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The Carbon and Oxygen Isotope Composition of the Marble Inscriptions of Aléria, Corsica

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Abstract: Aléria was the main city of the island of Corsica in ancient times. Archaeological excavations in the area where ancient Aléria once stood began between the 1950s and 1960s and brought to light numerous inscriptions mainly carved on slabs of white marble; they constitute an important source of knowledge of the city's institutions, urban topography, society, and economy. The provenance of the marbles, on which the inscriptions were carved, can add important information about the history of the city. A first visual examination of the slabs or slab fragments allows us to state that Carrara is probably the provenance of most of the marbles used. Practical reasons lead us to believe that the provenance of these marbles can be traced back to two main quarry areas: Carrara, or somewhere in Corsica. The determination of the stable isotope composition of these marbles could solve this problem. Carrara marble, in fact, has a narrow range of isotopic variability, with values typical of marine carbonates, that allows for a strong characterization. The petrographic method of investigation was used, as a second step, on a reduced number of marble inscriptions to evaluate the effectiveness of the isotopic characterization of Carrara. The results of the analysis confirmed that most of the gray and white marbles studied have Carrara as their quarrying area; they also revealed that in Corsica the presence of ancient local marble quarries is uncertain, even in Roman times.

Keywords: marbles; stable isotopes; inscriptions

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1. Introduction

The application of isotope geochemistry of carbon and oxygen to the study of marble provenance started with the seminal paper by V. Craig and H. Craig, "Greek Marbles: Determination of Provenance by Isotopic Analysis" [1]. This study aimed to demonstrate the effectiveness of the isotopic ratios of oxygen and carbon in identifying the geographical origin of the white marble quarries exploited in classical antiquity, a question the answer to which has been sought since the XIX century. It has been recognized ever since that a scientific approach was needed for this purpose, because identifying the provenance of a white marble by its visual, macroscopic features is often impossible. The method proposed by Craig and Craig was innovative and powerful compared to the techniques already in use, which were essentially chemical and petrographic. The authors showed that the isotopic compositions of carbon and oxygen measured in marble samples collected from four different quarry areas of Greece were significantly different. Consequently, it was reasonable to think that the different provenance of the marbles of ancient monuments could be traced simply by comparing their isotopic ratios with those available for the quarries. It was only necessary to collect enough isotopic data from each of the quarries exploited in antiquity and compare them with measurements carried out on unknown marbles of any ancient artifact. The method was promising, simple to implement and to apply; the isotopic reference database of the marbles used in antiquity could be easily visualized in a bi-dimensional diagram, therefore the attribution of an unknown marble could be displayed graphically. Unfortunately, it was incorrect in its initial conception. There were many more quarry sites of archaeological interest to be tested throughout the Mediterranean area than Craig and Craig considered, and many more data had to be collected before we had a complete picture of the isotopic features of an ancient quarry. New data collections showed that the use of the isotopic method alone was ineffective. Owing to the ever-growing number of sampled sites, as well as to the growing number of samples available per quarry, the fields of each quarry in the isotope space now display important overlaps because the dispersion of the data has widened considerably [2]. Currently, the discrimination between the white marbles exploited in antiquity in the Mediterranean basin by the isotopic method alone has become impossible to achieve. The marble isotopic reference diagram has been expanded and updated several times over the past fifty years [2–6]. Looking at the most recent isotopic update by [2], the limits of the isotopic method are quite evident, and the result of multiple provenances is the common outcome when trying blindfold isotopic assignment. A relief to this problem has come from the combined use of isotopic data and information from the traditional petrographic method on the unknown sample; this has been an almost standard approach for many years. Currently, the most common method of marble provenancing is the use of different cross-correlated approaches; the provenance assignment of an unknown marble of any artifact (statues, portraits, or architectural elements) is carried out using, either sequentially or simultaneously, the data from some of the following analytical techniques: cathodoluminescence microscopy [7–10], trace element analysis [11–17], EPR [18–20], just to mention the most frequently adopted, together with the classic techniques of petrography and isotopes. There are databases of ancient quarries related to each analytical method (some published, others private), created during the last few decades as a reference when studying a marble artifact.

It must be admitted that, even using different techniques, in many cases the assignment can be a difficult (or impossible) task, especially when dealing with marble artifacts that have no historical or archaeological background. In fact, various studies have shown that, on the basis of the specific problem under investigation and of the historical information available, the ability to reduce the number of possible provenances to the smallest possible number of outcomes allows for a more reliable identification of a marble's origin, i.e., by reasonably defining a subset of possible provenances and attempting to discriminate within this smaller set of possible alternatives [6]. This approach is also evidently useful when few and/or not very selective methods are used [21]. In practice it is almost obvious to say that the more defined the contours of a given archaeological context whose marble materials are to be studied, the easier it will be to answer questions regarding their provenance.

Some marble artifacts found in the archaeological site of Aléria, in Corsica (France), could lend themselves to being a case study to verify the above considerations. Aléria was the main city of the island of Corsica in ancient times. Archaeological excavations in this locality have taken place since 1955. They have revealed many inscriptions, mainly carved on white marble slabs, dating back to Roman times; this epigraphic heritage constitutes, in the almost total absence of literary evidence, an important source of knowledge of the institutions of the city, of the urban topography, and of the society and economy. It is a little-known heritage, which it is essential to review and study [19]. From this perspective, the knowledge of the origin of the marble used can bring further historical information, defining the relationship of the city of Aléria (and of the island) with the outside world and identifying whether there were marble exploitation activities on the island in Roman times.

The peculiar context of Aléria, its location and its strong connections with the nearby territories bordering the Tyrrhenian Sea, attested by its archaeological heritage, allows us to argue that its development and trade were mainly, if not exclusively, linked to those areas, even when it was under the influence of the Romans. Therefore, it is reasonable to contend that the supply of marble for Aléria artifacts came, when not from local quarrying activity, by importation from the Carrara site.

In this article we want to show the possibility of recognizing Carrara marble with the isotopic method alone, assuming that Carrara or hypothetical Corsican quarries are the possible provenances for the Aléria marble inscriptions. In view of this reduction in possible alternatives, this approach may be viable because Carrara is a classical marble that has one of the best defined and narrowest range of carbon and oxygen isotope compositions. The need to devise an approach such as this derives from the fact that all the analytical techniques used for the discrimination of ancient marbles are destructive but the isotopic one is so to a lesser extent; only a few hundred micrograms are needed for the analysis. When larger samples could be taken to enable thin sections to be made, petrography was eventually used to confirm or reject what the isotopes indicated.

Although Corsica is an island rich in ornamental stones of all kinds (including marble), and quarrying activity is as intense today as it was in the past, there is no direct evidence that the marble quarries of Corsica were exploited in antiquity. By discriminating between the two marble provenances, crucial information can be deduced about Corsican quarrying activity in Roman times.

1.1. Aléria Archaelogical Excavations and Importance of Epigraphy

Aléria is located on an isolated plateau in the middle of a vast coastal plain. Its history extends between the VI century BC and the VI century AD. During this time interval this area saw the first settlement of the Phocians, followed by the Etruscans; in the III century BC Corsica became a Roman colony. The Etruscan city is practically known only for its tombs, whereas the Roman city is known for the forum, for which the first modern excavations on the site began, and which today has only been partially cleared.

