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THE MOSAIC OF THE FRIGIDARIUM OF "VILLA BONANNO" IN PALERMO: MINERALOGICAL AND PETROGRAPHIC ANALYSES FOR IN SITU CONSERVATION AND RESTORATION INTERVENTIONS

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ABSTRACT

The topic of this study was the mineralogical and petrographic characterization of bedding mortars (made of different layers) and *tesserae* of Roman age (3rd century A.D.), taken from the mosaic of the *Frigidarium* of "*Villa Bonanno*", brought to light by archaeological excavations conducted in the historical centre of Palermo. The collected samples have been analysed by thin-section optical microscopy (PLM), and scanning electron microscopy coupled with energy dispersive spectrometry (SEM-EDS). The study was aimed to define the "recipe" (composition of aggregate and binder, aggregate size distribution, aggregate/binder ratio), in order to assess the provenance of raw materials (supply site/area) and to acquire useful information in order to formulate "restoration mortars" that should be most comparable with the original ones, for replacements and/or integration. Rock types constituting the coloured *tesserae* were also characterized by thin-section optical microscopy.

The mineralogical and petrographic investigations allowed establishing two different recipes used for the formulation of the studied mortars in terms of both compositional and textural features. The aggregate is composed by diverse proportions of detritic calcareous granules (both bioclasts and limestone fragments deriving from the local outcropping biocalcarenites and limestones), siliceous sand (monocrystalline quartz, chert and quartzarenite fragments), volcanic ash (pozzolana) and sometimes *cocciopesto*. The resulting hydraulic binder was the product of the 'pozzolanic reaction' between volcanic ash and the aerial lime (specifically made by the calcination of locally available magnesian limestone or dolostone). The coloured *tesserae* can be all classified as compact limestones of Mesozoic or Cenozoic age, likely of local provenance.

KEYWORDS: Sicily, Roman mosaics, bedding mortars, limestone tesserae, restoration

1. INTRODUCTION

Mortars can be considered one of the most significant building material regularly found in the archaeological structures, being employed with binder function in masonry, in internal/external wall rendering or finishing, with the function of bedding materials (floor tiles and mosaics) and even in the manufacture of decorative architectural elements.

As well known, they consist of a mixture of inorganic binders, sand-sized aggregate, water and different additives. The nature and the relative proportions of the various components will provide suitable workability to the fresh mixtures as well as appropriate physical, mechanical and aesthetic characteristics to the required finished product (Elsen, 2006).

The archaeometric study of Roman lime mortar turned out to be a main subject especially in the last two decades. A large number of studies focused on the mineralogical, chemical and textural characterization of historical mortars. They were thus considered as source of important information in the diachronic reconstruction of ancient material cultures all along the Mediterranean area.

Indeed, the combination of archaeological and historical studies with mineralogical, petrographic and chemical investigations provides useful data for assessing nature and provenance of the employed raw materials, the ancient manufacture technologies, the fixing procedures and information on the history of buildings and their different construction phases (Moropoulou et al., 2000; Moropoulou et al., 2003; Carò et al., 2008; Pavìa and Carò, 2008; Piovesan et al., 2009; Sanjurjo-Sánchez et al., 2010; Belfiore et al., 2015; De Luca et al., 2015; Lezzerini et al., 2017). The same importance can be stated in case of restoration issues (Chiarelli et al., 2015 and reference therein). Recent work on mosaics include Salama et al., (2017), Kaplan et al., (2017).

This work is aimed to discuss the mineralogical and petrographic investigations carried out on the bedding mortar and the coloured *tesserae* composing the floor mosaic of a Roman building of high Imperial Age (3rd century A.D.) excavated in the historical center of Palermo (Sicily) at *Villa Bonanno*, a public garden in front of the Royal Palace. It follows several others characterization studies previously carried out on the historical mortars of Palermo, (Montana, 1995; Alaimo et al., 1997, Randazzo et al., 2015; Montana et al., 2016).

The analysis of the sampled mortars has been carried out by means of the combined use of polarized light microscopy (PLM) and scanning electron microscopy coupled with energy dispersive spectrometry (SEM- EDS). The primary aim of this study was to establish the compositional and textural characteristics of the bedding mortar (composed of three layers), the nature of the coloured *tesserae* and the source of the corresponding raw materials. Such a characterization study may possibly be significant for the design of suitable integration mortars to be used in the restoration of this ancient monument.

Moreover, by comparing the compositional and textural data with the ones corresponding to local manufactures dating back to the same period up to more recent historical times, the evolution of 'material culture' in this field can be verified, especially in terms of procedures and selection criteria of raw materials.

2. HISTORICAL CONTEXT AND ARCHAEOLOGICAL EVIDENCES

The work of art analysed within this study is one of the outdoor mosaic floors of a Roman urban residence dated back to the 3rd century A.D., located in the southern part of the public garden named *Villa Bonanno* at Palermo. The garden was designed by Giuseppe Damiani Almeyda in 1905 and aimed to the architectural requalification of the area in front of the Royal Palace, known as *Palazzo dei Normanni* (Fig. 1).

A first building was discovered and excavated by F.S. Cavallari in 1868 and named *Casa A* after G.B.F. Basile in 1874 (Cavallari, 1872). In 1904 A. Salinas discovered a second building named *Casa B*. But it was only thanks to Ettore Gabrici that we could be assumed that the southern part of the *Casa A* was a building for bathhouse use. This can be understood from the comprehensive edition of the 1921 excavation data in which the same scholar deduced that the three rooms, so close to each other, were the *Frigidarium* (where the remains of the mosaic floor covered by this study are preserved), the *Calidarium* and the *Tepidarium* (Di Stefano, 1998).

The house, to this day, has been excavated almost entirely. It extends from North to South for a length of at least 80 m and a width of almost 22 m, occupying an area of about 1800 sqm. The building as a whole is also remarkable for the extraordinary richness of mosaic floors, now almost all detached and preserved at the Regional Archaeological Museum of Palermo.

