

## Italica (Seville, Spain): use of local marble in Augustan age

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*Submitted, September 2010 - Accepted, November 2010*

**ABSTRACT** - This study concerns 51 marble finds made of “Cipollino verde” coming from the ancient city of Italica (north of the modern city of Santiponce, 9 km NW of Seville, Spain), the earliest Roman settlement in Spain, founded in 206 B.C. The aim of this work was to determine their provenance from Greek and Italian quarries or from local quarries worked in the Iberian Peninsula.

Thin-section optical microscopy, X-ray powder diffraction, bulk rock chemistry and O, C and Sr stable isotope analyses were carried out. Results were compared with literature data on “Cipollino verde” marbles quarried in southern Euboea (Greece), Apuan Alps (Italy), Almería, Extremoz, Seville (Spain) and Évora (Portugal). These comparisons indicated twenty-five marble samples consistent with an origin from Italy (Corchia and Arni districts, Apuan Alps), twenty from Greece (Styra and Pyrgari districts, southern Euboea) and only six from Spain (Macael, Almería province).

**RIASSUNTO** - Si è effettuato lo studio di 51 reperti in marmo “Cipollino verde”, provenienti dall’antica città di Italica (a nord della moderna Santiponce, 9 km a NW di Siviglia, Spagna), la prima colonia romana in Spagna fondata nel 206 a.C. La finalità del lavoro è

stata quella di verificare se i marmi utilizzati provenissero da cave greche ed italiane o se potessero provenire anche da cave locali della Penisola Iberica.

Sono state effettuate analisi in microscopia ottica di sezioni sottili, diffrattometria a raggi X su polveri, chimica del campione globale ed analisi degli isotopi stabili O, C e Sr. I risultati sono stati confrontati con i dati di letteratura relativi ai marmi “Cipollino verde” anticamente coltivati nei settori estrattivi dell’Eubea meridionale (Grecia), delle Alpi Apuane (Italia), di Almería, Extremoz, Siviglia (Spagna) e di Evora (Portogallo). Il confronto ha indicato che 25 campioni provengono dall’Italia (Alpi Apuane, settori Corchia e Arni), 20 dalla Grecia (Eubea meridionale, settori Styra e Pyrgari) e soltanto 6 dalla Spagna (Macael, provincia di Almería).

**KEY WORDS:** “Cipollino verde” marble; mineralogy; petrography; geochemistry; stable isotopes; Italica; Spain.

### INTRODUCTION

“Cipollino verde” marble, historically known as “Marmor Carystium”, was widely used for carving many artefacts found in the Roman

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Fig. 1 - Amphitheatre of Itálica, aerial photo.



Fig. 2 - Geographical position of archaeological site of Itálica.

amphitheatre (Jiménez, 1982; Garcia Ramos *et al.*, 1989) of the ancient city of Itálica (Santiponce, Seville, Spain; Figs. 1 and 2). The studied samples are nine small fragments of artefacts of various kinds (Fig. 3), now in Seville's archeological Museum, and forty-two columns (Fig. 4) still *in situ*.

The aim of the study was to verify the hypothesis proposed by Canto (1978) and recently confirmed by Rodriguez Gutierrez (2001) that the marbles used for building the amphitheatre of Itálica came from Spanish ("Anasol" marble) or Portuguese ("Anasol"-type marble) quarries, rather than from the famous ones in Greece ("Marmor Carystium") and Italy ("Cipollino verde"). Such a hypothesis is also supported by the fact that, after the II century A.D., a significant increase in Iberian stone production was needed, to satisfy the increased demand of less expensive marble for private buildings (Pensabene, 1995, 1998). Indeed, the last building phase found in the Itálica archeological site dates back to the Severian Age (II-III centuries A.D.), at a time when, notoriously, few funds were available.

Chemical, mineralogical, petrographic and isotopic analyses as well as qualitative and

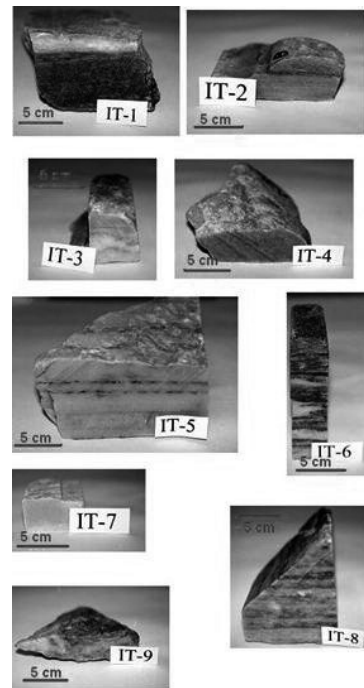


Fig. 3 - Photograph of nine marble fragments from amphitheatre of Itálica, which are preserved in the Archaeological Museum of Sevilla: IT1 column; IT2 frame (building structure); IT3 moulding; IT4 frame (building structure); IT5 frame (building structure); IT6 pavement; IT7 paving stone with moulding; IT8 block; IT9 column. All marble fragments are composed by calcite, except for the sample IT8 that is composed by calcite and dolomite.

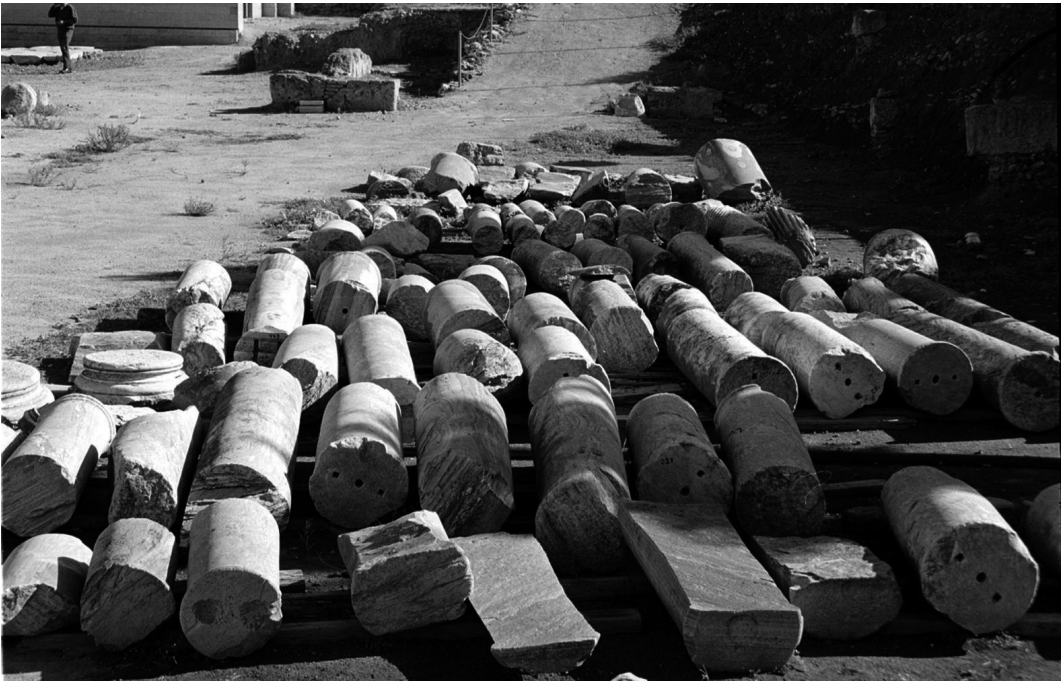


Fig. 4 - Photographs of some columns from the amphitheatre of Italica, which were sampled and analysed in this work.

quantitative determinations on insoluble residues were carried out on the sampled marbles. The data were compared with archeometric ones available in the literature, which refer to samples from ancient quarries all over the Mediterranean area: Greece, Euboea, greenschist facies (Karistos, Pygari, Styra, Brethela and Vatisation districts); Italy, Apuan Alps, greenschist facies (Arni, Isola Santa and Corchia districts); Spain, Almería, greenschist or amphibolite facies (Almaden de la Plata - Las Cabrerías and Los Covachos, Macael districts); Portugal, Évora, amphibolite facies (Viana do Alentejo and Vila Vicosa districts).

