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An archaeometric study of the Monument to Augustus of Saint-Bertrand-de-Comminges :
marble provenance and *in situ* pigment analysis

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Abstract

An in-depth archaeometric study was undertaken on the Monument to Augustus (Saint-Bertrand-de-Comminges, Occitanie, France), focusing on both the provenance of the marble and the analysis of the pigments in order to answer the questions about the original layout of the Monument and the quarry (ies) that supplied the marble used to create it. A multi-method protocol including petrography, cathodoluminescence, isotope and elemental analyses, as well as NMR was applied to identify the marble provenance. The results indicate that the marble used to sculpt the whole ensemble came from the same quarrying site, one of the Saint-Béat quarries, as suggested by the strong homogeneity in most of the isotopic and elemental data. Pigment analysis using hyperspectral imaging and portable XRF revealed that red ochre was widely used, sometimes combined with lead-based pigments to produce various shades. Overall, this archaeometric study suggests that the different elements of the Monument were created within the same time period and by the same craftsmen, although some questions remain regarding its exact location and the nature of its original structure. However, the question of whether or not all the pieces studied belongs to the same Monument remains unanswered.

Introduction

The Monument¹ to Augustus of Saint-Bertrand-de-Comminges is a remarkable group sculpture composed by free-standing captives and mannequins with weapons, that caught the attention of scholars and researchers since its discovery. This small town located in the Haute-Garonne department (France) is built partly on the ruins of the ancient *Lugdunum*

¹ In the present work the term “Monument” will be used to refer to the whole group of sculptures, while the term “trophy” will be used to refer to the various component parts of the Monument itself, i.e. three trophies - Naval, Gallic and Hispanic- and a Victory (*vid. infra*).

Convenarum, the city of the Convenes founded by Pompey in 72 BC at the foot of the Pyrenees (May, 1996). Excavations carried out by Bertrand Sapène² between 1926 and 1969 at the foot of the actual town unearthed an impressive collection of marble sculptures: up to 134 fragments, almost two-thirds of a triumphal monument, were unearthed (Schenk-David, 2003; Boube, 1996), most of which showed evident signs of having been cut up to be used for lime production.

Various hypotheses about the original appearance of the monument have been put forward over time, thanks to discoveries made during new excavations (Sapene, 1932; Picard, Ch., 1933; Picard, G. CH, 1957; Boube 1996; Schenck-David, 2003). All of these representations depict three distinct parts arranged linearly: a Gallic trophy, symbolising Augustus' victory over the Gauls, a Hispanic trophy representing his victory over the Cantabrians and Asturians in Spain, and a central Naval trophy.

However, the question of the Monument's original arrangement still remains unresolved. The location of the various fragments found during the excavations does not provide information about the Monument's position within the urban layout of the ancient town, nor whether the three parts (Gallic, Hispanic and Naval) belonged to the same monument indeed. There is also debate regarding the discovery of two different fragments representing a Victory: one depicting a torso with left arm on one side, and another one depicting a left leg preserved up to the knee (Fig. 1). Since no point of contact between these two fragments has been observed, two alternative options are possible: were they part of one same statue, as some scholars believe (Sapène, 1932; Boube, 2011)? Or did they belong to two separate statues, as proposed by G-Ch Picard (Picard, G.-Ch., 1957)? Additionally, the in-depth study of the style of the Victory (or Victories) has led to suggest that they may even belong to a different monument (Schenk-David, 2003).

The current presentation of the Monument at the Archaeological Museum of Saint-Bertrand-de-Comminges³ (Schenk-David, 2017; Schenck-David, 2003) reflects the latest excavation findings (Guyon et al., 1991), with the different parts of the Monument displayed separately: the Gallic trophy, the Hispanic trophy, the Naval trophy and the Victory (ies) (Figure 1).

All parts of this ensemble are made of white marble. whose colour and crystalline, saccharoidal appearance suggest that it comes from local quarries, particularly those of Saint-Béat (Sapène, Bertrand, 1947). Although this marble has some characteristics similar to those from Luni or Paros (Bedon, 1984), this local provenance, and more specifically from the Cap-de-Mont quarry was proposed by C. Costedoat (Costedoat, 1992), who conducted the first archaeometric study on four different fragments taken from various parts of the Monument: the Victory base, the Gallic base, the Naval trophy and the Gallic prisoner (see Figure 1, T1-3 and V1).

By consensus, many authors date the exploitation of the Saint-Béat quarries to at least the time when the Monument was being built (Bedon, 1984; Bessac and Sablayrolles, 2002). An inventory of quarries around Saint-Béat has already been proposed (Fabre and Sablayrolles,

² The archaeological excavations that uncovered fragments of the monument were carried out on the remains of the ancient city of Lugdunum Convenarium in 1926 by the Société Archéologique du Midi de la France. A summary of the excavation reports is available in (Lizop, 1935).

³ Musée Archéologique départemental, Ancienne gendarmerie, 31510 Saint-Bertrand-de-Comminges, France. Since the publication of J.-L. Schenck in 2003, the Augustean trophy moved from the Olivetain monks' convent to the actual museum but the general layout has been respected.

2002); however, it is difficult to identify which of them were exploited during antiquity due to their prolonged use over time (Royo, 2016). Nevertheless, evidence of ancient quarrying still exists, and two sites in particular have revealed traces of use linked to Roman times. They both are located on the left bank of the Garonne River: the Puy de Géry quarry which still bears scars of ancient exploitation and from which a few large marble blocks were likely extracted (Fabre and Sablayrolles, 2002), and the Rapp quarry, located at the top of the Mount Arrie; ancient traces of exploitation were fortuitously discovered there when the Société des Produits Azotés⁴ began clearing the northern face of this quarry, already known as “the Mailh de las Figuras” (Fabre and Sablayrolles, 2002). Unfortunately, this site was destroyed shortly after its discovery by an explosion linked to the quarry’s use for lime production (Sapène, 1947).

The present work continues previous research on this Monument in light of recent progress in archaeometric studies, attempting to answer two main questions. The first concerns the Monument itself: can we gather new arguments regarding whether the Victory, according to E. Boube (Boube, 1996) or the two Victories according to G.-Ch. Picard (Picard, G.-Ch., 1957) belong(s) to the Monument? Or should we consider that the Victory (or Victories) is(are) not part of it, as J.-L. Schenck proposes on archaeological, stylistic, and historical grounds (Schenck-David, 2003)?

