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ORIGIN OF ROMAN WORKED STONES FROM ST. SATURNO CHRISTIAN BASILICA (SOUTH SARDINIA, ITALY)

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ABSTRACT

The work aims to define the origin of the architectural stone elements worked by Romans and reused in the St. Saturno Basilica, between the late Antiquity and Romanesque periods. Thus, different rocks (marbles, various facies of limestones, volcanic rocks) used to construct the ancient building were sampled and analysed. All the different kinds of stones were sampled from the Basilica, taking precise reference to the various construction phases and structural changes of the monument occurred in the centuries.

The sedimentary and volcanic lithologies belong to the local outcrops of Cagliari Miocenic geological formation (e.g. limestone) and to other volcanic outcrops of south Sardinia, respectively. By means of a multi-method archaeometric study (mineralogical-petrographic observations on thin sections and ^{18}O vs ^{13}C stable isotope ratio analysis), the provenance of classical marbles used for manufacturing Roman architectural elements (column shafts, bases, capitals, slabs, etc.) were defined, which are thought to come from extra-regional sources.

The results show that the marbles come mainly from Apuan Alps (Italy) and subordinately from Greek quarrying areas.

KEYWORDS: Isotopic analysis, Carrara marble, Greek marble, provenance, Roman time, Romanesque, Medieval building, St. Saturnino Basilica

1. INTRODUCTION

The early St. Saturno (also called St. Saturnino) Christian Basilica (Fig. 1; Cagliari, Sardinia, Italy) was built in the V century AD over a sacred site since the origins of the town of Cagliari and it is considered one of the most significant Romanesque-style monument in the Mediterranean area. The first documented phase goes back to the VI Century AD, when St. Fulgenzio of Ruspe found the first convent near a previous Basilica. The original sepulchral function of the area was consolidated and implemented during the Roman Empire, where some excavations have revealed several Roman and Byzantine tombs; it became a Christian cemetery after the martyrium of St. Saturnino (beheaded in 304 AD). In this period, the original chapel of the church was built starting a long evolution of the building across half a millennium, until its Romanesque evolution (Figs. 1c, d, e, f).

During the centuries, the Basilica hosted a long succession of various religious communities and political events, with many construction interventions and restorations (Fig. 1h). In 1089, the "Vittorini" monks from Marseille arrived. In 1327, with the Aragon domination, the convent was partially demolished and the area used as a quarry for other constructions. In 1444, the area was bought back by the archbishop of Cagliari. At the beginning of the XIV century, the Basilica was abandoned and partially destroyed. In the late XVII century, the building was partly demolished to recover materials for the restoration of the Cagliari Cathedral. In the XVIII century, after various phases of use and decay, the area starts to receive the attentions of the archaeologists. After substantial allied air raid damages, suffered during the Second World War, extensive renovations and partial rebuilding were necessary. Actually, following the Greek Cross plan, the Basilica structure (Figs. 1a, b; Fig. 2) consists of the dome covered area from the V to VI century AD, with the nave and two aisles within a Paleochristian necropolis (Coroneo, 1993; Serra, 1988).

The formal technical reading of its architectural structure and elements is complicated by the frequent reuse of Roman artifacts during the Byzantine and Romanesque phases, as well as by the presence of diachronic source materials.

Several building stones (sedimentary, magmatic and metamorphic rocks) were employed in the site, together with different types of ancient mortars (from Roman concrete to Medieval bedding mortars). The naked-eye analysis of geomaterials present in the monumental complex highlights a significant number of lithologies (i.e. various kinds of limestones and sandstones, volcanic rocks, true marbles, etc.), some of which are in an advanced state of alteration. The different facies of limestones and volcanic rocks were especially used as squared and irregular ashlars to construct the main structure (wall of Basilica, cupola, etc.) and only subordinately for decorative elements (architrave, column, cornices). Sedimentary rocks (e.g., limestone, sandstone, etc.) mainly belong to Miocenic local outcrops. These rocks, particularly those of carbonate type, are widely used in the construction of historical buildings in south Sardinia (Columbu et al., 2017a). This is generally due to their more easy availability in the territory and especially to their better workability, if compared to silicate igneous or metamorphic rocks (Antonelli et al., 2014b; Bertorino et al., 2002; Columbu et al., 2014a; Columbu et al., 2015a). Also, some kinds of volcanic rocks (e.g., pyroclastites with dacitic or rhyolitic composition) characterised by low-medium welding due to their excellent workability (similar to those of carbonate rocks), are widely used as building materials in historical times in the island, from Punic-Roman to Romanesque (Columbu et al., 2014b, 2015b, 2017b, 2018a, 2018b, 2018c; Columbu, 2017, 2018 in press; Columbu and Garau, 2017; Columbu and Verdiani, 2012, 2014; Macciotta et al., 2001; Verdiani and Columbu, 2010).

Moreover, a variety of different imported coloured and white marbles was used (and re-used) for the decorative architectural elements of the S. Saturnino site. In the set of sampled stones from the St. Saturnino Basilica, due attention was paid to some limestones and volcanic lithologies and especially to the marble stones previously worked in the Roman period to realise several decorative elements (columns, capitals, base, architrave, etc.) and later reused in medieval times.

The main aim of this research is to define the origin of the raw material used in the realization of artistic elements, column basements, capitals, ashlars, bleachers and planking. Marble provenance has been quoted earlier in the Roman/Hellenistic periphery too (Al-Naddaf et al., 2010; Abu-Jaber et al., 2012).

Apart from providing extremely useful historical and archaeological information about the commercial material trade in ancient times, archaeometric investigations on the raw geomaterials are an important scientific issue for those who work in the preservation of monuments. In fact, the characterization of the materials (Berto et al., 2012; Columbu et al., 2018d; Lezzerini et al., 2016, 2018a, 2018b, Miriello et al., 2015; Ramacciotti et al., 2018) is the starting point for both the seismic assessment and the feasible restoration of artworks, especially if it is necessary to intervene with consolidation and protection methods that involve the use of chemicals (Antonelli et al., 2016; Tesser et al., 2017). In addition, the possibility of recovering original material from ancient quarries is extremely useful and important, both while experimenting treatment of stone with chemicals in laboratory and for possible direct replacement of deteriorated materials (Tesser et al., 2014).

