Lehrstuhl für Restaurierung

The Decorative Architectural Surfaces of Petra

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Vollständiger Abdruck der von der Fakultät für Architektur

der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktors der Philosophie

genehmigten Dissertation.

Vorsitzender: Univ.-Prof. Dr.-Ing. W. Koenigs

Prüfer der Dissertation:

1. Univ.-Prof. E. Emmerling
2. Prof. Dr.-phil. R. Gebhard

Universität Regensburg

Die Dissertation wurde am 05.10.2004 bei der Technischen Universität München

eingereicht und durch die Fakultät für Architektur

am 03.03.2005 angenommen

The Decorative Architectural Surfaces of Petra

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A Thesis Submitted in Partial Fulfilment of the Requirements of the Technische Universität München for the Degree of Doctor of Philosophy

March 2003
Technische Universität München

“ … the outside parts of the site being precipitous and sheer, and the inside parts having springs in abundance, both for domestic purposes and for watering gardens.” (Strabo XVI.iv.21)

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ACKNOWLEDGEMENTS

This study was conducted with the support of GTZ (German Technical cooperation), through the Petra Stone Preservation project. In that regard, I am very grateful to Dr. Helge Fischer for his support and encouragement throughout.

I would like to extend my sincere gratitude to Prof. Erwin Emmerling for his continuous advice and support in carrying out the research, and for allowing me to use the facilities at the Lehrstuhl für Restaurierung, Kunsttechnologie und Konservierungswissenschaft. I would also like to thank Prof. Dr. Wolfgang Hiller and Rupert Stadler from the Faculty of Chemistry at the Technische Universität München for use of the scanning electron microscope at the faculty and for their assistance and advice.

From the Bavarian State Department of Historical Monuments, I wish to thank Prof. Dr. Rolf Snethlage for letting me use the facilities at the department and his much appreciated support, Vojislaw Tucic for conducting x-ray diffraction analysis and his valuable interpretations, Christian Gruber for conducting FT-IR analysis, and for Mathias Kocher, Jürgen Pursche and Edith Woznik for their continuous help and generous advice. I wish also to thank Marianne Werner for assistance in conducting analysis at the scanning electron microscope at the Geology Department of Ludwig-Maximilians-Universität München (LMU).

Further support in the scientific analysis was provided by the Building Materials Section at the Getty Conservation Institute. Many thanks go to David Carson and Stefan Simon for ESEM analysis, Alice Ormsbee for x-ray diffraction analysis, Joy Keeney and Michael Schilling for binding media analysis and Francesca Casadio and Urs Mueller for various analyses conducted.

For assistance in fieldwork, sample collection and preparation, and in providing relevant literature, I wish to thank Hussein al-Sababha, Brigitta Hofer; Ralf Kilian and Nayef Haddad. Thanks also go to Dr. Fawwaz al-Khreysheh, Suleiman Farajat and Mohammad Shobaki from the Department of Antiquities, and to Prof. Martha Joukowsky for providing me with samples from the Great Temple excavation. I am also grateful to Dr. Pierre Bikai, Humi Ayoubi and Fatma Marii for their assistance in using the ACOR library.

My sincere thanks go to the team of the Petra Stone Preservation Project who, throughout my work with the project, provided support, advice and valuable knowledge that influenced this research in many ways, either directly or indirectly. In that regard, I wish to thank Dr. Talal Akasheh, Dr. Ziad al-Saad; Dr. Helge Fischer, Egon Kaiser, Dr. Bilal Khrisat; Dr. Michael Kühlenthal, Fatma Marii, Nicole Schenkel, Dr. Thomas Urban and Wanja Wedekind. I am greatly indebted to Dr. Stefan Simon for his invaluable advice and support throughout the course of this study.

Finally, my deep appreciation goes to my family who has always been very supportive, helpful and encouraging.

BIBLIOGRAPHIC ABBREVIATIONS

ADAJ	*Annual of the Department of Antiquities of Jordan*
BA	*Biblical Archaeologist*
BASOR	*Bulletin of the American Schools of Oriental Research*
PEQ	*Palestine Exploration Quarterly*
QDAP	*Quarterly of the Department of Antiquities of Palestine*
RB	*Revue Biblique*
SHAJ	*Studies in the History and Archaeology of Jordan*

GLOSSARY OF ARCHITECTURAL TERMS

Anta: a Pilaster forming the front end of the side wall of a temple. When there are columns between them they are said to be in antis.
Arch: curved structure, originally freestanding and formed by voussoirs to bear weight across an entrance, but also in the same form rock cut.
Architrave: lowest member below the frieze and cornice of the classical entablature.
Ashlar Masonry: large squared rectangular stones laid in horizontal courses.
Bevelled Ovolo: a moulding with a flat oblique profile receding downwards.
Biclinium: room with benches along two sides on which to recline when dining.
Cavetto: concave moulding of quarter round profile.
Cavetto Cornice: large concave moulding of quarter round profile. Usually above a fascia and torus in "Egyptian Cavetto Cornice".
Cella: central chamber of a temple.
Column: free standing vertical support with circular cross section.
Cornice: the upper member, above the architrave and frieze, of a classical entablature.
Crowsteps: crenellations with stepped sides, used on Nabataean tombs.
Dentil Elements: the moulding of rectangular or square section at Petra used in the position in which dentils would normally be expected to occur.
Dentils: small rectangular blocks, usually carved at the base of a cornice.
Egg and Tongue: decoration on an ovolo moulding consisting of egg shapes with a small wedge between them.
Entablature: a horizontal element of an architectural order consisting of an architrave, frieze and cornice, carried by vertical supports.
Façade: front face of a building.
Fascia: long large flat band.
Loculus: long recess cut in tomb chambers for placing the body in, sometimes with shelves, or with one or more graves carved into the floor.
Metope: plain or decorated panel between triglyphs.
Moulding: continuous profile or contour of a definite shape given to the edge of an architectural member.
Pediment: the part (originally triangular in shape) crowning the front of a building, especially the portico.
Pier: free standing vertical support with square or rectangular, rather than semi-circular, cross section.
Pilaster: engaged vertical support with rectangular rather, than semi circular cross section.
Pronaos: vestibule or porch of a temple.
Segmental Arch: an arch with the shape of a segment of a circle or ellipse, rather than a semi circle.
Segmental Pediment: a pediment with a circular or elliptical shape.
Taenia: the flat band projecting along the top of a Doric architrave.
Tholos: circular columnar structure.
Torus: large convex moulding of half round profile.
Triclinium: room with benched around three sides, on which to recline while dining.
Triglyph: grooved panel alternating with metope.
Vault: continuous arch; arched or vertically curved roof.

(From McKenzie 1990: 181-185)

CHRONOLOGY OF JORDAN

Palaeolithic	**1,500,000 – 17,000 BC**
Palaeolithic I	1,500,000 – 100,000 BC
Palaeolithic II	100,000 – 40,000 BC
Palaeolithic III	40,000 – 17,000 BC
Epi-Palaeolithic	**17,000 – 8500 BC**
Kabarian	17,000 – 10,000 BC
Natufian	10,000 – 8500 BC
Neolithic	**8500 – 4000 BC**
Early Neolithic	8500 – 5500 BC
Late Neolithic	5500 – 4000 BC
Chalcolithic	**4000 – 3200 BC**
Bronze Ages	**3200 – 1200 BC**
Early Bronze Age	3200 – 2000 BC
Middle Bronze Age	2000 – 1500 BC
Late Bronze Age	1500 – 1200 BC
Iron Age	**1200 – 539 BC**
Iron I	1200 – 920 BC
Iron II	920 – 539 BC
Persian Period	**539 – 332 BC**
Hellenistic Period	**332 – 63 BC**
Nabataean Period	**312 BC – AD 106**
Roman Period	**63 BC – AD 324**
Early Roman	63 BC – AD 106
Late Roman	AD 106 – 324
Byzantine Period	**AD 324 – 640**
Early Byzantine	AD 324 – 491
Late Byzantine	AD 491 – 640
Islamic Periods	**AD 630 – 1516**
Arab Conquest	AD 630 – 661
Umayyad	AD 661 – 750
Abbasid	AD 750 – 969
Fatimid	AD 969 – 1171
Crusaders	AD 1099 – 1291
Ayyubid	AD 1171 – 1263
Mamluk	AD 1260 - 1516
Ottoman Period	**AD 1516 – 1918**

(Compilation from Bienkowski 1991, Homés-Fredericq and Hennessy 1986, Kafafi 1990 and Yassine 1991)

ABSTRACT

Analysis of samples from decorative architectural surfaces in Petra, mainly those with paint remains, has provided information regarding the materials used, especially pigments, and the technology of plaster and paint application. Several monuments in Petra were sampled covering a range of different structures that includes rock carved tomb facades, rock carved chambers and freestanding structures.

Decorative painting was extensively used in Petra and, along with gilding, must have provided a rather colourful impression of the city set against the natural surrounding rock. The architectural elements of exterior façades seem to have been painted with the primary colours of red, blue and yellow, while interiors have more complex decorative schemes with a wider colour range that includes different hues of green, brown, pink, orange, black and white. Black and white colours were mostly used in depicting grid lines or colour zone separation lines.

In terms of raw materials used, it appears that the materials, including the pigments used, were ones that could be easily found in or close to the site of Petra. Pigments were ones that have been described by classical writers like Theophrastus, Dioscorides, Pliny and Vitruvius, and includes those that were popular at the time like red and yellow ochre, haematite, minium, green earth, Egyptian blue, carbon black, possibly umber, and calcium carbonate. Additionally, atacamite, sometimes in association with malachite, was found as the green pigment in some paintings. The occurrence of this pigment in its natural form in Petra, associated with malachite, confirms that it was an original material, rather than a weathering product of a copper bearing pigment. Aluminium hydroxide was also found, possibly as a white pigment or in some cases as a substrate for madder or other type of lake. Sometimes pigments were mixed together to give a certain colour hue, such as Egyptian blue with yellow ochre for green, or red ochre with soot for brown.

Regarding plaster support layers, the two types of plaster mixes used were lime and gypsum based. There were also instances of lime/gypsum mixes. Often, stucco was moulded in gypsum, to which sand (quartz) aggregates were sometimes added. Aggregates used in plasters apparently represent sand collected from river beds, and includes mainly quartz, with rock fragments, especially of calcitic nature. The presence of dolomite in the region close to Petra explains its presence in the plaster mixes as well as in the sculptured statues and column elements. The binder/aggregate ratio values are in some cases close to those set by Pliny and Vitruvius.

In the application of paint, again different methods have been found. The technique of fresco painting was used in some cases, while in others a secco-tempera or lime-secco technique was implemented. Sometimes, lime was added to the pigment and applied over a gypsum plaster, while at other times, gypsum or an organic binder, such as beeswax or tragacanth gum, was used with the pigment that was applied over a lime plaster support. It was also found that a method of application was used, whereby a fine gypsum layer was applied prior to the pigment layer. In this case gypsum was used as an adhesive (gesso).

Several polished surfaces have been found, with evidence that a polishing instrument had been used. No confirmation regarding the material used in the pigment layer that provides the shine was obtained. It is possible that in some cases a type of mineral wax, possibly extracted from bitumen, was used.

Evidence for possible repainting or repair of existing paint layers could be detected only in a few rare cases. In some interiors, there is evidence of plaster reapplication. It is possible that for most exterior painted plaster and stucco the whole structure of support, preparation and paint layers was removed and replaced by newer decorative surfaces, instead of repainting and repairing existing ones.

With regard to plaster and paint application on walls, hints at the various tools used could be noted. Instruments like pointed edges that were used to create incised lines for the separation of different zones of colour, and rulers for marking clear edges of the plaster must have been used. Wooden pegs, iron nails and copper tacks were used to hold stucco mouldings.

Although, from the technological point of view, many features of the decorative surfaces in Petra have parallels in contemporary cultures, nevertheless, many significant aspects appear to be rather peculiar to the site. Also, even though it seems that certain procedures were followed, still there appear to be variations in applications that could be due to individual craftsmen and their method of working.

ZUSAMMENFASSUNG

Die Analyse von Proben dekorativ gestalteter Architekturoberflächen in Petra, vor allem solcher mit Farbresten, hat Informationen zu verwendeten Materialien, insbesondere den Pigmenten, sowie zur Putz und Maltechnologie erbracht. Verschiedene Denkmale in Petra wurden beprobt und untersucht, darunter eine breite Auswahl von Grabfassaden, aus dem Felsen geschlagene Räume, sowie freistehende Strukturen.

In Petra sind dekorative Malereien und Oberflächengestaltungen weit verbreitet und haben, zusammen mit zahlreichen Vergoldungen, zu einem farbenvollen Eindruck der Stadt, in deutlichem Kontrast zum umgebenden natürlichen Fels, beigetragen.

Die architektonischen Elemente der Aussenfassaden wurden in den Primärfarben rot, blau und gelb gehalten, wohingegen die Innenräume ein komplexeres dekoratives Schema aufweisen, mit einer grösseren Bandbreite an Farben, darunter verschiedene Grün-, Braun-, Rosa-, Orange-, Schwarz- und Weisstöne. Schwarz und Weiss wurden hauptsächlich für Raster oder Trennlinien zwischen verschiedenen Farbzonen verwendet.

Was die Rohmaterialien anbelangt, so scheint es, dass diese, einschliesslich der Pigmente, in oder in direkter Nachbarschaft zu Petra gefunden werden können. Es sind die Pigmente, die von klassischen Autoren wie Theophrast, Dioscorides, Plinius und Vitruv beschrieben wurden, darunter Roter und Gelber Ocker, Hämatit, Mennige, Grüne Erde, Ägyptisch Blau, Kohlenschwarz, vermutlich Umbra, und Calcit. Zusätzlich konnte Atacamit, manchmal zusammen mit Malachit, als Grünpigment in manchen Wandmalereien nachgewiesen werden. Das Vorkommen dieses Pigments in Petra, zusammen mit Malachit, bestätigt dass es wohl als natürliches Pigment verwendet wurde, und nicht als Verwitterungsprodukt eines anderen kupferhaltigen Pigments anzusehen ist. Ebenso wurde Aluminiumhydroxid gefunden, (eventuell als Weisspigment, oder auch) als Trägermaterial für Krapprot oder einen anderen Lack. Manchmal wurden Pigmente gemischt, um einen bestimmten Farbton zu erzielen, wie Ägyptisch Blau mit Gelbem Ocker für Grün, oder Roter Ocker mit Russ für Braun.

Was die Putzträger anbelangt, so basieren die beiden verwendeten Putzsysteme entweder auf Kalk oder auf Gips. Es gibt auch Kalk-Gips-Mischungen. Häufig wurden Stuckelelemente in Gips abgeformt, dem mitunter ein Sand (Quarz) Zuschlag beigefügt wurde.

Die Gegenwart von Dolomit in der Region um Petra erklärt dessen Vorkommen sowohl in den Putzmischungen, als auch in Skulpturen und Säulenelementen. Die Bindemittel/Zuschlag-Verhältnisse sind in einigen Fällen denen von Plinius oder Vitruv vorgeschlagenen sehr ähnlich.

Verschiedene Maltechnologien konnten nachgewiesen werden. Auf der einen Seite wurde die Freskotechnik angewandt, in anderen Fällen eine Secco-Tempera oder auch Kalk-Secco Technik. Manchmal wurde das Pigment mit Kalk vermischt und über einem Gipsputz aufgebracht, während an anderen Stellen, Gips oder ein organisches Bindemittel, wie Bienenwachs oder Tragacanth mit dem Pigment auf Kalkputz aufgetragen wurden. In manchen Fällen wurde eine dünne Gipsschicht direkt unter der Malschicht gefunden, vermutlich als adhäsive Grundierung (gesso).

Es wurden verschiedene polierte Oberflächen gefunden, mit dem Nachweis der Verwendung eines Polierinstruments. Es konnte kein Additiv in der Malschicht nachgewiesen und mit dem Glanz Verbindung gebracht werden. Es ist möglich, dass in manchen Fällen ein mineralisches Wachs, eventuell aus Bitumen extrahiert, zur Anwendung kam.

Nur in sehr wenigen Fällen konnte Übermalungen oder Ausbesserungen vorhandener Farbschichten nachgewiesen werden. In manchen Innenräumen wurden aufeinanderfolgende Putzphasen gefunden. Es ist möglich, dass für die meisten bemalten Putze und Stuckapplikationen im Aussenbereich der gesamte Aufbau von Träger, Grundierung und Malschicht entfernt wurde und durch neue dekorative Oberflächen ersetzt wurde, anstatt übermalt oder ausgebessert zu werden.

Was die Putz und Malschichtapplikation an Wänden angegeht wurden Hinweise auf verschiedene Werkzeuge gefunden. Instrumente mit ausgeformter Spitze wurden verwendet, um Linien zur Abtrennung von verschiedenen Farbzonen einzudrücken. Ebenso mussten Lehren zu Ausziehung klarer Putzkanten benutzt werden. Holzdübel, Eisennägel und Kupferklammern wurden für die Befestigung von Stuckelementen verwendet.

Obwohl, aus technologischer Sicht, viele Eigenschaften der dekorativen Oberflächen in Petra Parallelen zu zeitgenössischen Kulturen aufweisen, so scheinen doch einige wichtige Aspekte ortsspezifisch zu sein. Ebenso könnten, obwohl es scheint, dass bestimmte Vorgehensweisen befolgt wurden, technologische Variationen auf individuelle Handwerker und Künstler sowie deren Arbeitstechniken zurückgeführt werden.

1. INTRODUCTION

1.1 Background

Petra remains a fascinating site two millennia after its establishment as the capital of the Nabataean kingdom. The whole story of the Nabataeans and their unique capital is still unfolding, despite the numerous surveys, excavations and researches carried out since 1898, following its rediscovery to the western world in 1812 by the Swiss explorer Johann Ludwig Burckhardt. The fact that historical records are very scanty and inscriptive material are very few concerning the city, its people and their way of life, does not help in gaining better insight into the history and material culture of the city. In fact, many aspects of the unique architecture of the city remain unknown until now. The study of the building technologies and materials of the Nabataeans has not yet reached full maturity. When the wall paintings of Rome, Pompeii (Augusti 1967) and Ancient Egypt (Lucas and Harris 1999) were being studied in detail and scientific analysis was being carried out on the materials, research in Petra was still in its infancy, with surveys and excavations targeted at gaining an understanding of the city, its planning, and its architecture. Also, the impressively carved monuments, set in the colourful sandstone mountains have attracted a lot of attention, with studies aiming at analyzing their architectural styles, while fragile wall painting remains whether inside carved chambers, on rock carved façades, and on built monuments have unjustly not received the same level of attention. Conservation of monuments and architectural surfaces in Petra has been carried out recently in a systematic and well studied manner more than ever before (Kühlenthal and Fischer 2000). The methodology for the conservation of the sandstone façades has been established, and is now being carried out according to agreed upon international norms and standards. However, there is yet no established methodology for the conservation of architectural surfaces in terms of plasters and moulded stucco. Several carved chambers have painted walls that are by now covered either with soot or with mud and straw as a result of previous Bedouin habitation. Conservation work has been conducted on some painted plasters (Franchi and Pallechi 1995), yet much more still needs to be done. Many of other painted plaster remains are left completely in the open and are under the effects of exposure to sunlight, wind and rain. Moulded stucco that once covered whole walls of monuments is now represented by only few meagre remains. Documentation and research into the technology of materials in Petra in terms of mortars in general and in particular the exterior plasters of rock carved façades is fairly recent (Shaer 1997; 2000).

As more excavations are continuously uncovering new aspects of the architecture of the city, more and more of the material heritage is being exposed to the environmental elements that cause a threat to its integrity and permanence. Weathering and human factors have a large impact on the state of deterioration of monuments. It is true that, recently, conservation is slowly becoming an integral part of archaeological expeditions, where some excavated sites in Petra undergo conservation work hand in hand with archaeological excavation and necessary scientific research is conducted. Nevertheless, many of the previously excavated sites are deteriorating with a lack of documentation and scientific study and without developing a proper conservation approach. This is in particular evident concerning many of the painted plasters and decorative stucco wall coverings of the monuments in Petra.

1.2 Purpose and Scope of the Investigation

This study aims primarily at filling a gap in the field of conservation science in the country of Jordan in general and in Petra in particular. Knowledge of the technology of the ancients in terms of materials and applications is a necessary step prior to any conservation effort aimed at preserving decorative plasters and stuccoes. Additionally, the in-depth investigation of cross-sections helps to "reconstruct" the original appearance of surfaces which is an invaluable tool to conservation. It also provides information regarding the state of preservation of plaster and paint layers.

The study attempts at identifying Nabateaen methods of applying plaster and paint layers, and to find out what could be termed as Nabataean pigments. This helps in gaining some knowledge concerning the building technology of the Nabataeans, and hence their culture and history, and to compare it with the other contemporary cultures, which allows to find out more about cultural influences.

Furthermore, the study includes a compilation of a number of sites that have decorative plaster and stucco remains and the respective analysis of their plaster and paint layers. It does not include other types of mortars such as those used in lining cisterns or in binding blocks of stones, and, it is not intended to constitute a thorough study of artistic styles of painting, as this would constitute a research on its own. A wide spectrum of sites with painted plaster and stucco remains were chosen for the study. In-depth investigation of the stratigraphy of plaster and paint layers, and identification of materials was conducted.

1.3 Methodology of the Study

The methodology implemented in this study involved several aspects: literature review, fieldwork and scientific analysis. Fieldwork was conducted in Petra in order to survey and document decorative plaster and stucco applications, especially those with painted surfaces, or with suspected remains of paint. These surfaces were sampled, and were chosen to cover a wide range of different plaster remains. Effort was made to sample plasters on structures that are usually inaccessible, by using ropes and ladders. Such structures include the stairway associated with the "Baths", areas of the carved tomb façades and built structures that are unreachable due to their height. Regrettably, a number of façades, although with visible painted plaster remains, could not be sampled due to their difficult accessibility. For further systematic study and sampling of such façades, the construction of a scaffolding would be required for each case. Samples were prepared and subjected to scientific investigations, leading to the identification of the stratigraphy of plaster layers and materials.

A literature review was conducted on the decorative stucco and plaster applications in Petra and in other contemporary cultures. Information gathered from the scientific research led to a conclusion concerning what can be considered as "Nabataean Pigments", and Nabataean techniques of applying decorative renders.

2. SAMPLING OF THE MATERIAL AND METHODS OF ANALYSIS

2.1 Sampling and Sample Preparation

Samples were taken to represent a broad spectrum of the different monuments of Petra, ranging from tomb façades, to temples and residential complexes. On the one hand, there were samples that did not show on visual examination an exterior painted layer, but were suspected to contain a coloured surface, and thus were sampled to find if any colour remains existed and to find out the decorative properties of some exterior surfaces. Also, other samples were taken from very obviously painted surfaces, including some of the very well known mural paintings of Petra. Figures 1 and 2 show the location of samples taken from the areas of Petra and Siq el-Barid.

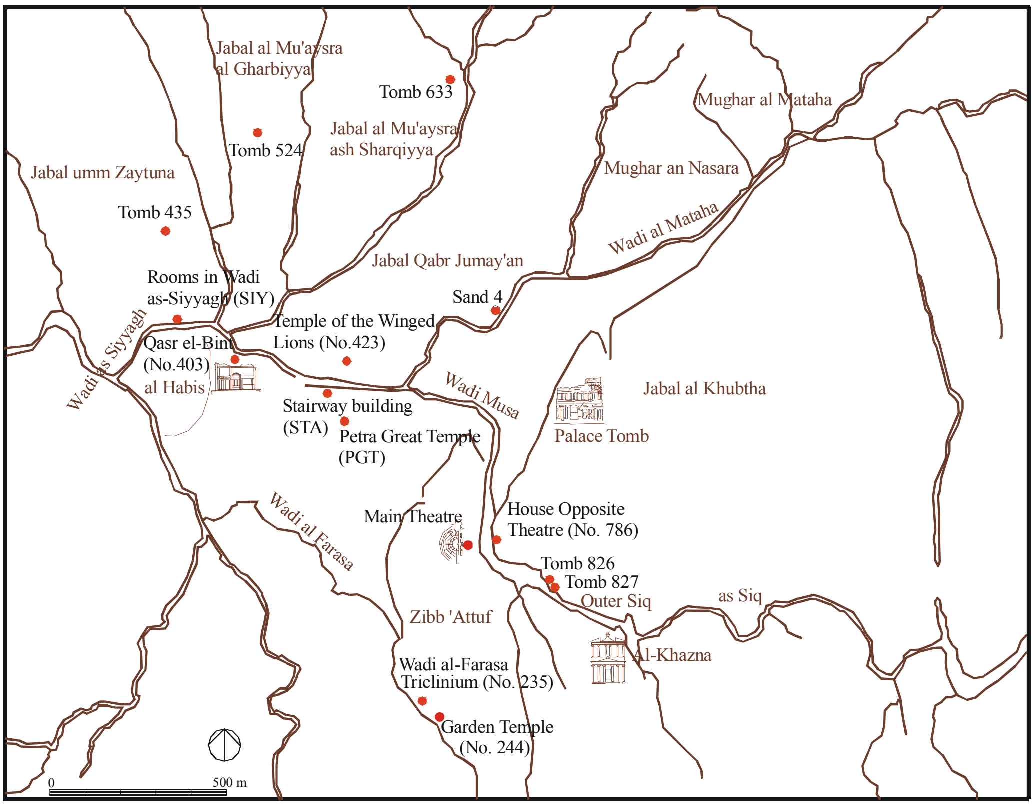


Figure 1. Map of Petra showing the location of sample provenance.

