PETROGRAPHIC & MICROSTRATIGRAPHIC ANALYSIS OF MORTAR-BASED BUILDING MATERIALS FROM THE TEMPLE OF VENUS, POMPEII

Rebecca Piovesan

Department of Geosciences, University of Padova, Italy
(rebecca.piovesan@unipd.it)

Emmanuele Curti

Archaeological School of Matera, University of Basilicata, Matera, Italy

Celestino Grifa

Department of Geological and Environmental Studies,
University of Sannio, Benevento, Italy

Lara Maritan

Department of Geosciences, University of Padova, Italy

Claudio Mazzoli

Department of Geosciences, University of Padova, Italy

Introduction

Recipes for mortar-based building materials may change over time and differ in various construction and restoration phases. They normally reflect craftsmen's knowledge, availability of raw materials, and also the importance of the building in which they are found. The present research focuses on mortar-based materials from several construction and renovation phases of the Temple of Venus, at Pompeii, Italy, in order to identify any changes over time in production recipes.

The Temple of Venus, who was both the main and polyad divinity of Pompeii, is located on the southwestern side of the town (Figure 1), and underwent numerous reconstructions and renovations until the eruption of Vesuvius buried it under a thick layer of pumice in 79 AD. The site of the temple had probably been a holy place since Archaic times, connected with the Etruscan worship of Venus. The area was certainly occupied again in the late 4^{th}-3^{rd} centuries BC, when the Sannites entered it. It was completely redesigned in about 130 BC, during definitive Romanisation. The sanctuary of Roman Republic times was then renovated during the Julian and Claudian ages, but was almost completely destroyed during the earthquake of 62 AD. At the time of the eruption of Vesuvius in 79 AD, rebuilding was still under way, as attested by findings of building elements. A recent new hypothesis on the debated location of the harbour of Pompeii suggests that the Temple of Venus had not only religious but also trade connotations (Curti, 2007, 2008). This new interpretation places the harbour on the southwestern side of Pompeii, outside the town walls, near the market and right in front of the Temple. Therefore, the Temple of Venus becomes an extremely interesting case study with which to follow continual religious and political changes through architectural renovations in Pompeii.