Two side corridors lead to the spa area, made up of two larger environments and smaller accessory compartments: the central compartment, decorated by a white and black mosaic floor with a *peltarion* (of which remains only a fragment), was intended to serve as the *Apodyterium* (dressing room). The passage to *Frigidarium* was marked by a threshold (Scovazzo, 1992). At the SO corner there was a step leading to a bathtub decorated with white mosaic and walls originally covered with marble slabs, while another bathtub was placed in the opposite corner. Underneath this room, a canalization system was brought to light. We can describe the *Frigidarium's* flooring mosaic like an *Opus Tessellatum*, with a threshold consisting of three heart-shaped leaves and other phytoform motifs, and a floor showing polychrome fish bone decorations surrounded by a frame composed of a braid of goblets (Fiorentini Roncuzzi, 1984).

The constituent materials of the *Tessellatum* are different natural stones (Fig. 2). The layers of mosaic decoration reflect faithfully the stratigraphy described by Marco Vitruvio Pollione in his *De Architectura* (translation by Migotto, 1990): 1) *statumen*; 2) *rudus*; 3) *nucleus*; 4) *sovranucleus*; 5) *tessellatum* (Fig. 3). We can therefore say that the manufacture of the *Frigidarium* flooring mosaic has required several stages of execution: the setting up of a substrate, the mixture of the different mortar layers, the creation of the composition and the bedding of the *tesserae*.

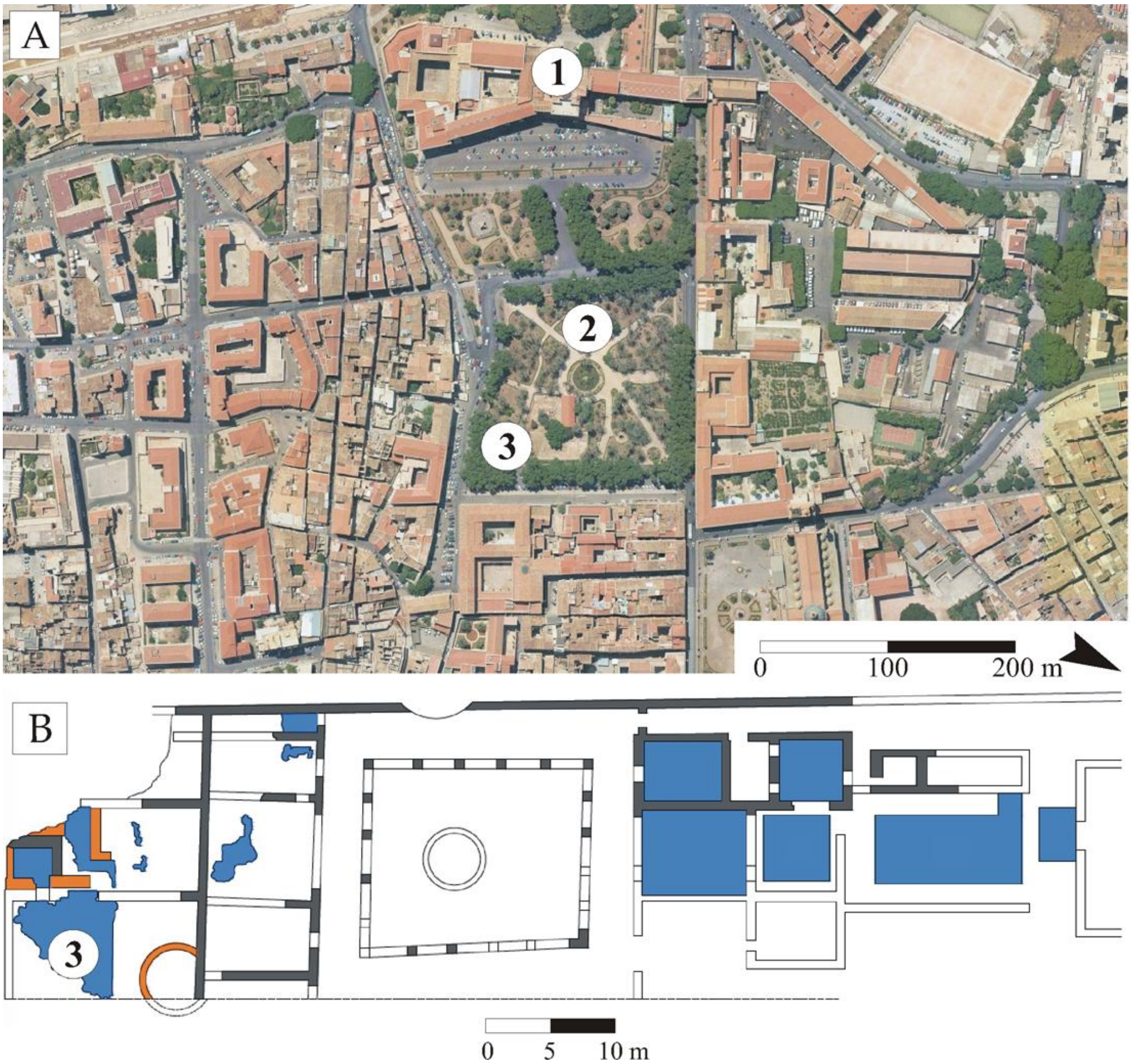

Figure 1. A) Aerial view of "Villa Bonanno" at Palermo (Sicily): 1 = Royal Palace - Palazzo dei Normanni; 2= Villa Bonanno; 3 = Frigidarium mosaic; B) Planimetric sketch of the Casa A.

Figure 2. A) Overview of the Frigidarium mosaic; B) Detail of the frame composed of a braid of goblets; C) Digital relief of the whole mosaic decorations.

Figure 3. .A) Graphic reproduction of mosaic stratigraphy: 1 – statumen. 2 – rudus. 3 – nucleus. 4 – bedding layer (sovranucleus). 5 – tessellatum (after Getty Conservation Institute and Israel Antiquities Authority, 2003); B) Detail of the Frigidarium mosaic stratigraphy.

3. MATERIALS AND METHODS

The sampling was preceded by a detailed visual in situ examination of the whole mosaic, also with the aid of portable digital microscope, considering the various layers of mortar (*rudus*, *nucleus* and *sovrancleus*) and the polychrome stone *tesserae*.