To address this first, albeit ambitious, question required an analytical approach on fragments specifically selected from different parts of the Monument using an analytical strategy already described in previous works (Gutiérrez Garcia- M. et al., 2019; Pianet et al., 2019; Pianet et al., 2023). This strategy, which eliminates some sources step by step to arrive at a comprehensive proposal regarding provenance, can also be applied to a series of samples to determine whether or not they all come from the same deposit.

The second question concerns the quarries that supplied the marble for the creation of this Monument. Although the use of marble from Saint-Béat, where numerous white marble quarries have already been identified, has been confirmed, the analysis of a group of artefacts collected in a well-documented context can also provide new information about Roman quarrying in this area, notably providing clues about quarries exploited during antiquity whose existence is not yet known.

To obtain reliable results in determining the provenance of the quarries that supplied the various elements constituting the Monument, the strategy combines traditional methodologies (Lapiente Mercadal 2014; Antonelli and Lazzarini, 2015; Al-Bashaireh 2021): petrography and measurements of the isotopic ratio of carbon and oxygen, quantification of minor elemental contents and ¹³C NMR. This approach necessarily involves the creation of a reference database as comprehensive as possible of marbles of the Saint-Béat region. The combination of independent data, processed separately or collectively, enables the determination of the marbles' origins.

Moreover, the Monument also shows clear traces of colour, which is quite uncommon not only in the area but on white marble sculptures in general. They range from pink to red to red-brown, as already remarked a few years after its discovery and recording by E. Boube. Archaeological sources also report that the colour has slowly faded over time (Boube, 1996). Today, traces are still visible on several sculptures of the trophies: in particular, on the male

⁴The Société des Produits Azotés (SPA) was a company located in Saint-Béat near to the Rapp quarry.

and female (Gallia) captives, and on the mannequin of the Gallic trophy; on the female captive (Hispania) and trunk of the Hispanic trophy; on the eagle of the Naval Trophy, and on the foot support of the Victory. To complete the archaeometric study of this symbolic work which had its place in the *Ornamenta* of the cities of Roman Antiquity (Schenck-David, 2003; Schenck-David, 2017), an unprecedented non-invasive chemical analysis was carried out to study the aforementioned traces of polychromy.

Materials and Methods

Sampling

Samples from the Monument: 16 samples were taken to cover most of the different parts of the Monument so that the archaeometric study could be as representative as possible. The sampled areas are displayed in Figure 1 and reported on Table S 1. Each sample was taken from unsculpted, not visible, not altered and where it was possible to extract a small piece easily using a chisel and hammer, in agreement with the curator. A detailed description of the sampling of the various elements of the Monument can be found in the Supplementary Materials (S2).

Samples from quarries: a total of 40 samples were selected as follows:

- 10 samples collected at the “Chateau” quarry, located on the right bank of the Garonne in the commune of Saint-Béat (Cap-de-Mont);
- 10 samples collected at the “Lavigne” quarry, located opposite the previous quarry and on the other side of the river (Mont-Rié); and
- 11 samples from the quarry located in the commune of Marignac.

8 representative samples of the ancient “Rapp” quarry, that come from 8 altars known to have come from this quarry thanks to the description and photographs taken by Bertrand Sapène (Sapène, 1947); these altars are currently deposited at the Musée Archéologique of Saint-Bertrand-de-Comminges, where they were sampled under the strict supervision of the curators in charge. These altars were used as a reference for the Rapp quarry, which was accidentally destroyed in 1946, as explained in the introduction.

To these 39 samples analysed in the present work, were added the isotopic values obtained by H. Royo Plumedon 35 more samples coming from the quarries studied herein : (Royo Plumed, 2016)

The localization of these quarries is reported on Figure S3.

Marble provenance

The analytical strategy developed combines petrographic, cathodoluminescence, and isotopic ratio data with elemental analysis and ^{13}C NMR as previously described (Gutiérrez García- M. et al., 2019; Pianet et al., 2019; Pianet et al., 2023).

Petrography. The preparation of the thin sections was carried out by the team at the Autonomous University of Barcelona. These thin sections were subsequently stained with Alizarin Red-S to detect the presence of dolomite. The petrographic observation was carried out using a Nikon Eclipse 50iPOL microscope with a coupled Cmax DC-10000-P digital camera (ICAC facilities).

Cathodoluminescence. The cathodoluminescence microscopy (CL) was performed on the same polished thin sections observed by POM; a state-of-the-art optical CL device,

CATHODYNE (NewTec Scientific, Nîmes, France), with an accelerating voltage ranging between 9 and 11 kV and a current intensity between 230 and 240 μA was used. The images were captured with a 2.5x lens, with the following camera control parameters: Shutter speed (acquisition time): 1 second (sometimes longer when the response is very low), Main gain: 10x, Red gain: 2.0x, Green gain: 1.0x, Blue gain: 1.9x.

Isotopic analyses. The extraction of CO_2 was carried out using a Kiel III device, manufactured by Thermo Finnigan (Scientific and Technological Centres of the University of Barcelona facilities). The carbonate samples (50 to 65 μg) were treated with phosphoric acid (100%) at a temperature of 70°C. The reaction time was 4 minutes. The Kiel Carbonate III device is connected to a MAT-252 isotope ratio mass spectrometer, also manufactured by Thermo Finnigan, where the analysis of the produced CO_2 takes place. The calibration of the results was performed using the following internal standards: RC-1 ($\delta^{13}\text{C}$ V-PDB = +2.78‰, $\delta^{18}\text{O}$ V-PDB = 2.08‰) and CECC ($\delta^{13}\text{C}$ V-PDB = -20.77‰, $\delta^{18}\text{O}$ V-PDB = -17.56‰). These internal standards were calibrated against the following international standards: NBS-18 ($\delta^{13}\text{C}$ V-PDB = -5.1‰ and $\delta^{18}\text{O}$ V-PDB = -23.2‰) and NBS-19 ($\delta^{13}\text{C}$ V-PDB = +1.95‰ and $\delta^{18}\text{O}$ V-PDB = -2.20‰). The error associated with the results is generally less than or equal to ± 0.02 delta units for $\delta^{13}\text{C}$ and less than or equal to ± 0.06 delta units for $\delta^{18}\text{O}$.

