EVALUATION OF MORTAR MICROSTRUCTURES IN ANCIENT ROMAN CONCRETE FROM OSTIA, ITALY, WITH **PETROG** SOFTWARE

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ABSTRACT

The ancient city of Ostia, at the mouth of the Tiber River 15 km downstream from Rome, is built mainly of brick-faced conglomeratic concrete structures that have remained largely intact for nearly 2000 years. Petrographic evaluation of volcanic ash–hydrated lime mortars from seven second century CE structures provides new insights into the builders' selection of pozzolans and processing of lime and ash. PETROG software facilitated modal analyses of point counts through creation of a systematic catalog of diverse pozzolanic and cementitious microstructures, and a high resolution optical image of each point. A primary classification of each site was logged in the searchable PETROG database as pozzolanic aggregate, cementitious phase, or void space and further qualified in the software database with additional information. For aggregate, this includes lithological provenance of ash from the Roman volcanic province, authigenic clay or zeolitic surface textures, primary crystal fragments, and characteristics of ceramic fragments. For cementitious phases, this includes characteristics of the cementitious matrix and optical properties of discrete cementitious textures. For lime, calcite textures and purity of masses of relict putty were recorded and, for voids, the geometry of cracks, spherical, and sub-rounded spaces. The high level of detail recorded at each point allows in depth analysis of each specimen and quantifies comparisons among samples beyond what is possible with standard petrographic assessments. Results from modal analysis suggest three distinct mix designs containing zeolites and/or authigenic clays that functioned as natural pozzolans. Variations in these mixes represent specific technical decisions made by ancient builders. The empirical reasoning behind these decisions is an important but rarely explored area of archaeological research. Petrographic analysis with PETROG software has lead to a better understanding of the construction industry in ancient Ostia by quantifying preferred or proprietary mixes apparently used by different groups of builders.

INTRODUCTION

The archaeological site at Ostia, Italy, located on the west coast of central Italy, approximately 15 km from Rome at the mouth of the Tiber River, provides a unique opportunity to study ancient mortar technology in both qualitative and quantitative terms. The city is built of mainly brick-faced conglomeratic concrete structures, many of which have been standing since the first and second centuries CE. The fact that so many of these structures are still intact, and in some cases sufficiently robust to support usable upper floors, is a testament to the quality of construction and skill of the ancient builders. The large number of concrete structures makes the city an ideal laboratory for studying the use and production of ancient mortar and concrete on a city-wide scale.

In the last 40 years, microscopic analysis has become an indispensable tool in evaluation of both modern and historic mortars.(1) Optical microscopy of mortar fragments allows for preliminary descriptions of many different features including the type and quality of the cementitious matrix; the current condition of the mortar; the type, size, and abundance of aggregate inclusions; and the presence or absence of pozzolans.(2-3) Old mortars benefit from detailed microstructural analysis in the same ways that modern concretes do, and the RILEM TC 165-COM technical committee has prescribed various petrographic and microscopic analytical techniques, especially when building conservation is concerned.(4) Detailed thin section analysis with the petrographic microscope can reveal ~~more~~ specific information about the nature and microstructure of mortar components, the presence of angular or spherical voids and cracks, the degree and causes of degradation, and the integrity of the bond at the interface between matrix and aggregate.(5-7) When the original production processes are little understood or completely unknown, quantified compositional data can help identify the original material selection and mixing and installation techniques. However, historic mortars require a careful distinction between primary and secondary cementious phases.(8) Modal analysis through point counting of thin sections quantifies the abundance of diverse mortar components and also provides qualifying descriptions that illustrate processes of mortar preparation, installation, and weathering over time.(9) Point counting can be a tedious and time consuming process, even with mechanical automatic stage steppers, but the data generated are vital to the accurate assessmen of historic mortar samples.

As noted above, traditional studies of historic mortar commonly include petrographic methods to describe the samples and to identify the geologic components of a mortar mix. Rarely, however, do these studies address the more profound archaeological issues regarding the specific behaviour and methods of ancient builders and the construction industry in which they were involved. This research project introduces a more explicitly archaeological study to specifically address those issues. The methods presented here apply microscopic analysis to samples from ancient brick-faced masonry structures, in an attempt to go beyond simple descriptions of mortar compositions in order to provide richer information about ancient mortar production and the construction industry as a whole in ancient Ostia. Variations in mortar durability and mix design represent specific technical decisions made by ancient builders throughout the mortar production and installation process, and evaluating these decisions can provide clues about the intent and expertise of these individuals.(10) Further, they provide a basis for exploring the decision processes of ancient builders that can lead to a better understanding of the complexity of ancient construction industries worldwide.

