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Archaeometric investigation of a Late Roman marble statue from Kaucana (RG) with considerations on the diffusion of Thasos marble in Sicily

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Abstract

In this work, a Roman white marble fragment of a headless body and a limestone ballast have been studied. The artifacts were discovered during the underwater archaeological explorations carried out in the Late Roman Harbor of Kaucana in Palmento of Punta Secca (RG; Sicily). Petro-archeometrics analysis to identify their provenience were performed with the aim to constraint archaeological hypothesis. In particular, to characterize the white marble we used a multi-technique approach to the petrographic description including the distinctive parameters AGS, MGS and GBS carried out by optical microscopy (MO), whereas mineralogical and chemical analysis were obtained respectively by means of X-Ray Diffraction and X-Ray Fluorescence with a portable instrument. Furthermore, the determination of the $\partial^{18}O$ and $\partial^{13}C$ isotopic ratios gave important information for the identification of the provenience of marble by comparison with literature data. Regarding the ballast, the characterization of the limestone was carried out by traditional petrographic, mineralogical and chemical methods. Finally, information about morphology and causes of underwater deterioration suffered by the materials was obtained by SEM-EDS analysis. All the data strongly suggest the provenance from Capo Vathy quarry in Thasos island (Greece) for the marble. Whereas for the ballast, both a Thasian and south Sicilian origin is excluded. This paper contributes to reconstructing the marble routes from Greece to the western parts of the Roman Empire.

Key words: white marble; Thasos; archaeometry; underwater archaeological explorations; Kaucana Late-Roman Harbor.

Introduction

During the underwater archaeological explorations carried out in the Late Roman Harbor of Kaucana in Palmento of Punta Secca in the south-eastern coast of Sicily, several specimens of amphorae, ballast materials and planking were discovered at a depth of about 5 meters, by the Sea Superintendence of Palermo from 2009 to 2011.

During the archaeological research, several wrecks dating from different historical periods, were found. The archaeological importance of the Kaucana Harbor, representing a significant ancient slipway for ships coming from Greece to Sicily (Pelagatti, 1966, 1968-69, 1972), is point up by the recently imposed interdiction of the area to navigation, anchoring, fishing and diving activities.

Among the recovered materials, two specimens have been selected for their archaeological and scientific significance: a fragment of headless marble body and a limestone ballast recovered near the marble body.

Several issues are related to the archaeological records in underwater environment (Aquilia et al., 2010); in particular, the absence of stratigraphic position makes the identification of material coming from different shipwrecks difficult. Numerous hypothesis have been proposed about the studied statue,: a) the marble body could be part of a shipment, which was broken during a shipwreck; b) it could have belonged to another wreck, transported to the discovery site by the strong marine currents active in the area; c) it could be a damaged statue that was recycled and used as ballast material.

The provenance determination of the samples studied require a multi-technique approach. In fact, this problem is particularly difficult to resolve for the white marble, due to the similarity of macroscopic features (color, structure, texture, luster and impurities) between marbles of different origin (for example Thasos, Volos, Drama, Proconnesian, Priene, Naxos, Carrara, Pentelicus, Docimium). During recent decades, important results have been achieved through different analytical approaches: trace elements geochemical studies (Rybach and Nissen, 1964; Conforto et al., 1975) such as Ca/Sr ratio (Lazzarini et al. 1980), obtained throught non-destructive X-Ray Fluorescence; the petrographic features such as average grain size (AGS), type of crystal shape (GBS) and structure, maximum grain size of calcite/dolomite (MGS) and assessment of accessory minerals; the isotopic ratios $\partial^{18}O$ and $\partial^{13}C$ (Craig and Craig, 1972; Lazzarini, 2004a).

Materials and methods

The archaeological remains analysed in this work are a fragment of headless body of white marble, labeled ST1 (Figure 1a), and a large limestone ballast labeled CZ1 (Figure 1b).

The marble headless body presents distinct features of male statuary, with developed pectoral and trapezius and high symmetry; these elements suggest an upright posture of the statue. The absence of limbs, head and trademark do not allow a certain archaeological attribution of the artifact. Nevertheless, for its sculptural characteristics, it dates to a late Roman period. Specimen CZ1 is medium to coarse grained yellowish limestone. It is a block of limestone with a spherical shape and weight of about 8 kg. The finding context, the shape and size clearly indicate its use as ballast.

In both studied samples, alteration patinas are observable on the surface of the samples due to submarine degradation processes.

For ST1 specimen, relevant petrographic features as AGS, MGS, GBS and the presence of characteristic accessory minerals, are detected by thin section analysis performed by the polarized transmitted light microscope Nikon Eclipse E400POL.

Moreover, the mineralogical characterization

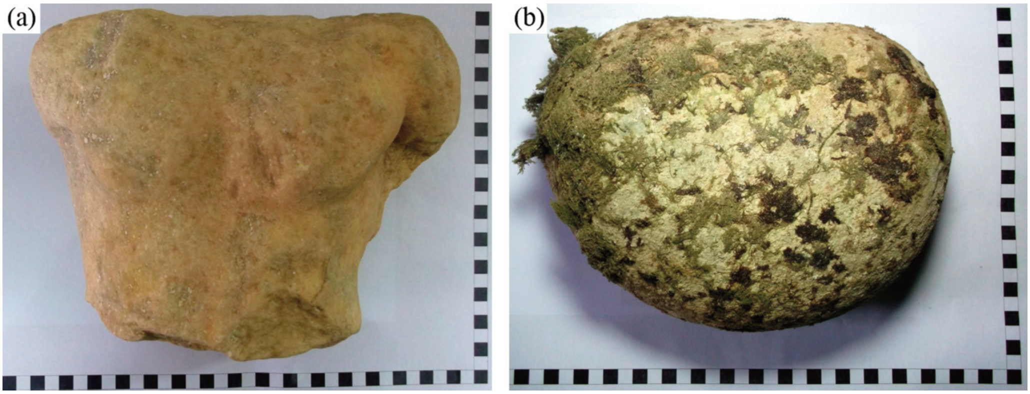

Figure 1. Archaeological records. Fragment of a headless body of white marble, labeled as ST1 (a), and large boulder of carbonate rock, labeled as CZ1 (b).