The first important excavations date back to 1955–1960 and continued at different times. They marked the discovery of the forum and the annexed districts which constitute the administrative, commercial, and religious heart of the city. During these excavations, several inscriptions mainly carved on slabs of white marble were discovered [19]. The importance of the epigraphic findings is for several reasons: they contribute to the definition of urban landscapes, to the knowledge of the city's institutions, to information on Corsican society in Roman times, and they provide new perspectives on insular settlements thanks to cities and peoples found in inscriptions for which there is no information in the texts. This study into the specific Corsican context, allows us to see in a new light not only the epigraphy of Corsica, but also the process according to which the Romanization of the island took place. The creation of settlements, the association of the elites with the imperial cult, and the integration of the natives into the army through specialized bodies all contributed to making this island and its inhabitants part of the Roman world.

The inscriptions found on the island of Corsica to date are fewer than 250, mostly (about 170) unearthed from excavations carried out at Aléria [22]. Although the vast majority of them are engraved on marble, this was not the only material used as a support. In addition to marble, other types of stone were used: breccias, granites, and schists which may have an insular (i.e., local) origin, because these types of rock crop out extensively in Corsica. Corsican quarries evidently were not sufficient for the ancient engravers. Indeed, several other types of rock were imported to be worked on in Corsica. They are in some cases easily distinguishable because they do not exist on the island and therefore had to be brought from elsewhere. These are rocks which, compared to the local stones, evidently presented an appearance more in tune with the aesthetic habits of the island's inhabitants who were familiar with the customs of the capital of the Empire, Rome. Among the imported stones there is the travertine which was used as a support for various inscriptions (about ten) all found on the site of Aléria, and which probably came from the mainland or from Sardinia [22]. However, the predominance of the use of white marble is evident, probably mostly imported; gray varieties of marble, also widely used, could have come from quarries exploited on the island of Corsica.

The provenance of the marbles on which the inscriptions were carved can add important information to the history of the city of Aléria. This information makes it possible to define the relationship of the city and the island with the outside world, its trade routes, and to identify if there were activities for the exploitation of marble on the island in Roman times.

1.2. The Corsican Marbles

Corsica is in the center of the western Mediterranean Sea, between the Liguro-Provencal and Tyrrhenian basins. Geologically, it predominantly consists of Variscan granitoid basement rocks (in practice, mainly Carboniferous to Permian magmatic and volcanic rock successions) with a discontinuous Mesozoic to middle Eocene sedimentary cover that was part of the European foreland during the Alpine orogenesis [23]. In the North-Eastern region, the so called "Alpine Corsica", the Variscan basement is overthrusted by a nappe stack of oceanic- and continental-derived units. The Alpine chain in Corsica consists of the lower *Schistes Lustrés* nappe system, an oceanic-derived high-pressure/low-temperature metamorphic domain, and the upper only slightly metamorphosed Balagné nappe composed of non-metamorphic or slightly metamorphosed ophiolite units. The eastern coastal areas are sites of recent Miocene and Quaternary sedimentation (Figure 1).

The synthetic summary on Corsican geology allows us to deduce that the Corsican territory is unquestionably rich in ornamental stones of all kinds. As for colored stones: granites, diorites, and porphyries, Corsica has immense varieties. The richness of their colors and the originality of their structure should ensure a place of respect in ornamental stones. However, the island is not so rich in totally white marbles, rather there are gray or *cipollino* varieties in such quantities as to be exploitative. There are two main marble quarrying districts in Corsica which have been active at different times in the recent past; they are located around the localities of Brando and Corte (Figure 1). The first is of a certain renown, and it was quarried in diverse fronts producing different varieties (gray/white marbles and *cipollino*); geologically, this marble belongs to the rock series of *schistes lustrés* which constitutes the major part of alpine Corsica, and its age dates back to the Upper Cretaceous. The second was also quarried in different areas around Corte and comprises the marble of Corte *s.s.* and La Restonica. Macroscopically, the marble of Corte is a dark gray in prevalence, saccharoidal and fine-grained. That of the Restonica is gray-and-white banded, up to *cipollino* with green, gray and purple tinges, with large crystals; this variety also outcrops farther south close to the locality of Venaco. All these marbles have been extracted in the past but mainly in the XIX century when they acquired a certain fame and were even exported [24]. In addition to these two relatively larger districts, several marbles were quarried in the recent past in different Corsican locations, but the quarrying activity was short-lived. Currently none of these quarries is active. There is no evidence (either from the literature or from the field work) of the exploitation of marble quarries in ancient times, particularly in Roman times. However, it is reasonable to believe that, since the marble trade in the Mediterranean basin was prosperous and its use for ornamental purposes was notable, especially in the imperial era, it is strongly possible that stones and marbles were exploited in Corsica during that period.

Figure 1. Simplified geological map of Corsica (modified after [25]).

1.3. Carrara

Carrara is one of the best known architectural, decorative, and statuary stones used in antiquity. In the Carrara area the extraction of ornamental stones is very ancient, with the production of a great variety of marbles. That quarrying took place in Roman times is well known. The colony of Carrara (Luni) was founded in 177 BC along the ancient coastline to be the port city located in a strategic position for the transport and trade of marble, which was mainly extracted from the bottom of the three main marble basins north-east of Carrara: Torano, Miseglia and Colonnata. The variety of Carrara marble widely exploited by the Romans was the purest "white" marble, especially for statuary or inscriptions [26], but also a gray, or gray-banded, variety, the latter better known as *bardiglio*. Recent studies have shown that the exploitation of the Apuan marbles dates back even to pre-Roman times [27,28].

Geologically, the marble exploited in antiquity belongs to the Lower Jurassic level (Hettangian) of the so-called autochthonous unit which is characterized by a Paleozoic basement on which rests a metasedimentary succession from the Upper Triassic to the Oligocene age. The rocks of the Mesozoic cover are represented by Triassic deposits from continental to coastal marine followed by dolomites, dolomitic marbles and marbles (Grezzoni, Megalodont Marbles, Dolomite Marbles and Marbles) attributable to a carbonate platform sedimentation (Upper Triassic—Lower Liassic) and characterized by episodes of emergence with the formation of lateritic-bauxitic levels and breccias (*Breccia di Seravezza* and schists).

Carrara classical marble is mineralogically a pure marble, therefore with a content of calcite >98%. It is characterized, from the microstructural point of view, by a polygonal granoblastic structure, represented by an aggregate of equigranular crystals with straight or slightly curved boundaries and a weak or absent preferential crystallographic orientation. Within this type of microscopic texture, it is possible to observe a certain variability in the average grain size of the calcite crystals, but this aspect generally affects the Apuan marbles and only marginally the classic Carrara marble. Some studies have pointed out the presence inside the Apuan marbles, and also within the areas of classical Carrara exploitation, of microstructures that can be connected to compositional variations (e.g., phyllosilicate content) and dynamic recrystallization processes. In particular, it is possible to observe microstructures characterized by bimodal distribution of grain size, an association of small size calcite crystals (<0.1 mm) and larger size crystals (0.5–0.3 mm) with irregular (sutured) granular boundaries [26,29–31]. In many cases a strong crystallographic or shape preferential orientation is evident. This microstructural variability has been associated with fracture/fault damage zones.

