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BUILDING MATERIALS OF THE THEATRE OF MARCELLUS, ROME*

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The building materials of the Theatre of Marcellus, 44–11 BCE, reflect Roman builders' careful selections of tuff and travertine for dimension stone and volcanic aggregates for pozzolanic concretes. The vitric–lithic–crystal Tufo Lionato tuff dimension stone contains a high proportion of lava lithic fragments, which increase its compressive strength and decrease water sorption, enhancing durability. Sophisticated installations of travertine dimension stone reinforce the tuff masonry, which is integrated with durable concrete walls and barrel vaults. The pozzolanic mortars of the concretes contain harenae fossiciae *mainly from the intermediate alteration facies of the mid-Pleistocene, scoriaceous Pozzolane Rosse pyroclastic flow. They have pervasive interpenetrating pozzolanic cements, including strätlingite, similar to high-quality, imperial era mortars. Concrete walls are faced with refined Tufo Lionato* opus reticulatum *and* tufelli, *and* opus testaceum *of fired, greyish-yellow brick. The exploratory concrete masonry, which includes some of the earliest examples of brick facings and strätlingite cements in Rome, and the integration of these materials in complex architectural elements and internal spaces, reflect the highly skilled workmanship, rigorous work-site management and technical supervision of Roman builders trained in republican era methods and materials.*

KEYWORDS: ANCIENT ROME, CONCRETE MASONRY, POZZOLANIC MORTAR, VOLCANIC AGGREGATES, VOLCANIC TUFF MASONRY, PETROGRAPHIC CHARACTERISTICS

INTRODUCTION

The central purpose of this paper is to investigate the hypothesis that the construction of the Theatre of Marcellus marks a decisive transition to an ethos of systematized imperial era construction methods and materials. Descriptions of the building materials of the theatre (Figs 1 and 2), initiated in 44 BCE and constructed mainly between 23 BCE and 17 BCE (Calza Bini 1953; Fidenzoni *c*. 1970; Ciancio Rossetto 1999, *LTUR V*, 31–5; Sear 2006; Ciancio Rossetto and Buonfiglio in press), provide an observational framework to assess the expertise of Roman builders of the latest republican and earliest imperial eras in Rome. Petrographic and mineralogical analyses reveal the compositions of durable volcanic ash-hydrated lime pozzolanic mortars and provide a more rigorous foundation for distinguishing between Tufo Lionato and Tufo di Tuscolo tuff dimension stones (Jackson *et al*. 2005; Jackson and Marra 2006). Certain passages of *De architectura* (31–27 BCE), written by Vitruvius just prior to the main period of construction of the theatre (Sear 1990), provide additional insights into building technologies at the beginning of the Augustan age.

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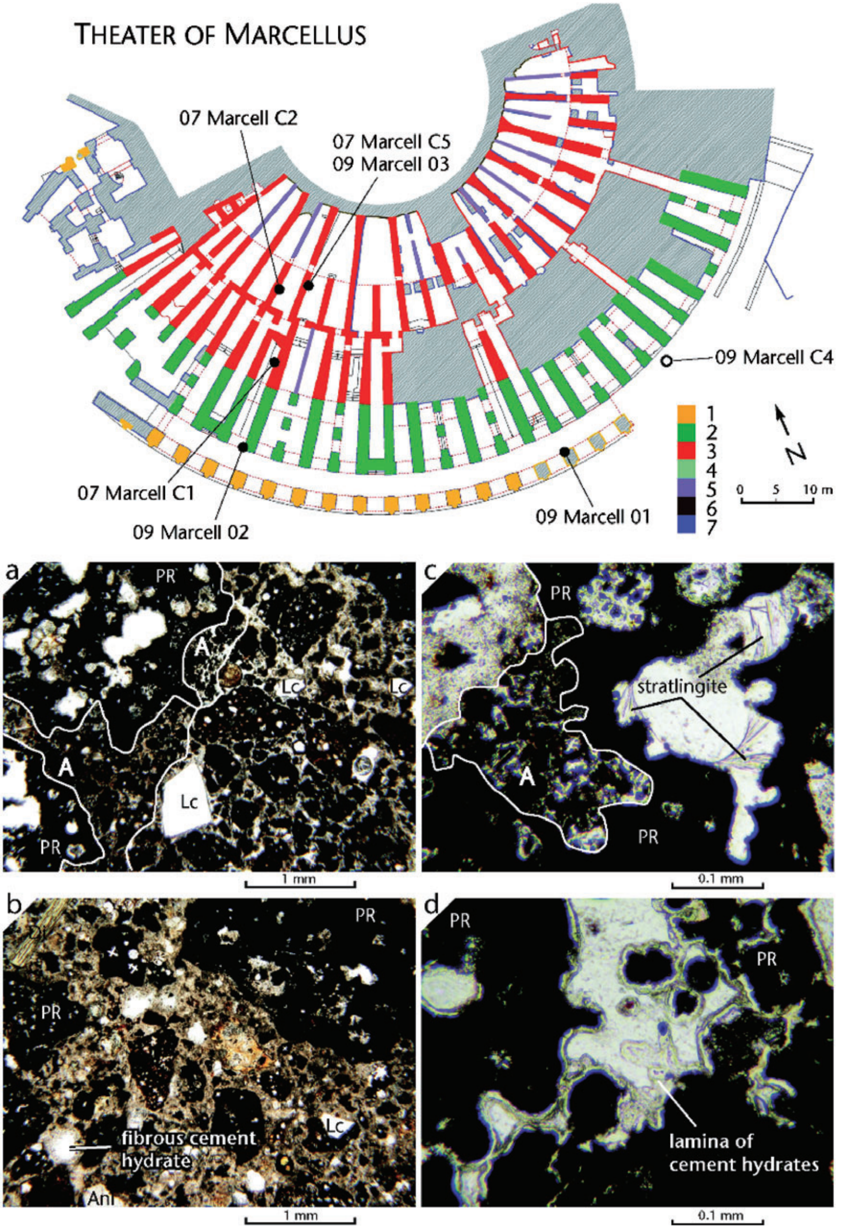