Elemental analysis by ICP-OES. Around 100 mg of each of the samples, with the exception of SBC 7 and 8 for which no sufficient quantity of material was taken, were demineralized in order to measure the content of the following 8 elements: Al, Mg, Mn, Si, Ti, Sr, K, Fe, according to the protocol described previously (Gutiérrez Garcia- M. et al., 2019). The solutions were analysed using a Varian ICP-OES 720ES (ICMCB Bordeaux facilities). The contents are expressed in ppm (w:w).

^{13}C NMR. The different samples were powdered and used to fill up a 4 mm diameter CP-MAS rotor. ^{13}C NMR spectra were recorded on a 400 MHz Bruker Avance II spectrometer equipped with a CP-MAS probe (CESAMO facility) using a simple one pulse sequence using a 90° nutation angle of 5 μs , a relaxation delay of 300s and a scans number of 32 as previously described (Gutiérrez Garcia- M. et al., 2019).

Statistic process. All collected data were analysed with R version 4.2.0 (2022-12.0+353) (R Core, 2022) using the dimensio 0.2.2 package (Frerebeau, 2021).

***In situ* pigments analysis**

Portable digital microscopy (DM). A portable microscope Dino-Lite (AM7915MZT) connected to a computer via USB cable was used for image acquisition in different areas of the Monument showing traces of colouring matter (See Figure 1). Observations were conducted at different magnifications (approximately 50x and 200x) with a 5-megapixel resolution. The captured images were processed using the DinoCapture 2.0 software.

Visible Near Infrared Hyperspectral Imaging (Vis-NIR-HSI). Hyperspectral imaging enables the detailed spectral analysis of materials across a large area by recording a continuous range of spectral data throughout the entire image. The study was conducted using the Specim IQ hyperspectral camera (SPECIM Spectral Imaging Ltd, Finland). It operates within a spectral range of 400 to 1000 nm, providing a spectral resolution of 7 nm and an acquisition interval of 3.5 nm, resulting in 204 spectral bands. Calibration of the data was carried out with a white Spectralon® standard. The camera was positioned between two halogen lights, symmetrically

placed at a 45-degree angle in front of the sculptures for optimal illumination. The acquired data cubes were processed using ENVI 5.0+IDL software.

For data cube processing, ENVI's Spectral Hourglass Wizard (ENVI-SHW) was employed to streamline the spectral analysis by extracting and analysing key image components. This step-by-step workflow begins with the Minimum Noise Fraction (MNF) technique, which is used to reduce noise and enhance data quality. Next, significant image areas are pinpointed by isolating "spectrally pure" pixels using the Pixel Purity Index (PPI). The n-D Visualizer is then utilised to examine these key components, referred to as endmembers, facilitating the identification of pigments. Once the endmembers specific to the red and black pigments were identified, the Mixture Tuned Matched Filtering (MTMF) mapping technique was applied to visualise their distribution within the image. The MTMF algorithm integrates the Matched Filter (MF) method with Linear Unmixing. The Matched Filter partially unmixes pixels to isolate endmembers, maximising the response of known endmembers while minimising interference from other pixel elements. To further refine the analysis and reduce false positives, the MF results are combined with the infeasibility measure from linear unmixing, which assesses how much the MF result is a mixture of the target and background. An infeasibility score of zero indicates that no false positives are present in the MF result, with properly matched pixels exhibiting an MF score greater than zero and an infeasibility score close to zero.

Visible Near Infrared Fiber-Optic Reflectance Spectroscopy (FORS). FORS spectroscopy allowed for the non-invasive punctual analysis of pigment traces (Picollo, M. et al., 2019). Reflectance spectra were collected by a 20 W halogen lamp (HL2000, Ocean Optics) paired with a Thorlab spectrophotometer, which detects light in the visible and near-infrared range (200-1000 nm). Measurements were taken using a Y-shaped optical fibre bundle composed of seven fibres (400 nm in diameter—six illumination fibres surrounding one collection fibre) with a beam diameter of 3 mm. The probe was positioned perpendicularly to the surface to collect reflectance spectra with a spectral resolution of less than 2 nm. The instrument was calibrated with a white Spectralon® standard.

Portable X-Ray Fluorescence (pXRF) Spectroscopy. In situ analyses of 23 sampling points were performed using a portable XRF Olympus Vanta analyzer, series M (serial number 840957). The instrument is equipped with a 40 kV Silver X-ray tube and silicon drift detector. Spectra were acquired with two different energy beams, set at 10 kV and 40 kV, for 30 s each, to detect both heavy and light elements. The content of 21 elements (Mg, Al, Si, P, S, K, Ti, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Mo, Ag, Ba, Hg, Pb) was assessed to determine the possible presence of pigment traces in specific areas of the Monument, pXRF measurements were taken on spots where colouring matter seemed to be present as well as spots without colour for comparison. Data interpretation was carried out by the software PyMCA (Solé, V. A. et al., 2007).

RESULTS

Marble analysis

Petrography and cathodoluminescence

A preliminary visual examination has made it possible to identify two very slightly distinct groups (see S2 for the macroscopic description of each part of the Monument studied). The Hispania, Gallia and Naval trophies are made of a high quality white marble with an

heterogeneous granulometry characterised by larger, isolated, and scattered grains up to 2 mm or larger within a fine grain matrix. This marble emits a notably intense odour when scratched and it is somewhat translucent. The Victoria, however, presents marble with slightly different features: while it is also white, its appearance differs from the trophies in that the grain size is less heteroblastic. It is more translucent and does not emit a foul odour when scratched.

