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Mortars and plasters from the Bruttii - Roman city of Taureana (Palmi, RC, Italy) - preliminary data

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Abstract

In this work we present the preliminary results of the analysis of some plaster and mortar samples taken from the site of Taureana (Palmi, RC), an important Bruttii - Roman city. Two different construction phases of the city are investigated and refer to the presence of Bruttii (IV - I B.C.) and Roman (I B.C. - IV A.D.) settlements. The studied materials were collected from different architectonical structures and characterized by means of optical microscopy (OM), SEM/EDS and X-ray diffraction (XRD) analyses. The study allowed to obtain preliminary interesting information about the evolutions in this chronological lap of production technology of plasters and mortars used in the different architectural structures. Furthermore, the petrographic observations have allowed the provenance of raw materials to be determined.

Key words: Taureana; plaster; mortar; archaeometry; SEM-EDS; Bruttii village.

Introduction

This work is part of a wider project aimed at studying mortars of different sites in Sicily (Capo Peloro, Halesa, Messina e Terme Vigliatore) and Calabria (Barone et al., 2007, 2008a, 2008b, 2011).

The study of ancient mortars represents an important aspect in investigating archaeological and historical buildings (Elsen, 2006). In particular, a complete archaeometric characterization of these materials allows the resolution of important archaeological and conservation problems such as provenance of raw materials, comprehension of manufacturing processes (Moropoulou et al., 2000), identification of different construction phases (Crisci et al., 2001), weathering processes and preservation or restoration actions (Elert et al., 2002).

In this work, we present the preliminary results of the analyses of a set of plasters and mortars sampled during a recent archaeological excavation in the area of Taureana (Palmi, Reggio Calabria). The main goal of this project is to characterize the building materials and highlight possible changes in the different structures relative to different time periods. Given the importance of the site, the sampling has been carried out with the intent to obtain at least one specimen, which is representative of each archaeological building and construction phase, in order to draft the peculiar trait of manufacturing production processes in the city. In particular, the characterization of studied materials has been carried out by means traditional petrographic, mineralogical and chemical analyses with the aim of obtaining basic information about materials and degradation processes and schedule further sampling and investigations.

Archaeological and Geological setting

The city of Taureana is a wide and important archaeological area situated in Southern Calabria (Agostino, 2001, 2005; Agostino and Sica, 2011) (Figure 1).

Archaeological excavations of the area testify that the site was occupied from proto-history to Middle-Ages. The earliest archaeological evidence is represented by the remains of huts referred to the Bronze Age and dated to approximately 2000-1100 B.C. After a gap, during which not-settled Greeks occupied the area from VIII to VII sec. B.C., the site was settled by the first Bruttii village dated between

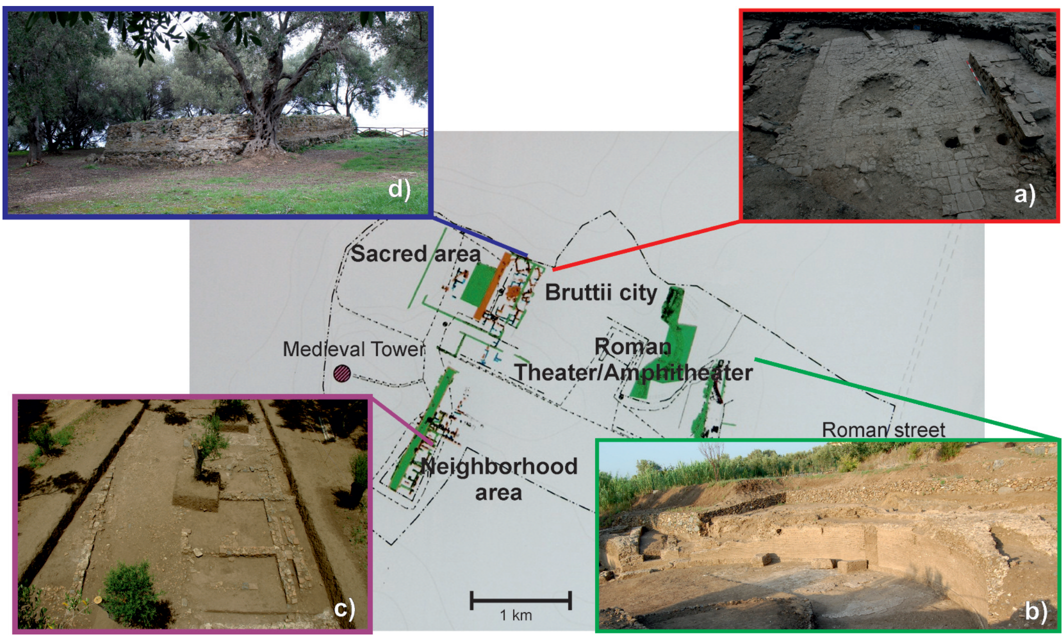

Figure 1. The archaeological site of Taureana (Palmi, RC, Italy). Structures and points of sampling. a) House of Mosaic; b) Roman theater/amphitheater; c) Neighborhood area; d) Sacred area.

