Petrographical and geochemical criteria for a chronology of Roman mortars between the 1st century BC and the 2nd century AD: the Curia of Pompey the Great

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Abstract

Thirteen samples of mortar collected from different masonry structures of the Curia of Pompey the Great and from three mixtilinear basins located within the Sacred Area of Largo Argentina were studied.

Despite the use of the same volcanic deposit, known as "Pozzolane Rosse", to produce the fine aggregate in all these mortars, it was possible to highlight some distinctive features through the combination of geochemical analyses on selected trace elements and petrographic analysis under an optical microscope, allowing us to distinguish among the three groups of mortars.

These types of mortars reflect a perfect coincidence between the diversity of the volcanic materials used and the different construction phases identified and documented by the analysis of the stratigraphic units: a first construction phase of Pompeian age, a second one of Augustan age and, finally, one of the medieval period. Furthermore, it was possible to ascertain two phases of construction of the basins, the second coeval with the interventions of the Augustan period.

Finally, this study increases the knowledge on the methods of exploitation and selection of volcanic materials used to produce mortars in Roman times, identifying additional elements useful to establish their origin and chronology of use.

Keywords: Roman mortars; "Pozzolane Rosse"; Petrography; Area Sacra di Largo Argentina; Theater of Pompey.

Introduction

The identification of the volcanic materials used as fine aggregate in the mortars of the Roman era and the criteria for their selection and use over the centuries have been addressed in numerous studies and publications over the past 20 years (Jackson et al., 2007, 2009, 2010; Marra and D'Ambrosio, 2013; Marra et al., 2013, 2015a, 2015b; D'Ambrosio et al., 2015; Secco et al., 2019, 2020).

In particular, the petrographic analysis in thin section has been integrated with a geochemical "fingerprinting" method based on the properties of trace elements (i.e., Zr, Y, Nb, Th, Ta, Ti) insensitive to alteration processes. This allowed the identification of materials in very small, weathered quantities, which would not have been possible to study with classical petrographic methods (Marra et al., 2011). These studies permitted a reconstruction of a chronology of use characterized by a first "experimental" phase, corresponding to the first two centuries since the introduction of the concrete in Rome starting from the late 2nd century BC (Mogetta, 2015; Marra et al., 2015a). During this first phase, heterogeneous materials have been used, both of a volcanoclastic nature (sedimentary deposits containing reworked volcanic materials), and purely volcanic, cropping(?) out near the construction sites (Marra et al., 2015a).

The period following this initial phase, starting from the end of the 2nd century BC, was characterized by the almost exclusive use of a specific volcanic deposit known by geologists as "Pozzolane Rosse" (De Rita et al., 1988; Marra and Rosa, 1995) (red pozzolans), which where systematically cultivated in dedicated tunnels: the "*arenari*" (Marra et al., al., 2015a).

The "Pozzolane Rosse" are a pyroclastic deposit (ignimbrite) erupted 456,000 years ago from the volcanic district of Colli Albani (Karner et al., 2001). This super-eruption emplaced several tens of km^3 of magma in the form of pyroclastic flows (Freda et al., 2010). The deposit (locally called "*pozzolana*") is a weakly coherent aggregate of ash, scoria and lapilli which is widely used to produce mortar even today. The petrographic and chemical factors that give to the "Pozzolane Rosse" ideal "pozzolanic" qualities were discussed in Jackson et al. (2010).

The term *pozzolana*, probably used already in the late imperial age, derives from the city of Pozzuoli (*Puteoli*), in the Campi Flegrei, where pyroclastic deposits were extensively cultivated as aggregate for mortars in the *Pompeii* region since the 3rd century BC (Miriello et al., 2010). Pliny the Elder (*Naturalis Historia* 16.202; 35.166), Strabo (*Geographia* 5.4.6) and

Seneca (Quaestiones Naturales 3.20.3) use the adjective puteolanus to indicate precisely those Campania deposits that *Vitruvius* (*De Architectura*, 2.6.1) defines *pulvis* (see Jackson et al., 2007; D'Ambrosio et al., 2015).