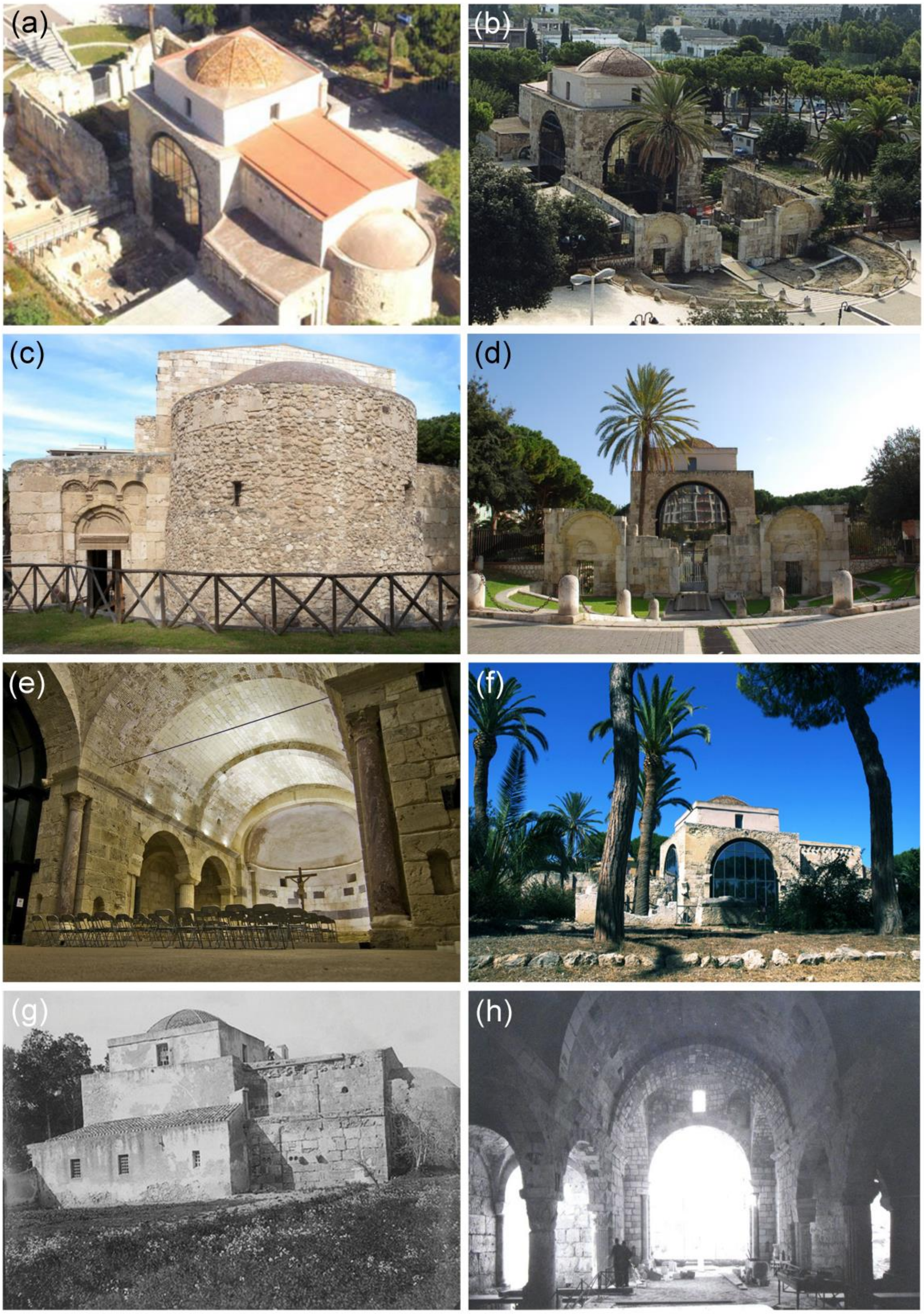


Figure 1. St. Saturnino Basilica: (a) aerial view from South-East, (b) aerial view from north-west, (c) main apse from external yard, (d) the façade, (e) inner main nave in year 2006, (f) south side of Basilica from buffering area, (g) St. Saturnino Basilica in year 1905, (h) restoration works during 40's.

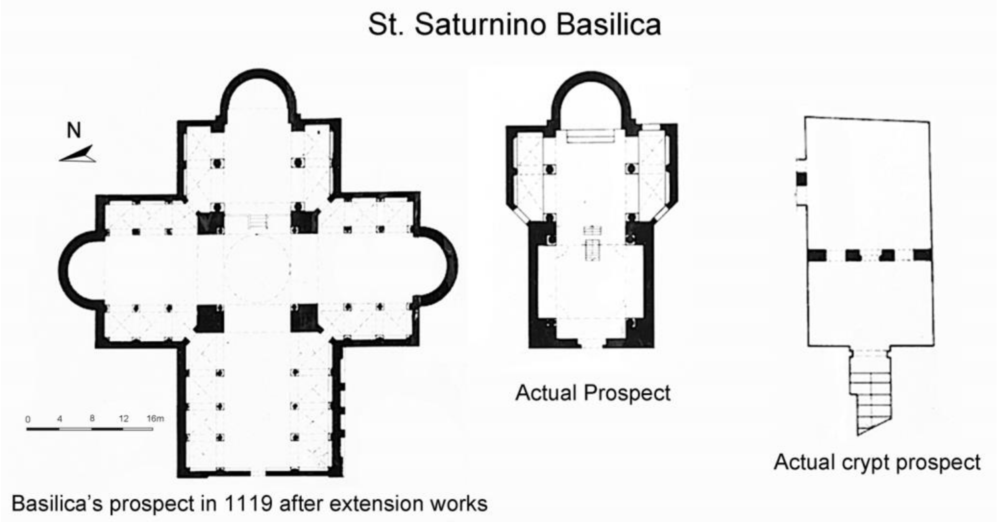


Figure 2. The plants of St. Saturnino Basilica in year 1119 and 2017.

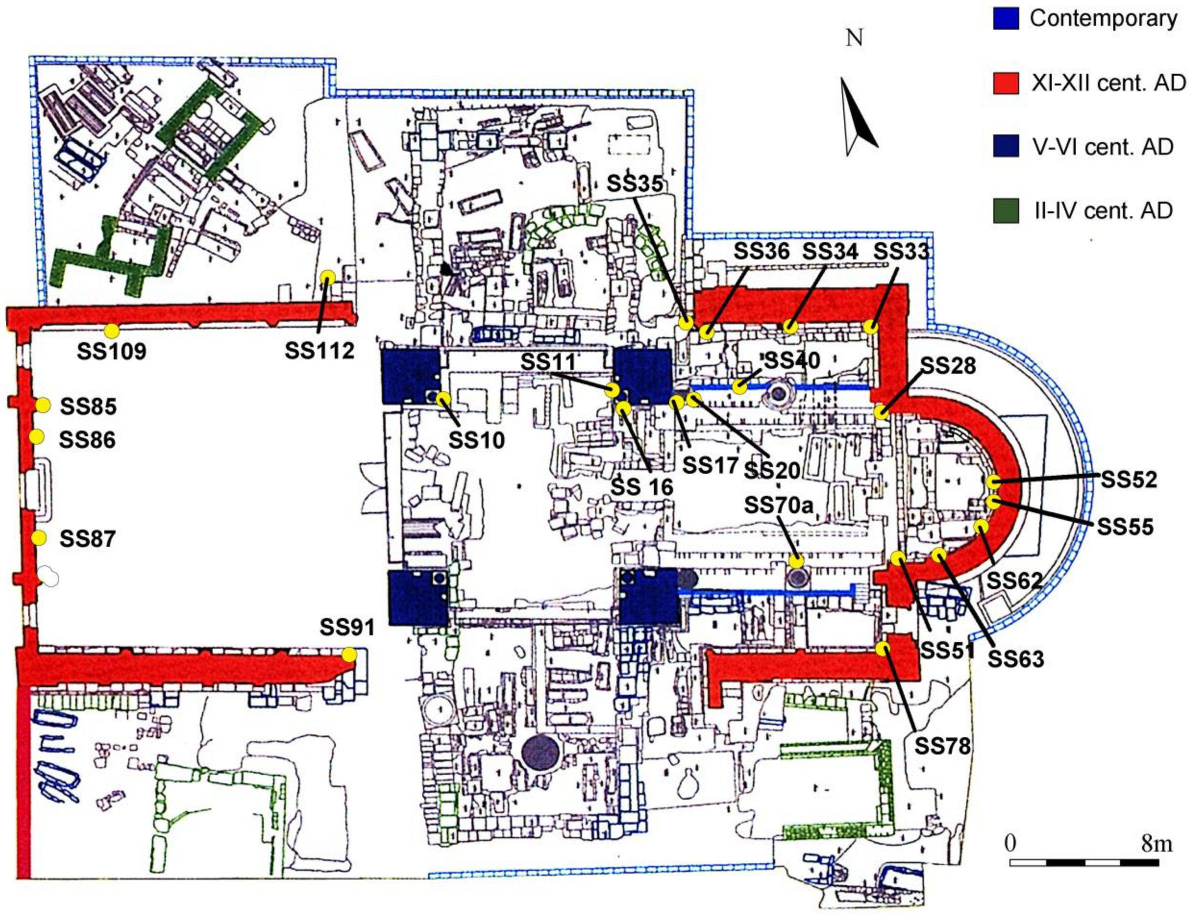
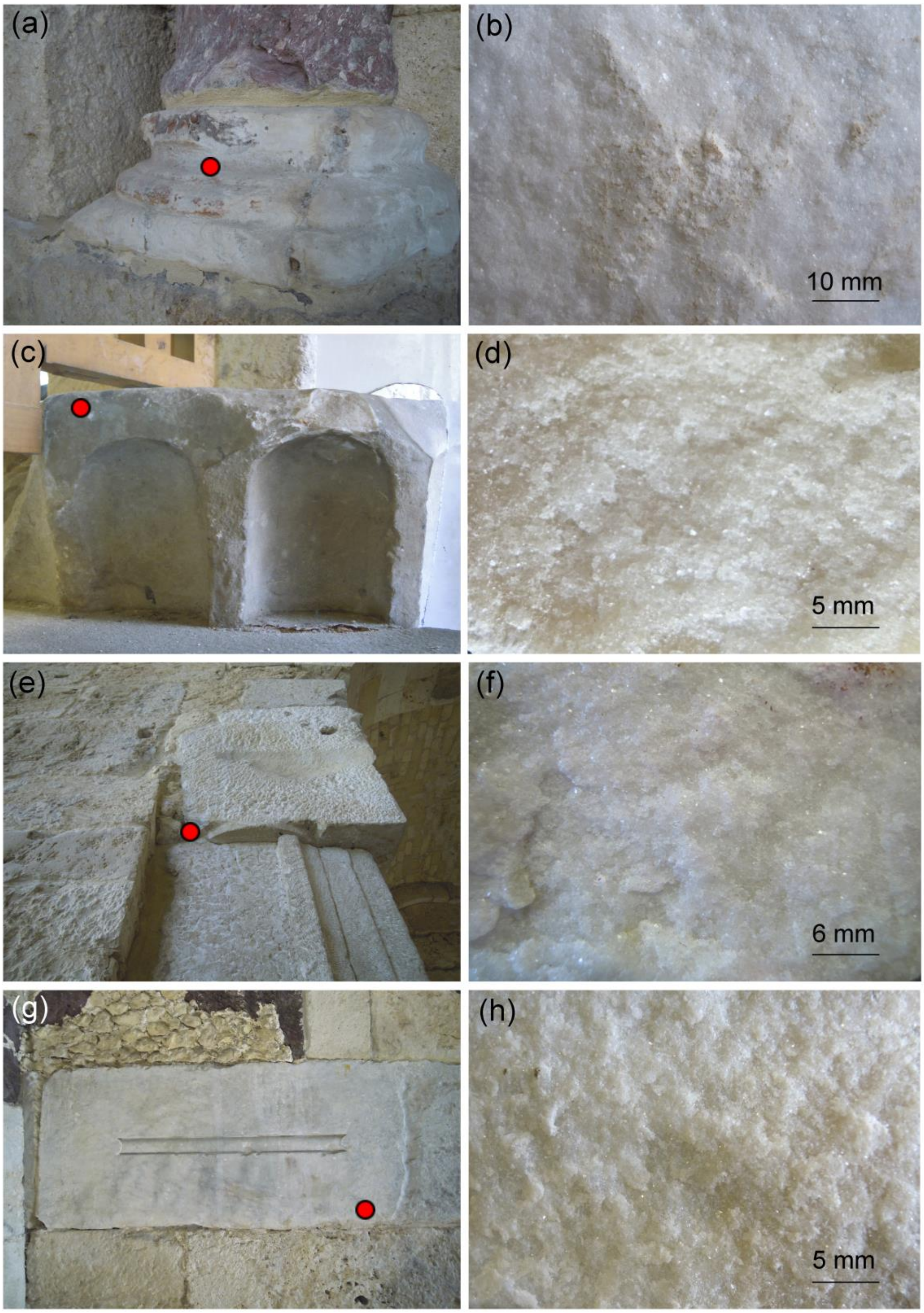