Figure 1 *A plan of the ground level of the Theatre of Marcellus (after Ciancio Rossetto and Buonfiglio in press). 1, Travertine dimension stone; 2, Tufo Lionato dimension stone; 3, Augustan age concrete with Tufo Lionato* opus reticulatum *facing; 4, Augustan age concrete with* opus testaceum *brick facing; 5, later Julio-Claudian age concrete with Tufo Giallo della Via Tiberina* opus reticulatum *facing; 6, Julio-Claudian age conglomeratic concretes; 7, structures of Late Antiquity. The photographs show the following: (a) wall core, sample 07-MARCELL-C1—grain-supported fabric of Pozzolane Rosse, intermediate alteration facies, with pozzolanic cements in ash accretions (**A**); (b) concrete substructure, sample 09-MARCELL-C4—Pozzolane Rosse, upper intermediate alteration facies, and fibrous cement hydrate in spherical voids; (c) wall core with Tufo Lionato facing (Fig. 2), 07-MARCELL-C5—strätlingite cement in scoria with a cemented ash accretion (**A**); and (d) 07-MARCELL-C5, lamina of cement hydrates, now partially altered to calcite, in a cemented ash accretion.*

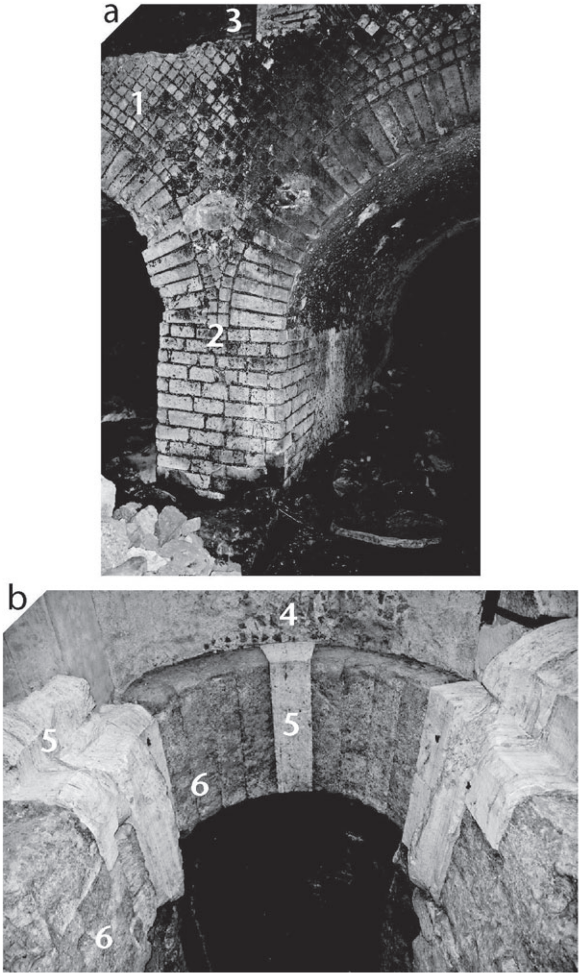


Figure 2 *Photographs of the concrete and stone masonry of the Theatre of Marcellus: (a) concrete walls, with facings of Tufo Lionato* opus reticulatum *(1) and small rectangular blocks (2), and brick* opus testaceum *overhead (3); (b) a concrete barrel vault with Tufo Lionato* caementa *(4), adjacent to a Tufo Lionato cut stone barrel vault (5) reinforced with travertine (6).*

Studies that focus on a so-called 'architectural revolution' in the early second century CE describe the new, concrete architectural forms that began to appear under Nero (54–68 CE) (MacDonald 1982). They emphasize 'a key and critical ingredient', which was initiated 'by the middle of the first century CE': brick-faced concrete (Lechtman and Hobbs 1987, 85). These architectural studies tend to be somewhat dismissive of the advancements in concrete technologies developed by republican and Augustan age builders (Ward-Perkins 1977, 63, 101, 144; MacDonald 1982, 11; Lechtman and Hobbs 1987, 89, 92, 104, 102, 111). Instead, they highlight the consequences of the fire of 64 CE and a new class of 'urban freedmen' of the 'latter half of the first century CE', 'who built and who used the monuments' (Lechtman and Hobbs 1987, 88, 121). By contrast, earlier 20th century studies give descriptions of the republican concretes and their constituent aggregates, and acknowledge Augustan era builders' expertise, but are constrained by a lack of analytical data and geological understanding of the Roman pyroclastic deposits (Van Deman 1912a,b; Frank 1924, 36–8; Blake 1947, 316–17, 333–52; Lugli 1957, 394–401, 426–9). Nevertheless, recent analyses confirm the technical expertise of the first century BCE builders (Jackson *et al*. 2005, 2007) and their architectural innovations (Gerding 2002). The present study contributes to isolating the point at which these builders achieved a very high quality pozzolanic concrete. A few generations later, builders of the later first century CE used this material in more dramatic architectural forms.

The mortars of earlier republican era concrete structures along the Capitoline Hill contain excavated sands, or *harenae fossiciae*, from fluvially reworked, epiclastic sediments derived from the underlying mid-Pleistocene stratigraphic sequence. They present friable, porous fabrics as well as pervasive flaws resulting from poor compaction (Jackson *et al*. 2007, 2010a). In contrast, the Theatre of Marcellus mortars have more compact and coherent fabrics; a specific aggregate mix design of mid-Pleistocene Pozzolane Rosse volcanic ash from an intermediate alteration facies; and well-developed pozzolanic cements, similar to high-quality mortars of the later Augustan through Trajanic eras (Chiari *et al*. 1992; Jackson *et al*. 2007, 2009, 2010a).