The "Pozzolane Rosse" have been the ubiquitous ingredient in the preparation of mortars since the end of the 2nd century BC, testifying to a real "revolution" in the technique of preparing concrete and in the methods of procuring the material used as the fine aggregate. This revolution is closely linked to the intense public and utilitarian building activity promoted by the members of the most influential families of the City to show their power and political influence, exploiting the potential offered by the use of the new construction technique represented by the concrete work (D'Alessio 2014; Davies, 2017).

The analyses carried out on samples of mortars collected from monuments of imperial age show that the "Pozzolane Rosse" constituted the fundamental element of all the fine aggregates of Roman mortars up to the 2nd century AD (Marra et al., 2015).

Starting from the 3rd century AD, the sporadic integration of a new, similar layer of pozzolana, known as "Pozzolane Nere", stratigraphically above the previous one, is testified by tunnel cultivation in the same areas where the *arenari* were located (Marra et al., 2015a).

At the passage between the 2nd and 3rd centuries AD, the first use of a third, stratigraphically higher, layer of pozzolan (Pozzolanelle; Karner et al., 2001) is documented (Marra et al., 2015). This deposit crops out extensively throughout the eastern suburbs of the City and was therefore cultivated, unlike the older deposits, in the open air. The possible reasons for the transition to the cultivation of "Pozzolanelle" and their more extensive use, likely linked to an ever-greater need for supply, have been discussed in Marra et al. (2015a).

In this work, we test the possibility of distinguishing the mortars realized between the 1st century BC and 2nd century AD by examining "Pozzolane Rosse" though petrographic and geochemical characteristics of the aggregate. Such approach provides a further criterion for distinguishing the chronology of use and therefore establishing an indirect dating method of archaeological structures. We collected 10 samples of mortar from different walls of the Curia of Pompey and 3 samples from 3 mixtilinear basins in the Sacred Area of Largo Argentina. We also analyzed the composition of the aggregate, following the classification approach developed in recent works (Marra et al., 2011; Marra and D'Ambrosio, 2013; Marra et al., 2015a, 2015b; D'Ambrosio et al., 2015). The study was divided into two phases; the first one sought to identify the origin of the volcanic aggregate by means of geochemical analyses. Once the almost exclusive use of the pyroclastic deposit of "Pozzolane Rosse" was established, the second phase attempted to further discriminate elements through the study of thin sections under the optical microscope.

The Curia of Pompey

The Curia of Pompey is mentioned in ancient literary sources especially in relation to the death of Gaius Julius Caesar who was assassinated in this very place on the Ides of March in 44 BC, during a meeting of the Senate. It was an almost square building (24 x 27 m) located outside the eastern axis of the porticoes of the theater of Pompey (*Porticus Pompeiana*). The large monumental complex was inaugurated in 55 BC by *Gneus Pompeus Magnus* (Pompey the Great) and represented in the *Forma Urbis*, the marble plan of the city of Rome drawn up at the time of the Severi (III AD) (Monterroso-Checa, 2010; Monterroso-Checa et al., 2017).
The building has been represented and interpreted in different ways, although the most reliable historical plans are those developed by Marchetti-Longhi and Gatti (Marchetti Longhi, 1975). Recent studies have shown that the Curia of Pompey was not an exedra of the portico of the Pompeian complex, but a standalone building that occupied the central part of the eastern side of the arcades (Monterroso-Checa et al. 2017).
The remains of the Curia are still visible inside the Sacred Area of Largo Argentina, along its western side (Figure 1). Recent research has made it possible to identify the different construction phases and the original organization, from the Republican age (Phase I) to the contemporary era (Phase IX). The construction phases I (61-55 BC), II (27-14 AD) and V (medieval times) (Monterroso-Checa et al., 2017) are the subject of the present study.
The original phase (Phase I - 61-55 BC) includes the concrete foundation made with pozzolanic mortar and tuff stone (Tufo Lionato, Marra et al., 2017), above which there is a concrete base bounded by three rows of Tufo Lionato blocks, and the internal walls in reticulated work of pozzolanic mortar and Tufo Lionato caementa (Monterroso-Checa et al., 2017).
In the Augustan age (Phase II, 27 BC - 14 AD), a concrete structure covered with reticulated work was built in the center of the back wall of the building, where the *suggestus* that raised the chair of the *princeps senatus*, the most important of the senators, was once located. This is the very place where, according to ancient sources, Gaius Julius Caesar was assassinated. This structure constitutes a block of 6.5 meters wide and at least 2 meters high that completely occupies the central place of the Curia and leans against the back wall of the building (Monterroso-Checa et. al., 2017). Augustus, indeed, as the ancient historians testify (Cassius Dio, 47, 19; Suet. *Aug.* 31.9; *Div. Iul*. 88), aimed to "cancel" forever the place of the

assassination of Caesar at the hands of the senators, and expiate for the guilt of the most grievous murder in the history of Rome after that of the founder Romulus.

