DISCRIMINATING CRITERIA OF PYRENEAN ARTIES MARBLE (ARAN VALLEY, CATALONIA) FROM SAINT-BÉAT MARBLES: EVIDENCE OF ROMAN USE

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Abstract

The "Val d'Aran" is a valley situated on the Atlantic side of the Pyrenees. Located in the northwest corner of Catalonia, has easy connection with France by the course of the Garonne River, which forms the main communication route, flows over land Aquitaine and empties into the Atlantic Ocean near Bordeaux. Under Roman control, the Aran Valley was part of the *Novempopulania* province.

Five of the most significant archaeological artefacts found in the Valley have been analyzed to investigate the provenance of the marble used for their manufacture. These archaeological pieces dated from 2nd to 5th century AD, are currently deposited in the "Musèu dera Val d'Aran". A combination of techniques with Optical Microscopy, Cathodoluminescence (CL) and Isotope-Ratio Mass Spectrometry was applied to know their marble source.

To carry out the comparative study with quarry marbles, local outcrops were examined and sampled. Marbles from the quarry of Arties were specially taken into account since, at least from the medieval times, were used with building purposes. The nearby Roman quarries of Saint-Béat have also been taken into consideration. The analytical results after applying the same methodology to both marble samples, artefacts and quarries, allow differentiating the two marble sources, Arties and Saint-Béat.

Keywords

Arties marble quarry, Saint-Béat marble, Roman use, Archaeometry

Introduction

The Arties marble quarry is located in the Aran Valley in the northwest corner of Catalonia bordering with the regions of Aragon in Spain, and the Midi-Pyrénées in France (fig. 1). The Pyrenean Belt forms a natural barrier that historically has limited communication with neighbouring lands. The Garonne River´s headwaters are to be found in the Aran valley, though three different locations have been proposed as the principal source, even one of them located on the slopes of the Aneto Peak in the Aragonese Pyrenean side, flowing by way of a sink hole known as the "Forau de Aigualluts". After about 4 km of underground route through a karstic system, water emerges away at the "Uelhs deth Joèu" on the other side of the mountain in the Aran Valley.

The Garonne follows the Valley northwards into France by the Haute-Garonne department, breaks through Aquitaine land and flows into the Atlantic Ocean near Bordeaux. The river is the main communication route of the Valley reason by why connection with the south of Aquitaine has been easier than other territories. During Roman times, the Aran Valley was part of the Gallo-Roman territory of *Novempopulania* at the end of the 3rd century AD, with its capital in *Elusa* (current Eauze).

From that time numerous stone testimonies are preserved such as steles, tombstones, votive altars, etc. The existence of Roman remains in the Aran Valley is known for a long time, drawing the attention of scholars of the 19th century (Gourdon 1884). Ancient artefacts were frequently reused in walls of Romanesque churches along the territory, which impede their spatio-temporal contextualization. Currently, several of them are exhibited in the "Musèu dera Val d'Aran" at Vielha, the capital of this territory.

Nearby well known Roman marble quarries are those of the Saint Béat district, about 35 km north from Vielha. Traditionally, without any archaeometric analysis, there was thought that marbles from Saint Béat were the raw material of all the Roman marble pieces found

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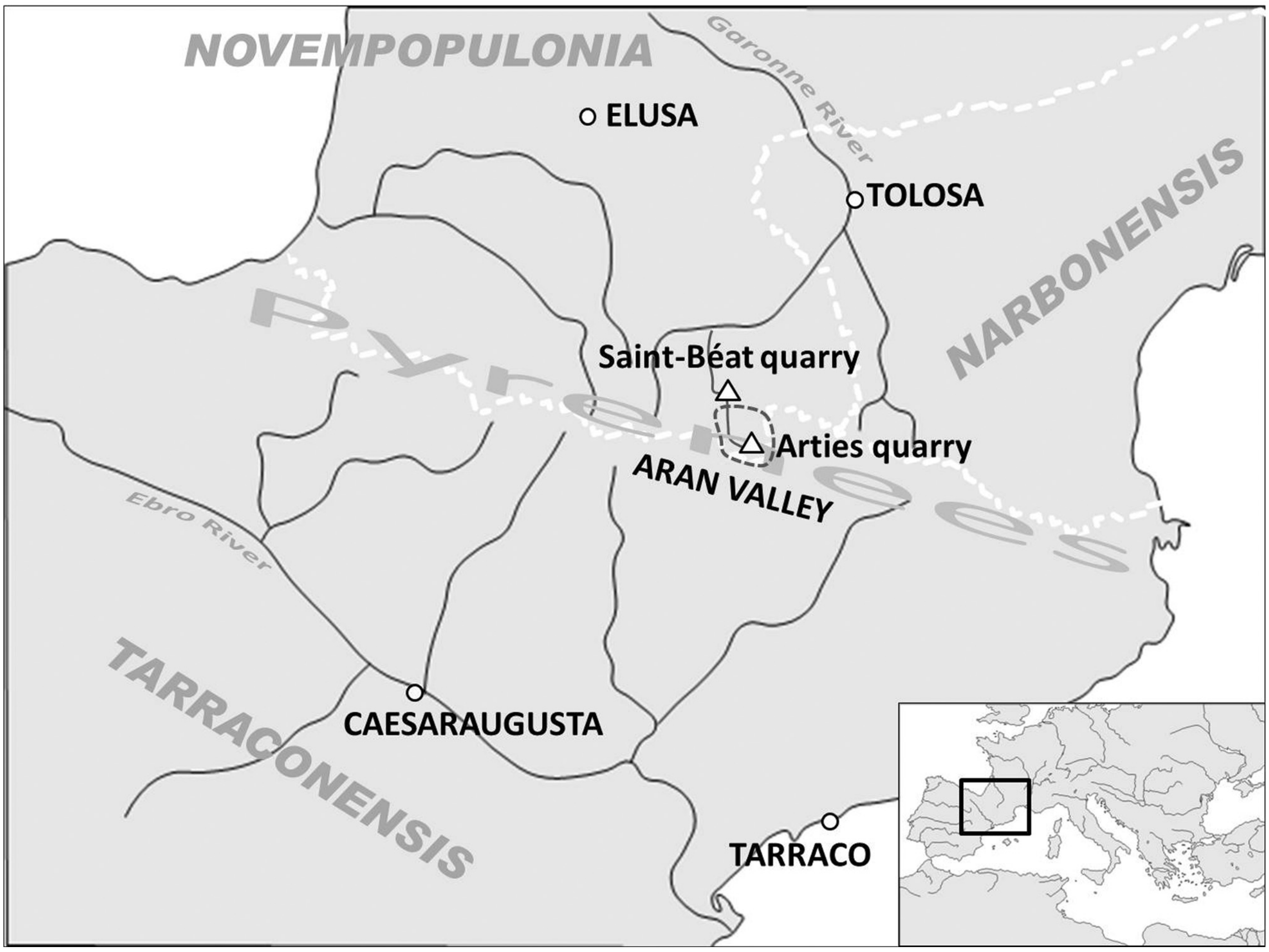