Other samples were collected from the area of as-Sabrah. These constitute rock and earth materials suspected to represent provenance of the raw materials used in the preparation of pigments. Also, sand was collected from the river beds and compared to the aggregates used for mortar mixes.

Samples were taken by means of scalpels, and when the renders were extremely hard, by means of chisels. They were then put in small glass or plastic containers, depending on their size. The samples mainly represented the external surface layer and often the ground layers. When possible, the sample included the whole sequence of layers as well as the substrate. Each sample was given a sample number – the first three digits representing the respective monument name or number, followed by the sequential number of the sample taken for that particular monument. Additionally, samples were documented photographically and by means of drawings and sketches, locating accurately the sample on the documented elevations and plans of the monuments in question. Samples were then prepared for microscopic analysis, x-ray diffraction analysis and FT-IR-Spectroscopy. A few of the samples were subjected to mortar analysis that includes binder/aggregate ratio analysis and grain size distribution analysis.

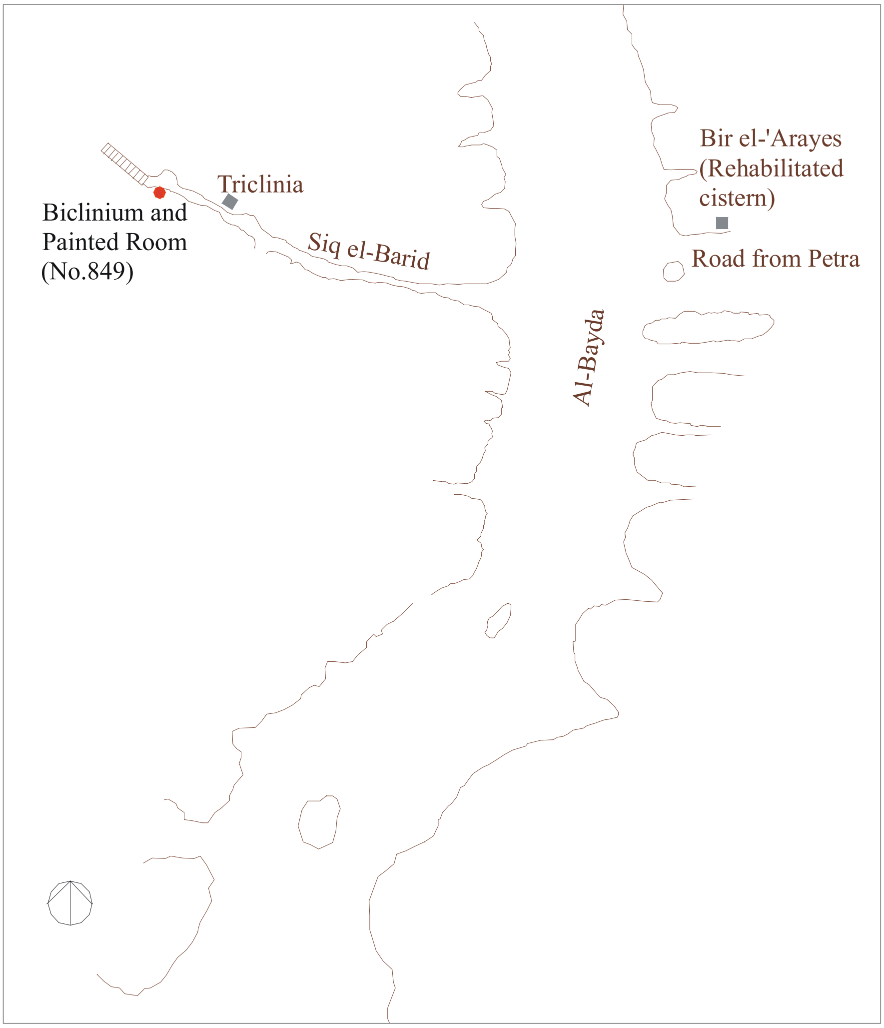


Fig. 2. Map of al-Bayda and Siq el-Barid showing the sampled monument.

Parts of samples were embedded in “Technovit 2000 LC” resin and hardened under UV-light in “Technotray CU”. Samples that were relatively thick (i.e. thicker than 1 cm), were embedded in “Epofix” under vacuum, by placing in a dessicator connected to a vacuum pump for 10-30 minutes. After hardening of the samples, cross-sections were made by grinding and polishing under dry conditions by using “LaboPol 1” machine with paper of decreasing coarseness starting with paper of grade no. 320. Manual polishing followed by using “Micro mesh” (up to 8000 mesh).

2.2 Methods of Analysis

Several methods of laboratory analyses were carried out on the samples. Crucial to the study was the investigation of the types of mortar constituents of the plaster layers and the top painted surface layer, as well as identifying the pigments present and their binding media when possible. Additionally, it was important to study the microstructure of the layers, their strata and methods of application.

2.2.1 Optical Microscopy

The stratigraphy of the paint and plaster layers was determined by observing the sections. Preliminary examination of the plaster/paint layer was done with a "Leica MZ 8" stereo binocular microscope. Detailed examination and photographic documentation of the sections was done by a "Leica DMRP" optical microscope in reflected light with attached "Leica MPS 60" camera, or a Leitz microscope with attached WILD "MPS 05" camera.

2.2.2 Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (SEM/EDX)

Scanning electron microscopy is used to study the surface and internal structure of the samples, complementing the method of using optical microscopy. It works under high vacuum conditions, where a high energy electron beam is passed through a series of magnetic lenses, and two sets of magnetic scanning coils cause it to be deflected. The primary beam hits the sample to give a deflected back-scattered electron current as a result of its interacting with electric charges of the atoms at the surface of the sample, and gives secondary electron emission, which is ejected from the atoms due to collisions with primary electrons. They can be detected by a scintillation or semi-conductor counter, and a magnified picture of the electron emission over the surface of the sample can be displayed (Tite 1972: 246-248). Secondary electrons give more information on the surface topography of the sample, while the Backscattered Electron picture allows conclusions on the elemental composition. Heavy elements appear brighter.

The sections were coated with carbon and then investigated in the scanning electron microscope (ZEISS DSM 960 A), at the geology department of the Ludwig-Maximilians-Universität München (LMU). By means of EDX analysis, the elemental composition was determined and element distribution images were taken.

In the element distribution pictures (false) colours are attributed to an element's X-ray Fluorescence frequency, for example: red to element A, green to element B and blue to element C. According to the law of additive colour mixture, yellow, magenta or cyan areas contain two recorded elements. As an example, a mapping where Ca is marked green and Sulfur is marked red, a yellow colour on the screen denotes a mixture of Ca and S, and hence Calcium sulphate ($CaSO_4$) in any of its hydrate forms (Anhydrite, Hemihydrate, Gypsum). Areas of the sample that contain none of the recorded elements stay dark, whereas areas which contain all recorded samples are white.

Another scanning electron microscope that was used in this research is the JEOL, JSM-5900LV, at the faculty of Chemistry at the Technische Universität München (TUM). In that system, it is not possible to attribute different colours to three elements simultaneously. The environmental scanning electron microscope used at the Building Materials Section of the Getty Conservation Institute is a Philips XL30-FEG ESEM, and does not require the coating of the sample with a conducting layer of carbon, while working in environmental mode.

2.2.3 X-ray Fluorescence Spectrometry

X-ray fluorescence is appropriate for the analysis of pigments, whereby the elements present in the sample can be identified. In this method, the sample is irradiated with primary x-rays, displacing electrons from the inner orbits of the atoms. The inner electron energy levels get filled by electrons from the outer levels. This results in the release of energy that appears as fluorescent x-rays with different wavelengths (λ). Determining these wavelengths gives the identification of the different elements in a sample, and the intensity of the wavelengths give an approximate value of an element's concentration (Tite 1972: 267).

2.2.4 X-ray Diffraction (XRD)

X-ray diffraction measurement is a method by which the mineral phases and chemical compounds are identified. The sample is hit by monochromatic x-rays, which penetrate the crystal and are reflected from the atomic layers in the crystal lattice. The sample produces x-ray intensity maxima, at angles (theta), determined by the spacing between the crystal planes of the minerals present. These minerals are then identified by studying the diffraction pattern.

X-ray diffraction analysis was conducted at the Zentrallabor of the Bayerisches Landesamt für Denkmalpflege (BLfD). Diffractograms were recorded by means of a Phillips PW 1760, on silicon-single-crystal sample carriers. The detection limit for mineral phases in mixtures is above 3%. In order to enhance the resolution for pigment analysis, an attempt was done to remove coarse aggregate particles prior to analysis by means of manual sieving.

Some X-ray diffraction analysis was conducted at the Getty Conservation Institute, with Brucker D8 Discover (GADDS), at standard conditions.

2.2.5 FT-IR Spectrometry

Infra-red spectrometry can be used to analyze molecular organic and inorganic matter, and in this study was used as an attempt to identify organic binding media in the paint layers. In this method, infra-red radiation is focused on the sample in question. If the frequency of this radiation excites a resonance vibration of the inter-atomic bond in the sample, then the radiation gets absorbed, otherwise, it will pass through the sample. Measuring how much radiation is absorbed for each wavelength, gives information on the inter-atomic bonds, and hence mineral phases and chemical compounds consisting of molecules with a permanent dipole momentum can be identified (Tite 1972: 289).

For the analysis of binding media, FT-IR spectra were recorded in KBr-Pellet-Technique (13 mm) of samples and sample eluates by means of a Bruker IFS 48. The eluations were performed by dispersing a small quantity of the sample over 24 hours in the chosen solvent (water, ethanol or chloroform respectively), and subsequent filtering and evaporation of the solvent. The residue was then analyzed in KBr-Pellet-Technique.

2.2.6 Gas Chromatography with Mass Spectrometry (GC-MS)

Gas Chromatography with Mass Spectrometry is another technique that was used for identifying organic binding media such as plant gum and wax. The samples were first treated with reactive chemicals, whereby the type of medium may necessitate a different procedure of pre-treatment. Pre-treatment was conducted according to procedures developed at the Getty Conservation Institute. Samples were prepared using a GC-MS procedure for analyzing proteins, oils and plant gums. Proteins were identified by comparing the composition of amino acids in the sample with those of reference materials such as casein, glue and egg by correlation coefficients and other mathematical procedures. Oils were identified according to peak ratios, and plant gums were identified by comparing the composition of monosaccharide in the sample to that in the standard reference material. For TBDMS quantitative analysis, a Hewlett Packard 5972 gas chromatograph/mass spectrometer was used.

2.2.7 Binder/Aggregate Ratio Measurement

Separation of binder and aggregates in a lime mortar mix was done by dissolving the binder in acid followed by filtering the mixture. For that, 200 ml of HCl of 32% concentration was added to 300 ml distilled water. Part of this acid mixture was poured over a weighed sample of mortar and left for a few hours until the binder was completely dissolved. Afterwards, the mixture was filtered through a funnel and dried in a Heraeus oven at ca 110°C. Upon drying, the resulting weight of the sample was measured and hence the ratio of binder to aggregate was calculated. This ratio is a mass ratio, and is actually calculated according to the measured $CaCO_3$ (B_M(M%)). Due to the difference in molecular weight between $CaCO_3$ and $Ca(OH)_2$, the originally used binder content (B_O(M%)) can be derived according to the formula given by Wisser and Knöfel (1987: 124-126): $B_O=74*B_M/(100-0.26B_M)$. The B/A ratios for the present measured (m) and the original (o) are: B/A=1:(100-B)B. The B/A (MP) ratio is then given in mass parts. In order to transform it to volume based B/A(VP) ratio, it is necessary to know the bulk densities, which are provided as approximate values according to Gödicke-Dettmering (1997: 322) to 1.46 g/cm^3 for the aggregate and 0.46 g/cm^3 for a high lime binder. To be noted is that this method can be used in a reliable manner only when the binder is completely made of lime and no calcareous aggregate is present.

2.2.8 Grain Size Distribution/Sieve Analysis

After the binder had been dissolved in the above mentioned method, the remaining aggregates were sieved in a “Retsch” sieving machine for 20-30 min. The aperture sizes for the sieves are 0, 63 µm, 125 µm, 250 µm, 500 µm, 1000 µm, 2000 µm and 4000 µm. The sieves were weighed before and after the sieving operation, and the difference in weight gives the resultant weight of each grain size section. The cumulative percentage of aggregates (by mass) finer than each sieve size it passed through is then calculated. Based on these calculations a graph is plotted of the percentage cumulative passing versus the grain. Based on the largest grain size, the ideal grain size distributions curves (Fuller Line) are established and compared with the actual distribution found in the mortars.

2.2.9 Thin Sections

Thin sections were prepared at the Building Materials section of the Getty Conservation Institute. The samples were first impregnated with blue dyed epoxy resin in vacuum, and then were cut into ca 1 mm thin slices with a diamond saw and afterwards polished to a standard thickness of 30 µm. These were afterwards partly covered with glass or left uncovered and investigated under the polarising microscope in transmitted light.

3. ANCIENT DECORATIVE PLASTERING AND PAINTING

3.1 Introduction

In studying the decorative renders of the Nabataeans, it would be virtually impossible not to address the technology of such renders that was once present in contemporaneous cultures and ones that preceded the Nabataean civilization. Such cultures, whether in good or contentious relations with the Nabataeans, or even if they merely had trade relations, must have interacted greatly with the Nabataeans. Thus, what follows is a description of ancient plasters and pigments that were used in the ancient world, consisting of Greece, Rome, Egypt, Mesopotamia and China.

There are various sources for ancient texts that describe pigment preparation and its application in antiquity. Of notable mention are classical writers such as Theophrastus, Vitruvius, Pliny and Dioscorides.

Theophrastus was a Greek writer who wrote in the fourth century BC on a number of topics ranging from literature to the history of plants. His treatise *On Stones* deals with minerals and their products, and is considered as the first known scientific source of its kind.

Vitruvius (Marcus V. Pollio) was a Roman architect and engineer, who completed in 27 BC his ten books on Architecture (*De Architectura, libri decem*). Each book consists of a different topic related to architecture or engineering. Book 7, in addition to discussing the construction of pavements, roads, mosaic floors, vaults, along with the appropriate techniques of preparing and applying plaster and stucco, deals also with the technique of wall painting and types of pigments. Vitruvius dedicated chapters 7-14 of Book 7 for the description of colours.

Pliny the Elder, Gaius Plinius Secundus, lived between AD 23-79. He was the author of many books which did not all survive, the most famous of which is his *Naturalis Historia* (Natural History), written in 37 books. Books 33-35 are dedicated to minerals, mining and history of art, in which he describes all of the different types of pigments used at the time, while book 36 includes some recommendations on the preparation of lime mortar.

Also during the first century AD, Dioscorides wrote his medical encyclopaedia, *De Materia Medica*, which includes descriptions of metals, pigments and minerals and their usefulness in pharmaceuticals.

Scientific research that focused on ancient pigments started during the beginning of the 19th century. An outline of the history of this research and the methods used is provided by Frizot (1982). Chaptal (1809) was the first to publish his findings on several pigments found in Pompeii, followed by Humphrey Davy in 1815 and Chevreul (1850) whose findings were related to the pigments used at a Gallo-Roman tomb. De Fontenay (1874) presented his results on a number of analyzed pigments and Berger (1904) published his book on the ancient painting techniques of the Egyptian, Greek and Roman cultures. During this period, there were several significant findings, of which is De Fouqué's identification in 1884 of calcium copper silicate as the blue pigment found in Pompeii in 1814, and, Laurie's research dealing with the method of production of this Egyptian blue pigment (Laurie et al. 1913). Several studies and manuscripts followed, of which the compilation by Lucas in 1926 of ancient Egyptian technologies (Lucas and Harris 1999) including several sections on Egyptian painting, and, a study by S. Augusti (1967) on the colours of Pompeii, are considered as major works relating to specific cultures. To the present day, current research is continuously revealing new aspects of ancient painting techniques and materials.

3.2 Ancient Plaster and Stucco

3.2.1 Introduction

Applying plaster to walls started very early on in history and could be found since prehistoric times. Plaster was prepared by mixing clay, lime, gypsum or pozzolana with water and sometimes adding materials such as sand, crushed bricks, stone hair and straw (Forbes 1965b: 242). In simple terms, a mortar is a mixture of a binder, with aggregates such as sand or crushed stone and water, with the addition of some other materials known as additives. A binder is the medium that acts as a cementing material of a mortar, i.e. binds aggregates together. The characteristics of a mortar depend on the nature and proportion of the original constituents, the size of aggregates used and the proportion of water (Mamillan 1980: 43). Fibrous additives like straw were added to a mortar to add reinforcement (Borrelli 1999: 4). The choice of material used as binder depended largely on cultural traditions that were dictated by the materials available. Historically, three types of binders were used: clay, lime and gypsum.

Gypsum mortar was used by the Egyptians as early as the third millennium BC and lime mortar and plaster was already known in the ancient Near East since the pre-pottery Neolithic period (ca 7200-6000BC), and can be found at numerous sites like Çatal Huyuk, Jericho and Abu Hureyra in Syria (Brown 1996: 3). Notably, it has been found at the Neolithic site of 'Ayn Ghazal in Jordan (Brown 1996: 14; Rollefson and Kafafi 1994: 18), while the Neolithic site of al-Bayda, close to Petra, has revealed two types of plaster: a clayey sandy mixture and a purely lime plaster mixture (Kirkbride 1966: 22-23). Apparently, lime mortar does not occur in Egypt before the Greco-Roman period (Lucas and Harris 1999: 74). During the Hellenistic period, lime mortar was used by the Greeks by the third century BC, and it was widely used in the Roman Empire (Adam 1994: 79). These mortars were non-hydraulic and were produced from the available raw materials (Adam 1994: 73).

In this study, apart from its use as a general term, the term *mortar* is used to denote the material that is used to bind stone blocks or when applied as a layer to level walls or floors. *Plaster* is used in referring to exterior wall coatings which are applied as a finish or as a base for painting, and can be applied in one to three layers (Milner 1976: 181). The term *stucco* refers to fine grained mortar that is moulded or sculpted into decorative shapes while still wet. Stucco was extensively used by the ancient Egyptians and Greeks for decorative sculpting or as a ground for painting (Milner 1976: 180-181). Finally, a *wash* is the very thin layer (<1mm thick), lime based and without coarse aggregates. It was most probably applied by brushing (Brown 1990: 187).

3.2.2 Techniques of Plaster Application

Regarding the plastering of walls, Pliny (XXXVI, LV) recommends the application of three layers of sand mortar and two of marble mortar, while

Vitruvius (VII, iii, 4-7), recommends the application of three layers of rough sand mortar, followed by three other successive layers of finer mortar made with marble powder, upon which the final layer of paint should be applied on wet plaster. After the application of the plaster layers and proceeding on to the painting process, Vitruvius recommends the polishing of the plaster with plasterer's tools "liaculorum":

> "After they are rendered solid by the use of the plasterer's tools and polished to the whiteness of marble, they will show a glittering splendour when the colours are laid on with the last coat."

Although not all Roman plaster was executed in the manner recommended by Vitruvius, there are nevertheless examples of the application of 6 layers, such as in the Farnesina villa in Rome (Ling 2000: 55). In stucco vaulting, Vitruvius (VII, iii, 1-3) recommends fastening wooden strips in a curve and tying to them flattened reeds, above which lime and sand mortar is poured, and a final coat applied to the lower surface.

3.2.3 Ancient Plasters

Clay Plaster

In addition for its use in making mud bricks, clay was used to bind blocks of stone. It is a natural binder, consisting of the finest of the soil constituents with a certain amount of clay minerals (Borrelli 1999: 4). In Egypt, clay mortar was made from the Nile alluvium that consists of clay and sand, mixed with water with added straw in some cases (Lucas and Harris 1999: 75).

Clay plaster can be found in Egypt as early as Pre-dynastic times. There were two main types of clay plaster that were used, a coarse one and generally mixed with straw, and another of finer quality that was often used as a finishing coat for the coarser plaster. Usually, with some exceptions, clay plaster was coated with a gypsum based one, providing a surface for painting (Lucas and Harris 1999: 76). The coarser plaster is similar to the clay mortar, and includes Nile alluvium, calcium carbonate and little gypsum, which is an accidental inclusion. The other type of plaster, which is of better quality, is made up of clay and limestone naturally found at the foot of the hills and in the plateau (Lucas and Harris 1999: 76). In ancient Mesopotamia, clay plaster that included chopped reeds or straw was used (Forbes 1965b: 243).

Gypsum Plaster

Gypsum mortar is less durable than lime mortar, as it is more soluble when exposed to water. However, at high temperatures, it will dehydrate if the relative humidity is very low, causing it to crumble and decompose (Sayre 1976: 197). The advantage of using gypsum as a binder for mortar production is that it can be prepared at a much lower temperature than that required for quicklime, and hence requires much less wood for burning, which is favourable in areas where timber is not very abundant (Ashurst 1988: 29).

Gypsum plaster was extensively used in Egypt as a coating for walls, a finish over clay plaster, a support for painting and for the repair of walls before painting (Lucas and Harris 1999: 76-77). It occurs in nature as sedimentary deposits that are associated with limestone, shale and evaporate deposits (Ashurst 1988: 27).

Gypsum is a hydrated calcium sulphate mineral ($CaSO_4 \cdot 2H_2O$). When heated to a temperature of 130-150°C it becomes a hemihydrate ($CaSO_4 \cdot 0.5H_2O$) (Ashurst 1988: 27):
$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot 0.5H_2O + 1.5H_2O$

The are two types of hemihydrate: α-hemihydrate is produced by wet calcination process (in the presence of water vapour), it is well crystallized and not very porous, and, β-hemihydrate is prepared by dry calcinations, and accelerated by the presence of gypsum dust or salt.

Upon heating the hemihydrate to 150-160ºC it becomes "Plaster of Paris", which when mixed with water sets to form hardened gypsum:
$CaSO_4 \cdot 0.5H_2O + 1.5H_2O \rightarrow CaSO_4 \cdot 2H_2O$

If the gypsum is originally heated at a temperature which is over 160-170ºC then "anhydrite" is formed, and is basically anhydrous calcium sulphate. Anhydrite, if used as plaster, requires an accelerator like sulphates of aluminium or potassium, for an efficient reaction when mixed with water. Anhydrite is also sometimes used with lime putty (Ashurst 1986: 27-28).

Pliny (XXXVI, LIX) discusses the different types of gypsum, its fast setting characteristic and that it:

> "is a serviceable whitewash and is used with pleasing effect for making moulded figures and festoons in architecture."

Lime Plaster

Lime mortars can be divided into two groups: non-hydraulic (hydrated) mortars which set in air and hydraulic mortars which are not soluble in water and have the ability of hardening in water (Cronyn 1990: 116).

Limestone is the raw material that is used for producing lime based mortars. Limestone has $CaCO_3$ as its basic ingredient, that when crushed and heated to a high temperature (850-900°C) it decomposes to produce calcium oxide (quicklime) and releases carbon dioxide gas (Ashurst 1988: 1; Borrelli 1999: 5):
$CaCO_3 \rightarrow CaO + CO_2$

If lime is being produced from a dolomitic limestone ($CaMg(CO_3)_2$) then magnesium oxide (MgO) is also produced.

When the quicklime is mixed with a lot of water, it produces a calcium hydroxide ($Ca(OH)_2$), known as slaked lime.
$CaO + H_2O \rightarrow Ca(OH)_2$ + heat

In this process, known as slaking, all of the CaO present is required to be slaked in order for the mortar to perform well. MgO, if present at all, would also transform into $Mg(OH)_2$, though it would take it a longer time. Thus, if some of the magnesia that is present in the lime mix remains unhydrated, this will cause expansion on hydration (Mamillan 1980: 38). Such a problem can be overcome if slaking is given enough time (Borrelli 1999: 6).

When this slaked lime is stored in pits and covered with water we have what is known as lime putty. Slaking for a long time allows the lime to have better plasticity and workability, by turning the putty into "greasy mass" (Ashurst 1988: 2-3; Borrelli 1999: 6). Vitruvius (VII, ii. 1-2) described the method of crushing, burning and slaking lime:

> "1.We now pass from the preparation of pavements to plasterer's work. It will be necessary to obtain lumps of the best lime and crush it long before it is required; so that if any lump be imperfectly burnt in the kiln, owing to the long crushing, it is forced by the moisture to lose its heat and is tempered to an even quality. For when it is applied fresh and not thoroughly slaked; if, without due care it is spread containing rough lumps, it causes blisters. And these lumps of lime, when they get a thorough slaking after the work is begun, break up and destroy the surface of the stucco. 2. Now when attention is given to the slaking and care is taken in preparing the work, a trowel is to be taken and the lime which is being slaked in the pit is to be chopped as one chops wood. If lumps are met in the chopping, the lime is not slaked. When the trowel is drawn out and dry and clean, it shows that the lime is poor and absorbent; when, however, the lime is rich and duly slaked, it chips around the tool like glue, and shows that it is properly mixed."