Sacred Area of Largo Argentina - the mixtilinear basins

Along the western side of the Sacred Area of Largo Argentina, between Temple B and the remains of the Curia of Pompey, there are 2 basins of different sizes with a north-west/south-east orientation (V2 and V3 in Figure 1). The basins are realized in concrete with leucitite coarse aggregate and have inner coating of *signino*. They are about 75 cm deep, with walls about 60 cm thick and have a rectangular plan which, at one of the long sides, to the north, opens with a small semicircular apse.

A third basin (V1) with an east/west orientation and a more complex and articulated plan is located between the northern side of Pompey's Curia and the northern *forica* (Marchetti Longhi, 1975).

The basins were realized after the construction of Temple B (101 BC) and prior to the first half of the 1st century AD, when they were obliterated by the rooms of a brick building that occupies the area between Temple B and the back wall of the Curia of Pompey (Coarelli, 1981).

Methods of analysis

A large number of papers in the last fifteen years has shown the exceptional care by Roman constructors in producing mortar and concrete (Jackson et al., 2006, 2007, 2009, 2010; Bianchi et al., 2011). The analysis of over a hundred thin sections in these years has revealed the extremely homogeneous features of the mortars descending from a strict selection of the aggregates and their sieving, including the mixing of different aggregates to prepare particular lightweight mortars for the vaulted structures (Lancaster et al., 2010; Marra et al., 2013).

The high accuracy and reliability, as well as the limitations of using trace elements ratio measures on very small samples of volcanic materials have been widely discussed in previous literature (Marra and D'Ambrosio, 2013; Marra et al., 2013, 2015a, 2015b, 2016; D'Ambrosio et al., 2015).

Bulk samples of the volcanic component separated from the mortar aggregates were analyzed for trace element composition by Lithium Metaborate/Tetraborate Fusion ICP-MS at the Activation Laboratories, Canada. Fused sample is diluted and analyzed by Perkin Elmer Sciex ELAN 6000, 6100 or 9000 ICP/MS. Three blanks and five controls (three before sample group and two after) are analyzed per group of samples. Wet chemical techniques were used to measure the loss on ignition (LOI) at 900°C. International rock standards have been used for calibration and the precision is better than 5% for Rb and Sr, 10% for Ni, Zr, Nb, Ba, Ce, and La, and 15% for the other elements. Full analytical data are reported in Supplementary Material #1.

Results

Geochemical analyses

Following separation by hydrochloric acid bathing, four samples (N1, N2, N3, N4), collected from walls of the Curia referable to the first (N1), to the second (N2 N3) and to the fifth (N4) construction phase, were preliminarily subjected to geochemical analysis.

All four separates were made up of red and black volcanic scoriae (Figure 2), showing the characteristic appearance of " Pozzolane Rosse" (Jackson et al., 2010), which is the volcanic deposit selectively exploited to produce mortars in Rome from the end of the second century BC, and throughout the first century AD (Marra et al., 2015a).

N1 differs from N2, N3 and N4 for a more heterogeneous particle size and a more abundant fine fraction. It also contains only light-colored red scoriae. Among the others, N2 and N3 are identical in morphometric characteristics and proportion of red and black scoriae. N4 is distinguished by a slightly finer particle size and a different proportion between aggregate and matrix, with the latter more abundant than N2 and N3.

The results of the geochemical analyses were used to identify the nature of the aggregates by means of two classification diagrams that make use of the ratios of some "immobile" chemical elements, characteristic of the original magmas and which are little affected by the alteration processes of the rocks: the Zr/TiO2 vs. Nb/TiO2 diagram, and the Zr/Y vs. Nb/Y diagram (Figure 3a, b). The diagram with the abundances of the "rare earths" was also used (Figure 3d) as a further element of comparison between the analyzed samples.