Fig. 1. Historical and geographical contexts. The location of the Arties quarry, in the Aran Valley, and the district of Saint-Béat quarries are shown.

in the Aran Valley. However other local marble exploitation has been recognized in the area, as that located in the village of Arties, about 6 km east from Vielha. Additional marble outcrops in the Valley seem to be sporadically used as building materials and especially for the Romanesque churches dispersed over trough the Valley.

The main objective of this contribution is the marble characterization of the Arties quarry by a multi-method approach to differentiate from Saint-Béat varieties. The study includes macroscopic and microscopic petrographic analysis, optical-CL and the determination of the C and O isotopic signature. The final aim is to assign the marble provenance of a set of selected archaeological artefacts applying the same methodology.

The identification of marble provenance was carried out comparing the analytical data obtained with a wide marble collection, whether the published Hispanic quarries (Lapuente *et al.* 2000, Àlvarez *et al.* 2009), or published and unpublished data[6] of certain Pyrenean quarries (Costedoat 1995) and from the most important Mediterranean extraction sources (Herz 1985, Gorgoni *et al.* 2002, Attanasio *et al.* 2006) exploited in antiquity.

Geological Setting

From the geological point of view, the Aran Valley is a Silurian-Devonian Synclinorium (Zwartz 1979) situated in the northern side of the Axial Pyrenean Zone, the metamorphic and igneous basement of the Pyrenees. In the Axial Zone, Palaeozoic rocks crop out with superimposed Variscan and Alpine deformations. Hercynian structures are recognized in two principal parts of the crustal basement, a medium to high-grade infrastructure and a low-grade suprastructure. From the North to the South, in this part of the Axial Zone, three structural domains have been distinguished. They are the so called Garona-Bossot Dome, the Aran Valley Domain and the Alta Ribagorza Domain (De Sitter, Zwart 1962). The first one is part of the infrastructure of the Pyrenean Belt in which the outcropping rocks show medium-to-high grade metamorphism with Variscan north-vergent