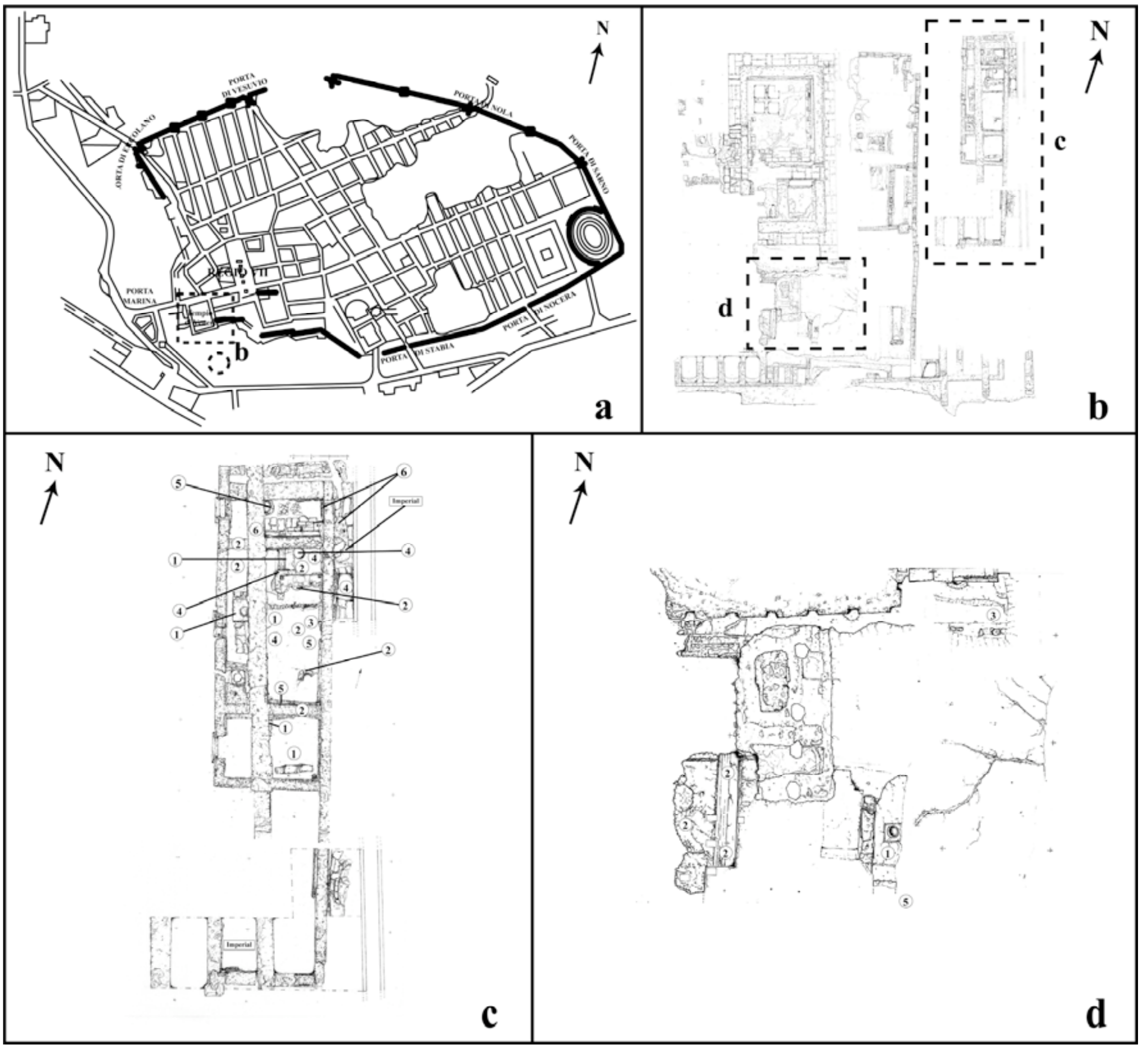

Figure 1. Map of Pompeii and the Temple of Venus. a) Plan of archaeological site, b) Temple of Venus, c) Details of northern excavated area, d) Details of southern excavated area.

Sample Selection

During excavations at the Temple of Venus by the Postgraduate School of Archaeology, University of Basilicata, between 2004 and 2008, thousands of fragments of mortar-based building materials were unearthed. In this study, we analysed a selection of 127 of these samples, mostly from the southern and northern areas of the site (Figure 1B). The samples were dated archaeologically from the end of the 4th century BC to the 1st century AD and divided into six age groups (Table 1).

Stratigraphic units were dated and related chronologically on the basis of ceramic type. The samples were also subdivided according to their architectural provenance into three groups: walls, floors, and hydraulic structures (conduits, wells and cisterns) (Table 1), and then analysed petrographically and microstratigraphically. Identified aggregate particles were also compared with samples of sand collected from 14 localities along the Neapolitan coastline, from Cuma to Castellammare di Stabia in order to determine the provenance of the raw materials (Figure 2).

Figure 2. Geological sketch of Mount Vesuvius and surrounding areas. Modified after Revellino et al. (2004). 1 = Alluvial, lacustrine and coastal sediments, 2 = Potassic to ultrapotassic lavas and volcaniclastic deposits, 3 = Limestone and dolostone, 4 = Silico-clastic and carbonate deposits, evaporates, 5 = Faults.

Age		Walls					Floors		Hydraulic S.	
		Arriccio		*Intonaco*						
		VSRA	CRA	I	C	M	VSRF	CRF	VSRH	CRH
	End 4^{th}-3^{rd} BC	9	1	1	3	1	4	1	2	-
Republican times	Second half 2^{nd} BC	25	3	3	11	8	12	7	5	4
	1^{st} BC	8	1	2	2	7	-	-	-	-
	Augustan age	3	-	-	1	2	1	-	1	1
Imperial times	Julio-Claudian age	13	-	1	5	4	4	2	1	1
	Flavian age	2	-	-	-	-	-	-	-	-
Unknown age		18	1	-	1	-	4	4	-	-
	Samples									
Walls	89	93%	7%	15%	31%	54%	-	-	-	-
Floors	28	-	-	-	-	-	69%	31%	-	-
Hydraulic structures	10	-	-	-	-	-	-	-	58%	42%

Table 1. Time distribution of differing types of mortars and relative abundances in various architectural features of provenance structures. VSRA = Volcanic scoria-rich *arriccio*, CRA = Clinopyroxene-rich *arriccio*, I = *Intonachino*, C = *Cocciopesto*, M = *Marmorino*, VSRF = Volcanic scoria-rich floors, CRF = Ceramic-rich floors, = VSRH = Volcanic scoria-rich hydraulic structures, CRH = Ceramic-rich hydraulic structures.

Analytical Methods

All samples were analysed by optical microscopy, following macroscopic and microstratigraphic analytical procedures for study of mortar-based building materials described in UNI Norm 11176:2006 'Cultural heritage - Petrographic description of a mortar' proposed by the Italian Organization for Standardization, a member of the International Organization for Standardization (ISO). These procedures are applicable to mortars and plasters, where 'mortar' is a material composed of an inorganic binder plus an aggregate with dimensions of <5 mm (Prentice, 1990), and 'plaster' is a type of fine-grained, often multi-layered, mortar which provides a smooth coat to a wall or other surface.

The definitions, originally introduced by Vitruvius (1999), and used again by Mora *et al.* (1984) were adopted to define differing portions of the multi-layered plaster, normally composed of the following microstratigraphic sequence: scratch coat, *arriccio*, and *intonaco*. As defined by Mora *et al.* (1984) and Vitruvius (1999), the scratch coat is a very rough rendering applied to smooth the surface of a wall, *arriccio* is a sequence of "not less than three coats of sand and mortar, besides the rendering coat" (Vitruvius, 1999, p. 89) and *intonaco* is a series of finishing layers made of limewash and very fine sand, which may also be painted (Figure 3). Floors and hydraulic structures also display a multi-layer structure, but usually with a simpler microstratigraphy, composed of a preparation layer and one or two finishing layers (Figure 3). The filler, including various types of rocks and minerals such as carbonate rocks, ground ceramic materials and volcanic sand, was likely to have been chosen according to the required aesthetic and physical properties of the mortar-based materials, such as colour and brightness, and hydraulicity and weathering durability, respectively.