The PETROG system developed by Conwy Valley Systems simplifies and automates the entire point counting process, allowing for rapid, systematic data collection. The system includes a motorized stepping stage (the "MicroStepper"), which attaches to the rotary stage of a polarizing microscope and is powered by an external control box (Figure 1-2). The MicroStepper is digitally controlled by the PETROG software, which allows the petrographer to record detailed information at each point. Data are recorded as items within a primary classification, with more specific sub-level qualifiers added to improve detail. Data classes and specific items are incorporated into the software's user-interface as selectable tick lists, which call up the additional qualifier lists when third or fourth levels of data are required (Figure 3). As with other automated point counting hardware, after each point is recorded the stage moves in a pre-set increment to ensure regulated advancement across the sample. The PETROG software, however, also records and tracks the x-y coordinate for each point, allowing the user to easily stop and restart the counting process or relocate specific points of interest. When a camera is attached, high resolution digital images are displayed on the computer monitor within the data collection interface and a photomicrograph is automatically collected at each point.

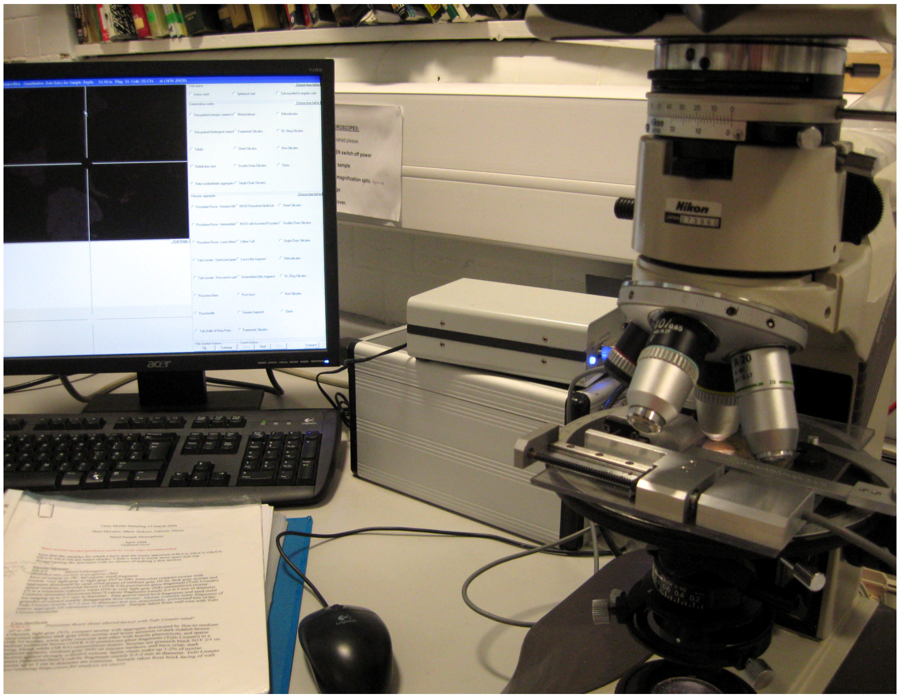

Figure 1: PETROG system set-up during point count, showing MicroStepper, control box, and software data entry screen.

