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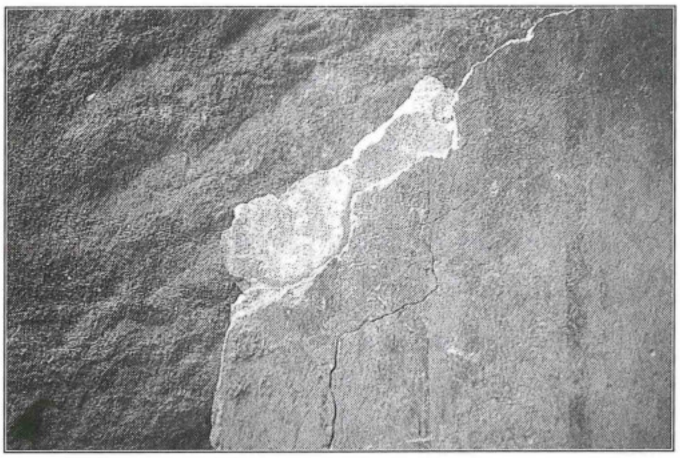
The Wall Paintings at Petra and Bayḍa in Jordan: Mineralogical-Petrographic Study of the Causes of Deterioration and Proposals for Their Restoration

This study was carried out to define the state of preservation and determine the causes and effects of the deterioration of the wall paintings in two tombs located at Petra and Bayḍa.[1] The latter Nabataean locality, smaller and less well-known but equally interesting, lies about 5 km north of Petra.

The frescoes discovered in 1979 in the Petra valley are fragmentary, covering the walls of a small chamber (approximately 3 x 3 m) dug into the northern bank of Wādī aṣ-Ṣiyyagh. The painted motifs are architectural, of unquestionable Hellenistic influence (Zayadine 1987). In the past, partial restoration and consolidation limited to a band of about one metre in the central zone of the west wall was carried out by personnel from the Madrid Institute of Restoration.

The chamber concerned was dug out using a rather crude excavation technique utilizing a long-handled instrument. Deep curved furrows, irregular and often imbricated, are visible, indicating inversion of the working position (FIG. 1). The base for the paintings is formed by a triple layer of mortar (FIG. 2). The first layer in direct contact with the rock wall is of very uneven thickness and was applied for the purpose of smoothing out the irregularities in the walls. It is uneven, having not been smoothed on the outer face, and has a coarser structure than that of the two layers above it. The second layer has a quite even thickness of about 1 cm and the granulometry of the aggregate is finer and better sorted. The frescoed layer of mortar has a very even thickness of approximately 0.5 cm.

The state of preservation, even upon initial visual inspection, appears extremely precarious. In many zones the layers of mortar are peeling off from the walls. Parts of the frescoes are covered by a layer of straw mixed with small amounts of clay and dung. Where this coating is absent, the paintings are darkened, in some cases to the point of being indecipherable, by encrustations formed of combustion residues resulting from human activities during the period when the chamber were utilized as a dwelling place by Bedouin families. Moreover, zones covered by a whitish efflorescence are present even in



1. Petra frescoes. Traces of working on the rock walls.

2. Petra frescoes. The triple layer of mortar and the layer of "coating" are visible.

[1] This work was supported by MURST (40%, R. Franchi) and forms part of a broader research programme that was carried out for three years in the Petra region by an interdisciplinary team of specialists from a number of Italian Universities (Urbino, Florence, Pisa, Bari and Salerno). R. Franchi is responsible for the section on geological and mineralogical-petrographic studies.

the restored areas.

The frescoes at Baḍya — of Alexandrine influence, dating from about the first half of the first century AD (Zayadine 1987) — were painted in a biclinium dug out in the rock along Sīq al-Bārid. The north wall is frescoed with isodomic panels. The alcove is decorated with thickly interwoven grapevines, birds — which must originally have been very brightly coloured — and hunting putti. These wall paintings were also executed on a triple layer of mortar, of similar thickness and texture. The rock walls were prepared more carefully than those at Petra. The furrows, cut by chiseling, are continuous, parallel, and very uniform; deeper and further apart on the walls, shallower and closer together in the vaulting and the ceilings. The extreme state of deterioration of both painted surfaces and layers of mortar is immediately apparent. The greatest damage has undoubtedly been caused by smoke from fires. The surfaces are completely blackened and covered with strongly adherent encrustations of soot and greasy substances. The latter, especially in the vicinity of the fireplaces, have unfortunately penetrated to a depth of several millimetres, due to the porosity of the plastering.