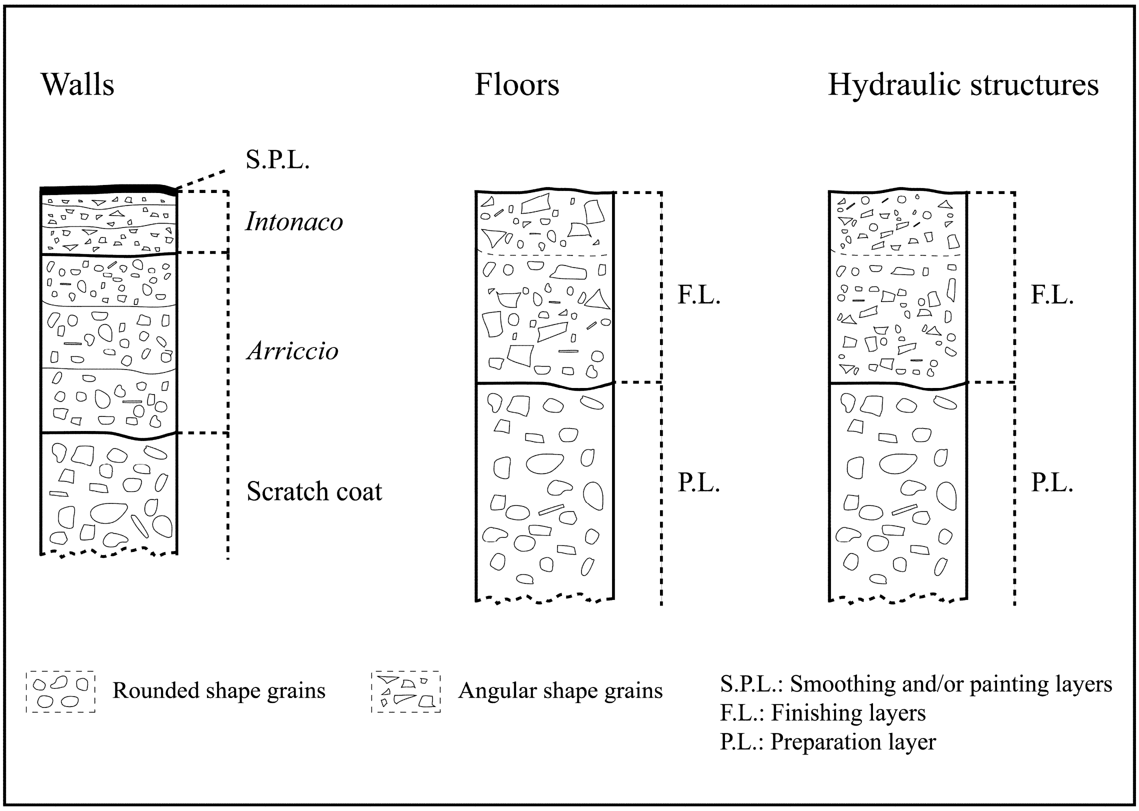

Figure 3. Microstratigraphy of walls, floors and hydraulic structures. Thicknesses of layers are not to scale.

Selected samples of the main petrographic groups were also studied by scanning electron microscopy (SEM) for microtextural and microchemical characterisation. Concentrations of the major elements Al, Fe, Si, Ca and Mg were also determined by analysis of selected areas of the binder with an energy-dispersive X-ray system (EDS). The hydraulicity of mortar, measured by the hydraulicity index (HI), is defined by Boyton (1966) as:

$$HI = \frac{Al_2O_3 + Fe_2O_3 + SiO_2}{CaO + MgO}.$$

According to this equation, the higher the index, the greater the property of the mortar to harden in a wet or water-saturated environment. The hydraulicity index should be lower than 1.2, which corresponds to the upper limit for quick-setting limes. Higher HI values in the analysis indicate the presence in the selected area of small silicate rock or mineral fragments, which increases Al_2O_3, Fe_2O_3 and SiO_2, without reflecting the real amount of hydraulic reaction products. Hydraulicity was also determined for lumps of lime, which were interpreted as a measure of the purity of the limestone used for its preparation (Charola and Henriques, 2000).

Petrography and Microstratigraphy

Petrographic and microstratigraphic analyses indicated that all samples were composed of a sequence of layers, mostly representing preparation and finishing layers of floors and hydraulic structures, and *arriccio* and *intonaco* on walls (Figure 3). The layers have various textural characteristics, aggregate compositions and matrix properties. The three classes of mortar-based building materials analysed here were found to have differing petrographic and microstructural features, and are described below.

Walls

Most of the wall samples are composed of several layers of preparatory plaster or *arriccio* covered by one or more poorly adherent *intonaco* layers. In some cases, smoothed and/or painted layers were also found, strongly adhering to the *intonaco* (Figure 3). The *arriccio* consists of strongly adherent grey plaster layers characterised by medium to fine sand-sized aggregate, medium to high porosity and low cohesion. The *intonaco* layers are composed of fine sand and limewash, and have low porosity and high cohesion.