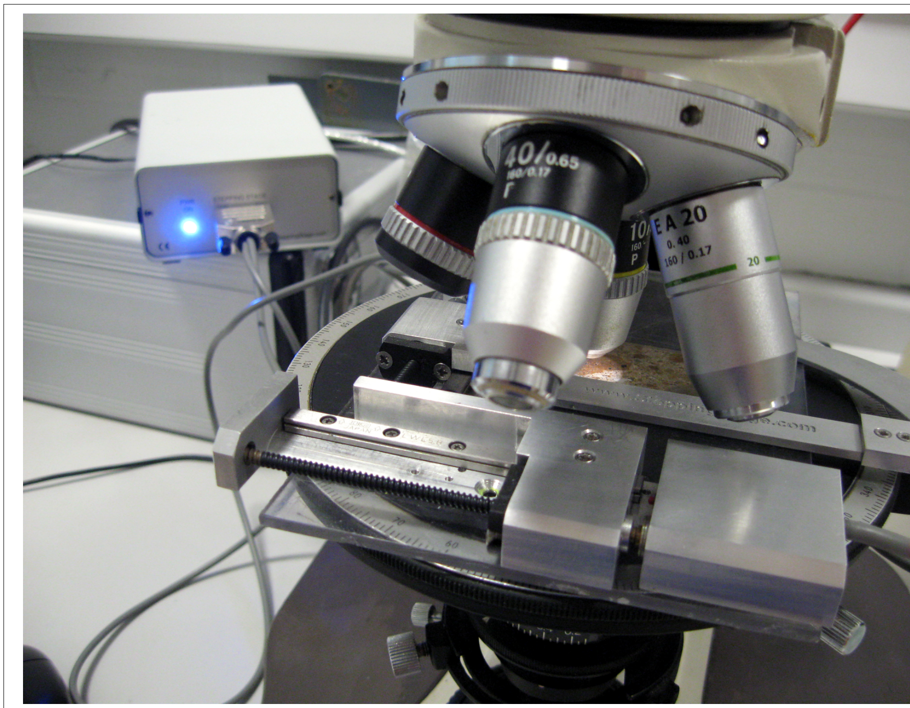

Figure 2: Detail of MicroStepper attached to microscope stage.

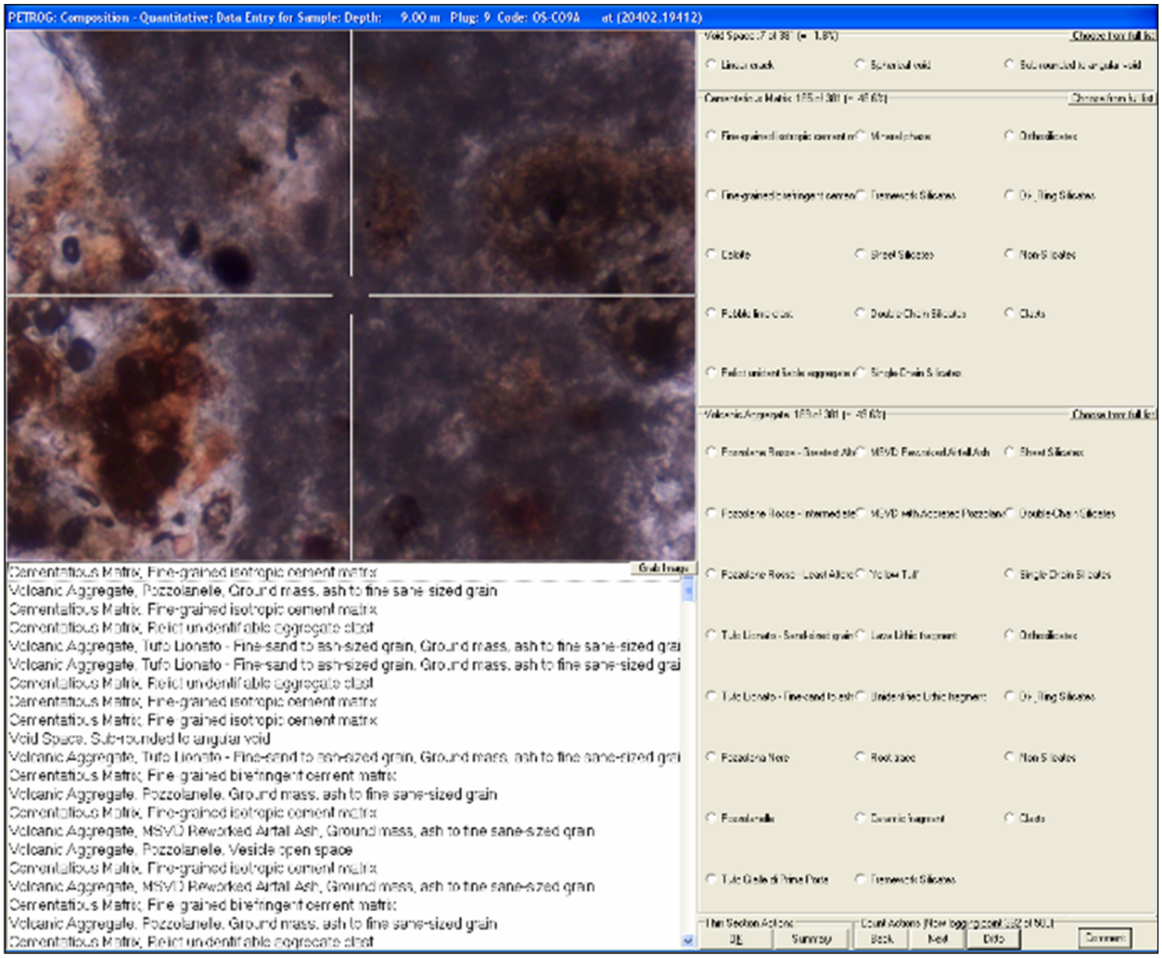

Figure 3: Computer screen shot of point count in progress showing PETROG software data collection interface, including tick lists, live video image, and previously recorded points.