IV-II sec. B.C. and represented by a limited number of domestic buildings. After the first construction phase, archeological research has highlighted two different edification periods: the second phase of Bruttii city and the Roman city of Taureana. The first one has been dated to II-I B.C. by an ancient Roman brick stamp; it is mostly represented by some domestic and commercial buildings and an important public/private structure (House of Mosaic). It is a complex and wide structure, covering about 400 m^2 composed of several decorated rooms in which a prestigious opus vermiculatum was discovered. The second one is dated between I B.C. - IV A.D. and represents a moment during which the city was equipped with a Sacred area represented only by a platform (1.70 meter high) and an arcade area; the latter is 5 meters wide and exhibits a double set of parallel walls made of concrete and preserved at the foundation level. The other very important building is the Roman (I - IV A.D.) theatre/amphitheatre represented by a west-oriented cavea placed on a natural slope. This structure is evaluated as an unicum in Southern Italy for its architectonical and dimensional characteristics. The walls of the structure are made of concrete and covered by stones and bricks. The neighborhood area is characterized by a series of residential structures placed near a great Roman street about 5 m wide.

At the end of IV A.D. the Roman city of Taureana was gradually abandoned and despoiled to build the surrounding rural district and the Medieval church of S. Fantino, rising up from an ancient Roman structure.

Due to this complex archaeological stratification, it is quite difficult to distinguish archaeological materials ascribable to the different construction phases. For these reasons, a preliminary sampling of mortars and plasters took into account the two intermediate construction phases of the city, keeping out proto-historical and medieval phases.

Going on the geological setting (Figure 2), the area is characterized by Paleozoic magmatic and metamorphic basement (Rottura et al., 1991). In the site, the magmatic association is represented by the Taureana pluton (Bonfiglio, 1964), characterized by a gray crystalline quartz diorite composed by plagioclase, biotite, amphibole and pyroxene. In the same area, schists and gneiss rich in amphibole and biotite also crop out; the assemblage of minerals is represented by plagioclase (microcline and orthoclase), ribbon of quartz and biotite. A common trait of this latter litotypes is the presence of tourmaline.

With regard to the metamorphic basement, the diorite-kinzigite formation crops out on the Taureana cliff (Faraone, 1968; Ortolano et al., 2013). It is characterized by a sequence mainly consisting of: i) garnet-sillimanite gneiss (kizingite) formed by (in order of abundance) quartz, sillimanite, biotite, garnet, feldspar (plagioclase commonly twinned), while zircon, graphite, apatite and pyrite are present as accessory minerals; ii) gneiss characterized by biotite, quartz and feldspar as mineral assemblage with titanite, zircon and apatite as accessory minerals; iii) pyroxene-garnet rich rocks in which diopside and grossular are present in association with feldspar and quartz.

The sedimentary cover in this area is represented by siliciclastic sands (Tortonian), boundstones with corals (Messinian), evaporitic limestones (Messinian), chalk (Lower Pliocene), conglomerates and sands (Lower Pliocene), Blue Clays (Lower-Upper Pliocene) and marine terraces deposits (Pleistocene) (Grasso et al., 1996).

It is worth noting that plutonic rocks are used as building stones in Roman period, as is testified by the presence of ancient quarries in the area (De Vuono et al., 2006; Antonelli et al., 2010). Moreover, the presence of an aggregate quarry in the site known as Tower of Taureana (Faraone, 1986) testify the use of metamorphic kinzigite rocks as an aggregate in the local construction industry.