Freshly slaked quicklime can be used as a lime wash after sieving the lime putty and adding enough water to it, and sometimes pigments (Ashurst 1988: 44-45).

On the other hand, when quicklime is mixed with just enough water it produces a hydrated lime, which is in fact dry powder calcium hydroxide (Borrelli 1999: 6):
$CaO + H_2O \rightarrow Ca(OH)_2$

For slaked lime to set, it should be exposed to air, where it reacts with the carbon dioxide to form a hard calcium carbonate (Ashurst 1988: 4; Borrelli 1999: 7):
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$
The proportion of binder to sand in non-hydraulic lime mortar is between 1:1 and 1:4 (Ashurst 1986: Fig. 1).

Vitruvius (II, iv, 1-3) prefers the use of sand gathered from river beds rather than pit sand for use in stucco, claiming that pit sand, although good for concrete construction, will lead to the formation of cracks in stuccowork. He also states that if pit sand is used it should be three parts sand with one part lime, while if river sand is used, it should be in two parts sand and one part lime. He adds that in the addition of grinded and sifted brick, the mortar will have a better composition. Moreover, he recommends the production of lime from hard coarse grained stone for its use in structures, while lime produced from soft stone to be suitable for stucco. Pliny (XXXVI, LIII-LIV) gives a similar recommendation:

> "…for white limestone produces a better quality. Lime made from a hard stone is more effective for walling, while that made from porous limestone is more suitable for plastering…Of sand, there are three varieties: there is quarry sand, to which has to be added one-quarter of its weight in lime; and river or alternatively sea sand, to which must be added one-third. If one-third of crushed potsherds also is added, the material will be improved."

When materials like volcanic rock, ash or earth (Pozzolana), tuff or pumice are added to hydrated lime there is a faster hardening of the mortar, which does not require carbon dioxide. Pozzolana has compounds of silica and alumina that react with the calcium hydroxide to produce calcium silicate hydrate and calcium aluminate hydrate (Borrelli 1999: 7):
$Ca(OH)_2 + H_2O + \text{pozzolana} \rightarrow CSH + CAH$
The addition of crushed brick, pottery or iron slag produces a hydraulic set that is similar to the use of pozzolana (Ashurst 1988: 6).

The use of pozzolana as an additive in mortar is attributed to the Romans and became a main ingredient in what is known as Roman concrete. Pliny (XXXV, XLVII) and Vitruvius (II, vi, 1) have both noted the special quality of pozzolana that is found in the area of "Puteoli", and its ability to strengthen a lime mortar.

Hydraulic lime is produced from burning limestone that contains silica and alumina, and can be natural hydraulic lime if the limestone contains a certain amount of clay. Upon heating a mortar mixture, pozzolanic compounds are produced at a temperature of 900ºC, and sintering occurs at a temperature exceeding 1000°C whereby calcium silicate and calcium aluminates are formed and a clinker is produced (Ashurst 1988: 7-8). The proportion of binder to sand in a hydraulic mortar is in the range of 1:2.5 to 1:4 (Ashurst 1986: Fig. 1). According to the European norm (EN 459), a lime mortar is referred to as a hydraulic mortar on the basis of certain strength value.

3.3 Ancient Painting

3.3.1 Introduction

> "The question as to the origin of the art of painting is uncertain and it does not belong to the plan of this work. The Egyptians declare that it was invented among themselves six thousand years ago before it passed over into Greece – which is clearly an idle assertion. As to the Greeks, some of them say it was discovered at Sicyon, others in Corinth, but all agree that it began with tracing an outline round a man's shadow and consequently that pictures were originally done in this way, but the second stage when a more elaborate method had been invented was done in a single colour and monochrome, a method still in use at the present day. Line-drawing was invented by the Egyptian Philocles or by the Corinthian Cleanthes, but it was first practised by the Corinthian Aridices and the Sicyonian Telephanes…" (Pliny XXXV, V).

These were the words of Pliny the Elder, written during the first century AD, as his own interpretation on the origin of painting. Nowadays, it is common knowledge that painting existed much earlier than that. In fact, the art of painting can be traced to prehistoric times. Natural mineral oxides were already used in the Palaeolithic period (Forbes 1965b: 211), and red ochre was used by Neanderthal man on buried corpses (McLaren 1986: 1). However, it was Cro-Magnon man who discovered the art of painting, as witnessed in the cave paintings of Lascaux in southwest France and the caves of Altamira in Spain where paintings in red, yellow and black were found. Charcoal remains used for painting in black were dated to 15000 BC at Lascaux. In addition to this black soot, the other pigments included yellow and red ochres, black manganese oxide and calcite white (Delamare and Guineau 2000: 17; McLaren 1986: 1). It seems that the technique of painting involved making a drawing outline in charcoal and after damping the surface pigment powders were applied by blowing (Ling 2000: 51).

In Jordan, painted plaster remains can be found very early on in history. Particularly in the area of Petra, scanty painted plaster remains were found at the Neolithic site of al-Bayda during the excavations that were carried out in the 1960s by D. Kirkbride (1966: 13, 15, 22-23). Colour traces included purple red, ochre red, brown, black lines, and red painted on a greyish green surface.

At the Iron Age Site of Tell Dayr 'Alla, red and black paint was found on a 7 mm plaster made of chalk and chopped straw over the clay plaster which coated mud brick walls (van der Kooij and Ibrahim 1989: 65). The wall painting consisted of drawings and a text in alphabetic script of northwest Semitic language. For the black ink, soot from burning oil lamp was used, while for the red, an iron oxide mineral was used.

Extensive ancient wall paintings have been found decorating the interiors of several tombs at Quwaylibe (Abila) in Jordan. Dated to the Roman period, these paintings consist of a variety of themes, including human, mythological, animal and geometric representations. One of the most well known wall paintings in Jordan are those covering the interior walls and ceilings of Qusayr ʻAmra, dated to the Umayyad period and inscribed as a World Heritage since 1985.

3.3.2 Techniques of Ancient Painting

In ancient times, wall paintings could be prepared on three different supports, which include wooden panels that were then fixed to the wall, the wall itself or by having a rendering over the wall (Ling 2000: 48). The application of painting was sometimes done directly on stone, or accompanied with a fine layer of whitewash, as found in some Egyptian paintings (Lucas and Harris 1999: 354-355). However, this was not the usual technique, where alternatively, lime or gypsum plaster was often applied as the ground. In Egypt, and since pre-dynastic times, wall paintings were often drawn on a ground of gypsum plaster. Clay was not very suitable for application as a ground for painting, although it has been identified in the case of some mural paintings in Egypt (Lucas and Harris 1999: 353-354). Gypsum, being the characteristic plaster that was used in Egyptian painting, was applied in two different types. The first one is of a coarse quality applied to level out the stone surface, followed by a finer one in order to smooth out the surface, which was often painted over with a whitewash to fill any existing pores (Lucas and Harris 1999: 354).

Regarding binding media for paintings, i.e. the material applied to fix pigments on surfaces, Goffer (1980: 167), defines three types of application techniques: the first is done by applying the medium before the pigment itself – such as in a *fresco* – the second method is by mixing the binding medium with the pigment, and the third is by applying the binding medium after applying the pigment.

> "When the colours are carefully laid upon the wet plaster, they do not fail but are permanently durable, because the lime has its moisture removed in kilns, and becoming attenuated and porous, is compelled by its dryness to seize upon whatever happens to present itself. It gathers seeds or elements by mixture with other potencies, and becoming solid with whatever parts it is formed, it dries together so that it seems to have the qualities proper to its kind." (Vitruvius VII, iii, 8).

This was the description of Vitruvius regarding one of the two main techniques employed in ancient painting, namely *fresco* painting. The term *al fresco* has been used since the fourteenth century, though the technique could be described since classical times. In order to be applied, pigments were made into a paste by mixing them with water or with an organic binder. Consequently, the two techniques usually employed for painting are fresco and tempera. In fresco painting, the pigment is first mixed with lime and water, and then applied to the surface being painted, which consists of damp lime plaster. During the carbonation process of the lime – calcium hydroxide carbonated to produce calcium carbonate – the pigments attach to the plaster and become incorporated with the hardened plaster

(Tite 1972: 356; Doerner 1984: 265). For achieving a successful result in fresco, the wall backing as well as the plaster undercoats should not be too dry that would allow them absorb the water required in the setting of the fresco paint layers, which in turn should not become dry too fast (Ling 2000: 50).

Real fresco can be found in ancient Crete and Mycenae as early as 2500 BC. During the second millennium BC, paintings were applied over two layers of plaster with the upper layer being of a finer quality. It is thought that the painted plaster of ancient Greece was executed in the fresco technique, where additionally the painting was sometimes burnished to ensure the proper fixing of pigments (Ling 2000: 53). The technique referred to as *fresco secco* was also sometimes applied. It involves mixing pigments with lime water, which in turn reacts with the carbon dioxide in the air and the colours are then fixed by the precipitation of calcium carbonate; the binder being the lime mixed with the pigments (Ling 2000: 51).

Fresco painting is the technique that ensures durability and longevity of a wall painting. However, not all pigments are compatible with lime in the fresco technique, as they are known to lack resistance to lime, such as copper and lead based pigments. This fact was already recognized by Pliny (XXXV, XXXI):

> "Of all the colours those which love a dry surface of white clay, and refuse to be applied to a damp plaster, are purple, indigo, blue, Melian, orpiment, Appian and ceruse. Wax is stained with these same colours for encausting paintings, a sort of process which cannot be applied to walls but is common for ships of the navy, and indeed nowadays also for cargo vessels…"

Hence we find that at some classical sites like Pompeii, both fresco and tempera techniques were employed (Forbes 1965b: 254). Tempera painting involves the pigment being applied on the surface with an organic binder such as gum or a protein-rich material. Another technique used was by applying wax as a binding medium for pigments (Tite 1972: 356).

The use of fresco painting has already been noted in south Jordan, where the wall paintings at a Roman fort and an Abbasid castle at al-Humayma are believed to have been true frescoes, since calcite was detected in all samples analyzed and no organic binders could be found (Corbeil, Oleson and Foote 1996: 426).

The fresco technique of painting was not used in Egypt, where painting in tempera was popular, nor was it known in ancient Mesopotamia (Forbes 1965b: 249). This is probably due to the fact that the Egyptians used gypsum as a plaster, a material that dries quickly, and hence is not suitable for fresco application. There, tempera painting was done by first applying a layer of *gesso*, which can either mean that the layer consists of gypsum and glue or only of gypsum (Lucas and Harris 1999: 354).

Moreover, with fresco painting, only the area of the wall that could be kept damp during a work day could be painted at one time. Upon continuing the work and addition of fresh plaster, a joint becomes evident between the two parts of the wall painting, which is in turn concealed by incorporating it within the decorative scheme (Ling 2000: 50). There is evidence of such joints in many Roman wall paintings. The division of the walls into three zones (*pontate*) is probably a result of the procedure of fresco painting (Ling 2000: 55). A fresco could also be achieved with secondary paint layers (Ling 2000: 58).

Painting in oil was alien to ancient Egypt and Mesopotamia (Forbes 1965b: 244). Egyptian painting was executed by using an organic adhesive such as size (glutinous material), gum, or egg-white as a binder (Berger 1904:6-8; Forbes 1965b: 244). Pigments mixed with gum can last for a long period, and when needed, the mix can be softened with water and then used. Layers of pigment mixes could be applied on top of one another (Forbes 1965b: 246). In addition to these materials, Lucas (Lucas and Harris 1999: 352) has noted the use of beeswax as a binder as well as a varnish for painting. It has been proved that the wax used by the Egyptians was in a pure form (Serpico and white 2000: 411). Beeswax is produced by the secretions of organs of the bee and is used in making up the cells of the honeycomb. The wax can be produced by melting the honeycomb in boiling water and then straining to get rid of the impurities (Gettens and Stout 1966:5; Masschelein-Kleiner 1995: 43).

Additionally, the use of animal glue and possibly honey or plant nectar as a binder, sometimes in conjunction with gum, has been recently confirmed (Newman and Halpine 2001: 25).

Gum Arabic was known in Mesopotamia, and was imported to Egypt from Punt and southern Arabia. Gum from the Acacia tree was often used. Sometimes honey was added to gum or size, in order to keep it from becoming very brittle (Forbes 1965b: 244). Gum Arabic is the main kind of gum used as a medium in painting, and is produced from the different species of *Acacia* trees. Its method of preparation has been described to include grinding it to powder, then slowly stirring it to distilled water that has been boiled, in a ratio of one of gum to two of water, and leaving it to stand for a whole day, after which it can be decanted (Gettens and Stout 1966: 28). The most exploited species of acacia is *Acacia Senegal*, found in the large area from Senegal to the Red Sea and the Indies. Gum is produced by making incisions in the tree trunk of 5-10 cm. It is composed of calcium, magnesium or potassium salts of an organic acid (Masschelein-Kleiner 1995: 49-50).

Analysis of several samples from ancient Egyptian painting has shown the presence of monosaccharides (arabinose and galactose), coming from plant gums, the source of which doesn't seem to have been *Acacia Senegal*, but rather *Acacia Nilotica* (Newman and Halpine 2001: 25).

Another type of gum is gum Tragacanth which comes from the leguminous shrubs of the genus *Astragalus*. It contains small amounts of gum, starch and cellulose, as well as a large quantity of bassorin – a mucilaginous substance made up of carbon, hydrogen and oxygen, which swells in cold water. Gum Tragacanth does not dissolve in water (Gettens and Stout 1966: 28). Although a high quality of this gum can be obtained by taking it from the roots, it is usually produced by cutting incisions in the stem (Masschelein-Kleiner 1995: 50). *Astragalus* is found in the high slopes (altitude 1,200-2,000 a.s.l.) of Turkey, Syria-Palestine, Iraq and Iran. Although there are over 1,500 species of *Astragalus*, only a few of them produce gum, the best coming from *A. gummifer* and *A. gossypinus*, while *A. bethlehemicus* and *A. cruentiflorus* may also have been exploited – the former is found in Syria, Lebanon, Israel and Jordan, while the latter in Palestine (Newman and Serpico 2000: 478).

In his study of Roman paintings at Pompeii, Augusti (1950) concluded that the paintings were executed in pure tempera, and that the pigments were mixed with calcium soap with the addition of hot wax. Although this theory has been contested (Ling 1991: 201), however, a more recent analytical study of a Roman painting (Sciuti et al. 2001), provided a similar result as that of Augusti and concluded that a water/soap solution was used.

The process of painting did not end at the point of applying paint:

> "Eventually art differentiated itself, and discovered light and shade, contrast of colours heightening their effect reciprocally. Then came the final adjunct of shine, quite a different thing from light. The opposition between shine and light on the one hand and shade on the other was called contrast, while the juxtaposition of colours and their passage one into another was termed attunement." (Pliny XXXV, XI).

The Egyptians had two types of varnish, a dark one and a more translucent yellow one (Serpico 2000: 459). Although Lucas (Lucas and Harris 1999: 357) concluded that the black varnish was neither bitumen nor pitch, recent studies have shown that it was actually derived from bitumen, while the yellow varnish was found to be a pistacia resin (Serpico 2000: 459-460). Beeswax was also sometimes used as a varnish in ancient Egypt, applied either over the whole painting or over certain colours (Forbes 1965b: 247). These represented the first implementation of encaustic painting that was very popular in Egypt during Roman times. Moreover, Vitruvius (VII, ix, 3-4) describes the use of "Punic" wax in encausting as follows:

> "But if anyone proceeds in a less crude fashion, and wishes a vermilion surface to keep its colour after the finishing of the wall is dry, let him apply with a strong brush Punic wax melted in the fire and mixed with a little oil. Then putting charcoal in an iron vessel, and heating the wall with it, let the wax first be brought to melt, and let be smoothed over, then let it be worked over with waxed cord and clean linen cloth…".

3.3.3 Ancient Pigments

> "some colours are sombre and some brilliant, the difference being due to the nature of the substances or to their mixture. The brilliant colours, which the patron supplies at his own expense to the painter are cinnabar, Armenium, dragon's blood, gold-solder, indigo, bright purple; the rest are sombre. Of the whole list some are natural colours and some artificial. Natural colours are sinopis, ruddle, Paraetonium, Melinium, Eretrian earth and orpiment; all the rest are artificial, and first of all those we specified among minerals, and moreover among the commoner kinds yellow ochre, burnt lead acetate, realgar, sandyx, Syrian colour and black." (Pliny XXXV, XII).

Pliny provides two different sets of classes for pigments. In the first set, he divides them into plain pigments (*colores austeri*) and the more vivid ones (*colores floridi*), which were the more expensive pigments. In the second set, Pliny divides the pigments into two classes: the natural and the artificial.

Although pigments and dyes are both used as colouring agents, one should distinguish between them. The word pigment comes from the Latin word *pigmentum*. According to Forbes (1965b: 211), pigments are what painters use in applying paintings, and they are the dry crystalline or amorphous powders of colour that are mixed with a certain medium for paint application. Pigments form suspensions rather than dissolve in binding media and solvents, while dyes are soluble in water or other liquids and are used to paint materials like textiles, wood and paper. Dyes are nearly all of organic nature, while pigments can be organic or inorganic. The size of a pigment particle is generally larger than 0.1 μm, while dissolved dyes have a particle size of less than 1 ηm, and other coloured compounds which have a particle size between these two are considered as "colloidally dispersed pigments" and in solution resemble dyes (Kühn 1986: 171).

> Goffer (1980:167) defines pigments as being:
> "finely divided, insoluble coloured materials used to impart colour to other materials. Pigments do not usually combine, chemically or otherwise, to the material to which they impart colour; they must be deliberately attached to the surface to which they are applied, by means of a *binding medium*."

Pigments can be of natural origin or artificially manufactured. Natural pigments include those of mineral (inorganic), animal or vegetal (organic) origins. Such pigments were used from early times (Goffer 1980: 168). Several pigments could be synthesized already in antiquity, and include lead white, red lead, verdigris and Egyptian blue (Kühn 1986: 173). Later on in time, "lakes" started to be manufactured by treating a dye, which is normally water soluble, with chemicals, making it insoluble and hence able to precipitate. These could then be used as pigments (Goffer 1980: 168). Pigments are considered to be fine grained if they have a particle size that is less than 1 μm, medium grained if they have a particle size that is 1-10 μm, and are coarse grained if their particle size is bigger than 10 μm (Kühn 1986: 174).

Black Pigments

Black pigments are generally either carbon based or occur as the natural mineral pyrolusite. In Egypt, Most of the black pigments analyzed were found to consist of carbon, mostly of soot that is finely divided, charcoal (Forbes 1965b: 232; Lee and Quirke 2000: 108) and possibly bone black (Lucas and Harris 1999: 339-340).

Elemental Carbon Pigments

These are considered as the first artificially produced pigments and comprise lampblack, vegetable blacks, and animal blacks (Goffer 1980:170). Lampblack, as the name denotes, is made from the smoke produced from burning oil lamps. Vegetable black was made from the charring of vegetable, such as wood, producing a charcoal that consists mainly of carbon, in addition to some minerals. Animal black is produced from calcination of bone or ivory, and contains the elements calcium and phosphorus.

Vitruvius (VII, x, 2) describes the production of carbon black as follows:

> "A vaulted apartment is built like a sweating chamber, and is covered carefully with a marble facing and smoothed down. In front of it a small furnace is built with outlets to the chamber, and the mouth of the furnace is carefully enclosed so that the flame does not escape. Resin is placed in the furnace. Now the fiery potency burns it and compels it to emit soot through the outlets into the chamber. The soot clings round the walls and vaulting of the chamber. It is then collected and in part compounded with gum and worked up for the use of writing ink; the rest is mixed with size and used by fresco-painters for colouring walls. But if this cannot be obtained, we must satisfy our requirements without holding back the works by the delay involved. Brushwood or pine-chips must be burnt, and when they are charred they are to be pounded in a mortar with

size. Thus the fresco-painters have a not unpleasant black colour. Again, a black colour even more pleasant that this is produced if the dregs of wine are dried and burnt in a furnace, and applied to the walls after being ground with size. The use of the finer wines will allow us to imitate not only black but indigo."

Meanwhile, Pliny (XXXV, XXV) gives the following description:

> "…black paint can be made in a variety of ways from the soot produced by burning resin or pitch, owing to which factories have actually been built with no exit for the smoke produced by this process. The most esteemed black paint is obtained in the same way from the wood of the pitch-pine. It is adulterated by mixing it with soot of furnaces and baths, which is used as a material for writing. Some people calcine dried wine-lees, and declare that if the lees from a good wine are used this ink has the appearance of Indian ink. The very celebrated painters Polygnoyus and Micon at Athens made black paint from the skins of grapes, and called it grape-lees ink. Apelles invented the method of making black from burnt ivory; the Greek name for it is elephantinon. There is also an Indian black, imported from India, the composition of which I have not yet discovered. A black is also produced with dyes from the black florescence which adheres to bronze pans. One is also made by burning logs of pitch-pine and pounding the charcoal in a mortar…The preparation of all black is completed by exposure to the sun, black for writing ink receiving an admixture of gum and black for painting walls an admixture of glue. Black pigment that has been dissolved in vinegar is difficult to wash out."

Dioscorides says soot is used by painters, while the best kind of carbon – regarding medicinal uses – comes from glass furnaces (Riddle 1985: 163).

Analysis of black paint used on Middle Kingdom coffins in ancient Egypt appeared to contain carbon, which in many cases is finely grained indicating lampblack or soot, while in few instances it appears to have been produced by crushing charcoal (Middleton and Humphrey 2001: 12). Also, black and grey pigments used in the wall painting of the Second Tomb at Vergina in Greece were found to consist of amorphous carbon (Filippakis 1979: 57).

Pyrolusite (MnO_2)

This manganese dioxide is a naturally occurring black ore, which was ground and sieved to produce black pigment (Goffer 1980:170), has been identified in ancient Egypt (Lucas and Harris 1999: 340), though Forbes (1965b: 232) doubts its use. Pyrolusite has been also detected in association with carbon black in samples from other sites such as Thera (Frizot 1982: 49).

Blue Pigments

There were several natural blue pigments that were used in antiquity. However, in classical times, the most popular was the artificially produced Egyptian blue, that was in some places the only blue pigment used in painting. Pliny (XXXIII, LVII), gives an idea of the blue pigments present at the time as follows:

> "The blue pigment is a sand. In old days there were three varieties: the Egyptian is thought most highly of; next the Scythian mixes easily with water, and changes into four colours when ground, lighter or darker and coarser or finer; to this blue the Cyprian is now preferred. To these were added the Pozzuoli blue, and the Spanish blue, when blue sand-deposits began to be worked in those places. Every kind however undergoes a dying process, being boiled with a special plant and absorbing its juice; but the remainder of the process of manufacturing is the same as with gold-solder.
>
> From blue is made the substance called blue wash, which is produced by washing and grinding it. Blue wash is of a paler colour than blue, and it costs 10

> denarii per pound, while blue costs 8 denarii. Blue is used on a surface of clay, as it will not stand lime. A recent addition has been Vestorian blue, called after the man Vestorius who invented it; it is made from the finest part of Egyptian blue, and costs 11 denarii per pound."

Azurite ($2CuCO_3 \cdot Cu(OH)_2$)

Azurite is a basic copper carbonate and can be found in nature as a blue mineral (Goffer 1980: 172). It is found in the upper portions of copper deposits, and is usually associated with malachite ($CuCO_3 \cdot Cu(OH)_2$) (Gettens and FitzHugh 1993a: 23). Although it occurs naturally in the Sinai and the Egyptian desert, and was used in Egypt in pre-classical times (Lucas and Harris 1999: 340), it does not appear to have been widely used as a pigment in Egypt and the classical world (Gettens and FitzHugh 1993a: 25; Lee and Quirke 2000: 111). Nevertheless, it has been detected as the blue pigment used for painting the sculptural relief of the "Archer" on the west pediment of the Aphaia Temple in Aegina, dated to the 5th century BC (Brinkmann and Koch-Brinkmann 2001: 101), and hence appears to have been well known in classical Greece. Azurite was a very important pigment in Far Eastern painting, and was widely used by the Sung and Ming dynasties in China (Gettens and FitzHugh 1993a: 25), and was one of the pigments used for the polychromy of the terracotta army of the first Chinese emperor (Thieme 2001: 53).

Preparation of the pigment is done by merely grinding, washing, levigating and sieving it. Coarse grinding produces a darker hue of the pigment than fine grinding (Gettens and FitzHugh 1993a: 25). Azurite is reported to become darker if exposed to sulphur, and can transform to a green colour in the presence of salts by alteration to basic copper chloride such as paratacamite or atacamite (Gettens and FitzHugh 1993a: 27; Scott 2002: 110), possibly even basic copper sulphates such as bronchantite ($Cu_4SO_4(OH)_6$), antlerite ($Cu_3SO_4(OH)_4$), or even malachite ($CuCO_3Cu(OH)_2$).