The PETROG system facilitates the collection of far more information at each point than traditional automatic point counters, which generally allow up to 20 individual data classes in an analogue device. The software makes it possible not only to quantify the basic mortar components, but also to record a greater number of observational features, such as textural information, structural relationships, and alteration or degradation features in addition to the standard identification of compositional components. All information is stored in a database, and reports can be exported for data comparison and analysis. Analytical tools within PETROG create simple pie charts to visualise the volume percentage of the primary data classes in, for example, a three term ratio of Void Space:Cementitious Matrix:Aggregate. Simple descriptive statistics allow for quick and easy preliminary comparisons between samples. Ternary graphs can be generated from user-selected data to compare specific features or types of qualifying data, such as proportions of different types of aggregate within each sample, different alteration facies of a single lithology, or even the different types of voids. With this information it is possible to model compositional variations in the original mortar mix designs. Although one of the objectives in this project is to illuminate the choices made by the ancient builders, this alone is not the most important aspect of this research. The archaeo-historical perspective seeks to potentially understand why such choices were made. The combination of a rich data set and robust tools for data analysis provided by the PETROG system creates an opportunity for these complex data investigations.

METHODS

Seven structures built between 117 CE and 160 CE were included in this research. These particular structures were chosen because they are representative of the different types of brick-faced concrete structures built in the Hadrianic period, a time when the technology had become widespread throughout Ostia (Figure 4). The sample suite included a private domestic property (*Casa Basilicale*); several large mixed commercial and residential complexes (*Casa a Giardino*, *Caseggiato del Larario*, *Caseggiato del Serapide*, *Insula dell'Ercole Bambino*); a public bath house (*Terme del Foro*); and a commercial storage warehouse (*Piccolo Mercato*). This particular group represents both small and large-scale construction projects undertaken by the multiple groups of builders identified by J. DeLaine's research into these structures.(11) Samples from both the mortar facing and concrete core of each structure were collected for detailed petrographic analysis in order to assess their material properties and to identify mortar components. The information gleaned from this study was intended to help illuminate the original mortar production and installation techniques chosen by the ancient builders.

Figure 4: Seven ancient brick-and-mortar conglomeratic concrete structures in Ostia, Italy.

The initial examination of hand samples included visual assessment with a stereomicroscope to identify pozzolanic aggregates at the macroscale and to describe the surface textures of the mortar fragments. Preliminary investigation of two thin sections per structure confirmed the various types of aggregate present in each sample and the degree of ~~obvious~~

degradation and disaggregation within each sample. The apparent density of and extent of carbonation of the cementitious matrix were also recorded.

A Nikon Optiphot 2 polarizing microscope was used for all thin section analyses, and the MicroStepper was attached to the stage while point counting. Preliminary thin section investigation revealed that pozzolanic aggregate particles in all the samples varied from several centimeters to sub-millimeter in size. It was therefore necessary to calibrate the stepping stage to move at an interval that included as many of the smaller particles as possible without over-representing the larger clasts. Because the average particle size was approximately 1 mm, a step size of 1.000 mm was chosen for each count. The 10X objective lens was used for all point counting. A PixeLink CMOS microscope camera was attached to the microscope to display a live video of the microscope field of view and collect high resolution digital images as each point was counted and recorded. Points were identified in the centre of the image under cross hairs on the computer video display. The target count was between 500 and 600 points, and each point count took between four and six hours to complete.

The PETROG software required each point to be categorized as one of three primary data classes with at least one sub-level of additional qualifying information. The data classes and qualifiers defined during preliminary thin section investigation were coded into the PETROG concrete database prior to data collection by Ricki Walker of Conwy Valley Systems. Primary classes, individual items, and qualifying descriptors appeared in the software user-interface as selectable tick lists along with various mineral classifications that appear in PETROG's standard list (Figure 5). A total of 398 possible classifications were available to select at each point, and further qualifying data or additional notes were appended as needed.

The Void Space class included item options for linear cracks, spherical voids, and sub-rounded to angular voids. These features were recorded separately because they provide different types of clues to the original mortar preparation and current degree of degradation. Linear cracks can indicate mortar shrinkage, structural damage, or other post-installation deterioration of the mortar. Spherical voids, on the other hand, may suggest air entrainment or the presence of excess free water during mortar production, which would indicate new and important information about the methods used by ancient builders. Large, irregularly shaped voids could be the result of air bubbles entrapped in the cementitious matrix due to flaws in compaction, material loss or leaching over the life of the sample, or artefacts from thin section preparation.