Methods of Examination

The various layers of mortar, as well as the efflorescence and the clay and straw coating found on the Petra paintings were examined by X-Ray Diffraction. In the latter samples, the products of recrystallization obtained after extraction by leaching were also analyzed. In addition, the amount of total carbonate was determined chemically, in order to check the diffractometric data. The petrographic characteristics were studied in thin section under an optical microscope.

Using a Scanning Electron Microscope (SEM) and an Energy-Dispersion Spectrometry system (EDS), the painted surfaces were examined with special attention paid to the mineralogical neoformation phases produced by deterioration.

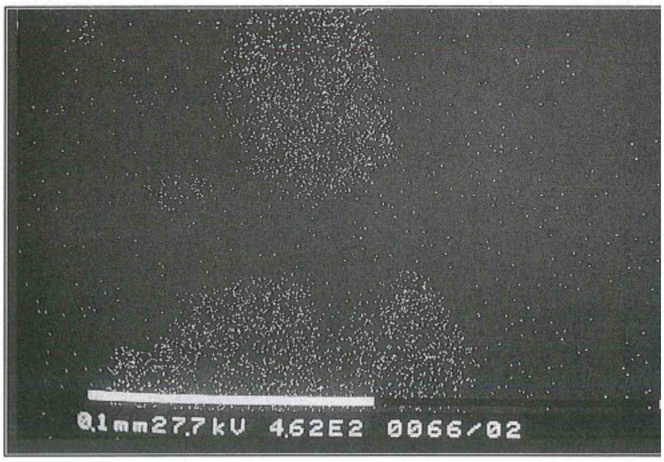
Results

The principle mineralogical composition of the samples from the various layers of mortar in the two frescoed sites showed no significant differences, either qualitative or quantitative. Analysis revealed the presence of quartz, with contents ranging from 70 to 80%; calcite (17-20%); and kaolinite (3-5%). The latter mineral is characteristic as cementing material of some levels within the sandstone outcrops in the Petra area (Franchi 1990), from which the quartz aggregate used to prepare the mortar was obviously taken.

Diffractometric analysis performed on surface samples showed the occasional presence of whevellite and weddellite. These calcium oxalate hydrates can form not only due to the metabolic activity of lichens, but als through the oxidation of organic substances (protein that may have been used as fixatives in mixing the co ours. The efflorescence was found to consist of calciu sulphate (FIG. 3). This mineral is also present, in diffe ent concentrations, on all the surface samples, frequentl in association with potassium nitrates (FIGS. 4, 5, 6). O

3. Closely packed microcrystals of calcium sulphate (SEM).

4. Association of calcium sulphate and potassium nitrate (SEM).



5. X-ray maps of sulphur executed on the same zone as that of FIG.

the frescoes at Petra alone, sodium chloride at times was found in large quantities in addition to the above-mentioned minerals (FIG. 7).

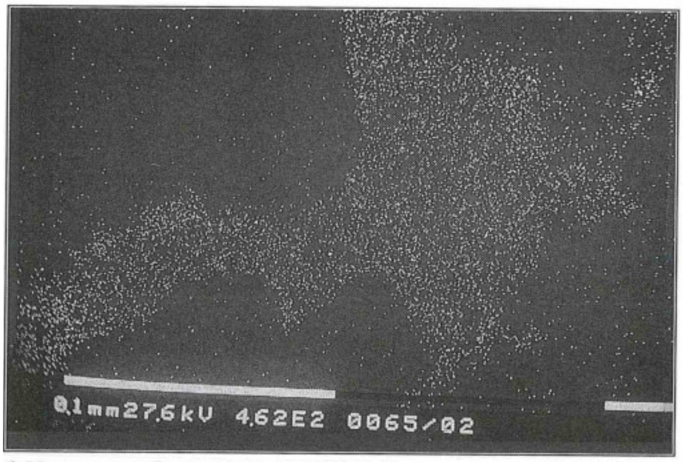
The mineralogical investigation conducted on the layer of the "clay and straw coating" added (by the Bedouins) onto the Petra frescoes have shown that the inorganic part consists of quartz and — in much lower percentages — calcite, dolomite, and traces of argillaceous minerals. The products of extraction by leaching — using distilled water — were found to consist of sodium chloride and potassium chloride. The abundance of these salts, sodium chloride in particular, on both the painted surface and the coating suggests that the frescoed room may have been utilized in the past as a salt store. No natural origin is possible, since the sandstone, from the Cambrian epoch, in which the chamber was dug out, contains absolutely no chlorides. The distance (and the elevation, around 850-1100 m above sea level) of the Petra area from the Dead Sea and from the Gulf of 'Aqaba ensures that it cannot be reached by marine aerosols. Moreover, these salts were not found at Bayḍa. Encrustations of sodium chloride, up to 1 cm thick, have instead been found in the Khazna (the Treasury) located at the opening of the Siq at Petra. May we postulate that the name of the tomb — the Treasury — was derived from the great amounts of salt that may have been stored there and from the increased commercial importance that this product may have assumed after the decline of Petra as a strategic zone and routing centre for the caravans providing communication between the Far and Near East and the Mediterranean.