Carrara marbles from the classical quarry basins were sampled for isotope analysis by different authors [5,19,26]; it was evident from numerous studies that the isotope results defined a rather tight range both for carbon and oxygen. Carbon isotope values of Carrara marbles generally do not vary by much and tend to cluster around 2‰ V-PDB, whereas oxygen isotope values range between −0.5 and −3‰ V-PDB. In addition, outside these areas the isotopes reported in the literature did not give very different values, as for instance at Serravezza or in the nearby quarrying districts where not fully white Carrara marbles were exploited. These areas were probably not active in Roman times and were cultivated for different varieties, such as the typical *bardiglio* marble from Trambiserra, the *cipollino* variety with a green hue from the Apuan Alps sectors of Arni, Isola Santa and Monte Corchia [32], or the *breccia di Serravezza*. All these marbles showed isotopic values similar to those of Carrara "white", sometimes showing only a slight tail towards negative values as regards oxygen isotopes. Carrara marbles result in general to have inherited the isotopic compositions of the carbonate protolith (the *calcare massiccio*) with slight or no modifications, indicating a metamorphic process with a low fluids to rock ratio. Fault damage zones, sometimes recognized within the homogeneous Carrara marble, have macroscopically shown a gradual transition in texture from undeformed to fractured marble up to a *cataclasite* at the core of the fault. This *cataclasite*, composed of angular/subangular clasts of marble hosted within an orange to brownish matrix prevalently consisting of fine-grained calcite, has a more variable oxygen isotopic composition. Caused by interaction with meteoric fluids that found preferential routes through these damage zones, $\delta^{18}O$ may show extreme negative values as low as −14‰ (vs. V-PDB); carbon isotope composition seems to be unaffected by this process and the isotopic values remain close to 2‰ [33]; such values were also reported recently by other authors [34,35]. However, these marbles were never reported as being exploited by Romans, probably because of their poor mechanical properties and exterior quality. As far as we know, no-one has found a range of isotope values different from that reported in the relevant literature for the areas of Carrara (Miseglia, Torana, Colonnata) where pure, compact marble was quarried in Roman times.

For this study the Carrara isotope data from [6], integrated with 12 further data returns from a recent sampling of the most renowned quarry fronts today considered to be of the highest quality, will be used as a reference database. The new data did not significantly extend the range of $\delta^{18}O$ and $\delta^{13}C$ observed in the database of [6]. The mean standard deviation and minimum/maximum values of the reference database of Carrara were reported in Table A1 of Appendix A. It is also shown graphically in Figure 2a,b using the 99% confidence ellipse fitted to the data (the data markers defining the ellipse are not shown, the markers in Figure 2 represent the sample data of the inscriptions). Carrara marble exploited in Roman times has a very low probability of showing isotopic values that fall outside the ellipse.

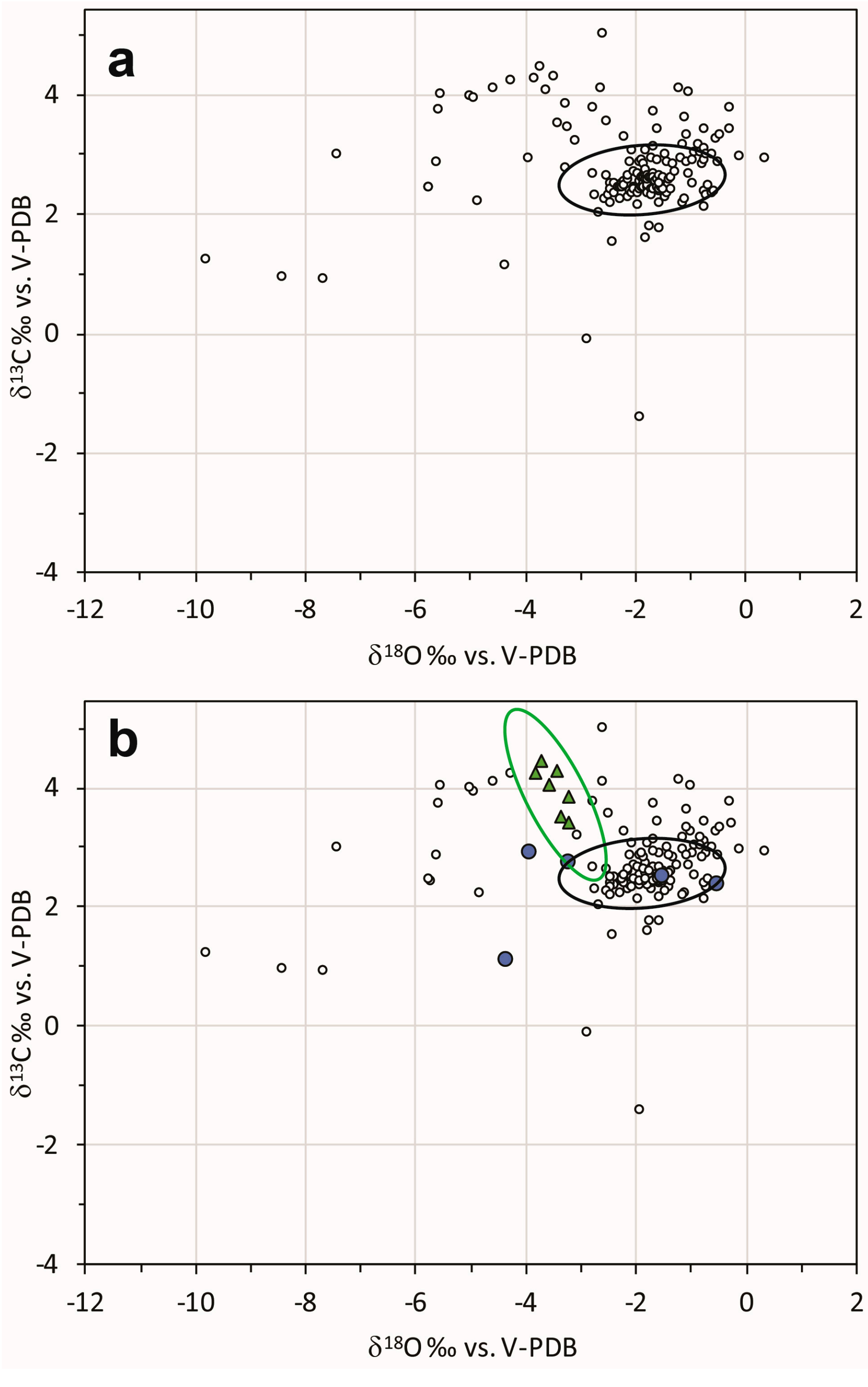

Figure 2. Stable isotope scatterplots of the marbles from Aléria; (**a**) the open circles represent the totality of the samples analyzed from the inscriptions, the Carrara 99% probability ellipse is drawn according to indications of [36] (data markers that define the Carrara ellipse are not shown); (**b**) the green triangles represent the samples macroscopically attributed to *greco scritto* (enclosed in a 95% probability ellipse); colored stones are also indicated with a blue circle marker; the Carrara 99% probability ellipse is drawn as in (**a**).

2. Materials and Methods

The marbles of the epigraphs found in Aléria are kept in the Jérôme Carcopino Departmental Museum of Archaeology, located near the Aléria archaeological site.

One sample was taken from each of 159 slab fragments on which Greek or Latin inscriptions are visible. The samples were carefully collected from the fracture surfaces in the form of tiny chips using a small hammer and a chisel, avoiding weathered material and patinas. Whenever possible, the samples were split into two parts, one to be used for thin-section preparation, the other to be powdered for isotopic analysis.

The entire set of samples was analyzed for oxygen and carbon isotopes analysis. Oxygen and carbon isotopes were determined on about 150–200 µg of calcium carbonate powder by the continuous flow—isotope ratio mass spectrometry technique. A Thermo Gasbench II automatic preparation device was used for phosphoric acid digestion at 72 °C and gas-chromatographic CO_2 purification. A Finnigan™ Delta Plus mass spectrometer measured the carbon and oxygen isotope ratios of CO_2, expressed in the usual delta notation ($\delta^{18}O$ and $\delta^{13}C$), representing relative deviation in parts per mil (‰) with respect to the V-PDB (Vienna Pee Dee Belemnite) international standard. Data normalization to the V-PDB scale was conducted using laboratory standards calibrated against NBS-18 and NBS-19. The international standard used was for both oxygen and carbon isotopes, and analytical precision was better than 0.10‰ for both carbon and oxygen. Isotope measurements were carried out at the IGAG-CNR (Istituto di Geologia Ambientale e Geoingegneria—Consiglio Nazionale delle Ricerche) Laboratory of Stable Isotopes.