#### HISTORICAL DATA

According to the historian Appianus of Alexandria (Storia Romana, VI, *De Rebus*

*Hispaniensibus*), the Roman city of Italica was founded in the year 206 B.C. by Publius Cornelius Scipio - also known as Scipio Africanus or Scipio the Elder - as a place of settlement for soldiers wounded in the battle of Ilipa (Second Punic War). The Emperor Marcus Ulpius Trajan was born in the city in A.D. 53, as was his successor, Aelius Hadrian, in A.D.76. From the early XVII century A.D., the new city of Santiponce was built over the ancient Roman ruins of Italica. Excavations of the Italica site date back to the XVIII century and are still ongoing. Its amphitheatre, one of the largest in the Roman Empire, dates back to the age of the Emperor Augustus and was built in at least three periods (A.D. 30-37, A.D. 60-80, and II-III centuries A.D.). Archeological data show that the last construction phase was certainly characterised by the use of less expensive stone

materials and many of the shafts made of "Cipollino verde" show evidence of fractures, some of which were repaired in the quarry. In addition, pieces from ancient dressed statues were widely used as raw material for building the fountain proscenium, as well as marble slabs of various kinds for floors and niches (Rodriguez Gutierrez, 2001).

Although this constructive period was characterized by limited economic resources, there is evidence of significant building activity in the city. In particular, the use of large quantities of imported marble not only suggests the maintenance of trade routes, but also the economic stability of the city.

The amphitheatre fell into disuse in about the IV century A.D., and was stripped during the course of the following centuries. On the occasion of the Islamic invasion, many stone materials were used to build the city of Santiponce in the early XVII century A.D. and, long before, the Monastery of San Isidoro del Campo in 1301.

#### ANALYTICAL PROCEDURES

Petrographic, X-ray powder diffraction (XRPD) and X-ray fluorescence (XRF) analyses, as well as C, O and Sr stable isotope analyses were carried out to characterize the samples. An appreciable content of dolomite was determined by both X-ray powder diffraction analyses and the S-alizarin test.

XRPD analyses were performed on both whole samples and insoluble residues (IR), obtained from 100 mg at least of powder, by automatic diffractometry (PHILIPS PW 1130/00 instrumentation, with unfiltered  $\text{CuK}\alpha$  radiation at 40 kV/20 mA, data recorded in range 3-70° 2 $\theta$ , scan speed 1°/min, step time 2s/step, 1° divergence slit, 0.1 mm receiving slit, 2° anti-scatter slit).

Major and trace elements were determined by XRF (SIEMENS spectrometer, Cr anti-cathode

tube) on 6 g of powder.

Quantitative determination of insoluble residues (IR) was obtained on about 10 g of powder by chemical attack, with acetic and hydrochloric acids for calcitic and calcitic/dolomitic samples, respectively (Jurik, 1964).

Total volatile components were determined by loss on ignition (LOI) at 1000°C on 400 mg of powder; CO<sub>2</sub> contents were estimated by the gas volumetric method (calcimetry).

O and C stable isotope analyses were performed on a FINNIGAN MAT 252 mass spectrometer. CO<sub>2</sub> was extracted from very small samples (0.15 mg) by adding H<sub>3</sub>PO<sub>4</sub> at 70°C in a Kiel II automatic carbonate device (modified by McCrea, 1950). <sup>13</sup>C/<sup>12</sup>C and <sup>18</sup>O/<sup>16</sup>O isotopic ratios are expressed in conventional notation, i.e., deviation from PDB standard per thousandth.

Sr isotopic ratios were measured on a VG 54E Micromass spectrometer on 100 mg of the carbonate fraction obtained by sample dissolution in 2.5 N ultrapure HCl. Data acquisition and reduction were performed following the procedure of Ludwig (1994).

#### PETROGRAPHY

Two groups of "Cipollino verde" marbles can be distinguished by their appreciable contents of dolomite. All samples contain the following accessory minerals: epidote, sphene, zircon, hematite, and relatively abundant phyllosilicates. In general, marbles with lower content of phyllosilicates contain both potassium feldspar and subordinate plagioclase as accessory minerals.

#### MARBLES WITHOUT DOLOMITE

In these samples, dolomite could not be detected by either XRPD analyses or the S-alizarin test.

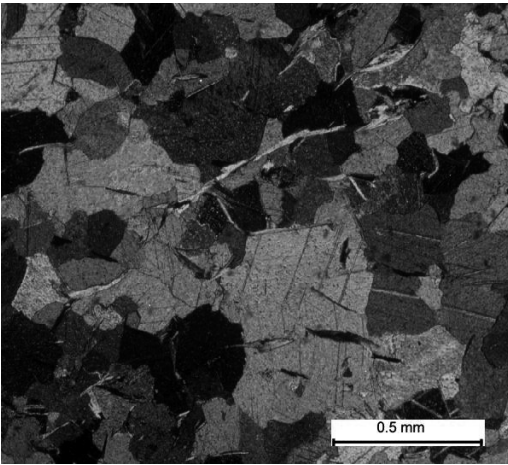


Fig. 5 - Microphotograph of thin section of marble without dolomite - Lithotype I (NX).

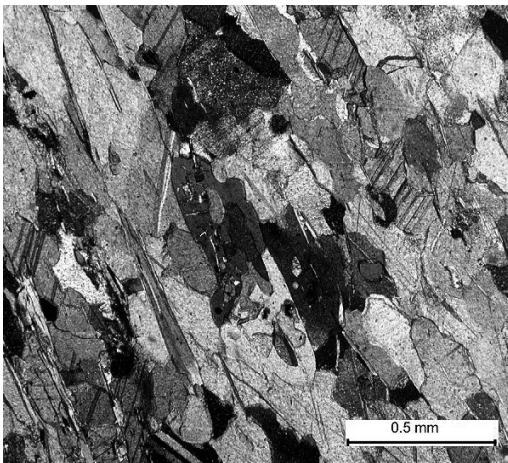


Fig. 6 - Microphotograph of thin section of marble without dolomite - Lithotype II (NX).

*Lithotype I (samples ITC 3, 12, 13, 28, 44)*

These samples typically have isotropic/homeoblastic/granoblastic textures, with calcite grains with curved/straight grain-boundary shapes (Fig. 5). The softly striped characteristics of these marbles are due to the presence of

phyllosilicate ribbons. The main grain size of calcite crystals ranges from 0.4 to 1 mm, with a maximum of about 1.5 mm. Secondary minerals are quartz, tremolitic amphiboles (samples ITC 3 and 13), chlorite, muscovite and, in some samples, phlogopite (with typical yellowish-brown pleochroism) and phengite. Sub-rounded and interstitial quartz is the most abundant secondary phase among secondary minerals; aggregates of quartz crystals can also be observed associated with seams of phyllosilicates, in some cases sharing the same direction of deformation and, in others, appearing as large relict grains with poikiloblastic inclusions.