The Zr / TiO2 vs. Nb / TiO2 of Figure 3a shows how the four aggregates have extremely similar compositions that fall within the "Pozzolane Rosse" compositional field. Three of the analyzed samples (N2, N3, N4) show a linear distribution corresponding to that of the composition of the " Pozzolane Rosse " also found in the second diagram in Figure 3b. Sample N1, on the other hand, is clearly displaced towards higher Nb/Y values. Similarly, sample N1 displays an offeset plot also in the Th/Ta vs. Nb/Zr diagram of Figure 3c. Such offsets, caused by Y and Ta depletion, have been shown to depend, with the same original composition, on a more severe degree of geochemical alteration and weathering (Marra et al., 2011). Since all the samples analyzed underwent the same acid treatment, the different degree of alteration in N1 is undoubtedly attributable to its original conditions, suggesting an origin from an area where the volcanic deposit has undergone particular post-depositional processes in environmental conditions different from those common to all the other samples. This deduction is further supported by the diagram in Figure 3d, where samples N2, N3 and N4 have compositional characters identical to each other and clearly distinct from those of N1. Therefore, the first three aggregates most likely come from the same extraction sector, as also suggested by red and black centimeter-sized scoriae in their macroscopic appearance. N1 certainly comes from a different area. Its macroscopic characters --reddish scoriae and abundant fine fraction--are similar to those of the Republican-age mortars, such as those of the Temple B of Largo Argentina (late 2nd and first half of the 1st century BC) (Marra et al., 2015a). These mortars were extracted in tunnels (*arenari*) in the urban sector of Rome and generally have a greater degree of alteration than those of the imperial age. They were probably extracted from deposits located in the area south of the city which are characterized by greater thicknesses (Figure 4).

Petrographic analyses

The analysis in thin section under the optical microscope of six mortar samples collected from the walls of the Curia di Pompeo (CP6, CP7, CP8, CP9, CP10, CP12) and of three samples collected from the adjacent basins (V1, V2, V3), confirmed the extensive use of "Pozzolane Rosse" in the aggregate. The mortars of the basins are also characterized by the presence of brick fragments that have been mixed with the evident intention of making these mortars more waterproof, adopting a composition close to that of "cocciopesto" or "signino". In the case of the basins studied, however, the proportion of " Pozzolane Rosse" volcanic scoriae is much greater than brick fragments, compared to the classic cocciopesto.

Due to the compositional uniformity of the aggregates the analysis of macroscopic characters was also used in order to classify them, similarly to what has already been done in the case of the four previously studied samples (N1, N2, N3, N4).

The observations under the optical microscope, however, have highlighted some peculiar elements of the volcanic scoriae, which allowed the use of further discriminating elements (Fig.5 and Fig. 6). Unlike what has been observed so far in other Roman mortar samples (Marra et al., 2015a; 2015b), the thin sections of the samples studied showed that various scoria clasts had primary calcite crystals and a smaller portion had volcanic glass (for the origin and petrological implications of calcite see Gozzi et al., 2011).

While the observation of calcite, as also suggested by its presence in mortars of different epochs (see Table 1), is not considered a very discriminating element and is essentially linked to the good workmanship of the thin sections, the presence of volcanic glass, which is rare in the Colli Albani pyroclastic rocks (Gaeta et al., 2021), constitutes a strongly discriminating element on the origin of the aggregate. Actually, the presence of volcanic glass indicates peculiar zone of the Pozzolane Rosse deposit characterized by high cooling rate (Gaeta et al., 2021). Considering the presence or absence of glassy scoria clasts and the macroscopic characters related to their size (granulometry) and color (proportion between red and black scoria), the aggregates of the analyzed mortars were classified and grouped by homogeneous phases, as described below and summarized in Table 1.