In *De architectura*, Vitruvius states that *harenae fossiciae* comes in four varieties: *rubra*, *nigra*, *cana* and *carbunculus*. The red (*rubra*) or black (*nigra*) volcanic sands were excavated from the Pozzolane Rosse pyroclastic flow, erupted from Alban Hills volcano at 456 ± 3 ka (Marra *et al*. 2009; Jackson *et al*. 2010a). The Theatre of Marcellus mortars mainly contain the dark- to moderate-reddish brown (10R 3/4 to 10R 4/6) *rubra* variety, from a moderately altered horizon, associated with hydrolytic alteration of a mid-Pleistocene (456–407 ka) paleosol (Jackson *et al*. 2010a). Quarries about 2.5 km south of the Capitoline Hill may have been an early source for the ash (DeLaine 1997, 84–5; Jackson *et al*. 2007).

METHODS OF ANALYSIS

Petrographic, mineralogical and geochemical descriptions of the Pozzolane Rosse pyroclastic flow (Jackson *et al*. 2010a) provide a basis for the identification of the alteration provenance of the pozzolanic mortar aggregate (Table 1). Petrographic observations of the primary volcanic components of the Pozzolane Rosse ash, mainly scoriae, volcanic glass (vitric), rock (lithic) and crystal fragments, as well as their secondary, or authigenic, textures, mainly opaline silica, clay (halloysite) and zeolite (mainly phillipsite and chabazite) surface coatings, and the characteristics of the cementitious matrix, were recorded on page-sized printouts of scanned thin sections. Observations of the tuffs followed a similar procedure. The petrographic data were augmented with JEOL 6700F Field Emission scanning electron microscope images (SEM) (6/7/Hosler) in the backscatter electron mode (BSE) with energy-dispersive X-ray spectrometer (EDS) analyses, and X-ray diffraction analyses using a Scintag PADV X-ray diffractometer, equipped with a Ge solid state detector and Cu–K_α radiation, 35 kV/30 mA at the Pennsylvania State University Materials Characterization Laboratory. Major oxide compositions of mortars were obtained by high-resolution inductively coupled plasma mass spectrometry, by Activation Laboratories, Ontario. The cementitious matrix was lightly scratched from the mortar and sieved to <0.6 mm, and the scoriaceous Pozzolane Rosse aggregate was hand picked and sieved to >2 mm and <10 mm. For the tuff analyses, the altered vitric matrix and glass fragments were scratched out and sieved to <2 mm. Translations of *De architectura* come from the Latin of Granger (1931–4), Gros *et al*. (1997) and Callebat *et al*. (1999).

Table 1 *Petrographic characteristics of pozzolanic mortars from the Theatre of Marcellus*

Structure	*Sample*	*Volcanic ash aggregate (*harenae fossiciae*)*	*Rubble aggregate (*caementa*)*	*Mortar quality*
Wall, outer circumferential ambulatory	07-MARCELL-C1	Pozzolane Rosse intermediate alteration facies, fine palagonitic sand, 2–3%; and good penetration of cements, now mainly altered to calcite	Wall core, Tufo Lionato	Quite carefully selected aggregate, but somewhat poorly compacted
	07-MARCELL-C2	Pozzolane Rosse intermediate alteration facies, and occasional least altered facies with zeolitic alteration, fine palagonitic sand, 2–3%; and good penetration of pozzolanic cements, now mainly altered to calcite	Mortar joint between thick yellow brick	Quite carefully selected aggregate, but somewhat poorly compacted
Radial pier, inner circumferential ambulatory	07-MARCELL-C5	Pozzolane Rosse intermediate alteration facies, and occasional least altered facies with zeolitic alteration, fine palagonitic sand, 2–3%; and pervasive cements, now somewhat altered to calcite	Wall core, Tufo Lionato	Very carefully selected aggregate, well compacted, and highly coherent
Substructure (drill core)	09-MARCELL-C4	Pozzolane Rosse upper intermediate alteration facies, sometimes with thick yellow halloysite; fine microscoriae fraction appears partially absent; pervasive cements, including strätlingite and vaterite	Tufo Lionato	Somewhat carefully selected aggregate, somewhat well compacted and highly coherent

BUILDING MATERIALS OF THE THEATRE OF MARCELLUS

The Theatre of Marcellus occupies the active floodplain of the Tiber River (Bencivenga *et al.* 1995), in the southernmost area of the Campius Martius. The enormous structure, 130 m in diameter and nearly 32 m tall, sits on an annular concrete ring 6.35 m thick, with Tufo Lionato *caementa*, which rests on wooden piles driven into clay (Ciancio Rossetto 1995). The foundation ring reaches to the inner circumferential walkway, beyond which there are linear foundation walls up to the orchestra. The plan view (Fig. 1) shows the types of dimension stone and concrete facings of the theatre.