Dispersed needle-like muscovite crystals occur along the boundaries of calcite grains, although most of the calcite is found in small seams of muscovite-chlorite. Accessory minerals linked to phyllosilicates are epidote, clinozoisite and hematite; sub-idiomorphic potassium feldspar (ITC 12 and 13) with Karslbader macle, and large poikilitic and less abundant albitic plagioclase (ITC 28) were also identified.

*Lithotype II (samples ITC 1, 2, 4, 7, 9, 23, 32, 42, 47)*

These samples are characterized by anisotropic/heteroblastic/granoblastic textures, with both calcite and phyllosilicate crystals elongated parallel to the main striped direction (Fig. 6). Secondary minerals are quartz, K-feldspar and albitic plagioclase (samples ITC 4 and 32). The main grain size of the calcite crystals ranges from 0.5 to 1 mm, with a maximum of about 1.8 mm.

*Lithotype III (samples ITC 5, 6, 15, 22, 24, 26, 30, 39, 51)*

These samples are characterised by anisotropic/heteroblastic texture, calcite crystals with undulating extinction, and deformed twins. Two subgroups were defined on the basis of both calcite grain sizes and contents of quartz and phyllosilicates.

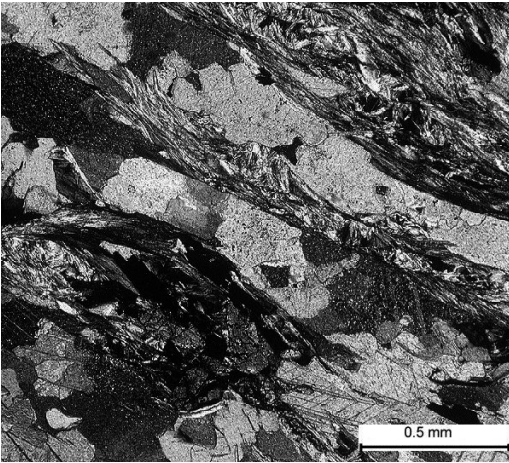


Fig. 7 - Microphotograph of thin section of marble without dolomite - Lithotype IIIB (NX).

Lithotype III A (samples ITC 22, 30, 39) groups samples with calcite crystals ranging from 0.2 to 0.8 mm and low quartz and phyllosilicates, showing more evident striped features. Accessory minerals are K-feldspar (ITC 22) and heavy minerals.

Lithotype III B (samples ITC 5, 6, 15, 24, 26, 51) groups marble samples with calcite crystals

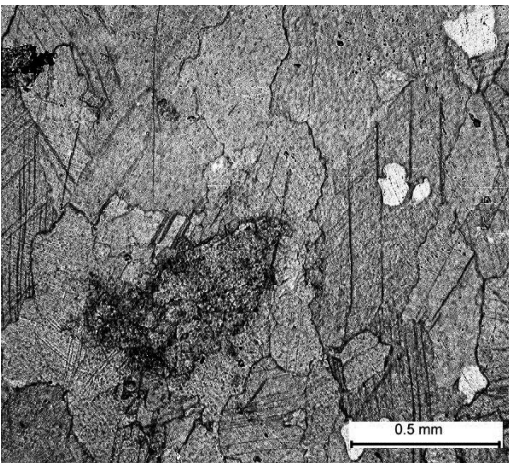


Fig. 8 - Microphotograph of thin section of marble with dolomite - Lithotype IV (NX).

with high quartz and phyllosilicate contents (Fig. 7). Some samples show lepidoblastic texture and occasionally develop a mosaic texture of calcite crystals with undulating extinction. Quartz is present in association with feldspars, e.g., sample ITC 24. Accessory minerals are epidote, clinozoisite, sphene, zircon and hematite.

#### MARBLES WITH DOLOMITE

These calcitic marbles containing dolomite are grouped on the basis of dolomite, quartz and phyllosilicate contents.

*Lithotype IV: Marbles with low contents of dolomite, quartz and phyllosilicates (samples ITD 10, 11, 25, 27, 41, 46, 48, 50)*

This set of samples has homeoblastic/heteroblastic textures and includes equally sized (sample ITD 25) to elongated calcite grains, mean sizes ranging from 0.3 to 1 mm in diameter (Fig. 8). In the samples with highly heteroblastic textures (samples ITD 11, 27, 41, 50), calcite grain size is up to 4 mm in diameter. Dolomite occurs as small crystals, sometimes oriented and associated with small amounts of quartz and phyllosilicates.

*Lithotype V: Marbles with low contents of dolomite and more abundant quartz and phyllosilicates (samples ITD 8, 14, 17, 21, 31, 33, 34, 35, 36, 49)*

Homeoblastic (samples ITD 14, 31, 33, 36) and heteroblastic (samples ITD 17, 21, 49) textures were observed. In samples showing heteroblastic textures, calcite grain sizes range from 0.07-0.1 mm to 3-4 mm. Small crystals of slightly banded dolomite also occur (Fig. 9). Quartz and phyllosilicates are abundant. The largest quartz crystals are idiomorphic and may contain inclusions of apatite. Chlorite is the most abundant phyllosilicate phase and is associated with muscovite and hematite crystals. Other accessory minerals are epidote, sphene,

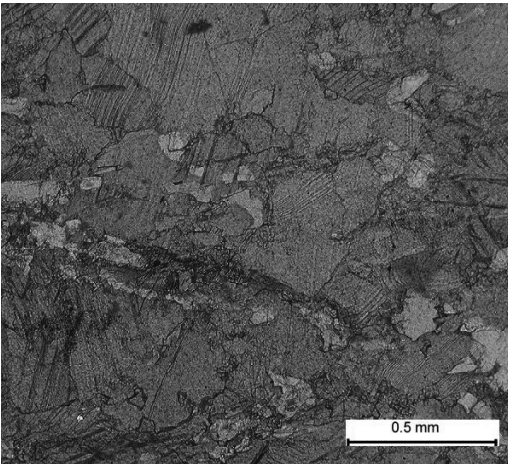


Fig. 9 - Microphotograph of thin section of marble with dolomite - Lithotype V (NX).

clinozoisite, zircon, hematite, magnetite and K-feldspar.

*Lithotype VI: Marbles with abundant dolomite and scarce quartz and phyllosilicate contents (samples ITD 16, 18, 29, 37, 38, 40, 43)*

According to the spatial distribution of the dolomite crystals, these samples are distinguished into two subgroups. The first is characterised by clearly banded dolomite and the second by

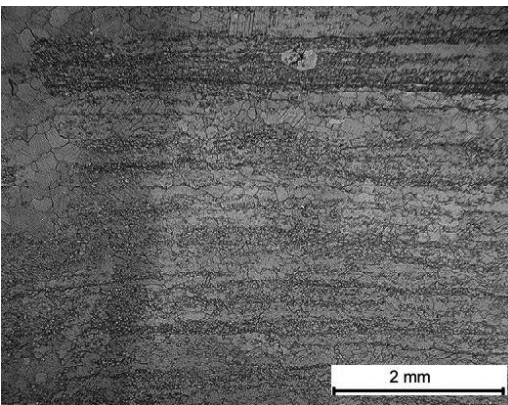


Fig. 10 - Microphotograph of thin section of marble with dolomite - Lithotype VIA (N//).

dispersed dolomite.

