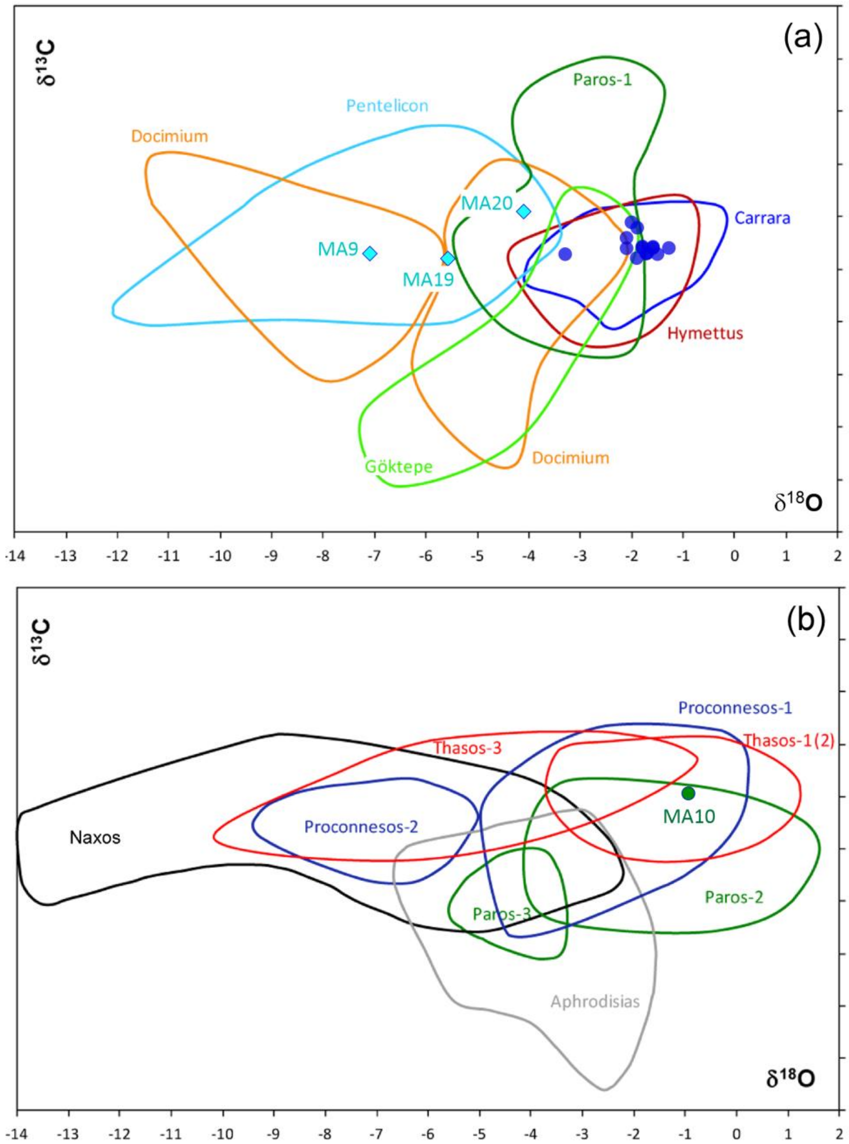

Figure 5. Comparison of the Isotopic Signatures of the White Marbles Coming from S. Omobono Site with the Database Proposed by Antonelli and Lazzarini (2015). (a) Fine Grained Marbles; (b) Medium-to Coarse-Grained Marbles