6. These quarries are currently under study by H. Royo, one of the authors of this paper, as part of his PhD degree.

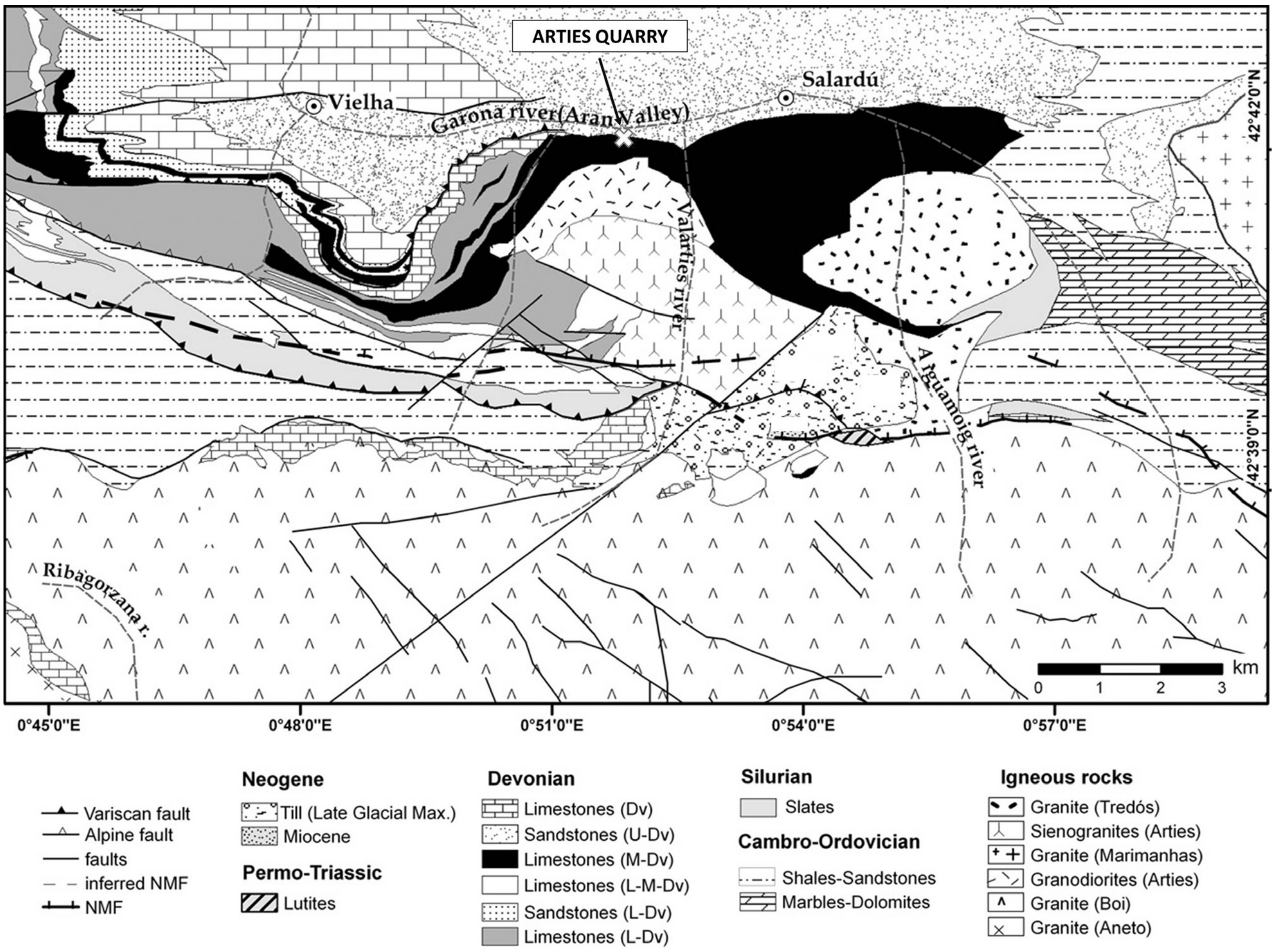

Fig. 2. Geology of the area around Arties Quarry (modified from Ortuño *et al.* 2008, 249). Arties quarry outcrop is located near to Arties granite that intrudes the Devonian limestones with development of marbles, within its aureole of contact metamorphism, unmarked on the map.

recumbent folds and associated subhorizontal foliation. The Aran Valley Domain is located within the suprastructure and the main Variscan structures are upright folds, with an associated, mainly steep-lying, foliation with low grade syntectonic regional metamorphism. The boundary of the Garona Dome and the suprastructure is a "décollement" level observed at the base of the Silurian deposits (Garcia-Sansegundo 1996). The third domain named the Alta Ribagorza Domain, is also part of the suprastructure and the difference with the previous is the important development of Alpine structures.

The outcropped rocks in the Aran Valley are mainly folded Devonian series in which two main deformation phases have been recognized. The first are E-W trending and northward vergent asymmetric folds and the second comprises N-110-E trending upright or south-vergent folds that are responsible for the current configuration of the Aran Valley Synclinorium.

The Devonian rocks form a thick series with remarkable facies changes, ranging from siliciclastic in the northern area, to slates and limestones in the middle and south zones. The marble quarry of Arties is located in the southern limb of this Synclinorium, where the marble outcrop derived from Devonian carbonate sequences was affected by the contact metamorphism associated with the intrusion of Variscan plutonism (fig. 2).

The Maladeta granitic batholith is one of the most voluminous Hercynian intrusions from more than twenty emplacements placed in the Pyrenees during the Variscan orogeny. It is a complex granitic mass composed of four principal juxtaposed plutons, each one being normally zoned and two differentiated units, the Aneto and the Bohí, have been documented (Charlet 1977; Arranz 1997). In this latter unit, granites range mainly from granodiorites to monzogranites, but tonalites, diorites and gabbros have been locally recognized (Tahüll facies) and a great variery of different stocks of sienogranites and granites s.s. occur. The thermal metamorphism is post-Westphalian but pre-Permian since the Permo-Triassic conglomerates frequently bear granite pebbles from the erosion of the batholiths. In these aureoles, metamorphism produced from only pure recrystallized calcite (marbles) to calc-silicates with idocrase-diopside-wollastonite-grossularie or quartz-epidote-calcite, both in the calcareous sequences, and andalucite-cordierite in the pelitic ones. Chiastolite passing to sillimanite has been recognized in the Siluri-

Fig. 3. View of Arties quarry front, seen from the north side. Samples were taken on the embankments of the actual access ramp located in the foreground.

an ampelitic sequences. All the Maladeta Massif were tectonic affected and locally sheared with mylonites production along a complex fracture lines of Variscan age reactivated during the Alpine times. In this particular part of the Axial zone different main faults and thrusts with E-W Pyrenean direction have been recognized (fig. 2).

Arties Quarry

One of the smaller plutonic masses of the Maladeta Massif is the Arties granite, composed mainly of granodiorite and sienogranite lithotypes. It occurs in the most northern part of the Bohí unit and intrudes the Devonian limestones of the Aran Sinclynorium with development of marbles within its aureole of contact metamorphism.

The marble outcrop is mostly covered by vegetation but its northern front is opened with easy access to the way which runs along the Garonne River. It is situated no more than 500 m west from the village of Arties.

Nowadays, the extraction front measures about 175 meters long and 45 meters high (fig. 3) and after visual inspection, no marks or evidence of ancient work were found. It is known that was sporadically active and recently was reopened to extract stone for the restoration repairs of the Romanesque church of the village.