**Lithotype VI A - Clearly banded dolomite (samples ITD 16, 29, 37, 43):** this group comprises samples with calcite crystals ranging from equally sized (sample ITD 16) to elongated, and allotriomorphic dolomite crystals, ranging from 0.2 to 0.3 mm in diameter (Figs. 10 and 11). The calcite crystals from 0.2 to 0.8 in size show undulating extinction and deformed twins. Quartz is present as subrounded and intersertal grains. Slightly oriented chlorite is associated with hematite and magnetite. Acicular crystals of muscovite are scarce, and K-feldspar, albite, plagioclase and tremolitic amphibole were identified only in sample ITD 16.

**Lithotype VI B - Dispersed dolomite (samples ITD 18, 38, 40):** dolomite crystals, ranging from 0.2 to 0.5 mm in size, are subidiomorphic and show no clear orientation. Quartz and phyllosilicate contents are scarce; K-feldspar and albite are rare.

*Lithotype VII: Marbles with abundant dolomite, quartz and phyllosilicates (samples ITD 19, 20, 45)*

A heterometric mosaic texture of sutured calcite crystals, ranging from 0.3 to 1.2 mm in diameter, is the typical feature of these marbles.

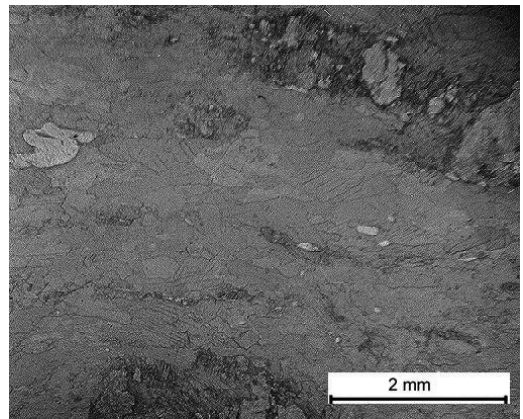


Fig. 11 - Microphotograph of thin section of marble with dolomite - Lithotype VIA (N//).

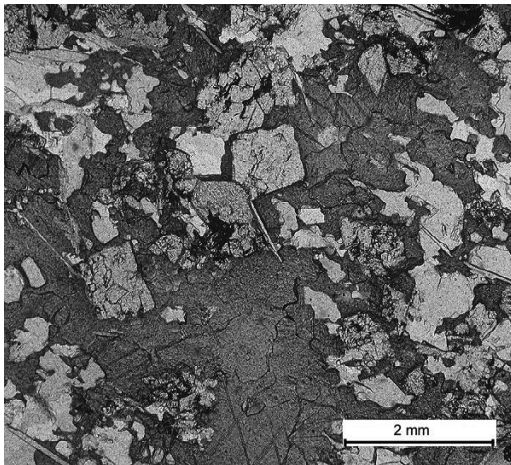


Fig. 12 - Microphotograph of thin section of marble with dolomite - Lithotype VII (N//).

Dolomite shows euhedral crystals ranging from 0.2 to 0.5 mm. Interstitial quartz or subrounded crystals and aggregates of quartz, with undulating extinction, are present. Some idiomorphic quartz crystals with epidote and apatite inclusions were identified. Samples ITD 19 and 20 contain tremolitic amphibole. Secondary minerals are chlorite, muscovite, phlogopite (samples ITD 19, 20), phengite, identified only diffractometrically, and rare biotite (Fig. 12). Main accessory minerals are sphene, zircon and hematite. Sample ITD 45 is characterised by allotriomorphic quartz crystals, showing undulating extinction together with large calcite crystals.

TABLE 1  
Major (wt%) and trace (ppm) element contents of samples with dolomite (ITD).

With dolomite	ITD8	ITD10	ITD11	ITD14	ITD16	ITD17	ITD18	ITD19	IT2D0	ITD21	ITD25	ITD27	ITD29	ITD31
SiO <sub>2</sub>	12.79	4.01	3.19	7.06	3.51	10.91	2.05	18.24	35.74	9.63	3.39	1.39	15.08	6.49
TiO <sub>2</sub>	0.06	0.06	0.06	0.07	0.05	0.05	0.01	0.14	0.26	0.24	0.02	0.02	0.09	0.01
Al <sub>2</sub> O <sub>3</sub>	1.66	1.57	1.57	2.07	1.31	1.21	0.74	4.34	9.70	5.87	0.61	0.57	2.48	0.38
Fe <sub>2</sub> O <sub>3</sub> *	1.00	0.67	0.61	0.69	0.57	0.58	0.27	1.68	3.39	3.46	0.31	0.45	1.17	0.21
MgO	1.03	1.00	1.00	1.10	3.60	0.86	0.75	1.44	2.39	2.62	0.84	0.74	1.33	0.68
MnO	0.14	0.16	0.17	0.17	0.11	0.13	0.14	0.15	0.20	0.14	0.19	0.17	0.14	0.13
CaO	47.94	51.15	51.60	49.25	48.96	47.23	53.03	39.20	24.60	41.51	52.27	54.32	43.13	50.97
Na <sub>2</sub> O	0.04	0.02	0.01	0.18	0.00	0.00	0.00	0.37	0.83	0.14	0.03	0.00	0.18	0.00
K <sub>2</sub> O	0.33	0.27	0.26	0.35	0.14	0.19	0.12	0.72	1.69	0.93	0.06	0.08	0.41	0.04
P <sub>2</sub> O <sub>5</sub>	0.05	0.05	0.06	0.05	0.05	0.05	0.03	0.04	0.11	0.08	0.05	0.05	0.09	0.05
LOI	<b>34.96</b>	<b>41.13</b>	<b>41.46</b>	<b>39.01</b>	<b>41.69</b>	<b>38.89</b>	<b>42.86</b>	<b>33.71</b>	<b>21.11</b>	<b>35.40</b>	<b>42.27</b>	<b>42.27</b>	<b>35.99</b>	<b>41.15</b>
Tot	<b>100.00</b>	<b>100.10</b>	<b>99.99</b>	<b>99.99</b>	<b>99.99</b>	<b>100.08</b>	<b>100.01</b>	<b>100.02</b>	<b>100.03</b>	<b>100.03</b>	<b>100.04</b>	<b>100.06</b>	<b>100.08</b>	<b>100.10</b>
Rb	9	6	9	11	3	8	0	26	61	34	4	5	15	1
Sr	447	618	688	628	993	491	900	1719	1374	638	720	664	588	799
Y	10	7	7	7	0	0	5	11	12	8	4	5	8	5
Nb	nd	0	0	0	2	0	0	0	3	0	0	0	0	0
Zr	nd	0	0	0	0	0	0	10	53	20	0	0	0	0
Cr	99	45	16	24	12	43	140	26	60	101	108	79	106	168
Ni	55	27	27	29	12	25	17	39	66	117	18	16	52	16
Ba	127	144	144	167	97	128	92	166	271	224	132	75	145	109
La	7	12	8	3	0	5	0	8	19	16	10	0	28	0
Ce	17	0	0	14	3	11	7	33	47	14	0	13	21	0
V	17	14	13	39	11	13	16	34	87	51	7	7	26	5
IR	17	8	7	12	9	14	4	27	54	23	5	3	21	8

IR = insoluble residue (wt%); Fe<sub>2</sub>O<sub>3</sub>\*=Fe tot; LOI = loss of ignition; - = below detection limit.