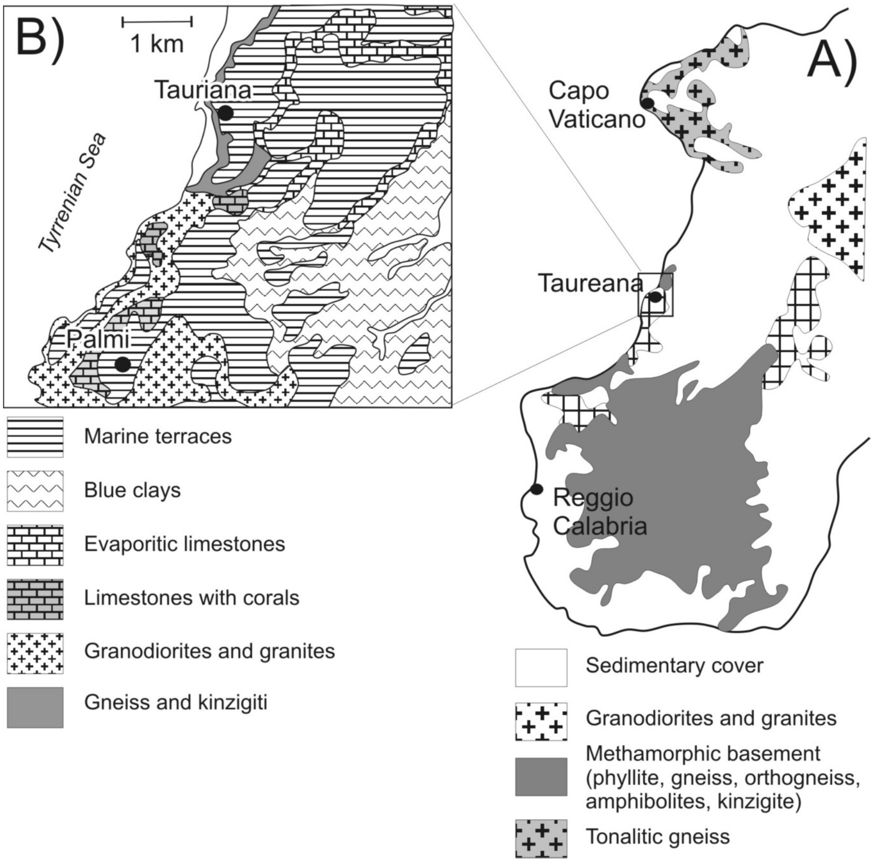

Figure 2. A) Geological setting of the crystalline basement of the southern Calabrian Arc (modified from Amodio Morelli et al., 1976); B) Geological sketch map of the Tauriana area (modified from Grasso et al., 1996).

Materials and methods

Twelve samples were taken from different parts of the Taureana archaeological site as representative of plasters, jointing mortars and pavement mosaics. In Table 1 label, description and provenance of each sample are summarized. On each sample, a preliminary macroscopic description with the colour determined through Munsell soil colour chart (Munsell Index = M.I.) (Munsell, 1994) and the state of conservation was done.

Samples TA6 (Figure 3a) and TA7 are two fragments of mosaic pavement characterized by white stone tesserae. Two different layers under the tesserae are recognizable in the samples; the first one is homogeneous and without aggregates, the second one has a light grey colour (M.I. 7.5 YR 7/1) and presents heterogeneous clasts in the binder. The degree of adhesion between the layers is good; finally, samples show a medium strength and a good degree of preservation.

The wall plasters and mortars (TA8, TA9, TA13) have a pale brown (M.I. 10 YR 6/3) - light yellowish brown (M.I. 10 YR 6/4) colour and a

Table 1. Description and provenance of each sample.

Sample	Description	Provenance
TA 6	Pavement mosaic	Bruttii city - House of Mosaic (II - I B.C.)
TA 7	Pavement mosaic	Bruttii city - House of Mosaic (II - I B.C.)
TA 8	Wall plaster and mortar	Bruttii city - House of Mosaic (II - I B.C.)
TA 9	Wall plaster and mortar	Bruttii city - House of Mosaic (II - I B.C.)
TA 13	Wall plaster and mortar	Bruttii city - House of Mosaic (II - I B.C.)
TA 11	Foundation mortar	Sacred area
TA 16	Jointing mortar	Sacred area (I B.C. - I A.D.)
TA 17	Jointing mortar	Sacred area (I B.C. - I A.D.)
TA 19	Jointing mortar	Neighborhood area (I - IV A.D.)
TA 10	Foundation mortar	Roman theater/amphitheater (I - IV A.D.)
TA 20	Jointing mortar	Roman theater/amphitheater (I - IV A.D.)
TA 21	Jointing mortar	Roman theater/amphitheater (I - IV A.D.)

fine-grained sandy aspect. The degree of cohesion is good; they show a medium strength and a good degree of preservation. An example of this group can be observed in Figure 3b.

Mortars include samples TA16, TA17, TA19, TA20, TA21; they have a light grey colour (M.I. 10 YR 7/2). Macroscopically, it is possible to observe the presence of heterogeneous inclusions and millimetric lumps; globally, they show low strength and a medium degree of preservation. An example of this group can be observed in Figure 3c.

Samples TA10 (Figure 3d) and TA11 are similar in typology (pavement mortars) and aggregates. They are characterized by the presence of crushed ceramics (grog) in the binder that can reach centimeter sizes. In these samples the cohesion is good and strength is medium; they also show a good degree of preservation. These samples could be an example of opus signinum (crushed ceramics mixed with lime) recovered respectively in the Roman theatre/amphitheatre and in the Roman sacred area.

All of the samples were studied in thin section by optical microscopy, using a polarized transmitted light microscope Nikon Eclipse E400POL. SEM-EDS measurements were collected by an ESEM-FEI Inspect-S electron microscope coupled with Oxford INCA PentaFETx3 EDX spectrometer, a Si(Li) detector equipped by a ultra thin window ATW2, by using a resolution of 137 eV at 5.9 keV (Mn $K\alpha 1$). The spectral data were acquired in ESEM (Environmental Scanning Electron Microscope) condition at working distance of 10 mm with an acceleration voltage of 20 kV, counting times of 60 s, count for second approximately 3000 cps with dead time below 30%. The results were processed by INCA software Energy. This software uses the XPP matrix correction scheme developed by Pouchou and Pichoir (Pouchou and Pichoir, 1991, 1988).