The structural and textural characteristics of the layers of mortar in the two frescoes are remarkably similar, except for the lower layer of the one from Petra, whose granulometry is slightly coarser and is less well sorted (FIG. 8).

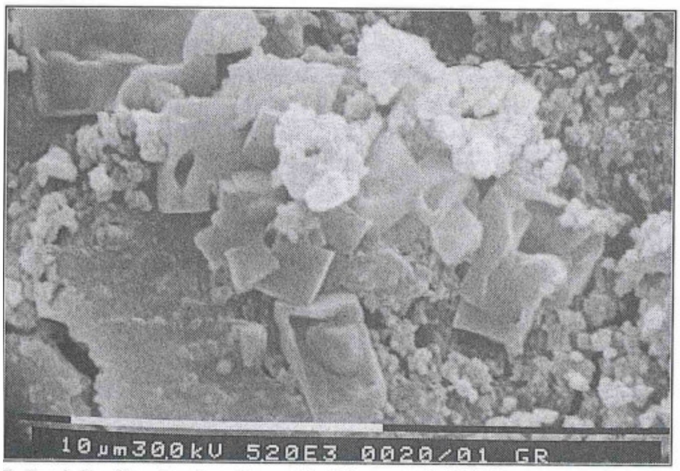
The aggregate consists almost exclusively of quartz, while other kinds of material are very rare. Some grains of siltstone and of carbonate rock were also noted. As accessories, zircon, tourmaline, and titanite were found. The latter minerals are present, again as accessories, in the sandstones at Petra. The binder is well carbonated and evenly distributed. The porosity is low and the pore size is always small. No dissolution phenomena were observed.

The paintings were executed on a layer a few millimetres thick, formed of fragments of calcareous rock finely ground and bound with lime (FIG. 9). The mineralogical and petrographic properties reveal careful selection of raw materials as well as a good and constant technique of application of the layers of mortar at both sites. As no thorough historical and/or artistic studies have been carried out, the two works of art cannot be precisely dated, but the impression given on the whole by the available information is that the two paintings, or more precisely the underlying layers of mortar that form their bases, were realized at much the same time, if not actually by the same workers.

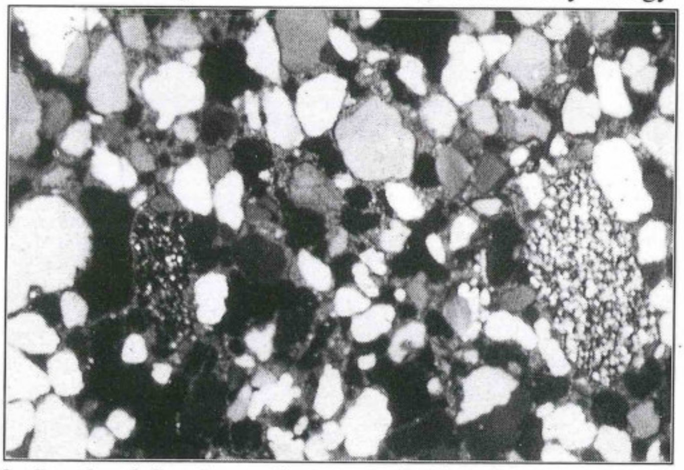
The mean percentage values of the semi-quantitative elemental analysis conducted on the surfaces by energy-



6. X-ray maps of potassium executed on the same zone as that of FIG. 4.



7. Partially dissolved sodium chloride crystals (SEM).



8. Sample of first layer of mortar underlying the Petra frescoes viewed under optical microscope. The granulometry is somewhat dispersed. Some siltstone is visible (n+, ~25x).

dispersion spectrometry are reported in TABLES 1 and 2.

