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Petrographic Examination of Plaster from the Umayyad Aqueduct to Ramla

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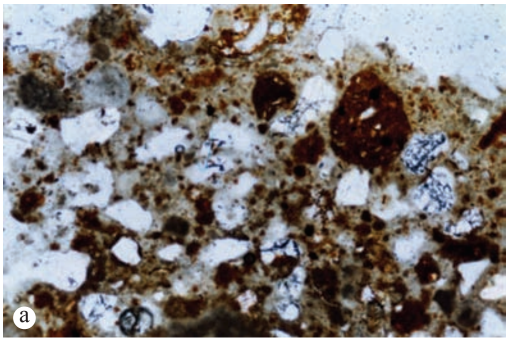
The petrographic and mineralogical composition of the multi-layered plaster from the Gezer–Ramla aqueduct (see Gorzalczany, this volume) was analyzed to identify its composition and phases of application, as well as to assess the presence of secondary deposition features. The excavator, Amir Gorzalczany, distinguished two plastering episodes: the earlier pink plaster covered the whole inner surface of the aqueduct; the second episode consisted of dark gray plaster applied over the same surfaces, with the addition of a fill of light gray mortar in the angles formed by the sides and floor of the channel. The mortar was covered by a third, thin coat of whitish rendering, above which was a thin “travertine-like” surface.

A wedge-shaped specimen of the plaster, measuring about 10 cm in height and width and 3 cm in thickness, was taken from the edge of the floor of the aqueduct (see Gorzalczany, this volume: Plan 2; Fig. 7). Two samples were prepared for petrographic analysis: Sample 1 (c. 3 cm thick) was chipped from the pinkish plaster at the edge of the triangular specimen (nearest the side and floor of the channel); Sample 2 (c. 5 cm thick) was retrieved from the core of the specimen. In general, the plaster’s cross-section shows the following sequence from bottom to top (not including an underlying bed of large ceramic sherds): (1) pinkish plaster; (2) dark-gray plaster; (3) gray infill; (4) white plaster; and (5) burnished or travertine-like layer.

Petrographic thin sections were prepared by slicing and polishing a slide to 0.03 mm thickness, after impregnation with polysterene resin under vacuum. These sections were examined under a polarizing light microscope (Olympus-2). Petrographic descriptions are according to Kempe and Harvey 1983, Bullock et al. 1985, Gibson and Woods 1990, Goren and Goldberg 1991 and Vandiver, Druzik and Galvan 1995.

Petrographic Description

Layer 1: Hydraulic Grog-Lime Plaster of High Quality with Signs of Corrosion (Fig. 1)
This layer consists of a lower, light pink layer, graduating into an upper, dark pink layer. In



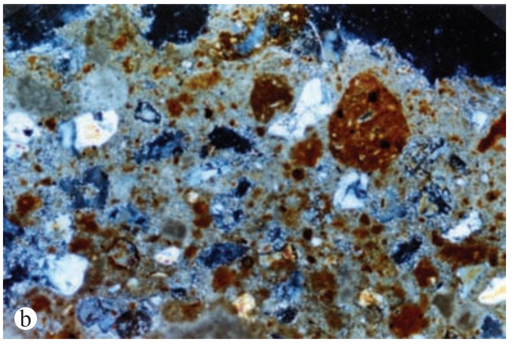


Fig. 1. Layer 1, grog-lime plaster: (a) PPL (plane polarized light); (b) XPL (crossed polarized light). Magnification c. 4 × 10.