A selection of 43 samples was cut into thin sections for petrographic and mineralogical study under a polarizing microscope. Due to the destructive nature of the methods, many of the inscriptions only allowed isotope analysis which requires minimal sampling (<<1 mg). Therefore, the selection strategy was based, firstly, on the available quantity of each sample. In order to have a number of thin sections representative of the full range of isotopic results, some thin sections were considered, even in cases where these could show only a few grains of rock. They were cut and polished in the Thin Section Laboratory of the IGAG-CNR. Textures, microstructures, crystal boundary shapes and grain size features were observed, providing descriptive parameters generally considered to be diagnostic for determining the type and origin of a marble [18,37–39].

3. Results

The totally white marbles are predominantly calcite and were isotopically analyzed using the following procedure. The samples were not analyzed by diffractometry for calcite—dolomite composition because they were too scarce to allow for more than isotope determination. When powders remained from the isotopic analysis, they were used to react with cold dilute HCl which always promptly produced CO_2 outgassing indicating that the powder samples were mainly calcitic.

Large variations in oxygen and carbon isotopes occur in the marbles of the archaeological samples, from −9.79‰ to +0.37‰ for $\delta^{18}O$ (vs. V-PDB) and from −1.87‰ to +4.54‰ for $\delta^{13}C$ (vs. V-PDB). The results are displayed in Figure 2a and listed in Table A2. $\delta^{18}O$ is not co-variant with $\delta^{13}C$; most of the data (about 64%) fall within the 99% probability level ellipse of the Carrara marbles (Figure 2a), indicating that many more marble samples than expected may not belong to Carrara. The isotopic compositions which fall outside the Carrara range in the isotope space show no evident clustering characteristics and are mostly scattered towards higher values for $\delta^{13}C$ and lower values for $\delta^{18}O$ compared to Carrara. This may indicate that these data do not represent a single provenance. Furthermore, there is no clear relationship between isotopes and macroscopic characteristics which are specifically the level of whiteness or the abundance/pattern of gray bands or streaks.

A few samples (7) were excluded from the above considerations because they were taken from fragments of colored stones as macroscopically evident. These samples are: MA2018.7617, a calcitic alabaster; MA2018.7747, a sandstone with a small carbonate fraction; and MA2018.7619, MA2018.7624, MA2018.7635, MA2018.7638, MA2018.7717 which are breccias with marble or calcareous clasts and a matrix of different colors (yellow, purplish, brownish). Their compositions (except for the alabaster which has a much more negative $\delta^{18}O$ than the rest of the samples shown in the figure and the sandstone which gave no results) are indifferently distributed along the entire isotope data range and only in a few cases overlap with the isotope field of Carrara (Figure 2b).

Macroscopically, there is also a group of white marbles that has the typical appearance of *greco scritto* marble. They correspond to a well-defined range of isotope compositions with values around −3.50‰ and +3.50‰ for oxygen and carbon, respectively (Figure 2b).

Table A1 summarizes the macroscopic characteristics of the samples with isotopic results and provenance interpretation.

The 43 samples in thin section were observed under a polarizing microscope to define the main petrographic features: texture, microstructure, maximum grain size of carbonate crystals (MGS), and boundary shapes. The results of these observations are described in detail in Table 1 and can be summarized as follows. Samples with the typical isotope composition of Carrara almost exclusively exhibit the petrographic features of this marble, i.e., a fine-grained aggregate of quasi-equigranular crystals with straight or slightly curved grain boundaries, absent preferential crystallographic orientation, and an MGS $\leq$ 1.0 mm. A second group with a carbon isotope composition higher than that of Carrara has heteroblastic microstructures, often coarse grain size and variable oxygen isotope composition but in general lower than the Carrara range. In this group it is also possible to enclose the *greco scritto* group of samples, even though none of the samples attributed to this type of marble was cut for thin section. MA2018.7772-1, white in appearance and considered part of the slab of other fragments of *greco scritto*, actually shows these petrographic features (Table 1). Another group with very low oxygen isotope compositions (indicatively lower than −5‰) has even more variable petrographic characteristics (coarse- or fine-grained, different textures and structures) and carbon isotopes. Figure 3 shows a selection of photomicrographs which takes into account the isotopic groups described above.

Table 1. Mineralogical–petrographic features from thin section observations, isotopic values, and resultant provenance interpretation of the gray/white marbles of the inscriptions. Petrographic data: Ho—homeoblastic; He—heteroblastic; n.d.—not determined.

Inv. Number	MGS (mm)	Texture	Microstructure	Crystal Boundaries	δ^{13}C	δ^{18}O	Provenance
MU.7785	0.8	He	polygonal, mosaic	straight, curved	+1.81	−1.43	Carrara
MU.7775	n.d.		microsparite—equant fine-grained texture	n.d.	+2.40	−1.05	
MU.7749	0.5	Ho	polygonal, mosaic	straight, curved	+1.99	−1.81	Carrara
MA2018.7743	0.6	He	mosaic	straight, curved	+2.02	−1.74	Carrara
MU.7792	2.0	He	mosaic	curved	+1.89	−0.57	
MA2018.7719	n.d.	He	few coarse-grained crystals	curved, straight	+2.41	−5.59	
MU-22-3-1-13	1.6	He	polygonal, mosaic, medium- to coarse-grained	straight, curved	+2.43	−1.86	Carrara
MU.7629	0.6	Ho/He	polygonal, mosaic	straight, curved	+2.41	−2.06	Carrara
MU.7780	0.5	Ho/He	polygonal, mosaic	straight, curved	+2.14	−1.72	Carrara
MA2018.8450	0.3	Ho	polygonal, mosaic	curved, straight,	+2.38	−1.83	Carrara
MA2018.7741-2	0.7	Ho/He	polygonal, mosaic	curved, straight	+1.96	−1.91	Carrara
MU.7787	0.5	Ho	polygonal, mosaic	curved, straight	−1.87	−1.89	Carrara (patina?)
MU-SN	0.5	Ho	polygonal, mosaic	curved, straight	+1.56	−2.65	Carrara
MA2018.7779	0.5	Ho	polygonal, mosaic	curved, straight	+2.05	−2.35	Carrara