Marble from this quarry is predominantly veined, with white and grey bands and a bluish-grey hue (fig. 4). As it is affected by intensive joints, the size of the extracted blocks, with certain exceptions, is limited to less than 1 m^3. Depending on the banded distribution, it can be found areas where only greyish white marble occur.

Analytical characterization of arties marble

Regarding methodology, marble characterization and provenance determination were carried out using a sequential approach, taking into account petrography and CL as the first step, and combined with the value of C and O stable isotopes.

Petrography was systematically applied for studying the macroscopic and microscopic features of the marble stone. After visual examination, colour and main mineral components with their relative grain size and orientation and distribution were characterized. The polarizing optical microscope was used to determine a set of mineralogical and textural parameters with a particular diagnostic significance for marble discrimination (Lazzarini *et al*. 1980; Gorgoni *et al.* 2002). Particular attention was paid to the grain size, measuring the maximum grain size (MGS), and their fabric with the grain boundary shape (GBS) and the identification of deformation microstructures. A stain with Red S Alizarin allowed calcite and/or dolomite identification.

Optical CL analysis was carried out using CL8200 Mk5-1 equipment coupled with a NIKON Eclipse 50iPOL optical microscope. The electron energy applied to the thin-sections was 15-20 Kv and the beam current was operated at 250-300mA. The observed CL-patterns were registered taking digital photograph using an automatic digital NIKON COOLPIX5400 camera. The combination of petrography and CL has been proved in various areas of Classical quarries in Greece, Italy and Turkey (Barbin *et al.* 1989, 1992), assisting the

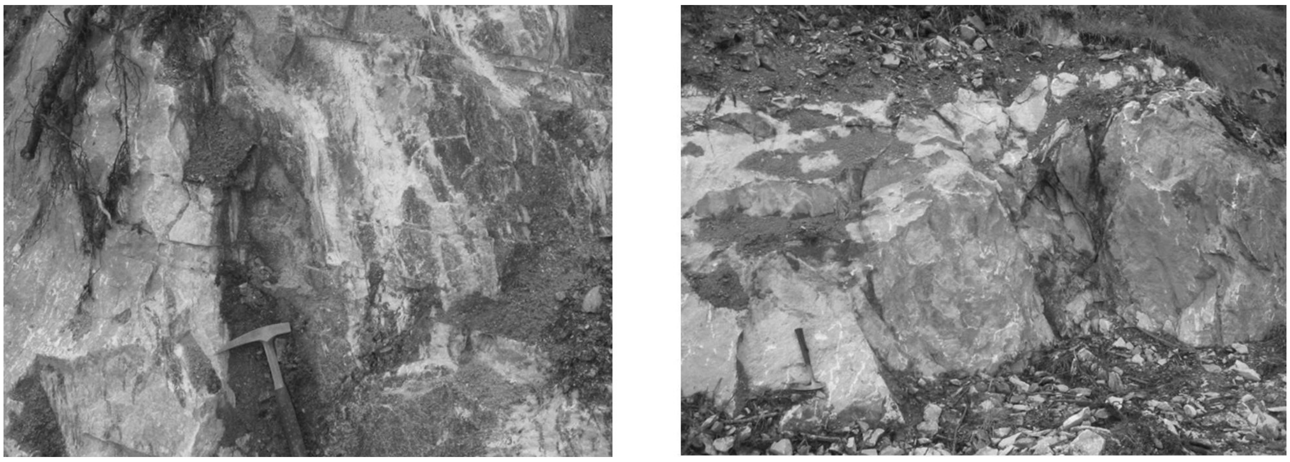

Fig. 4. Two different views of the Arties marble outcrop. On the left, detail of the grey-white banded predominant variety. On the right, an area of greyish white variety, with scarce narrow greyish veins.