GEOCHEMISTRY

Major and trace elements measured on both samples with calcite+dolomite (ITD, 28 samples) and samples with calcite (ITC, 23 samples) are listed in TABLES 1 and 2. The results of chemical analyses fully matched the parageneses observed by optical microscopy on thin sections and determined by X-ray powder diffraction.

The chemical data show that the examined rocks, except for sample ITD 20, are essentially made up of calcite. Assuming that all CaO and MgO contents are related to the calcite and dolomite phases, these two minerals account for approximately 84% and 6% by weight on

average, and their contents range, respectively, from 44-97% and from 0-16% by weight.

As regards trace elements, ITD versus ITC samples show significantly higher average contents of Zr (28 vs. 13 ppm) and Cr (87 vs. 65 ppm), and lower average contents of Ni (37 vs. 57 ppm), Ba (137 vs. 193 ppm) and V (19 vs. 34 ppm).

The average values of insoluble residues (IR) are respectively 17 wt% and 13wt% for ITC and ITD samples.

The strontium, oxygen and carbon isotopic compositions of samples with calcite+dolomite or calcite are listed in TABLES 3 and 4, respectively. The data show that the <sup>87</sup>Sr/<sup>86</sup>Sr isotopic ratios vary within a small range (ITC

TABLE 1  
... continued

With dolomite	ITD33	ITD34	ITD35	ITD36	ITD37	ITD38	ITD40	ITD41	ITD43	ITD45	ITD46	ITD48	ITD49	ITD50
SiO <sub>2</sub>	6.39	6.61	7.93	7.10	1.95	2.25	2.25	4.65	2.80	14.84	22.91	5.23	5.59	7.22
TiO <sub>2</sub>	0.08	0.04	0.03	0.06	0.01	0.01	0.01	0.05	0.04	0.01	0.06	0.05	0.04	0.09
Al <sub>2</sub> O <sub>3</sub>	2.00	1.14	1.23	1.98	0.42	0.38	0.45	1.49	1.26	1.73	2.06	1.46	1.42	2.87
Fe <sub>2</sub> O <sub>3</sub> *	1.12	0.59	0.51	0.93	0.21	0.15	0.14	0.67	0.55	0.59	1.15	0.63	0.74	1.12
MgO	1.05	0.82	0.66	1.06	0.86	0.57	0.49	1.04	0.93	0.55	1.24	1.16	2.76	1.38
MnO	0.13	0.14	0.14	0.13	0.16	0.14	0.12	0.15	0.17	0.21	0.13	0.14	0.14	0.18
CaO	49.59	49.92	49.26	49.47	53.58	53.93	54.27	50.70	52.30	45.33	42.89	48.61	48.52	47.96
Na <sub>2</sub> O	0.10	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.01	0.81	0.00	0.00	0.04	0.17
K <sub>2</sub> O	0.37	0.20	0.19	0.35	0.07	0.05	0.06	0.25	0.22	0.09	0.38	0.25	0.23	0.49
P <sub>2</sub> O <sub>5</sub>	0.04	0.04	0.05	0.06	0.03	0.03	0.04	0.05	0.04	0.03	0.07	0.05	0.04	0.06
LOI	<b>39.21</b>	<b>40.50</b>	<b>40.08</b>	<b>38.86</b>	<b>42.85</b>	<b>42.49</b>	<b>42.21</b>	<b>41.00</b>	<b>41.67</b>	<b>35.89</b>	<b>29.21</b>	<b>42.42</b>	<b>40.57</b>	<b>38.44</b>
Tot	<b>100.07</b>	<b>99.98</b>	<b>100.10</b>	<b>100.01</b>	<b>100.15</b>	<b>99.99</b>	<b>100.05</b>	<b>100.07</b>	<b>99.99</b>	<b>100.08</b>	<b>100.09</b>	<b>99.99</b>	<b>100.09</b>	<b>99.99</b>
Rb	13	6	7	13	3	0	1	7	5	3	9	11	9	20
Sr	757	770	778	843	699	733	799	601	712	636	487	669	715	832
Y	7	7	7	7	3	4	3	6	6	7	23	6	6	11
Nb	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zr	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	26	36	44	67	444	138	137	53	51	37	68	107	151	36
Ni	39	23	21	35	17	13	17	27	29	14	53	39	113	81
Ba	169	141	132	136	88	108	95	124	122	119	194	114	102	179
La	18	4	5	9	5	17	4	9	7	14	20	4	0	8
Ce	10	0	0	20	0	0	0	2	0	0	18	5	3	11
V	13	8	17	18	7	4	4	17	14	7	15	16	14	39
IR	11	10	11	12	4	4	4	8	6	19	28	9	11	14

IR = insoluble residue (wt%); Fe<sub>2</sub>O<sub>3</sub>\*=Fe tot; LOI = loss of ignition; - = below detection limit.

TABLE 2  
Major (wt%) and trace (ppm) element contents of samples without dolomite (ITD).

Without dolomite	ITC1	ITC2	ITC3	ITC4	ITC5	ITC6	ITC7	ITC9	ITC12	ITC13	ITC15	ITC22
<b>SiO<sub>2</sub></b>	11.90	11.92	25.39	8.27	3.17	16.78	6.50	12.17	8.79	7.66	3.68	4.32
<b>TiO<sub>2</sub></b>	0.18	0.15	0.06	0.13	0.05	0.13	0.05	0.11	0.07	0.10	0.04	0.07
<b>Al<sub>2</sub>O<sub>3</sub></b>	4.50	4.83	1.10	3.60	1.32	3.58	1.11	2.29	2.24	3.13	1.34	1.87
<b>Fe<sub>2</sub>O<sub>3</sub>*</b>	2.35	2.16	0.68	1.54	0.70	3.04	0.58	1.48	0.90	1.47	0.63	1.02
<b>MgO</b>	1.51	1.75	0.77	1.11	0.82	2.11	0.61	1.12	1.04	1.51	1.07	1.25
<b>MnO</b>	0.13	0.12	0.12	0.12	0.16	0.14	0.13	0.15	0.16	0.15	0.15	0.15
<b>CaO</b>	43.57	42.63	42.88	45.87	51.72	41.12	50.62	45.89	47.17	43.66	51.50	50.27
<b>Na<sub>2</sub>O</b>	0.09	0.07	0.00	0.06	0.02	0.03	0.02	0.10	0.11	0.10	0.00	0.00
<b>K<sub>2</sub>O</b>	0.96	0.90	0.18	0.68	0.23	0.63	0.21	0.38	0.38	0.51	0.22	0.31
<b>P<sub>2</sub>O<sub>5</sub></b>	0.06	0.06	0.06	0.06	0.05	0.07	0.04	0.06	0.04	0.05	0.05	0.05
<b>LOI</b>	<b>34.76</b>	<b>35.41</b>	<b>28.76</b>	<b>38.54</b>	<b>41.77</b>	<b>32.36</b>	<b>40.12</b>	<b>36.24</b>	<b>39.14</b>	<b>41.69</b>	<b>41.42</b>	<b>40.72</b>
<b>Tot</b>	<b>100.01</b>	<b>100.00</b>	<b>100.00</b>	<b>99.98</b>	<b>100.01</b>	<b>99.99</b>	<b>99.99</b>	<b>99.99</b>	<b>100.04</b>	<b>100.02</b>	<b>100.10</b>	<b>100.04</b>
<b>Rb</b>	31	29	8	20	4	19	4	14	9	17	6	4
<b>Sr</b>	588	634	1515	1351	644	510	710	1089	723	1488	752	664
<b>Y</b>	8	6	6	5	7	13	8	4	7	8	7	7
<b>Nb</b>	-	-	-	-	-	-	-	-	-	-	-	-
<b>Zr</b>	5	4	-	-	-	-	-	-	-	-	-	-
<b>Cr</b>	90	50	32	34	69	412	27	32	24	40	41	52
<b>Ni</b>	65	72	26	36	29	206	27	44	32	60	29	45
<b>Ba</b>	219	235	119	248	125	197	164	243	162	178	136	141
<b>La</b>	12	-	14	13	13	13	12	13	7	-	9	5
<b>Ce</b>	12	3	5	-	7	29	-	-	11	15	-	4
<b>V</b>	47	41	12	45	39	36	9	30	29	35	16	21
<b>IR</b>	22	22	28	16	7	27	9	18	14	15	7	9