Petrographic analysis confirms the macroscopic description of all the samples: an uneven granoblastic texture, generally bimodal, with large isolated macrocrystals surrounded by smaller ones, forming the 'core-mantle' type, with some differences in grain size (Table 1, and S4a). These profiles are fairly similar to those of the quarries in the Saint-Béat district (including Rapp, Cap-de-Mont, Mont-Rié and Marignac), that exhibit a large range of petrographic texture. They have been largely studied by P. Lapuente and H. Royo-Plumed (Royo-Plumed *et al.*, 2018, Lapuente, 2022) : in their work, they described two distinct lithotypes of white marbles for the quarries of Saint Béat (which include Rapp, Cap-de-Mont and Mont-Rié) called STB-1 and STB-2 and two lithotypes for the quarries of Marignac, MGN-1 and MGN2 (see Table 1). The lithotypes STB-2 or MGN-2 that show the uneven granoblastic texture forming the "core-mantle" type, can be recognized in all the samples taken off the different parts of the Monument.

The cathodoluminescence response further highlights this bimodality with a heterogeneous pattern: sometimes, the large grains appear dark, while the matrix shows a uniform dark reddish-orange tone with medium intensity, as commonly seen in marble from the Saint-Béat/Marignac quarries (Table 1 and S4b). Although slightly different, the cathodoluminescence characteristics of SBC 3 and SBC 7, showing a very low intensity, are closely aligned with those of these quarries (Royo-Plumed, 2016) .

Table 1. Mineralogical-petrographical, cathodoluminescence features of the trophy samples (in red, Hispania trophy, in green, Gallia trophy, in blue, Navy trophy, in black, victory) and of the two main district of the local quarries. Legend: ID: Type: C, calcitic, Fabric: An, Anisotropic; Is, Isotropic; CPO, Crystallographic Preferred Orientation; C: preferred orientation of Carbonates. (), slightly visible parameter. MGS, Maximum Grain Size in mm; MFS, Most Frequent Size in mm; GBS, Grain Boundary Shape: S, Straight, C, Curved, L, Lobate. Texture : Gr, granoblastique, Ho, homogenous, He, heterogenous Accessory minerals and remarks: Dol, dolomite; Ep, Epidote; Fsp, feldspars; Mi, Mica; Opq, opaque minerals; Pl, plagioclase; Py, pyrite; Px, pyroxene; Qz, quartz; Scp, scapolite; FeOx, iron oxides (except for the pyroxenes and iron oxides, the abbreviations follow the recommendations of Siivola and Schmid, 2007). Cathodoluminescence, CL: S, Strong; F, Fair Intensity ;L, Low Intensity, Ho, homogenous distribution.* data from Royo-Plumed thesis (Royo-Plumed, 2016).

Sample/ Quarry	Description/ Lithotype	Type	Fabric	Texture	MGS (mm)	MFS (mm)	GBS	Accessory min. and remarks	CL
SBC1	<i>Hispania</i>	C	(An)	He Gr	1.62	0.5-0.8	S/C	Scp	FHo
SBC2	<i>Hispania Base</i>	C	Is	He Gr	2.80	0.1-0.2	C	Opq, Qz	FHo
SBC3	<i>Hispania Trunk (lower.)</i>	C	Is	He Gr	1.72	0.2-0.4	C	Py	LHo

SBC4	Gallia Female	C	Is	He Gr	1.53	0.1-0.5	C	Opq, Pl, Px, Qz, Scp, FeOx, Py, Dol	LtoFHo
SBC5	Gallia Captive	C	Is	He Gr	3.11	0.3-0.8	C/S	Py, Zr, Qz	F to LHo
SBC6	Gallia Rheno	C	(An) (CPO,)	He Gr	1.21	0.2-0.5	C/S	Zr.	F to LHo
SBC7	Gallia Trunk (lower p.)	C	Is	He Gr	1.00	0.4-0.7	S/C	Opq	LHo
SBC8	Gallia Trunk (upper p.)	C	(An)	He Gr	1.30	0.8-1.0	S/C	Opq, Qz, Fsp	FHo
SBC9	Navy Tritoness	C	Is	He Gr	0.80	0.1-0.5	C/S	Opq	LHo
SBC10	Navy trunk behind Tritoness	C	Is	He Gr	1.00	0.3-0.5	C/L	Qz	FHo
SBC11	Victory Base	C	(An)	Gr He	2.00	1.2	C/S	_	FHo
SBC12	Victory Torso	C	Is	Gr He	1.00	0.6-1.0	C/S	Qz	FHo
SBC13	Hispania Mannequin neck	C	Is	He Gr	2.22	0.45-0.5	S/C	Opq	FHo
SBC14	Hispania trunk (upper p.)	C	Is	He Gr	2.04	0.55-0.6	C/S	Qz	FHo
SBC15	Navy Tritoness Tail	C	Is	He Gr	1.32	0.45-0.6	C/L	Qz	FHo
St-Béat*	STB-1	C	(An)	Ho Gr	1,6	0.3-0.6	C	Qz, FeOx, Scp, Mi, Ep	F-to HHo
	STB-2	C	Is	He Gr	6,5	0.1-0.5	C/S	Qz, Py	L to FHo
Marignac*	MGN-1	C	Is	Ho Gr	1,9	0.2-0.4	C/S	Dol, Px, Pl, Mi, Opq	LHo
	MGN-2	C	(An)	He Gr	2,3	0.2-0.6	C/S	Dol, Px, Scp	LH to FHo

Isotopic measurement.

Figure 2 displays the reference diagram of the $^{13}\text{C}/^{18}\text{O}$ isotopic field for the 4 quarries of interest. They stem from values measured on a set of 74 geological samples (35 from the Unizar and 39 from Archéosciences reference collections): To the 39 geologic samples presented in the material part, were added 35 isotopic values available in H. Royo Plumed thesis (Royo Plumed, 2016). Then, confidence ellipses were constructed from 24 samples for Cap-de-Mont, 18 for Mont-Rié, 22 for Marignac and 10 for Rapp and are represented in figure 2 as ellipses of different colors depending on the quarry. (See S5a and b for detailed values).

The confidence ellipses were calculated using the “confidence_ellipse” function (R Studio) with a confidence level of 95%. The isotopic fields characterising each quarry overlap considerably: the isotopes of Mont-Rié, Rapp and Cap-de-Mont group are in the same area,

whereas Marignac has a much more dispersed isotopic signature that encompasses the isotopic fields of the other quarries (figure 2).