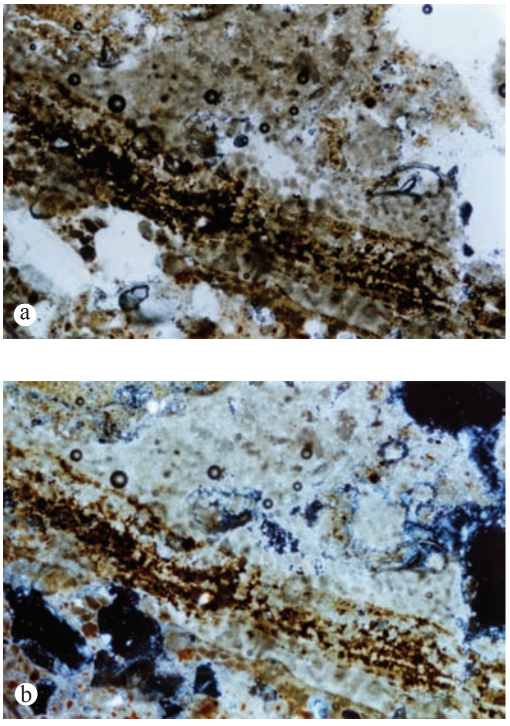


Fig. 2. Layer 2, dense lime mortar with abundant charcoal fragments: (a) PPL; (b) XPL. Magnification c. 4 × 10.

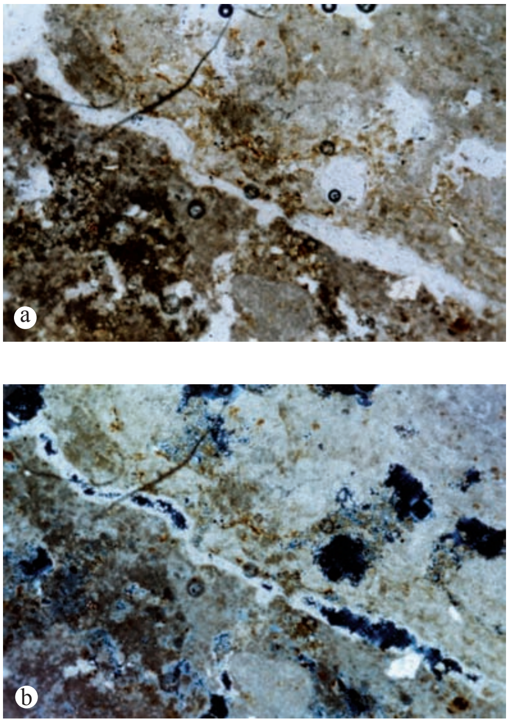
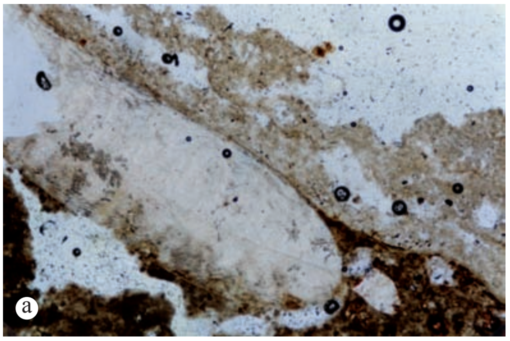


Fig. 3. Layer 3, mud-lime mortar (top) and Layer 4—dense lime mortar (bottom). Note signs of secondary microsparite precipitation in pores and particularly on walls of the fissure running through the sample: (a) PPL; (b) XPL. Magnification c. 4 × 10.

thin section, both layers are composed of a strongly heterogeneous matrix of lime mixed with crushed pottery (grog), albeit in different proportions. The matrix is composed of micritic calcite and shows uneven secondary carbonation, possibly due to a pozzolanic reaction between lime mortar and siliceous tempering aggregate. Crude aggregate (0.5–1.0 mm in size), constituting approximately 20% of the mix, includes marl, limestone, marine shells and chert. In addition, there are occasional ceramic sherds up to 10 mm in size. The marl additives are secondarily perforated due to dissolution and corrosion by running water; as a result, micritic calcite precipitated in the pores. Fine aggregate, constituting up to 50% of the mix, consists of crushed pottery (grog) and sand-sized quartz, all carefully sorted. The plaster is quite dense, though vesicular (c. 10% consisting of pores). The coloration of the plaster is apparently due to the large amount of crushed pottery. Interestingly, the potsherds were prepared from *ḥamra* soils, fired either at high or low temperatures.