On the basis of grain size, sphericity, roundness, and composition of aggregate plus the aggregate:binder ratio, two types of *arriccio* and three types of *intonaco* were identified. Their petrographic and microstructural features are listed in Table 2.

Arriccio

Two types of *arriccio* were distinguished, according to composition and relative abundance of various types of aggregate particles.

Volcanic scoria-rich *arriccio*

Most *arriccio* layers in wall samples belong to this type. It has a homogeneous matrix, consisting mostly of crypto- to microcrystalline calcite, with a high HI of 0.08 to 3.36, especially when the aggregate is medium silt-sized. In some cases, sub-millimeter lumps of lime, probably due to incomplete carbonation, were also identified. The aggregate:binder ratio is always about 1:1. The filler shows a wide grain-size distribution, ranging from granules to very fine sand, the coarse to medium sand fraction being most abundant. This fraction is mainly composed of rounded to well-rounded fragments of leucite-bearing volcanic rock, of leucititic or trachytic composition, and spherical scoria particles associated with abundant angular and sub-angular crystals of green and colourless diopside (Figure 4A), of medium sphericity. A few crystals of sanidine and plagioclase feldspar, black and yellow fragments of altered volcanic glass, rare flakes of biotite, and very rare crystals of Ti-rich andradite (melanite) also occur.

Clinopyroxene-rich *arriccio*

This plaster is very similar to the former type as regards the composition and grain size of its aggregate. It differs in terms of its higher aggregate:binder ratio, which ranges from 1.5:1-1:1, as well as the higher relative abundance of clinopyroxene crystals compared with fragments of volcanic rock and scoriae (Figure 4B).

Arriccio		Volcanic scoriae-rich *arriccio*	Clinopyroxene-rich *arriccio*
Aggregate	Aggregate to Binder	1:1	about 1:1
	Grain size	Granules to very fine sand	Very coarse to very fine sand
	Main fractions	Coarse to medium sand	Coarse to medium sand
	Sphericity	High to medium	Medium
	Roundness	VS and VRF: well-rounded to rounded grains. Cpx and Bt: sub-	Mainly sub-angular to sub-rounded
	Distribution	Homogeneous	Homogeneous
Matrix	Matrix	Micrite-like to spotted	Micrite-like to spotted
	Hydraulicity Index (HI)	From 0.08 to 3.36	From 0.14 to 4.10

Intonaco		*Intonachino*	*Cocciopesto*	*Marmorino*
Aggregate	Aggregate to Binder	about 1:1	1:1	about 1:1
	Grain size	From granules to very fine sand	From granules to coarse silt	From granules to coarse silt
	Main fractions	Coarse to medium sand	Coarse to fine sand	Medium to very fine sand
	Sphericity	High to medium	High to low	From high (L) to very low (SC)
	Roundness	VS and VRF: well-rounded to rounded	Very angular to rounded	From strongly angular (SC) to sub-rounded (L)
	Distribution	Homogeneous	Homogeneous	Homogeneous
Matrix	Matrix	Micrite-like	Spotted	Micrite-like
	Hydraulicity Index (HI)	From 0.14 to 0.19	From 0.19 to 0.38	From 0.04 to 0.06

Table 2. Classification of *arriccio* and *intonaco*. Grain size after Wentworth (1922). Cpx = Clinopyroxene, Bt = Biotite, VS = Volcanic Scoriae, VRF = Volcanic Rock Fragment, L = Limestone, SC = Sparry calcite.

Intonaco

Three types of *intonaco* were detected in wall plaster samples, and were classified, according to the composition of their aggregate particles, as *intonachino* (siliceous minerals and rock), *cocciopesto* (crushed pottery or bricks) and *marmorino* (limestone and calcite).

Intonachino

This type of *intonaco,* which is not common in wall samples, has an almost pure crypto- to microcrystalline calcite matrix, with sporadic lumps of lime, a low HI (0.14-0.19) and an aggregate:binder ratio of about 1:1. The filler shows homogeneous distribution, and grain size ranges from granules to very fine sand, coarse and medium sand classes being the most frequent. The filler is composed of fragments of volcanic scoriae and volcanic rock, frequently associated with sub-angular to angular crystals of diopside and, less often, sanidine, plagioclase, biotite and melanite (Figure 4C).