On selected samples, the mineralogical composition of the binder was determined by

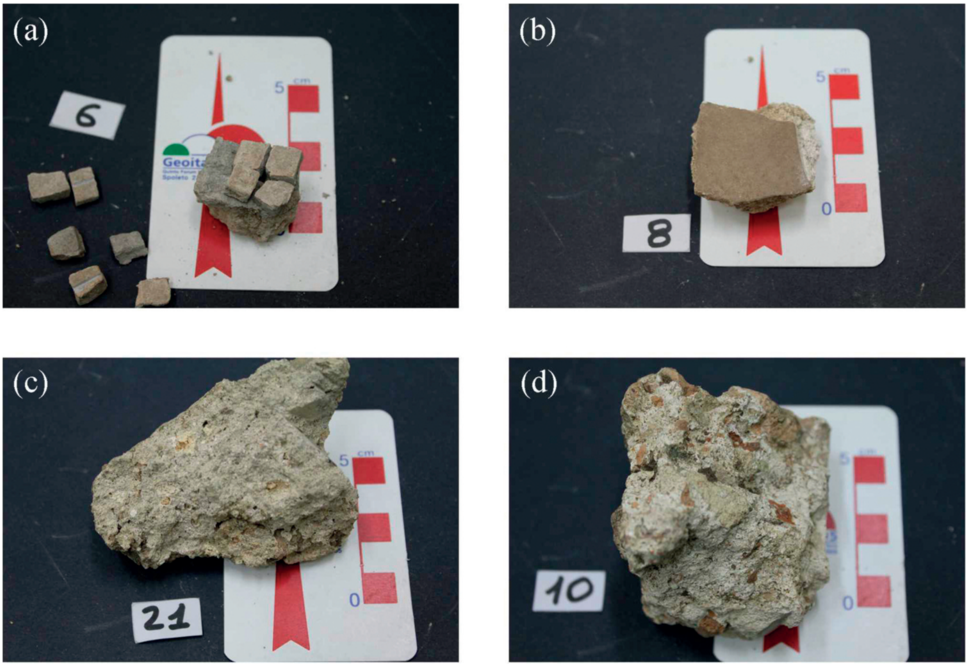

Figure 3. Macrophotographs of sample TA6 (a), sample TA8 (b), sample TA21 (c), sample TA10 (d) as example of analyzed materials.

means of X-ray diffraction. Data were collected on the fine grain size fraction of gentled crushed mortars using a Siemens D5000 instrument, with Cu Kα radiation, 40 kV, 30 mW and Ni filter.

Results

Petrographic analysis

A selection of samples was analysed in thin section to obtain more detailed information about binder-aggregates features and to show similarities and difference among the specimens (Table 2).

Samples TA16, TA19 and TA21 are examples of jointing mortars and are representative of different archaeological structures. In thin sections, samples TA16 and TA19 (Figure 4a) show comparable typologies of aggregates (granitic and medium-high metamorphic rocks, quartz and feldspar, ceramic fragments with sub-rounded shape) and high aggregates: binder ratio but differ for the binder that is darker in TA19; both are also rich in lumps, voids and micro-fractures. The jointing mortar TA21 (Figure 4b) is characterized by coarser-grain size (0.25-7 mm) and sub-angular shape of aggregates in a micritic yellowish-brown binder; furthermore, in this sample grog is absent.

The pavement mosaics (TA6 and TA7) are similar and have two layers: a thin bedding layer and poor in aggregates with abundant lumps and spar calcite in the binder and a nucleus layer thicker and rich in aggregates with an inhomogeneous binder that shows lumps, air voids and micro-fractures (TA6, Figure 4c; TA7, Figure 4d). In TA7 the aggregates, made of granitic and medium-high grade metamorphic rocks, rare garnet and biotite, have sizes between 0.125-2.5 mm, moderate sorting, and sub-rounded shape. Finally, both samples show

Table 2. Petrographic features on thin sections of plasters and mortars. Proportion of aggregates and porosity has been determined on the basis of the chart for estimating proportion of mottles and coarse fragments in Munsell soil colour chart (Munsell, 1994).