Table 1. *Cont.*

Inv. Number	MGS (mm)	Texture	Microstructure	Crystal Boundaries	$\delta^{13}C$	$\delta^{18}O$	Provenance
MU.7786	0.5	Ho	polygonal, mosaic	straight	+1.99	−1.58	Carrara
MA2018.7619	n.d.		microsparite—equant fine-grained texture	n.d.	+1.92	−0.53	*breccia corallina*
MA2018.8462	n.d.	He	mosaic	curved, straight	+2.97	−1.59	Carrara
MA2018.7724-9	2.8	He	mosaic	sutured, curved, embayed	+3.28	−5.54	
MA2018.7724-13	n.d.	He	mosaic	straight, curved, embayed	+3.52	−5.00	
MA2018.8454	0.5	He/Ho	mosaic, lineated	curved, embayed	+0.48	−8.38	
MA2018.8461	2.8	He	mosaic	straight, curved, (sutured)	+2.60	−2.05	
MA2018.7641	1.8	He	mosaic, coarse-grained	curved, embayed	+0.78	−9.79	
MA2018.7717	n.d.		microsparite—equant fine-grained texture	n.d.	+2.47	−3.92	calcareous breccia
MA2018.7791	1.5	He	mosaic	curved, straight	+1.99	−5.72	
MA2018.7724-1	2.2	He	mosaic	curved, embayed	+3.55	−5.50	
MU.7776	0.5	Ho/He	polygonal, mosaic	straight, curved	+1.73	−2.44	Carrara
MA2018.7742	2.2	He/Ho	mosaic	curved, sutured	+2.01	−0.66	
MA2018.7733	0.5	He	mosaic	straight, curved	+2.34	−1.48	Carrara
MA2018.7643	0.5	He/Ho	mosaic	curved, embayed	+1.89	−2.46	Carrara
MA2018.7724-11	2.8	He	mosaic	curved, embayed	+3.47	−4.91	
MA2018.7633	2.5	He/Ho	mosaic, evident bimodal grain size	curved, sutured	+3.64	−2.59	
MUepig1	0.4	He/Ho	polygonal, mosaic	curved, straight	+2.24	−1.24	Carrara
MA2018.7740-1	2.0	He	mosaic	curved, sutured	+3.10	−2.48	
MA2018.7782-3	0.7	He	mosaic	curved	+2.03	−1.87	Carrara
MA2018.7666	3.0	He	mortar, mosaic	curved, embayed	+2.63	−0.72	
MA2018.8449	0.5	He/Ho	mosaic, lineated	curved, embayed	+2.12	−1.58	
MA2018.7772-1	2.1	He	mortar, mosaic	curved, embayed	+3.77	−4.24	
MA2018.7781-1	0.5	Ho	mosaic	straight, curved	+1.96	−1.55	Carrara
MA2018.7644	0.5	Ho/He	mosaic, lineated	sutured, straight, curved	+0.46	−7.66	
MA2018.7638	1.8	He	mosaic	sutured, curved, embayed	+0.68	−4.38	
MA2018.7745	1.0	He	mosaic, fine—medium-grained	curved, embayed	+2.54	−7.38	
MA2018.7784-2	1.8	He	mortar, mosaic	curved, embayed, sutured	+2.87	−1.04	
MA2018.7752	2.4	He	mosaic, coarse-grained	straight, curved, sutured, embayed	+3.65	−4.55	

Two samples are present with anomalously negative carbon isotope compositions, combined with a relatively high oxygen composition; they are two pure white marbles, with medium—large grain size evaluated macroscopically.

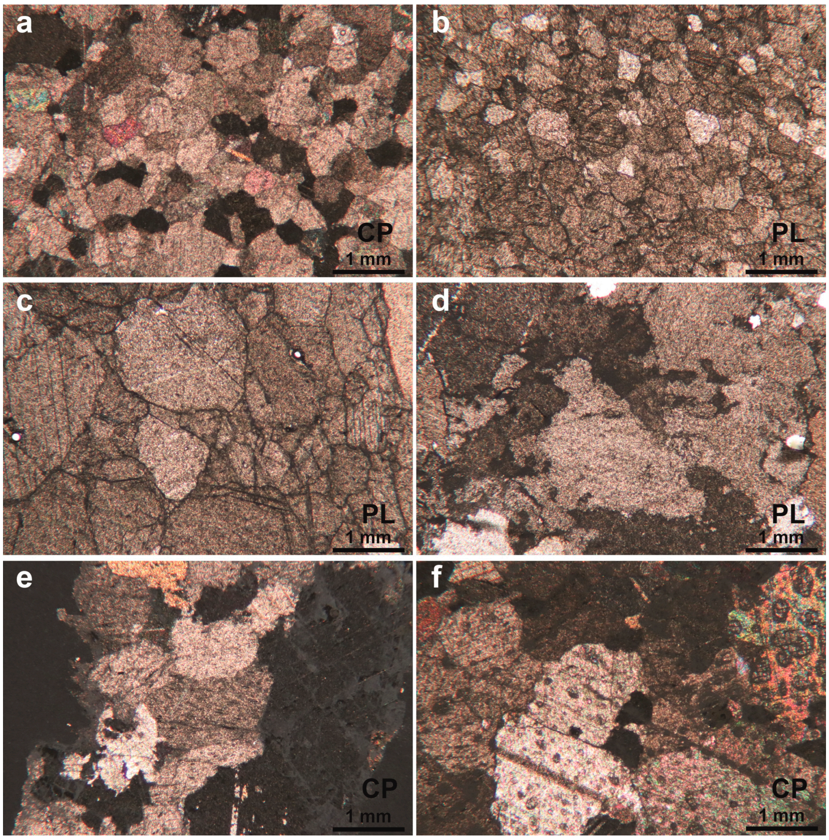

Figure 3. Selection of photomicrographs: (**a**) MU.7776, Carrara; (**b**) MU-SN, Carrara; (**c**) MU.8461, probable local quarry; (**d**) MA2018.7740-1, probable local quarry; (**e**) MA2018.7724-9, probable local quarry; (**f**) MA2018.7742; probable local quarry. CP—cross polarized light; PL—plane polarized light.

4. Discussion

4.1. Provenance of Colored Stones

In the collection of samples for this study, a few fragments of epigraphs have peculiar macroscopic characters; some of them are not marbles. They show an appearance that can enable a provenance determination due to their polychrome characteristics. These are small, isolated fragments and represent inscription support of different sizes (Figure 4). Several catalogs in books or on the web of the most utilized colored stones used in Roman times [40,41] (Corsi collection published by the Oxford University Museum of Natural History web catalogue—http://www.oum.ox.ac.uk/corsi/ (accessed on 1 February 2023) [42], Ispra web catalogue on litho-mineralogy—https://www.isprambiente.gov.it/it/attivita/museo/collezioni-litomineralogiche (accessed on 1 February 2023), physical Musei Capitolini collection, etc.) were used as reference for comparison and identification. The attributions are summarized in Table A1 and Figure 4. The isotopic compositions and, in some cases, the petrographic observations in thin section, have contributed to confirming the provenance attribution. As for the calcitic alabaster, its provenance from Hierapolis was definitely confirmed by the carbon isotope composition which, as reported by [43], strongly characterizes the *alabastro fiorito* variety. In addition, the attribution of MA2018.7638 to the *pavonazzetto* variety is fully confirmed by the isotopes and petrography which indicate the Afyon provenance of the marble clasts of the breccia sample [2,6]. The Ephesian attributions of the *greco scritto* are surely supported by the isotopic compositions which indicate a provenance from the Hasançavuslar quarry, whose reference isotope data and grain sizes are provided by [44], to which these samples are similar. The attribution of the colored stones through the isotope comparison between the sample data and data in the literature is graphically shown in Figure A1 in Appendix A.