Samples CP6 and CP8 have macroscopically and microscopically identical characters. Among the mortars of the masonry, the scoriae present in the aggregate are the only ones characterized by the presence of glassy, scarcely vesiculated scoria clasts with euhedral leucite (Fig. 5a and 5b). Furthermore, the macroscopic characters are substantially the same as those observed in the aggregate of samples N2 and N3. However, they are clearly distinguished from those related to sample CP10. This last sample, as well as the sample CP12, are characterized by the presence of fine- to medium-grained, leucite-bearing granular rocks, enclosed in the Pozzolane Rosse scoria clasts (i.e. Fig. 5c e 5d). Moreover, the sample CP10 has a fine particle size and light red scoriae, in a very similar way to what was observed in sample N1. This differs from N2 and N3 for some additional compositional characteristics relating to the trace elements, highlighted by the geochemical analyses carried out on the first set of samples.

It can therefore be established with sufficient certainty that CP10, CP12 and N1 belong to the first Pompeian phase, while CP6, CP8, N2 and N3 belong to the second Augustan phase. The CP7 sample, taken from masonry referable to the fifth construction phase, has intermediate characteristics between these two groups of mortars, showing a slightly finer grain size than CP6 and CP8, but with the presence of both red and black scoriae in a similar proportion. It is also distinguished by the presence of large leucite (up to 5 mm in diameter), quartz characterized by subgrains (Fig. 6a), and euhedral sanidine (Fig. 6b) and by the absence of glass. These macroscopic and microscopic characteristics make it identical to the N4 sample which among those previously studied, is the only one on which the thin section has been made. Remarkably, both these samples are collected in the walls of the fifth construction phase.

The CP9 sample, taken from the same masonry from which N4 was taken, and referable to the fifth construction phase, is the only one in which elements other than the "Pozzolane Rosse" appear in the aggregate. In fact, a clast characterized by an oxidized hematite core, surrounded by crystals of sanidine and quartz, was observed, indicating an inclusion of sedimentary rock, deriving from the reuse of previous materials. This suggests a "late" character of the mortar. Although clasts of this sort are probably an occasional presence, the overall characteristics of the aggregate are similar to those of the CP7 and N4 samples, forming a group of mortars with characteristics different from those of the first and second phase.

In particular, samples CP6, CP8, N2 and N3 show a good sorting of the aggregate which indicates a probable sieving and particular care in the preparation of the mortar. CP10, CP12 and N1, on the other hand, have a finer and more heterogeneous particle size, but they lack large scoriae, suggesting a selection of the aggregate also in this case. The mortars of the third group, on the other hand, are poorly classified and heterogeneous, and are on the whole, distinguished by the lesser care in their preparation.

In regards to the mortars of the basins, a substantial uniformity is observed in the compositional characteristics, with the presence of "Pozzolane Rosse" aggregate and a small fraction of brick fragments. In the macroscopic compositions, only the aggregate of the sample V3 is slightly finer than the other two. However, comparison with the macroscopic characteristics of the mortars of the masonry is not possible given the different specificities of these mortars and of the concrete realized for the basins, which is made with lava *ceamenta*. On the other hand, the presence of volcanic glass in the scoriae of sample V1 is extremely significant (Fig. 6c) and discriminating, which suggests that the origin of this aggregate is the same as that used in samples CP6 and CP8 of the masonry of phase 2. It is therefore possible to think that basin 1 was built later than basins 2 and 3 but simultaneously with the interventions of the second phase. This hypothesis is supported by the presence of leucite-bearing, granular lithic clast enclosed in the Pozzolane Rosse scoria clasts in V2 and V3 samples (Fig. 6d).

Conclusions

The analyses conducted on the mortars of the Curia walls highlight a perfect coincidence between the diversity of the compositions, the origin of the volcanic materials used, and the different building phases identified and documented by the analysis of the stratigraphic units. In fact, there is a clear distinction in the composition of the samples collected from masonry