		Bruttii city - House of Mosaic (II - I B.C.)				Sacred area (I B.C. - I A.D.)		Neighborhood area (I - IV A.D.)	Roman theater/amphitheater (I - IV A.D.)
		TA6 Pavement mosaic	TA7 Pavement mosaic	TA8 Wall plaster and mortar	TA9 Wall plaster and mortar	TA16 Jointing mortar	TA11 Foundation mortar	TA19 Jointing mortar	TA21 Jointing mortar
AGGREGATES	composition	Spar calcite fragments in the bedding layer; in the nucleus: granitic and metamorphic rocks (schist and gneiss) (40%), spar calcite (40%), quartz (10%), feldspar (5%), biotite (5%), rare garnet	Aggregates absent in the bedding layer;in the nucleus: granitic and metamorphic rocks (schist and gneiss) (50%), spar calcite (20%), quartz (15%), feldspar (10%), biotite (5%), rare garnet	Aggregates absent in the plaster; in the mortar: granitic and metamorphic rocks (schist and gneiss) (60%), quartz (15%), garnet (10%), feldspar (5%), biotite (5%), tourmaline (5%)	Aggregates absent in the plaster;in the mortar: granitic and metamorphic rocks (schist and gneiss) (70%), quartz (10%), garnet (5%), feldspar (5%), biotite (5%), tourmaline (5%)	Granitic and metamorphic rocks (schist and gneiss) (60%), quartz (30%), feldspar (10%), rare grog	Abundant grog (2 typologies) (60%), granitic and metamorphic rocks (schist and gneiss) (25%), quartz (10%), biotite (5%)	Granitic and metamorphic rocks (schist and gneiss) (40%), quartz (20%), feldspar (microcline) (20%), grog (20%).	Granitic and metamorphic rocks (schist and gneiss) (60%), feldspar (microcline) (15%), biotite (15%), quartz (10%), rare tourmaline
	morphology	Sub-rounded	Sub-rounded and angular	Prevalently rounded; sub-angular	Prevalently rounded	Rounded	Rounded and angular	Rounded and angular	Angular
	grainsize distribution	Nucleus: Medium fine Min 0.25 mm; Max 1.75 mm Med 0.75 mm	Nucleus: Medium fine Min 0.125 mm Max 2.5 mm Med 0.75 mm	Medium Min 0.25 mm Max 4.5 mm Med 1 mm	Medium Min 0.25 mm Max 3.25 mm Med 1 mm	Medium Min 0.25 mm Max 2.5 mm Med 1.25 mm	Very coarse Min 0.25 mm Max 10 mm Med 2.5-5 mm	Medium Min 0.25 mm Max 5 mm Med 1.25 mm	Very coarse Min 0.25 mm Max 7 mm Med 2.5 mm
	sorting	Moderate	Moderate	Good	Good	Moderate	Moderate	Moderate	Good
	aggregates: binder ratio	30%	30%	50%	50%	50%	50%	30-50%	50%
	distribution clast	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Very heterogeneous	Homogeneous	Very heterogeneous
BINDER	colour	Nucleus: Grayish brown	Nucleus: Yellowish brown	Grayish brown	Grayish brown	Yellowish brown	Yellowish	Dark brown	Yellowish brown
	lumps	Present	Present	Present	Present	Present	Present	Present	Rare
	porosity	Bedding layer: 10% Nucleus: 20%	Bedding layer: 5% Nucleus: 20%	Plaster: 5-10% Mortar: 20%	Plaster: 5-10% Mortar: 20%	20%	15%	10%	25%