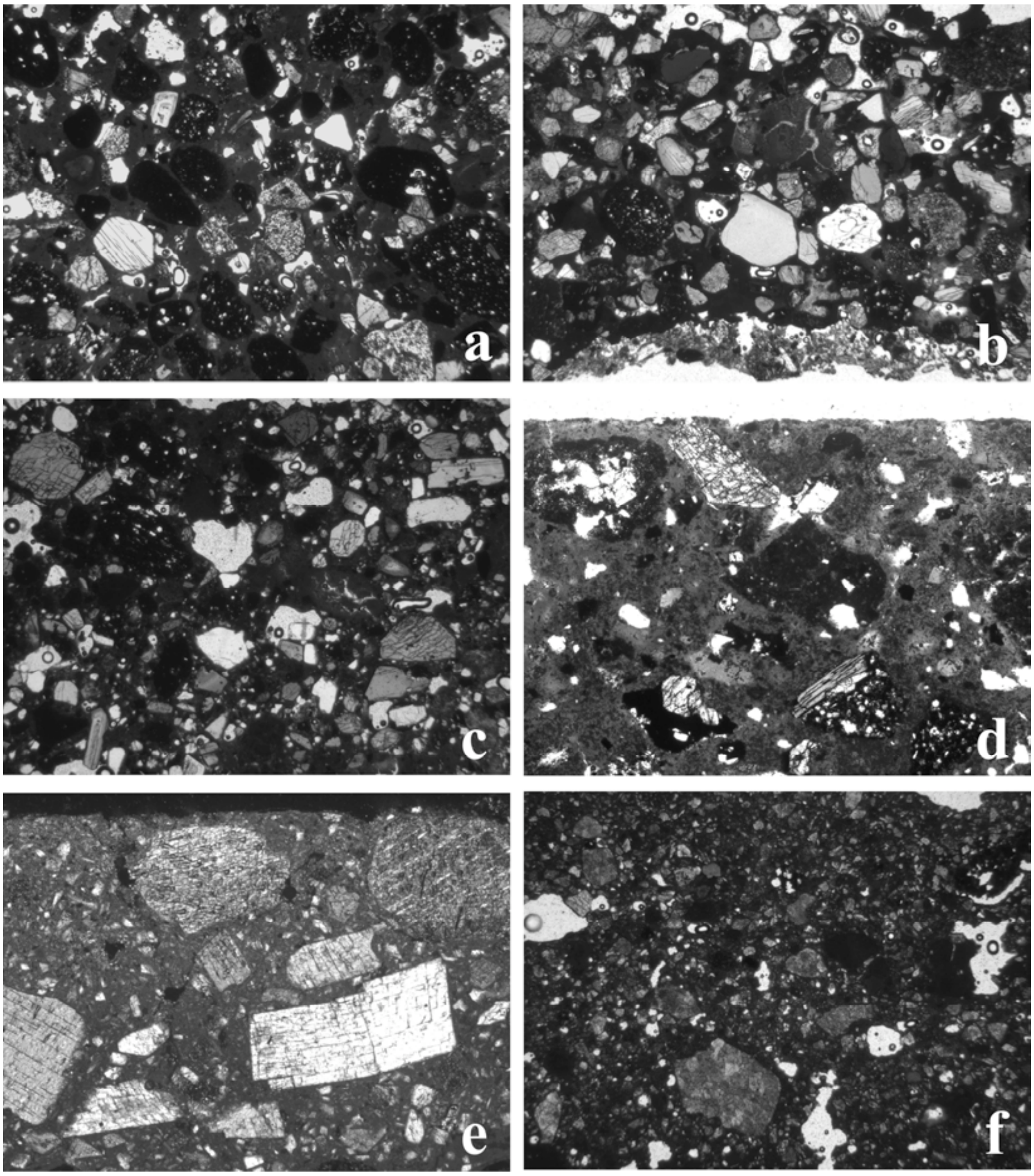

Figure 4. Polarising light micrographs of mortar samples. a) Volcanic scoria-rich *arriccio*, b) Clinopyroxene-rich *arriccio*, c) *Intonachino*, d) *Cocciopesto*, e) *Marmorino* with sparry calcite, f) *Marmorino* with limestone. All images taken in plane polarised light. Image width = 8.2 mm, except d and e = 3.9 mm.

Cocciopesto

Intonaco layers of *cocciopesto* are quite common in the wall samples. They have a spotted matrix (Figure 4D), composed of cryptocrystalline calcite and hydrated calcium silico-aluminates, with a relatively high HI (0.19-0.38; Table 2) and an aggregate:binder ratio of about 1:1. The aggregate grain size ranges from granules to coarse silt, with modal values of coarse to fine sand. Angular fragments of ground ceramic materials or 'grog' are most common, with a few well-rounded fragments of rock, scoriae, and altered glass, all of volcanic origin (Figure 4D). Rare crystals of diopside, sanidine, plagioclase and garnet and flakes of biotite also occur. Two types of grog were distinguished within the aggregate of the *cocciopesto intonaco*. The first contains rounded sand-sized inclusions of volcanic rock and volcanic scoriae, and relatively few angular crystals of diopside, plagioclase and opaque minerals, and the second contains quartz, feldspars and rare opaque minerals.

Marmorino

The third type of *intonaco, marmorino,* has a micrite-like matrix (Figure 4E,F) composed of crypto- and microcrystalline calcite, with a very low HI (0.04-0.06). The filler exhibits homogenous distribution within samples, and wide grain-size from granules to coarse silt, with maximum frequency in the medium to very fine sand classes. The aggregate consists of euhedral crystals of calcite, associated with occasional fragments of volcanic scoriae and rare crystals of diopside and feldspar (Figure 4E). In some cases, the carbonate fraction of the aggregate is composed of well-rounded fragments of micritic limestone rather than crystals of spathic calcite (Figure 4F).

Floors

Petrographic and microstratigraphic analysis of floor samples revealed that they consisted of preparatory and finishing layers with similar compositional and textural characteristics (Figure 3). According to the petrographic composition of the filler, two types of plasters were identified (Table 3).