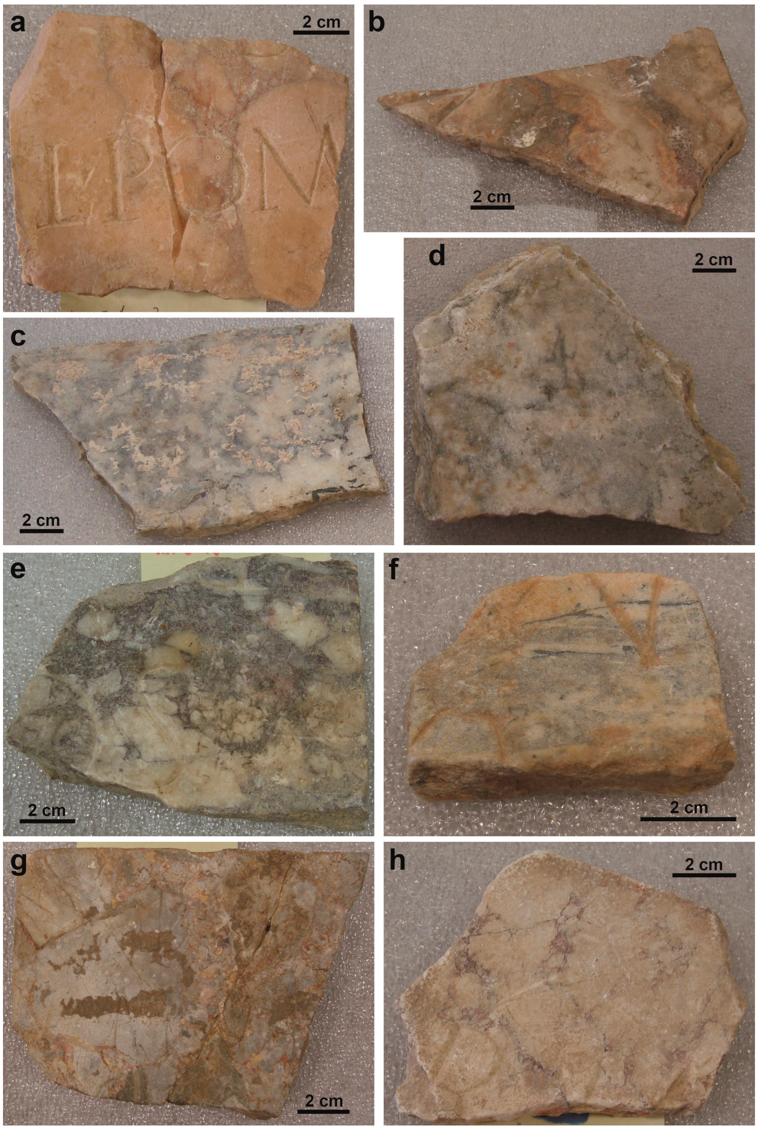

Figure 4. Photos of the fragments of polychrome marbles used as support for the inscriptions: (**a**) *giallo antico*; (**b**) *alabastro fiorito*; (**c**,**d**,**f**) *greco scritto*; (**e**) *pavonazzetto*; (**g**) *breccia di Aleppo*; (**h**) *breccia corallina*.

The recognition of *giallo antico*, *breccia corallina* and *breccia di Aleppo* is solely entrusted to the macroscopic appearance. The isotopes of *giallo antico* have a reference for comparison in the data of [4] and the oxygen isotopic composition of our sample does not fall within the range of these data (Figure A1). A few data (n = 11) were reported by [4] and a larger sampling of the *giallo antico* quarries of Chemtou can certainly expand this isotopic range.

Only one sample of colored stone (MA2018.7717) has no provenance attribution; it is a dull white—light gray calcareous breccia with a pale orange matrix; the quality of the stone seems very poor, and it is possible that it does not belong to any of the colored stones widely used in antiquity.

4.2. Gray and White Marbles

The investigation into the origin of the white marbles of the Aléria inscriptions was carried out first through isotopic analysis, as it was considered an effective method for identifying the provenance either from Carrara or from the island of Corsica. Our initial working hypothesis did not consider other possible provenances. Figure 2b shows the data acquired from the isotopic analysis; data representing the colored breccias (n = 5) and *greco scritto* marbles (n = 7) (alabaster does not appear because its isotopic composition is out of the range of the graph) are distinguished using different markers. The gray and white marbles are represented in the isotope space by 152 points (*greco scritto* marbles are included). It is evident that many of these marbles (about 64% of the total) fall into the field we have defined as Carrara marble. On the one hand, it is possible that some samples, actually Carrara marbles, may nevertheless fall outside, albeit close to, the probabilistic 99% ellipse of Carrara. This underestimates the number of Carrara marbles used for the inscriptions. On the other hand, it is possible that some marbles may have an isotopic composition that falls within the Carrara range even though in reality they are not from Carrara. Petrography can provide an insight into the degree of success or failure in isotope-only assignment. A total of 21 out of the 40 white marbles of which we have thin sections (43 was the total but this included three colored stones), were isotopically assigned to Carrara (about 53%); after the petrographic examination, it is evident that 2 of these 21 are not from Carrara (MU.8461 [Figure 3c], MA2018.7742 [Figure 3f]—see the descriptions in Table 1), therefore it is possible that a small percentage (likely below 10%) of the samples within the Carrara ellipse in the isotope graph may have an incorrect attribution. Concerning the rest of the thin section samples whose isotopic composition falls outside the Carrara ellipse in the isotope diagram, thin section examination has shown that none of them are actually Carrara marbles (see Table 1). This would indicate that marbles that do not have the typical isotopic composition of Carrara are actually to be assigned to another provenance. The observations in thin section of non-Carrara marbles show that there is no uniform petrographic character for particular isotopic compositions, especially with reference to grain size. A heteroblastic texture and coarse grain size are, in general, dominant.

Isotopic data outside the Carrara range do not show clusters, and this aspect agrees with the inhomogeneous petrographic features. This may suggest that there is no specific quarry on which Aléria relied for the supply of marbles other than Carrara. The exception represented by the group of *greco scritto* marbles is not significant as it is fairly certain that the different fragments sampled come from the same inscription. These non-Carrara marbles could be ascribed to Corsican local quarries, but it is difficult to say whether they are the quarries described in paragraph 1.2. Having an approximate macroscopic description that defines them as dark in appearance, with mottled gray to *cipollino* patterns, in some cases they could correspond to the marble sampled from the inscriptions; however, the information so far acquired on their properties is too scarce for a full comparison.

5. Conclusions

In this study, an attempt was made to distinguish Carrara marble from other indefinite Corsican provenances of marble inscriptions found in archaeological excavations of the Aléria site. The method used to carry out this study is based on the almost exclusive use of stable isotopes of carbon and oxygen since it, although destructive, requires minimal quantities of material.

This approach relies on the assumption that the origins of the marbles from Aléria could have only two possibilities, Carrara or somewhere in Corsica, because for most of the inscriptions there would have been no need to import stones from distant and renowned sites of marble extraction; consequently the procurement of these marbles for Aléria may have followed a principle of proximity, i.e., using local marbles or, in the absence of these, the closest supply point to Corsica which is Carrara.

Isotopes of carbon and oxygen constrain the marble of Carrara used in antiquity quite well due to their narrow range. The isotopic data shows that about 64% of the marble fragments from the Aléria inscriptions come from Carrara. Micro-petrographic observations were used to test the isotopic approach and showed that samples that have the typical Carrara isotopic signature are almost always confirmed as coming from Carrara quarries.

However, the premises of this study may not seem entirely correct, because some fragments from colored prestigious stones and *greco scritto* marble were found in the collection of epigraphs, even if in a really limited amount. The fact that most of the identified non- gray/white marbles are from Turkey (the *pavonazzetto* fragment from Afyon, the *breccia corallina* from south-western Anatolia or Bithynia, the alabaster from Hierapolis, the *breccia di Aleppo* from the Greek island of Chios just off the western Turkish coast, *greco scritto* from Ephesus) may be a coincidence; they were marbles widely used in Rome (with the exception of *breccia di Aleppo* whose use and diffusion is still uncertain). It is also true that the fragments of *greco scritto* could belong to the same slab. It is therefore a rather small percentage of marbles which have a distant origin. These exotic marbles were probably exceptions, stored in the warehouses of the port of Luni and transported from there together with the usual supply of Carrara marbles. Their occasional presence does not suggest a trade with Turkish quarries on a regular basis.