Figure 3. Sampling points of stones in St. Saturnino Basilica.

2. MATERIAL AND METHODS

In this study, a set of 24 specimens were sampled and analysed to define their origin (Tab. 1, Fig. 3): 8 whitish marbles, 5 coloured marbles, 8 limestones and 3 volcanic rocks (Tab. 1; Figs. 4, 5, 6, 7). The sampling of the various rocks was done on the basis of the representativeness of the lithotypes recognized in the preventive mapping of the Basilica's masonry, and according to the recognized construction phases and the different sectors of the archaeological site.



.Figure 4. Sampled marbles (on the left) with macroscopic features (on the right): (a,b) sample SS16, (c,d), sample SS17, (e,f), sample SS20, (g,h), sample SS51.

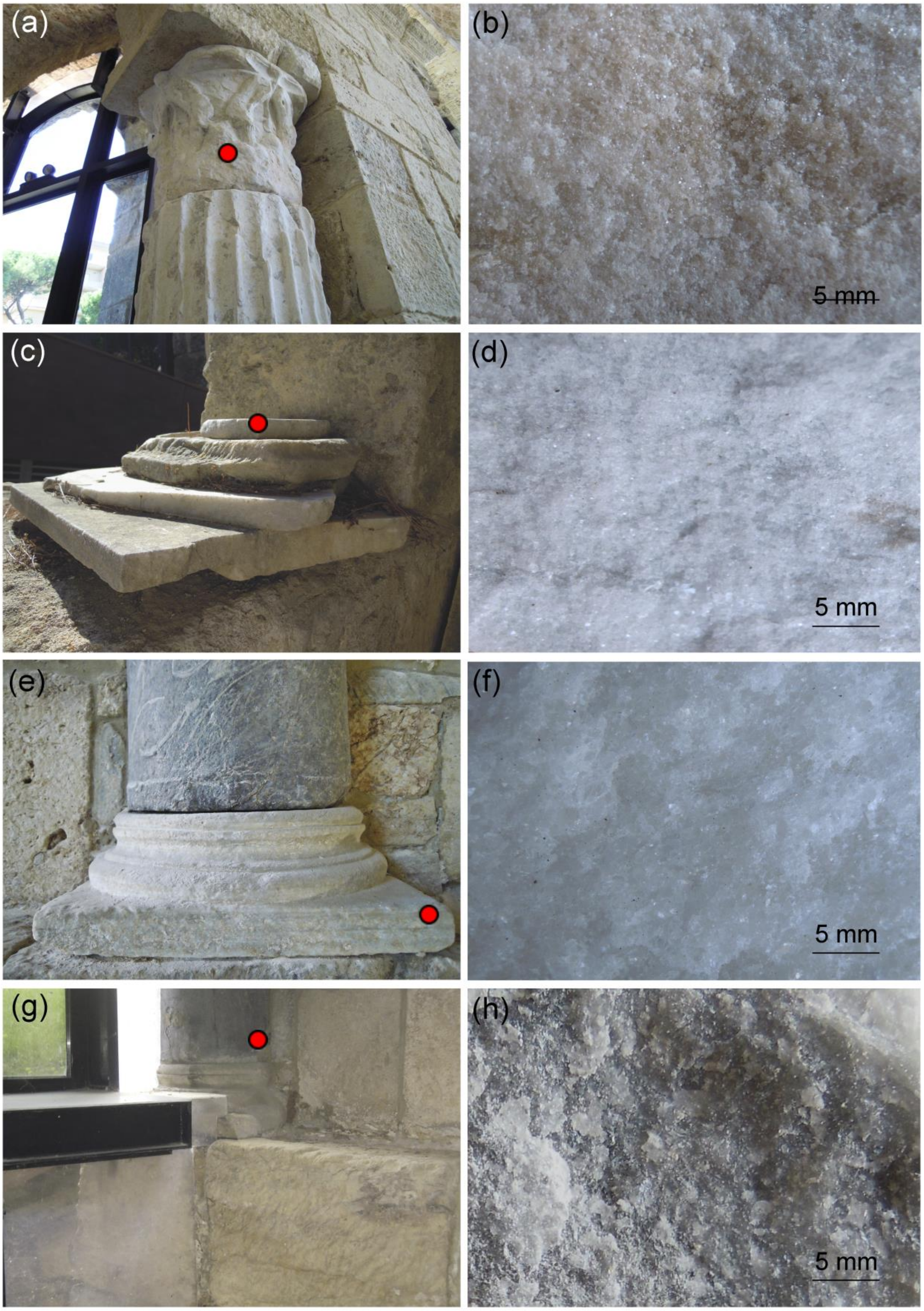


Figure 5. Sampling points of marbles (on the left column) with macroscopic features (on the right column): (a,b) sample SS70a, (c,d) sample SS112, (e,f) sample SS34, (g,h) sample SS36.