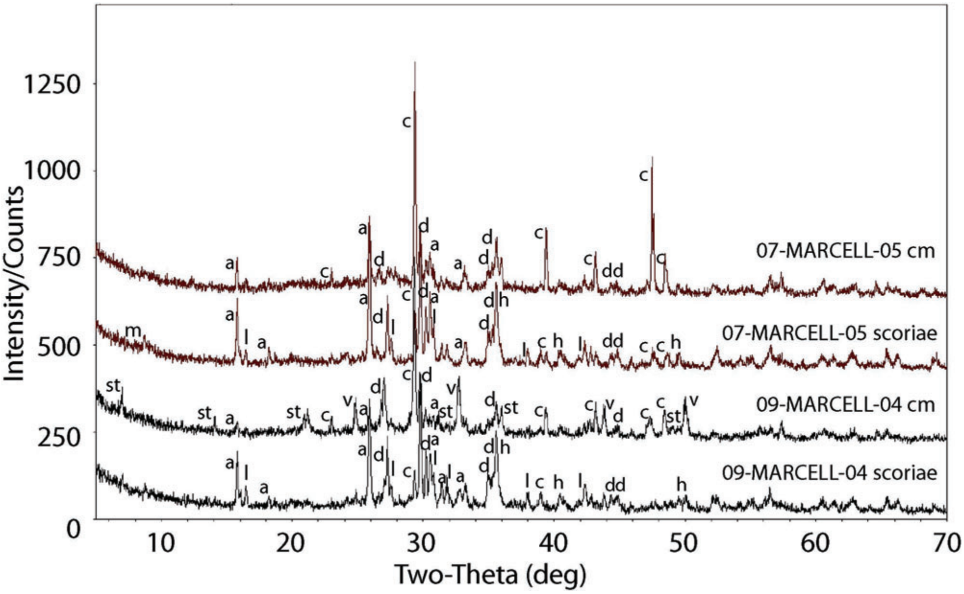
Mortars of pozzolanic concretes

Petrographic analysis of four representative mortars of the Augustan age construction of the Theatre of Marcellus reveals a general uniformity in mortar aggregate compositions (Fig. 1 and Table 1). All contain the intermediate alteration facies of Pozzolane Rosse, which forms a strongly grain supported fabric at the sand-sized particle scale. Scoriae vesicles retain occasional traces of unreacted illuvial halloysite surface coatings, and scoria perimeters retain accretions of fine ash deposited within a transitional Bt to Bw horizon during mid-Pleistocene pedogenesis (Jackson *et al.* 2010a). The 07-MARCELL-C2 *opus testaceum* mortar joint also contains very dusky red (10R 2/2) scoriae with unreacted chabazite surface coatings, indicating that builders excavated into the lower horizons of the pyroclastic flow and the zeolitic least altered facies (Jackson *et al.* 2010a).

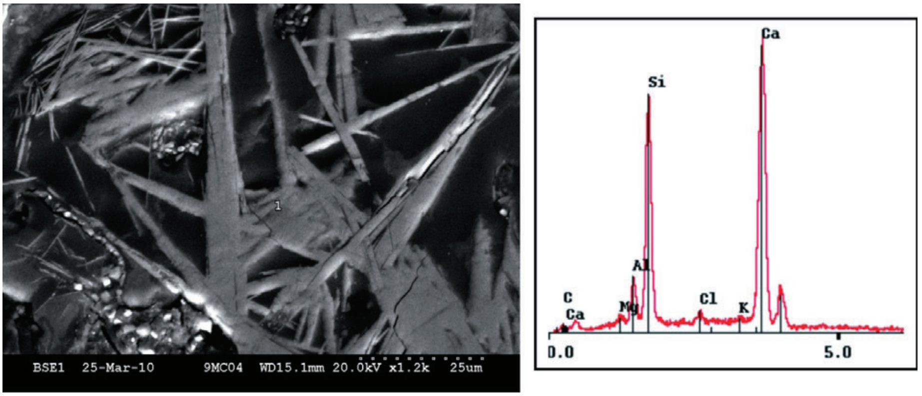
Scoriae are generally <1 cm in diameter, although scoriae 2 cm in diameter are not uncommon. This suggests that builders roughly screened the Pozzolane Rosse ash, removing the coarse gravel-sized fraction (Delaine 1997, 110; Jackson *et al.* 2007, fig. 5). Vitruvius does mention the sifting of sands 'either from the gravel of the river bed or from the sea shore' (*De arch.* 2.4.2) for mortars, but this is in the case where *harenae fossiciae* are not available.

Mortar from a wall core (07-MARCELL-C1) and a *opus testaceum* mortar joint (07-MARCELL-C2) have this characteristic aggregate fabric, but common irregularly shaped <0.5 mm voids (Fig. 1 (a)). The more compact mortar of the 07-MARCELL-C5 wall core has a specific gravity of 1.804, similar to the wall mortars of the Markets and Forum of Trajan, which range between 1.73 and 1.83, giving an average unit weight of 1790 kg m^{-3} (Jackson *et al.* 2009). Scoriae in the mortar from the base of the 6.35 m thick substructure (09-MARCELL-C4), have common thick, yellow, illuvial clay surface coatings, indicating that some of the ash was excavated near the top of the Pozzolane Rosse pyroclastic flow. The fine microscoria fraction seems to be missing (Fig. 1 (b)); perhaps it was lost in transport from the quarry. These are the main features that might suggest a possible construction date at 44 BCE, prior to the main Augustan building phase between the third and second decades of the first century BCE.

Coarse diopside and leucite are present within scoriae and as crystal fragments, yet much of the fine leucite less than 1 mm in diameter has been replaced by analcime or dissolved. X-ray diffraction analyses of scoriae from two coherent mortars, 07-MARCELL-C5 and 09-MARCELL-C4, record this mineral assemblage (Fig. 3 (a)), also described by Chiari *et al.* (1992). The diffractograms of the <0.6 mm fraction of the cementitious binding matrix of these mortars show analcime, but only weak peaks for leucite. This is because fine leucite crystals were systematically dissolved or replaced by analcime (Jackson *et al.* 2010b). The substructure mortar, sample 09-MARCELL-C4, shows strätlingite cement, a durable calcium-aluminate-hydrate (C_2ASH_8), that gives good compressive strength to modern cements (MacDowell 1991)



(a)



(b)

Figure 3 *Theatre of Marcellus mortars: (a) X-ray diffractograms of the cementitious binding matrix and scoriae (l, leucite; d, diopside; a, analcime; v, vaterite; c, calcite; h, hematite; st, strätlingite); (b) An SEM–EDS image and analysis of strätlingite microstructures in the mortar of the concrete substructure (after Jackson* et al. *2010b).*

(Fig. 3 (b)). It also occurs in certain cemented ash accretions and scoriae vesicles of the 07-MARCELL-C5 wall core (Fig. 1 (c)), as do lamina of cement hydrates, now partially altered to calcite (Fig. 1 (d)). Strätlingite, or gehlinite hydrate, has been identified in imperial age mortars only in the substructure of the Colosseum (Massazza and Pezzouli 1981) and in the wall core of the Great Hall of Trajan's Markets (Jackson *et al*. 2009). The substructure mortar has less calcite than the wall core mortar (Fig. 3 (a)) and, instead, contains vaterite, an unstable polymorph of calcium carbonate that precipitates from acqueous solution within the calcite stability field (Albright 1971; Ogino *et al*. 1987).