referable to the first construction phase of the Pompeian age, to that of the Augustan age and, finally, to that of the medieval period. All the available archaeometric and archaeological data derived from the stratigraphic reconstruction, agree in defining three construction phases: the original by Pompey; the "structural closure" of the central wall of the Curia, site of the assassination of Caesar committed by Augustus; and, the final post-ancient phase. The latter is marked by a reuse of the materials of the Curia that had lost its original function.
The data deriving from the analysis of the mortars taken from the mixtilinear basins are also of considerable interest. It demonstrates two different construction phases with an intervention during the Augustan era, hitherto never hypothesized by scholars. In fact, the construction of the counter-podium of temple B dates back to this period (Caprioli, 2011). The new data therefore indicates that the intervention involved the construction of a third basin (V1), for the arrangement of the area north of the Curia's back wall.
From a methodological point of view, this study confirms the potential for ICP trace-element analysis as a fast tool to identify the origin of the volcanic aggregate employed in Roman mortars. By plotting the data in simple classification diagrams published in the literature, this methodology can be applied by non-specialized scholars and is particularly useful when dealing with small amount of deeply weathered materials, due to the small amount necessary ($\geq$5 g) and to the insensibility of the immobile elements (Nb, Zr, Y) to the chemical alteration processes.
However, this study also highlights the indispensable role of petrographic analysis in thin section to achieve detailed information that enables the investigators to recognize the provenance from specific exploitation areas as a function of the petro-chemical compositional features of the aggregate. The latter may vary in function of the timing and the modality of emplacement of the pyroclastic deposits, which account for progressively different magma composition during the eruption, as well as for different environmental conditions superintending to the post-depositional geochemical processes.

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Data availability statement

The data that supports the findings of this study are available in the supplementary material of this article

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FIGURE CAPTIONS

Figure 1 - Plan of the Sacred Area of Largo Argentina showing the archaeological survey of the Curia of Pompey (drawing by R. Martín-Talaverano and J.I. Murillo-Fragero) and of three basins. The main construction phases and the position of the mortar samples collected for geochemical and petrographic analyses are shown (see text for explanation).

Figure 2 - Aggregates of mortars after separation from lime through hydrochloric acid bath.

Figure 3 - Geochemical classification diagrams. a) Zr/TiO_2 vs. Nb/TiO_2 diagram showing the close clustering of the analyzed samples, including one reference outcrop samples PR-C, within the previously defined compositional field of Pozzolane Rosse (Marra et al., 2015). b) Zr/Y vs. Nb/Y and (c) Th/Ta vs. Nb/Zr diagrams showing the outlier composition of sample N1; according to Marra et al. (2011) such anomalous compositions are due to Ta and Y depletion, as a consequence of strong weathering processes.

Figure 4 - a) Geologic map of the area of Rome showing the outcrops of the "Pozzolane Rosse" pyroclastic-flow deposits and the sectors dedicated to their exploitation. Areal trend of the estimated thicknes of the deposit (isopach lines) is also shown. A: area of the earliest tunnel exploitation; B possible area of later tunnel exoploitation, C: area of later open-air exoploitation; b) longitudinal section showing the grainsize variation and the alteration zone at the interface with the exogenus agents of a pyroclastic-flow deposit (see text for comments).

Figure 5 Photomicrographs at the optical microscope (plane-polarized light) of the CP6, , CP8, CP10, CP12 sample. Glassy, scarcely vesiculated scoria clast in the CP8 sample (a). Magnification of the glassy scoria clast occurring in the CP6 sample (b). Leucite-bearing granular rock in the CP10 sample(c). Fine-grained, leucite-bearing granular rock in the CP10 sample (d).

Figure 6 Photomicrographs at the optical microscope (a and b crossed nicols; c and d plane-polarized light) of the CP7, CP9, V1 and V2 sample. Quartz characterized by subgrains in the CP7 sample (a). Euhedral sanidine in the CP9 sample (b). Glassy scoria clast in the V1 sample (c). Fine-grained, leucite-bearing granular rock enclosed in the V2 sample. The Pozzolane Rosse scoria clast including the leucite-bearing granular rock is characterized by the typical star-like leucite (d).

TABLE 1 - Mortars of the Curia of Pompey. For the N1, N2, N3 samples no thin sections were made, therefore the observation is based only on the macroscopic characters of the aggregate whose composition was determined by analysis on trace elements. Legend: PR: Pozzolane Rosse; AR: sandstone; LA: brick; C: coarse; M: medium; F: fine; R + B: red and black scoriae; R: red scoriae; LBGR: Lct-bearing granular; rocks; GSC: glassy scoria clast; QTZ: quartz; SAN: sanidine.