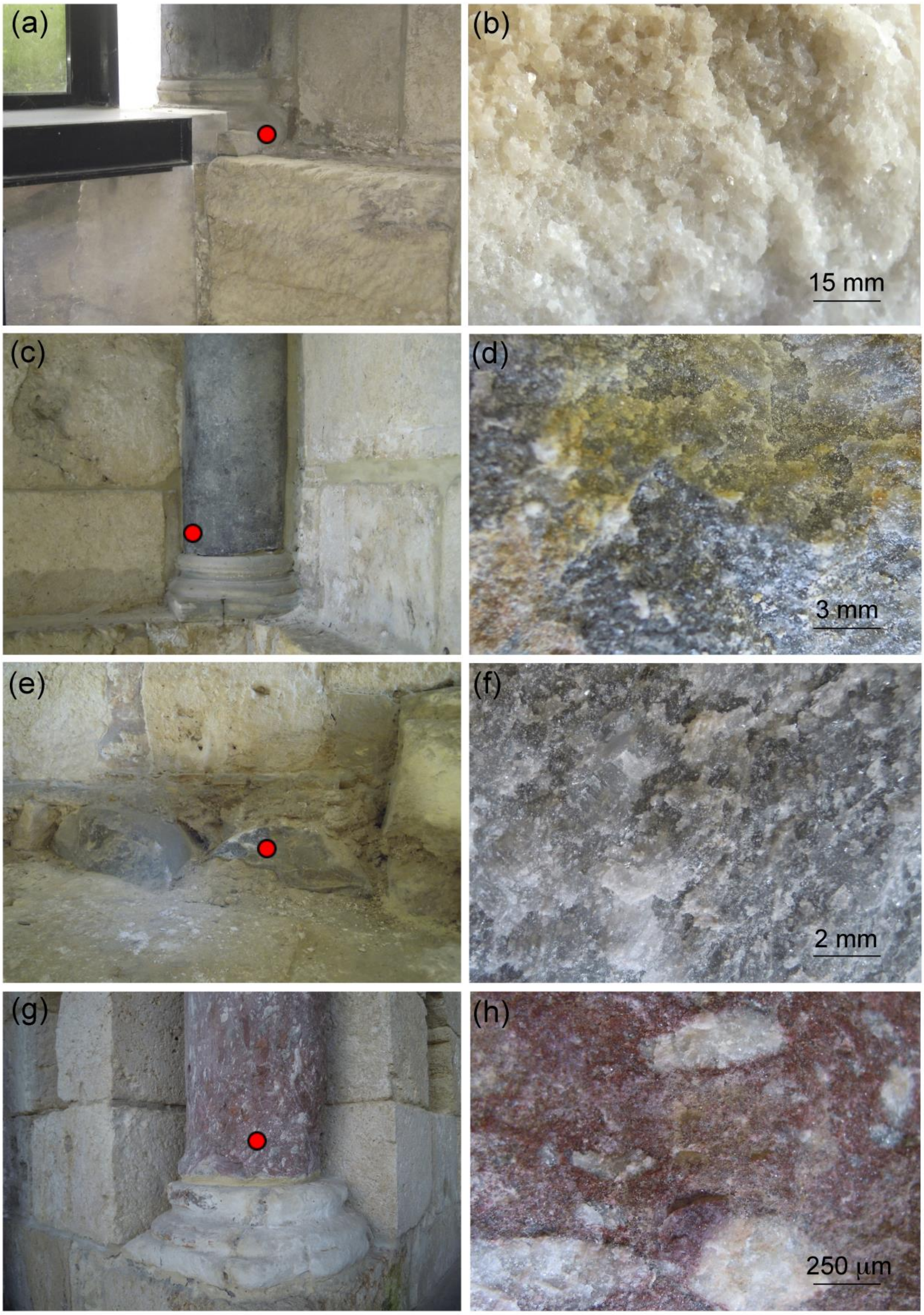


Figure 6. Sampling points of marbles (on the left column) with macroscopic features (on the right column): (a,b) sample SS35, (c,d) sample SS33, (e,f) sample SS63, (g,h) sample SS11.

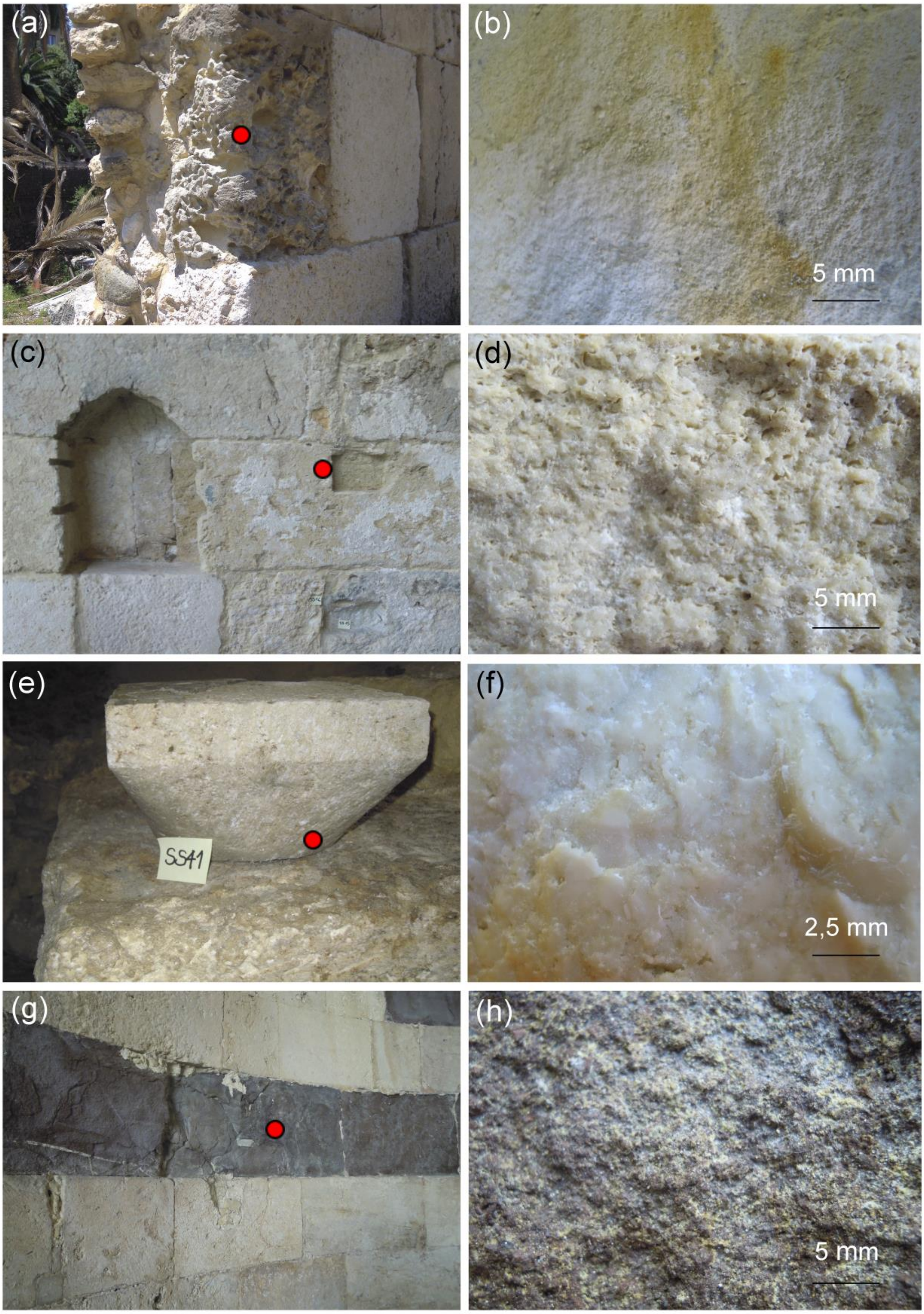


Figure 7. Sampling points of stones (on the left column) with macroscopic features (on the right column): (a,b) "Pietra cantone", sample SS91, (c,d) "Tramezzario", sample SS85, (e,f) "Pietra forte", SS41, (g,h) sample SS52.

Table 1. Sampled and analysed stones taken from the St. Saturnino Basilica and from the archaeological site. The measured heights refer to the current interior floor of the Basilica.

Sample	**Origin from monument**	**Masonry element**	**Sampling height (cm)**	**Lithology**	**Stone-matrix colour**	**Alteration and deposition on surface**
SS16	Main nave	Column base	40	Marble	Whitish	Red biological patina and ochre Ca-oxalate film (?)
SS17	Main nave	Column base (Roman ex column shaft)	55	Marble	Whitish	Beige Ca-oxalate film (?)
SS20	Main nave	Architrave segment	252	Marble	Whitish	Ca-carbonate crust
SS51	Apse	Wall ashlar (Roman ex architrave)	129	Marble	Whitish	Absent
SS70a	Main nave	Capital	219	Marble	Whitish	"Crystal sugar corrosion" with strongly decohesion, exfoliation and flaking
SS112	Roman north necropolis (II-IV cent. AD)	Slab (thickness about 3 cm)	72	Marble	Whitish	Biological patina and carbonate crust
SS34	North nave	Column base	41	Marble	Whitish	Ca-carbonate crust and ochre Ca-oxalate film (?)
SS35	North nave	Column base	26	Marble	Whitish	Absent
SS33	North nave	Column shaft	66	Marble	Greyish	Absent
SS63	Apse	Wall fragment (ex Roman column shaft)	-34	Marble	Greyish-black	Absent
SS36	North nave	Column shaft	30	Marble	Greyish-black	Absent
SS78	South nave	Column shaft	43	Marble	Grey-greenish-black	Absent
SS11	Main nave	Column shaft	47	Brecciated marble	Reddish matrix with whitish fragments	Decohesion, differentiated alteration
SS10	Main nave	Wall ashlar	73	Biohermal limestone	Yellowish	Absent
SS86	External courtyard	Column base	45	Biohermal limestone	Yellowish	Absent
SS87	External courtyard	Column base	58	Biohermal limestone	Yellowish	Absent
SS28	Main nave	Wall ashlar	-20	Marly limestone	Whitish	Decohesion
SS40	North altar digging	Below floor level ashlar	-22	Marly limestone	Whitish	Decohesion, micro-efflorescence
SS91	External courtyard	Wall ashlar	132	Marly limestone	Whitish	Decohesion, pitting, patinas, alveolisation
SS85	External courtyard	Column shaft	67	Biocalcare nite	White-Yellowish	Pitting
SS109	External courtyard	Column shaft	77	Biocalcare nite	White-Yellowish	Pitting
SS52	Apse	Wall ashlar	122	Volcanic	Purple with black inclusions	Micro-efflorescences
SS55	Apse	Wall ashlar	124	Volcanic	Purple with black inclusions	Micro-efflorescences
SS62	Apse	Wall ashlar	134	Volcanic	Purple with black inclusions	Micro-efflorescences

Each sample was thin sectioned and studied under the polarized light microscope (PLM), to describe and estimate the most significant petrographic features useful for differentiating the ancient white marbles and widely used in archaeometric studies (see, for example Antonelli et al., 2014a; Columbu et al., 2014; Moens et al., 1988; Lapuente, 1995; Lazzarini andAntonelli, 2003; Lazzarini et al., 1995; Pensabene et al., 2012;): fabric, maximum grain-size (MGS), calcite boundary shapes, occurrence and distribution of accessory minerals. The obtained petrographic data were compared with those reported in the literature and with reference samples taken from ancient Mediterranean quarries (the LAMA Collection, University IUAV of Venice).