This step allowed us to carefully check the good correspondence of the macroscopic features of the mortars (thickness, prevailing grain-size, sorting, relative abundance of aggregate, colour) in the perimeter points where their complete stratigraphy could be observed. In addition, the colour range of the tesserae was carefully observed as well.

For obvious constrains it has been possible to collect only a limited number of samples and small volumes of materials for the laboratory analyses. Overall, 3 representative samples of the bedding mortar (one for each layer) and 6 stone *tesserae* (one for each identified colour) were collected.

A schematic description of the collected samples is given in Table 1. Sampling has been performed according to the UNI EN 16085:2012. The samples have been collected by means of hammer, chisel and scalpel and stored in sealed plastic bags for the transfer to the laboratory.

Table 1. List of the analysed samples.

Sample code	Layer	Thickness	Cohesion
PVM-1	*Sovranucleus*	0.5 - 2 cm	Low
PVM-2	*Nucleus*	2 - 8 cm	Low-medium
PVM-3	*Rudus*	8 - 15 cm	Low-medium
Sample code	Typology	Thickness	Colour
PVT1	*Tesserae*	1.2 cm	White
PVT2	*Tesserae*	1.5 cm	Black
PVT3	*Tesserae*	1.3 cm	Green
PVT4	*Tesserae*	1.2 cm	Yellow
PVT5	*Tesserae*	1.4 cm	Pink
PVT6	*Tesserae*	1.3 cm	Brown red

Thin-section petrography was carried out on all the samples by a Leica DC 200 polarizing microscope equipped with a digital camera. The relative abundance of sandy aggregate (expressed as area %) was determined by conventional comparative tables (Matthew, 1991).

For SEM-EDS analysis, the samples were stuck with silver glue on pure aluminium stubs (10-mm in diameter) and carbon coated prior to imaging and analysis. They were observed by secondary electron imaging mode (SEI) for emphasizing microstructure and particle morphology.

Semiquantitative microchemical analyses were carried out by a Leica LEO 440 equipped with a Link Analytical ISIS energy-dispersive spectrometer (operating conditions: 20 KV accelerating voltage, 1.2 nA beam current, working distance equal to 10 mm and counting times up to 100 s).

4. RESULTS AND DISCUSSION

4.1. *Bedding mortars*

4.1.1. *Rudus*

It corresponds to the mortar preparatory layer directly placed over the *statumen*. The latter is a bed of calcareous stones (Fig. 3) that is generally aimed to make more resistant the underlying soil and get better drainage of infiltration waters in order to reduce water retention.

The studied *rudus* layer can be classified as a hydraulic mortar obtained by mixing aerial lime to an aggregate composed of natural volcanic ash (*pozzolana*), fragments deriving from crushed brick/tiles (*cocciopesto*) and natural silico-calcareous fluvial sand of local provenance. This layer shows two distinguishing features: 1) high aggregate/binder ratio (high relative abundance of aggregate); 2) greater relative abundance of local sand of sedimentary origin among the aggregate constituents.

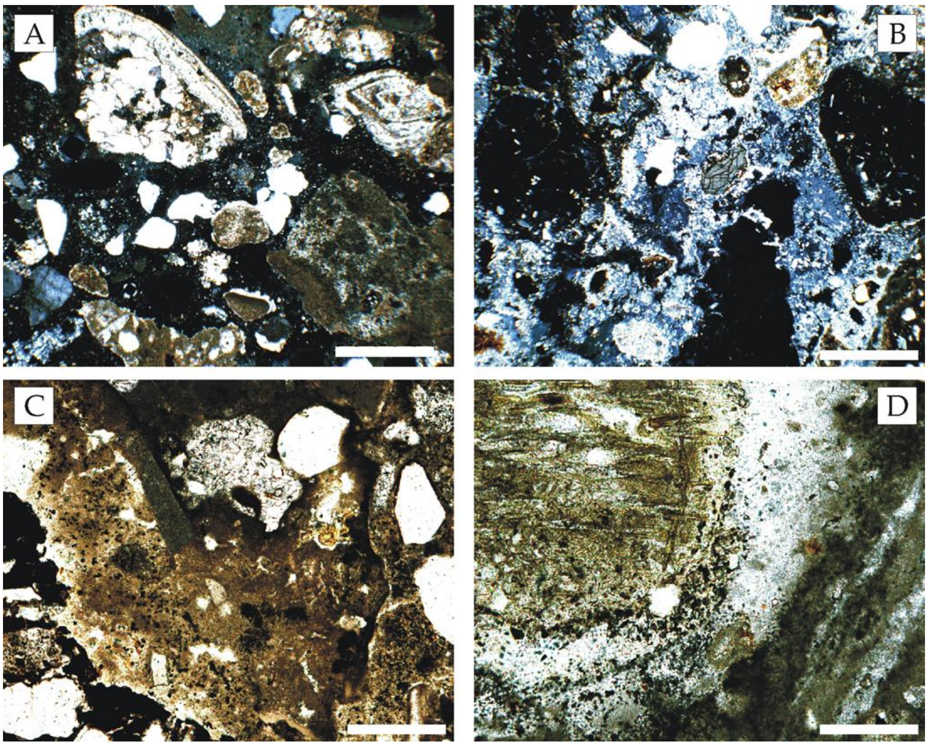

Figure 4. Thin-section photomicrographs of the rudus layer: A) and B) binder-aggregate overview (crossed polars, scale bar = 0.5 mm); C) lime lump rich in iron oxides (plane polars, scale bar = 0.2 mm); D) area of pozzolanic reaction around a volcanic glass fragment (plane polars, scale bar = 0.1 mm).

Grain size distribution of sandy aggregate is rather heterogeneous, with large *cocciopesto* fragments of up to 15 mm in size. The sandy aggregate is poorly sorted with prevailing size falling in the medium and coarse sand classes (0.25-1 mm). Both finer sand fractions (0.06-0.125 mm) are relatively less represented. The relative abundance of sandy aggregate is somewhat high and stands on the 70-75% (area).