Table 2 *Chemical compositions of the cementitious binding matrix of two well-consolidated mortars from the Theatre of Marcellus*

Oxides (wt%)	*07-MARCELL-C5* Wall core (23–17 BCE)*	*09-MARCELL-C4† Substructure (44?–17 BCE)*
SiO_2	38.62	27.44
Al_2O_3	12.80	9.84
TiO_2	0.53	0.36
Fe_2O_3	6.00	4.10
CaO	14.30	26.80
MgO	2.43	2.04
MnO	0.15	0.10
Na_2O	1.63	1.88
K_2O	2.28	0.79
P_2O_5	0.47	0.32
LOI	16.57	21.84
Ca/Si	0.37	0.98
Si/Al	3.02	2.78

*07-MARCELL-C5, wall core with Tufo Lionato *tufelli* facing.

†09-MARCELL-C4, drill core of theatre substructure, sampled at ~6.35 m below the present ground surface.

The major element compositions of the cementitious matrix of the wall core, 07-MARCELL-C5, and substructure, 09-MARCELL-C4 (Table 2), show typically high values of Si/Al, 2.78–3.02, and high $Na_2O + K_2O$, 2.67–3.91 wt%, similar to the Augustan age mortars with Pozzolane Rosse aggregate from the Basilica Aemilia and Temple of Castor and Pollux (Roy and Langton 1989, 38 (FP-11A, CF-2)). Ca/Si in the substructure mortar, 09-MARCELL-C4, is relatively high, 0.98. There, calcium-aluminate cement hydrates remained somewhat intact, as shown by the presence of strätlingite (Fig. 3). This seems to reflect curing of the mortar in a moist environment away from contact with atmospheric carbon dioxide for more than 2000 years.

Volcanic tuff building stone

Greyish brown to moderate brown (5YR 3/2 to 5YR 3/4) tuff, reinforced with travertine blockwork, is the predominant dimension stone of the Theatre of Marcellus. Based on the abundance of lava lithic fragments in the tuff blocks of the annular, external ambulatory (Fig. 1), Jackson and Marra (2006) identified this dimension stone, erroneously, as Tufo di Tuscolo, a tuff rich in lava lithic fragments that resembles the most lithic-rich Tufo Lionato, but was quarried at the summit of the Alban Hills volcano at Tuscolo (De Rita and Giampaolo 2005; Jackson *et al*. 2005). New analyses provide petrographic and mineralogical criteria to distinguish the tuff building stones.

The Tuscolo tuff erupted during the final Tuscolano–Artemisio eruptive phase, so it is quite similar in age to Tufo Lionato (De Rita *et al*. 1995; Karner *et al*. 2001). It has variable proportions of leucitic lava rock fragments and deep orange-brown (5YR 5/6) palagonite (glass) fragments (Fornaseri *et al*. 1963, 136–42). Investigations of specimens from the Roman quarry at Tuscolo (Fig. 4 (a)), the piers of the Vespasian to Tiberius age walls of the Colosseum (Fig. 4 (b)) and the Domitian age arena substructure (Beste 2002; Rea 2002; De Rita and Giampaolo 2005, 181–2) indicate that these are lithified tuffs, with strong phillipsite cements (Fig. 5). The lava fragments derive from older, hardened lava flows, which were shattered during the explosive movement of magma through the edifice of the volcano, and then incorporated into eruptive mixtures ejected as pyroclastic flows. The tuff also includes a distinctive italite volcanic glass, coloured olive black (5Y 2/1) in plane-polarized light, with abundant leucite and diopside phenocrysts, and dusky yellowish green (10GY 3/2) diopside in its groundmass (Figs 4 (a) and 4 (b)). Primary volcanic diopside and authigenic phillipsite are the predominant crystalline components (Figs 4 (b) and 5). The radial piers of the Colosseum also contain large, light brown (5YR 5/6), friable, porous dimension stone blocks composed predominantly of this italite glass, as do soft, friable horizons within the Roman quarry at Tuscolo. The 1930s olive grey (5Y 3/1) tuff reconstruction of the south-west perimeter of the Theatre of Marcellus (Jackson and Marra 2006, fig. 6f) is unequivocally Tufo di Tuscolo; it has abundant, glassy, italite fragments in thin section and strong diopside peaks in the X-ray diffractogram (Figs 1 and 5; 09-MARCELL-01).