of the sample are obtained by XRD analysis (diffractometer Bruker D8 Advance) while chemical composition is achieved by Portable XRF analysis (PXRF) "Alpha 4000" (Innov-X Systems). PXRF measurements have been performed in air both on the altered surface and on freshly cut section of the samples. The equipment consist of an X-ray tube (Ta anode) and high resolution Si PiN diode detector (FWHM < 220 eV at 5.95 keV for Mn Kα line). The characteristic peaks of Ta anode has been removed using a 2-mm thick aluminum filter. The spot size is ~ 170 mm^2. The measurements and elaborations have been obtained by means of Compaq iPAQ Pocket PC handheld interface. The calibration has been performed on international standards using the software "Soil LEAP II" (Light Element Analysis Program). The concentration of selected elements have been obtained through two consecutive measurements each requiring 60 s: the first one with X-ray tube operating at 40 kV and 7 µA, the second one with X-ray tube operating at 15 kV and 5 µA.

Isotopic ratios have been obtained by mass spectrometry Thermo Scientific DELTA V. The composition of the C isotope is determined by the reaction between phosphoric acid (H_3PO_4) and calcium carbonate ($CaCO_3$), by using the preparation device Thermo-Scientific GasBench II, which automatically allows the extraction of CO_2. Samples are prepared by reacting 1 mg of material with phosphoric acid for 60 min. at T = 50 °C.

The CZ1 specimen characterization has been carried out by traditional minero-petrographic and chemical approach as above.

Finally, alteration patinas observed on the samples surfaces have been analyzed with ESEM (Environmental Scanning Electron Microscope) FEI Inspect-S. This electron microscope is coupled with Oxford INCA PentaFETx3 EDX spectrometer. Spectral data are acquired with the following experimental set-up: distance 10 mm; 20 kV; time of acquisition 60 s (3000 cp/s). The results have been processed using the software INCA Energy with matrix correction "XPP" (Pouchou-Pichoir 1984-1985).

Results

Mineralogical and petrographic analysis

The white marble headless body (ST1) shows isotropic texture and granoblastic-eteroblastic fabric with numerous triple joint boundaries (Figure 2a).

The grain boundary shape (GBS) is

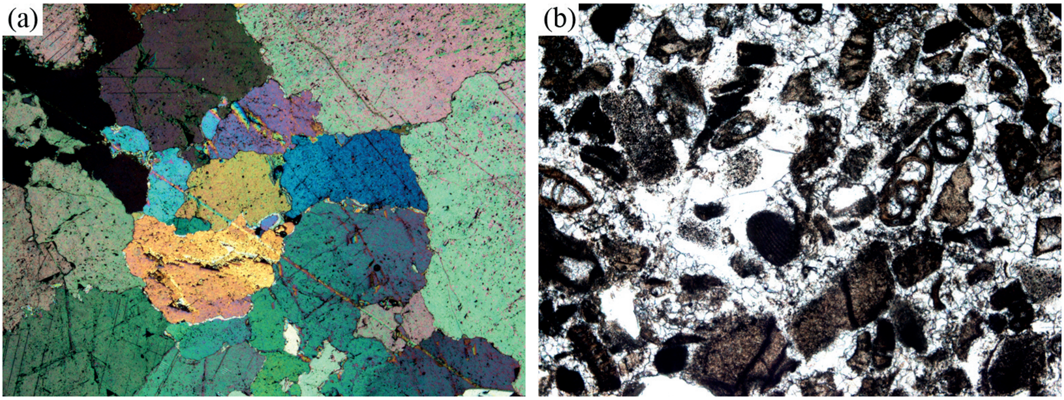

Figure 2. Photomicrograph of samples ST1(a) and CZ1 (b).

prevalently sutured to embayed, curved in some cases. The average grain size (AGS), calculated on 77 crystals, is 1.5 mm, while the maximum grain size (MGS) is 2.2 mm. The more common accessory minerals is the white mica. The specimen don't exhibits stains or veins at macroscopic and microscopic inspection. Micro-fractures are recognizable by means of thin section observation.

The XRD and SEM analyse furnished additional discriminant data, evidencing dolomite as the main phase and calcite and white mica as accessory minerals. Finally, the SEM analysis of alteration patinas showed the presence of high Fe abundance, due to iron oxides/hydroxides encrustation (Figure 3). Moreover, sporadic Pb particles observed on the surface could be interpreted as due to the

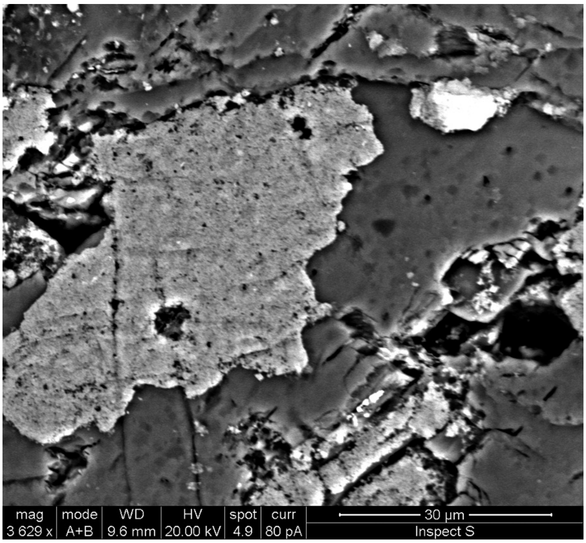

Figure 3. SEM image. Alteration patinas on ST1 sample - 3629 X magnification.

presence of lead on the ship.