Items recorded in the Cementitious Matrix class were categorized as isotropic cement matrix, birefringent cement matrix, calcite crystals, mineral phases, or pebble lime clasts. Relict aggregate fragments that were too small to confidently identify lithologic provenance were also included in this class. The optical properties of the cementitious matrix were noted to record the variation between isotropic and birefringent cements both in the matrix and in voids.

Volcanic aggregate lithologies were provisionally identified during initial stereoscope analysis of samples and thin section investigations. Previous work completed on similar mortar samples from Rome was used for reference in identifying potential lithologies.(12) Given that Ostia lies only 15 km distant from the City, builders hypothetically would have used the same types of material. Various lithologies were included as item selections within the Volcanic Aggregate class, with additional petrographic features also recorded as sub-level qualifiers. Points within lithic aggregate fragments were identified as either volcanic groundmass, authigenic material within vesicles or on grain edges, primary mineral grains, or vesicle open space. Additional types of inclusions, such as ceramic fragments and unidentified lithic fragments, also were recorded.

Figure 5: Detail of PETROG data entry user-interface, showing tick lists.

PETROG automatically collected photomicrographs at each point as classification data were selected from the tick lists and before the MicroStepper advanced. The images constitute a valuable documentation of the entire data set of mortar fabrics (Figure 6). All images were labelled with the X-Y coordinates , providing an easy reference for all features.

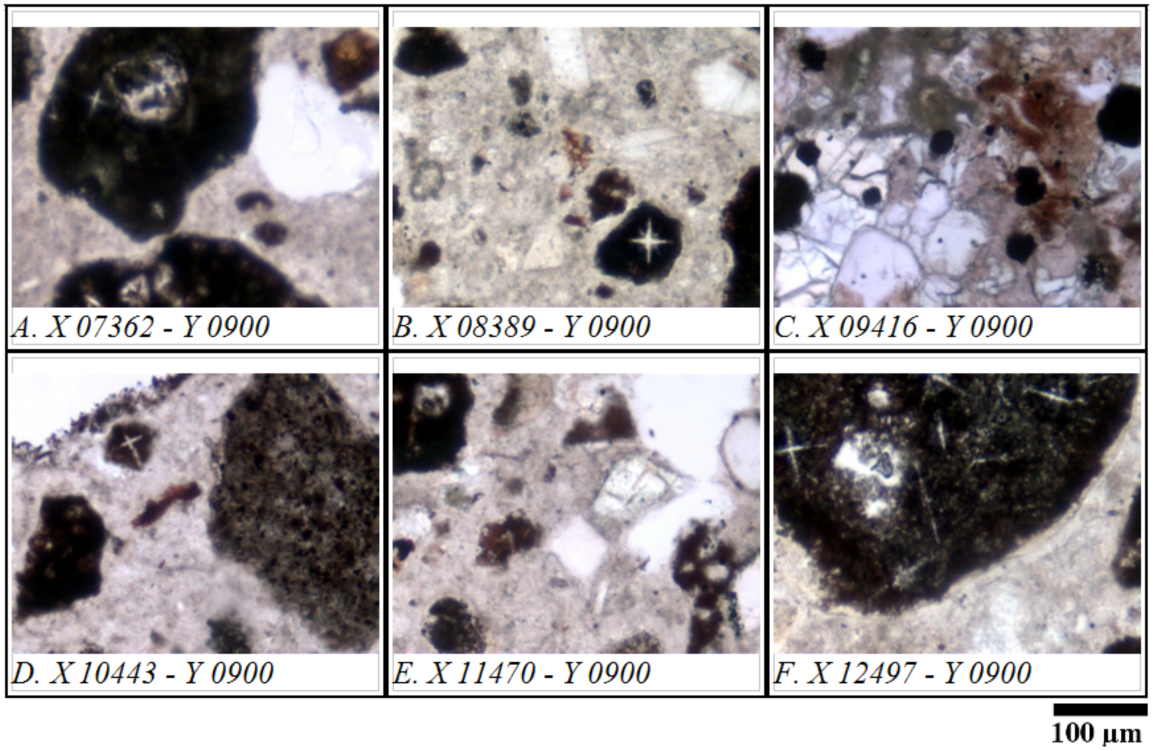

Figure 6: A- F. Successive photomicrographs automatically captured during a single transect across thin section, showing variations in the cementitious matrix, void spaces, and aggregate size and texture.