Table 1. Petra frescoes: chemical composition of the surface (in %).

	P1	*P2*	*P3*	*P4*	*P5*
Si	27.34	2.95	19.60	12.62	4.43
Al	3.24	0.97	9.58	6.02	1.73
Fe	1.48	1.52	15.70	5.50	2.20
Mg	–	1.24	0.64	1.39	0.96
Ca	67.36	80.29	41.12	54.38	74.17
Na	–	3.04	2.52	1.48	5.63
K	–	1.27	3.78	2.45	1.48
Ti	0.52	–	1.30	0.85	–
P	–	1.44	–	–	–
Cl	–	3.61	2.65	1.05	3.91
S	–	3.66	3.22	14.22	5.44

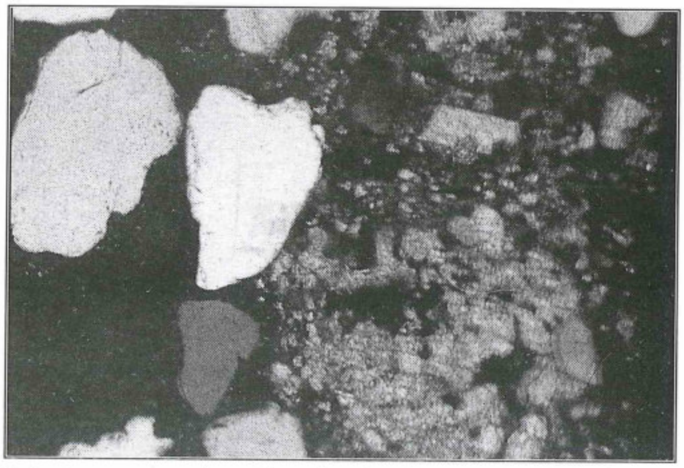
Table 2. Bayḍa frescoes: chemical composition of the surface (in %).

	B1	*B2*	*B3*	*B4*	*B5*
Si	4.60	4.89	11.20	16.84	6.63
Al	2.11	1.72	3.81	3.41	2.46
Fe	4.48	3.14	8.55	2.10	5.11
Mg	–	0.21	0.87	–	0.92
Ca	79.16	77.02	65.59	72.17	77.48
K	–	1.19	4.32	1.04	1.57
Ti	–	0.45	1.14	0.53	0.66
Cl	–	–	0.52	0.19	0.17
S	9.63	11.34	3.97	3.69	4.97

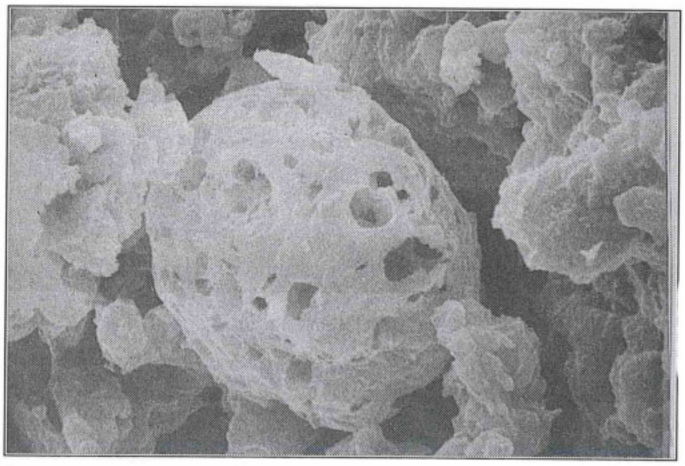
For each sample, at least five analyses were carried out over areas chosen in order to cover approximately the entire surface of the fragments (about 1 cm^2). The characteristic elements produced by transformation reactions induced by deterioration, both natural and following human activity, are essentially: sulphur, indicating the presence of calcium sulphate (already identified, along with the other neoformational mineralogical phases, through diffractometry), chlorine, sodium, potassium, and phosphorus. The latter element, which was found only at Petra beneath the "clay and straw" coating, is certainly of organic origin. The remaining elements are perfectly compatible with the composition of the aggregates, of the binder, the mortars, and the preparatory layer for the painting consisting, as previously mentioned, of fragments of carbonate rocks with a low magnesium content.