IR = insoluble residue (wt%); Fe<sub>2</sub>O<sub>3</sub>\*=Fe tot; LOI = loss of ignition; - = below detection limit.

0.70772-0.70802; ITD 0.70767-0.70793);  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values are particularly low in samples characterized by the presence of tremolite (ITC 3, 4, 13; ITD 16, 19, 20).

#### COMPARISONS AMONG ARTEFACTS AND QUARRY MARBLES

Both minero-petrographic, chemical and isotopic data and insoluble residue contents obtained on samples from the amphitheatre at Italica were compared with literature data regarding "Cipollino verde" marble from ancient quarries in Greece (calcitic), Italy (calcitic, calcitic/dolomitic and dolomitic), Spain (calcitic and dolomitic) and Portugal (calcitic and calcitic/dolomitic) (Tucci, 1982; Azzaro *et al.*,

1987; Lapuente *et al.* 1988, 2000; Lapuente, 1995; Lapuente and Turi, 1995; Lazzarini *et al.*, 1995; Barbieri *et al.*, 1996; Negri Arnoldi *et al.*, 1999; Morbidelli *et al.*, 2007).

Petrographically, all samples - except ITC 3, 4 and 13 and ITD 16, 19 and 20, which revealed the presence of albitic plagioclase associated with calcitic epidote, muscovite and tremolitic amphibole, and which were thus ascribed to the amphibolitic metamorphic facies - correspond to the greenschist metamorphic facies (Lopez Sanchez-Vizcaino *et al.*, 1997; Masi *et al.*, 1999).

The average IR content in ITC samples, 17 wt%, was consistently higher than those of "Cipollino verde" marbles from Euboea (mean

TABLE 2  
...continued

Without dolomite	ITC23	ITC24	ITC26	ITC28	ITC30	ITC32	ITC39	ITC42	ITC44	ITC47	ITC51
SiO <sub>2</sub>	8.45	13.89	20.93	11.29	5.03	5.85	5.43	7.32	19.20	7.48	8.14
TiO <sub>2</sub>	0.10	0.12	0.21	0.12	0.05	0.08	0.07	0.09	0.18	0.05	0.08
Al <sub>2</sub> O <sub>3</sub>	2.87	3.49	6.73	4.49	1.66	2.17	1.71	2.41	7.63	1.68	2.89
Fe <sub>2</sub> O <sub>3</sub> *	1.27	1.95	3.32	1.62	0.80	0.94	0.83	1.09	3.77	0.92	1.22
MgO	1.15	1.54	2.21	1.77	0.96	1.11	1.00	1.39	2.53	1.05	1.23
MnO	0.16	0.12	0.15	0.13	0.14	0.14	0.13	0.18	0.17	0.14	0.12
CaO	46.81	43.07	34.54	43.00	50.62	49.16	50.20	47.53	35.54	49.13	47.40
Na <sub>2</sub> O	0.30	0.19	0.28	0.21	0.00	0.11	0.01	0.15	0.07	0.07	0.05
K <sub>2</sub> O	0.43	0.59	1.29	0.88	0.30	0.38	0.29	0.41	1.55	0.32	0.52
P <sub>2</sub> O <sub>5</sub>	0.09	0.06	0.08	0.06	0.05	0.06	0.04	0.07	0.07	0.04	0.06
LOI	<b>38.35</b>	<b>35.01</b>	<b>30.33</b>	<b>36.49</b>	<b>40.38</b>	<b>40.00</b>	<b>40.39</b>	<b>39.43</b>	<b>29.28</b>	<b>39.18</b>	<b>38.32</b>
Tot	<b>99.98</b>	<b>100.04</b>	<b>100.06</b>	<b>100.05</b>	<b>99.99</b>	<b>99.99</b>	<b>100.11</b>	<b>100.07</b>	<b>99.99</b>	<b>100.04</b>	<b>100.02</b>
Rb	12	23	48	31	9	17	12	16	63	13	14
Sr	716	612	472	600	770	747	1151	738	548	839	687
Y	10	10	10	10	7	7	5	10	9	7	8
Nb	-	-	-	-	-	-	-	-	-	-	-
Zr	-	2	22	-	-	-	-	-	30	-	-
Cr	96	51	62	44	30	61	38	38	93	39	38
Ni	42	68	108	57	30	41	34	59	105	42	61
Ba	185	152	275	248	135	157	158	146	416	125	282
La	24	8	8	24	-	7	3	22	7	22	13
Ce	7	8	15	6	4	-	-	21	14	4	13
V	33	30	56	66	13	21	16	28	121	12	31
IR	15	22	35	21	9	11	10	13	35	12	14

IR = insoluble residue (wt%); Fe<sub>2</sub>O<sub>3</sub>\*=Fe tot; LOI = loss of ignition; - = below detection limit.

TABLE 3

*Average values - Al<sub>2</sub>O<sub>3</sub>, MgO, CaO - of findings and "Cipollini verdi" calcitic (ITC) and dolomitic (ITD) marbles from Italy (Arni, Isola Santa and Corchia), Spain (Macael, Los Covachos and Las Cabreras), Portugal (Vila Vicosa and Viana do Alentejo) and Greece (Euboea).*

		Italy		Spain		Portugal	Greece
wt%	ITC	Arni	Isola Santa	Macael	Los Covachos	Vila Vicosa	Euboea
Al <sub>2</sub> O <sub>3</sub>	2.98	0.48	3.85	2.40	0.82	1.71	1.65
MgO	1.33	1.24	0.72	1.43	0.53	0.63	0.71
CaO	45.98	50.41	47.77	49	52.76	47.59	51.09
wt%	ITD	Arni	Corchia	Macael	Las Cabreras	Viana do Alentejo	
Al <sub>2</sub> O <sub>3</sub>	1.93	0.91	1.56	1.50	6.47	2.43	
MgO	1.21	1.04	1.48	1.73	1.83	1.60	
CaO	48.27	53.40	50.84	50.02	35.18	44.72	

TABLE 4  
Oxygen, carbon and strontium isotopic.