Qualitative mineralogical composition of the samples was investigated by X-ray powder diffraction (XRPD), using a PANalytical Empyrean diffractometer (instrumental conditions: Ni filtered CuKα radiation obtained at 40 kV and 40 mA, 5-60° 2θ investigated range, 0.02° step, 2s counting time per step).

Carbon and oxygen stable isotopes of marbles were measured by mass spectrometry (McCrea, 1950). Carbonate powders were reacted with 100% phosphoric acid at 70°C using a Gasbench II, connected to a Thermo Finnigan Five-Plus mass spectrometer. All values are reported in per mil relative to V-PDB by assigning a ^{13}C value of +1.95 and an ^{18}O value of -2.20 to the reference material NBS 19, TS-Limestone (Coplen et al., 2006; Friedman et al., 1982). Reproducibility was checked by replicate analysis of laboratory standards. Oxygen isotope values of dolomite and siderite were corrected using the phosphoric acid fractionation factors given by Kim et al. (2007) and Rosenbaum and Sheppard (1986).

3. RESULTS AND DISCUSSION

3.1. *Sedimentary stones*

The mineralogical-petrographical investigation by PLM and XRPD analyses on the sedimentary rocks highlights the presence in the S. Saturnino Basilica of four main lithologies.

The more used stone is a porous, marly limestone (samples SS28, SS40, SS91), characterised by a macroscopic colouration generally tending to light yellow (colour space: CIELAB 88*3*36), alternating with slightly darker facies of yellow tones (CIELAB 65*3*28). Also macroscopically, this limestone shows a strong alteration due to a low cementing degree, which is evidenced by a strong surface decohesion and spontaneous fall of material, in the form of powder or particulate granules of $10 < \phi < 100$ µm. At the optical microscope, it presents a lime-mud supported matrix (Figs. 8a, b), consisting of crystal-granules of calcite (about 90% vol. of total granules), often as well-developed crystals with size frequently between 10-30 µm. Crystal-granules of quartz, micas (biotite and subordinate illite), K-feldspar, opaque minerals, rare montmorillonite and kaolinite (in order of abundance) are also present. Various kinds of crystal-clasts, with size ranging from 90 to 600 µm, are present. Bioclasts (about 20% vol. of the rock; Fig. 8b) are represented by planktonic and bentonic foraminifera skeletons (about 25-30%, mainly Globigerinidae), elongated crinoid fragments, curved fragments of brachiopods, bryozoans, etc. Due to the presence of foraminifera and the massive presence of mud, this rock belongs to sub-littoral deposition environment, with oxygenated seawater and normal salinity.

According to Folk (1959), based on the volumetric matrix content (that is > 2/3), its allochemical and bioclastic contents, this limestone can be classified as biomicrite. According to Dunham (1962), due to its sustained mud-texture and scarce terrigenous grains (in any case to a degree well below 10% vol.), it can be classified as wackestone. However, on the basis of mineralogical and petrographical analyses and taking into account the depositional environment, it can be better classified as a poorly cemented marly limestone, consisting of mainly microcrystalline mud and variable presence of bioclastics.

XRPD analysis also highlights the presence of gypsum (and other original salts of marine deposition), formed in the sindepositional phase or resulting from the secondary sulfatation of Ca-carbonate. On the base of these results, we can say that this rock is the *Pietra Cantone* limestone, belonging to the local geological Miocenic formation (Tortonian) of Cagliari, a complex geological-tectonic context of Sardinia widely outcropping inland from Cagliari within the "Fossa Sarda" graben (Vardabasso, 1962), (Advokaat et al., 2014; Casula et al., 2001; Cherchi and Tremolieres, 1984).

Despite its high porosity (28-36 vol%; Columbu et al., 2017a), low mechanical resistance and dissolution problems of the Ca-carbonate matrix (with amount of $CaCO_3$ on average of 75-80%, also variable between 64 and 89%; Barrocu et al., 1981), this stone has been widely used on the historical buildings of all periods, from Nuragic, to Phoenician-Punic, Roman and medieval (Columbu et al., 2015a; Columbu and Verdiani, 2014), probably also for its easy workability. However, due to the hygroscopic volume variations of the clay minerals (about 15-20%) and sea salts, this limestone is easily degradable, with consequent decrease of mechanical strength.

In addition to the *Pietra Cantone*, another stone used in the St. Saturnino Basilica is a compact limestone rock characterized by a generally tending to white colour (colour space: CIELAB 98*-3*-1), with macroscopic fossiliferous components giving beige shades (according to CIELAB 48*0*17). Macroscopically, it exhibits strong cohesion and near-absence of alteration, with weak superficial deposits located in the surface macropores. In thin section, cut parallel to the surface of the sampling container, the rock has all the features of a massive bio-hermetic and biostromal limestone. This lithotype is characterized by a low stratification with a fossiliferous component (90%vol.), immersed in a microcrystalline carbonate cement with a $CaCO_3$ content of 90%, associated with a quantitatively low terrigenous component

(10% vol.). The fossiliferous remains consist mainly of fragments of elongated crinoids, brachiopods of briozoids, foraminifers (Amphistegina, Miogypsina, Elphidium, Rotalia, etc.), algae (litotams) and unidentifiable bioclastic fragments (Figs. 8e, f) with centimetre dimensions. The depositional environment is littoral and infralittoral, with high energy and paleobatimetry less than 30 m. In the studied arches of the monument, there are discordant surfaces and mixed breccia, highlighting the instability of the sedimentation basin of this rock.

Based on the results obtained, and by comparing the association of the planctonic microfaunas (referring to Tortonian), it can be seen that such limestone samples in biohermal and biostroma facies correspond to the *Pietra Forte* formation, belonging to the Miocenic stratigraphic sequence of Cagliari. This rock is a cliff limestone rich in organoleptic shellfish and especially algal (litotams) and large foraminifers, with briozoic colonies that characterize the colour variation from whitish to beige. Although very difficult to work, it was widely used in the historic Cagliari. Unlike the *Pietra Cantone*, this rock is very tenacious from a mechanical point of view, due to its low porosity (< 3%) deriving from a more cohesive calcitic microstructure. However, in some cases the presence of cavities with variable dimensions (from 5 to 30 □m), which locally reduces the physical-mechanical resistance, is observed in this rock with consequent occasional fracturing. On a larger observation scale (in the outcrop), cavities grow on a much larger dimension, generated by karst processes that affect the physical-hydraulic properties of the rocky stock.

Based on the observed fauna, the Pecorini stratigraphic position (1972) and Cherchi (1974) show a Tortonian age and an affinity with other analogous formations in the Gulf of Oristano, Messinian and perhaps even in Pliocene.

The presence of ivory white limestones, with intermediate characteristics between the *Pietra Cantone* and the *Pietra Forte*, was also observed. These rocks consist of a clayey limestone with organogenic fragments (Figs. 8c, d) of macrofauna (fragments of lamellibranchi and gasteripods) and microfauna (Globorotalia sp., Globigerina sp.). The rock is characterized by the presence of millimeter minute clasts, giving the rock a granular appearance, unlike the *Pietra Cantone* (that shows a smaller grain). The $CaCO_3$ content ranges from about 80 to 90%.

Based on a comparison with the local formations of Cagliari area, this facies belongs to the formation of *Tramezzario* (referred to the Tortonian; Pecorini and Pomesano Cherchi, 1969), a rock well known and exploited already from the Punic civilization, due to its good workability associated with good mechanical strength. Observing the outcrop, *Tramezzario* is often intercalated in *Pietra Forte* with limited or lenticular layers. Its good mechanical properties result from a high degree of compactness, characterized by low porosity (< 6%). Locally, however, it may have a widespread microfracturing, which makes it less resistant to physical-mechanical strength. In addition, unlike the *Pietra Cantone* limestone, due to the low presence of clay minerals (i.e., phyllosilicates) it is a poorly hygroscopic rock, therefore particularly suitable to be employed as a building material, as evidenced by the wide use in the historical building of Cagliari area.