Conclusions

All the scientific analyses, as well as on-site observations, have shown the generally poor state of preservation of the two frescoes and have also made it possible to identify the causes of deterioration and related physical and chemical phenomena. Some problems, for example the loss of adhesion of the mortar to the walls — in some cases between one layer and another — and the neoformation of salts, are common to both sites. The soot deposits also are present at both Petra and Bayḍa, but in the latter case they are particularly pronounced. It was however obvious that the main cause of chemical change of the surfaces derived from the utilization of the two chambers as dwellings, probably at different periods, the last of which may have been quite recent. Smoke from the burning of wood (FIG. 10) — as well as other materials — and the cooking of food releasing steam together with nitrated substances and sulphur dioxide have led to the formation of nitrates and calcium sulphate on the surfaces. Analyses performed on sections perpendicular to the exposed surface, utilizing the SEM, have revealed the presence of these compounds even to a depth of several millimetres. In spite of the predominantly dry climate, dissolution, migration through the pores of the mortars,



9. Last preparatory layer for painted surface, made of fragments of carbonate rocks and lime (n+, ~50x).



10. Carbonaceous particles on painted surfaces at Bayḍa (SEM).

and recrystallization within them, have occurred. The situation of the wall paintings at Petra is, as regards chemical aggression, even more alarming than that of Bayḍa due to the presence, along with the other salts, of sodium chloride, whose corrosiveness and motility may have been accentuated by direct reaction with hypoazotide (generated by the combustion of wood) in the presence of steam, with the consequent formation of hydrochloric acid and sodium nitrate (Cadle 1982: 141).

As for conservative restoration, the problems to be dealt with are:

- Reattachment of the mortar that is coming away from the walls. This can be done utilizing a lime mortar around the edges of the fresco and, if necessary, in the inner zones, with localized injections of acrylic resin, mixed with inert materials selected from among the finer, purified fractions of the sandstone itself.
- Removal of the layer of "clay and straw" coating. This can be done either dry, by mechanical means, or after softening with moderate amounts of deionized water. In any case, on-site tests will have to be performed on small surface areas.
- Surface cleaning and desalinization. This step is especially important, and is the most difficult and painstaking one. It must be done in such a way as to remove even the deeply-penetrated salts, obviously without damaging the layers of paint by overly aggressive methods or products. It will be necessary to apply adsorbent pads made of Japanese paper, loaded with a saturated solution of ammonium carbonate and ethylenediaminetetracetic acid (EDTA), also containing surface active agents. In this way the combustion products of the deposits can also be removed, at least partially. Obviously, in this case also, it will be necessary carry out on-site tests on small areas of the fresco to determine the time for which the pads should be applied in order to be most effective. Laboratory experiments, on fragments of blackened, but not frescoed mortar, have yielded promising results while showing the impossibility, and this will be especially true for the painted layers, of complete removal without running the risk of damaging still further the frescoed surfaces.
- Reattaching the painted layers. This is to be carried out in the detached areas only, with infiltration or impregnation of acrylic resins in emulsion or solution.
- Temperature fluctuations: The two frescoes, although painted inside rock chambers, are negatively influenced by changes in climate. The enormous differences in temperature between day and night and the consequent different thermal gradients between the painted structures and the surrounding atmosphere can lead to condensation on the surfaces. Moreover, while the climate in general is rather dry, there are periods of very heavy rainfall — even snow is a not uncommon occurrence — and of high atmospheric humidity, which inevitably influence the micro-climate of the two chambers.

The completion of the microclimate study of the two environments, through repetition of point measurements of temperature and humidity on the frescoes and continuous recordings of the same parameters in the air inside the two chambers, will provide indispensable data for the development of a project designed to eliminate or at least limit the influence of external climate factors on the two frescoes.

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