Samples with dolomite ITD	$^{87}\text{Sr}/^{86}\text{Sr}$	$\delta^{18}\text{O}$	$\delta^{13}\text{C}$
8	0.70770	-4.00	2.53
10	0.70772	-3.03	2.41
11	0.70772	-2.92	2.45
14	0.70784	-3.64	2.38
16	0.70786	-7.18	1.41
17	0.70771	-3.06	2.36
18	0.70781	-2.58	2.34
19	0.70779	-6.68	1.48
20	0.70776	-7.00	2.00
21	0.70776	-3.03	2.35
25	0.70767	-2.93	2.41
27	0.70779	-2.64	2.29
29	0.70770	-3.10	2.34
31	0.70776	-2.22	2.53
33	0.70783	-2.60	2.40
34	0.70780	-2.29	2.55
35	0.70793	-2.81	2.41
36	0.70784	-3.95	2.34
37	0.70780	-3.12	2.38
38	0.70778	-3.41	2.20
40	0.70776	-3.24	2.40
41	0.70771	-3.46	2.30
43	0.70774	-2.92	02.41
45	0.70770	-2.40	2.30
46	0.70779	-3.12	2.32
48	0.70773	-3.26	2.32
49	0.70775	-2.95	2.42
50	0.70785	-2.90	2.31

value 8.64 wt%), the Italian Apuan district of Isola Santa (13.25 wt%), the Spanish Los Covachos (6.19 wt%) and the Portuguese Vila Vicoso (14.62 wt%). The average IR content in ITD samples, 13 wt%, was higher than those of Apuan marbles from Mount Corchia (mean value 7.79 wt%) and the Spanish Macael

TABLE 5  
Oxygen, carbon and strontium isotopic composition of sample with dolomite.

Samples without dolomite ITC	$^{87}\text{Sr}/^{86}\text{Sr}$	$\delta^{18}\text{O}$	$\delta^{13}\text{C}$
1	0.70784	-3.34	2.23
2	0.70782	-2.97	2.22
3	0.70785	-8.25	1.90
4	0.70779	-7.75	1.80
5	0.70773	-3.23	2.29
6	0.70785	-4.14	2.17
7	0.70776	-4.32	2.19
9	0.70775	-3.25	2.33
12	0.70802	-3.64	2.50
13	0.70779	-7.70	1.83
15	0.70795	-2.71	2.46
22	0.70796	-3.20	2.50
23	0.70780	-3.47	2.41
24	0.70788	-3.21	2.35
26	0.70773	-4.33	2.04
28	0.70778	-3.25	2.21
30	0.70785	-2.78	2.45
32	0.70785	-2.64	2.43
39	0.70779	-2.86	2.41
42	0.70785	-2.68	2.47
44	0.70788	-4.14	2.30
47	0.70772	-2.33	2.52
51	0.70776	-4.13	2.07

(Almeria, 11.09 wt%) and lower than those from the Spanish Las Cabrerias (37.53 wt%) and the Portuguese Viana do Alentejo (20.61 wt%). Average  $\text{Al}_2\text{O}_3$ , MgO and CaO in ITC samples (TABLE 5) were comparable with those of "Cipollino verde" marbles from Euboea (Styra and Pyrgari districts) and Macael (Spain). The same in ITD samples were comparable with those of Italian Apuan marbles from Mount Corchia and Spanish ones from Macael.

In ITC samples, trace elements (Rb, Sr, Ba, La) are comparable with those of lithotypes from Euboea and Macael. In ITD samples, Rb, Zr, Ba and Ce were comparable with "Cipollino verde"

marbles from Macael and Rb, La, Ce and V with those from Mount Corchia.

Isotopically, ITC samples have  $^{87}\text{Sr}/^{86}\text{Sr}$  values (0.70772-0.70802) comparable with those of Spanish marbles from Macael (0.70774-0.70832) and Euboean ones from Styra (0.70772-0.70792), and have  $\delta^{13}\text{C}$  values (1.80-2.52), comparable with Euboean ones from Pyrgari (1.80-2.58). The  $\delta^{18}\text{O}$  values (from -8,25 to -2,33) are not comparable with similar values in marbles so far studied. ITD marbles have  $^{87}\text{Sr}/^{86}\text{Sr}$  values (0.70767-0.70793) comparable with those of Apuan marbles from Mount Corchia (0.70764-0.70804) and the Spanish ones from Macael (0.70774-0.70832). The values of  $\delta^{13}\text{C}$  (1.41-2.55) and  $\delta^{18}\text{O}$  (from -7.18 to -2.22) of ITD samples are not comparable with those of marbles.

The charts  $\delta^{18}\text{O}$  vs.  $\delta^{13}\text{C}$ ,  $^{87}\text{Sr}/^{86}\text{Sr}$  vs.  $\delta^{13}\text{C}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  vs.  $\delta^{18}\text{O}$  (Figs. 13-14) define the areas of membership of the marble quarries of Greece, Italy, Spain and Portugal (Morbidelli *et al.*, 2007). Plotting the values of O, C and Sr isotopes measured on the two groups of samples, ITD 16, 19 and 20 clearly plot steadily in the Macael field and other samples in that of Corchia, and Arni has to be excluded, due to the higher value of the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio (0.70794-0.70852) with respect to that of ITC and ITD samples (0.70767-0.70793).

ITC 3, 4 and 13 plot under Macael and under the common field Macael and Greece (Fig. 14). The presence in the paragenesis of tremolitic amphibole in these three samples, never found in Greek marbles from Euboea, may be related to Spain. ITC 6, 7, 15 and 22 are attributable to Greece, since Isola Santa must be excluded ( $^{87}\text{Sr}/^{86}\text{Sr}$  0.70789-0.70794) for the isotope values of O, C and Sr ( $^{87}\text{Sr}/^{86}\text{Sr}$  0.70776-0.70796;  $\delta^{13}\text{C}$  2.17-2.50;  $\delta^{18}\text{O}$  from -2.71 to -4.32). The remaining samples plot in the fields of Greek marbles.

## CONCLUSIONS

In this work, 51 samples of the marbles historically known as “Marmor Carystium” were studied, coming from the archeological site of the amphitheatre built in the Trajan period (II century AD) of Italica (Santiponce, Seville, Spain). The aim was to verify Canto’s hypothesis regarding the use of the site, based on historical and archeological data, not only of marble from the Imperial quarries in Greece (southern Euboea - “Marmor Carystium”) and Italy (Apuan Alps - “Cipollino verde”) but also of the lithotypes, macroscopically identical and less expensive, quarried from ancient sites in Spain (Almeria, Anasol) and Portugal (Evora “Anasol-type”). Comparisons of minero-petrographic, chemical and isotopic (O, C, Sr) results from artefacts with those found in the literature on quarried marbles revealed the ancient supply sources of these materials. That the marbles of the calcitic/dolomitic finds come from Euboea may be excluded *a priori*, since the lithotypes quarried in this district of Greece are always calcitic marbles. Several discriminating parameters were found: STRUCTURE (saccharoid and lepidoblastic, saccharoid and heteroblastic, heteroblastic and lepidoblastic, saccharoid); TEXTURE (isotropic and banded, schistose, isotropic and schistose, isotropic and slightly undulating); PARAGENESIS (calcite, calcite and dolomite, dolomite, tremolitic amphibole, graphite, titanite); METAMORPHIC FACIES (greenschist, greenschist/amphibolitic, amphibolitic); CONTENTS (IR,  $\text{Al}_2\text{O}_3$ , MgO, CaO, Cr, Sr, Nb, Zr); and RATIOS ( $\delta^{18}\text{O}$  vs.  $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}$ ,  $\delta^{13}\text{O}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}$ ).