The ballast (CZ1) is compact, white-cream and fine size limestone, characterized by grain-supported texture (Figure 2b); it may be classified as biosparite (Folk, 1959) or grainstone (Dunham, 1962); allochems are mainly bivalve fragments, foraminifera, gastropods, crinoids, echinids plates, and brachiopods embedded in sparitic cement. The porosity (5%) is mainly intra-particle. Veins filled by sparite and red iron oxides are also present.

Chemical and isotopic analysis

The result of the portable X-Ray Fluorescence (pXRF) performed on samples ST1 (on the altered surface measurement (a) and on the unaltered inner portion measurement (b)) and CZ1 are summarized in Table 1, where above the detection limits elements are reported. The marble presents lower Ca, Sr and Fe (in the unaltered portion) with respect to the limestone.

The $\partial^{18}O$ and $\partial^{13}C$ isotopic values independently obtained on two fragments of the studied marble are reported on Table 2. On the whole, the isotopic data are comparable with measurements reported in literature for numerous marbles quarried in different areas.

Discussion

The white marble statue

The provenance of the marble statue has been carried out by comparing petrographic, mineralogical and isotopic data with those of hundreds of Greek and Roman white marbles synthetically reported in Table 3 (Bruno et al., 2000; Capedri et al., 2004; Gorgoni et al., 2002; Lazzarini et al., 1980).

The petrographic parameters AGS, MGS and GBS suggest, as possible provenance of the samples, Thasos, Volos, Drama, Proconnesian and Priene quarries (Gorgoni et al., 2002) while Naxos, Carrara and Pentelic marbles have been excluded respectively for higher and lower MGS values. In addition, Docimium and Volos marbles are excluded too, for their different structural and color characteristics respectively (Lazzarini et al., 1980).

The presence of dolomite as the more abundant phase allows to select only dolomitic marble quarries such as Thasos (Cape Vathy quarry), Macael (Spain) (Bruno et al., 2000) and Naxos (Greece) (Capedri et al., 2004), and to exclude all marbles containing dolomite only as accessory mineral.

From the chemical point of view, it has been

Table 1. pXRF chemical data obtained for ST1 and CZ1 samples; measurement on the altered surface (a) and measurement on the unaltered inner portion (b).

Sample	Ca	Mn	Fe	Sr
CZ1	960259 ± 23566		428 ± 26	908 ± 17
ST1 (a)	610148 ± 14007	152 ± 15	2641 ± 72	31 ± 2
ST1 (b)	513931 ±10692	82 ± 11	170 ± 16	27± 2

Table 2. $\partial^{18}O$ and $\partial^{13}C$ isotopic values; two measurement (a, b) are performed on the marble spacemen.

Sample	$\partial^{18}O$	$\partial^{13}C$
ST1 (a)	$\partial^{18}O$ = -4.50‰	$\partial^{13}C$ = 2.64‰
ST1 (b)	$\partial^{18}O$ = -4.40‰	$\partial^{13}C$ = 2.52‰

Table 3. Petrographic, mineralogical and chemical data of Greek (1), (2), (3), (4), Anatolian (1), (2) and Italian white marbles (Bruno et al., 2000; Capredi et al., 2004; Gorgoni et al., 2002; Lazzarini et al., 1980).

Sample	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
ST1	X	none	white mica, calcite	1.5	sutured to embayed; curved in some cases	Ho/He	isotropic t.. Micro-fractures	19	M

Greek marbles (1)

Provenance	Quarry	n. samples	Munsell index	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
Naxos	Kinidaros	4	8-9.5	X	none	epidote, graphite; rare Qz and Fe ore	6.7-9	curved to embayed	He	highly strained text, whit bent and broken polys. Twins	15.1±0.2 - 28.8±1.4	
Naxos	Apirantos	2	8.5-9	X	none	Fe ore and graphite. rare Qz and epidote	3.5-5.2	curved to embayed	He	highly strained text, whit bent and broken polys. Twins	10.9±0.2 - 11.1±0.3	
Naxos	Filoti	2	8.5-9.5	medium	none	Graphite	0.4-1.8	straight	Ho	polygonal t. with traces of recrystallization	8±0,4 - 10.7±0.7	
Naxos	Moni	2	7-7.5	medium	rare gray vein	white mica, Fe ore. Rare Qz, Feld., epidote, graphite	1.4-7.4	curved to embayed	He	strained foliated texture	7.3±0.2 - 10.1±0.3	
Naxos	Apollona	4	8-9	medium	rare gray vein and yellow spot	Epidote, Fe ore. Rare Qz, white mica and graphite	1.2-2.6	embayed	He	Traces of recristallization, mosaic, with strongly strained crystals	8.3±0.3 - 9.1±0.2	
Naxos	Melanes							embayed	He	mosaic, sometimes lineated, with strained crystals		

Symbols: Qz: quartz; Ho: homogeneous; He: heterogeneous; Dol: dolomite (A, accessory; P, subordinate to calcite; M, main carbonate present).

Table 3. Continued ...