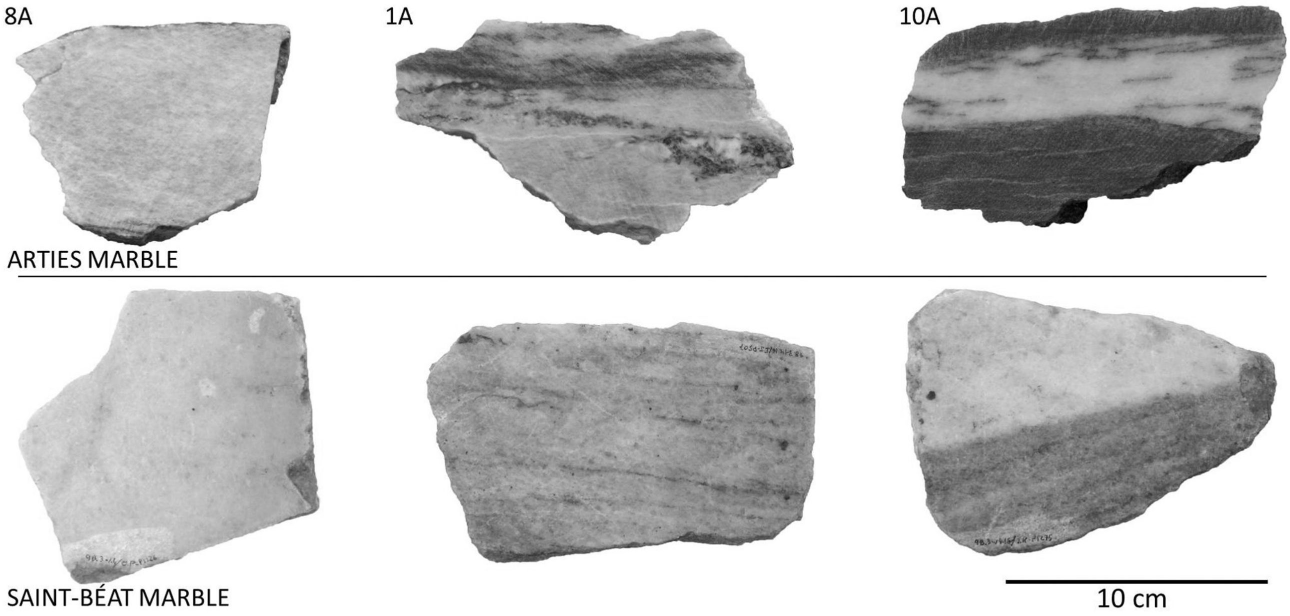

Fig 5. Visual appearance of Arties quarry samples (upper raw). The variability observed in the marble of Saint-Béat is also shown for comparison (lower raw).

study of marble provenance when isotopic ratios of different quarries overlap.

Oxygen and carbon stable isotopes were determined on the calcitic marble samples by isotope ratio mass spectrometry with Finnigan MAT 252 equipment. A Finnigan MAT Kiel II automatic preparation device was previously used for phosphoric acid digestion at 72ºC and CO_2 purification, according to the procedure suggested by McCrea (1950). The results were expressed in terms of usual delta notation ^{13}C and ^{18}O in ‰ relative to the international reference standard PDB (Pee Dee Belemnite).

Macroscopic features

Arties marble is coarse grained and greyish white or light grey in colour. It often appears veined with irregular centimetric grey bands. The visual appearance of the quarry samples is shown in fig. 5. They exhibit different grey tones, bluish-grey and even some dark greys. These all show a peculiarity on the polished surface: an evident orientation of the larger grains, presumably calcite crystals, without any other macroscopic component.

Petrography

Under the optical microscope, Arties marble is composed of calcite and shows an anisotropic fabric with heteroblastic mortar texture (fig. 6). The megacrystals display the typical microstructure of a low-strained mylonite where porphyroclasts are abundant and appear completely surrounded by dynamically recrystallized grains, producing a core-mantle texture. The maximum grain size (MGS) is up to 10 mm while the average larger crystal size is 3.5 mm. Small crystals have an average size of 0.2 mm. Grain boundary shape (GBS) is mainly curved or concave-convex between the small crystals. These become included in the larger ones. The porphyroclasts show elliptical shapes with a preferred orientation of their longer axes, undulose extinction and deformed bent twins. Rotation and stretching of twinned porphyroclasts produced a very strong shape preferred orientation which is very distinctive of Arties marble. Rare small single crystals of dolomite and opaques have been occasionally observed. The anisotropic fabric and their dynamic recrystallization agree with the presence of shear zones and main tectonic faults concentrated in this northern contact of the Maladeta Massif.

Cathodoluminescence

The optical-CL of calcite in Arties marble shows a luminescent pattern with homogeneous distribution, medium intensity and characteristic dark orange colour (fig. 7). Some of the smaller crystals have a higher intensity that produces a distinctive mottled CL-pattern, around the larger crystals which are very homogeneous. Slight variations in the homogeneous CL intensity are observed in some samples, with moderately strong or even strong intensity.

C and O isotope signature

Isotopic data of Arties marble range from –4.44 to -3.53 ‰ (^{18}O) and from 0.77 to 1.56 ‰ (^{13}C). This isotopic signature is compared with that of the Saint-Béat marble in the diagram for the medium to coarse grained marbles (fig. 8).