From what has been said, the remaining data set, less than 36%, may represent locally sourced marbles. In any case, the distribution of these data in the isotope scatterplot is too wide both for carbon and oxygen; there are no obvious data clusters, which could suggest the presence of one or more local quarry sites. The petrographic observations confirm this. These considerations leave open the possibility both of the existence in ancient times of various small local quarries and of the presence of accidentally imported slabs of non-Carrara marble, as could have been the case with the presence of colored stones.

The data do not allow the existence of important local marble quarries to be deduced in Roman times and investigations into their presence have yet to be carried out.

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Data Availability Statement: All data are available in the article and Appendix A.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Mean, standard deviation and minimum/maximum values of the Carrara marble reference isotope database (‰ vs. V-PDB).

	δ^{13}C (V-PDB)	**δ^{18}O (V-PDB)**
mean	2.09	−1.90
min	1.06	−3.01
max	2.62	−0.46
std. dev.	0.18	0.48

Table A2. Stable isotope results of the marbles of Aléria and their macroscopic characteristics. The provenance of Carrara is based on isotopic information only; (n.d.—not determined).

Inv. Number	$\delta^{13}C$ (V-PDB)	$\delta^{18}O$ (V-PDB)	Annotations on the Macroscopic Appearance	Provenance
MA2018.7616	1.84	−1.68	white	Carrara
MA2018.7617	4.76	−15.57	calcitic alabaster—*alabastro fiorito*	
MA2018.7618	1.78	−2.24	white	Carrara
MA2018.7619	1.92	−0.53	breccia with reddish-brown matrix and white clasts—*breccia corallina*	Carrara
MA2018.7620	1.95	−1.69	gray—*bardiglio*	Carrara
MA2018.7621	2.04	−1.81	white	Carrara
MA2018.7622	1.82	−2.11	white	Carrara
MA2018.7623	2.24	−2.01	white	Carrara
MA2018.7624	2.32	−3.23	breccia with reddish-brown matrix and orange-ochre yellow clasts—*giallo antico*	
MA2018.7625	1.95	−1.99	white	Carrara
MA2018.7626	2.46	0.37	streaked gray	
MA2018.7627	2.36	−1.29	*bardiglio*	Carrara
MA2018.7628	2.94	−0.25	white	
MA2018.7629	2.41	−2.06	white	Carrara
MA2018.7631	2.16	−1.69	white	Carrara
MA2018.7632	2.21	−2.76	gray/white	Carrara
MA2018.7633	3.64	−2.59	gray/white	
MA2018.7634	3.31	−0.27	white	
MA2018.7635	2.06	−1.53	calcareous breccia with yellow-orange matrix and gray clasts	
MA2018.7636	1.89	−1.91	white	Carrara
MA2018.7637	1.99	−1.51	streaked gray—*bardiglio*	Carrara
MA2018.7638	0.68	−4.34	breccia with a purplish matrix and white marble clasts—*pavonazzetto*	
MA2018.7639	2.43	−0.71	gray	Carrara
MA2018.7640	2.10	−1.74	white	Carrara
MA2018.7641	0.78	−9.79	white	
MA2018.7642	1.98	−2.28	white	Carrara
MA2018.7643	1.89	−2.36	white	Carrara
MA2018.7644	0.46	−7.66	white	
MA2018.7646	2.18	−1.77	white	Carrara
MA2018.7647	2.60	−1.77	gray	Carrara
MA2018.7648	2.14	−1.63	white	Carrara
MA2018.7649	2.44	−1.56	gray	Carrara
MA2018.7650	2.17	−1.82	white	Carrara
MA2018.7651	2.08	−1.90	white	Carrara
MA2018.7652	1.14	−1.77	white	

Table A2. *Cont.*

Inv. Number	$\delta^{13}C$ (V-PDB)	$\delta^{18}O$ (V-PDB)	Annotations on the Macroscopic Appearance	Provenance
MA2018.7653	2.04	−2.22	white	Carrara
MA2018.7654	2.19	−1.80	white	Carrara
MA2018.7655	1.91	−2.07	white	Carrara
MA2018.7656	2.54	−1.42	*bardiglio*	Carrara
MA2018.7657	2.39	−1.90	gray	Carrara
MA2018.7658	2.82	−2.17	gray	
MA2018.7659	2.67	−1.65	white	Carrara
MA2018.7660	1.99	−2.00	white	Carrara
MA2018.7661	2.28	−1.79	streaked gray—*bardiglio*	Carrara
MA2018.7662	1.98	−5.71	white	
MA2018.7663	1.85	−2.71	white	Carrara
MA2018.7664	2.12	−2.11	white	Carrara
MA2018.7665	2.44	−0.93	gray	Carrara
MA2018.7666	2.63	−0.72	gray	
MA2018.7667	−0.57	−2.85	white	
MA2018.7668	1.29	−1.54	streaked gray—*bardiglio*	
MA2018.7669	2.15	−1.81	white	Carrara
MA2018.7670	1.78	−1.07	dark gray	Carrara
MA2018.7712	1.98	−1.76	white—veined gray	Carrara
MA2018.7713	2.13	−1.47	white	Carrara
MA2018.7714	2.18	−2.10	white	Carrara
MA2018.7715	2.48	−1.13	white	Carrara
MA2018.7716	1.66	−0.74	streaked gray—*bardiglio*	
MA2018.7717	2.47	−3.92	calcareous breccia	
MA2018.7718	1.99	−2.26	gray-white veined	Carrara
MA2018.7719	2.41	−5.59	gray	
MA2018.7720	2.11	−1.80	white	Carrara
MA2018.7721	1.88	−1.38	gray	Carrara
MA2018.7722	3.66	−1.18	white	
MA2018.7723	3.58	−0.99	gray-white	
MA2018.7725	2.40	−1.39	gray	Carrara
MA2018.7726	2.07	−1.59	white	Carrara
MA2018.7727	3.82	−3.82	gray/white	
MA2018.7728	1.88	−1.76	white	Carrara
MA2018.7729	3.17	−1.06	white	
MA2018.7730	2.40	−0.47	white	
MA2018.7731	2.70	−0.82	white	
MA2018.7732	1.85	−0.68	white	Carrara
MA2018.7734	2.80	−0.51	white	