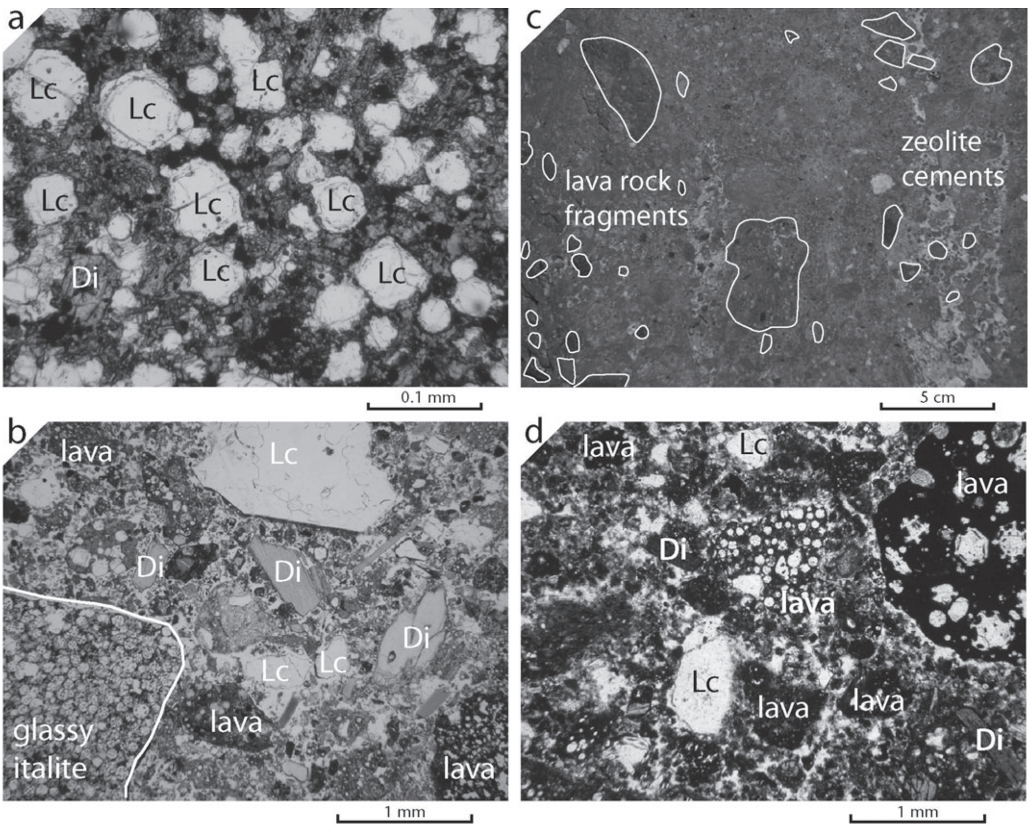


Figure 4 *Tufo di Tuscolo and Tufo Lionato tuffs, in plane-polarized light: (a) lithic–crystal–vitric Tufo di Tuscolo tuff from the Roman quarry at Tuscolo, sample 05-TdT-10—a characteristic italite fragment has an olive black (5Y 2/1) glassy matrix with euhedral leucite (Lc) and dusky yellowish green (10GY 3/2) diopside (Di); (b) Tufo di Tuscolo tuff from a first-floor radial pier of the Colosseum, sample 05-COLOSS-02, with a characteristic glassy italite fragment; (c) Tufo Lionato vitric–lithic–crystal tuff from the outer ambulatory of the Theatre of Marcellus—the outlines show lithic fragments greater than 1 cm in diameter; (d) Tufo Lionato of the outer ambulatory of the Theatre of Marcellus, sample 09-MARCELL-02, with common leucitic lava fragments and diopside, but not the characteristic glassy italite fragments of Tufo di Tuscolo.*

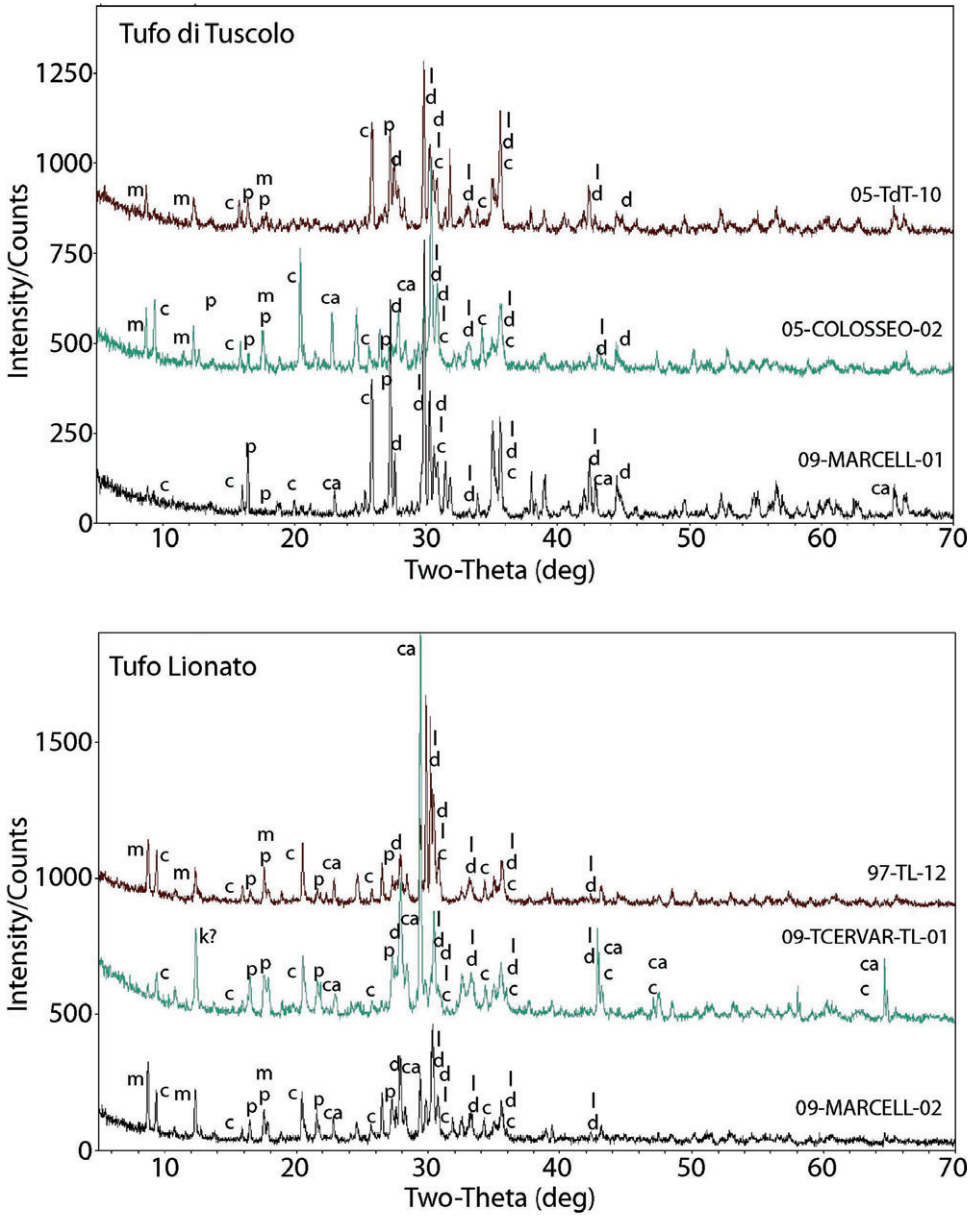


Figure 5 *X-ray diffractograms of the glassy <2 mm fraction of Tufo di Tuscolo and Tufo Lionato from quarries and ancient building stones: l, leucite; d, diopside; a, analcime; m, mica (biotite); p, phillipsite; c, chabazite; ca, calcite.*