Most of the values obtained for the Monument samples fall within or borderlining the isotopic field for quarries in the Saint-Béat district, although it is not possible to determine the precise quarry of origin. However, there is an outlier: SBC10. It has isotopic values that deviate significantly from the others ($^{12}\text{C}/^{13}\text{C}$: 3,048; $^{16}\text{O}/^{18}\text{O}$: -4,96), although it falls within the Marignac isotopic field. SBC10 is a fragment taken from the naval trunk, which shows three distinct sections in its restoration (see S6). Again, a second sampling was performed on another part of the trunk (SBC 16, only powder was sampled), and its isotopic values measured. A shift in the results ($^{12}\text{C}/^{13}\text{C}$: 3,24; $^{16}\text{O}/^{18}\text{O}$: -3,41) was observed, with the new values falling right next to all the other samples. Since no signs of alteration were detected at the time of sampling, the hypothesis that marble from a different site -but still within the quarrying district- was used during a later restoration could explain the discrepancy in isotopic values.

ICP-OES

After demineralization of all the geologic and SBC samples (except SBC7, 8, 14 and 15 for which the quantity of material sampled was insufficient for analyses), eight chemical elements were quantified using ICP-OES: Al, Fe, K, Mg, Mn, Si, Sr and Ti. All values are reported on table S5 and the PCA analysis of the archaeological samples alongside the geologic samples from Cap-de-Mont, Mont-Rié, Rapp and Marignac quarries are shown in figure S7. While the Mont-Rié, Cap-de-Mont and Rapp quarries display a high degree of overlap, the Marignac marble is characterised by significant dispersion, with Mg, B and Mn content varying greatly between samples. Given the highly variable Mg content in the Marignac quarry ($1,0 \pm 0,9 \%$), its inclusion in the PCA is debatable. However, the PCA performed on the same dataset without Mg yields a similar biplot (see S8), indicating that the variability in Mg content does not bias the results.

The analysed archaeological samples (represented by red circles, S7) are all located in the common area of overlap among the quarries, making it difficult to attribute their precise provenance. Nevertheless, the narrow zone in which all the samples cluster suggests that most of them likely originate from the same source.

NMR

^{13}C NMR provides additional information on the content of minor chemical elements: the ^{13}C chemical shift reflects molecular characteristics of calcite such as the substitution of calcium by other cations like Mg, Mn, Sr, etc. Meanwhile, the line width at half-maximum is proportional to the number of different ions involved in the carbonate substitution. Additionally, under the saturation conditions used to acquire ^{13}C spectra, the area of the resonance is inversely proportional to the content of paramagnetic ions, mainly iron oxide, making its measurement valuable (Gutiérrez Garcia- M. et al., 2019). The three NMR parameters for each quarry (see S5 for individual values) are as follow: Cap-de-Mont has an average area of $1,6 \pm 0,9$, a line width at half-maximum $\Delta v_{1/2}$ of 64 ± 8 Hz and a chemical shift of $170,48 \pm 0,04$ ppm; Mont-Rié has an average area of $2,4 \pm 1,9$, a $\Delta v_{1/2}$ of 66 ± 12 Hz and a chemical shift of $170,53 \pm 0,03$ ppm; Rapp has an average area of $1,2 \pm 0,7$, a $\Delta v_{1/2}$ of 72 ± 8 Hz and a chemical shift of $170,50 \pm 0,03$ ppm; Marignac has an average area of $1,8 \pm 0,6$, a $\Delta v_{1/2}$ of

69±8 Hz and a chemical shift of 170,55±0,03 ppm. Their chemical shifts confirm their calcitic nature (Pianet et al., 2023), their narrow line width at half-maximum indicates a low level of Ca substitution in the calcite and their moderate signal area suggests a low content of paramagnetic ions (Gutiérrez Garcia- M. et al., 2019).

The PCA score plot obtained using the NMR parameters did not allow for discrimination between the quarries, and the values obtained from the Monument samples fall within the confidence areas for the quarries (see S9). Two outliers can be observed: SBC10, as previously mentioned, and SBC6 which presents higher signal area and line width at half-maximum values than the other samples (4,8 vs an average of $2,2 \pm 0,4$ for the signal area and 80 Hz vs 62±6 Hz for $\Delta\delta_{1/2}$, resp). No satisfactory explanation can be provided for the NMR outlier values observed for SBC6, although it remains within the confidence area of Cap-de-Mont marbles (see S9, left).

Marble source

After applying a comprehensive archaeometric strategy combining geologic criteria -such as grain size, orientation, microstructure, boundary type- that provide information about the fabric of the marble itself, with chemical criteria related to the original sedimentary protolith, such as carbon and oxygen isotopic ratios, chemical composition, and molecular information about the stone's main component, the carbonate function, the interpretation of all results in combination provides strong, consistent arguments about the origin of the marble.

Although two qualities of marble can be visually distinguished between the Victory (samples SBC11 and SBC12) and all the other sculptures, the petrographic characteristics, isotopic fields and chemical data do not reflect these differences. This suggests that the marble most likely came from the same quarry, where blocks with different autoptic properties can be found (Royo Plumed, 2016). Was this a deliberate choice by the sculptor to enhance the work's appearance? Stylistic analysis contrasts the heavy drapery of Hispania and Gallia with the elegance of Victory (Schenck-David, 2003). Or could this stylistic divergence and execution reflect different hands or workshops, implying a different commission for the trophies? Unfortunately, the chemometric analysis of the archaeometric data does not provide a clear answer as to whether the Victory belonged to the same monumental ensemble or whether there were one or two statues of Victory. However, all the samples group together in the same zone (see Fig. 2, 3 and S7) suggesting that the same marble source was used for all of them.

This source can be attributed to the quarries of Cap-de-Mont, Mont-Rié, or Rapp as the marbles from these quarries cannot be distinguished using the analytical methods employed here. The combined chemical analyses exclude the Marignac quarry as a potential source, primarily due to its high and very dispersed Mg content, which can reach up to 1%. This is illustrated in figure S7, which shows the score plot obtained with all the chemical data combined. However, the Mg content is not in the form of dolomite, as indicated by petrographic analyses and NMR chemical shift determinations (170, 54 ppm – 170,8 ppm for pure dolomite; 170,5 ppm for pure calcite (Pianet et al., 2023)).