Floors		Volcanic scoria-rich f.	Ceramic-rich floors	Carbonatic layers
Aggregate	Aggregate to Binder	About 1:1	1:1	About 1:1
	Grain size	From granules to coarse silt	Pebbles to very fine sand	From granules to coarse silt
	Main fractions	Coarse to fine sand	Medium to fine sand	Medium to very fine sand
	Sphericity	High to medium	Medium to low	High to medium
	Roundness	VS and VRF: well rounded to sub-angular grains Cpx and Bt: sub-angular to angular	Angular to sub-angular	Various
	Distribution	Homogeneous	Homogeneous	Homogeneous
Matrix	Matrix	Micrite-like to spotted	Micrite-like	Micrite-like
	Hydraulicity Index (HI)	From 0.16 to 1.60	From 0.10 to 0.17	From 0.01 to 0.07

Table 3. Classification of floor mortar. Abbreviations as in Table 2.

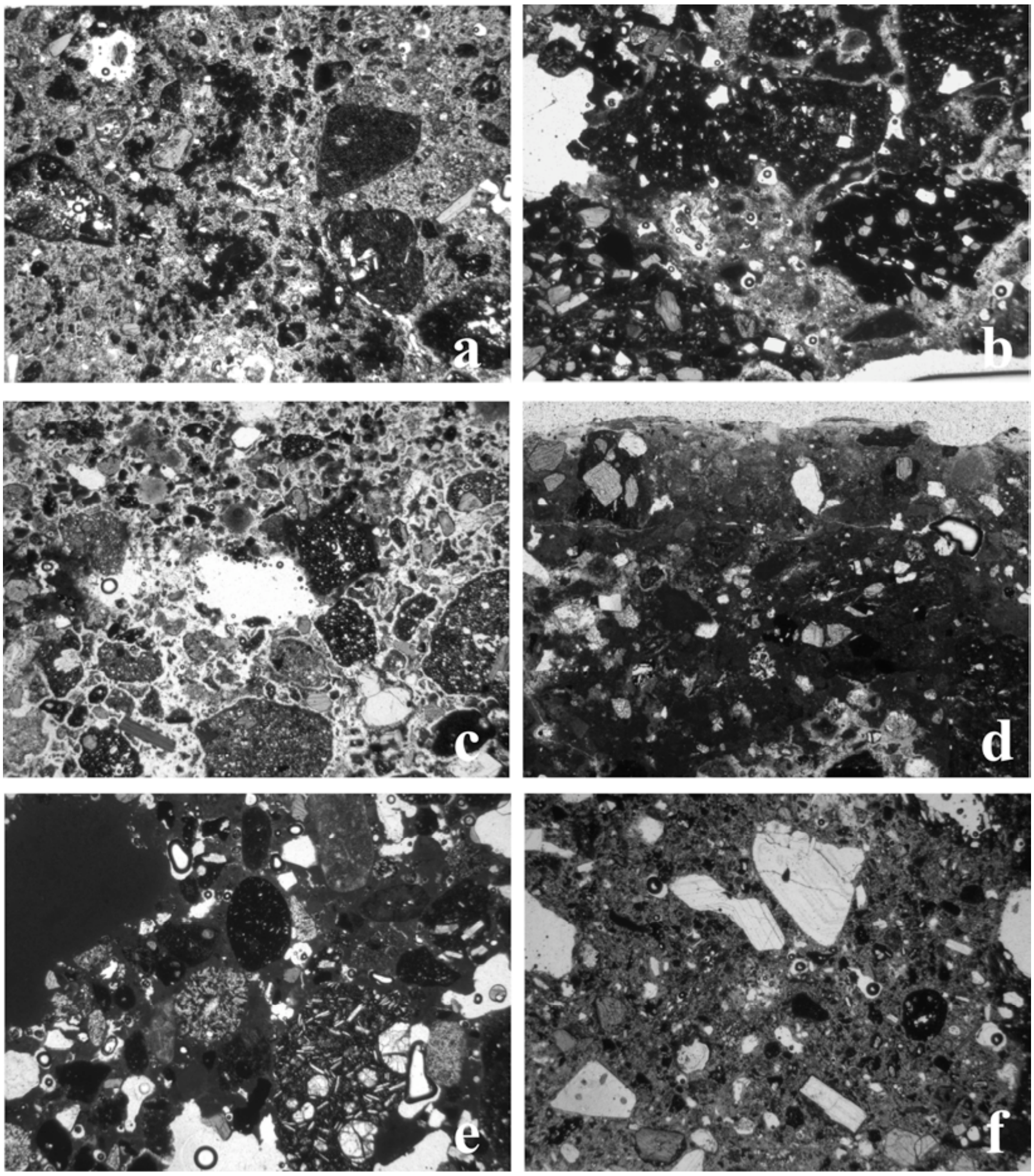

Figure 5. Polarising light micrographs of mortar samples. a) Volcanic scoria-rich floors, b) Ceramic-rich floors, c) Volcanic scoria-rich hydraulic structures, d) Ceramic-rich hydraulic structures, e) Micrite-like matrix with lime lumps, f) Spotted matrix. All images taken in plane polarised light. Image width = 8.2 mm, except d = 3.9 mm.