Table A2. *Cont.*

Inv. Number	$\delta^{13}C$ (V-PDB)	$\delta^{18}O$ (V-PDB)	Annotations on the Macroscopic Appearance	Provenance
MA2018.7735	2.19	−1.92	white	Carrara
MA2018.7736	2.54	−0.67	white	
MA2018.7738	1.92	−0.73	white	Carrara
MA2018.7739	2.09	−1.50	white	Carrara
MA2018.7742	2.01	−0.66	white	Carrara
MA2018.7743	2.02	−1.74	white	Carrara
MA2018.7744	2.96	−0.72	white	
MA2018.7745	2.54	−7.38	white	
MA2018.7747	n.d.	n.d.	sandstone	
MA2018.7748	2.71	−1.10	streaked gray—*bardiglio*	
MA2018.7750	1.93	−1.55	white	Carrara
MA2018.7752	3.65	−4.55	white	
MA2018.7753	1.99	−1.49	white	Carrara
MA2018.7754	2.00	−2.17	white	Carrara
MA2018.7755	2.15	−1.85	white	Carrara
MA2018.7756	2.36	−0.77	white	Carrara
MA2018.7757	1.97	−1.84	white	Carrara
MA2018.7767	1.88	−2.03	white	Carrara
MA2018.7768	2.06	−1.53	white	Carrara
MA2018.7769	1.95	−1.66	white	Carrara
MA2018.7779	2.05	−2.35	white	Carrara
MA2018.7789	3.39	−3.22	streaked gray—*bardiglio*	
MA2018.7790	2.53	−0.59	white	
MA2018.7791	1.99	−5.72	white	
MA2018.8448	2.49	−0.08	white	
MA2018.8449	2.12	−1.58	streaked gray—*bardiglio*	Carrara
MA2018.8450	2.38	−1.83	gray/green	Carrara
MA2018.8451	2.14	−1.32	white with patina	Carrara
MA2018.8453	2.16	−2.51	white	Carrara
MA2018.8454	0.48	−8.38	white	
MA2018.8455	1.95	−1.32	white	Carrara
MA2018.8456	2.20	−1.65	white	Carrara
MA2018.8458	2.57	−0.90	gray	Carrara
MA2018.8459	1.94	−2.43	white with patina	Carrara
MA2018.8462	2.97	−1.59	white	
MA2018.8463	1.07	−2.40	white	
MA2018.8463bis	2.87	−0.44	white with patina	
MA2018.8464	1.72	−1.12	streaked gray—*bardiglio*	Carrara
MA2018.7724-1	3.55	−5.50	white	

Table A2. *Cont.*

Inv. Number	$\delta^{13}C$ (V-PDB)	$\delta^{18}O$ (V-PDB)	Annotations on the Macroscopic Appearance	Provenance
MA2018.7724-9	3.28	−5.54	white	
MA2018.7724-11	3.47	−4.91	white	
MA2018.7724-13	3.52	−4.99	white	
MA2018.7733	2.34	−1.48	gray	Carrara
MA2018.7740-1	3.10	−2.48	white	
MA2018.7740-2	3.32	−2.76	white	
MA2018.7741-1	1.85	−2.45	white	Carrara
MA2018.7741_2	1.96	−1.91	white	Carrara
MA2018.7772-1	3.77	−4.24	white	
MA2018.7772-2	1.71	−1.55	streaked gray—*bardiglio*	Carrara
MA2018.7772-3	1.99	−2.21	white	Carrara
MA2018.7772-4	3.98	−3.70	*bardiglio*	
MA2018.7772-5	2.56	−0.79	white	Carrara
MA2018.7772-6	3.25	−1.65	white	
MA2018.7772-7	3.83	−3.44	*bardiglio*	
MA2018.7772-8	2.75	−3.05	white	
MA2018.7772-9	4.54	−2.58	white	
MA2018.7772bis-1	3.07	−3.37	*bardiglio*	
MA2018.7772bis-2	3.61	−3.58	*bardiglio*	
MA2018.7772bis-3	1.31	−1.72	white	
MA2018.7772bis-4	2.05	−0.92	gray	Carrara
MA2018.7772bis-5	2.47	−1.67	white	Carrara
MA2018.7772bis-6	2.22	−1.02	white	Carrara
MA2018.7772bis-7	2.98	−3.20	*bardiglio*	
MA2018.7781-1	1.96	−1.55	white	Carrara
MA2018.7781-2	2.10	−1.37	white	Carrara
MA2018.7782-1	1.77	−4.83	*bardiglio*	
MA2018.7782-3	1.91	−1.89	*bardiglio*	Carrara
MA2018.7784-1	1.80	−2.52	white	Carrara
MA2018.7784-2	2.87	−1.04	white	
MA2018.7784-3	2.19	−1.55	gray	Carrara
MA2018.7784-4	2.05	−2.43	white	Carrara
MA2018.7784-5	2.07	−2.18	white	Carrara
MA2018.7784-6	1.95	−1.48	white	Carrara
MU-SN	1.56	−2.65	white	Carrara
MU.7749	1.99	−1.81	white	Carrara
MU.7775	2.40	−1.05	*bardiglio*	
MU.7776	1.73	−2.44	white	Carrara
MU.7780	2.14	−1.72	white	Carrara

Table A2. *Cont.*

Inv. Number	$\delta^{13}C$ (V-PDB)	$\delta^{18}O$ (V-PDB)	Annotations on the Macroscopic Appearance	Provenance
MU.7785	1.81	−1.43	white	Carrara
MU.7786	1.99	−1.58	white	Carrara
MU.7787	−1.87	−1.89	white	
MU.7792	1.89	−0.57	white	
MU.8461	2.60	−2.05	white	Carrara
MUepig1	2.24	−1.24	gray	Carrara
MU-22-3-1-13	2.43	−1.86	white	Carrara

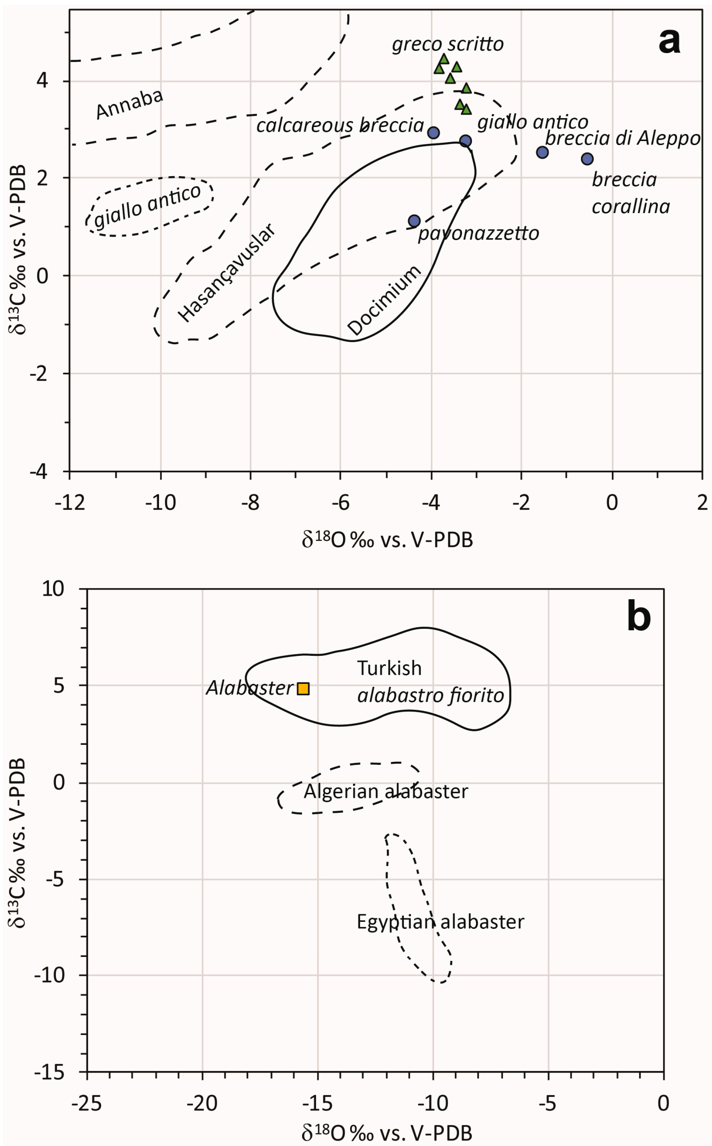

Figure A1. Stable isotope scatterplot of the colored stones from Aléria: (**a**) approximate isotopic fields of *greco scritto* (Annaba, Algeria [45], Hasançavuslar, Ephesus, Turkey [44]) *giallo antico* [4], Docimium [2] are shown; (**b**) isotopic fields of different calcitic alabasters exploited in antiquity [43].

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