According to Pliny (XXXV, XXVIII):

> "Armenia sends us the substance named after it Armenian. This also is a mineral that is dyed like malachite, and the best is that which most closely approximates to that substance, the colour partaking also of dark blue. Its price used to be rated at 300 sesterces per pound. A sand has been found all over the Spanish provinces that admits of similar preparation, and accordingly the price has dropped to as low as six denarii. It differs from dark blue by a light white glow which renders this blue colour thinner in comparison."

Theophrastus (Caley and Richards 1956: 57) talks about three kinds of *kyanos*, the Egyptian, the Scythian and the Cyprian, where the latter denotes azurite (Caley and Richards 1956: 183-184).

Cobalt Blue ($CoO \cdot Al_2O_3$)

This copper aluminate was discovered by Thénard in 1802, and is made by calcining a mixture of cobalt oxide and aluminium hydrate (Gettens and Stout 1966: 108). Riederer (1974: 104) found this pigment on Egyptian terracotta vases dating to 1370 BC. It appears to have been likely that cobalt was imported since it does not seem to occur in Egypt (Goffer 1980: 175; Riederer 1974: 105), though it is not known whether cobalt blue as a pigment was imported or was prepared in Egypt. Riederer (1974: 106) mentions the possibility that the cobalt blue found on the vases was achieved by applying a mixture of aluminium hydrate (clay) and a cobalt compound to the vase prior to firing, and with heating, the mixture reacted forming the blue coloured cobalt aluminium oxide.

Egyptian Blue ($CuCaSi_4O_{10}$)

Egyptian blue was the first synthetic pigment ever produced (Riederer 1974: 104). Manufacturing this pigment was invented in Egypt during the early dynastic period – the third millennium BC – and continued to be used for the next 3000 years (Tite, Bimson and Cowell 1984: 215; Riederer 1997: 23-27). It was not only used in Egypt but also all over the Near East, ancient Greece and throughout the Roman Empire. The Assyrians also knew how to produce it ca 1500 BC. It was identified on the wall painting of the Second tomb at Vergina (Filippakis et al. 1979: 56), at the first century BC site of Jericho (Rozenberg 1997: 69) and the Pompeian wall paintings (Augusti 1967: 62-72). It remained in use in Italy and central Europe until the Middle Ages. Other blue pigments, such as azurite, ultramarine, cobalt blue or glaucophane were very rarely used (Riederer 1997: 27). Egyptian blue pigment doesn't mix well with lime for application as in true fresco technique, but can be applied by pressing with a trowel, or with egg yolk in al secco painting (Forbes 1965b: 224).

In 1814, Egyptian blue was found in a pot at the site of Pompeii, and was identified by Fouqué in 1884 as calcium-copper tetrasilicate (Tite, Bimson and Cowell 1984: 215). Egyptian blue consists mainly of cuprorivaite, which is accompanied by copper wollastonite and a glass phase (Scott 2002: 259). This artificial synthetic pigment is produced by heating to a temperature of about 850ºC, silica with copper alloy filings or copper ore like malachite, lime and an alkali like natron ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$). The mix of these produces cuprorivaite, carbon dioxide and water vapour:

$$Cu_2CO_3(OH)_2+8SiO_2+2CaCO_3 \rightarrow 2CaCuSi_4O_{10}+3CO_2+H_2O$$

(Lee and Quirke 2000: 109; Riederer 1997: 23).

In analyzing samples from Egypt, minor components of pyrite (FeS), cassiterite (SnO_2) and titanomagnetite ($Fe_3O_4 \cdot Fe_2TiO_4$) were found – the latter probably the result of using sand from the desert (Lee and Quirke 2000: 109).

More recently, this pigment has been prepared by heating fine sand, copper carbonate and calcium carbonate at ٨٥٠°C for an hour. If the temperature is below 820°C, most of the silica remains uncombined in the mix, and at a temperature above 900°C, the resultant consists of quartz and green glass (Goffer 1980: 173).

Vitruvius (VII, xi, 1), wrote about the production of the Egyptian blue pigment, and says that it was discovered in Alexandria. He also mentions Vestorius, who founded a factory in Petuoli, and describes his method of producing Egyptian blue as follows:

> "The processes for making blue were first discovered at Alexandria; afterwards also Vestorius founded a factory at Peteoli. His method and his ingredients are sufficiently noteworthy. Sand is ground with flowers of soda to such fineness that it becomes like flour. Cyprian copper is sprinkled from rough files like fine dust so that it combines with the mixture. Then, it is rolled by hand into balls and they are put together to dry. When dry they are collected in an earthenware jar, and the jars are put in a furnace. In this way the copper and the sand

> burning together owing to the vehemence of the fire dry together, and, interchanging their vapours, lose their properties; and their own character being overcome by the vehemence of the fire, they acquire a blue colour."

Pliny (XXXIII, LVII), calls this pigment "Caeruleum", and distinguishes between three types: the Egyptian, the Scythian and the Cyprian, where he considers the Egyptian to be of the best quality, followed by the Cyprian. He mentions that from this blue a "blue wash" can be obtained by washing and grinding it, which then costs "10 denarii per pound", while the blue costs "eight dinarii", and adds that it is usually applied on a clay surface, since it would not withstand lime. Also according to Pliny, the Vestorian type – named after the man who invented it – is the best of all Egyptian blue pigments and "costs eleven denarii per pound".

According to Riederer (1997: 26), in ancient Greek literature, only Theophrastus mentioned a blue pigment, which could be Egyptian blue (Caley and Richards 1956: 55, 187). In *De lapidibus*, he mentioned an artificial blue pigment from Egypt, which could indicate that this pigment was produced in Egypt until this period and was brought from there by trade. He goes on to say that the artificially produced Egyptian pigment is considered as the best for making "pure pigments", and that four colours can be made from it: a pale tone of blue is produced by grinding it into very fine particles while a darker tone is made up of large particles. Here, he clearly describes the Egyptian blue pigment, and, Theophrastus was probably the first to note this relationship between the size of particles of Egyptian blue and the colour achieved. In fact, it has been established by now that Egyptian blue, when finely ground, produces a paler blue hue than when more coarsely ground (Lee and Quirke 2000: 109; Riederer 1997: 28).

Tite, Bimson and Cowell (1984: 234) found that the difference between dark and light blue is related to the cluster sizes of the crystals: coarse textured ones have darker blue colour, while fine textured ones have the lighter hue. The former being the result of single firing while the latter being the result of a two stage firing. Before the second firing stage, regrinding of the material was done. Additionally, there is the diluted blue, which is the consequence of high alkali content producing a large proportion of glass phase, and hence masking the blue phase of fine textured light blue.

Riederer (1997: 28) says that Egyptian blue is a very stable material that is not affected by organic media, alkaline mortars, or exposure to sunlight and heat. Furthermore, he says that it can only dissolve in hydrofluoric acid, and when heated to 1,050ºC, it will decompose to form a cupric and cuprous oxide mixture. Nevertheless, it has been found that Egyptian blue can degrade into a superficial green colour, as found in Old and Middle Kingdom Egyptian samples. In those samples, cuprorivaite ($CaCuSi_4O_{10}$) predominates over copper wollastonite ($(Ca,Cu)SiO_3$). The New Kingdom green samples, on the other hand, had the copper wollastonite predominating, and these were found to be of green frit (Lee and Quirke 2000: 110). It is claimed that the glass phase in Egyptian blue is able to devitrify and lead to the formation of copper chloride or malachite. This results in the change of the blue colour of the pigment to green and in making it friable (Lee and Quirke 2000: 110).

The most informative way for analyzing Egyptian Blue is by mounting a sample in resin, polishing it and analyzing it in a scanning electron microscope (Lee and Quirke 2000: 108).

In China, two artificially produced copper pigments, analogous with Egyptian blue, were reportedly found dating back to the Han dynasty (208 BC-AD 220). These are a blue barium copper silicate ($BaCuSi_4O_{10}$) (FitzHugh and Zycherman 1983) and purple barium copper silicate ($BaCuSi_2O_6$) (FitzHugh and Zycherman 1992).

Glaucophane ($Na_2Mg_2Al_3Si_8O_{22}(OH)_2$)
It is a sodium-magnesium-aluminum hydroxide-silicate, with sometimes iron replacing some of the magnesium (Goffer 1980: 173). Glaucophane as a mineral occurs in Crete and Santorini, and was found to have been used as a blue pigment in ancient Greece and Thera (Frizot 1982: 51).

Ultramarine ($(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$)
This pigment is a sodium/calcium aluminium silicate and is made from the mineral lapis lazuli. It has a deep blue colour, and consists of a mixture of minerals including blue felsparthoid lazurite (Goffer 1980: 173; Plesters 1993: 37). The process of refining ultramarine from lapis lazuli is a complex one (Kühn 1986: 172). Although lapis lazuli was used as a semi precious stone in early dynastic Egypt, and was described by Pliny and Theophrastus, who calls it the Scythian (Caley and Richards 1956: 183-184), there is still no evidence of its use as a pigment in ancient Egypt (Lee and Quirke 2000: 111; Lucas and Harris 1999: 343) or classical Greece or Rome. The first occurrence until now is in Afghanistan and goes back to the sixth-seventh century AD (Plesters 1993: 39).

Brown Pigments
Ochre pigments were often the materials used for producing brown colours. The brown colour of umber is the result of the additional presence of manganese dioxide in small quantities (Tite 1972: 355). Red, yellow and brown ochre was used in Egypt from the fifth dynasty to the Roman Period (Lee and Quirke 2000: 111). Ochre is composed of quartz sand, clay and iron oxide, while the term technically denotes the material produced from ochrous sand by fine grinding, whereby the sand is eliminated and the fine clay remains (Delamare and Guineau 2000: 15).

Brown hues of colour could also be produced by mixing several pigments. Often, brown pigments are red or yellow hues mixed with either black or white (Frizot 1982: 50). An example of this is the mixture of haematite, orpiment and carbon black that was found on an eighteenth dynasty papyrus. Also, a twenty-first or early twenty-second dynasty papyrus contained haematite and carbon black (Lee and Quirke 2000: 111). Ochre mixed with iron oxide, and soot mixed with iron oxide were found to have been used as brown pigments at Jericho during the first century BC (Rozenberg 1997: 66, 69). At the Roman fort in al-Humayma, Jordan (dated to second century AD), "maroon" paint was found to have been a mixture of red ochre and possibly bone black, while the brown colour used at the nearby Abbasid complex is a mixture of yellow and orange earth pigments and a black pigment that is believed to be charcoal (Corbeil, Oleson and Foote 1996: 426).

A brown colour was also achieved by applying red pigment over black – as for example haematite over black – or having yellow over haematite (Forbes 1965b: 229; Lucas and Harris 1999: 344). Additionally, at Bronze Age sites in ancient Greece, red was applied over blue to achieve a brown tone (Frizot 1982: 50).

Green Pigments

In addition to the usual green pigments that include naturally occurring minerals like malachite and green earth, a green colour could be achieved by mixing together blue and yellow pigments. Egyptian blue was sometimes mixed with yellow ochre (Forbes 1965b: 230; Grissom 1986: 143), and on some Egyptian papyri, it was mixed with yellow orpiment (Lee and Quirke 2000: 112-113). It also appears that Egyptian blue could be mixed with calcite to get a green colour (Filippakis 1979: 57). Analysis of a sample of green painted plaster from the eighteenth dynasty revealed the use of Egyptian blue with a yellow pigment that could not be identified and was suspected to be of organic nature (Lucas and Harris 1999: 345). Also, painters of ancient Crete and Greece created green hues by layering yellow and blue ones (Delamare and Guineau 2000: 28), such as the application of Egyptian blue under yellow ochre as in the painting of a tomb in Vergina (Frizot 1982: 51). Moreover, the addition of Egyptian blue to green earth would brighten it (Frizot 1982: 51), as has been found at the Roman Capitolium in Italy (Bugini and Folli 1997: 125). Green pigments found at Pompeii include verdigris, green earth and malachite (Augusti 1967: 100-107).

Atacamite ($Cu_2Cl(OH)_3$)

Atacamite is a basic copper chloride, found in samples dating from as early as the fifth dynasty in Egypt, and until as late as the end of the twelfth dynasty (Lee and Quirke 2000: 112). Green paint on several coffins belonging to the Middle Kingdom in Egypt possibly consists of atacamite and maybe even in association with malachite (Middleton and Humphrey 2001: 13). It has also been identified at the sculptural polychromy at Yungang in China, in association with malachite (Piqué 1997: 352-353). However, it has been argued that these were not always originally green pigments and that sometimes they are an alteration product of originally blue pigments (Lee and Quirke 2000: 112; Scott 2000: 47-48; 2002: 134-137).

Chrysocolla ($CuSiO_3 \cdot 2H_2O$)

Chrysocolla is a hydrated copper silicate of varying compositions. Its colour ranges are from bright green to blue green (Goffer 1980: 172). It was found in the analysis of green pigment in Egyptian material of the eighteenth dynasty (Lee and Quirke 2000: 112). Theophrastus mentions "*chrysokolla*" – the Greek term for the Latin word chrysocolla – as a pigment and that it is found in copper mines, but seems to use this term to denote any bright green mineral of copper (Caley and Richards 1956: 53, 105, 174).

Green Earth (terre verte)

Green Earth is basically a hydrous silicate of potassium/aluminium/ iron/magnesium (Goffer 1980: 172; McLaren 1986: 2). It is composed of siliceous minerals that have a dull green colour. The minerals which were potentially used as pigments were celadonite, glauconite, cronstedtite and chlorite. Green earth is principally prepared from either of the two clay minerals celadonite and glauconite. The former can be found in vesicular cavities or fractures in volcanic rock, the latter, is found as sediments in the form of small green pellets, i.e. green sand (Grissom 1986: 141). Celadonites, of pale bluish green hues, are rather rare in occurrence and were highly valued in comparison to the more abundantly found glauconites (Delamare and Guineau 2000: 28).

Vitruvius (VII, vii, 4) called it creta virdis:

> "Green chalk is found in many places, but the best is from Smyrna…"

While Pliny (XXXV, XXIX) mentions the "Appian" as being an imitation of malachite:

> "There are also two colours of a very cheap class that have been recently discovered: one is the green called Appian, which counterfeits malachite; just as if there were too few spurious varieties of it already! It is made from a green earth and is valued at a sesterce per pound."

The Romans produced pigments from green earth, which has been ascribed as originally an Etruscan or Gallic tradition (Delamare and Guineau 2000: 28). Green earth was found in the form of unused pigment and in the wall paintings at Pompeii (Augusti 1967: 100-101). Glauconite in particular, was largely spread throughout the Roman Empire and was even used in Dura Europos (Delamare and Guineau 2000: 28; Forbes 1965b: 232). Of interest is a green colour found on a painting in France dating to 10 AD. It is a mixture of celadonite, glauconite and Egyptian blue (Delamare and Guineau 2000: 29). Green earth was also found at Herod's Palace in Jericho (Rozenberg 1997: 69) and at the Roman wall painting at al-Humayma, south of Jordan, where it was identified as glauconite (Corbeil, Oleson and Foote 1996: 426).

Green Frit (Egyptian Green)

This material was found in several samples from Egypt and has been debated whether it was an originally green pigment or a product of transformation of Egyptian blue. According to Lee and Quirke (2000: 112), it consists of copper wollastonite ($(Ca,Cu)SiO_3$) and a glassy phase of copper, sodium chloride and potassium chloride, and, is produced by mixing the same ingredients used for making Egyptian blue, but with more lime and less copper. Pyrite (FeS) and covellite (CuS) might be found as minor components. It has also been suggested that copper wollastonite may have been the result of reducing conditions during the sintering of Egyptian blue, rather than intentionally intended as a pigment itself (Lee and Quirke 2000: 112; Riederer 1997: 28). According to Colinart and Pagés-Camagna (2001: 87), there is no evidence of Egyptian green as a product of the physical transformation of Egyptian blue, and, since the two pigments were found on the same object shows that they were used for different iconographic purposes. Experimental recipes conducted at the Research Laboratory of the Museums of France (LRMF), revealed that Egyptian green is produced by mixing the same compounds used for producing Egyptian blue but with more calcium and flux and less copper, under the same atmospheric conditions and at a temperature of 950-1150˚C (Colinart and Pagés-Camagna 2001: 87-88). The resulting product consists of parawollastonite ($CaSiO_3$) with 2% copper, residual silica and firing residues, all embedded in a silicate amorphous phase. Hence, it was concluded that although Egyptian blue and Egyptian green require the same materials and similar conditions for production, they are made by two different processes. According to Forbes (1965b: 230), this green frit occurs in Egypt from the sixth dynasty, but was unknown to the classical artists.

Malachite ($CuCO_3 \cdot Cu(OH)_2$)
This basic copper carbonate is found in abundance as a natural mineral. It is found in the Sinai and it was used by the Egyptians as a pigment on tomb paintings since the fourth dynasty (Gettens and FitzHugh 1993b: 184; Goffer 1980: 172; Lucas and Harris 1999: 345). Malachite was found on the polychromy of the Chinese terracotta army of the first emperor (Thieme 2001: 53), and on the polychromy of the "Archer" of the fifth century BC Greek temple of Aphaia (Brinkmann and Koch-Brinkmann 2001: 101).

Malachite is usually found in the upper zones of copper ores and is usually associated with azurite (Gettens and FitzHugh 1993b: 183). Classical authors like Pliny, Vitruvius and Theophrastus mentioned "chrysocolla" in their writings, although in fact they were referring to malachite (Forbes 1965b: 230; Gettens and Fitzhugh 1993b: 184). Preparation of malachite for use as pigment is done by crushing, grinding, washing and levigating it. Dark, medium and light tones of green correspond to coarse, medium and fine grinding of the mineral (Gettens and FitzHugh 1933b: 185). Natural malachite was often dyed with yellow dye-wood to get the right shade of green (Forbes 1965b: 230).

Verdigris ($CuO \cdot 2Cu(C_2H_3O_2)_2$)
This is a basic copper acetate that is artificially made by the treatment of copper minerals with vinegar (Goffer 1980: 172); the process includes piling copper plates with the residual remains of wine grapes after pressing, causing the copper to be covered with blue/green crusts that are then scraped off and used as pigment (Kühn 1993: 132).

Nowadays, the term verdigris refers to copper salts of acetic acid. Classical writers used the word to denote green corrosion products formed on copper surfaces and have explained its method of preparation. Although there is no conclusive evidence of its use in classical times (Kühn 1993: 131-132), nevertheless, its use as a pigment cannot be completely disregarded since it was described by these classical authors.

Theophrastus (Caley and Richards 1956: 57) describes the method of preparation of this pigment and says that it is done by placing "red copper" over residues of grape, and afterwards collecting the material that appears on the copper, with "red copper" apparently denoting copper without alloys, and the grape residues being wine lees (Caley and Richards 1956: 191). Pliny (XXXIV, XXVI), gives a similar description of its preparation:

> "…it is scraped off the stone from which copper is smelted, or by drilling holes in white copper and hanging it up in casks over strong vinegar which is stopped with lid; the verdigris is of much better quality if the same process is performed with scales of copper. Some people put the actual vessels, made of white copper, into vinegar in earthenware jars, and nine days later scrape them. Others cover the vessels with grape-skins and scrape them after the same interval, others sprinkle copper filings with vinegar and several times a day turn them over with spattles till the copper is completely dissolved. Others prefer to grind copper fillings mixed with vinegar in copper mortars…"

Vitruvius (II, XII, 1), says that verdigris is known as "aeruca", and again describes its method of preparation and says that it is similar to the preparation of white lead, and can be done by putting copper over vinegar and then closing the vessel with a lid.

Grey Pigments
In ancient Egyptian painting, grey was obtained by mixing together black and white, such as gypsum with charcoal or yellowish earth with lamp black (Forbes 1965b: 232; Lucas and Harris 1999: 346). Evidence shows that from the fourth and until the twentieth dynasty, the grey colour was achieved by mixing carbon black with gypsum. One instance was reported of mixing kaolinite with quartz on a papyrus (Lee and Quirke 2000: 113).

Orange Pigments
Egyptian samples of orange paint layers from the sixth dynasty to the Roman period were found to consist of red ochre, sometimes with a white pigment (Lee and Quirke 2000: 113). On an eighteenth dynasty papyrus it was found to be orpiment or pararealgar mixed with red iron oxide, in an early Ptolemaic papyrus it was found to be pararealgar, and in a late Ptolemaic one it was found to be similar to realgar (Lee and Quirke 2000: 113). Additionally, red and yellow were sometimes mixed to produce an orange colour, or by painting red over yellow (Forbes 1965b: 229; Lucas and Harris 1999: 346). Minium could also be used for achieving an orange hue, as it was found in samples from Herod's palace in Jericho, dated to the end of the first century BC (Rozenberg 1997: 66).

Pink Pigments
Mixture of Red and White Pigments
A Pink colour was often made by mixing red and white pigments (Forbes 1965b: 222), such as the mixing of ochre and a white pigment like gypsum in Egypt (Lee and Quirke 2000: 113; Lucas and Harris 1999: 346). At the site of Jericho (Rozenberg 1997: 68), a pink pigment was produced by heating goethite to a temperature of 850°C, turning it to red, and afterwards fusing it with white clay (kaolinite), while at Acre, it is claimed that the origin of the pink pigment used is a "ferroan dolomite" (Segal and Porat 1997: 89).

Madder lake
Madder is an organic red dye that is mainly taken from the root of the Rubia tinctorium plant found in Palestine and Egypt and occurring in Asia and Europe (Goffer 1980: 184). Pliny and Dioscorides have both described madder, and Vitruvius (VII, xiv, 1) mentions madder in the context of obtaining a purple colour:

> "Purple colours are also made by dying chalk with madder and hysginum. Other colours also are obtained from flowers…"

Madder is one of the best known lakes that is made by mixing the extract of its root with alum and precipitating it with sodium carbonate (soda), potassium arsenate or borax, leading to the precipitation of aluminium hydroxide (Kühn 1986: 173; Schweppe and Winter 1997: 122). Alizarin, purpurin and pseudo purpurin constitute the main colouring agents of this plant with colours ranging from scarlet to red, pink and bluish red (Schweppe and Winter 1997: 109). Also, according to the type of metal salt that is used as mordant, different colours can be obtained according to the metal, e.g. aluminium yields red and pink, while iron yields purple-black (Goffer 1980: 185). Madder was identified at Pompeii (Schweppe and Winter 1997: 111) and was found in a sample from Egypt dating to Greco-Roman times (Forbes 1965b: 222; Lucas and Harris 1999: 346). The use of madder lake appears to have been popular in the Middle East (Goffer 1980:

185) and madder painted over gypsum was identified in a tomb painting of the Hellenistic and Roman periods (Lee and Quirke 2000: 113).

Purple/Violet Pigments

The violet colour could be achieved by mixing Egyptian blue with red ochre or by heating haematite of an orange hue. Sometimes, the Romans produced violet by mixing a red lake with Egyptian blue or from the secretion of murex, which is a type of mollusc (Delamare and Guineau 2000: 28). About 10,000 molluscs produce one gram of purple dye, and there is ample evidence to suggest that Mediterranean molluscs were extracted at Tyre, Sidon and in the region of southern Italy (Delamare and Guineau 2000: 37). A clear fluid, produced in a gland near the head of the mollusc, is extracted from the shell, and when exposed to the sun and air it changes from white, to yellow, green, blue and then purple, which is then used as pigment (Ball 2001: 224).

From the 15th century BC, Tyrian purple was being produced in Asia Minor, and it is thought that the Greeks learnt its method of production from the Phoenicians (Ball 2001: 224). Pliny (XXXV, XXVI) calls this material "purpurissum":

> "Among the remaining colours which because of their high cost, as we said, are supplied by patrons, dark purple holds the first place. It is produced by dipping silversmiths' earth along with purple cloth and in like manner, the earth absorbing the colour more quickly than wool. The best is that which being of the first formed in the boiling cauldron becomes saturated with dyes in their primary state, and the next best produced when white earth is added to the same liquor after the first has been removed; and every time this is done the quality deteriorates, the liquid becoming more diluted at each stage. The reason why the dark purple of Pozzuoli is more highly praised than that of Tyre or Gaetulia or Laconia, places which produce the most costly purples, is that it combines most easily with hysginum and madder which cannot help absorbing it…"

Vitruvius (VII, xiii, 1-3) discusses the method of obtaining purple dye from sea shells, and claims that purple is a rather precious commodity:

> "We now turn to purple, which of all is most prized and has a most delightful colour excellent above all these. It is obtained from sea shells which yield the purple dye, and inspires in students of nature as much wonder as any other material. For it does not yield the same colour everywhere, but is modified naturally by the course of the sun…When the shells have been collected, they are broken up with iron tools. Owing to these beatings a purple ooze like a liquid teardrop is collected by bruising in a mortar. And because it is gathered from the fragments of sea shells it is called *ostrum*."

"Purpurissum" was identified by Augusti (1967: 75-76) as a pigment in Pompeii. It was also found at Jericho, while a dark violet pigment was found to contain cobalt phosphate ($CoPO_4$) and a lighter hue found in pigment bowls was produced by mixing blue and pink pigments (Rozenberg 1997: 68).