It is now well established that marble provenance studies require a “multi-method-approach”, combined with appropriate statistical data analysis and that combination of methods can also determine whether different parts of a work originate from the same quarry, provided that intra- quarry variability is smaller than inter- quarry variability. Unfortunately, the marbles

from the Cap-de-Mont, Mont-Rié and Rapp quarries exhibit similar properties, making it difficult to differentiate them, as shown in the various score plots. This suggests that the marble from these quarries likely come from the same vein, and supports the intuitive idea proposed by D. Attanasio (Attanasio et al., 2006) that the “variability of any marble property must be smaller within a single block than within a whole quarry”, an idea originally derived from Herz and Wenner’s work on using isotopic ratios to verify the composition of Greek stelae (Herz, Norman and Wenner, 1978). While we can conclude that the marble used to sculpt these pieces likely came from the same extraction site and was quarried at the same time.

Pigment analysis

Traces of pigments can be seen on different parts of the Monument, as shown on Figure 1 (*a* to *k*). For all of them, different measurements were collected using complementary non-invasive techniques: portable digital microscopy, allowing to capture images of objects at high magnification and thus giving an overview of the different hues of colour present on the sculptures, pXRF spectroscopy, to obtain information about the elemental composition of the material, Vis-NIR-HSI, that could map and provide information on the chemical nature of the pigment used, and finally FORS, a punctual analysis used to confirm the results obtained by HSI.

Visual observations and portable digital microscopy

Microphotographs of the areas investigated in situ are shown in Table S9. Observations show different hues of colour present on the sculptures, from pink to red, dark red, brown and black areas. In some cases, like for the hair, mouth and eyes of Hispania, the presence of a red pigment is clearly visible, due to the presence of well-defined coloured lines on the marble surface defining hair strands, lips and eyelashes (Fig. 4 a-b). Some crusts of red material can be observed on both sides of the Hispanic trunk. As for Gallia, a darker, brownish area seems to be present above the left foot, and a black line can be seen on the bottom part of the dress, both on the front (Fig. 4c) and at the back (Fig S10 a-b), which may suggest a line decoration painted with a black pigment. Traces of red colour can be observed on the front of the mannequin and on the back of the captive of the Gallic trophy. A dark red area can be observed on the fish tail of the Naval trophy, although the colour does not seem to be on the surface, but rather a coloration within the stone, suggesting a possible alteration or degradation rather than an intentional pigment application. Finally, red-pink coloured areas can be seen on the left and right sides of the foot plinth of the Victory sculpture (Fig. 5a); the colour appears lighter if compared with the other sculptures of the Monument.

Red

All analysed points showed presence of elements such as aluminium, silicon, sulphur, potassium, iron, as well as traces of titanium, manganese, and nickel. These elements are normally associated with earth pigments such as red ochre, which is constituted by haematite (Fe_2O_3) and clay components (Helwig, K., 2007). Lead was also detected on red areas on Hispania’s hair (Fig. 5), on the Hispanic trunk (right side), on the eagle of the Naval trophy, and on red traces on both captives of the Gallic trophy, suggesting the possible presence of a lead-based pigment. Reflectance spectra obtained by Vis-NIR-HSI (Fig. 5e) and confirmed by FORS punctual analysis on Hispania’s hair, show spectral features compatible with those of red ochre, with an inflection point at 584 nm and an absorption band at around 870 nm (Aceto

et al., 2014; Liang, H., 2012; Picollo, M. et al., 2019). Other endmembers identified by Spectral Hourglass Wizard (SHW) however displayed different spectral features, with a lower inflection point at around 564-568 nm, which could be compatible with the spectral profile of the pigment minium (Pb_3O_4) (FitzHugh, E. W., 1986). Similar results were obtained for the Victory (Fig. S11), even though Pb was only detected as a trace element in the XRF analyses. Minium was used in Roman times to obtain a bright red-orange colour (Augusti, S., 1976; Béarat, H., 1997); examples of its application on marble polychrome sculptures are well known (Barratte, F. et al., 2017; Del Monte, M. et al., 1998; Fink-Jensen, P., 2013; Rosing, M.T. and Østergaard, J.S., 2009). It is unclear whether the two pigments were mixed together or applied in separate layers on the marble support. The combination of red lead and red ochre is described by Pliny (NH, XXXVI, XXIII) and was also known as *sandyx* (Béarat, H., 1997; Neri, E. et al., 2022; Pliny, the Elder, 77) Further micro-invasive analyses would be necessary to fully understand the painting technique (Bracci et al., 2020). Nevertheless, this archaeometric campaign allows us to exclude the use of red ochre alone for the Monument of Saint-Bertrand-de-Comminges.

Black

The black lines present on the front and back of Gallia's dress show presence of Pb as well as other elements associated with earth pigments, and the reflectance spectrum obtained by Vis-NIR-HSI shows an inflection point at 560 nm (Fig. S10). The original colour of the line might have been difficult to determine. White lead has previously been found on Roman marble sculptures (Barratte, F. et al., 2017; Bracci et al., 2020) and its alteration to black is documented in the literature (Costantini, I. et al., 2020; Giovannoni, S. et al., 1990; Gliozzo, E. and Ionescu, C., 2021; Vagnini, M. et al., 2020), therefore a mixture with the white pigment was possibly used. Alternatively, red lead and other lead-based pigments are also known to darken to brown with exposure to air (Aze, S. et al., 2008), so the presence of *sandyx* and/or some other orange-brown mixture cannot be excluded. As for these results, the presence of a lead-based pigment, possibly mixed with an iron oxide pigment, can be supposed.

To conclude this section on the study of pigments, their *in situ* analysis has revealed a palette composed mostly of red ochre, with the probable addition of a lead-based pigment such as minium. Non-invasive techniques, including digital microscopy, pXRF, Vis-NIR-HIS and FORS, have provided insights into the elemental composition and distribution of these pigments on the components of the trophies. Red ochre and minium were both identified, sometimes appearing in combination, suggesting the use of a pigment mixture known in Roman times as *sandyx*, whereas black traces potentially formed through the alteration of white or red lead. The pigments observed show a coherent use of materials across the different components of the Monument to Augustus. However, a more in-depth analysis to answer questions about pigment provenance would have required to take samples containing pigments. Unfortunately, the areas where the pigments were found were not suitable for taking a sample without it being visible (as in the case of Hispania's hair in Figure 5), or were very altered and therefore very fragile, making it impossible to collect a sample (as in the case of Victory's foot, see S10).