Volcanic scoria-rich floors

This type has a crypto- to microcrystalline calcite matrix, with an average HI lower than that of the preparatory layers of the walls, and an aggregate:binder ratio of 1.5:1 to 1:1. The aggregate grain size ranges from granules to coarse silt, with a maximum frequency in the fine sand class. It is predominantly composed of well-rounded, highly spherical, sand-sized grains of volcanic rock, scoriae and glass (Figure 5A). Angular crystals of diopside are also common, and are associated with rare crystals of plagioclase, sanidine, biotite and garnet.

Ceramic-rich floors

This type of plaster is characterised by an aggregate composed of angular, medium to fine sand-sized fragments of grog (Figure 5B). Two types of grog were identified, closely matching those observed in the *cocciopesto*. The fragments are embedded in a spotted matrix composed of cryptocrystalline calcite and hydrated calcium silico-aluminates, with a HI of between 0.10-0.17.

A finishing layer was also observed in two of the floor samples, characterised by a micrite-like calcite matrix with a low HI (0.01-0.07), an aggregate:binder ratio of 1.5:1-1:1, and aggregate composed of predominant spathic crystals of calcite and subordinate rounded fragments of micritic limestone.

Hydraulic Structure

Within the conduit, well and cistern samples, two types of plaster were identified, one rich in volcanic scoriae and one characterised by grog (Table 4, Figure 5C,D). These mortars show strong textural and compositional similarities to those used in the construction of the floors, but they have a higher HI. Both types of plaster were used for both preparatory and finishing layers in the hydraulic structures. However, volcanic scoria-rich plaster was used more frequently for preparatory layers, and ceramic-rich plaster mostly, but not exclusively, for the finishing layers.

Hydraulic structure			
		Volcanic scoria-rich h.s.	Ceramic-rich h.s.
Aggregate	Aggregate to Binder	About 1.5:1	About 1:1
	Grain size	From pebbles to coarse silt	From pebbles to coarse silt
	Main fractions	Coarse to medium sand	Medium to fine sand
	Sphericity	High to medium	Medium to low
	Roudness	VS and VRF: well rounded to rounded grains. Cpx and Bt: sub-angular to angular	Angular to sub-angular
	Distribution	Homogeneous	Homogeneous
Matrix	Matrix	Spotted	Spotted
	Hydraulicity Index (HI)	From 0.59 to 2.68	From 0.22 to 2.31

Table 4. Table 4. Plaster features in hydraulic structures. Abbreviations as in Table 1.

Raw Materials and Technology

Binders

Petrographic analysis of the various mortar-based building materials from the Temple of Venus revealed that they have a lime-based matrix. Hydraulicity index values and the micrite-like (Figure 5E) vs. spotted (Figure 5F) microscopic aspect of the matrix suggest differing contents of hydrated calcium silico-aluminates, implying either the use of a lime prepared from impure limestone, or pure lime which underwent hydraulic reactions with a pozzolanic aggregate. The use of impure limestone in the preparation of the mortars is not supported by chemical analysis of the lime lumps, which generally have a high degree of purity and low chemical variability, with very low HI values (c. 0.02), even when they are found in mortars with a spotted matrix and high HI, suggesting that pure limestone was selected and ignited to produce lime. Pozzolanic aggregates such as those containing volcanic scoriae, volcanic glass and ground fragments of ceramic materials (Elsen, 2006) must therefore have been involved in hydraulic reactions. Lime lumps in hydraulic structures have higher HI, with values between 0.08 and 0.27, indicating that true hydraulic lime was probably used only to construct these architectural features. The use of pure lime in most of the applications is also confirmed by the observation that mortars with a carbonate aggregate such as *marmorino* and the carbonate layers of floors always have a micrite-like matrix with low HI (< 0.07), whereas samples from hydraulic structures always have a spotted matrix and high HI values (> 0.22).

The systematic differences observed in the matrix of *cocciopesto intonaco* and ceramic-rich floors (i.e., spotted matrix and high HI vs. micrite-like matrix and relatively low HI, respectively), may be related to the grain size of the aggregate, the former including the fine-grained fraction which was hydraulically reacted with lime, and the latter the sifted coarse-grained fraction, thus giving rise to the different chromatic effects.

All the other types of mortars show very variable HI, suggesting that varying amounts of the fine-grained pozzolanic fraction were originally present in the raw material used as aggregate, rather than being added intentionally to modulate hydraulicity.

The occurrence of lime lumps in a large number of samples indicates that some of the lime often did not react completely with water during slaking or with atmospheric CO_2 after application (Hughes *et al.*, 2001). This provides strong evidence that lime, water and aggregate were mixed without due attention, perhaps because of workers' lack of technological skills or acceptance by buyers of such wares.

Aggregates

The composition of aggregates in the mortar samples shows that three types of filler were commonly used: volcanic rock, grog, and carbonate rock. The mineralogy and petrography of the volcanic aggregate is compatible with the products of the Somma-Vesuvius volcano (Santacroce, 1987) and matches the composition of beach sands collected from the Vesuvian area, suggesting that local materials was used for the aggregate. Differences in the composition of the volcanic aggregate in volcanic scoria-rich *arriccio* and clinopyroxene-rich *arriccio* may be due to differing sources of local sand.