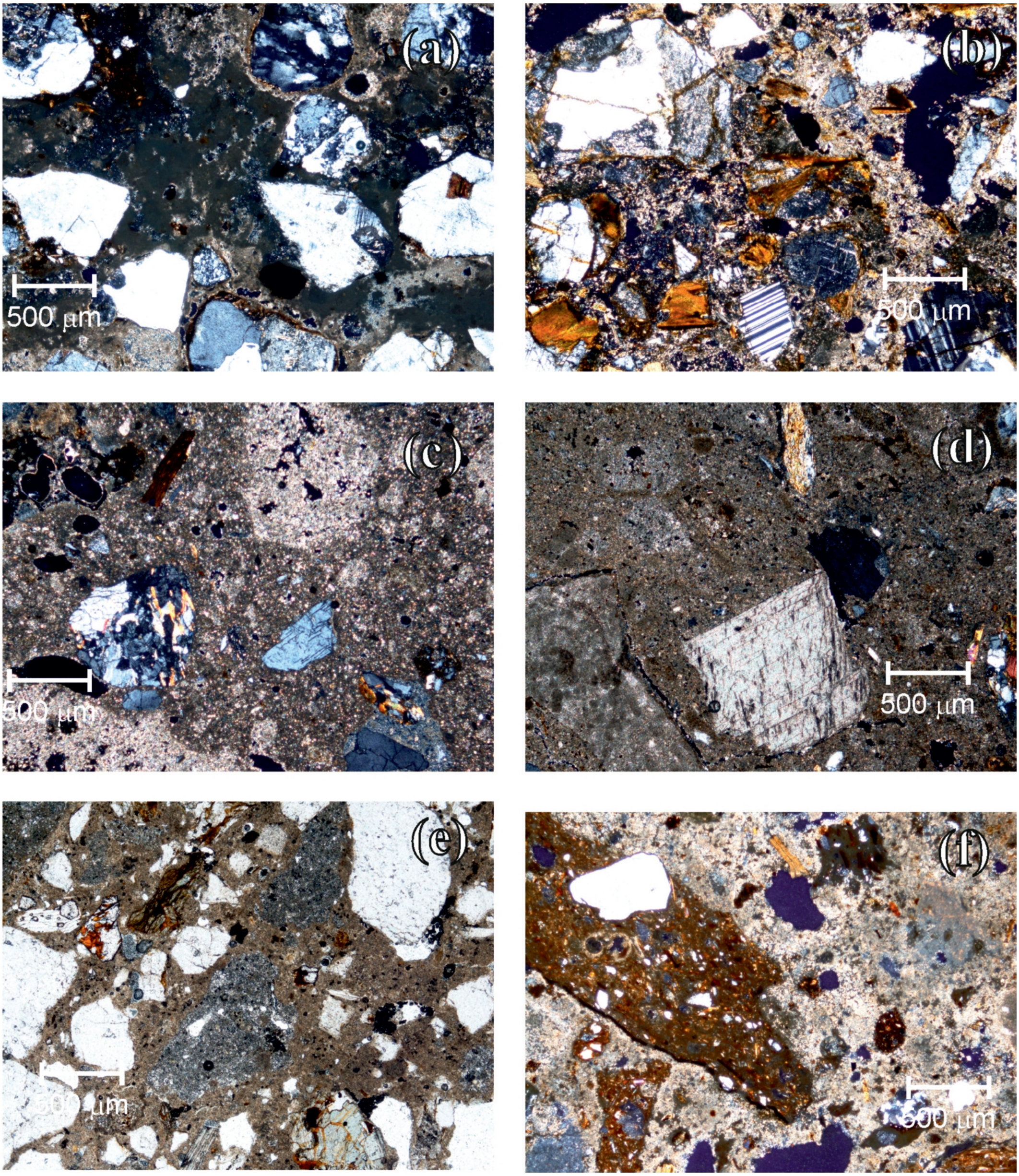

Figure 4. Microphotographs of plasters and mortars: (a) high degree of thickening and micritic binder in sample TA19; (b) very heterogeneous aggregate in sample TA21; (c) lumps in sample TA6; (d) spar calcite in the binder in sample TA7; (e) aggregate in sample TA8; (f) grog in sample TA11.

abundant carbonate rock fragments, similar to those observed in the bedding layer. The mosaics stone tessarae are made of a crystalline limestone with large crystals of spar calcite; fragments of polychaete, bryozoa and coralline algae have been identified only in the stone tesserae of sample TA7.

The two wall plasters and mortars analysed (TA8, TA9) are similar in terms of binder and aggregate characteristics. It is possible to identify three different layers: a thinner red-coloured one, without aggregates; an intermediate layer one characterized by a lump-rich binder and abundant primary porosity (20%); a thicker layer one rich in aggregates (TA8; Figure 4e), with granitic and medium-high grade metamorphic rocks, quartz, feldspars and rare spar calcite fragments; garnet and tourmaline are also present. The aggregates show good sorting and have a prevalently rounded shape, measuring about 1 mm in diameter.

In sample TA11, a thinner red layer and a thicker inner layer are recognizable. The latter one is characterized by aggregates formed by crushed ceramics (Figure 4f) and granitic and medium-high grade metamorphic rocks. The mean size of the aggregates varies from 0.25 mm to 1 cm. Binder is very heterogeneous, yellowish in colour, with micritic aspect and abundant lumps. Among the ceramic aggregates, it is possible to recognise two typologies which are distinguishable on the basis of the colour, the micas and the abundance of fossils in the groundmass. On the whole, aggregates have a sub-rounded shape and a moderate sorting.

Chemical and mineralogical analyses

SEM/EDS analysis allowed us to acquire information about binder/aggregate structure and chemical composition of the samples. Representative samples selected on the bases of archeological provenance and typology (mortar, plaster, etc.) are considered. Data are collected by using spot mode analysis on polished thin sections. The results are summarized in Table 3 in which the average composition of the binder and of the lumps is reported. Values are assessed on almost three point analyses.

The analyses performed on mosaic pavements (TA6, Figure 5a) show Ca-rich binder with low hydraulic index close to those measured on lumps. The almost pure spar calcite (CaO = 100%) observed as fragments in the sample TA6 could represent, in this context, a remainder of original limestone used in the preparation process of mortar.

In jointing mortars (TA16, TA19) binder is less homogeneous and millimetric strong chemical variations are observable (Figure 5b). The compact appearance of the Ca-rich areas (EDS-spectrum 3) reveal that secondary Ca-carbonate probably precipitated during time, while the very Si-rich areas (EDS-spectrum 2) are probably amorphous silica left back after leaching of Ca. Furthermore, the lumps have high CaO and low SiO_2 and Al_2O_3 contents. These data, together with the extremely low grog abundance suggest that the very high hydraulic index (~ 3) of the binder could be due to the addition of clay to the mixture. Furthermore long term weathering could increase the H.I. due to the leaching of Ca-phases.