Conclusions

The joint study of the origin of the marble and the chemical composition of the pigments used on the Monument to Augustus of Saint-Bertrand-de-Comminges reveals clear similarities in both the marble sourcing and the painting technique used. This indicates that the entire Monument was probably made at the same time, by the same craftsmen. However, the question of whether they constitute a single monument -an ensemble displayed in the same location in the ancient city- remains unanswered.

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Figure Captions:

Figure 1. Composition of the Monument to Augustus.

Sampling zone: SBC 1 to 16, Solid black circles represent our sampling points; T1,T2,V1 hollow black circles are those performed by C. Costedoat. *In situ pXRF, Dinolite, FORS and hyperspectral analysis:* a to k, Red circles correspond to red pigment traces and black square to black pigment traces analysed by, and the samples analysed in situ from a to k.

Figure 2. Isotopic reference diagram for the four quarries in the Saint-Béat district, along with their 95% confidence ellipses of each quarry with respect to their color (green for Marignac, orange for cap de Mont, blue for Mont-Rie, pink for Rapp) . The red symbols represent the measured values for samples SCB1 to 16, as shown in Figure 1.

Figure 3. Principal component analysis based on all the data (isotopes, ICP-OES, NMR) : on the left, the loading plot and on the right, the score plot. Confidence ellipses were calculated for each quarry. The red circles correspond to the data points for the samples numbered in Fig. 1. F1 is the first principal component representing the greatest possible variance explaining 38.1% of the data set. F2 is the second component representing the second largest possible variance explaining 21.1% of the data set. The data set contains 13 variables (Al, B, Fe, K, Mg, Mn, Sr, Ti contents; area line width at half-maximum and chemical shifts of NMR data, and O and C isotopic values) for all the marbles studied (39 quarry marbles and 12 SBC samples).

Figure 4. Red and black details on Hispania (a, b) and Gallia (c).

Figure 5. *In situ* red pigment analysis. a) Statue of Hispania. b, c, d) Distribution maps by MTMF mapping algorithm. e) Reflectance spectra of red endmembers. f) Microphotograph of red hair detail by digital microscopy. g) pXRF spectra collected on a coloured area (in red) and on a region without any trace of pigment (marble, in black).

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Authors contributions

IP designed and led the research. AI (for the pigments analysis) and IP (for the rest of the document) wrote it. MC carried out petrography and cathodoluminescence experiments and designed figure 1. MC and AG interpret petrographic and cathodoluminescence experiments and designed figure 1. IP performed ICP-OES preparation samples, implemented ¹³C NMR spectra, and analysed the entire data using PCA. AI, ZF and FG performed (implementation and interpretation) the pigments analysis for dino-lite, pXRF and Vis-NIR-HIS.