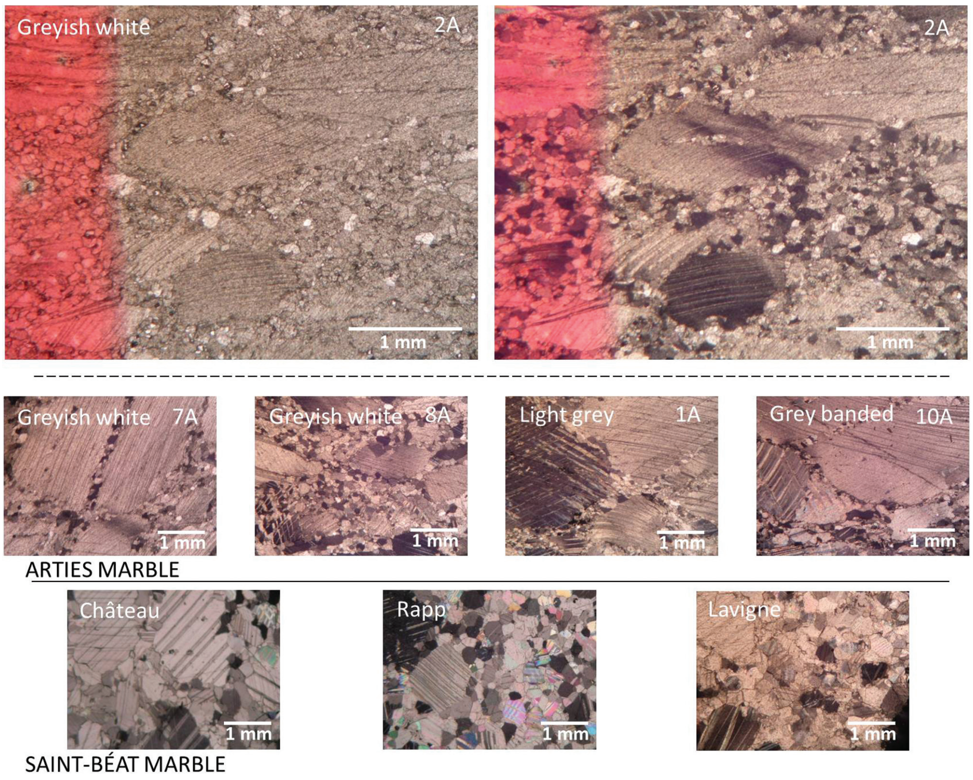

Fig. 6. Microscopic aspects of the Arties marble, in parallel (left) and crossed nicols (right), are shown in the first row: calcite marble composition (stained with Red-Alizarine), heteroblastic mortar texture (low-strained mylonite), orientated porphyroclasts, undulose extintion and deformed twins. In the second and the bottom rows (crossed nicols), different textural views of the Arties varieties and Saint-Béat marble of three different quarries are displayed for comparison.

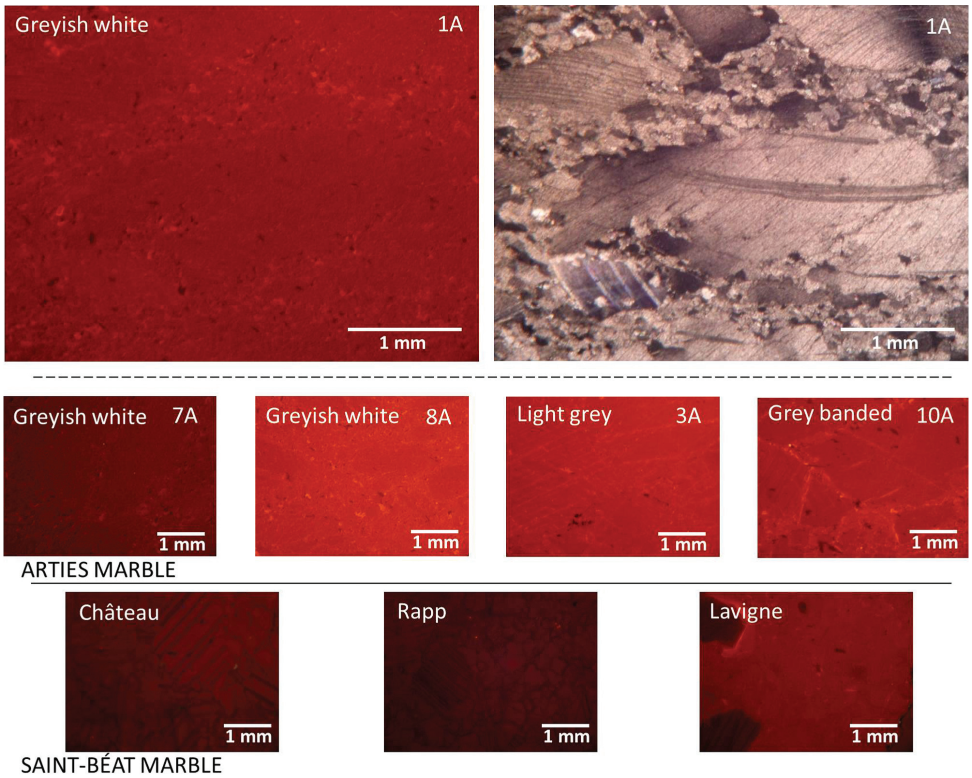

Fig. 7. Cathodoluminescence images of Arties and Saint-Béat quarry marbles. Homogeneous distribution and moderately strong CL intensity (first row, left) with the same view in crossed polarizers (right). The variability on the CL-pattern is shown in the second row and those from Saint-Béat marble in the bottom.

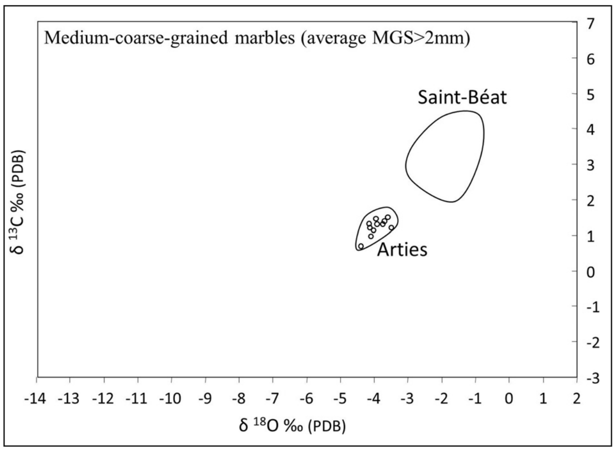

Fig. 8. C and O isotope signature values of Arties quarry samples and their distribution field along with an update of the Saint-Béat marble isotopic field for comparison.

Discriminating criteria from saint-béat marbles

The comparative study to discriminate Arties marble has been carried out considering that under the denomination of Saint-Béat marble have been included three quarry fronts located nearby Saint-Béat village. Following the same denominations proposed by Costedoat (1995), these fronts are called Château (from Cap du Mont on the right bank of the Garonne river), Rapp and Lavigne (from Mont Rié on the left bank). Visually in hand specimen, Arties marbles exhibit similar colours and veined patterns to that of the greyish varieties of Saint-Béat marbles (fig. 5). Only on a polished surface is possible to discriminate between both, through the typical oriented megacrystals presented in Arties marbles. Under the optical microscope, their patent crystal orientation, shown in fig. 6, makes a distinctive microstructure. Conversely, Saint-Béat marbles though also exhibit typical mortar texture, proper of dynamic recrystallization; their microstructures of deformation do not show a preferred orientation (fig. 6). Comparing both CL-patterns, Saint-Béat marble exhibits a faint homogeneous intensity in calcite, which is discriminatory in many cases (fig. 7). In other ones, the faint intensity has a heterogeneous distribution and dark relicts appear into the macrocrystals. In fig. 8, the isotopic signature of Arties marbles has been checked with the updated Saint-Béat isotopic field based on our own unpublished data, and with the isotopic clusters previously known (Costedoat, Alvinerie 1990; Costedoat 1995). The isotopic fields of Arties and Saint-Béat marbles are clearly separate each other.