Red Pigments

Red pigments include common ones like red ochre and haematite which were used by most ancient cultures like Egypt, Greece and Rome. Cinnabar was used in ancient China, while red lead (minium) was used in ancient Mesopotamia, and was introduced to Egypt by the Romans (Forbes 1965b: 216-217). The red pigments found at Pompeii include ochre, minium, realgar and orpiment (Augusti 1976: 77-92).

According to Forbes (1965b: 219), Pliny confuses the three red pigments, vermilion – which he calls "cinnabaris" and "minium" – cinnabaris also used for "dragon's blood", and red lead. Pliny calls the latter "minium secundarium" and considers it as vermilion of secondary quality. Pliny (XXXV, XXII-XXIII) writes:

> "According to Juba sandarach or realgar and ochre are products of the island of Topazus in the Red Sea, but they are not imported from those parts to us. We have stated the method of making sandarach. An adulterated sandarach is also made from ceruse boiled in a furnace. It ought to be flame-coloured. Its price is 5 asses per lb."
>
> "If ceruse is mixed with red ochre in equal quantities and burnt, it produces sandyx or vermilion – though it is true that I observe Virgil held the view that snadyx is a plant, from the line: Sandyx self-grown shall clothe the pasturing lambs. Its cost per lb. is half that of sandarach. No other colours weigh heavier than these."
>
> "Among the artificial colours is also Syrian colour, which as we said is used as an undercoating for cinnabar and red lead. It is made by mixing sinopis and sandyx together."

On the other hand, Forbes mentions that Vitruvius gives a better discussion, but still couldn't distinguish between them well. Minium was also used to denote the mixture of cinnabar and red lead. Pliny and Dioscorides used the term false sandarach for red lead (sandarach being the term used for realgar). Vitruvius called red lead sandarach. Sandyx was the mixture of red lead and red ochre; syricum or siricum referred to red lead or litharge, to sandyx or a mixture of sandyx and synopis (FitzHugh 1986: 109). Chinese texts also confuse between cinnabar and minium (FitzHugh 1986: 110).

Cinnabar (HgS)

There are two kinds of this mercuric sulphide that is also known as vermillion: the natural mineral and the synthetic pigment. More accurately, cinnabar refers to the natural mineral form of the pigment, while vermilion refers to the synthetic form, whether prepared in the wet or in the dry process (Gettens, Feller and Chase 1993: 159). Cinnabar occurs in its natural form in the mines of Almaden in Spain, in the Ferghana region of Turkestan and in the provinces of Kweichow and Hunan in China. Other sources of cinnabar are Russia, Yugoslavia, Germany and Italy, as well as Peru, Mexico, Texas and California (Gettens, Feller and Chase 1993: 160).

Cinnabar was known in Etruscan and Greek painting (Frizot 1982: 50) and was well known to the Romans. Natural cinnabar was one of the red pigments found used on the early Greek sculptural relief of the west pediment of the Aphaia temple at Aegina (Brinkmann and Koch-Brinkmann 2001: 101) and was one of the red pigments used in painting the hunting scene at the Second Tomb of Vergina (Filippakis et al. 1979: 55). It was not used during the dynastic periods of Egypt, nor in Early Mesopotamia (Gettens, Feller and Chase 1993: 159). However, an Egyptian Papyrus going back to the Ptolemaic or early Roman period was found to contain vermilion as a pink-red pigment (Lee and Quirke 2000: 114), and it was found in Egyptian and Roman paintings of the first century AD, as well as in the form of a dry pigment at Pompeii (Goffer 1980: 171; Gettens, Feller and Chase 1993: 174). Cinnabar was documented as a pigment in the Shang dynasty (ca 1650-1050 BC) and was one of the pigments used for the polychromy on the warriors of the Chinese terracotta army, probably dated to 206 BC. It was used alone for painting the red tones (Thieme 2001: 53), or was mixed with Han purple ($BaCuSi_2O_6$) in order to give a violet hue (Onggi 1993: 390).

Natural cinnabar is prepared by grinding it in a stone mortar (Gettens, Feller and Chase 1993: 160). Preparation of synthetic cinnabar was apparently invented by the Chinese (Goffer 1980:171), who discovered how to make it out of sulphur and mercury, and the knowledge of the process was possibly transferred to the west by the Arabs (Gettens, Feller and Chase 1993: 160-162).

Vitruvius confuses between minium and vermilion:

> "I will go on to describe the treatment of minium or vermilion…the ore is first extracted. Then, using certain processes, they find minium. In the veins the ore is like iron, of a more carroty colour, with a red dust around it. When it is mined, and is worked with iron tools, it exudes many drops of quicksilver, and these are at once collected by the miners."
>
> "When the ore has been collected in the workshop, because of the large amount of moisture, it is put in the furnace to dry. The vapour which is produced by the heat of the fire, when it condenses on the floor of the oven, is found to be quicksilver."
>
> "When the ore is dry, it is bruised with iron rammers, and by frequent washing and heating, the waste is removed and the colour is produced. When, therefore, the quicksilver has thus been removed, minium loses its natural virtues, and becomes soft and friable." (Vitruvius VII, viii, 1-2; ix, 1).

Theophrastus talks about the two kinds of cinnabar, the natural and the artificially prepared one (Caley and Richards 1956: 57-57), though it was never artificially produced by the ancients, he probably refers to the fact that it occurs either in a pure form, or as a mixture with other material from which it should be separated (Caley and Richards 1956: 193-194).

Haematite (Fe_2O_3)

Haematite is anhydrous iron oxide, which is hard, compact and occurs in columnar and reniform (kidney ore) shapes (Gettens and Stout 1966: 118). It was found to have been used in pre-classical times, and in a few instances in Egypt, during the sixth and the eighteenth dynasties (Forbes 1965b: 216; Lee and Quirke 2000: 114), and on coffin painting of the Middle Kingdom (Middleton and Humphrey 2001: 13). It was a common pigment that was used in early Greek painting, such as in the painting of the Second Tomb of Vergina (Filippakis et al. 1979: 55), and for providing the skin tone for the "Archer" on the sculptural relief of the Aphaia temple at Aegina, dated to ca 490 BC (Brinkmann and Koch-Brinkmann 2001: 101). Haematite was sometimes used as the stone for burnishing gold leaf (Gettens 1966: 118, 282).

Minium (Red Lead Pb_3O_4)

Minium can be found naturally or is produced by heating lead monoxide (lead white) until it is oxidized. It started to be used in Egypt during Greco-Roman times, where its earliest known use was found at Hawara of the Greco-Roman period (Forbes 1965b: 216). It was found in Chinese wall paintings, in Central Asia and in Persia (Goffer 1980:172). According to Forbes (1965b: 216), it was also known in ancient Mesopotamia, and was made by the heating of lead, ceruse and dross to form litharge. This was in its turn ground and heated, to produce red lead.

Red lead was one of the first pigments that were artificially prepared, and if the natural mineral was ever used as a pigment, then it was only at a very early date (FitzHugh 1986: 109). Evidence shows that artificially manufactured red lead was already known during the Han dynasty in China (second century BC – second century AD), and there is no indication of its use as a natural mineral there (FitzHugh 1986: 110).

Vitruvius, Pliny and Dioscorides describe the preparation of red lead. According to Vitruvius (VII, xii, 1) and Pliny (XXXV, XII), who calls it "sandarach", the production of red lead is done by roasting lead white (ceruse) until it changes colour to red.

Realgar (AsS)
Realgar is an arsenic sulphide which provides a bright red colour that is close to orange. It was found in a few instances in ancient Egyptian contexts of the eighteenth and nineteenth dynasties (Lee and Quirke 2000: 114), and in coffin painting of the Middle Kingdom (Middleton and Humphrey 2001: 13). According to Vitruvius (VII, vii, 5):

> "Orpiment, which the Greeks call arsenic is mined in Pontus. Red arsenic also, in many places, but the best is mined in Pontus close to the river Hypanis."

Red Ochre
Red ochre is a natural earth that consists of silica and clay, with iron oxide which gives it the red colour (Lee and Quirke 2000: 113). It was a very popular red pigment used in ancient Egypt, Mesopotamia, Greece and Rome. In Egypt it was in use since pre-dynastic times, and was abundant near the area of Aswan and in the western desert (Forbes 1965b:215) and continued to be used during the Roman period (Lee and Quirke 2000: 114). It was also used on the polychromy of the west pediment of the Aphaia temple in ancient Greece (Brinkmann and Koch-Brinkmann 2001: 101), and was detected in samples from Jericho dating to the first century BC (Rozenberg 1997: 65). Berger (1904: 17) mentions red ochre mixed with gypsum in one of the samples found in Pompeii.

Some types of red ochre, upon mixing with white yield a yellow hue (Goffer 1980: 171), while it has been noted that red ochre could be obtained by burning yellow ochre, when the latter is not available (Lucas and Harris 1999: 348). Various shades of red could be obtained by mixing different proportions of red ochre and calcite on the wall paintings of the Roman fort and Abbasid castle at al-Humayma in Jordan (Corbeil, Oleson and Foote 1996: 426).

Ancient writers give a detailed description of red ochre, its provenance and the different quality of the various types of ochre. Vitruvius (VII, vii, 2) writes the following:

> "Abundant *red* ochre, is extracted in many places, but the best is only found in a few, such as Sinope in Pontus, and in Egypt, in Spain in the Balearic Isles, and also in Lemnos, where the Roman government handed over the revenues to the Athenians."

Pliny (XXXV, XIII) provides further information, giving the cost of buying the ochre:

> "Sinopis was first discovered in Pontus, and hence takes its name from the city of Sinope. It is also produced in Egypt, the Balearic Islands and Africa, but the best is what is extracted from the caverns of Lemnos and Cappadocia, the part

> found adhering to the rock being rated highest. The lumps of it are self-coloured, but speckled on the outside. It was employed in old times to give a glow. There are three kinds of Sinopis, the red, the faintly red and the intermediate. The price of the best is 2 denarii a pound…"

And about the red ochre of Lemnos, Pliny (XXXV, XIV) writes:

> "…approximates very closely to cinnabar, and it was very famous in old days, together with the island that produces it; it used only to be sold in sealed packages, from which it got the name 'seal red-ochre'. It is used to supply an undercoating to cinnabar and also for adulterating cinnabar."

While concerning the other types of red ochre, he states:

> "Among the remaining kinds of red ochre the most useful for builders are the Egyptian and the African varieties, as they are the most thoroughly absorbed by plaster." (Pliny XXXV, XV).

Dioscorides (Riddle 1985: 156) also mentions red earth from Sinope in addition to Lemnian earth, which most probably comes from Lemnos.

White Pigments

Aluminium Hydroxide ($Al(OH)_3$)

Aluminium hydroxide (aluminium hydrate) is prepared from a solution of aluminium sulphate treated with soda ash or potash (K_2CO_3). It is a transparent white material that can also easily absorb dyes, and was often used as a substrate for dyes, or as filler for pigments. Alum ($AlK(SO_4)_2 \cdot 12H_2O$) was the source for making a dye base in classical times (Gettens and Stout 1966: 91-92).

Bone White

Bone white was produced by the burning of bone until it turned white, which was afterwards ground and used as a pigment, with a greyish white hue. It is composed mainly of calcium phosphate ($Ca_3(PO_4)_2$), with some calcium carbonate and other minor constituents (Goffer 1980: 169).

Calcium Carbonate ($CaCO_3$)

This white pigment is produced from limestone, marble, chalk and shells (Goffer 1980: 169). Calcium carbonate is white, and hence has been used as white pigment, as well as extender. Calcium carbonate pigments include calcite, chalk, lime white, shell white (aragonite) and coral. These can have various impurities such as quartz, magnesite, dolomite, clays, and colouring agents like haematite and carbon. Dolomitic limestone or ground dolomite can also be found (Gettens, FitzHugh and Feller 1993: 203-204). Calcium carbonate was the most widely used white pigment in antiquity (Frizot 1982: 49). It was used in ancient Egypt until the Roman period (Forbes 1965b: 233; Lee and Quirke 2000: 114; Lucas and Harris 1999: 249) and was found in the first century BC palace at Jericho consisting of calcite and dolomite (Rozenberg 1997: 65). Lime and chalk were both used by the Greeks and Romans (Forbes 1965b: 233; Goffer 1980: 169). Chalk is a soft rock and was used in paintings in Pompeii and ancient Greece (Augusti 1967: 51-61; Gettens, FitzHugh and Feller 1993: 204-205). Lime white is the thick paste of water-slaked lime when kept moist for weeks, and was used as a white pigment by Italian painters in fresco painting (Gettens, FitzHugh and feller 1993: 206).

It seems that a type of calcium carbonate favoured by the ancients was "Paraetonium", as described by Vitruvius and Pliny:

> "Paraetonium white has its name from the place where it is mined. In the same way Melian white has its name because a mine is said to occur in Melos, an island of the Cyclades." (Vitruvius VII, vii, 3).

> "Paraetonium is called after the place of that name in Egypt. It is said to be sea-foam hardened with mud, and this is why tiny shells are found in it. It also occurs in the Island of Crete and in Cyrene. At Rome it is adulterated with Cimolian clay which has been boiled and thickened. The price of the best quality is 50 denarii per 6lbs." (Pliny XXXV, XVIII).

Gypsum ($CaSO_4 \cdot 2H_2O$)
Calcium sulphate is basically gypsum, and was very widely used in ancient Egypt up to the Roman period as a white pigment (Forbes 1965b: 233; Lucas and Harris 1999: 349; Lee and Quirke 2000: 114). It was also used by the Greeks and Romans (Forbes 1965b: 233).

Clays
These are hydrated aluminium silicates of various types, of which the naturally found kaolinite ($[Al_2Si_2O_5(OH)_4]_2$) was the one that was mostly used (Goffer 1980:169). Besides calcium carbonate, some of the white pigments analyzed from Pompeii were found to be of clay origin (Augusti 1967: 51-61). Theophrastus (Caley and Richards 1956: 58-59), talks about the Melian, the Samian and the Kimolian earths, and mentions that the best to be used by artists for painting is the Melian. Pliny (XXXV, XIX) discusses Melinum as the clay pigment, rather than the Samian or Eritrian which are used in medicine, while he mentions the Cimolian earth in relation to medicinal uses and as a dye (Pliny XXXV, LVII). Regarding Melinum, he says:

> "Melinum also is a white colour, the best occurring in the island of Melos. It is found in Samos also, but the Samian is not used by painters, because it is excessively greasy. It is dug up in Samos by people lying on the ground and searching for a vein among the rocks. It has the same use in medicine as earth of Eretria."

Huntite ($CaCO_3 \cdot 3MgCO_3$)
This magnesium calcium carbonate is noted as a good painting material due to its bright colour, adhesiveness and fine grains (Lee and Quirke 2000: 114). It was detected as the white pigment on painted pottery bowls and sherds excavated at Koshtama in Nubia, and dated to 1600 BC (Riederer 1974: 103). It was also found in samples from Egypt dating to the twelfth dynasty, as well as the eighteenth to the twenty-second dynasty, and was identified as white pigment, either alone or in association with gypsum (Lee and Quirke 2000: 115). Recent research (Heywood 2001: 5-9), has shown that this pigment was very common in ancient Egypt from the Old Kingdom period and until Roman times, and occurs in the northwestern and eastern desert regions of Egypt and in Sinai.

Lead White ($2PbCO_3 \cdot Pb(OH)_2$)
Lead white is a basic lead carbonate that can be found in nature as well as synthetically produced since early times, by the corrosion of lead with vinegar (Goffer 1980: 170; Gettens, Kühn and Chase 1993: 68). It was a very important pigment in ancient times, and its method of preparation was described by Theophrastus, Pliny and Vitruvius. It was also already used in China in 300 BC (Gettens, Kühn and Chase 1993: 68).

Preparation of this synthetic pigment was made by exposing strips of lead in clay pots that had at the bottom a compartment with a solution of vinegar. The pots were stacked inside a shed that had horse manure, producing carbon dioxide and some heat. This, along with the action of vapours from acetic acid, transformed the lead to basic lead carbonate, which was then scraped, washed, dried and ground for use as a white pigment (Gettens, Kühn and Chase 1993: 68). Vitruvius (VII, xii, 1) describes this process by saying:

> "At Rhodes they place a layer of chips in a large vessel, and pouring vinegar over them, they put lumps of lead on the top. The vessel is covered with a lid lest the vapour which enclosed should escape. It is opened after a certain time and the lead is found to be changed into *cerussa*."

Theophrastus (Caley and Richards 1956: 57) gives a similar description, but with more detail:

> "Lead about the size of a brick is placed in jars over vinegar, and when this acquires a thick mass, which it generally does in ten days, then the jars are opened and a kind of mold is scraped off the lead, and this is done until it is all used up. The part that is scraped off is ground in a mortar and decanted frequently, and what is finally left at the bottom is white lead."

Pliny (XXXV, XIX) also discusses lead acetate:

> "…ceruse or lead acetate, the nature of which we have stated in speaking of the ores of lead. There was also once a native ceruse earth found on the estate of Theodotus at Smyrna, which was employed in old days for painting ships. At the present time all ceruse is manufactured from lead and vinegar, as we said."

Yellow pigments

> "…the yellow material which the Greeks call ochre. This is found in many places, as also in Italy. What used to be the best, the Attic, is not available now, …Hence the ancients used a large amount of yellow in their frescoes."(Vitruvius VII, vii, 1).

Indeed, yellow was a very common colour in antiquity, and most of the yellow pigments used in antiquity come from yellow ochre (Frizot 1982: 49).

Jarosite and Natrojarosite ($KFe_3(SO_4)_2(OH)_6$ and $NaFe_3(SO_4)_2(OH)_6$)

Jarosites are minerals of a pale yellow colour containing sulphates of iron, potassium and sodium. Jarosite, natrojarosite or a mixture of the two were identified on Egyptian artefacts from the Old Kingdom (2700-2200 BC) to the Ptolemaic period (332-30 BC), and have been confirmed to have been original pigments rather than a deterioration of iron bearing glass pigments – as previously speculated – since no iron could be detected, and, the original choice of yellow colour appears certain (Colinart 2001: 2-3). It was identified at Karnak (Le Fur 1994) and on Middle Kingdom coffins at Asyut and Beni Hasan (Middleton and Humphrey 2001: 13).

Lead Antimonite ($Pb_2Sb_2O_7$)

Lead antimonite, sometimes referred to as Naples yellow was much used in Babylonian glazes (Forbes 1965b: 229). It was already being manufactured during the eighteenth dynasty in Egypt (16^{th} to 14^{th} century BC), as a colorant for glass (Wainwright, Taylor and Harley 1986: 219-221). It is manufactured by roasting lead and antimony oxides or salts and was also used in glazing in Mesopotamia and Assyria.

Massicot (yellow lead oxide PbO)
Massicot (litharge) is obtained as a by product of the refining of silver (Forbes 1965b: 227). It was used in Egypt from the pre-dynastic periods to classical times, and has been found on a palette dated to 400 BC (Lucas and Harris 1999: 350).

Pliny (XXXV, XX) says that it was discovered by accident, and describes that it could also be produced from white lead:

> "Burnt ceruse was discovered by accident, when some was burnt up in jars in a fire at Piraeus. It was first employed by Nicias above mentioned. Asiatic ceruse in now thought the best; it is also called purple ceruse and it costs 6 denarii per lb. It is also made at Rome by calcining yellow ochre which is as hard as marble and quenching it with vinegar."

Orpiment (As_2S_3)
Another ancient yellow pigment was orpiment, which is a natural sulphide of arsenic. It was mentioned by Vitruvius and Pliny as not compatible with fresh plaster (Goffer 1980: 171). It was definitely used in ancient Mesopotamia (Forbes 1965b: 227) and was found on Egyptian material as early as the second dynasty (2900-2700 BC) (Colinart and Pagés-Camagna 2001: 85), the twelfth, eighteenth, nineteenth and twentieth dynasties, the Third Intermediate period and thirtieth or early Ptolemaic period and was used with yellow ochre on New Kingdom temple and tomb walls (Saleh et al. 1973: 144, 147; Lee and Quirke 2000: 115-116). It does not occur in Egypt, but rather in Syria and Anatolia. Thus, it was most probably imported from places like Persia, Armenia, and Asia Minor (Lucas and Harris 1999: 350). The Kharga Oasis and St John's Island in the Red Sea are considered also as possible sources of orpiment that are close to the Nile valley (Lee and Quirke 2000: 115). Orpiment was occasionally mixed with yellow ochre, or was used as a substitute for gold due to its bright hue (Colinart 2001: 3)

Yellow ochre
Yellow ochre is hydrated iron oxide, which is basically a natural earth consisting of clay and silica, and, owing its colour to the presence of goethite ($Fe_2O_3{\cdot}H_2O$). Pigments that have a high content of iron oxide, with a darker yellow colour, are sometimes classified as siennas (Goffer 1980: 170). It has been noted that only a few spots of this ochre are enough to give the impression of colour (Colinart 2001: 1). It was very commonly used in ancient Egypt (Lucas and Harris 1999: 349-350), where it was found as pigment in samples dating from the fifth dynasty to the Roman period (Lee and Quirke 2000: 115). It was also identified in yellow paint samples from Knossos (Frizot 1982: 49) and on the polychromy of the sculptural relief of the west pediment of the Aphaia temple at Aegina (Brinkmann and Koch-Brinkmann 2001: 101).

Yellow ochre was the most extensively used yellow pigment in the ancient world. Pliny (XXXIII, LVI) discusses yellow ochre with some detail:

> "Yellow ochre is strictly speaking a slime. The best kind comes from what is called attic slime; its price is two denarii a pound. The next best is marbled ochre, which costs half the price of attic. The third kind is dark ochre, which other people call Scyric ochre, as it comes from the island of Scyros, and nowadays also from Achaia, which they use for the shadows of a painting, price two sesterces a pound, while that called clear ochre, coming from Gaul, costs two asses less. This and the Attic kind they use for painting different kinds of light, but only marbled ochre for squared panel designs, because the marble in it resists the acridity of the lime. This ochre is also dug up in the mountains 20 miles from Rome. It is afterwards burnt, and by some people it is adulterated

> and passed off as dark ochre; but the fact that it is not genuine and has been burnt is shown by the acridity and by its crumbling to dust.
>
> The custom of using yellow ochre for painting was first introduced by Polygnotus and Micon, but they only used the kind from Attica. The following period employed this for representing lights but ochre from Scyros and Lydia for shadows. Lydian ochre used to be sold at Sardis, but now it has quite gone out."

Yellow ochre was also sometimes used as a ground for gilding (Forbes 1965b: 226). Pliny (XXV, XVII) provides a description for the preparation of a mixture for ochre that could be used as a base for gilding:

> "Half a pound of sinopis from Pontus, ten pounds of bright yellow ochre and two pounds of Greek earth of Melos mixed together and pounded up for twelve successive days make 'leucophorum', a cement used in applying gold-leaf to wood."

Gold Leaf

Gold leaf was often used in ancient Egypt and the classical world, especially on sculptural relief and moulded stuccowork. It was detected on the "Archer's" bow decorating the west pediment of the Apahia temple at Aegina (Brinkmann and Koch-Brinkmann 2001: 101). For attaching gold leaf, it was either glued directly to the surface, or was applied on an intermediate gesso layer (Ogden 2000: 164).

In ancient Egypt, gold could be mined in three different regions, producing three types of gold: the so-called "gold of Koptos", from Koptos, a trading centre on the Nile, the "gold of Wawat", from further to the south through Wadi Allaqi and Wadi Gabgaba, and "gold of Kush" from Sudan and parts of Ethiopia (Ogden 2000: 161). The quality of native Egyptian gold ranges from very high purity to that containing at least 40% silver (Colinart 2001: 1). Gold-silver alloy with less than 75% gold is known as "electrum", while "aurian silver" is when the quantity of gold present is 5-50% (Ogden 2000: 162).

Gold can be beaten into very thin leaves, by placing the foil between two parchment sheets and then beaten to extreme thinness (Gettens and Stout 1966: 115). Silver, copper, iron and tin can be found as trace elements in ancient gold (Forbes 1965a: 581). While copper was sometimes added to give gold a reddish colour, especially in the presence of silver, iron was added to achieve a burgundy-red tone (Ogden 2000: 163-164).

3.4 Ancient Styles of Painting

3.4.1 Colour and Meaning

It was only during the beginning of the nineteenth century that archaeologists began to find out that both, the architecture and sculpture of classical Greece had been once painted rather than left in its pure white form as thought before (Gage 1999: 11). This notion slowly began changing the perceptions regarding ancient art, and in particular classical art, as already noted in the 1950s by Malraux (1956: 47), where he mentions that Greek sculpture was not white as previously conceived.