Tufo Lionato was quarried in Rome during the early history of the city, and recent excavations indicate the use of this tuff in the fourth century foundation of the Temple of Apollo Medico, adjacent to the Theatre of Marcellus (Ciancio Rossetto 1995; Vitti in press). During the later republican era, it was quarried along the Aniene River (Strabo, *Geografica* 5.2.5; Frank 1924; Blake 1947; Lugli 1957; Jackson and Marra 2006). Overall, moderate to light brown (5YR 4/4 to

5YR 5/6) fresh surfaces show zeolite cements, mainly phillipsite and chabazite, with later calcite infill (Fig. 4 (c)). Palagonite fragments, dark yellowish orange to light brown (10YR 6/6 to 5YR 5/6) in plane-polarized light, generally make up 35–40 vol% of the tuff fabric, based on point counts (Jackson *et al*. 2005). Lava lithic fragments form >15 vol% of some tuff blocks. The zeolite cements are generally the predominant crystalline component of the tuff, as indicated by X-ray diffractograms (Fig. 5). Petrographic examination of numerous specimens of Tufo Lionato from quarries along the Aniene River and from two representative specimens from the building stones of the theatre reveals that these rocks do not contain the distinctive italite glass fragments of the Tuscolo tuff, although leucitic lava lithic fragments and abundant diopside crystal fragments are present (Fig. 4 (d)). The results of these analyses, and the absence at the Theatre of Marcellus of friable light to moderate brown (5YR 4/6 to 5YR 3 /4) dimension stone blocks composed predominantly of italite glass as at the Colosseum, indicate that the tuff is indeed Tufo Lionato.

Integrated dimension stone and concrete masonry

The approximately semi-circular foundation of the *cavea* has travertine and Tufo Lionato dimension stone (Fig. 1), while Lapis Albanus tuff was used in the large enclosure wall behind the *post scaneam* area. Large blocks of travertine *opus quadratum* form the semi-circular external façade. Large blocks of Tufo Lionato, 60 cm wide and 134–214 cm in length, form the internal walls of ambulacrum and the pillars of the internal façade, which opens into the arches of barrel vaults (*fornici*) that are reinforced with travertine keystone blocks and imposts (Fig. 2 (b)). Builders used the travertine, which has uniaxial compressive strength ($\mathbf{q}_u$) of about 83 MPa at 90–98% relative humidity and low water adsorption (**Ad**), about 0.07 wt%, to reinforce the Tufo Lionato blockwork, which has a much lower $\mathbf{q}_{u,}$ of about 26 MPa at 90–98% relative humidity, and a higher **Ad**, about 5 wt%, in the humid conditions of the theatre (Jackson *et al*. 2005). The greater proportions of lava lithic fragments in the Tufo Lionato (Figs 4 (c) and 4 (d)), and the lesser proportions of pumiceous glass, would have increased compressive strength and decreased water sorption, enhancing overall durability (Jackson *et al*. 2005).

The inner sectors of the theatre have conglomeratic concrete walls with Tufo Lionato *caementa*, and facings of Tufo Lionato *opus reticulatum* cut into small pyramids with a 6.5–7.5 cm square base, or Tufo Lionato *tuffelli* cut into small, regular, $30 \times 8 \times 8$ cm rectangular blocks (Fig. 2 (a)). In two sectors, the concrete walls of the internal circumferential walkways, or *ambulacri*, have facings of thick, greyish yellow (5Y 8/4) brick and mortar joints with very dark red (5R 2/6) Pozzolane Rosse aggregate. The bricks are about 4 cm thick and their dimensions vary from 21–23 cm across in walls (Fig. 2 (a)), to 21–25 cm across in archways, to 40 cm across in the arches of drains. These are some of the earliest examples of *opus testaceum* in Rome (Ciancio Rossetto 1999, *LTUR IV*, 3125; Gerding 2002). However, the source of clay, and whether it derives from the Velabrum area (Ammerman *et al*. 2008), is not known.

The high quality of the concretes, and the Tufo Lionato and travertine cut stone masonry (Fig. 2), and their intricate integration and installations in complex ambulatories and barrel vaults, are testaments to the builders' skill in the selection of geological building materials of the Roman landscape, and their quarrying techniques and work-site management. The concretes display a high degree of refinement and precision in the selection and execution of their Tufo Lionato *opus reticulatum and tuffelli* facings, and fired brick *opus testaceum* facings (Figs 1 and 2 (a)). These features resemble some of the concretes of the nearly contemporaneous Tomb of Caecilia Metella, from 30–20 BCE, which have red, well-fired, brick *opus testaceum* wall facings and *caementa* (Gerding 2002, 47–54, 162–7). The cohesive and compact tomb mortars contain the least altered facies of Pozzolane Rosse (Jackson *et al*. 2007).

The coherence and durability of the mortars of the Theatre of Marcellus could result from the consistent development of calcium-alumina-hydrate cements, including strätlingite. It is not clear, however, whether these mortars would have facilitated the construction of the upper levels of the complex monument through a more rapid gain in mechanical strength, as compared to the early republican era mortars with epiclastic aggregates (Jackson *et al*. 2007, 2010a). However, the gain in uniaxial compressive strength for experimental Pozzolane Rosse hydrated lime mortars occurs steadily over a 28-day period to 14 MPa (145 kg cm^{-2}) and then increases modestly to 15 MPa (155 kg cm^{-2}) at 90 days curing (Massazza and Costa 1977), or to 9.14 MPa at 28 days increasing to about 12 MPa at 90 and 180 days curing (Samuelli Ferretti 1997). In comparison, Portland cement mortars should acquire the equivalent of laboratory compressive strengths of at least 5–17 MPa at 28 days' curing (ASTM 2010). These data suggest that the builders of the theatre may have integrated 1–3 month curing times into their concrete construction schedule, and that the strength gains of their mortars may be similar to those of modern materials.