Finally, it must be emphasized that both marbles, Arties and Saint Béat, affected by dynamic metamorphism are well discriminated combining the microscopic fabric-texture together with the CL-pattern.

Archaeological artifacts from the aran valley

Thanks to the collaboration with the "Conselh Generau" and the "Musèu dera Val d'Aran" of Vielha, five of the most significant archaeological marble artefacts found in the Valley were sampled (fig. 9). They correspond to four Roman front urns or tombstones and one votive altar. Three marble pieces are exhibited at the museum and two belong to a private collectio[7]. They have been previously retrieved from Romanesque church walls. At least, three more pieces of similar features still remain embedded in walls of different churches of the Valley.

They are carved from white to whitish, or banded in white and grey, coarse grained marbles visually similar to Saint-Béat marbles. Fig. 10 shows the list of pieces, their chronology and macroscopic features.

In spite of having more local accessible marble outcrops in the Aran Valley, with evident use in the construction of Romanesque churches, until now their possible use in Roman times has not been considered. However, suspicions were raised after visual inspection of the marble quality of the Roman artefacts. One of

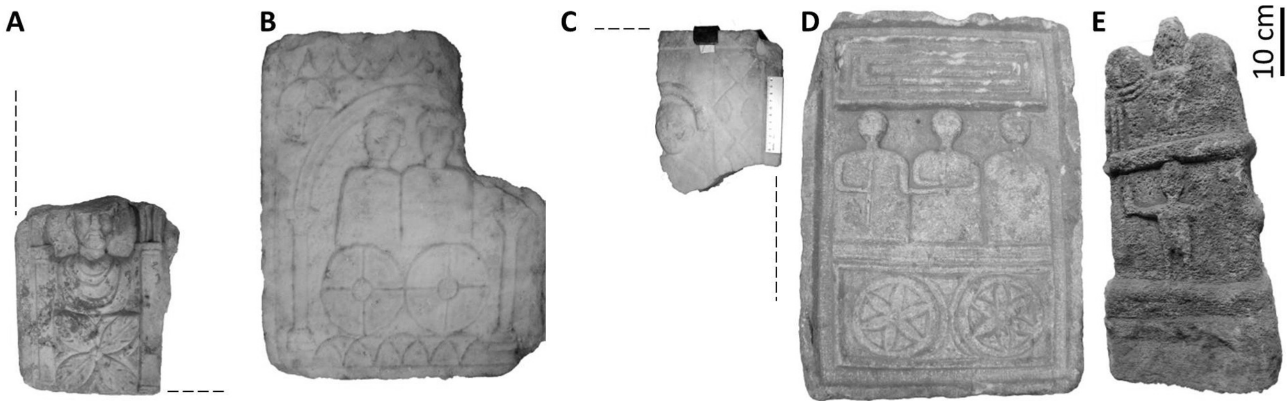

Fig. 9. Archaeological artifacts sampled from the Aran Valley (Val d'Aran). Four frontal of urn (A, B, C and D) and one small altar (ara) (E).

7. Our thanks to Francisco Jaquet for facilitating the sampling.

Sample	Archaeological Artefact	Current location	Location of the finding	Chronology	Stone type
A	Frontal of urn	Arties - private property	Montcorbau	2nd - 3rd cent. AD	White marble
B	Frontal of urn	Vielha - Musèu dera Val d'Aran	Gausac	2nd - 3rd cent. AD	White marble
C	Frontal of urn	Vielha - Musèu dera Val d'Aran	Gausac	Middle 3rd cent. AD	White marble
D	Frontal of urn	Arties - private property	Arties	3rd - 4th cent. AD	White marble
E	Small altar - ara	Vielha - Musèu dera Val d'Aran	Betren	3rd - 5th cent. AD	White marble

Fig. 10. List of the studied pieces.