From the compositional point of view, the detritic sedimentary fraction is composed of equivalent quantities of calcareous lithic fragments (quaternary biocalcarenites, bioclasts and Mesozoic-Tertiary compact limestones), and siliciclastic grains (monocrystalline quartz, polycrystalline quartz, quartzarenites and chert). Common, although comparatively less abundant than the aggregate of sedimentary origin, the aggregate of volcanic origin (fragments of trachytic rocks, vesiculated glassy scoriae, euhedral and/or twinned clinopyroxene, high-T K-feldspar (sanidine) sometimes euhedral and/or twinned). *Cocciopesto* fragments are large but relatively less common (Fig. 4 A-C).

Binder groundmass consists of portions of CSH and CAH (amorphous calcium and aluminum silicate hydrogels) forming slit-shaped colloidal masses, optically inactive, that are irregularly mixed with areas composed of microcrystalline calcite, that, on the contrary, are optically active and show birefringence. The pozzolanic reaction is mostly constrained around the volcanic lithic fragments and volcanic glass, which seem to be relatively more reactive than the monomineralic granules (Fig. 4 D).

When observed at SEM, the groundmass appears fairly heterogeneous with numerous lumps and micritic texture, where $CaCO_3$ (diameters mostly comprised between 0.1 and 3 microns) prevails over CSH and CAH. These areas are also affected by greater mesoporosity than the silicate hydrogels areas. The large plagues in which the 'pozzolanic reaction' has taken place have a different morphology, appearing as compact masses of submicrometric colloidal particles often fissured (Fig. 5A-B). The qualitative chemical analyses by EDS spectrometry demonstrate this remarkable compositional variability of the binder in which the two components are roughly the same (Fig. 5C). In some contexts, even the presence of negligible quantities of probably amorphous or slightly crystalline iron-manganese compounds has been noted (Fig. 5D). No evidences of biological activity were found.

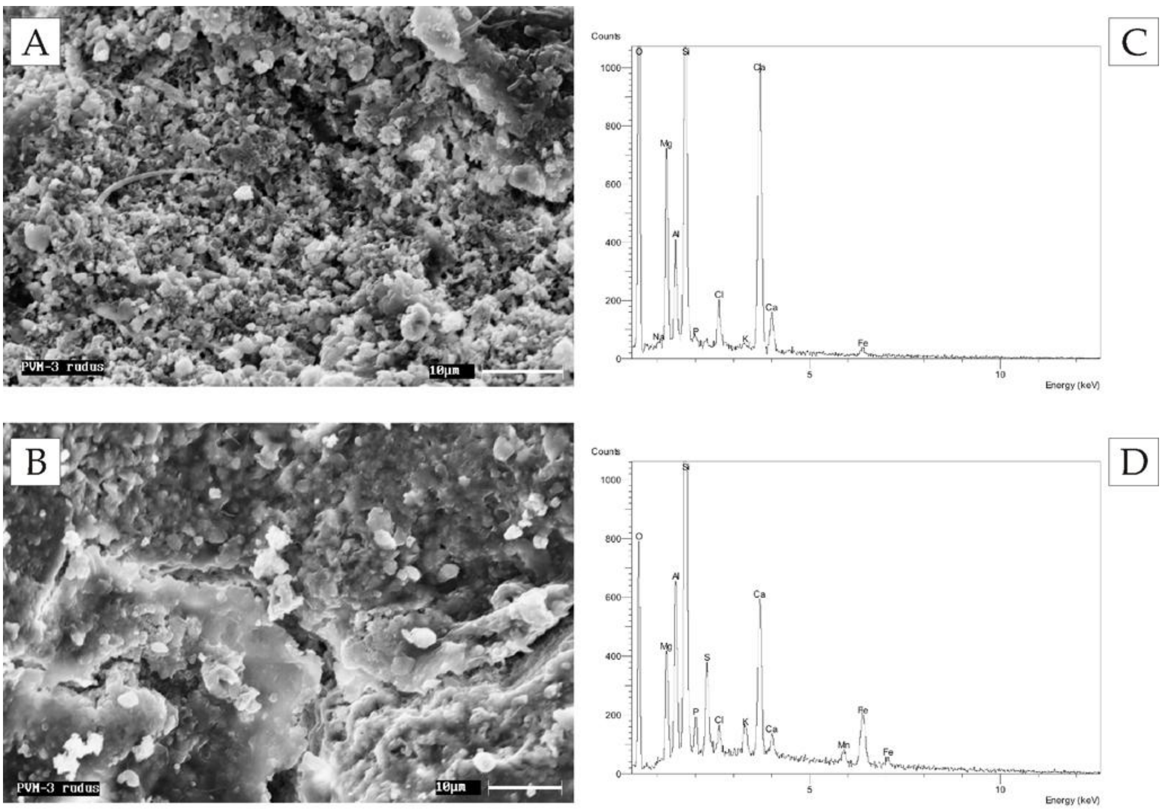

Figure 5. SEM photographs (secondary electron image SE) of the rudus layer: A) and B) general view of the groundmass; C) EDS spectrum representative of areas showing pozzolanic reaction; D) EDS spectrum showing the presence of small quantities of iron-manganese oxides/hydroxides.

4.1.2. *Nucleus*

It corresponds to the second mortar preparatory layer, which is positioned immediately above the *rudus*. The *nucleus* layer of the mosaic decorating the *Frigidarium* floor, likewise the *rudus* layer, can be classified as a hydraulic mortar obtained by mixing aerial lime with an aggregate composed of natural volcanic ash (*pozzolana*), *cocciopesto* and silico-calcareous fluvial sand of local provenance.

The distribution of the aggregate is heterogeneous with average relative abundance around 60-65% (area), being just lower than what was estimated in the *rudus*. Sorting is also heterogeneous ranging from very fine sand (0.06-0.1 mm) to very coarse sand (1-2 mm) or even granules (2-4 mm) and pebbles (4-64 mm), which are mostly consisting of large trachytic lithic fragments (5-6 mm). However, the aggregate grains falling into the medium (0.25-0.5 mm) and coarse (0.5-1 mm) sand classes are relatively more abundant.