Greek marbles (2)

Provenance	Quarry	n. samples	Munsell index	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
Paros	Ag. Anargiroi	2	9.5	X	none	Qz	3-3.5	embayed to sutured	He	strained, sometimes mortar texture	10.2±0.3 - 12.2±0.6	
Paros	Marpissa	3	9.5	X	none	Qz, graphite. Rare white mica and Fe ore	0.9-1.3	embayed	He	strained texture; traces of recrystallization	7.8±0.2 - 9.9±0.2	
Paros	Stephani							curved	He/Ho	mosaic		
Paros	Lefkes							curved to embayed	He	mosaic, sometimes with strained crystals		
Paros	Karavos							embayed	He/Ho	lineated, fine grain, with coarse stressed crystals		
Thasos	Limin	1	9.5	X	none	Qz, graphite	4.2	sutured	He	strongly recrystallized texture	10.4±1.2	
Thasos	Skira	4	8.9-9.5	X	none	White mica. Rare Qz, epidoto, Fe ore and graphite	1.5-9	sutured to embayed	He	highly strained texture, whit bent and broken polys	12.6±0.4 - 25.7±1.3	
Thasos	Aliki	8	7.5-9	X	gray and yellow veins. Rare gray spotted	White mica, graphite. Rare Qz, epidote and Fe ore	0.8-7.6	curved to sutured	He	strained-high strained t. white bent polys. Twins; mosaic, often lineated and stressed	5.4±0.3 - 19.8±1	
Thasos	Vaty							curved to sutured	Ho/He	mosaic, sometimes with strained crystals		M

Symbols: Qz: quartz; Ho: homogeneous; He: heterogeneous; Dol: dolomite (A, accessory; P, subordinate to calcite; M, main carbonate present).

Table 3. Continued ...

Greek marbles (3)												
Provenance	Quarry	n. samples	Munsell index	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
Crete	Matala	1	7.5	X	none	Graphite		strongly sutured	He	strongly recrystallized texture	9.1±0.4	
Penteli	Penesi	2	7-9	X	none	Fe ore, graphite. Rare Qz, white mica and epidote	0.6-0.9	embayed	He	somewhat strained and foliated texture	13.7±0.1 - 14±0.2	P
Penteli	Spelia	1	9.5	X	none	Qz, white mica, graphite	0.5	embayed to curved	He	somewhat strained and foliated texture plus traces of recrystallization	10.4±0.3	P
Mt. Himettos	Kessarian	3	5-6.5	medium	gray and yellow veins	Qz, white mica, Fe ore, graphite	0.3	curved to sutured	Ho	strongly layered texture, few large calcite crystals	7.9±0.4 - 10.9±0.4	
Volos	Giasteni	1	8	X	none	Graphite	0.9	sutured	He	layered texture with highly strained and deformed crystals	11.2±0.4	
Volos	Argalasti	1	8	X	none	white mica, Fe ore, graphite	1.3	sutured	He	layered texture with highly strained and deformed crystals	17.4±0.6	
Veria		1	9	X	none	Graphite	1.3	straight	Ho	poligonal text.	16±1.1	

Symbols: Qz: quartz; Ho: homogeneous; He: heterogeneous; Dol: dolomite (A, accessory; P, subordinate to calcite; M, main carbonate present).

Table 3. Continued ...

Provenance	Quarry	n. samples	Munsell index	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
Greek marbles (4)												
Kozani		1	9	X	none	Fe ore, graphite	0.7	straight	Ho	poligonal text.	11.8±0.4	
Drama	Aiax Lazarides	1	7.5-9	medium	rare gray veins	Qz, Epidote, Fe ore, graphite. Rare white mica	0.4-1.5	from embayed to curved to sutured	He		5±0.2 - 7.8±0.1	
Drama	Tylos Lazarides	1	6.5	X	none	White mica, graphite	1.4	embayed	He	strained, layered text.	12.8±1.5	
Drama	Monastiraki	1	4		gray veins	Qz, epidote, w. mica, Fe ore, graphite	0.7	embayed to sutured	He	straied, strongly layered text.	3.8±0.4	
Filippi		2	7.5-8	X	none	W. mica,Fe ore, graphite	10.9-11.8	sutured	He	highly strained text.	5±0.1 - 6±0.2	
Kavala	Zigu	1	7	X	none	epidote, graphite	0.9	sutured	He	Strained texture	12.9±0.4	
Stagira	Halkidiki	1	5.5		gray veins ans spots	w. Mica, graphite	2.2	sutured	He	strongly layered and strained text.	9±0.1	
Arnea	Halkidiki	1	6.5		gray spot	Qz, feld., white mica, graphite	0.7	sutured	He	strained and recristallized text.; little layering	8±0.4	

Symbols: Qz: quartz; Ho: homogeneous; He: heterogeneous; Dol: dolomite (A, accessory; P, subordinate to calcite; M, main carbonate present).

Table 3. Continued ...