DISCUSSION

The results of the mineralogical-petrographic and geochemical analyses were compared with the most updated databases for both the white and grey-and-white ancient marbles (Lazzarini and Antonelli, 2003; Attanasio et al., 2006, 2015, 2021; Antonelli et al., 2010; Antonelli and Lazzarini, 2015; Prochaska et al., 2018; Wielgosz-Rondolino et al., 2020; Antonelli and Nestola 2021; Wielgosz-Rondolino et al., 2024). The main petrographic features were also compared with those shown by reference samples taken from numerous ancient quarries in the Mediterranean area (LAMA's collection at the University IUAV of Venice). In particular, the microscopic study revealed that, apart from sample MA10, which is coarse-grained and presents an uncommon large MGS (7.2 mm), all the other marbles are fine-grained and show an MGS very often below 1 mm. For all these samples, at first glance, the provenance predominantly from Carrara (MA1-8 and MA11-18) and partly from Mount Penteli (MA9, MA19-MA20) seems to be certain and fully supported by their petrographic features and isotopic compositions. However, in the δ 13C versus δ 18O diagram of Figure 6a, they plot into the overlapping isotopic domains of the most part of the other fine-grained marbles considered in the data set. This apparent misclassification can be resolved by referring to their specific petrographic features (i.e. mainly straight boundary shapes of the crystals forming mosaic fabrics with frequent triple junctions), which are not consistent with those of the Docimian (Iscehisar, Afyon, Turkey), Hymettos (Attica, Greece) and Paros-Stephani (Cycladic islands; Greece) marbles (Attanasio et al., 2006; Antonelli and Lazzarini, 2015 and references therein). Furthermore, a possible origin of samples MA1-MA3, MA5, MA11 and MA18 from the quarries of Göktepe (Muğla, Turkey), is definitively ruled out by evaluating their MGS values, the presence of accessory phases (including dolomite), the strontium (Sr) and manganese (Mn) contents and the refined XRD data concerning the of the calcite unit-cell parameters. In fact, as proved by Attanasio et al. (2015; 2021), Antonelli, Lazzarini (2015), Prochaska et al. (2018), Wielgosz-Rondolino et al. (2020) and Antonelli, Nestola (2021), on the one hand, the Turkish lithotype is a very fine-grained and pure calcite marble, without accessory minerals (except, sometimes, for few graphite); on the other hand, the white marbles quarried in the southern districts 3 and 4 around the Göktepe village have low Mn (13-20 ppm, respectively) and high Sr (691-533 ppm, respectively) average concentrations, throughout the ancient sites. In particular, the Sr content of the Göktepe lithotype is at least three times higher than that measured for marbles from S. Omobono excavations and, consequently, they could not be assigned to these quarries. Furthermore, the refined data for *a* and *c* axes of the calcite unit-cells measured through XRD on samples MA1-MA8 and MA11-MA18 varied within the ranges 4.979-4.983 and 17.010-17.030, respectively; these values are not compatible with those recorded for Göktepe marble while they fit perfectly with those obtained for Carrara marble (Antonelli and Nestola, 2021). Apart from the clear analytical data, it should also be considered that, given the small to medium size of the blocks that could be extracted from its quarries, Goktepe marble was used exclusively for sculptural purposes, portraits, statues, small sculptures, while its use for architectural elements is unknown.

Lastly, as concerns sample MA10, its general petrographic characteristics observed on thin section (Table 2) seem to fit quite well with those of the marble worked on the northern Aegean Greek island of Thasos, in the Aliki (Thasos-2; Moens et al., 1992) supply district, were open cast quarries scattered over all the area.

Nevertheless, it has to be stressed that the large MGS recorded in the sample (Table 2) does not seem fully compatible with the Thasos calcitic variety. In fact, its maximum grain size usually does not exceed 5.8 mm (Antonelli and Lazzarini, 2015 and reference therein), except for only three samples from Fanari area (Thasos-1) reported by Attanasio et al., 2006, which feature an MGS up to 7.5 mm. Given that sample MS10 plots into a region of the isotopic diagram shared by many marbles (Fig. 6b), its origin still remains uncertain and a possible provenance from the Marmara (Proconnesos/Saraylar; Turkey) or Paros (Lakkoi/Chorodaki Valley; Greece) islands cannot be totally excluded. However, the archaeological evidences gathered so far indicates that Paros marble was mainly used for manufacturing valuable artefacts such as statues, sarcophagi, etc., rather than generic architectural elements (Bruno et al., 2002). Taking all the available data together, we believe sensible to limit the hypotheses of provenance to Thasos or Marmara islands (in descending order of probability).

CONCLUSION

A total of nineteen white marble samples coming from the archaeological site of S. Omobono (Rome - Italy) were studied using a multi-analytical approach based on the application of minero-petrographic, geochemical and isotopic analyses. This archaeometric study collected, for the first time, scientific information about the nature and provenance of the stone materials present in this Roman site, thus testifying the importance of the area.

More specifically, the most part of the samples has proved to come from the Apuan Alps district (Carrara). These samples cover a large period from the 1st to the 3rd century AD and belong to different architectural elements. Only sample MA10 consists of a marble that probably comes from the Fanari (or Aliki) district on the island of Thasos (Greece). It corresponds to a composite column base dated to the 1st - 2nd century AD.

Other samples coming from Greek sources and, in particular, from Mt. Penteli are MA9 (abacus fragment of the 1st - 2nd century AD); MA19 (a statue fragment of unknown period) and MA20 (a fragment of lacunar ceiling with rosette belonging to the second half of the 2nd century AD).

The study represents, together with recent research (Corradetti, 2018), an important starting point for the knowledge of the marble evidence present in the archaeological area of S. Omobono. It is connected to a perspective of research of the stone materials of the area (Brocato et al., 2019) that may, in the future, provide further useful information about the different provenances of the materials. This research could also help to identify the elements actually fitting the architectural structures and decorations of the Mater Matuta and Fortuna temples, in order to distinguish them from other finds/elements placed in the area of S. Omobono during late antiquity, the Middle Ages and the modern period.

AUTHOR CONTRIBUTIONS

Investigation, R.D.L, F.A, P.B., D.B., D.M., A.P., M.C., A.M., D.M.; writing—original draft preparation, R.D.L., F.A., P.B., D.M.; funding acquisition, P.B.; methodology, R.D.L., F.A., D.M.; supervision, D.M., F.A., P.B. All authors have read and agreed to the published version of the manuscript." Authorship must be limited to those who have contributed substantially to the work reported.

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CONFLICT OF INTEREST

There are no conflicts of interest of any kind.

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