Figure 1

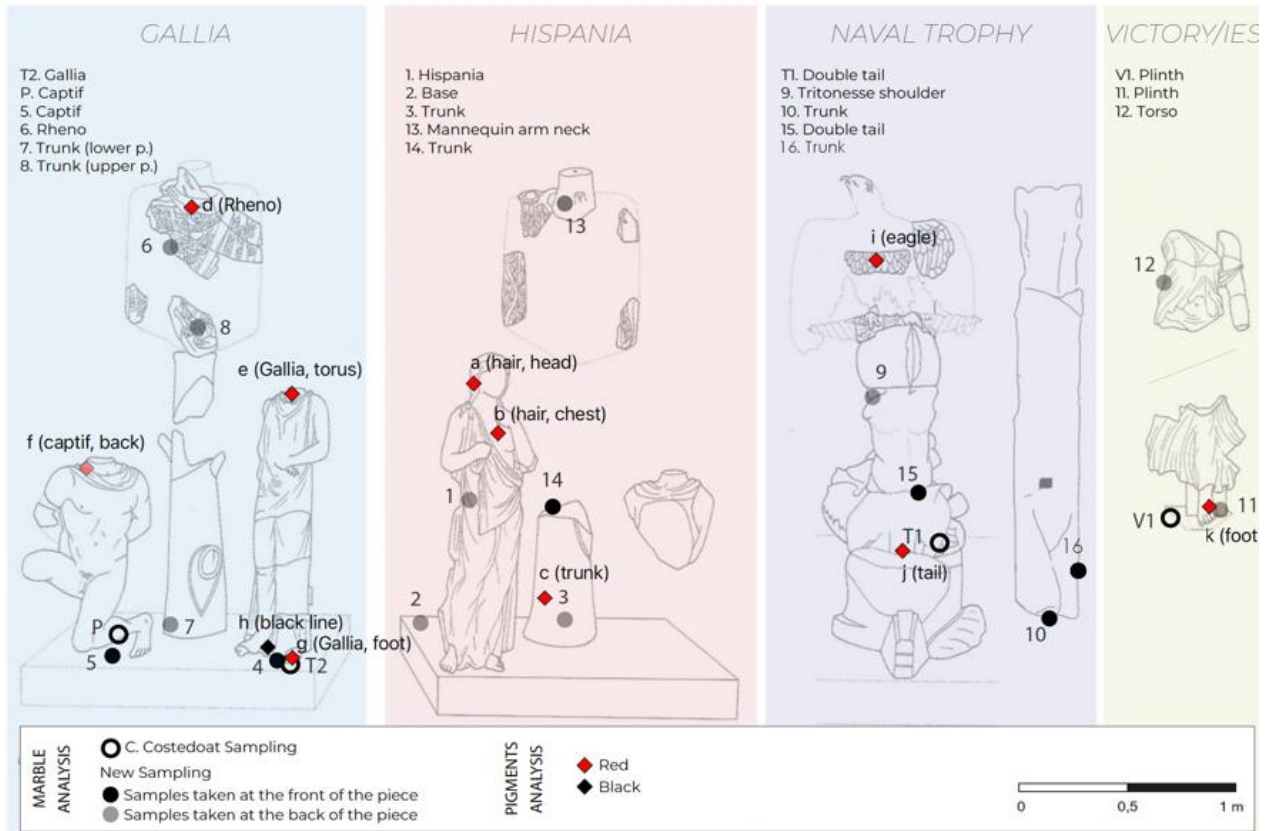


Figure 2

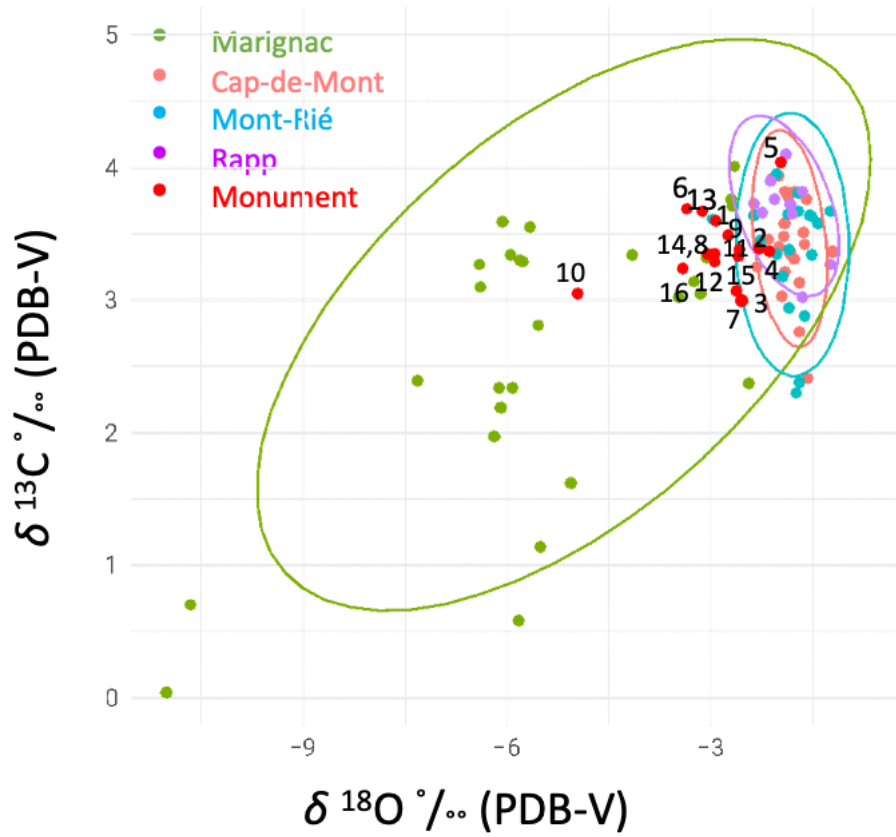


Figure 3

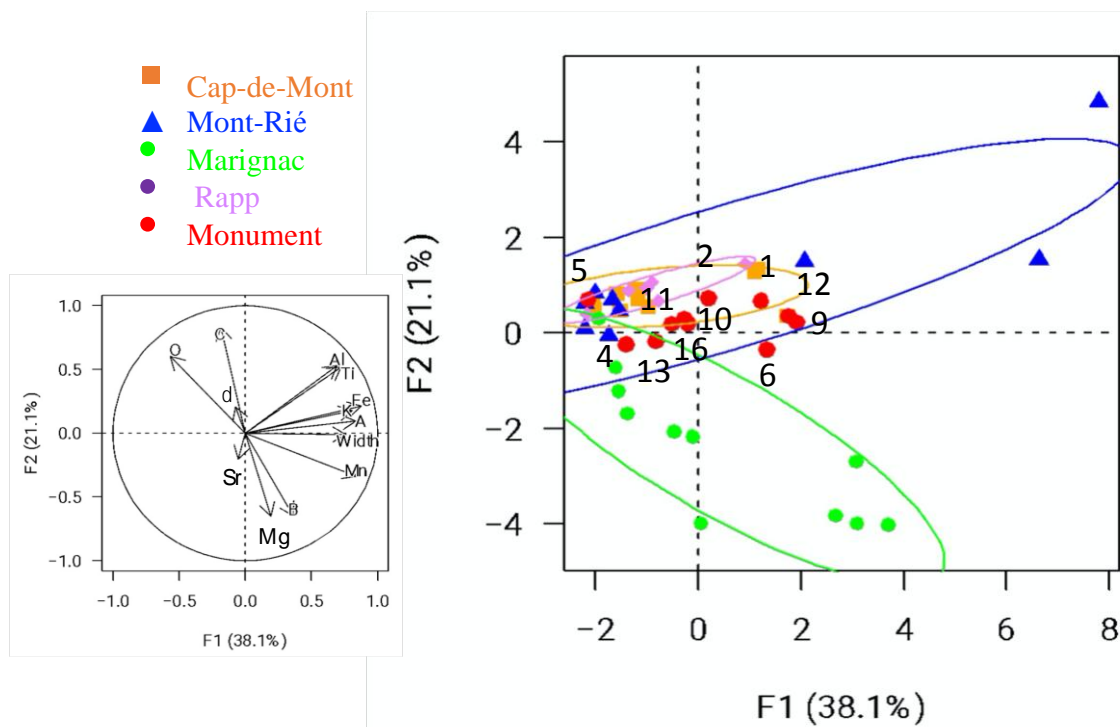


Figure 4

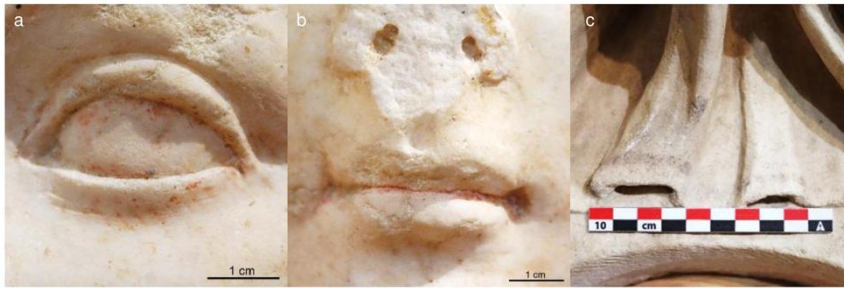


Figure 5