Anatolian marbles (1)												
Provenance	Quarry	n. samples	Munsell index	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
Prokonnesos	Kavala	1	9.5	X	none		0.3	curved	Ho	layered t. with large calcite cristals	17.7±1.5	
Prokonnesos	Saraylar	4	8-9.5	X	gray veins	graphite. Rare epidote, white mica, Qz	0.8-2.6	embayed to sutured	He	strained t. with bent twins and traces of recrystallization, often with deformed polysynthetic twins	8.2±0.7 - 11.9±0.4	
Ephesos	Kusini Tepe	2	8.5-9		gray - yellow veines	graphite. Rare epidote, white mica	1	sutured	He	layered mortar t. with strongly deformed crystals	29.3±2.7 - 34.9±1.8	
Ephesos	Belevi	1	7.5		gray veines	epidoto, white mica, graphite	2.6	sutured	He	layered mortar t.	7.1±0.9	
Ephesos	M.t Pion	1	4.5		gray veines	w. mica, graphite		sutured	He	strongly layered t.	7.2±0.7	
Priene	Kala Dere	1	8.5	X	none	Qz., graphite	0.8	curved to embayed	He	mortar t., recrystall. t.	11.3±1.8	
Penteli		3	6-8	medium	rare gray veins and spot	graphite. Rare Qz, epidote, white mica	1.1-1.5	embayed	He	strained	4.4±0.1 - 27.2±2.5	P
Lake Latmos	Kapokiri	7	6-9	X	rare veins and spots	epidote, white mica, graphite	0.8-4.9	curved to embayed	Ho	strainded and recrystallized t.	5.1±0.4 - 13.3±1.1	M
Teos	Sigacik	1	7	X	none	graphite		sutured	He	sheared recrystallized t. with large calcite crys.	13.9±1.1	A

Symbols: Qz: quartz; Ho: homogeneous; He: heterogeneous; Dol: dolomite (A, accessory; P, subordinate to calcite; M, main carbonate present).

Table 3. Continued ...

Provenance	Quarry	n. samples	Munsell index	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
Anatolian marbles (2)												
Euromos		1	7		gray veins	epidote, graphite	2.8	embayed	He	slightly layered and recrystallized t.	8.6±0.3	
Mylasa		3	2-8	X	none	rare graphite	0.3-1	embayed	Ho	polygonal, slightly recrystallized t.	5.6±0.01 - 13.4±1.3	
Stagira		1	8.5	X	none		6.1	embayed to sutured	Ho	slightly layered and recrystallized t.	17.6±1.6	
Stratonicea		1	5.5		gray spot	Qz, feld. - plag., epidote, graphite	3.9	embayed	He	layered t.	7.5±0.3	
Yagatan		1	8.5		yellow spots	Qz, epidote, graphite	1.9	sutured	Ho	recrystallized t.	21.8±2	
Alanya		1	7	X	none	Qz, graphite	1.2	sutured	He	strained, layered and recrystallized t.	11±0.2	
Aydincyk		2	5-8		gray spots	Graphite; rare Qz, epidote, w. mica	0.4	sutured	He	recrystallized t.	4.9±0.2 - 8.3±0.1	
Aphrodisias	S.E. quarries	4	7-9		none		0.4-3.9	embayed to sutured, curved	He	mosaic, sometimes lineated and stressed	8.7±0.6 - 17.1±0,1	
Docimium	Ischehisar	3	5.5-9.5	medium	yellow/gray veins and spots	graphite. Rare epidote, white mica, Qz	1.3-1.7	sutured	He/Ho	strained t. with traces of recrystallization	21.9±0.8 - 34.6±4	
Ak Dag	Denizli	1	8.5	X	none	Qz, feld. - plag., epidote, graphite, Fe ore	1	curved to embayed	He	layered t. with traces of recrystallization	7±0.1	

Symbols: Qz: quartz; Ho: homogeneous; He: heterogeneous; Dol: dolomite (A, accessory; P, subordinate to calcite; M, main carbonate present).

Table 3. Continued ...

Italian marbles												
Provenance	Quarry	n. samples	Munsell index	Color uniformity	Vein or spot	Accessory minerals	AGS	GBS	Texture	Minero-petrographic characteristics	Ca/Sr	Dol
Carrara	Fossa Cava	5	5.5-9		gray spots	Qz, graphite. Rare w. mica	0.4-0.7	straight to curved	He	strongly recrystallized t.	4±0.2 - 6.5±0.2	A
Carrara	Franti Scritti	2	8-9		none	Qz, white mica, Fe ore, graphite	1-1.3	straight to curved	He	polygonal t. with traces of recrystallization	7.2±0.3 - 10.4±0.7	A
Carrara	Torano	1	9.5	X	none		0.4	strsight, curved	Ho	poligonal t., with triple points, often mosaic	11.2±0.7	A
Carrara	Orto di Donna	1	9	X	none	Qz, graphite	1	sutured	Ho	recrystallized polygonal t.	9.5±0.4	A

Symbols: Qz: quartz; Ho: homogeneous; He: heterogeneous; Dol: dolomite (A, accessory; P, subordinate to calcite; M, main carbonate present).

taken in to account the geochemical Ca/Sr ratio, determined using the Ca and Sr Ka peak area, which is a powerful tools in the determination of provenience for ancient marble (Lazzarini et al., 1980). The similarity of the measured ratio with those of the Thasos marble, as show in Table 3 is worthy of notice.

Finally, the $\partial^{18}O$ and $\partial^{13}C$ isotopic values projected on isotopic diagram for marble with MGS > 2 mm (Lazzarini, 2004) confirms that the ST1 sample is a dolomitic marble quarrying in Cape Vathy (Thasos) (Figure 4, Table 2).

The limestone ballast

Petrographic description has been compared with those of Sicilian limestones, showing only partial similarity in particular with the Oligocene-lower Miocene Ragusa Formation limestone, cropping out near the Kaucana site and locally named Comiso stone. This latter, nevertheless, is microscopically significantly different in porosity, grain-size and type of allochems.

The chemical composition is typical of limestones with high Ca; particular attention was given to the Ca/Sr and Ca/Fe ratio since these elements were useful in the identification of limestones from south-eastern Sicily (Barbera et al., 2012). As show in Figure 5, sample CZ1 is separated from Sicilian calcarenites for higher content of Ca/Fe and Ca/Sr ratios. A similarity with Scicli Stone (CTS) is excluded petrographically.