In samples with high abundance of crushed ceramic (TA11, Figure 5c) the binder is more homogeneous with hydraulic index of about 1.04. Overall, the high H.I. value of the samples could be ascribe to very fine brick powder dispersed in the binder; however, in order to confirm this hypothesis further analyses are needed.

Regarding the degradation processes affecting these plasters and mortars, the presence of halite and hyphae of lichens is note worthy (Figure 5d); moreover, sulfates and chlorides are evidenced by the presence of SO_3 and Cl in some analyses.

In order to investigate the mineralogical composition of the studied samples, XRD analysis have been carried out. In particular, the XRD spectra of two representative samples

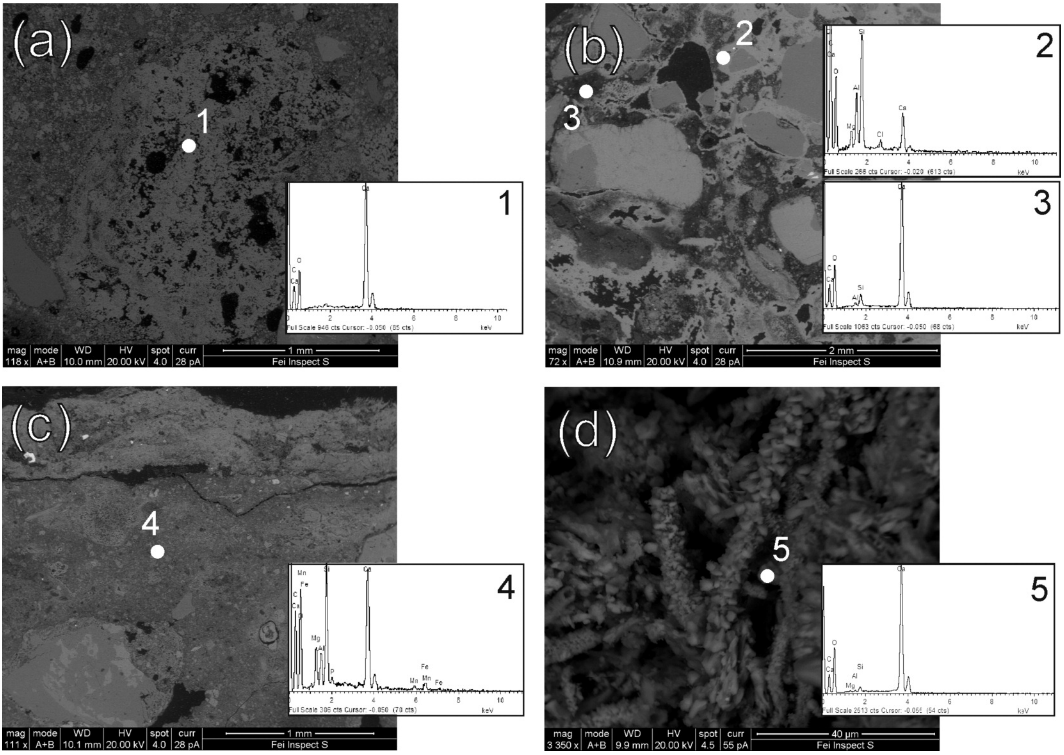

Figure 5. SEM images of plaster and mortar samples: (a) lump and Ca-rich binder in sample TA6; (b) millimetric chemical variation in binder in jointing mortar sample; (c) high content of SiO_2, Al_2O_3, Fe_2O_3 in samples with grog; (d) hyphae of lichens associated to calcium oxalate and halite in sample TA7.

characterized respectively by high (TA11) and low (TA8) H.I. are reported in Figure 6, evidencing the presence in the TA11 sample of hydraulic phases in accordance with SEM-EDS chemical analysis.

Discussion and conclusion

The study of the mortars recovered at Taureana reveals some similarities among the samples; in spite of different chronological attribution, all the analysed samples have an aggregate made mainly of granitic and high grade metamorphic rocks with moderate differences in sorting, aggregates: binder ratio, grain size and shape of the clasts. Crushed ceramics (grog) are abundant only in samples TA11 and TA19. The petrographic features of aggregates support the hypothesis that the material was supplied locally. In particular, the presence of rock fragments of biotite schist and gneiss allows the use of local rocks related to the diorite-kizingite formation of Taureana. Finally, the granitic rock fragments are probably related to the pluton of Taureana.