Layer 2: Dark Gray Hydraulic Charcoal-Lime Plaster of High Quality (Fig. 2)

In thin section, the dark gray plaster is composed of dense, strongly carbonated lime mortar with an abundance of charred organic material and very little mineral tempering. The boundary between Layer 1 and this layer is very sharp, suggesting that the dark gray plaster is related to a new plastering episode rather than a burnishing of the underlying layer. Carbonation is not uniform, possibly due to incomplete burning of marl. It is important to note that the fine aggregate (e.g., sand or crushed pottery) in this layer was minimal.



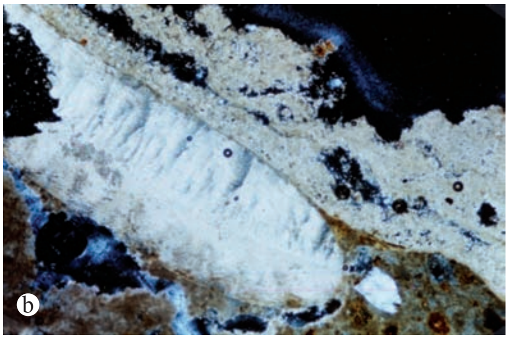
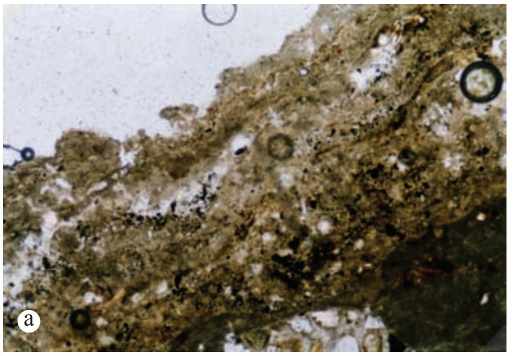


Fig. 4. Layer 4, large shells rendering white coloration to plaster: (a) PPL; (b) XPL. Magnification c. 4 × 10.



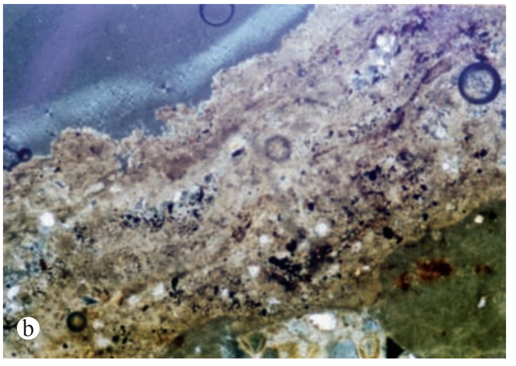


Fig. 5. Layer 5, burnishing plaster layer with burnt organic materials and silt microlaminae (surmised travertine deposit). Note upper part of rounded piece of crude *kurkar* aggregate in Layer 4 (bottom): (a) PPL; (b) XPL. Magnification c. 4 × 10.

Layer 3: Inferior Quality Mud-Lime Mortar, Strongly Corroded (Figs. 2, 3)

In thin section, the gray infill proved to be a porous strongly calcified mud-lime mortar with a few pieces of charcoal 0.5 mm in size (upper part of photograph; Figs. 2 and 3). The major aggregate is marl, up to 1 mm in size, similar to that used in the plaster of Layer 1. Noticeable is the absence of quartz sand temper, as well as shells and *kurkar* aggregate. Heated burnt limestone was probably carefully mixed with local clayey soil, possibly of *rendzina* type (definitely not the *ḥamra*-grumusol association characteristic of the Israeli coastal plain). The sample is strongly affected by secondary dissolution and corrosion, which resulted in high porosity reaching up to 30% and secondary sparitic calcite precipitation along fissures (Fig. 3) and in the cavities within the marl aggregate. Here, some ferruginization (due to wet-dry cycling formation of tiny ferric oxides precipitates) can be also observed.