According to the analytical results, 25 samples come from Italy (Apuan district of Corchia), 6 from Spain (Macael) and 20 from Greece (Styra and Pyrgari). The results also confirm the albeit limited use at Italica of local marbles (of “Anasol” and “Anasol-type”) as well as stone from the ancient Imperial quarries in Greece and

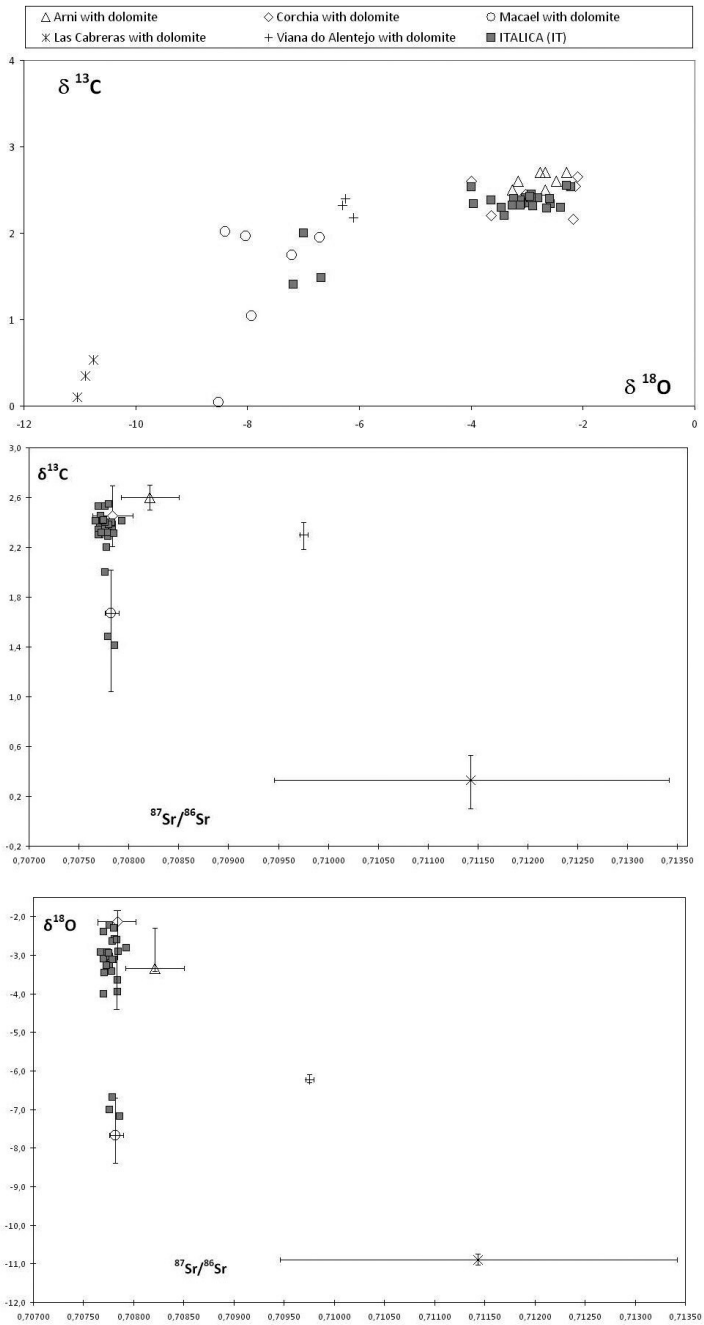


Fig. 13 -  $\delta^{18}\text{O}$  vs.  $\delta^{13}\text{C}$ ,  $^{87}\text{Sr}/^{86}\text{Sr}$  vs.  $\delta^{13}\text{C}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  vs.  $\delta^{18}\text{O}$  binary diagrams showing isotopic data of samples characterized by the presence of dolomite and those available in literature.

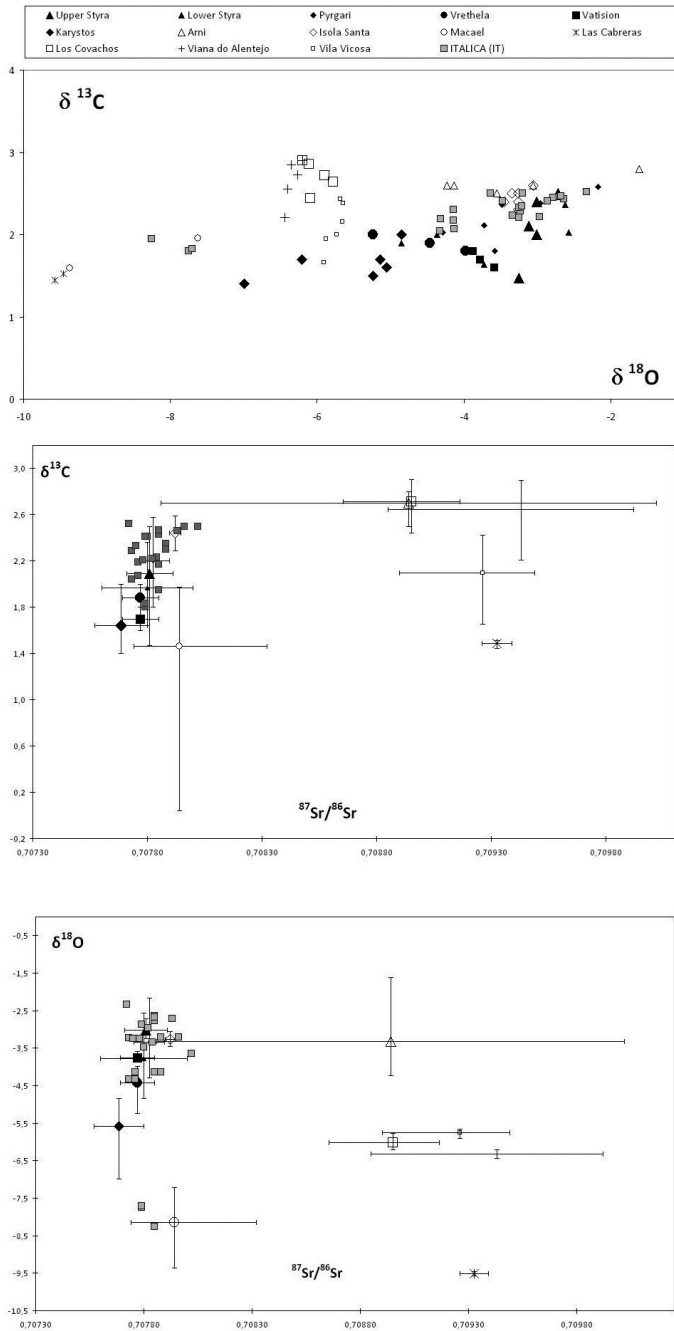


Fig. 14 -  $\delta^{18}\text{O}$  vs.  $\delta^{13}\text{C}$ ,  $^{87}\text{Sr}/^{86}\text{Sr}$  vs.  $\delta^{13}\text{C}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  vs.  $\delta^{18}\text{O}$  binary diagrams showing isotopic data of samples characterized by the absence of dolomite and those available in literature.

Italy. It should be recalled that, during Imperial times, not only “Cipollino verde” but also other valuable types of marble (*Bardiglio*, *Breccia dorata*, *Breccia di Serravezza*, *Luni*, etc.) were quarried from the Apuan Alps - as indeed they are today - and were found in the archeological site of Italica, both in the form of blocks and slabs, and in many artefacts.

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