Indeed, colour played a vital role in the cultural and religious representations of ancient societies. As early as the end of the second millennium BC in China, the different colours had different meanings in the ritual system of the Shang, whereby the colours were related to specific contexts (van Ess 2001: 67). Based on recent studies, it appears that there were only four basic colour terms, namely for red, white, yellow and dark that were inscribed on the oracle bones of the Shang. These terms were often related to sacrificial animals, and according to van Ess (2001: 68), the lack of terms for blue and green in the oracle bones could possibly be due to the fact that there was no blue or green sacrificial animals, although evidence seems to suggest that terms for blue and green did not yet exist in the third century BC (in the *Book of Changes*, heaven is "dark" and earth is "yellow"). In the Five Elements speculations which started during the period of the fourth or third century there is the element of earth being yellow, fire as red, metal as white, wood as green and water as black, although according to van Ess (2001: 69), there were originally four colours representing the four directions, with yellow as the colour of the centre being added later. This notion could be further seen in the fact that the colours seemed to correspond to the four seasons: spring being green like the east, summer red like the south, autumn white like the west and winter black like the north. Also, there seems to also have been a dynastic cycle of the three colours of black, white and red: the Xia dynasty ruled under the black colour, the Shang under white and the Zhou under red (van Ess 2001: 69). The Qin ruled under black and the element of water, while the Han, although initially ruled under black, they later changed it to yellow and then to red (van Ess 2001: 69-70). Ancient records also show that wearing coloured garments was reserved to the officials and dignitaries, whose wives also wore their robes in the colours that reflected the ranks of their husbands, with red representing the highest ranks and being the colour of the Zhou and the Han dynasties (van Ess 2001: 70).

In ancient Egypt, the main aspects of representational art, according to Ball (2001: 69), is that it reflects the normal daily life of Egyptians in an ideal way. The colours used were meant to "represent the visible world, and to convey symbolic concepts, through which a sacred environment was created" (Taylor 2001: 164). In fact, colour terms sometimes had implications of symbolic or emotional nature, such as the reference to "red things" as anything of evil nature in Papyrus Ebers (Pinch 2001: 182). Although Egyptian magical objects bear a variety of colour hues, however, in a single magical spell, one does not usually find a mention of more than four colours. The four basic colour terms most often found in the Egyptian language are for black, white, red and green/blue. It has been argued that the artist was also a ritual practitioner, and there are a number of references relating to writings or drawings in blood of certain animals and of human blood (Pinch 2001: 182-183). Sometimes, in the use of colour in magical spells, a colour could play the role of another, as for example, in the "Typhonian ink" mentioned in spells of the Roman period, the recipe of which included "red Typhon's" ochre and "a fiery red poppy"; although the extract of the poppy might not be red, it was nevertheless considered as having the "essence of redness" (Pinch 2001: 183).

According to Pinch (2001: 183), a reason why there were few colour terms could be due to "word play" whereby the four mentioned colour terms could have different symbolism according to the what the spell is intended to do. The term for white has different meanings of light and silver. Silver was related to the moon and to the god Toth (god of magical knowledge) (Wilkinson 1994: 84, 109), and it was the material from which the bones of the gods were made of (Robins 2000: 25). White was the colour worn by ritual practitioners (Kees 1943: 445). Black, although associated with crop fertility and the resurrection of Osiris (Kees 1943:

418-422), it could also be the colour of demons. In magical rituals, black was mainly used for protection and for warding off dangerous beings (Pinch 2001: 183). Green could refer to the resurrection of Osiris, but also the term for green has many connotations referring to "freshness, newness, vigour, flourishing and papyrus" (Pinch 2001: 183).

Yellow was a colour that represented life and growth to the ancient Egyptians, as it was derived from the sun, and was also known to represent the flesh of the gods (Colinart 2001: 1; Colinart and Pagés-Camagna 2001: 85), and especially of goddesses (Baines 2001: 154). Women's flesh and some food items were also painted in yellow, while gold was sometimes used for yellow for its symbolic value, as it was associated with immortality, represented the gods' flesh and was considered to assist the dead in speaking and eating in the afterlife (Colinart 2001: 1; Robins 2000: 25). It was used to represent the god Re and other divinity, with orpiment sometimes substituting gold (Colinart 2001: 1; Colinart and Pagés-Camagna 2001: 85).

Red signified dangerous things, but could be of powerful protection with appropriate handling, symbolizing such things as fire, and associated with the enemies and divine order (Pinch 2001: 184). It also has positive connotations, and, was sometimes used instead of the golden yellow colour symbolizing the sun disc. Red, along with green, was used for colouring the dress of goddesses in order to differentiate it from the dress of human women (Baines 2001: 154).

In studying the use of colours by the ancient Greek artists, one should take into consideration the concept of having a restricted palette of four colours by the renowned painters of the time, as mentioned by Pliny (*Natural History*) and Cicero. Pliny (XXXV, XXXII), discusses how these artists – Apelles, Aeton, Melanthius and Nichomachus – used only white, yellow, red and black colours, and how art was much more highly regarded then than during the current time when a wider range of colours was used:

> "four colours only were used by the illustrious painters Apelles, Aeton, Melanthius and Nichomachus to execute their immortal works – of whites, Melinum; of yellow ochres, Attic; of reds, Pontic sinopes; of blacks, atramentum – although their pictures each sold for the wealth of a whole town. Nowadays when purple finds its way even on to party-walls and when India contributes the mud of her rivers and the gore of her snakes and elephants, there is no such thing as high-class painting. Everything in fact was superior in the days when resources were scantier. The reason for this, as we said before, it is values of material and not of genius that people are now on the look-out for."

Vitruvius (VI, v, 7-8), similarly talks about how modern painting became more lavishly coloured in accordance with the taste of the "client", while in the past, it was the craftsmen's skill that provided dignity for their buildings:

> "The aims which the ancients sought to realise by their painstaking craftsmanship, the present attains by coloured materials and their enticing appearance. The dignity which buildings used to gain by the subtle skill of the craftsman, is not even missed owing to the lavish expenditure of the client.
>
> For who of the ancients is not found to use minium as sparingly as the apothecary? But at the present day whole walls are covered with it everywhere. To it is added malachite, purple, Armenian ultramarine. And when these are applied, apart from any question of skill, they affect the vision of the eyes with brilliance. Because of their costliness they are excluded in the specification, so that they are charged to the client and not to the contractor"

According to Bruno (1977: 54-55), this restriction of three or four colours suggests the use of primary colours – i.e. a set of colours, that are not obtained by mixing other pigments, while in blending them all of the other colours could be obtained. The primary colours are red, yellow and blue, while orange, green and purple are secondary in the sense that they are each produced by mixing two of the primary colours. Moreover, Bruno (1977: 58-59) attributes the selection of white, yellow, red and black as the primary colours by the ancients to the discovery of chiaroscuro and shading: white seen as necessary at the time as it would have been the equivalent of light, and black would have been the equivalent of dark. An alternative to the proposal of the use of "primary colours" by the classical Greek painters is his hypothesis that these four colours were those used by the famous painters of the fifth century, who developed the art of chiaroscuro in painting (Bruno 1977: 67). Three dimensionality can be more easily achieved by using earth pigments rather than the other brighter ones (Ball 2001: 75). The notion of four primary colours in nature goes back to the period of early classicism (mid-fifth century BC), as reflected in the writings of Democritus and Empedocles, with the analogy of the mixing of the four colours with the harmony of the four elements of earth, air, fire and water (Bruno 1977: 56-57). It has been suggested that Pliny's limited palette of four colours is due to limited linguistics at the time, whereby a bigger range of colours could not be presented, as for example red and green could be confused and so were yellow and blue.

Democritus mentions white as being a function of smoothness while black of roughness, and spoke of red in relation to heat and green as made of solid and void (Gage 1999: 12). Plato and Aristotle followed in presenting their own theories on colour, where Plato relates colour to the ray of vision sent by the eye, while Aristotle, among other writings states that the mixture of light and dark produces intermediate colours, claiming the unmixed intermediate colours being crimson, voilet, leek-green, deep blue and grey or yellow.

In fact, Greek painters did not only use earth pigments, but also the other brighter pigments. Gage (1999: 29-30) argues that it is highly improbable that the famous Greek artists would have suddenly abandoned the use of the bright blue colour that was much used from Mycenaean to Hellenistic times, and claims that the painters of the fourth century BC were not in fact aware of a restriction presented by a four colour palette. Additionally, he mentions that it was not until the time of Aëtius that there were four basic colours, white, black, red and yellow, and these were related to the four elements. The omission of blue in the list of colours used by classical writers and the inclusion of black certainly presents a certain dilemma. Democritus presents white, red, green and black when he discusses the analogy of Empedocles, whereby the other colours are derived from these four by mixing, while Aëtius (late first or early second century AD), substitutes yellow for green (Bruno 1977: 73; Gage 1999: 12). Although it could be plausible that black was mistakenly mentioned instead of blue, it has nevertheless been suggested that there existed a black that was "capable of appearing blue, or a blue that for some reason was described by ancient writers as black" (Bruno 1977: 77).

Furthermore, the Greek spectrum of colours from white to black, i.e. light to dark, with yellow as the closest to light, red and green being in the middle, and blue closest to dark, could be the reason why Pliny excluded it, as it might have been considered a variation of black (Ball 2001: 15). Bruno (1977: 79-87) discusses the role of blue in shading in early classical painting: "…restricts the use of blue to the role of a darkener in the process of shading, while the colors we usually identify as the body colors of the major forms may be grouped around just four color names – red, yellow, white, and black – as in the ancient literature" (Bruno 1977: 83). Hence, he concludes that this four colour palette, an invention of the early classical painters, came to be used also by the later painters as this practice of using a restricted palette came to "symbolize the simplicity and austerity of an earlier age" (Bruno 1977: 87).

Of all the colours, purple was a highly esteemed hue, at least at the time of Pliny's writing, although it was neither part of the four colour palette, nor a primary colour. Pliny (IX, XXXVI) mentions purple as a colour worn by the highest officers:

> "It is the badge of noble youth; it distinguishes the senator from the knight; it is called to appease the gods."

In Roman times, purple came to be considered as a "royal" colour and by the beginning of the fourth century AD it became associated with the Roman emperor (Ball 2001: 225; Gage 1999: 25). The reason why purple held such an important meaning owes to the fact that it was grouped with red, which represented fire and light, was associated with the divine, and had an affinity with gold (Gage 1999: 26).

3.4.2 Aspects of Painting Styles in the Classical World

The earliest records which describe wall paintings and the artists who produced them are those of classical Greece, such as in the accounts of Pliny (*Natural History*; XXXV, I-II):

> "…first we shall say what remains to be said about painting, an art that was formerly illustrious, at the time when it was in high demand with kings and nations and when it ennobled others whom it deigned to transmit to posterity. But at the present time it has been entirely ousted by marbles, and indeed also finally by gold…"
>
> "The painting of portraits, used to transmit through the ages extremely correct likenesses of persons, has entirely gone out…people tapestry the walls of their picture-galleries with old pictures, and they prize likenesses of strangers, while as for themselves they imagine that the honour only consists in the price…"

On famous painters Pliny (XXXV, XXXIV) notes:

> "I will now run through as briefly as possible the artists eminent in painting; and it is not consistent with the plan of this work to go into such detail; and accordingly it will be enough just to give the names of some of them even in passing and in course of mentioning others, with the exception of famous works of arts which whether still extant or now lost it will be proper to particularize."

Although much of ancient Greek painting has been long lost as it was mostly executed on wooden panels, nevertheless, recent discoveries, along with academic research regarding the wall paintings of Macedonian tombs provide new insight into Greek artistic achievements (Ling and Prag 2000: 193; Miller 1999: 75). According to the ancient writers, the golden age of Greek painting is known to have been during the late fifth and fourth centuries BC, when artists acquired fully illusionistic techniques, linear perspective, the use of shade and light and casting shadows for setting objects in space (Ling 1991: 5). The tombs with figured painting have been dated to the period between 350 BC and 300 BC and represent the period when Macedonia was the major Greek power under the reigns of Philip, Alexander and Cassander (Miller 1999: 87).

Several tombs at Lefkadia and Vergina were found with painted façades and interiors. The Prince's Tomb at Vergina has its exterior architectural elements painted in red, blue and white, while its only surviving interior painting depicts racing chariots on a deep blue ground (Ling and Prag 2000: 201). Another tomb found in Vergina with painting is that ascribed to Philip II, the father of Alexander the Great, and depicts a forest hunting scene in brown, green and grey colours (Ling and Prag 2000: 199). The third tomb discovered in Vergina, the Tomb of Persephone, although the smallest in size, yet it has retained magnificent fresco paintings along three of its sides, whereby the lower 1.5 m of the wall is painted in red, topped by a frieze with painted griffins, each two facing each other, on a blue painted background (Ling and Prag 2000: 197). Above the frieze are three different paintings represented on the three walls. The southern wall has a painting of three seated female figures representing the three Fates, while the eastern wall has a painting of a seated woman, the goddess Demeter mourning her daughter, and finally the northern wall has a representation of Pluto carrying Persephone in his chariot and is preceded by Hermes (Andronikos 1994: 49-92; Ling and Prag 2000: 197). The paintings along the three walls had a preliminary design which was incised in the plaster. The wall painting along the north wall has several incisions which are not in accordance with the final painting, and hence, as Andronikos (1994: 92-99) concludes, the painting was not reproduced according to a set design or stencil. Furthermore, the preliminary design was intended mainly to establish the composition of the painting rather than to draw exact outlines. It appears that not all Macedonian tombs were executed in this manner, as they not all have evidence of preliminary incised designs, and hence it is assumed that drawings were made first on a material and were later transferred to the wall (Andronikos 1994: 96-99). The paintings were executed in the fresco technique (Ling and Prag 2000: 198), with the predominance of red and yellow colours, limited blue and the absence of green colour (Andronikos 1994: 119). According to Andronikos (1994: 120; 126-130), the painter of the Rape of Persephone is Nichomachos since its in the classical tradition of painting, while that of the Tomb of Philip would probably be Philoxenos, the pupil of Nichomachos, with a new style that flourished later in the Hellenistic era.

Subjects relating to mythology and history were prominent in Greek painting, as those of personifications and portraits came to be popular as well (Ling 1991: 5). Tomb paintings of ancient Macedonia represented themes relating to the passing of the dead into the next world, hunting or chariot racing, and banqueting. The paintings were executed by very skilled artists as shown by the quick brushstrokes providing a naturalistic rendering of figures. The colours used for the murals mainly included different hues of purple, pink, red, yellow and brown, rather blue and green (Ling and Prag 2000: 203). It appears that landscape played an important role in artistic wall painting, whereby figures were reduced in scale in relation to landscape (Ling and Prag 2000: 204).

The tombs at Lefkadia were the earliest Macedonian tombs to have been discovered, whereby a few of them have retained interesting paintings (Ling and Prag 2000: 194). The Great Tomb has a quite elaborately painted façade which consists of four Doric columns, topped by an architrave, a fillet (taenia), a frieze of triglyphs and metopes, a cornice and sima. Above that is a frieze with a painted battle scene. The architectural elements are painted in red or blue colours: the taenia is red, the triglyphs are blue, and the cornice and sima are red and blue. The paintings of centaurs and Lapiths inside the metopes were done in tones of brown and grey in addition to some yellow hues. The battle scene in the frieze is made in relief and painted in natural tones, set against a blue background. The four figures painted inside the intercolumniations are likewise of naturalistic colours.

Regarding later Greek painting – during the Hellenistic period – not much could be learnt from literary sources, although it appears that there wasn't much accomplished in terms of representational art, while more popular was the masonry style of painting (Ling 1991: 7). Vitruvius (VII, v, 1) mentions this style of decoration:

> "…the ancients who first used polished stucco, began by imitating the variety and arrangement of marble inlay…"

The masonry style represents an imitation of ashlar masonry. It goes back to at least the end of the fourth century BC, and appears to have been well spread during the third and second centuries BC. Stucco was used for moulding in relief ashlar masonry and other architectural forms with the application of colour to hint at the use of different stone types (Ling 1991: 12).

Most of the surviving wall paintings of the Roman period were found at Pompeii, Herculaneum and other cities, which were buried in the year AD 79 by the volcanic eruption of Mount Vesuvius. Burial under volcanic ash has helped in preserving those cities, and especially their wall paintings. In 1882, the scholar August Mau divided the Roman paintings at Pompeii into four different styles on the basis of how the wall was treated and how space was painted. Other studies followed, such as those conducted by H.-G. Beyen (1938), M. Borda (1958) and K. Schefold (1952), contributing to further subdivisions of the four styles.

The masonry style, a very common decoration during the second century BC, has come to be known as the "First" Pompeian Style of Roman wall painting. Red, yellow and black was much used with a different colour given to the margins of the stones. According to Ling (1991: 16-18), in the east the choice of colours was done in a manner that was consistent with the structural logic. This was not the case in other places, like Pompeii, where blocks could be painted in different colours in a random sequence and the patterns were unified for adjacent walls. Thus, the masonry style became an interior decorative style that broke away from the pure imitation of ashlars. Abstract geometric patterns became popular, of which the cubic design was derived from a pattern usually used for pavements and formed diamond shapes in three colours. What evidence exists regarding the ceiling decoration, suggests that the imitation of coffering was sometimes executed.

The use of illusionistic means in depicting architectural elements – a characteristic of the "Second Style" – can already be found in the late third century BC, such as evidenced along the walls of the tomb at Lefkadia (Ling 1991: 21). However, this technique was not yet fully developed as it would be after 80 BC at Pompeii, marking the emergence of this style (Ling 1991: 23; Ramage 1991: 61). The Second Style is characterized by the imitation of architectural features and the use of shading and perspective on flat plaster rather than moulded stucco. The first stage of that style is known by its progression from a closed to an open wall, while the second stage is characterized by treating each wall in the room as a separate unit, with the composition balanced symmetrically about the central bay (Ling 1991: 23; Ward-Perkins and Claridge 1979: 97-98). The ceiling decoration predominantly consisted of the imitations of coffers and panels, with a wide variety of decorative shapes placed within the coffers (Ling 1991: 42).

Next was the Third Style, which remained very popular until the middle of the first century AD. The division between the Second and Third styles appears to have been around 15 BC, and seems to reflect classicism of the formal art at the court of Augustus (Ward-Perkins and Claridge 1991: 101). This style did not depend anymore on illusionism and the search of three dimensional depth, but rather favoured surface effects and high ornament. The architectural structures were replaced by delicate motifs resting on a flat black dado with minimum depth and volume to structures, and, a central picture represented within a framed panel (Ling 1991: 52-53; Ward-Perkins and Claridge 1979: 99). Large surface areas were rendered in solid colours that were mainly of red, black and white colours, and could also be occasionally in blue and green. Schemes which became very popular in the earlier phase of the Third Style were those consisting of candelabra which could already be found in Second Style painting. In the later stages of the Third Style, blue, green and yellow colours were more used, along with a larger variety of other colours, and a bigger freedom in alternating these colours according to the zones. There was more complex ornamental detail and figures became set in the composition at varying levels with more volume provided for the composition (Ling 1991: 57-58).

Regarding ceiling decoration (Ling 1991: 62-66), work in stucco included framed rectangular schemes with figures and ornaments placed inside in relief, while painted plaster consisted of pure ornamental patterns with unobtrusive figures set against a neutral background. There were three kinds of decorative schemes which include the centralised arrangements, patterns painted all over the ceiling, and organic compositions. In the first group are schemes such as panels or figures along the four sides of a central field, with a white background. The all over decoration consisted of complex patterns such as a network of lozenges, squares and triangles or overlapping octagons, with colours used such as yellow, purple and white on a black background.

Organic compositions consisted of floral and vegetal motifs. A typical example of such a composition is the vaulted ceiling of the tomb of Pomponius Hylas, dated to between AD 19 and 37. There, the painting of the vault is made up of vine-scrolls, birds and representations of cupids, and, the semi-dome decoration consists of two Victories and a female figure in addition to the vine scrolls, all set against a white background (Ling 1991: 65-66). Another example is the decoration of the vault of one of the rooms of the House of Orchard at Pompeii, where within the vine scrolls are figures of birds and cupids, and objects such as masks, musical instruments, vases and drinking horns, set against a uniform black background. The centre of the vaulted ceiling has a representation of Dionysus seated on a panther.

The latest examples of Third Style wall paintings are dated from the middle of the first century AD, while the last phase of Pompeian wall painting – the Fourth Style – started just after the earthquake of AD 62 (Ward-Perkins and Claridge 1991: 101). The Fourth Style is characterised by putting together elements and forms of older styles in news ways, sometimes elaborately reviving the open wall theme of the Second Style while keeping Third Style fantastic forms, and with ceiling decorations having a major tendency for richness (Ling 1991: 71-100). In this style, the palette becomes more restricted, while vegetal motifs become more luxuriant figures. The Fourth Style continued until the end of the first century AD.

Although much of Roman painting is known to have earlier Greek models, nevertheless, it can be considered as a reflection of the Romans' attitude and beliefs (Strong 1988: 63-64). The Pompeian styles were at the time when Rome was an important centre for art, and the Romans were much involved in interpreting and developing Hellenistic art, adopting Greek divinities and expressing their ideas in Greek art and literature.

4. THE SITE: PETRA

4.1 An Ancient Capital

Petra is located about 260 km south of Amman, the capital of Jordan (Fig. 3). Geologically, it lies near the western edge of the Arabian plate, 15 km east of the Dead Sea "Rift" zone. This Dead Sea Rift is a transform plate boundary that connects the Red Sea to a plate convergence zone in the north, along which many seismic activities can take place (Kovach et al. 1990: 61). The centre of Petra has an area of about 12 km^2, while the whole Archaeological Park is about 264 km^2, and includes the Nabataean site of Siq el Barid, north of Petra. Petra rises to an altitude of 900-1500 m a.s.l., and has a semi-arid climate with an average annual precipitation of 200 mm and mean annual relative humidity of 50%, which is much lower during the months of April and October. The temperature reaches 39°C in summer, while in winter it can go as low as 0°C (National Atlas of Jordan). Geologically, the site belongs to the Ram Sandstone group that has an age from the lower Cambrian to the Ordovician, and includes the Umm Ishrin (mid to late Cambrian, 540-520 Ma) and Disi (Late Cambrian to early Ordovician, 520-490 Ma) sandstone cropping up in most of Petra (Barjous and Jaser 1992: 6-7). Most of the monuments in Petra were built out of the Umm Ishrin sandstone, which was more suitable than the Disi sandstone, the latter being very weak and susceptible to weathering (Barjous and Jaser 1992: 29). The Umm Ishrin sandstone is composed of at least 90% quartz, and minor components such as feldspars and iron oxides, with traces of minerals like muscovite, chlorite, kaolinite and illite (Barjous and Jaser 1992: 35).

There is very strong archaeological evidence for occupation in the area long before the establishment of the Nabataean kingdom over 2000 years ago, which can be traced to as early as Neolithic times. The Neolithic villages of Bayda and Ba'ja, lying to the north of Petra, and Basta located to the southeast of Petra are witness to that. There is also evidence of Iron Age habitation at the top of the cliff known as Umm al-Biyara in Petra, preceding Hellenistic, Nabataean and Roman periods.

Petra was the capital of the Nabataean kingdom, whose days of glory were between the first century BC and the first century AD. The kingdom occupied a vast land whose borders shifted often, but generally speaking extended to the area of the Negev in the west, reaching the Hauran in the north, the Sinai, and the area of Hegra to the south (Hammond 1973: 29).

The Nabataeans were of Arab origin who roamed the Arabian Peninsula, before finally settling and establishing their kingdom. The exact location of their original habitat has not been conclusively established, though the current opinion seems to favour southern Arabia (Hammond 1973: 10-11; Starcky 1955: 87), rather than northeast Arabia (Graf 1990: 67). They spoke Aramaic, an early Semitic language that was the predecessor of Nabataean and Arabic, and left us stone carved inscriptions in Nabataean and Greek letters. It is not yet clear as to when exactly they settled in this region, though we know of their mention in the account of Diodorus of Sicily, which establishes their presence as early as 312 BC. In his account, Diodorus describes when Antigonous, the Hellenistic ruler of Syria and a former general of Alexander the Great, held an unsuccessful campaign against the Nabataeans and attempted to annex their kingdom (Diodorus XIX; 94).