VITRUVIUS, ON FINE WORKMANSHIP AND ARCHITECTURAL COLLABORATION

Julius Caesar purchased and cleared land in the southernmost Campius Martius and probably laid the foundations of the Theatre of Marcellus substructure in 44 BCE, the year of his assassination (Cass. Dio 53.49.2). The theatre was essentially complete in 17 BCE, and inaugurated in 13/11 BCE (Augustus *Res Gest.* 4.9; Suetonius *Aug.* 29.4), about 15 years after initiation of the imperial era, which began when Octavian was formally declared 'Augustus' in 27 BCE (Cass. Dio 53.16). The Theatre of Pompey, dedicated in 55 BCE, was the first permanent theatre in Rome, and may have been larger and more complex (Pliny, *Naturalis historia* 33.54; 35.58, 114, 126, 132; Cicero, *In Pisonem* 65) but less is known about the quality and composition of its stone and concrete materials, because the building is covered by later constructions (Gagliardo and Packer 2006; Packer *et al*. 2007).

In his writings for Octavian at the inception of the imperial era, Vitruvius wrote (*De arch.*, 6.8.8, 6.8.1), 'as explicitly as he could . . . how buildings can be carried out so as to avoid failure, and how precautions must be taken in the first stages . . . ', so that, 'buildings, which start from the level of the ground, if the foundations are laid as we have described in previous books with references to city walls and theatres, will assuredly be solid and durable'.

Most significantly, he states:

> It is not in the power of an architect to control the quality of the kinds of materials that it is necessary to employ, because not all of the same kinds of materials are found in all places, as was explained in the first volume (Vitruvius, *De arch.* 5.7.5). Besides, the owner decides if the building is to be in brick (*latericio*) or rubble (*caementicio*) or squared stone (*saxo quadrato*). In this way, the test of excellence of all work can be considered in three parts: fine workmanship (*subtilitate*), magnificence (*magnificentia*), and design (*dispositione*). When the work has achieved a magnificent appearance, the praise for the expense goes to the owner; when the [workmanship is] fine, the management by the overseer is pronounced good; and when it has true beauty due to proportion and symmetry the glory goes to the architect.
>
> These [plans] then [are] most appropriately made, when he [the architect] accepts the counsel of the workmen (*fabris*) and from ordinary or uneducated people (*idiota*). For all

people, not only architects, are able to commend that which is well done; but the difference between the ordinary person and the [architect] is that [for] the ordinary person it would be a wonder if he were able to understand the plan without having seen [the work] completed; [on the other hand] the architect, having already imagined it before it is begun, has a definite [idea] of what the work will be with respect to [its] elegance, beauty, and quality of design (*De arch.*, 6.8.9–10).

Vitruvius acknowledges the role of personal patronage and investment in the creation of magnificent architectural works; the importance of work-site management on discriminating craftsmanship; and the success of the architect who is open and receptive to the recommendations of both skilled workers and master craftsmen (*fabris*) and unskilled workers and labourers (*idiota*), and perhaps ordinary people as well. Here, he describes the ethos of the transition to imperial era construction materials and methods, which are embodied in the Theatre of Marcellus.

Vitruvius may be describing the personal involvement and collaborative relationship that Augustus, as the owner (*domini*), or a close associate might have had with the builders of the theatre. Indeed, the architectural forms and technical innovations of the Tomb of Caecilia Metella provide another remarkable example of the architectural transition from the late republican to the early imperial period (Gerding 2002, 126–7), in which 'the architects had to use all of their skill and imagination in order to comply with the wishes of the [building] commissioners', who may have included M. Licinius Crassus, Consul in 30 BCE, and son of Caecilia Metella (Gerding 2002, 71–3). Both monuments anticipate the high standards of later imperial era monumental construction: they have durable Tufo Lionato and travertine dimension stone; exploratory concrete masonry, which includes brick-faced structural elements; and an innovative architecture of complexly shaped interior spaces. This is masked, however, at the Theatre of Marcellus by a rather conventional travertine façade (Ward-Perkins 1977, 68). Over his lifetime, Augustus strove to promote the traditions of republican Rome within his new imperial system (Favro 1996). In improving and beautifying the city, he and his associates repaired many venerable structures whose friable, 'ashy-grey' concretes had been constructed with *harenae fossiciae* from epiclastic deposits, and weakly durable tuff masonry, such as Tufo del Palatino and Tufo Giallo della Via Tiberina, which may have been in the process of deterioration (Jackson and Marra 2006; Jackson *et al.* 2007, 2010a).

CONCLUSIONS

Analyses of the concrete building materials of the Theatre of Marcellus reveal mortars with Pozzolane Rosse volcanic ash of the intermediate alteration facies screened to grain-size fractions generally less than medium gravel, and a small amount of palagonitic sand, 2–3 vol%. The reaction of this aggregate mixture with hydrated lime produced pervasive and interpenetrating calcium-alumina-hydrate cements, including strätlingite, which are particularly well developed in a thick substructure.

Petrographic and mineralogical studies of the tuff dimension stone of the theatre indicate that it is Tufo Lionato, with a relatively high proportion of lava lithic fragments. The lithic-rich fabric most probably enhanced the compressive strength of the dimension stone. The tuff does not seem to include the distinctive italite volcanic glass, coloured olive black (5Y 2/1) in plane-polarized light, with abundant, coarse, dusky yellowish green (10GY 3/2), of Tufo di Tuscolo. This suggests that the principal use of the Tuscolo tuff in Rome was in 70–90 CE, for the construction of the Colosseum and its arena substructure.

The dimension stone and concrete building materials of the Theatre of Marcellus, and their installation in a complex internal architecture, embodies the ethos of the transition to imperial era construction technologies, which apparently forms the basis of Augustus' modernized imperial building programme. The new materials and methods of concrete and cut stone construction, including the early use of *opus testaceum* concrete facings, are a testament to the collaborative skills of the builders of the theatre, and their ability to build upon the techniques and expertise that their predecessors developed during the later republican era for cut stone and pozzolanic concrete masonry.

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