The aggregate is composed of prevailing volcanic materials consisting of lithic fragments (vesiculated glassy scoriae and trachytic rocks), euhedral or sub euhedral crystals of clinopyroxene and sanidine (both sometimes twinned). The sedimentary fraction is once again composed of bioclasts, lithic fragments of compact limestones, monocrystalline quartz, chert and fragments of quartzarenites. It is appreciably subordinated with respect to the volcanic fraction of the aggregate (Fig. 6A-C). *Cocciopesto* can be considered a subordinate constituent as well. The binder groundmass has a fairly heterogeneous structure characterized by frequent lumps consisting of irregular masses of amorphous CSH/CAH consolidated hydrogels developed mainly around volcanic ash granules ('pozzolanic reaction' rims), interposed into areas formed of microcrystalline calcite (micrite) characterized by evident optical activity (Fig. 6D).

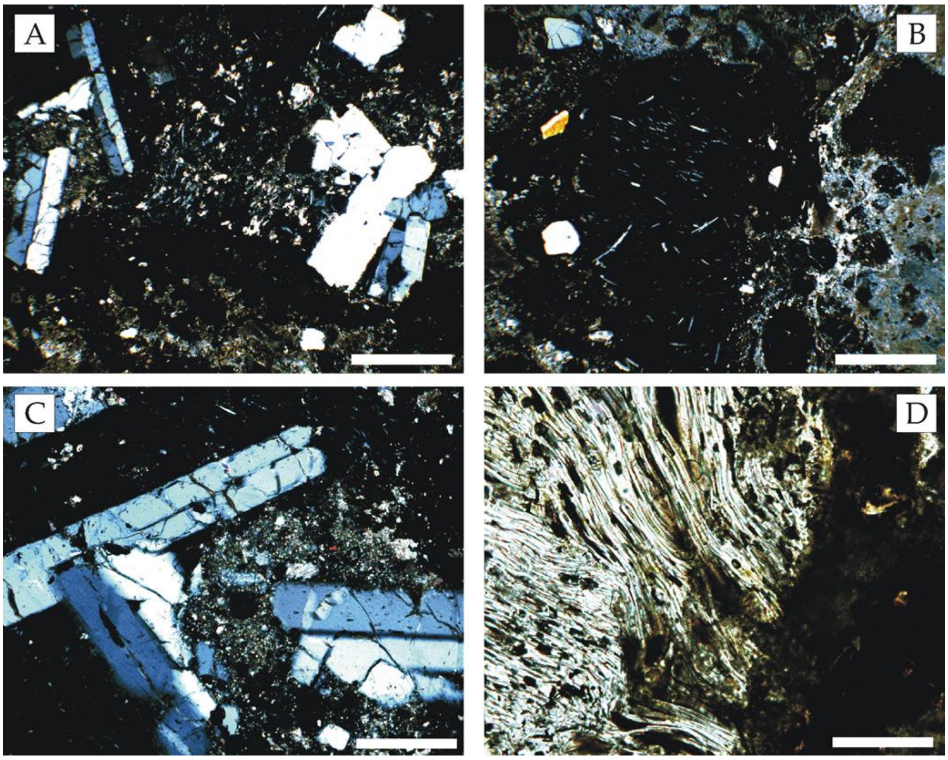

Figure 6. Thin-section photomicrographs of the nucleus layer: A) euhedral and twinned sanidine crystals (crossed polars, scale bar = 0.5 mm); B) trachytic lava fragments (crossed polars, scale bar = 0.5 mm); C) detail of the contact between euhedral sanidine crystals and the groundmass (crossed polars, scale bar = 0.2 mm); D) pozzolanic reaction at the external rim of a vesiculated volcanic glass fragment (plane polars, scale bar = 0.1 mm).

Once again by SEM-EDS analysis, the volcanic glassy scoriae and the groundmass of the trachytic fragments demonstrated to be particularly reactive with lime. The unreacted portions of binder are composed of calcium carbonate particles with rather variable sizes but generally less than 5 μm. The smaller particles are aggregated to form larger lumps, even up to 10-15 μm, with irregular morphology (Fig. 7A-B). The microtexture appears far from homogeneous and is evidently characterized by the diffused presence of macropores (diameter > 0.05 μm), irregular in shape. The degree of adhesion of the binder to the grains of the sandy aggregate is quite satisfactory. In conclusion, the binder of the *nucleus* layer can be considered a fairly chaotic mixing of portions where the pozzolanic reaction has taken place consistently (Fig. 7C-D) and areas where the well-carbonated lime microparticles prevail.

These latter portions of the groundmass are characterized by a remarkable meso- and macroporosity and granules with a predominant size ranging from 0.1 to 3 microns. Only negligible traces of biological activity were observed in the *nucleus* layer.