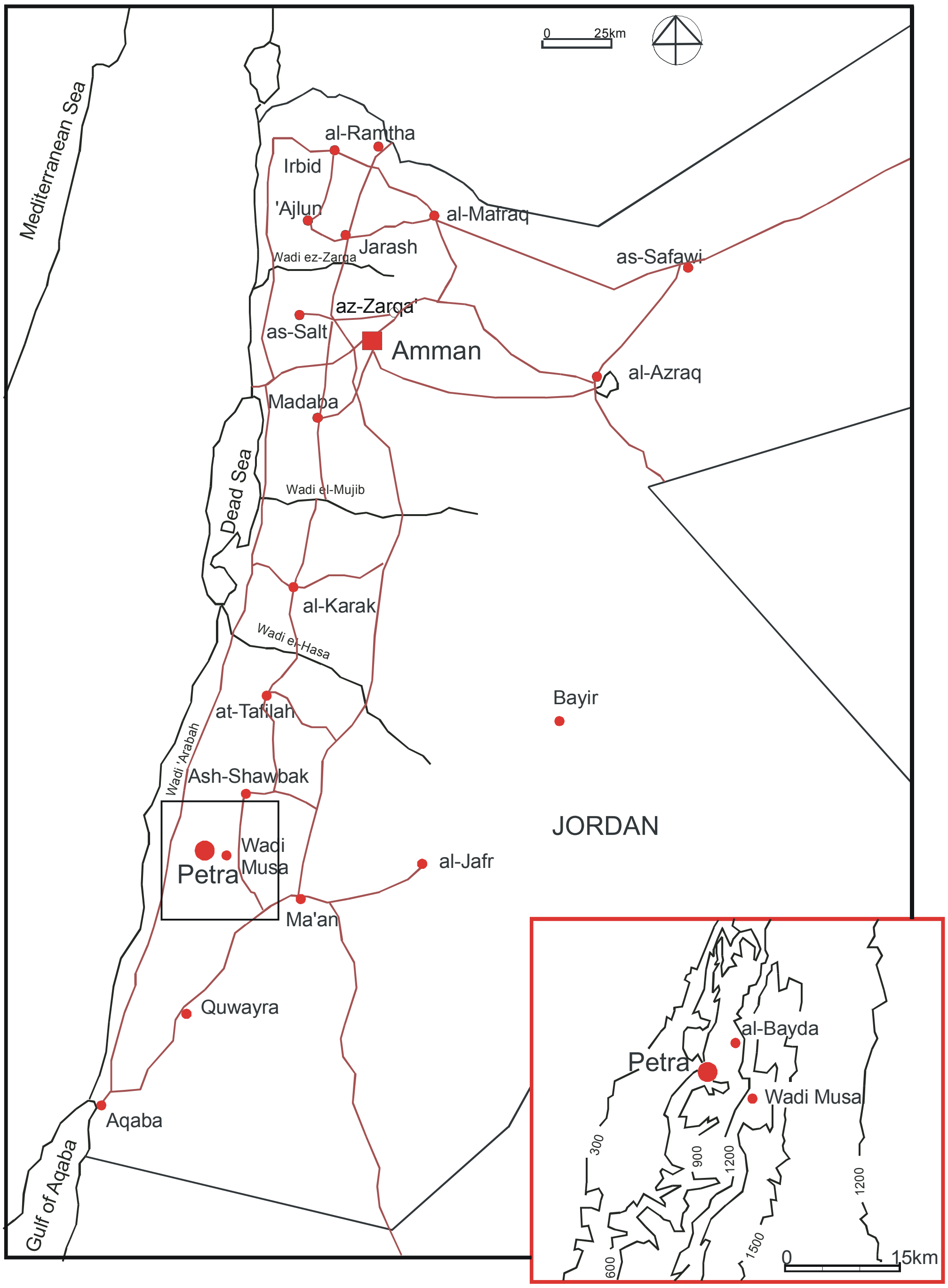


Figure 3. Location of Petra (after the Communication Map of Jordan-Royal Jordanian Geographic Center).

Apart from Petra's easily defended location, and the presence of two major springs that could provide water for the large settlement, it was primarily its position along the major trade routes that provided the criteria for choosing it as the capital. Petra was near the trade route of silk and spices, going from China, India and Arabia to Rome and the Mediterranean, and the route leading to Gaza, the Sinai and hence to Egypt. In fact, the livelihood of the Nabataeans depended greatly on trade and on this strategic position along these caravan routes. Petra was a thriving city with massive building activity, ingenious structures for water collection and harvesting that provided water for the inhabitants all year through, abundant agricultural land, and large public spaces and paved streets.

The site of al-Bayda, situated about 3 km to the north of Petra appears to have been an important suburb of the city centre. There, along a small gorge in the rock, known as Siq el-Barid, are several structures carved along both of its sides, which include several triclinia, a biclinium and cisterns, among many other structures.

Aretas I was the first king known to have reigned over the Nabataean kingdom in the second century BC, followed by a succession of kings, the last being Rabbel II. Rabbel II ruled until AD 106, when the Roman emperor Trajan managed to annex Petra and make it part of the new Province of Arabia with Bosra in the north as the capital (Starcky 1955: 102-103). The annexation of Petra was inevitable, as its prosperity dwindled during the first century AD due to the fact that the Romans were able to shift the trade routes, and, the city of Palmyra located further to the north gained more importance than Petra. Nevertheless, Petra continued to exist as an important city, even during the Byzantine period when it became an important ecclesiastical centre (Starcky 1955: 106), as witnessed by the recent discovery of several churches in Petra and a hoard of papyri with text, dated to the sixth century AD (Bikai 1996: 481-486; Bikai 1996: 487-489; Frösén 2000: 395-424).

During the first half of the seventh century AD, Islamic forces penetrated into Jordan, marking AD 630 as the beginning of the Islamic conquest. With the establishment of the Umayyad dynasty in AD 661 in Damascus and the Abbasid dynasty in AD 750 in Baghdad, the importance of Petra dwindled even more. During the 12th century AD, the two forts of al-Habis and al-Wu'eira in Petra were built by the Crusaders as part of their fortifications from Jerusalem to Aqaba. The Crusaders were defeated by Salaheddin in 1189. After that, Petra started slowly to be forgotten until it became lost to the western world. It was only in 1812 when the Swiss explorer J.L. Burckhardt visited the site that it was identified again as ancient Petra. Several explorers followed in the footsteps of Burckhardt, namely Irby and Mangles who visited the site in 1818, and David Roberts who in 1839 made several accurate drawings of Petra and its monuments, during his travels in Egypt and the Holy Land.

Recording and documentation of the monuments of Petra started immediately after that, whereby Brünnow and Domaszewski recorded about 800 features of Petra when they visited the site in 1898, and furthermore, provided a numbering system for the façades. This documentation was complemented by many other early scholars, like Dalman, Wiegand and Bachmann, Kohl and Wright. Archaeological excavations started in 1929 with the work of Horsfield and Conway, and continued with many other excavations such as those of Albright in 1934-1936 and Parr in 1954, and have been going on until the present day.

4.2 The Architecture

The Nabataeans left us very few written sources that tell us about their kingdom, their culture and their way of life. Nevertheless, undoubtedly, what they have left us in Petra in terms of monumental architecture as well as structures built for water harvesting, can only bear witness to the importance of the Nabataean capital. Two types of construction techniques can be found in Petra. The first is the carving and chiselling of structures and their respective façades out of the surrounding sandstone mountains; while the second lies in the more conventional form of building in large quarried sandstone blocks. Both techniques were used to create numerous structures of diverse architectural styles reflecting various cultural influences and interactions.

Rock carved façades are certainly not a feature that is only found in Petra. However, their execution at such a monumental scale in Petra (Fig. 4), where the planning of the city was very much dependant on such monuments, is truly the most outstanding and particular feature of the site.

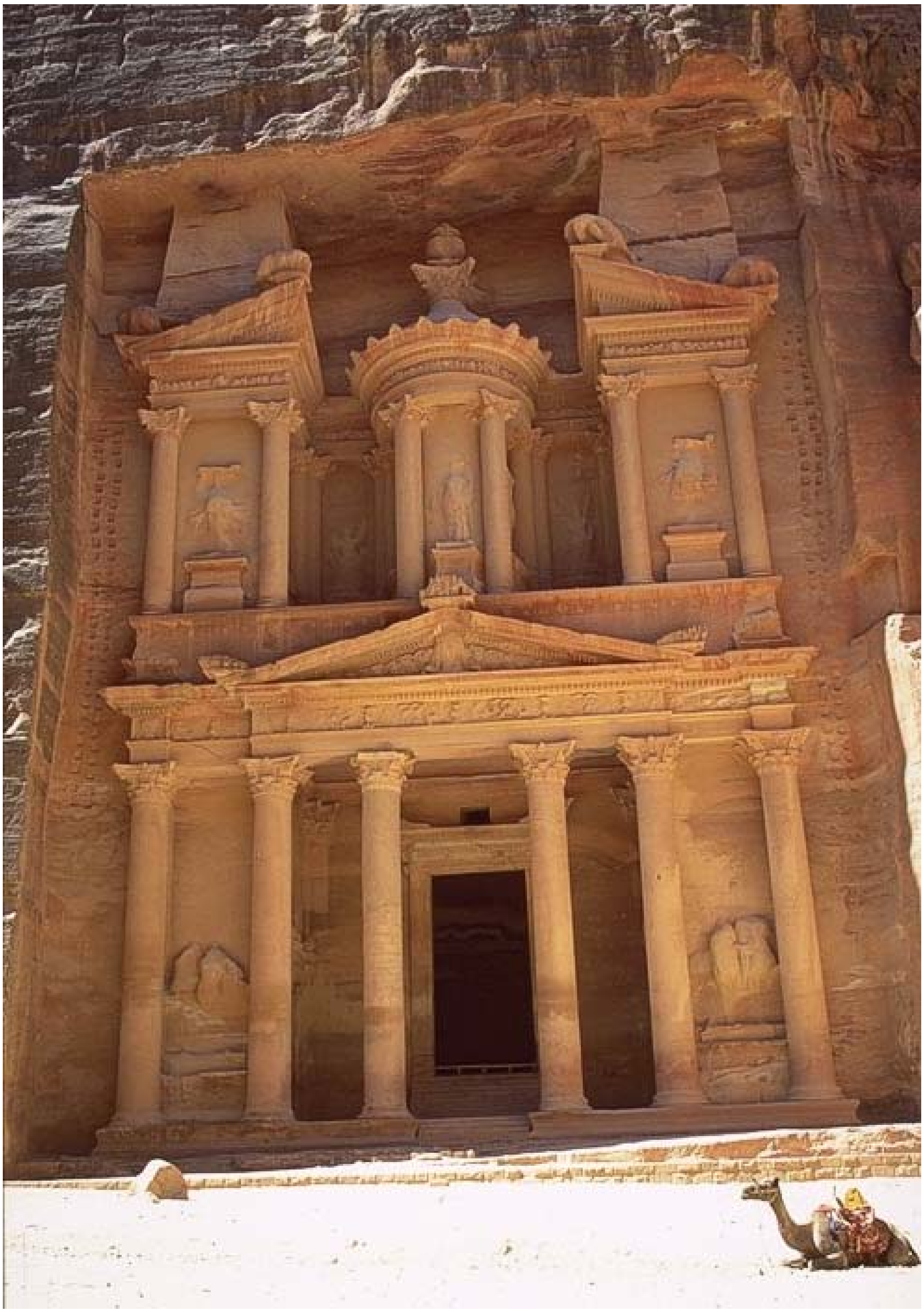


Figure 4. The façade of al-Khaznah, probably the most famous monument in Petra.

The rock carved façades in Petra are either set in the mountain from which they are carved or protrude from it, and hence there is always a separation between the façade and natural rock. This feature helps to achieve a sense of individuality and monumentality for a building that is in reality a part of the natural surroundings.

Hammond (1973: 77) mentions that the carving procedure for the façades was done from the top to bottom, and that as a first step, a flat smooth surface of the façade was created, followed by the carving of details. This hypothesis was based on several unfinished tombs in Petra that reveal such a sequence of work (Fig. 5). Although this assumption holds true for some of the rock hewn façades, it cannot be taken as a general rule. Unfinished tombs found throughout Petra show cases where carving was done at the top and the bottom of a façade simultaneously, or where detailed architectural features were carved at the same time as the carving of the monument from top to bottom (Fig. 6). Very often, in order to simplify the carving process, the ceiling was executed following the lithology of the sandstone layers.

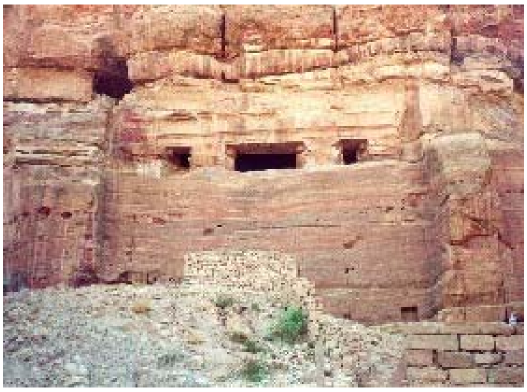


Figure 5. Unfinished façade near Qasr el-Bint.

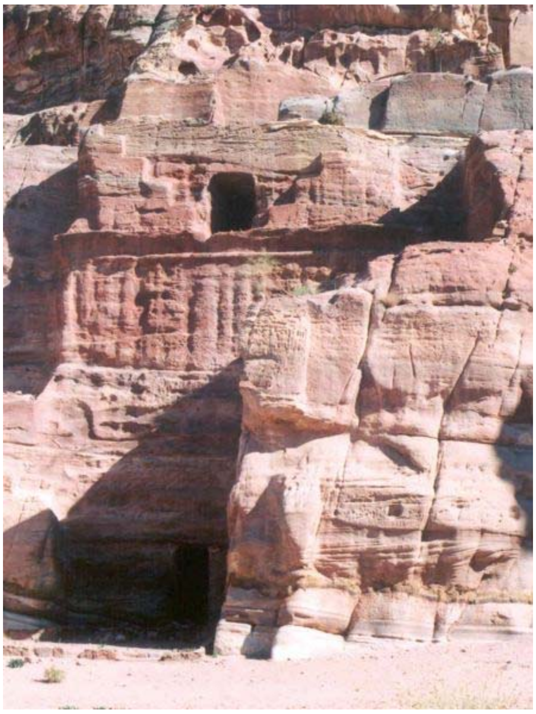


Figure 6. Unfinished façade in Wadi al-Farasa.

Most of the façades have quarried stone insets that have been added to rock carving in order to complete the architectural features of the monuments, especially where quarried stones of good quality were needed to replace weaker parts of the rock. In most cases, insets did not represent stone blocks that have been carved to fit exactly a certain allocated space. The exterior faces of the stones were finely carved and dressed and then fitted by adding smaller pieces of rubble and mortar fillings.

Upon close examination of the tool marks of several of Petra's façades and finished stone blocks, it seems that the tools used are invariably the pick-axe, as well as the pointed, tooth and flat chisels that are used with the help of a hammer. The pick-axe was used only in carving, and, a depiction of such a tool has already been noted (Shaer and Aslan 1997: 224-225; Fig. 17). The pointed chisel was used for both, carving and dressing. It was the most widely used type of chisel, by which the dressing of long, fine parallel lines – characteristic of Nabataean sandstone surfaces – was conducted. The tooth chisel was used for dressing narrow architectural elements creating diagonal or short horizontal lines, and, the flat chisel was used for making a smooth surface of the stone with marks that are similar to a hatching of successive straight lines along the vertical and horizontal edges of architectural features. Close inspection of the tool marks of Tomb 633 has revealed that two different persons, one right handed, and the other left handed were carving together a small area of the facade.

Templates depicting the profile of façade elements can be found at the monuments, such as in the case of Tomb 826 (Shaer and Aslan 1997: 226-227) (Fig. 7) and Tomb 633. These depictions were probably executed by the architect or master mason as instructions for the stone carvers. They show the sequence of cornice elements in their approximate proportions. This seems to imply that the carvers retained certain knowledge of the right proportions of architectural elements, and the final product depended very much on their individual skill.

Figure 7. Cornice profile incised along the side wall of Tomb 825.

There is a variety of individual architectural motifs that are obviously borrowed from other cultures such as the Assyrian, Egyptian, Hellenistic and Roman. Of such motifs, is the crowstep that appears either in a repetitive manner in one or two rows at the top of a tomb façade, or as a set of five large steps facing each other. Such a motif seems to be an Assyrian influence (Kennedy 1925: 45-46), and it has been noted that this can also be seen in Syrian-Phoenician art, such as at the fifth century BC necropolis of Amrit (Schmidt-Colinet 1981: 69-72). The urn, which is found crowning many of the tombs in Petra, is also of Assyrian influence, as is the sculptured lion (De la Croix and Tansey 1980: 55). The lion was a well known motif in Syria and Ba'albak in Lebanon during the Hellenistic period, and also in the southern Arabian Peninsula (Glueck 1965: 287). The obelisks, as well as the rounded cavetto cornice with the torus element above it, are motifs borrowed from Egyptian architecture.

Moreover, there is a number of architectural features that appear to be of classical Hellenistic origin and are evident mainly in the classical cornice elements and the pediments. To be noted is that the columns, entablatures and pediments which were used in ancient Greek architecture for structural purposes, can also be seen on the carved façades, which in fact do not need any structural support. Thus, such features were used for decorative purposes and were transformed into new shapes of which are baroque forms of broken and segmental pediments that are in fact non-structural elements (McKenzie 1990: 87-88). The "tholos", which is the circular structure found crowning some of the monuments like al-Khazna (Fig. 4), has been attributed to the Hellenistic period as a feature decorating private houses and palaces (Wright 1962: 35). It has also appeared on the wall paintings of

Pompeii in the middle of a courtyard, while in Petra it is found at the top of façades and crowned by an urn (McKenzie 1990: 92).

According to the study done by McKenzie (1990), it was found that the earliest examples of baroque forms of pediments and entablatures can be found in Ptolemaic Alexandria, where they could all be dated to before 100 BC. These forms are very much reflected in the architecture of Petra and are also depicted in second style Pompeian wall painting. Macedonian influences in the architectural formation of the tomb façades and plaster decorations in Petra have also been noted (Haddad 1998: 161-171). The question whether the architecture of Petra was directly influenced by the Greek and Hellenistic traditions or indirectly through Alexandrian forms, is not resolved. Nevertheless, it is evident that there are various cultural influences on the architectural and artistic expressions in Petra. The Nabataeans, however, managed to blend these influences, and develop their architectural style into something that is uniquely their own.

4.3 Decorative Plaster and Stucco

Plastering was considered in Nabataean times as a profession by which craftsmen could be identified, as attested by an inscription that mentions two stelae of al-'Uzza and "Lord of the Temple", the work of which was executed by a certain "Wahballāhī the plasterer" (Cantineau 1932: 7-8).

Indeed, despite the natural beauty of the colourful sandstone from which Nabataean buildings were formed, it is probable that all structures had their façades covered with decorative plaster or moulded stucco, or both. Major rock hewn façades such as al-Khaznah (Fig. 8) and the Palace Tomb (Figs. 9 and 10) still have some traces of painted plaster remains, or even paint applied directly on stone.

Figure 8. Painted remains on the façade of al-Khaznah.

Figures 9 and 10. Painted remains on the façade of the Palace Tomb.

The Nabataean mansion at az-Zantur (Kolb 2001; 1997; Kolb and Keller 2000) is witness to the existence of the once lavishly decorated residences inside the ancient capital. Room "3" of this building has remains of decorative stucco applied in the Masonry Style of red and yellow panels. Although this decoration is similar to Pompeian "First Style", the excavators have established that the building was not erected prior to the year AD 20. The illusionistic architectural representations in room "1" have been compared to Roman paintings of the Augustan Age (Kolb 2001: 443).

Plaster remains have been noted by several scholars and archaeologists who excavated in Petra. These remains include plain white plaster, painted plaster, stucco and sometimes paint applied directly on stone. The painted plaster can be found as decorative architectural patterns or as motifs depicted from nature, while moulded stucco can be found either as an imitation of ashlar masonry or as decorative architectural forms. Table 1 provides a list of structures, classified according to type of feature (rock carved tomb façade (F); rock carved chamber or structure (C); Freestanding monument (FS)) with the respective observation on type of rendering, the reference provided, and any previous investigation.

Table 1. Compilation of features with decorative plaster and stucco.

Type	Monument	Type of rendering	Previous analysis
F	No. 62 – al-Khaznah	Painted plaster remains on the carved vases of the lower frieze and dentils of central doorway, also above bay to the right as reddish carinations on the vase and frieze background (McKenzie 1990:33; 141)	
F	No. 64	Plaster remains at top right side of façade and next to crowsteps (Shaer 1997: 40)	
F	No. 67	Plaster found on the façade (Parr 1968: 14-15)	Parr (1968: 14): analyses at Building Research Station at Watford: plaster= 2 sand/ 1crushed limestone and quartz, gypsum less than 0.5%. Colour applied on surface as a slurry
F	No. 70	Plaster remains on bottom part of cornice and fascia (Shaer 1997: 40)	
F	No. 114	Thick plaster remains between crowsteps and below torus (Shaer 1997: 47)	
F	No. 116	Thick plaster remains between crowsteps and below torus (Shaer 1997: 47)	
F	No. 127	Plaster remains between crowsteps (Shaer 1997: 47)	
F	No. 239 (Roman Soldier's Tomb)	Painted stucco on top stone block of left niche with a male figure holding a cloak (McKenzie 1990: 147); plaster remains on the 3 vaulted niches along north wall; some remains of moulded stucco; plaster below middle niche made up of 2 layers, white, fine grained with beige outer surface; bottom layer is 0.7 cm thick, top layer is 0.2-0.3 cm thick; patch of plaster covering the upper stone block of the left niche with remains of stucco (Shaer 1997: 47, 103)	
F	No. 244 – Garden Temple	Exterior stucco moulded in the form of ashlar masonry on the left part of the façade (Shaer 1997: 47, 111)	
F	No. 430	Plaster on and between the steps, on the fascia below torus, on the frieze and on architrave; on architrave plaster appears red while on frieze it's blue (Shaer 1997: 53, 59)	
F	No. 431	Plaster remains between crowsteps and on bottom of torus mouldings (Shaer 1997: 53)	
F	No. 432	Plaster on the torus and parts of fascia; regular holes on façade (Shaer 1997: 59)	

Type	Monument	Type of rendering	Previous analysis
F	No. 433	Plaster below the torus, appearing as a fascia	
F	No. 435	Plaster between crowsteps, probably red; on the torus and fascia, probably blue; thin remains on flat surface below	
F	No. 436	Few remains of plaster between crowsteps	
F	No. 471	Plaster remains between the crowsteps and below torus mouldings; plaster below torus is laid out in a horizontal manner; traces of white plaster or limewash between the stone dressing; holes regularly carved on the façade (Shaer 1997: 59)	
F	No. 495	Plaster between crowsteps (Shaer 1997: 53)	
F	No. 505	Plaster traces between stone dressing, row of holes on the façade (Shaer 1997: 53)	
F	No. 519	Plaster remains on the façade covering the left pilaster flanking the doorway, white with reddish brown surface and 0.5cm thick (Shaer 1997: 53, 103)	Sample CO519-01: white, reddish-brown surface, 0.5cm; xrd: quartz; calcite; (kaolinite or chlorite?) (Shaer 1997: 120).
F	No. 522	Plaster on the torus and frieze, with holes cut into the façade (Shaer 1997: 53)	
F	No. 523	Smooth plaster surface on architrave, and holes carved into façade (Shaer 1997: 53)	
F	No. 524	Stucco with colour that resembles that used in the Hauran (Horsfield 1938: 27-28). Plaster remains on sub-attic, frieze and architrave, also between the stone dressing found on lower part of the façade and the flanking pilasters; plaster on sub-attic is of a reddish colour, the frieze has red and blue colors (Shaer 1997: 53)	
F	No. 526	Remains of stucco cornice in the groove topping the doorway (Zayadine 1987:131)	
F	No. 537	Plaster remains below the torus with row of regularly carved holes (Shaer 1997: 53)	
F	No. 539	Plaster between crowsteps and below upper torus (Shaer 1997: 53)	
F	No. 542	Plaster remains on upper left corner between large crowsteps (Shaer 1997: 53)	
F	No. 558	Plaster remains between crowsteps and on fascia	
F	No. 575	Stucco cornice and pediment (Zayadine 1987:131)	
F	No. 633	White plaster on capital of left pilaster, appears to have been used to patch up the capital; painted plaster covering the wall and ceiling of its squarish façade, plaster of back wall has red colour, that of the ceiling has red and blue colour (Shaer 1997: 53, 114)	Sample CO633-06: red plaster from niche; xrd: quartz, gypsum, whevellite, kaolinite, anhydrite, haematite Sample CO633-07a: blue plaster, has brownish surface; xrd: quartz, gypsum, whevellite, kaolinite, haematite Sample CO633-07b:blue plaster of niche: quartz, gypsum, whevellite, cuprorivaite Sample CO633-07c: from the blue coloured plaster of the niche: quartz (57.2%); anhydrite (16.9%), calcite (8.6%), dolomite (8.2%),gypsum (4.2%), Kaolinite (4.5%) (Shaer 1997: 121)