3.2. *Volcanic stones*

The volcanic rocks sampled in the walls of the apse of the St. Saturnino Basilica are characterized by various colours: they are usually red-brown in colour (CIELAB 37*1*5), and subordinate violet (CIELAB 17 *25 *19) and greenish facies (CIELAB 27*-15*24).

Macroscopically, they exhibit an obvious physical-mechanical alteration depending on the degree of rock-welding (from low to medium-low). Physical degradation is preferentially manifest in the glass matrix, with decohesion and detachment of the material, or according to flow plans with exfoliation processes.

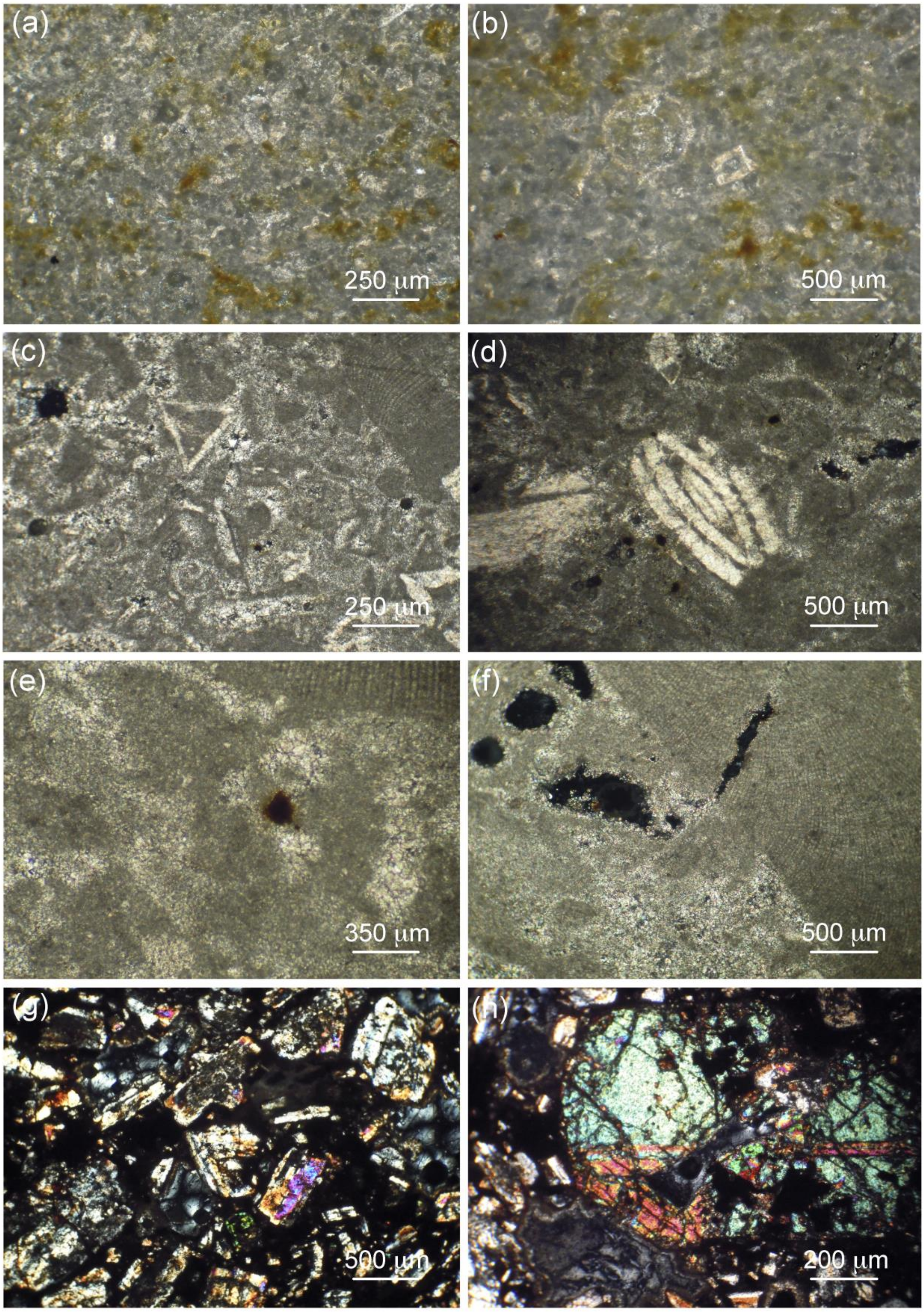


Figure 8. Microscopic features of stones in crossed Nicol photos: (a,b) biomicrite "Pietra cantone", sample SS40, (c,d) biosparite "Tramezzario", SS85, (e,f) biolithite "Pietra forte", SS10, (g,h) andesine, SS52.

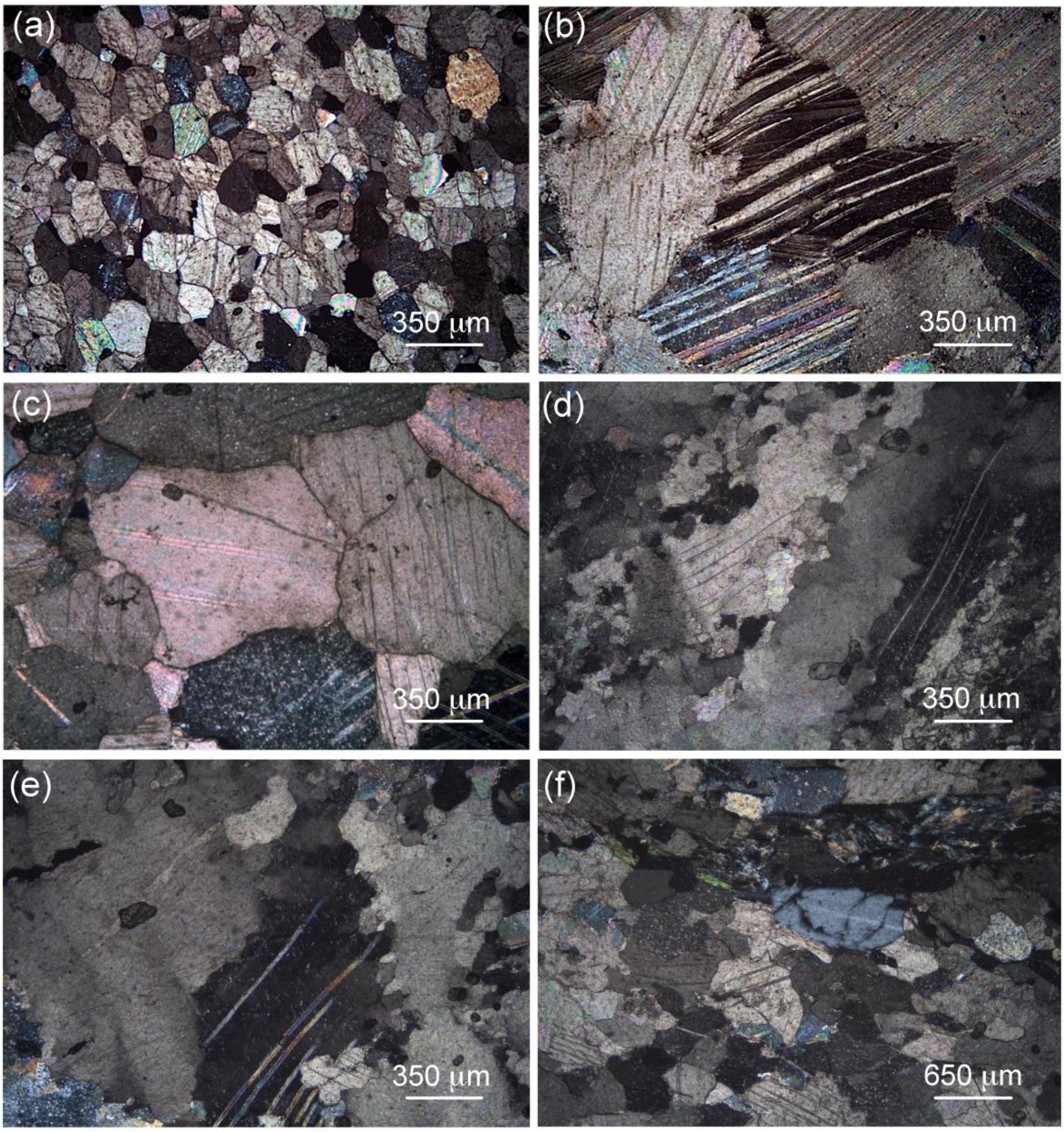


Figure 9. Photomicrographs in crossed polarized light showing the typical miscostructures of the analysed marbles: (a) Carrara marble, SS112, (b) Thasos marble, SS34, (c) Paros marble, SS35, (d) Lesbium marble, SS63, (e) Lesbium marble SS33, (f) Iassense marble SS78.