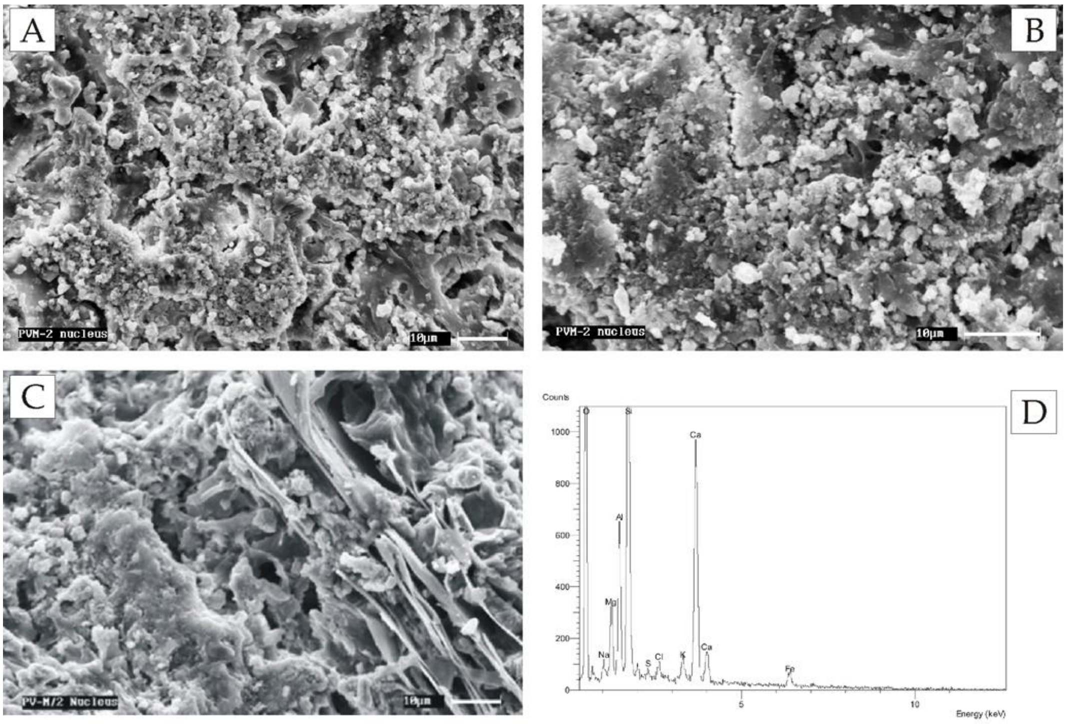

Figure 7. SEM photographs (secondary electron image SE) of the nucleus layer: A) portion of the groundmass composed of a mixture of CSH/CAH and micrite; B) macroporosity of the groundmass; C) reaction rim of a vesiculated volcanic glass fragment; D) EDS spectrum representative of an area where the pozzolanic reaction has taken place.

4.1.3. Sovranucleus

The *sovranucleus* can be considered the ultimate bedding mortar layer that, in fact, surrounds the mosaic *tesserae* and adheres to the underlying *nucleus* level. In the same way like the previously described underlying layers, it can be classified as hydraulic mortar obtained by mixing aerial lime with an aggregate com-posed of *pozzolana*, *cocciopesto* and local fluvial sand deriving from the erosion of sedimentary rocks.

The distribution of the aggregate is quite heterogeneous with variable relative abundance (expressed as area%) ranging from 25% to 60% (average around 45%). Sorting of the aggregate is also heterogeneous ranging from very fine sand (0.06-0.1 mm) up to large particles of *cocciopesto* (also 1-4 mm). Medium sand granules (0.25-0.5 mm) and coarse sand (0.5-1 mm) are also common. From the compositional point of view, the aggregate consists of roughly equivalent amounts of volcanic grains (vesiculated glassy scoriae, trachytic lithic fragments with alkaline feldspar microcrystals, euhedral and subhedral crystals of sanidine, clinopyroxene and rare plagioclase) and sedimentary grains (monocrystalline and polycrystalline quartz, sandstone fragments, chert, bioclasts, limestone fragments, biocalcarenite fragments). *Cocciopesto* fragments are quite large in size but relatively less frequent than the other components (Fig. 8A-C). Binder groundmass shows a heterogeneous lumpy structure. It is composed of amorphous CSH/CAH alternating to areas composed of microcrystalline calcite. Micritic areas are well recognizable due to their optical activity. It should be noted that the pozzolanic reaction rims are also recognizable around large *cocciopesto* fragments, which however are much less intense than those around the volcanic grains. The vesiculated glassy scoriae and the groundmass of the trachytic lithic fragments were found to be particularly reactive (Fig. 8D).

SEM-EDS observations concerned the micro morphological and ultra-structural aspects of the binder. The groundmass of the sample has a diffuse macroporosity (diameter > 0.025 µm) with irregular shaped macropores having diameters up to about 100 µm (Fig. 9A). In this case, a significant biological activity is confirmed by the detection of fungal hyphae and spores (Fig. 9B). SE imaging coupled with EDS analysis confirms the hydraulic nature of the binder, as evidenced by the considerable abundance of Si and Al in the corresponding spectrum (Fig. 9C-D). It is also evident that the starting aerial lime mixed with the volcanic ash was magnesium rich. Traces of S and Cl were also detected being indicative of contamination by soluble salts likely deriving from the millenary deposition of marine spray (aerosol). The presence of small amounts of phosphorus in the EDS spectra may be related to the above-mentioned biological activity, while the small amounts of iron and potassium, on the other hand, are related to the volcanic raw materials.

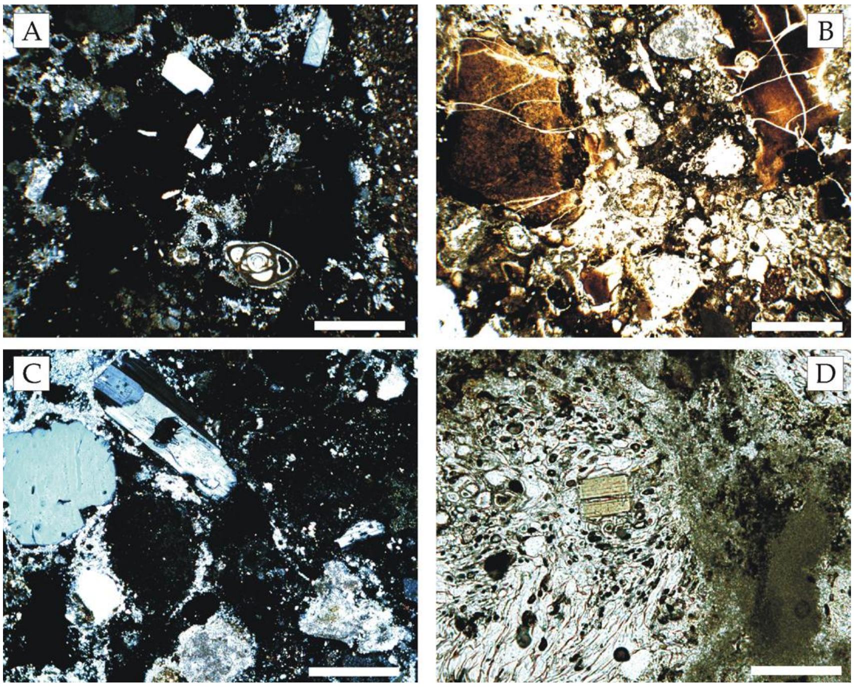

Figure 8. Thin-section photomicrographs of the sovranucleus layer: A) optically inactive binder groundmass surrounding a bioclast (crossed polars, scale bar = 0.5 mm); B) slit-shaped colloidal masses composed of amorphous calcium and aluminum silicate hydrogels (plane polars, scale bar = 0.5 mm); C) sanidine crystals together with grains of sedimentary origin (crossed polars, scale bar = 0.2 mm); D) reaction rim arround a vesiculated volcanic glass fragment (plane polars, scale bar = 0.1 mm).