RESULTS

Table 1 illustrates the type of data recorded and reported as volume percentages by PETROG. Thin section analysis and point counting with the PETROG system revealed three distinct mortar mix designs within the sample collection. Although all samples contain multiple types of pyroclastic volcanic materials, each mix mortar type displayed a dominant aggregate material derived from specific eruptive units within the Roman Volcanic Province.(15) The most common material was excavated from zeolitized pyroclastic flows from the nearby Colli Albani volcanic district and associated epiclastic deposits. Pyroclastic rocks from the Monti Sabatini volcanic district north of Rome were present in much smaller quantities. The selection and use of material rich in zeolites and clays is significant because they contribute~~d~~ to pozzolanic reactions within the mortars, producing durable cementitious phases and thus increasing the long-term cohesion of the concretes strength and durability.(13) The presence of these types of materials suggests an empirical understanding of the behaviour of various pozzolanic components and builders' deliberate selections of aggregate materials. No discernible differences were found in the composition of mortars in the brick facing and the conglomeratic cores of the concrete structures.

Table 1: Data report exported from PETROG, including Classes, Items, and Qualifiers.

PETROG: Edit Composition - Quantitative;			Well: Mortars; Depth: 1.00 m Plug: 17 Code: OS-C17	READ ONLY
Or.%	Ed.%	Class 1	Item level 1	Qual. level 1
0.2	0.2	Cementatious Matrix	Biotite	
0.4	0.4	Cementatious Matrix	Calcite	
0.2	0.2	Cementatious Matrix	Calcium Pyroxenes	Dissolving
1.4	1.4	Cementatious Matrix	Calcium Pyroxenes	Etched/pitted
0.2	0.2	Cementatious Matrix	Calcium Pyroxenes	Fresh
0.2	0.2	Cementatious Matrix	Calcium Pyroxenes	Wholly replaced by analcime
0.2	0.2	Cementatious Matrix	Calcium Pyroxenes	Wholly replaced by halloysite
0.4	0.4	Cementatious Matrix	Fine-grained birefringent cement matrix	
4.4	4.4	Cementatious Matrix	Fine-grained birefringent cement matrix	
13.6	13.6	Cementatious Matrix	Fine-grained birefringent cement matrix	
1	1	Cementatious Matrix	Fine-grained isotropic cement matrix	
6.2	6.2	Cementatious Matrix	Fine-grained isotropic cement matrix	
0.2	0.2	Cementatious Matrix	Framework Silicates	Wholly replaced by analcime
0.4	0.4	Cementatious Matrix	Leucite	Etched/pitted
0.6	0.6	Cementatious Matrix	Leucite	Wholly replaced by analcime
0.2	0.2	Cementatious Matrix	Leucite	Wholly replaced by halloysite
0.2	0.2	Cementatious Matrix	Leucite	
0.2	0.2	Cementatious Matrix	Opal	Fresh
0.4	0.4	Cementatious Matrix	Pebble lime clast	
0.2	0.2	Cementatious Matrix	Relict unidentifiable aggregate clast	Undifferentiated
1	1	Cementatious Matrix	Relict unidentifiable aggregate clast	
6.4	6.4	Cementatious Matrix	Relict unidentifiable aggregate clast	
0.2	0.2	Cementatious Matrix	Sheet Silicates	Wholly replaced by halloysite
0.2	0.2	Void Space	Linear crack	
0.4	0.4	Void Space	Spherical void	
0.2	0.2	Void Space	Sub-rounded to angular void	
2	2	Void Space	Sub-rounded to angular void	
0.2	0.2	Volcanic Aggregate	Ceramic fragment	
0.4	0.4	Volcanic Aggregate	Ceramic fragment	
0.2	0.2	Volcanic Aggregate	Lava Lithic fragment	
0.2	0.2	Volcanic Aggregate	Leucite	Wholly replaced by analcime
0.6	0.6	Volcanic Aggregate	Pozzolana Nere	Ground mass, ash to fine sane-sized grain
2.8	2.8	Volcanic Aggregate	Pozzolana Nere	Ground mass, ash to fine sane-sized grain
1	1	Volcanic Aggregate	Pozzolana Nere	Ground mass, sand-sized grain
0.4	0.4	Volcanic Aggregate	Pozzolana Nere	Mineral Phase
0.2	0.2	Volcanic Aggregate	Pozzolane Rosse - Greatest Alteration Facies	Cement filling
0.8	0.8	Volcanic Aggregate	Pozzolane Rosse - Greatest Alteration Facies	Ground mass, ash to fine sane-sized grain