Petrographic analysis of the grog inclusions in the crushed ceramic plaster (*cocciopesto*) suggests that the two types of ceramic were used indiscriminately. The presence of volcanic inclusions compatible with the Somma-Vesuvius complex in one type of grog, and the quartz and feldspar inclusions in the other, suggests that both locally produced and imported ceramics were used as fillers.

The carbonate-bearing plasters contain filler composed of euhedral spathic crystals of calcite. This material may have been ground from crystalline calcite veins occurring in limestone. As such, its origin is not easy to determine.

Conclusions

Archaeometric study of mortar-based building materials from the Temple of Venus at Pompeii has permitted several distinct mortar recipes to be identified, characterised by their microstratigraphy, petrographic features of the aggregate, and their matrix. These various types were deliberately prepared for specific applications, due to their different hydraulicity, or for aesthetic purposes. *Cocciopesto* plaster containing crushed ceramic was used in hydraulic structures, perhaps because of its superior hydraulic performance with respect to other types of plaster. It may have been used as *intonaco* on walls, due to its warm hues and resistance to damp.

The recipes used to construct the various mortar-based features at the Temple of Venus remained constant from the 4th century BC to the 1st century AD, suggesting the persistence of technological tradition (Table 1).

The ubiquitous presence of grains of volcanic origin, consistent with the volcaniclastic deposits of Somma-Vesuvius in many different types of plaster, clearly indicates that the raw materials were local in origin, probably alluvial or beach deposits in the Vesuvian area. The small grain size, high sphericity and roundness of the volcanic aggregate in many samples indicate great standardisation in the selection of the raw materials, which were probably quarried from identified sources as early as the 4th century BC.

Mortars used in hydraulic structures, in which specific performance was required, or on surfaces with specific aesthetic features such as *intonachino*, *cocciopesto*, *marmorino* and ceramic-rich floors, were produced by careful mixing of good-quality raw materials, and generally display relatively homogeneous textural features and hydraulicity. Other mortars, such as those used in *arriccio* and volcanic scoria-rich floors, generally covered by a finer finishing layer and a floor decoration (i.e., *opus signinum*), display greater variability in aggregate grain-size distribution, microscopic aspect of the matrix (i.e., micrite-like vs. spotted) and HI, suggesting that less attention was paid to their preparation. The finding of lime lumps in all types of mortars suggests that production was not sufficiently checked or that skilled workers were not readily available.

As regards the *marmorino* filler, the occurrence of carbonate sequences of pure limestone outcropping near Pompeii (Figure 2) indicates that these raw materials were locally available, although specific provenance markers are missing.

Acknowledgements

The authors are grateful to the staff of the Institute of Geosciences and Georesources, CNR, Padova, for their analytical support, and to G. Walton, who revised the English text.

References

Boyton, R.S. 1966. *Chemistry and technology of lime and limestone*. 2nd edition. John Wiley & Sons Inc., New York.

Charola, A.E. and Henriques, F.M.A. 2000. Hydraulicity in lime mortars revisited. In: Bartos, P., Groot, C. and Hughes, J.J. (Eds.) *Proceedings of the International RILEM-workshop "Historic Mortars: Characteristics and Tests", Paisley, 2000,* RILEM Publications: 5-105.

Curti, E. 2008. Il tempio di Venere Fisica e il porto di Pompei? In: Guzzo, P.G. and Guidobaldi, M.P. (Eds.) *Nuove ricerche archeologiche nell'area vesuviana (scavi 2003-2006)", Roma*: 47-60.

Curti, E. 2007. La Venere Fisica trionfante: un nuovo ciclo di iscrizioni dal santuario di Venere a Pompei. In: *Il filo e le perle. Studi per i 70 anni di Mario Torelli*, Venosa: 57-71.

Elsen, J. 2006. Microscopy of historic mortars – a review. *Cement and Concrete Research*, 36:1416-1424.

Hughes, J.J., Leslie, A. and Callebaut, K. 2001. The petrography of lime inclusions in historic lime based mortars. In: *Proceedings of the 8th Euroseminar on Microscopy Applied to Building Materials. Athens, Greece, September 2001*: 359-364.

Mora, P., Mora, L. and Philippot, P. 1984. *Conservation of wall paintings*, Butterworth & Co., London.

Prentice, J. E. 1990. *Geology of construction materials*, Chapman and Hall, London.

Revellino, R., Hungr, O., Guadagno, F.M., Evans, S.G. 2004. Velocity and runout simulation of destructive debris flows and debris avalanches in pyroclastic deposits, Campania region, Italy. *Environmental Geology*, 45:295-311.

Santacroce, R. (Ed.) 1987. *Somma-Vesuvius, Quaderni de "La Ricerca Scientifica"*. Progetto finanziato "Geodinamica". Monografie finali, 8. CNR Roma.

UNI EN 11176. 2006. *Cultural Heritage - Petrographic description of a mortar.* Milano.

Vitruvius, P. 1999. *The ten books on architecture*. I.D. Rowland trans., Cambridge University Press.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology*, 30: 377-392.