In thin section, they have a porphyric structure (index, about 38-40% vol.) in which phenocrysts of plagioclase, clinopyroxene, opaque and rare amphibole are immersed in an inequi-granular hypoialine groundmass, mainly isotropic and locally anisotropic. The colour index of these rocks is comprised between 4 and 6.

Phenocrysts of opaque are always submillimetre, in the order of 4-5 % of the total phenocrysts. Plagioclases (around 86-90% vol.) are characterized by subhedral and euhedral habits and size from 0.1 to 1.5 mm. Anorthite content is in the 40-50% range (andesine plagioclase), with an evident zoning often characterized by the presence of corroded and partially reabsorbed nuclei (Fig. 8g), surrounded by oscillatory zoning edges. The related crystals are frequently turbid, due to a caolinitization alteration; relict crystals are often found.

Phenocrysts of pyroxene (about 6-8%) are mainly monoclinic (clinopyroxene) in augitic facies (1 to 4.5 mm in size) with subhedral habit; seldom, a rhombic pyroxene (orthopryroxene) is found.

Clinopyroxene phenocrysts (Fig. 8h) often form monomineral aggregates, sometimes together with orthopyroxene, plagioclase and opaque, thus conferring to these rocks a glomerular-porphyric structure. Orthopyroxene crystals are generally isolated and idiomorphic. Opaques are included in clinopyroxene phenocrysts or at the edge of the orthopyroxenes.

Table 2. Data of fine grained white marbles. Qtz=Quartz, Ms=Muscovite, Gr=Graphite, He=Hematite, Py=Pyrite, Mag= Magnatite, Pl=Plagioclase, Ap=??, Chl=Chlorite, Dol=Dolomite.

Sample	Qtz	Ms	Gr	Ore min. & Fe-oxides	Pl	Ap	Chl	Dol*	MGS	Calcite crystals boundaries	Micro-structure	Fabric	δ^{13}C (PDB)	δ^{18}O (PDB)	Probable Origin
SS16	±	±		±				±	0,42	straight, curved	HO	Mosaic, with some triple points	1,35	-3,51	Carrara
SS17			±	±					0,80	curved ± straight	HO/HE	Mosaic	2,21	-2,38	Carrara
SS20	±	+	±	+ (He, Py)	±				0,45	straight, curved	HO	Mosaic, with some triple points	2,32	-2,43	Carrara
SS34	+	+/++	±	++ (Py)					2,55	sutured	HE	Mosaic with strained crystals	3,68	-0,88	Thasos Aliki
SS35		±	++			±			2,75	curved	HE	Mosaic	1,68	-2,57	Paros Lakkoi (Paros-2)
SS51	+++		±	± (Py)					1,05	curved ± straight	HO/HE	Mosaic, slightly foliated	1,95	-1,02	Carrara
SS70a	+	±		+ (He, Py)					0,70	curved, embayed	HE	Mosaic with patches fine grained	2,06	-1,93	Carrara
SS112	+	±	±	+ (He, Py, Mag)	++			±	0,65	straight ± curved	HO	Polygonal with triple points	2,59	-1,63	Carrara

There are also wrecks of olivine, strongly corroded and altered in iddingsite.

Groundmass is basically consisting of plagioclase, clinopyroxene, orthopyroxene and opaques, with a high percentage of glass (about 80% of the whole). Glass has a typical brown colour that affects the macroscopic colour of the rock.

Based on the determined percentage content of sialic minerals (QAPF; Streckeisen, 1974) and on the average content of anorthite in plagioclase, these rocks are classifiable as andesites.

In light of these preliminary petrographic analyses and of a comparison of the macroscopic and microscopic characteristics with similar volcanic lithologies outcropping in some areas of southern Sardinia, it is conceivable to formulate some hypotheses concerning the origin of the ashlar volcanics used in the walls of the St. Saturnino Basilica: i) they may come from burial material of some ancient Roman sites located around the Roman city of *Caralis* (today Cagliari); for example, from the same vulcanite ashlars used in the tiers of Nora's theatre, which have very similar features; (ii) they may originate directly from some nearby volcanic outcrops (e.g., the districts of Sarroch-Pula, Siliqua), where andesites and dacites with petrographic characteristics similar to those found in St. Saturnino outcrop exist. Further geochemical analyses will surely highlight the origin of such volcanics from the outcrops in southern Sardinia or from other Sardinian archaeological contexts.

3.3. *Crystalline marbles*

In order to locate the provenance of marbles, the results of the mineralogical-petrographic and isotopic analyses were compared with the most up-to-date databases for both the white and streaked, veined or banded grey-and-white Mediterranean ancient marbles (Antonelli and Lazzarini, 2015 and references therein).

With regard to pure white marbles – unlike the coloured ones, which usually can be adequately identified to the naked eye – an effective determination of their provenance requires a combination of different analytical methods. Following Antonelli and Lazzarini (2015), the most probable origins of the marbles used for all the sampled artifacts (cf. Tab. 2, last column) were defined by integrating the basic petrographic characterisation under a polarizing microscope with the geochemical analysis of the C and O stable isotopes.

A summary of all mineralogical and petrographic data collected for each analysed marble is reported in Tab. 2 and Fig. 9.

The isotopic data were plotted into two distinct diagrams (Figs. 10, 11), based on the maximum grain size (MGS), which display the isotopic fields for fine-to-medium (MGS < 2 mm; Fig. 10, Tab. 2) and medium-to-coarse (MGS > 2 mm; Fig. 11, Tab. 2) white marbles, respectively.

As shown in Fig. 10, the isotopic signature of the fine-grained samples (SS16, SS17, SS20, SS51, SS70a, SS112) falls mainly into the overlapping area formed by the Lunense, Hymettus, Paros-1, and Göktepe domains. However, the recorded petrographic features (i.e. grain size and MGS, microstructure and fabric, grain boundary shapes, accessory phases; cf. Tab. 2 and Fig. 9) fit well only those typically defined for the Lunense marble: a source from the Apuan quarries of Carrara seems therefore unequivocal. In fact, only the Göktepe marble may at times show some petrographic features quite similar to those described for the Apuan variety; such a marble, however, is described as a pure and very fine-grained one, without accessory phases, which was used for statuary (Attanasio et al., 2015). In contrast, the analysed samples belong to architectural elements and they contain significant amounts of several accessory minerals (Tab. 2); thus, a possible origin from the Turkish region of Muğla can be easily ruled out.

For what concerns the two coarse-grained white marbles (samples SS34, SS35), the determination of the source area points to the Greek region. Sample SS34 is made of strained calcite crystals, with sutured grain boundary shapes forming a heteroblastic mosaic (Tab. 2). These petrographic features correspond to those known for the marble from the Aliki quarries in the Island of Thasos (Thasos 1-(2)); also the isotopic data indicate this source (Fig. 11). Finally, in the case of sample SS35, the marble shows an heretoblastic mosaic made of calcite crystals with typically curved boundary (Tab. 2; Fig. 9) and an isotopic signature (Fig. 11) pointing to the Lakkoi quarries in the Cycladic island of Paros (Paros-2).

The hypothesized provenances from Carrara for most of the analysed marbles agree with preliminary data from Grillo and Prochaska (2014), who used a combination of isotope analysis with the multivariate analysis including the trace elements. The petrographic and isotopic data (Tab. 2) of greyish marbles (SS33, SS63) show that they have macroscopic pattern, microscopic characteristics and isotopic composition (Fig. 12) typical of the *bigo antico* quarried at Moria, in the island of Lesbos (also called *marmor lesbium*; Lazzarini et al., 1999).

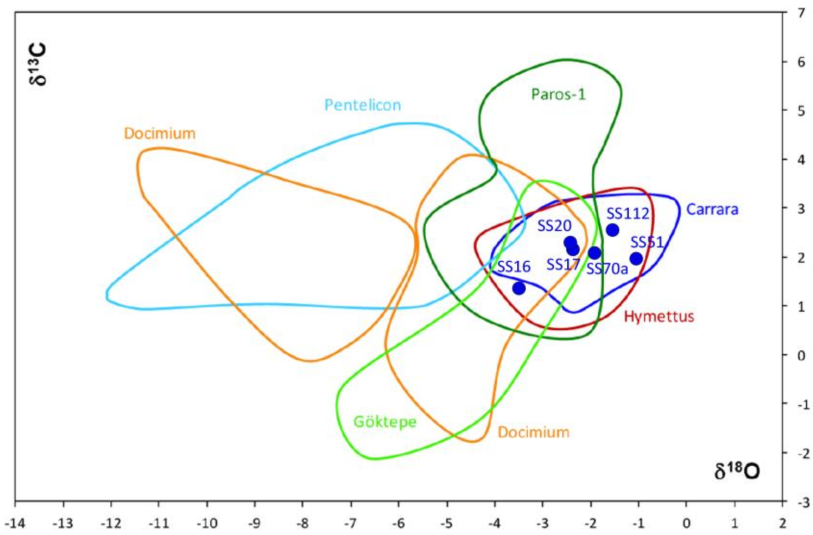


Figure 10. Isotopic signature of SS16, SS17, SS20, SS51, SS70a, and SS112 samples, comparedwith the reference database (after Antonelli and Lazzarini, 2015) for white marbles with MGS < 2 mm.