2.8	2.8	Volcanic Aggregate	Pozzolane Rosse - Greatest Alteration Facies	Ground mass, ash to fine sane-sized grain
0.6	0.6	Volcanic Aggregate	Pozzolane Rosse - Greatest Alteration Facies	Ground mass, sand-sized grain
1.6	1.6	Volcanic Aggregate	Pozzolane Rosse - Greatest Alteration Facies	Ground mass, sand-sized grain
0.4	0.4	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Authigenic Surface coating (vesicles)
0.2	0.2	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Ground mass, ash to fine sane-sized grain
0.6	0.6	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Ground mass, ash to fine sane-sized grain
3	3	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Ground mass, ash to fine sane-sized grain
0.8	0.8	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Ground mass, sand-sized grain
2.6	2.6	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Ground mass, sand-sized grain
0.2	0.2	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Mineral Phase
0.2	0.2	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Vesicle open space
0.6	0.6	Volcanic Aggregate	Pozzolane Rosse - Intermediate Alteration Facies	Vesicle open space
0.6	0.6	Volcanic Aggregate	Pozzolane Rosse - Least Altered Facies	Ground mass, ash to fine sane-sized grain
2.4	2.4	Volcanic Aggregate	Pozzolane Rosse - Least Altered Facies	Ground mass, ash to fine sane-sized grain
0.4	0.4	Volcanic Aggregate	Pozzolane Rosse - Least Altered Facies	Ground mass, sand-sized grain
0.8	0.8	Volcanic Aggregate	Pozzolane Rosse - Least Altered Facies	Ground mass, sand-sized grain
0.2	0.2	Volcanic Aggregate	Pozzolane Rosse - Least Altered Facies	Mineral Phase
0.4	0.4	Volcanic Aggregate	Pozzolanelle	Cement filling
0.4	0.4	Volcanic Aggregate	Pozzolanelle	Ground mass, ash to fine sane-sized grain
3.8	3.8	Volcanic Aggregate	Pozzolanelle	Ground mass, ash to fine sane-sized grain
0.4	0.4	Volcanic Aggregate	Pozzolanelle	Ground mass, sand-sized grain
2.2	2.2	Volcanic Aggregate	Pozzolanelle	Ground mass, sand-sized grain
8.6	8.6	Volcanic Aggregate	Pozzolanelle	Ground mass, sand-sized grain
0.4	0.4	Volcanic Aggregate	Pozzolanelle	Indeterminate filling
0.2	0.2	Volcanic Aggregate	Pozzolanelle	Mineral Phase
0.2	0.2	Volcanic Aggregate	Pozzolanelle	Vesicle open space
0.8	0.8	Volcanic Aggregate	Pozzolanelle	Vesicle open space
2.8	2.8	Volcanic Aggregate	Pozzolanelle	Vesicle open space
0.2	0.2	Volcanic Aggregate	Pozzolanelle	
1.2	1.2	Volcanic Aggregate	Tufo Lionato - Fine-sand to ash-sized grain	Ground mass, ash to fine sane-sized grain
5	5	Volcanic Aggregate	Tufo Lionato - Fine-sand to ash-sized grain	Ground mass, ash to fine sane-sized grain
0.2	0.2	Volcanic Aggregate	Tufo Lionato - Fine-sand to ash-sized grain	Ground mass, sand-sized grain
0.2	0.2	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Authigenic Surface coating (vesicles)
0.2	0.2	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Cement filling
0.4	0.4	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Ground mass, ash to fine sane-sized grain
0.2	0.2	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Ground mass, sand-sized grain
0.6	0.6	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Ground mass, sand-sized grain
3.2	3.2	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Ground mass, sand-sized grain
0.4	0.4	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Indeterminate filling
0.2	0.2	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Undifferentiated
0.2	0.2	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	Vesicle open space
0.2	0.2	Volcanic Aggregate	Tufo Lionato - Sand-sized grain	
0.6	0.6	Volcanic Aggregate	Unidentified Lithic fragment	Ground mass, ash to fine sane-sized grain
0.2	0.2	Volcanic Aggregate	Unidentified Lithic fragment	Ground mass, sand-sized grain
0.4	0.4	Volcanic Aggregate	Unidentified Lithic fragment	Mineral Phase
0.2	0.2	Volcanic Aggregate	Unidentified Lithic fragment	
100	100			