Conclusion

The reported analytical results are coherent and suggest a Thasian provenance for the white marble, in particular from the Cape Vathy quarry. This result has quite an interesting archaeological significance.

The identification of the studied headless body

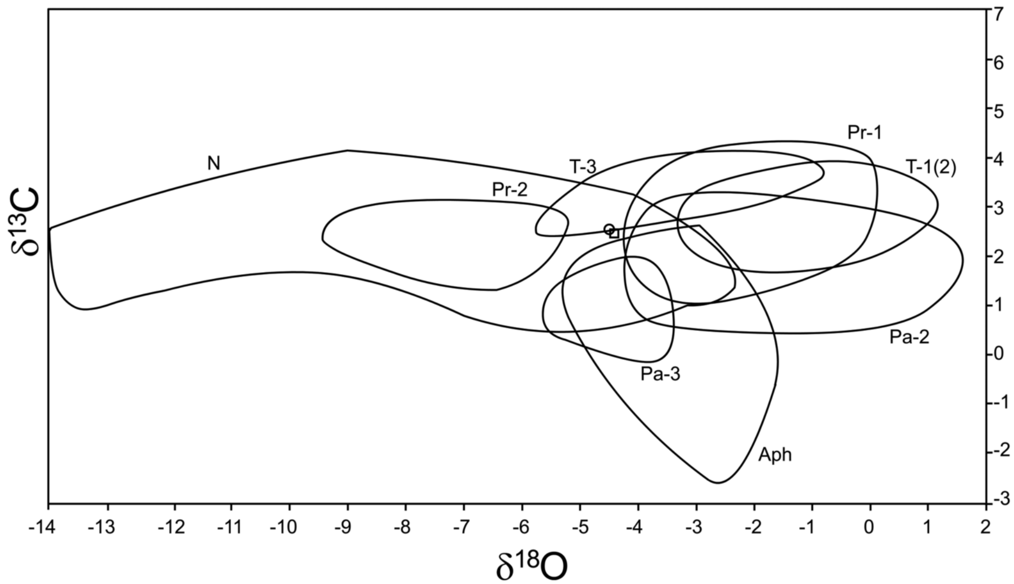

Figure 4. Isotopic reference diagram by Lazzarini (2004b) for marble with MGS > 2 mm; N = Naxos; Pr-1, Pr-2 = Proconnesian; T-1, T-2 = Thasos (calcic); T-3 = Thasos (dolomitic); Aph = Aphodisius; Pa-2 = Paros from Lakkoi; Pa-3 = Paros from Karavos. The sample ST1 falls in the Thasos-3 area.

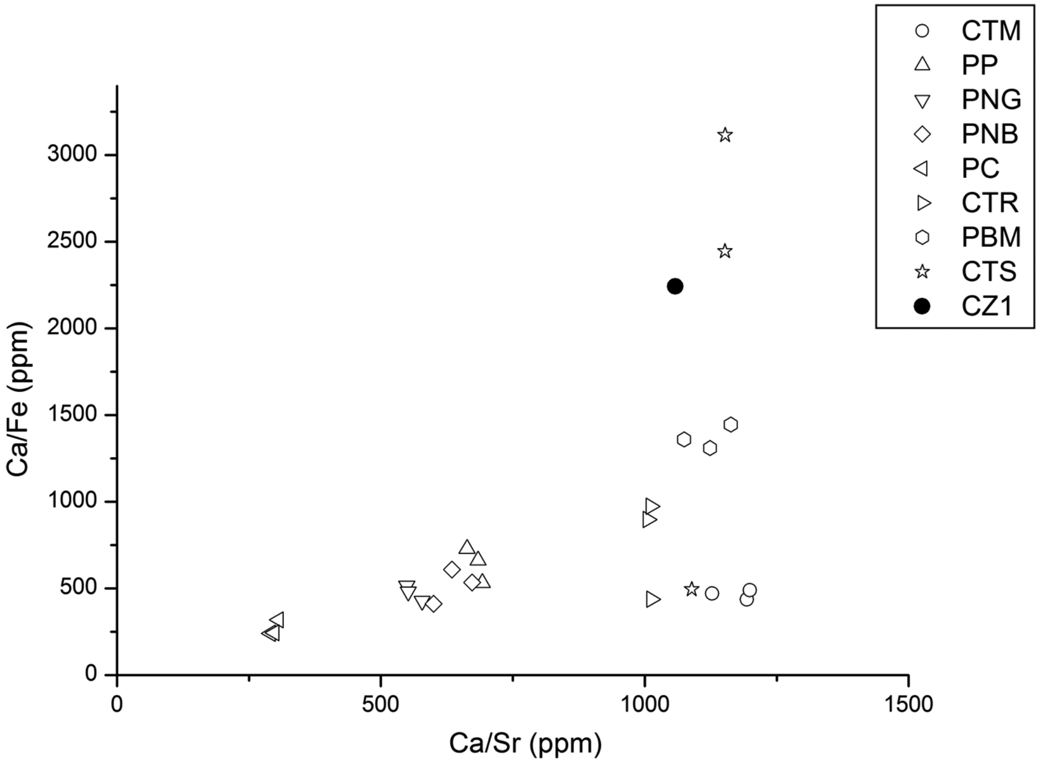

Figure 5. Ca/Fe vs. Ca/Sr diagram for CZ1 and Sicilian limestone. CTM = Modica limestone; PP = Pitch limestone; CTR = Ragusa limestone; CTS = Scicli limestone; PBM = Melilli limestone; PC = Comiso limestone; PNG = Noto yellowish limestone; PNB = Noto white-cream limestone.

provenience in fact highlights the wide diffusion of Thasos marble artifacts, as recently was attested by the provenance attribution of white marble statues found in the Roman Empire, and in particular in Italy and in Sicily (Figure 6); in fact, about 130 statues have been found in different Italian sites (Herrmann, 1999; Herrmann et al., 1977; Sodini, 1980).