On the contrary, the study of greyish-black marble of sample SS36, despite its macroscopic and petrographic characteristics being very similar to those of *marmor lesbium*, did not provide definitive results, because isotopic data fall outside the current reference field (Fig. 12) defined by Lazzarini et al. (1999). It is noteworthy that, as observed by the authors, the reference database contains also some "spurious" quarry samples, which fall outside the main isotopic domain probably because they suffered a slight depletion in heavy isotopes due to hydrothermal alteration. Consequently, a possible origin from Lesbos cannot totally be ruled out for SS36. Nevertheless, greyish stones with macroscopic features quite similar to those of our *bigio antico* also outcrop in the Lapanu area (Sulcis), in south Sardinia. The hypothesis of a local origin of this kind of stone finds some potential archaeological evidences in the nearest Punic-Roman city of Nora (Pula, south Sardinia), where some columns of the House of the "*atrio tetrastilo*" present characteristics comparable to those of sample SS36.

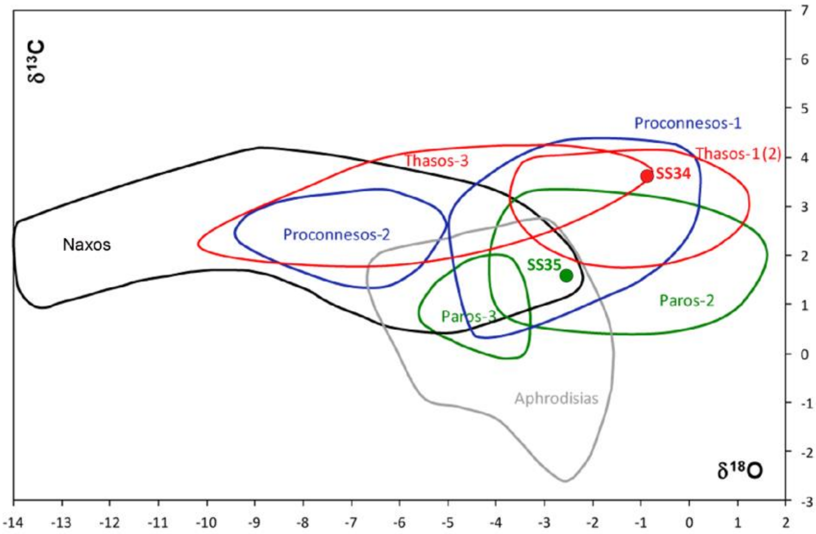


Figure 11. Isotopic signature of SS34 and SS35 samples, compared with the reference database for classical white marbles with MGS > 2 mm (from Antonelli and Lazzarini, 2015).

Finally, concerning the reddish marble of sample SS11, both the macroscopic examination and petrographic analysis highlight that it consists of a metabreccia with crystalloblastic-homeoblastic to lepidoblastic fabric, a rather fine grained carbonate matrix embedding clasts of white to greyish marbles (Figs. 6g, h), variable in size (from 1 to 200 μm), and abundant hematite dispersed along the boundaries of calcite crystals or concentrated in small nodules. Most likely, the columns manufactured with this marble come from Iasos, Caria (Turkey), where *marmor iassense* (also called *marmor carium* or *cipollino rosso*) was quarried.

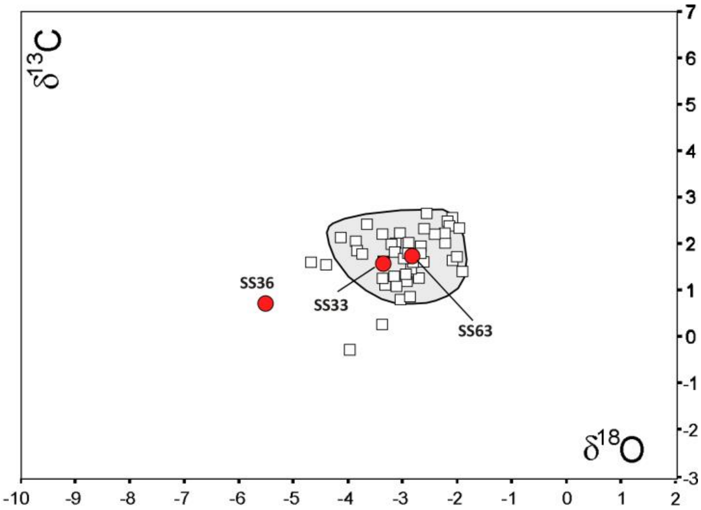


Figure 12. Isotopic signature of the samples SS33, SS36, SS63, compared with the reference database for the marmor lesbium (bigio antico) proposed by Lazzarini et al. (1999).

4. CONCLUSIONS

The results of this research allowed defining the mineralogical-petrographic characteristics and the origin of a part of the numerous geomaterials used in the construction of the St. Saturnino Romanesque Basilica.

The main construction materials of the Basilica are different facies of local limestone rocks, such as massive biohermal limestones, porous limestones and biocalcarenites. These lithologies come from several ancient quarries in the Cagliari region (southern Sardinia), where the stratigraphic units of *Pietra Forte*, *Pietra Cantone* and *Tramezzario*, belonging to the Miocene formation, outcrop.

These limestones, frequently employed in civil and historical architecture, were inhomogeneously used in the structure of the Basilica, in order to realize the squared ashlars of the masonry and sometimes some occasional decorative elements (frames, jambs, etc.). However, some of these materials have been reworked in stages following the Romanesque period, in some cases with the reuse of ancient material or by mixing reuse material with new replacement material. For example, the dome overlapping the intersection of the original aisles of the Greek cross of the early stage of Paleochristian plantation of the monument (IV-VI cent. AD), was rebuilt in the lower medieval (?) or in more recent phases by reutilizing irregular ashlars of *Tramezzario* and *Pietra Forte* limestones. Moreover, the vaulted roof of the Basilica's main nave has been reconstructed, in recent stages of restoration (after major damage due to World War II bombings), with new replacement ashlars of *Pietra Cantone* limestone.

For the realization of the decorative elements of the Romanesque Basilica, marbles of not-local origin were used. These latter comprise highly prized and prominent marbles imported from all over the Roman empire or following the Early Christian complex of St. Saturnino (V-VI cent.). Regarding to the "coloured marbles", the combined petrographic and isotopic study of the greyish samples point to *Marmor lesbium* (one of the so-called *"bigi antichi"*) from Lesbos island (Greece).

Regarding the marble used for the two red columns supporting the wall of the cupola, the visual and petrographic analyses indicate the brecciated facies of *marmor iassense* (also called "*cipollino rosso*") from Iasos, Caria (Turkey).

Furthermore, based on visual observations, Carystum marbles (*"cipollino verde"* from Euboea island; Lazzarini et al., 1995) were recognized in the Romanesque reuse of decorative elements worked in the Roman times.

With reference to the white marbles, the petrographic and isotopic data show that they originate mainly from Carrara quarries, used as constructive elements for bases, capitals, columns, but also slab plates, architraves, jambs, etc. In addition, among the white marbles, some of Greek varieties were identified: from Aliki, in the Thasos island and from Lakkoi, in the Paros Cycladic island.

The presence of Carrara and Greek marbles of Roman tradition in the St. Saturnino basilica, together with the geometric and stylistic analysis of decorative and architectural elements, point out that probably most of these stones are derived from bare material of the Roman construction phase. They are, therefore, probably part of the original temple, at which time there is no precise information or safe historical-archaeological evidence. For example, the lateral columns of the main nave were re-elevated in the Romanesque phase, using shafts of originally Roman columns that, considering their diameter, were obviously much higher in height than the present ones.

The andesitic volcanic rocks used for some ashlars of the abside wall of the Basilica (which represent a limited part with respect to the other stones) are certainly from a local source. They show petrographic characteristics very similar to the rocks outcropping in the two main volcanic districts of Sarroch-Pula and Siliqua (both distant around 30 km from St. Saturnino site). These areas were well-exploited by the Romans in the historical times, with the construction of the ancient cities of Nora (near Pula, south-west Sardinia) and other artifacts (e.g., important Roman aqueduct to *Caralis*) in the Siliqua sector or surrounding areas (e.g., Medau Casteddu?), respectively. It is also probable that the volcanic ashlars found in the Basilica actually are Roman burial materials coming from Nora's site (i.e., from the theatre tiers).

Further investigations (in progress) with new analyses will help to support the classification and origin of the volcanic rocks and a second set of white marble samples.

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