The point counts suggest three types of mortar, based on dominant aggregate types: 1) Pozzolane Rosse dominated mortar; 2) Tufo Lionato and Pozzolanelle dominated (two types of material from a single Villa Senni eruption of Colli Albani); and 3) no single strongly dominant lithology, but the material shows an abundance of autigenic clays and erosional textures, suggesting the aggregate is epiclastic in nature. The group of Pozzolane Rosse dominated mortar (*Piccolo Mercato*, *Casa Basilicale*, and *Insula dell'Ercole Bambino*) roughly aligns with a group of buildings that DeLaine believes were probably built by the same group of builders.(11) The mortar with the epiclastic material is present in two structures that happen to be the largest buildings in the study, *Casa a Giardino* and *Terme del Foro*. The third group with the Villa Senni dominated mortar, *Caseggiato del Larario* and *Caseggiato del Serapide,* have no obviously clear connection based on structure type, specific age, size, or location within the city. They do share certain structural elements and brick types, which suggests they too may have been built or designed by the same builders.

All mortar samples contain fibrous calcium-aluminum-silicate-hydrate phases that apparently formed through cementitious processes within the vesicles of volcanic clasts or voids in the cementitious matrix. These microstructures indicate firm bonding of pozzolanic aggregate within the mortar, and reduction of porosity over time. They provide firm−evidence for the builders' selections of high quality pozzolanic aggregates and the sophistication of mortar production and installation methods in ancient Ostia. Similarly, many samples show fibrous cementitious phases spanning or even filling cracks in the cementitious matrix, providing evidence of self-healing over long periods of time. Fibrous cementious phases were visible in all thin sections but were not necessarily included in all point counts because the cross hairs may not have centred upon these very fine-grained microstructures. This discrepancy underscores the ~~need~~ importance of qualitative microstructural descriptions alongside quantitative modal analysis to achieve the most informative and accurate result.

DISCUSSION

Precise microstructural analyses of thin sections of the Ostia mortar samples has made it possible to evaluate the different mortar types in terms of ~~the~~ quality of production, durability of the final product and, perhaps, the skill of individual Roman builders. The fact that the three predominant mortar types are so clearly distinct is quite interesting. All three types are of equal empirical quality and have performed to the same standard, and we would like to know more about why there are such clear differences among their aggregate compositions and microstructural characteristics. It is possible, for example, sociocultural or personal reasoning governed these varied choices, rather than rigorous technical or mechanical standards. This may have been as simple as preferred or proprietary mixes used by specific groups of builders, which could possibly suggest a complex organization of supply lines of lime and pyroclastic rock building materials.

Great care was taken to distinguish between the microstructures that developed during initial hydration and those that formed during subsequent alteration and degradation. With these observations, it was possible to consider how the various mix designs may have directed those changes. For example, the predominantly epiclastic mortar samples from the bathhouse (*Terme del Foro*) contained unique features that indicated this mortar has performed – and was produced – rather differently than the others. This mortar showed the greatest evidence of dissolution and redeposition of components of the cementitious matrix, in particular, unusually high concentrations of calcite-rich material along the rims of spherical voids and in cracks. This mortar contained the greatest abundance of large pebble lime clasts, suggesting a higher proportion of under-slaked or poorly-hydrated lime.(14) If these features were simply a result of the mortar mix design, then other samples with epiclastic material should exhibit the same qualities. The data analysis, however, showed this was not the case. Instead, it seems that the heat and humidity that permeated the walls of the bathhouse caused mobilization of cementitious hydrates during the active life of the building. This is the kind of information that is required to determine the specific conditions that contributed to mortar durability or degradation within individual structures.

The mortars of several structures are quite similar to the standardized imperial era formulation described in contemporary structures in Rome; these have similar aggregate profiles derived from the Pozzolane Rosse pyroclastic flow and aluminous cementation hydration products.(15-16) These parallels suggest potential connections between the local building economies of both cities. Comparison of the Ostian mortars with those from Rome suggests broad regional patterns of a shared technology, which may have gone unnoticed without rigorous and highly detailed petrographic analysis.

CONCLUSION

The highly refined database structure inherent to the PETROG software provides an innovative framework for collecting far more microstructural and compositional information than is possible with a traditional point counting device. With nearly 400 data classifications available for quick selection, the software far outstrips the performance of 10-, 12-, or even 20-channel point counters. A vast amount of data can be collected swiftly, easily, and with rigorous standards. The photomicrographs captured at every point simplify the illustration of mortar components and microstructural features. The comprehensive data set facilitated a deeper exploration into mortar preparation techniques in ancient Ostia than would be possible with traditional microscopic analysis. These data make possible the careful characterization of mortar fabrics, descriptions of the activities of the individuals who produced the mortars, and the extent of their technical expertise, which leads to questions about why certain builders made specific technological choices.

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