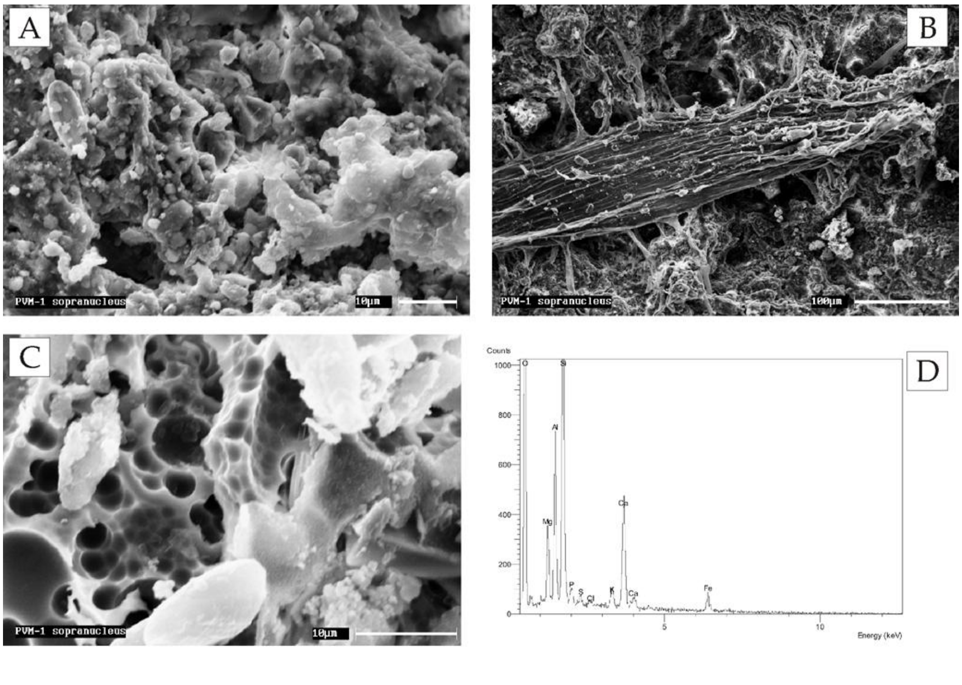

Figure 9. SEM (secondary electron SE) images of the sovranucleus layer: A) macroporosity of the groundmass; (B) evidences of biological activity; (C) vesiculated volcanic glass fragment; (D) EDS spectrum representative of pozzolanic reaction area.

4.2. Tesserae samples

Erratic *tesserae* samples were carefully collected from the mosaic corresponding to every detected colour. In total 6 different colours were recognized: white, black, green, yellow, pink, brownish red. The petro-graphic descriptions of the individual *tesserae* are shown schematically in Table 2. All the Rock types constituting the *tesserae* can be classified as limestone (wackestone), although characterized by variable compositional and textural features, while no glass and/or ceramic tesserae have been recognized in this case study. The different colours depend on textural (matrix/cement ratio) and compositional aspects (relative abundance of chromophoric elements and their oxidation state).

Table 2. Concise microscopic description of tesserae samples.

Sample code	Colour	Microscopic description
PVT1	white	compact shallow water limestone
PVT2	black	calcilutite with recrystallized radiolarians
PVT3	green	calcilutite with plancktonic microfossils
PVT4	yellow	shallow water well cemented limestone
PVT5	pink	marly limestone with planktonic foraminifera
PVT6	brownish red	calcilutite with plancktonic microfossils

White and yellow *tesserae* have been both realized using relatively shallow water limestones characterized by the presence of bivalve molluscs, calcareous algae and recrystallized benthic foraminifera. Both the Rock types are well cemented by spathic calcite. Only in the yellow limestone moderate amounts of iron oxides/hydroxides were detected as very fine particles scattered in the micritic groundmass (Fig. 10A and 10B).

Green and brownish red *tesserae* are both composed of deep-water calcilutites with planktonic microfossils. A dense network of microfissures filled with spathic calcite affects the green rock type. It is homogeneously impregnated by iron oxides/hydroxides colloidal particles (Fig. 10C). The brownish red rock type shows a more or less equivalent network of microfissures filled of spathic calcite with respect to the previous one. The groundmass is impregnated by relatively larger amounts of iron oxides/hydroxides (Fig. 10D).

The pinkish *tesserae* are constituted by a pelagic marly limestone rich in planktonic foraminifera (*Globotruncana*) locally known as '*Scaglia*' and dated back to the wide time interval between late Cretaceous (Cenomanian) and Eocene. This rock type is homogeneously impregnated by iron oxides/hydroxides, sometimes with dendritic development (Fig. 10E).

The black *tesserae* have been manufactured by using a pelagic calcilutite showing recrystallized radiolarian. The groundmass is extensively impregnated by iron and manganese oxide/hydroxide with characteristic dendritic growth (Fig. 10F).

In any case, the predominant colour is related to the presence of different amounts of iron oxides/hydroxides at different degrees of crystallinity and, only in the case of the black sample, manganese oxides are involved as well. The provenance of all the described rock types can be likely considered local or regional. Detailed micro-paleontological analyses are requested in order to obtain a precise stratigraphic setting.