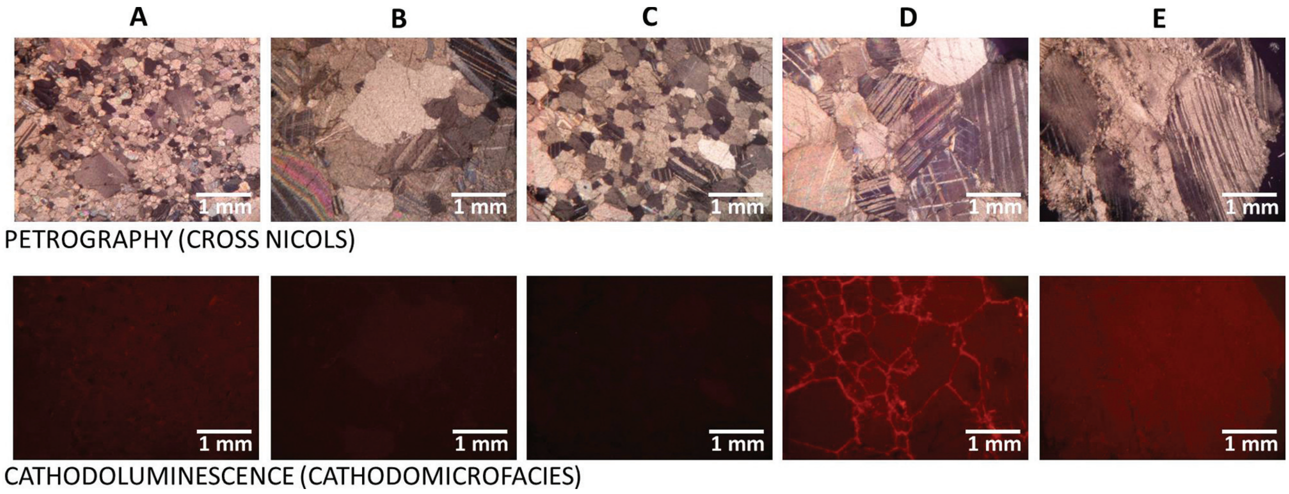

Fig. 11. Microscopic aspects in crossed nicols, and cathodoluminescence images of the studied archaeological artefacts.

them exhibits a coarse grain size which made a rough carving style, slightly different from the rest. Another point to be taking into account, which could reinforce the possible Roman use of the quarry, is the existence in the area of a baths complex, currently abandoned, located right beside the old Roman road that runs along the Valley (Márquez Pérez de Aguilar 1878, 11-12; Cots i Casanha *et al.* 1990, 132).

Marble sources and evidence of roman use

The petrographic and CL features of the five archaeological artefacts were compared with those from quarries used in antiquity, both Pyrenean and Hispanic and with the most important Mediterranean quarries (fig. 11). Isotopic analysis has been used complementally, to aid the next step marble identification (fig. 12).

As figures 11 and 12 show, samples A B, and C exhibit common features and therefore they can be assigned to the same marble source. Comparing with petrographic-CLpatterns of the quarry marbles, they match well with Saint-Béat marble. In the isotopic diagram, they are also fall into the restricted isotopic field of Saint-Béat quarry fronts reinforcing the assignment of this marble source. Their chronology ranges from the 2nd to the 3er century AD, which is concordant with the date of the exploitation of these Gallo-Romain marbles.

Concerning sample D, their petrographic and CL characteristics differ from those of the local quarries examined. Its isotopic signature match with several well known Classical marble sources but is completely different from the petrographic point of view. However, though the marble provenance remains unknown, the possibility of being another local raw material is not rejected. At this respect, it must be emphasized that other marble outcrops in the area, with quality suitable for sculpturing purposes, could have been exploited, if not with a regular extraction, perhaps temporally used, especially those closer to the *villas*.

Regarding marble provenance of sample E, the petrographic and CL features are identical to those described for marbles of Arties quarry. However its isotopic signature plotted on the diagram does not fall into the Arties isotopic field which has been defined with 10 quarry samples. On the other hand, the isotopic data of the archaeological sample also fall outside the Saint-Béat isotopic field (fig. 12). Therefore taking into account the complete similarity in petrographic and CL features, this sample E points to an Arties marble source.

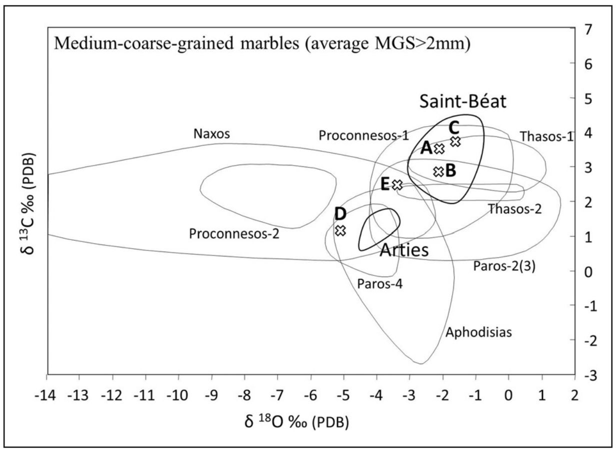

Fig. 12. C and O isotope signature values of archaeological samples with the distribution fields of Arties quarry determined in this work, and update of Saint-Béat and the most important Mediterranean classical marbles (Gorgoni *et al.* 2002), all compatible with a MGS coarser than 2 mm.

Summarizing, according to the multi-method approach, three samples (A, B and C) have been clearly recognized as the variety of white Saint-Béat marble. With respect to piece D, its marble quarry is at the moment uncertain, but other local sources are being studied which could produce more positive results. The marble origin of piece E is certainly ascribed to the quarry of Arties in the Aran Valley, after petrographic and CL features. This conclusion is somewhat failing on the ^{13}C isotope signature compared to the data of the quarry marbles taken in a modern extraction face. However in this case, petrography complemented by CL is a discriminate approach to distinguish Arties from Saint-Béat marbles.

It should be pointed out that this is the first testimony of using Arties marble in Roman times, in agreement with the archaeological hypothesis. Its late chronology, from the 3rd to the 5th century AD, must be also taking in consideration along with other factors as the coarse grain size and the limits on the dimensions of extracted blocks which could have been inhibited an extensive use. On the other hand, the nearby district of Saint-Béat, where better quality marble was regularly exploited, at least from the 1st century BC (Sapène 1946; Fabre, Sablayrolles 1995), is certainly another point to bear in mind to understand the wide distribution not only along the Aran Valley, or over other Gallo-Roman territories, but also on the southern side of the Pyrenees.

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