Relatively to Sicily, some white marble artifacts dated from I sec. B.C. to the V sec. AD found in the sites of Morgantina (Di Grazia, 2008) and Halesa (Triscari et al., 2011), has been attributed to a Thasos provenience on the basis of archaeometric research. On the whole, these data may open new perspectives in relation to possible trade routes by which Thasos marble artifacts were transported from Greece to Italy and Sicily.

In this context the limestone ballast is problematic since it's petrographic and chemical data exclude a south Sicilian provenance while in the Thasos island similar limestones do not outcrop (Demadis et al., 1989; Proedrou, 1979, 1988). It was probably part of a ballast loaded on the ship during an intermediate stop or on a previous trip. Alternatively, the finding of this chopper near the statue may be accidental and due to strong marine currents.

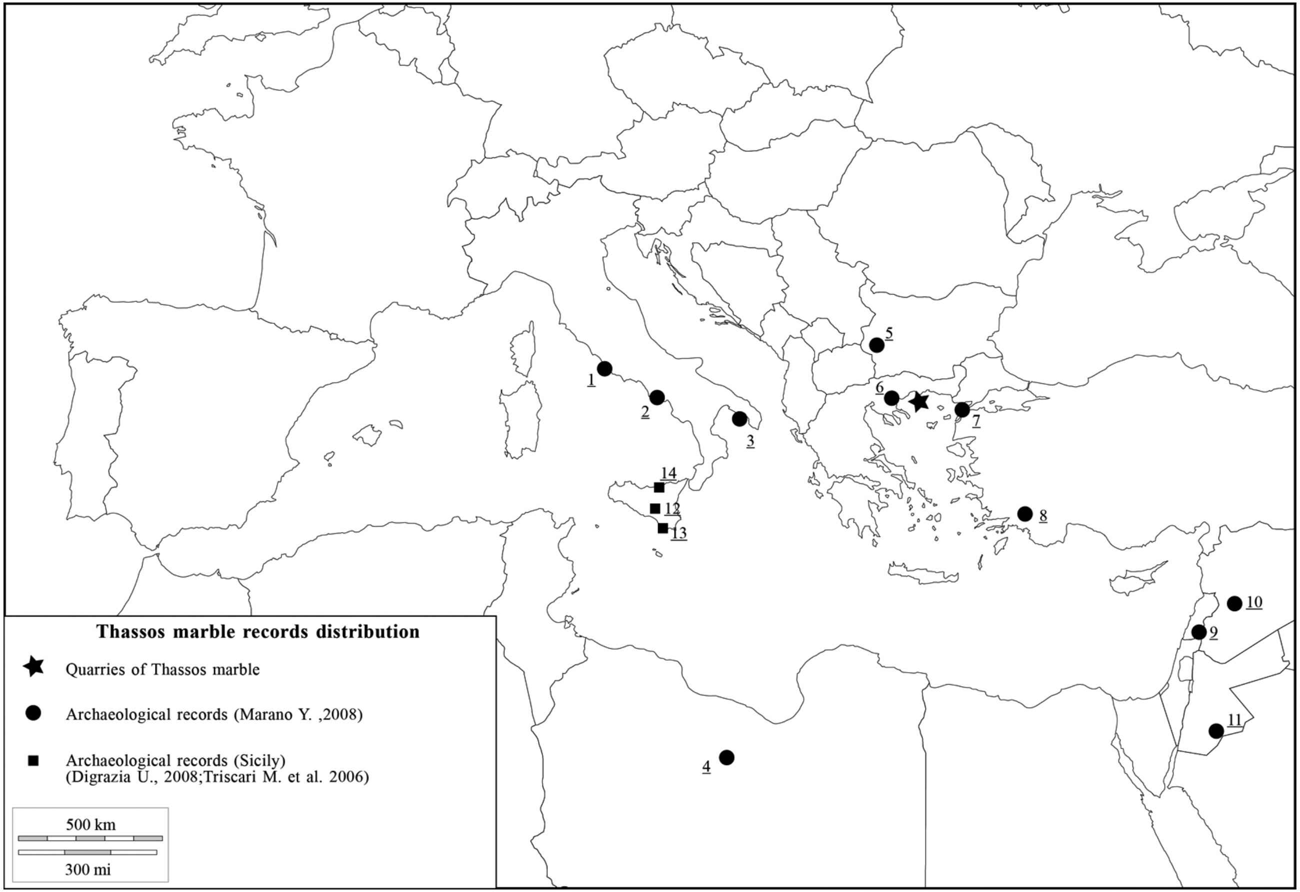

Figure 6. Spread of archaeological records in Thasos marble in the Mediterranean area. 1) Rome (RM - Italy), statuary, sarcophagi, architectonic elements; 2) Baia (NA - Italy), capitals; 3) San Pietro in Bevagna (TA - Italy), sarcophagi; 4) Lybia, artifacts; 5) Macedonia, sarcophagi; 6) Thessaloniki (Greece), rilief; 7 - Samothrace (Greece), artifacts; 8 - Ephesus, bas-rilief; 9 - Palestine, artifacts; 10 - Syria, artifacts; 11 - Jordan, architectonic elements; 12 - Morgantina (EN - Sicily - Italy), statuary; 13 - Kaucana (RG - Sicily - Italy), statuary; 14 - Halaesa (Sicily - Italy), statuary.