The sporadic presence of spar calcite aggregates, and SEM-EDS analyses performed on the lumps suggest the use of sparitic crystalline limestone as raw material. The only limestones outcropping in the Tauriana area are the coralline boundstones and the evaporitic

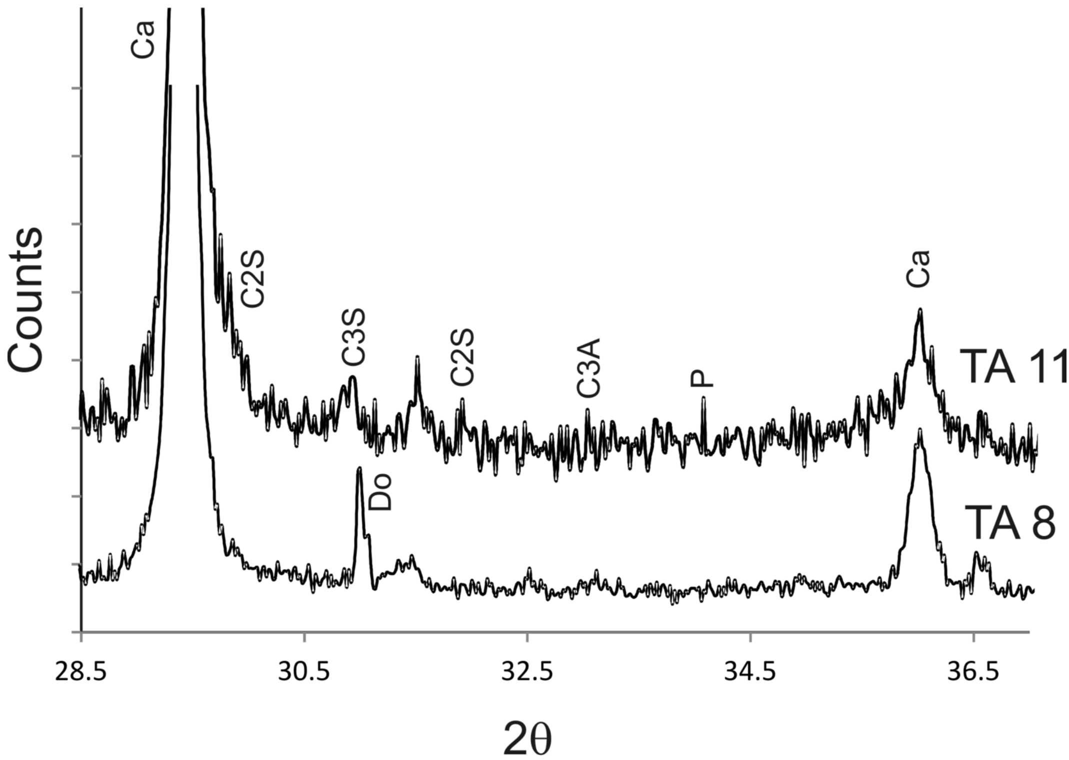

Figure 6. X-ray diffratograms of samples TA8 and TA11: Ca = calcite; Do = dolomite; C2S = belite; C3S = alite; C3A = tricalcium aluminate; P = portlandite.

limestones (Grasso et al., 1996) that could have been used as raw material, as well as for the production of the lime. However, the petrographic analysis of the mosaic tesserae and the presence of sparitic crystalline limestone in the lumps contrast with this hypothesis. For this reason, it isn't possible to exclude that the binder was produced reutilizing decorative limestone present in the historic buildings, as archaeological evidence testifies.

The high hydraulic index measured in the binder of jointing mortar samples is probably due both to the presence of grog as aggregates (TA16, TA19) and to the use of clay in addition to the lime, as it has been previously observed in Roman mortars in Capo Peloro - Messina (Barone et al., 2011).

The variation in the mineralogical and petrographic features of the studied samples may be, in this context, attributed to the technological evolution in the considered time laps or to their use with various functions in different types of buildings.

The differences between the studied wall plasters and mortars belonging to the Brutti phase and the jointing mortars are imputable to their functionality. On the contrary, the compositional and textural variation of the jointing mortars which belong to the Roman period (I B.C. - IV A.C.), may be correlated to different periods and architectural structures. In particular, the data highlight a similarity between samples coming from Sacred Area TA16 (I B.C. - I A.D.) and Neighborhood Area TA19 (I A.D. - IV A.D.), even if they are not contemporary. In both samples, the aggregates have similar textural features and are formed by abundant granitic, high-grade metamorphic fragments and rarely grog, suggesting the use of the same raw materials. The more recent (I - IV A.D.) jointing mortar TA21 sampled in the Roman theatre shows differences in terms of aggregates composition (prevalently made of high grade metamorphic rocks with abundant biotite and microcline and without grog), aggregates abundance (high aggregates: binder ratio), texture and structure (heterogeneous distribution, good sorting and angular shape of the aggregates), suggesting different formula in the production process of mortar.

Finally, the abundance of grog in aggregates and the petrographic and chemical characteristics of the foundation mortar coming from the Sacred Area (TA11) are probably indicative of the use of a specific mixture dedicated to groundwork structure.

Further study of plaster and mortar samples coming from the site of Taureana is under way. In this framework, additional mineralogical, chemical and physic-mechanic analyses will be carried out either on samples coming from the already studied archeological and historic buildings or from the until now unexplored medieval area of the city.

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