Layer 4: White Hydraulic Lime Plaster of Inferior Quality (Figs. 4, 5)

The whitish plaster in thin section is composed of a heterogeneous micritic calcite matrix showing uneven secondary carbonation, to which a large amount of crude and fine aggregate was added. The crude aggregate, constituting about 40% of the additives, is significantly coarser than in the pink plaster of Layer 1, reaching up to 2 mm in size. It includes complete marine shells (Fig. 4), not sorted or sieved as in the Layer 1; rounded pieces of *kurkar* (Fig. 5), almost absent in Layer 1; and marl pieces, secondarily perforated by water corrosion, causing precipitation of micritic calcite in the pores. The fine aggregate, in contrast, constitutes less than 10% of the additives and includes crushed pottery and sand-sized quartz, poorly sorted. The plaster is quite dense, with apparently secondary corrosion cracks, filled with microsparitic calcite similar to that described above.

Layer 5: Fine Lime Mortar as a Burnishing Layer, Altered by Posterior Processes

The so-called travertine-like(?) layer identified by Gorzalczany (this volume), in thin section appears, rather, to be a burnishing of the surface of Layer 4 (Fig. 5), showing signs of corrosion and secondary re-precipitation of calcite. Note the occurrence of tiny charred particles and clear layering, which are the result of plaster application rather than natural accumulation of wind-blown or fluviatile silt. However, if it is mortar, it is still not clear why no sand aggregate was added. It can be speculated that secondary travertine deposition, if present, was superimposed on the burnished lime layer and its effects thus are indistinguishable.

POSSIBLE ARCHAEOLOGICAL IMPLICATIONS

Petrographic examination of the plaster from the Ramla aqueduct shows that cementing materials were manufactured by burning marl and limestone and tempering the paste with various aggregates. Layer 1 was clearly hydraulic, rendered waterproof by the addition of large quantities of crushed pottery (grog), amounting to 30–40% of the additives to the lime. The preparation of grog-lime mortar, described by Vitruvius as the key recipe for aqueducts, was very common in Israel during Roman–Byzantine times (see Gorzalczany, this volume: n. 10). When mixed with lime, grog stimulated the pozzolana bonding in the paste, and its eventual incomplete carbonation. Another type of hydraulic mortar recommended by Vitruvius in water- and other liquid-containing structures is charcoal-lime mortar. In the investigated sample, this is identified within Layer 2. Hence, plasters from the aqueduct of Ramla may be petrographically classified as "hydraulic lime mortar with either grog or charcoal."

During Roman–Byzantine times, aqueducts were plastered with several layers in order to enhance the durability of plaster against detrimental water impact (Porath 1984). The Gezer–Ramla aqueduct indeed contains several layers, although their application as one-episode plastering is very unlikely. We hold that they represent at least two different stages of plaster application separated by a time period of unknown duration. If the first episode, represented by the pink plaster of Layer 1, may be considered as grog-lime plaster of superior quality, the final episode, represented by the whitish plaster of Layer 4, is of inferior quality, probably because of a lower heating temperature and a much smaller amount of grog. It is probable that the charcoal-rich hydraulic plaster of Layer 2 marks an intermediate plastering episode. Alternatively, the excavator posits that Layers 2–4 may be several stages of a single plastering episode (see above and Gorzalczany, this volume).

Although the excavator originally identified the deterioration of the plaster as a travertine-like accumulation, thus far we are unable to identify unambiguous signs of travertine within the samples. However, there are definite signs of posterior alteration, exemplified by microsparitic calcite precipitation from running water within cracks and voids in different layers. It is important to emphasize that Layer 1 contains less microsparitic calcite as the result of secondary travertine-like precipitation than other layers.

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