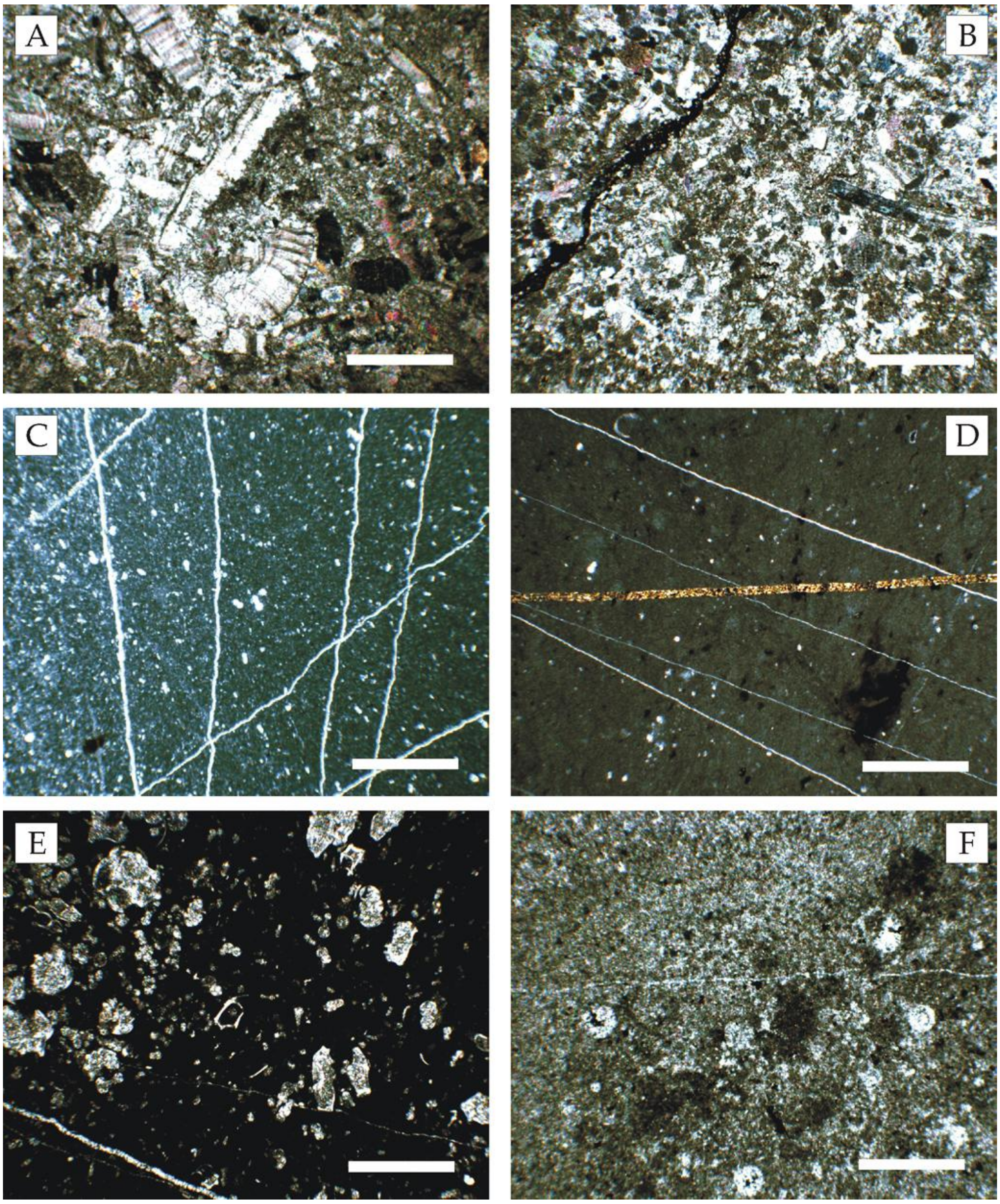

Figure 10. Thin-section photomicrographs of the analysed tesserae (crossed polars, scale bar = 0.5 mm): A) PVT1 sample; B) PVT4 sample; C) PVT3 sample; D) PVT6 sample; E) PVT5 sample; F) PVT2 sample.

5. CONCLUSION

It is well known that the addition of volcaniclastic material (erupted ashes) known as *pulvis Puteolis* or *pozzolana* (Puteoli is the Latin name for modern Pozzuoli on the Bay of Naples) to quicklime (CaO) in presence of water causes the growth of phases that, after curing, produce a hard and waterproof material. This discovery enhanced drastically the building methods all over the Roman Empire, and the *pozzolana* was therefore imported for specific uses in all the regions of the Empire that were served by sea routes (Siddall, 2000).

The archaeometric study of the bedding mortars taken from the mosaic of the *Frigidarium* belonging to the Roman *Domus* recovered at *Villa Bonanno* located in the historic centre of Palermo confirmed the above cited good practice of manufacture and revealed some interesting details about the choice criteria and mixing of raw materials. At the same time, the petrographic and compositional information, obtained by this archaeometric study, may be helpful to prepare well-matched mortars for restoration works. Indeed, although the scientific knowledge about the Roman mosaics of Sicily is still limited, such diagnostic studies are essential for the development of an orientation favourable to their in situ conservation.

The analysed samples were found in a quite poor state of conservation. The different mortar layers (*rudus*, *nucleus* and *sovranucleus*) showed rather similar qualitative compositions. The aggregate is constituted of various proportions of local detritic calcareous and siliceous grains. This sedimentary fraction mostly consists of bioclasts, deriving from the Quaternary calcarenites outcropping in the Palermo's plane, fragments of compact limestones from the carbonatic platform bordering the urbanized area at S-SE, monocrystalline quartz, chert and fragments of quartzarenites, deriving from the outcrops of the Numidian Flysch Formation. However, the most important component of the studied mortars are the volcanic glassy scoriae, volcanic minerals and lithic fragments from the above mentioned deposits located in the Gulf of Naples and belonging to the potassic and ultrapotassic Campanian Magmatic Province. Only negligible amounts of *cocciopesto* were pointed out.

The resulting hydraulic binder was the product of the 'pozzolanic reaction' between the volcanic ash (particularly the glassy scoriae) and the quicklime specifically made by the calcination of locally available magnesian limestone or dolostone (Montana, 1995, 1997; Randazzo et al., 2015; Montana et al., 2016). Solidified hydrogels of calcium silicates and aluminates showing microcracks, produced during the drying phase, form the pozzolanic reaction rims that surround the volcanic ash grains, characterizing the binder. Nevertheless, specially in the *rudus* layer, areas composed of micrite, i.e. microcrystalline calcite derived from the carbonation of $Ca(OH)_2$ during the curing phase, were observed as well.

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