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References

Aquilia E., Barone G., Bruno N., Mazzoleni P., Raneri S. and Tusa S. (2010) - Caratterizzazione di ceramiche archeologiche subacquee del porto piccolo di Siracusa, VI Congresso Nazionale di Archeometria "Scienza e Beni Culturali". Pavia, 15-18 febbraio 2010, 1-6, ISBN 978-88-555-3181-8.

Barbera G., Barone G., Crupi V., Longo F., Mazzoleni P., Majolino D. and Venuti V. (2012) - Non-Destructive Analyses Of Carbonate Rocks: Applications And Potentiality For Museum Materials, accepted. *X Ray spectrometry* (wileyonlinelibrary.com) DOI 10.1002/xrs.2425

Bruno M., Conti L., Lazzarini L., Pensabene P. and Turi B. (2000) - The marble quarries of Thasos: an archaeometric study. *Asmosia* VI, International conference, Venezia, 157-162.

Capedri S. and Venturelli G. (2004) - Accessory minerals as tracers in the provenancing archaeological marbles, used in combination with isotopic and petrographic data. *Archaeometry*, 46, 4, 517-536.

Conforto L., Felici M., Monna D., Serva L. and Taddeucci A. (1975) - A preliminary evaluation of chemical data (trace elements) from classical marble quarries in Mediterranean. *Archaeometry*, 17, 201-213.

Craig H. and Craig V. (1972) Greek marbles determination of provenance by isotopic analysis, *Science*, 176, 401-403.

Demadis E., Epitropou N., Tsompos P. and Zachos S. (1989) - Recent geological and tectonic results on Thasos Island and the prospecta of locating new Pb - Zn - Fe - Mn - Au mineralizn. *Bullettin of Geological Society of Greece*, 23, 1, 75-88.

Digrazia U. (2008) - Gli Acroliti di Morgantina. Le divinità di Demetra e Persefone - http://www.comune.aidone.en.it/ev/images/ACROLITI%20%20storia.pdf (date of access 2012).

Dunham R.J. (1962) - In: W.E. Ham, Classification of carbonate rocks. *American Association of Petroleum Geologists Memoir*, 1, 108-121.

Folk R.L. (1959) - Practical petrographic classification of limestones. *American Association of Petroleum Geologists Bulletin*, 43, 1-38.

Gorgoni C., Lazzarini L., Pallante P. and Turi B. (2002) - An updated and detailed mineropetrographic and C-O stable isotopic reference database for the main Mediterranean marbles used in antiquity. *Asmosia*, V, London, 115-131.

Herrmann J.J. and Sodini J.P. (1977) - Exportations de marbre thasien à l'époque paléochrétienne: le cas de chapiteaux ioniques. *Bulletin de correspondance hellénique*, 101, 471-511.

Herrmann J.J. (1999) - The Exportation of Dolomitic Marble from Thasos. A Short Overview. *Thasos*, 57-74.

Lazzarini L., Moschini G. and Stievano B.M. (1980) - A contribution to the identification of Italian, Greek and Anatolian marbles through petrological study and evolution of Ca/Sr ratio. *Archeometry*, 22, 2, 173-183.

Lazzarini L., (2004a) - Pietre e Marmi Antichi, natura, caratterizzazione, origine, storia d'uso, diffusione, collezionismo. CEDAM, Padova.

Lazzarini L., (2004b) - Archaeometric aspects of white and coloured marbles used in antiquity: the state of the art. *Periodico di Mineral*ogia, 73, 113-125.

Marano, Y. (2008) - Il commercio del marmo nell'Adriatico tardoantico (IV - VI secolo d.C.). Ph.D. Thesis, Department of History, University of Padova.

Pelagatti P. (1966) - Scavi e scoperte archeologiche nella provincia di Ragusa. *Archivio Storico Siracusano*, XII, 23-29.

Pelagatti P. (1968-69) - L'attività della Soprintendenza all'antichità della Sicilia orientale tra il 1965-68, (Naxos). *Kokalos*, 14-15, 344-364.

Pelagatti P. (1972) - Un ancoraggio bizantino sulla costa meridionale. *Sicilia Archeologica*, 5, 89-99.

Proedrou, P. (1979) - The Evaporite formation in the Nestos-Prinos graben in the northern Aegean sea, VII^th^ International Congress on Mediterranean Neogene, Athens, Greece. *Annales Geologiques des Pays Helleniques.*, II, 1013-1020.

Proedrou, P. (1988) - New age determination of the Prinos basin. *Bullettin of the Geological Society of Greece*, 20, 2, 141-147.

Rybach L. and Nissen H.U. (1964) - Neutron activation of Mn and Na traces marbles worked by the ancient Greeks. *Proceeding of Radiochemical Methods of Analysis*, Salzburg, 105 - 117.

Sodini, J.P., Lambraki A. and Kozelj T. (1980) - Aliki, I: Les carrières de marbre à l'époque paléochrétienne, Ecole française d'Athènes, Etudes Thasiennes, IX, Paris, 146.

Triscari M., Barone G., Di Bella M., Mazzoleni P., Sabatino G. and Tigano G. (2011) - Due statue femminili del II secolo d.C. ed altri "marmi" dal sito archeologico di Halesa (Tusa, Messina), Da Halesa ad Agathyrnum. Studi in memoria di Giacomo Scibona. Contributi alla conoscenza del territorio dei Nebrodi, V, S. Agata di Militello (ME), 125-138.

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