Type	Monument	Type of rendering	Previous analysis
F	No. 634	Plaster remains between the crowsteps and on the torus, fascia, entablature, left pilasters (Shaer 1997: 53)	
F	No. 649	Holes carved in doorway pediment filled with mortar (Shaer 1997: 59)	
F	No. 649 – Tomb with Armour	Has regularly arranged holes above the doorway, still filled with mortar that is spread beyond the extent of the hole itself, white and fine grained with beige exterior surface (Shaer 1997: 108)	
F	No. 652	Holes carved in doorway pediment filled with mortar (Shaer 1997: 53)	
F	No. 676	It has stucco with colour that resembles that used in the Hauran (Horsfield 1938: 27-28); Stucco revetment was used to cover a repair done on the façade (Zayadine 1987: 132); plaster/stucco applied on architrave, cornice and capitals (Shaer 1997: 53)	
F	No. 763 (Sextius Florentinus Tomb)	Interior decorative stucco (Zayadine 1987: 13); central loculus has its ceiling covered with plaster as well as the walls flanking the central loculus and above it; plaster is white/beige, hard with medium coarse grains, 0.5-1.5cm thick (Shaer 1997: 103)	Shaer CO763-01: whitish-grey, covered with soot, some aggregate, hard, 0.5-1.5cm; xrd: quartz, calcite; clay?; (mica), (chlorite) (Shaer 1997: 120)
F	No. 765 – Palace Tomb	Stucco remains (Laborde 1838: 188); painted details on lower entablature and painted dentils of the lower order in black and white (McKenzie 1990: 33; 163); third room from the right has a large niche with plaster remains; the groove along the bottom of niche is filled with a mixture of mortar and stone pieces with a top plaster layer that seems to have red and ochre colours; on right side of façade are painted details on lower entablatures and painted dentils in black and white (Shaer 1997: 47, 103, 106)	
F	No. 779	Plaster remains especially around the corners and covering the vaulted roof; plaster in 3 layers, topmost one is smooth, white, fine grained, 0.4cm thick; middle layer is of coarser quality, 6mm thick; bottom layer is crude, greyish colour, fine grains, hard, thickness reaching up to 2cm (Shaer 1997: 103)	Sample CO779-01: top layer of niche, white, fine-grained, smoothly applied, 0.4cm; xrd: quartz; calcite Sample CO779-02: middle layer of niche, white, medium coarseness, not smoothly applied, 0.6cm; xrd: quartz; calcite Sample CO779-03: bottom layer of niche, greyish, fine grained, hard, crudely applied, thickness reaching 2cm; xrd: calcite; quartz (Shaer 1997: 120)
F	No. 805	Plaster remains between crowsteps (Shaer 1997: 47)	
F	No. 813	Dowel holes with plaster remains; 2 plaster fragments and a stucco piece, all having an inscription in red-brown ink (Zayadine 1987: 13; 1974: 145, 148); mortar filled holes in the façade, plaster between crowsteps (Shaer 1997: 47)	

Type	Monument	Type of rendering	Previous analysis
F	No. 823	Plaster between crowsteps of the upper band and below the upper torus (Shaer 1997: 40)	
F	No. 825	Along the right side of the façade there are carved holes, one has an ancient piece of wood, another has a white mortar fill; some plaster remains in the middle of the façade; moulded stucco on the right capital below doorway pediment, soft, brittle, applied as a thin layer, fine grained, white, moulded in the shape of a flower motif of the capital (Shaer 1997: 40, 47, 108, 111)	Sample CO825-04: from hole in the middle entablature, white, fine-grained, hard; xrd: anhydrite; quartz; (dolomite) (p. 121) Sample CO825-05: from plaster remains on the façade, pinkish/beige surface, fine-grained, hard; xrd: gypsum (41.3%); quartz (24.0%); (dolomite) (12.2%), (kaolinite) (4%), (whevellite) (1.5%) Sample ST825-01: from floral motif, white, fine-grained, soft, brittle; xrd: quartz; anhydrite; (gypsum), (chlorite), (kaolinite or chlorite?) (Shaer 1997: 121)
F	No. 826	Plaster between crowsteps and on torus, with a bluish colour on the plaster of the torus (Shaer 1997: 40)	
C	No. 235- (Triclinium)	Extensive stucco decoration (Tarrier 1988: 55, 196); hard plaster remains with white/beige colour (Shaer 1997: 101)	Sample CO235-01: white/beige colour, hard, sample 0.3cm thick; xrd: calcite, gypsum, quartz (Shaer 1997: 120)
C	No. 717 (Triclinium)	Remains of white plaster between the stone dressing lines; carved holes (Shaer 1997: 97)	
C	No. 721; rock cut chamber	Plaster remains along the southeast corner (Shaer 1997: 97)	
C	No. 722 (Triclinium)	One of the carved holes has remains of fine grained relatively hard plaster around it; remains are thin with 2-3mm thickness, white with pinkish surface (Shaer 1997: 97)	
C	No. 725 – squarish room; rock cut	Niche in south wall has thin plaster remains; niche in eastern wall retains a lot of thick plaster reaching about 1.5-2cm thickness, white with smooth surface; holes cut into the wall (Shaer 1997: 97)	
C	No. 730 (Triclinium)	Plaster with pinkish surface and seems to have a blue colour in the niche and along the eastern wall; ca 1cm thick (Shaer 1997: 97)	
C	No. 733 – room; rock cut	Some kind of mortar remains on walls (Shaer 1997: 94)	
C	No. 734 – room; rock cut	Traces of a wash (Shaer 1997: 94)	
C	No. 738 – squarish room; rock cut	A lot of plaster remains, also found around the carved holes; white, and fine grained with 1cm average thickness (Shaer 1997: 94)	
C	No. 739 – squarish room; rock cut	Some plaster remains on the upper part of the corner connecting the eastern and southern walls	
C	No. 749 – squarish room; rock cut	Walls, ceiling and niche have plaster remains in 3 layers: bottom crude layer is 0.5cm thick, followed by a smoother 0.5cm layer, and a finer 0.1-0.2cm layer; similar plaster remains (Shaer 1997: 94)	

Type	Monument	Type of rendering	Previous analysis
C	No. 751 – squarish room; rock cut	Walls with a lot of remaining plaster; plaster is fine grained, white; a lot of carved holes present; niche on southern wall has plaster; plaster on right side of southern wall appears to have reddish colour (Shaer 1997: 94)	Sample CO751-01: white, finely grained; xrd: calcite, quartz; dolomite (Shaer 1997: 120)
C	No. 758; rock cut	Remains of thin plaster layer, few mm thick inside the pediment and square niche; fine grained with white colour; carved holes (Shaer 1997: 101)	Sample CO758-01: from pediment remains, white, fine-grained; xrd: quartz; calcite; (chlorite), (olivine), (gypsum), (clay?) CO758-02-from the square niche, white fine-grained; xrd: quartz; calcite, (chlorite?) (Shaer 1997:120)
C	No. 839 – al-Bayda	Plaster remains on northeastern corner of structure, in 2 layers; in other places it is found in one layer; first layer is 0.5cm thick, second layer 1.5-2cm thick (Shaer 1997: 110)	
C	No. 848 (Three room Triclinia)	Three walls of middle triclinium have stucco remains; upper half of western wall has a number of holes laid out in a regular manner; below holes are remains of a horizontal decorative stucco moulding, followed by remains of stucco imitating ashlar; these continue partly on the eastern and northern walls; the ceiling has remains of square shaped stucco moulding , while its centre has a round shaped stucco moulding; along the walls the stucco is applied in 2-3 layers, depending on the stone surface, sometimes in 4 layers; whole thickness is 2-5 cm (Shaer 1997: 111)	Sample ST848-01: from left side of northern wall, taken from upper layer, ca 1cm thick, white; xrd: quartz; calcite; (mica?), (chlorite), (kaolinite, or chlorite?) Sample ST848-02: from bottom layer of northern wall and it has a light grey colour, 0.5cm thick; xrd: quartz, calcite; kaolinite or chlorite?; (mica) (Shaer 1997: 121).
C	No. 849 (House in Siq el-Barid; rock cut)	A lot of plaster; vault decoration: painted vine decoration and figures (Horsfield 1938: 21-22; McKenzie 1990: 89; Tarrier 1988: 55; Zayadine 1987: 141); Stucco is fine, soft and white in colour (Shaer 1997: 103)	Sample ST849-01: from the wall which has a decoration imitating ashlar masonry, white, fine-grained; microscpic analysis: lime mortar with closely packed fine quartz grains, some pore spaces; point counting: lime= 30.4%; quartz= 68.9%; sandstone= 0.2%; charcoal= 0.5% (Shaer 1997: 145, 148; Figs. 124-125) Mortar analysis: quartz (70-80%); calcite (17-20%), kaolinite (3-5%) (Franchi and Pallecchi 1995: 100-101)
C	Room to the west of Tomb 228; rock cut	Plaster layers applied in two layers found covering the edges between walls and ceiling (Shaer 1997: 94)	
C	Chamber, north of Wadi as-Siyyagh;	Remains of pink plaster and white coating (Horsfield 1938: 15-25)	
C	Cave in Wadi as-Siyyagh	Fresco of red and ochre panels with blue and black frames in which doorways are depicted, some have a gable with eagle acroterion, one has sphinx with open wings (Zayadine 1981: 355, 140; 1987:140)	Mortar analysis: quartz (70-80%); calcite (17-20%), kaolinite (3-5%) (Franchi and Pallecchi 1995: 100-101)

Type	Monument	Type of rendering	Previous analysis
C	House opposite theatre; rock cut	Plaster with arches in red and white (Horsfield 1938: 19-20; Zayadine 1987: 140); along western wall the plaster is white, and where it joins the ceiling is another plaster layer which is painted black, red and yellow, continuing over the ceiling without the underlying white plaster layer; white plaster has a thickness of 0.5-2 cm – depends on tool marks – fine grained; plaster thickness near the edge of arch is ca 2 cm, and over the ceiling ca, 0.5-1 cm (Shaer 1997: 97)	Sample CO786-01: from the western wall, white plaster, fine-grained with lime inclusions, hard, 0.5-2cm, surface pecked over; xrd: quartz; (calcite), (chlorite or kaolinite?) (Shaer 1997: 120)
C	3 rooms arranged in north-south direction on the way to el-Habis; rock cut	Plaster remains and holes are found on the walls of the middle and northern rooms (Shaer 1997: 97)	Sample CO395-01: from north wall of middle room, plaster is white and fine grained with pinkish surface,0.3-0.5cm thick, depends on tool marks; xrd: quartz, calcite (Shaer 1997: 120)
C	Southern house on el-Habis; rock cut	Decorative panel (Zayadine 1986: 247; 1987: 132)	
C	Northern house on el-Habis; rock cut	Three tiers of painted stucco decoration (Zayadine 1986: 247; 1987: 132)	
C	Three rooms probably part of potter's workshop; north of a potter's kiln	Thick grey plaster in the main hall (Zayadine 1981: 357)	
FS	Freestanding house/Katuteh	Painted plaster fragments, some moulded (Bennett 1962: 239)	
FS	az-Zantur	Large surfaces of stucco decoration in masonry style; paintings in illusionistic architectural style (Kolb 2001; 1997)	
FS	Villa/Wadi Musa	East wall of large hall with frescoes in bright colours of red, yellow, olive green, greyish blue, black and white; another room has designs of green grasses, bunches of grapes and olive branches ('Amr et al. 1997: 470)	
FS	No. 403 Qasr el-Bint	Remains of stucco on southern and western walls of the temple; painted plaster found on cella with holes used for keying plaster and forming an architectural scheme (Kohl 1910; Laborde 1838: 164; McKenzie 1990: 137; Zayadine 1987: 135)	
FS	No. 408 – Stairway and Baths	Moulded architectural pieces such as dentils, sima and corona with a drip cornice; stucco remains on dome interior and on walls of staircase, where the painting depicts red and yellow panels (McKenzie 1990: 138)	
FS	No. 423 – Temple of Winged Lions	Interior painted plaster, some gilded, applied in two phases; plaster affixes of floral or human heads, sculptured plaster fragments, fresco panels; first phase included Greco-Roman motif painting that was pecked over and repainted with solid colours; columns originally covered with plaster and later replastered to have a smoother finish (Hammond 1977-8: 85; 86; 91; 97-100)	Red colours were found to contain cinnabar (HgS), or red lead (Pb_3O_4), with Fe_2O_3 and $Fe_2(SO_4)_3$; yellow paint was ferric sulphate $Fe_2(SO_4)_3$, $Fe_2(SO_4)_3.9H_2O$, and ferric oxalate $Fe_2(C_2O_4)_3$, while blue was achieved by using copper sulphate $CuSO_4$ (Hammond 1996; 65-66).

Type	Monument	Type of rendering	Previous analysis
FS	Great southern Temple	West Corridor walls, built up to and behind the West Anta Pier had painted plaster with red, yellow, green and blue colours; columns were also found with red and white plaster; in the excavations behind the West Anta Wall, many decorative stucco fragments were found that include egg and tongue and egg and dart motifs, in addition to vegetal elements, painted cornices pieces and a stone capital fragment with traces of gold leaf (Joukowsky 1998: 121); seems that all columns were plastered with alternating convex flutes with borders of flattened ridges; the plaster was white, with some remains of red coloured plaster (Basile 1998: 194)	
FS+C	Theatre	Davit holes were plastered, some walls associated with the orchestra, some column drums had plaster fluting(Hammond 1965: 14, 30-31, 45)	

4.4 Weathering and State of Preservation of the Monuments

Despite the survival of many monuments in Petra for over 2000 years, nevertheless, these structures cannot be considered in a good state of preservation. Weathering and deterioration can be noted for most of these monuments, and can be observed in several forms: structural failure of built monuments, the great extent of natural weathering evident on the sandstone façades, deterioration of all types of mortars, plasters and decorative stucco, and the often broken, dysfunctional hydraulic works.

Natural weathering has been the major factor leading to the continuous deterioration of sandstone façades, caused by erosion due to sand, wind and rain. The fact that the rock carved façades are part of sandstone mountains does not help, since humidity and soluble salts present within the rock are major causes for weathering. When water evaporates as a result of high temperature and low humidity, these soluble salts move towards the stone surface and crystallize to form salt efflorescence and sometimes crusts, eventually leading to the detachment and loss of the original stone surface, as evident in such forms as granular disintegration and flaking. Moreover, the nature of the sandstone, with its high porosity and characteristic limonite veins is an additional factor leading to fast deterioration. There is marked weathering along these veins, which in turn continues to cause more advanced stages of decay on the façade, such as alveolar weathering. In addition to lost parts characterized by some outbreaks in the stone, there is often massive loss of stone material on the façades, as evident by large sized alveoli, major back-weathered surfaces and extant parts of missing stone insets. Back-weathered areas along the bottoms of façades are assumed to be largely due to water absorption by capillary rise.

Moreover, the breakdown of the Nabataean hydraulic system has caused great amounts of water to run through the site, accumulating in some areas, and causing flooding during heavy rainfall, thus maximizing the negative effects of water on the preservation of the site.

The stone surfaces of monuments have collected a number of deposits along the years, in the form of surface crusts, biogenic growth, vegetation and soot, the latter as a result of Bedouin habitation of the caves.

Earthquakes, namely the two massive ones that occurred in AD 363 and AD 747, have severely destroyed the city causing the collapse of many of its built structures. Tectonic movements have caused the occurrence of joints and faults in the sandstone mountains. Carved façades being part of the rock itself have been adversely affected by such features, resulting in the further deterioration of monuments.

Plaster and stucco have had their own share of deterioration, to an extent that in most areas they have completely either disappeared or undergone irreversible damage. Most of the exposed decorative plasters on the monuments have disintegrated and detached from façades and walls that in due course have been lost forever. In some cases, only faint traces can be observed that give an allusion to the once brightly painted façades. Again, natural elements like rain, wind, sand and insolation have led to the gradual loss of the original surface of the plaster and its disintegration. Very often, plaster surfaces have lost their adherence to the stone surface, and have become eroded even along the surface that faces the rock. Moreover, excavations continuously reveal decorative painted plaster and stucco that are very fragile, cracked and sometimes crumbly. If care is not taken and no immediate conservation work is executed, they are in danger of being completely lost. All major excavations in Petra have yielded such remains (Hammond 1977-8; Joukowsky 1988).

Concerning painted plaster in the interiors of carved chambers, again we are faced with serious conservation problems. Although many show evidence of original painted plaster remains, much of it has disappeared by now. There are a few caves that still retain decorative painting, which nevertheless have several types of deterioration problems, evident in the presence of considerable amounts of soluble salts within the plaster, some sulphation on the surface, or thick soot layers accumulating on the original painted surfaces. Finally, it should be mentioned that these caves are not easily accessible to the visitor, and while they can be a major attraction, they are not well presented and no interpretative material is available.

5. DECORATIVE ARCHITECTURAL SURFACES IN PETRA

5.1 Rock Carved Façades

5.1.1 Introduction

The rock carved façades were perhaps the most studied in the past in terms of architectural styles and typologies. The work of Brünnow and Domaszewski (1904) is considered as the first extensive survey and documentation of the monuments in Petra, which includes classification of the carved tomb façades into seven groups, based on their main architectural elements. Although there have been other classifications (Browning 1973; Dalman 1908; Kennedy 1925), nevertheless, they were all based on divisions according to relatively similar architectural features.

The first group of tombs according to the classification of von Domaszewski (1904: 137-158) comprising the "Pylon Tombs", is characterized by one or two rows of crowsteps with a torus and sometimes with a fascia below it (see Fig. 25, Tomb 826). The second group of tombs, which is that of the "Step Tombs", has a set of five steps at the top, facing one another, with a cavetto cornice and a torus below. The "Proto-Hegr Tombs" are similar to the "Step Tombs", but have additionally pilasters below the cavetto, while the "Hegr Tombs" have an attic and a classical cornice below the cavetto (see Fig. 12, Tomb 633). The fifth group, namely the "Arch Tomb" is characterized by an arch decorating the whole façade (Fig. 11), while the "Gable Tomb" is decorated by a gable. The last group, called the "Roman Temple Tombs", refers to the façades which have a combination of various architectural elements of classical type (see Fig. 4, al-Khaznah).

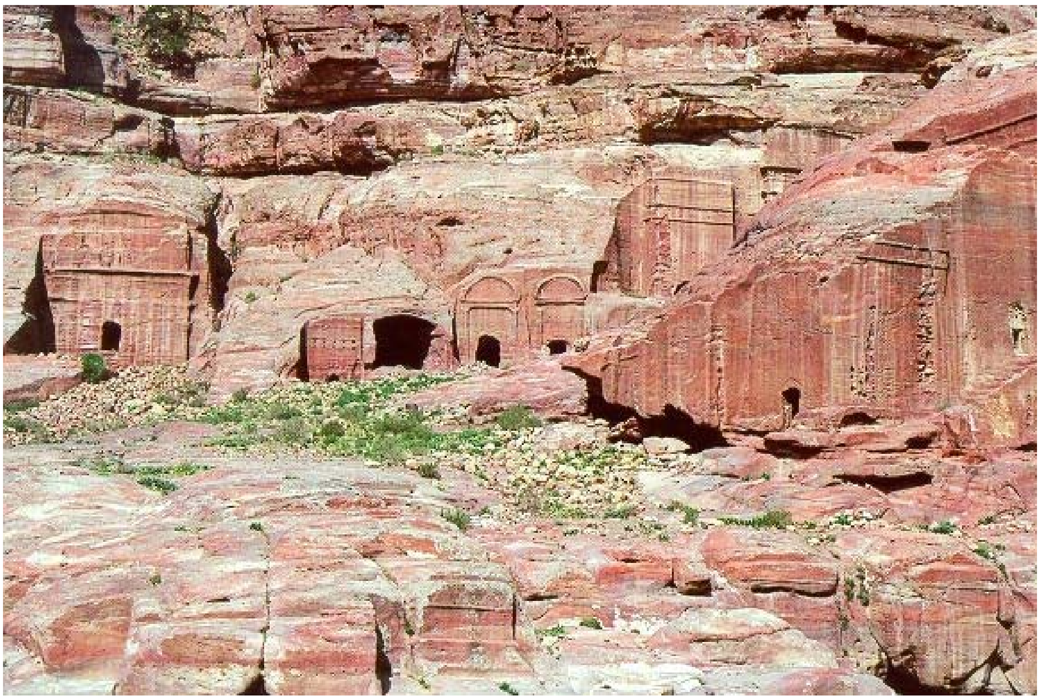


Figure 11. Facades comprizing "Arch Tombs", "Pylon Tomb" and a "Step Tomb".

Although many of the façades were noted to have painted plaster remains, yet most of it has disappeared as part of the weathering process of the monuments. Within the scope of the present study, samples from painted plaster remains of these tomb façades were collected, prepared and examined with optical microscopy, scanning electron microscopy, and sometimes x-ray diffraction and binder/aggregate ratio analysis.

5.1.2 Tomb 633 – Turkmaniyya

Tomb 633, also known as Turkmaniyya or Qabr at-Turkman, is located along the western bank of Wadi Abu ʻUllayqa, and on the eastern rock side of Jabal al Mu'aysra ash Sharqiyya. Brünnow and Domaszewski (1904: 362) classified this tomb as being of the Hegr type. Its façade consists of two sets of large steps, a cavetto cornice, an attic storey with four "dwarf" pilasters, and a classical cornice (Fig. 12). Below the cavetto are a fascia and a torus followed by dwarf pilasters. Each has a bevelled base and recessed plinth. According to McKenzie (1990: 167), the right dwarf pilaster has a Nabataean Type 2 capital, while the middle ones have a Type 3 Nabataean capital. The dwarf pilasters rest on the classical cornice, which is made up of a sima, bevelled ovolo, corona, dentil element and another bevelled ovolo. The cornice stands on top of a plain fascia, a fillet, cyma reversa and an architrave consisting of two fasciae. Supporting the cornice are two inner half columns and two outer pilasters each with an engaged quarter column and two inner half columns, while the capitals are Type 1 Nabataean with a short necking band.

The interior plan of the tomb consists of two rooms. The first room is about 10x10.25 m, while the second room is about 10.65x5.5 m with a recess along its back wall measuring ca 5x2.5 m and in turn leads to another recess of about 2.4x0.8 m. The connection between the two rooms is in the form of a passage about 2.35 m long and was probably originally 1.9-2.00 m wide. Upon clearing the 1 m level of debris inside the tomb, it was found that the inner room has seven carved recesses in its floor that would have served as individual graves. Additionally, it has the remains of eight short walls, which in turn would have been built to form graves as well. In front of the recess of that room are two sets of holes carved in the floor, each set forming an L-shape.

The façade was carved from the natural rock except for most of its third lower part which was built of stone, and from which nothing has remained. The fact that the lower part was constructed, rather than carved, is revealed by the presence of tool marks along the bottom of the two right pilasters, indicating that these two rock cut pilasters were continued with stone blocks. The uppermost right step has been built out of quarried sandstone blocks as has been the extreme right corner of the cavetto cornice. Additionally, the left part of the cavetto, which is broken, has square shaped dowel holes showing that this part was finished by inserting pieces of stone for the cavetto (Fig. 13).

Almost one third of the façade, constituting its lower part, has completely disappeared. Just above the portion of the disappeared part and between the two inner supports is a Nabataean inscription. Above the inscription is a rectangular niche of about 80x58 cm, inside of which are what appear to be the remains of two busts. The bust on the right is without head while the one to the left is hardly recognizable, where only the backing – consisting of mortar and pieces of stone – is present. Some substantial red and blue painted plaster remains are evident inside the niche, on its back and top sides.

Figure 12. Façade of Tomb 633.

The well preserved inscription is one of the few surviving Nabataean funerary inscriptions. Although it does not provide either the date of the tomb or the name of the owner, it nevertheless gives insight into the original plan of the whole tomb complex. The inscription is sharp and finely carved, with the background very smoothly dressed.

The Nabataean inscription is written in five lines within a rectangular frame of 4x1.25 m. Each of the right and left edges of the frame have a shape of an axe-head in the middle of which are the remains of two patches of a plaster with a yellowish/bluish colour, giving the impression of large bolts or screws. The bottom part of the inscription has an incised sketch of a profile (Fig. 14) that was meant to be used as a template for the stone masons to carry out the carving of the architectural elements.

Figure 13. Tomb 633 dowel holes.

Figure 14. Tomb 633 incised profile.

The latest interpretation of the inscription is the one given by Zayadine (1991: 282), based on the translation by Milik (1959) – who was the first to translate it – and that of Jobling in McKenzie (1990: 35), and reads as follows:

> 1. "This tomb and the chamber within and the smaller chamber behind it, in which are the burials in the form of loculi,
> 2. the courtyard in front of them, the guest rooms in it, the benches and the triclinia, the cisterns for water, rock walls and retaining walls
> 3. as well as the rest of the architectural structures that are in the area, these are dedicated (*herem*) and consecrated to Dhu-Sharä, the god of our Lord [the king], to his protected throne and to all gods,
> 4. by the acts of consecration as specified therein, Dhu- Sharä, his throne and all gods watch over the acts of consecration so they will be observed and there will be no change.
> 5. or division of whatever is included in them [the acts]; and no one will be buried in this tomb except for whom authorization is set in the acts of consecration for ever".

None of the other structures, which were probably built in front of the façade as mentioned in the inscription, has survived. Some remains are probably still buried in front of the façade.

According to Zayadine (1970: 46; 1991: 282), the tomb is dated to the reign of king Malichus II (AD 40-70) on the basis of its style and also by comparing its composition with that of tomb F4 in Mada'in Saleh, which is dated to AD 63/64. McKenzie (1990: 35) also attests that date.

The façade of this tomb has remains of mortar and plaster at various locations. There is mortar that was used for joining the stone insets at the top right part of the façade, namely the right most crowstep and the right part of the cavetto cornice. The mortar of the latter had been previously analyzed and found to contain lime and gypsum as the binder (Shaer 1997: 117). Additionally, plaster applied in three to five layers and coating the top of the cavetto cornice with a slope towards the outside was found to be purely made of lime mortar with a certain mix of aggregates (Shaer 1997: 121). This plaster had the function of draining the water away from the top of the cavetto, and thus protecting it from the adverse effect of water stagnation or seepage from the edges, that could cause damage to the façade. Hence it was necessary for this plaster to be a durable one with the advantage of being able to protect the stone.

Moreover, a mortar that was used as a repair for the capital left of the niche seems to be of a lime-gypsum mix on initial inspection. Also of interest to this study, is the decorative plaster and paint that was used to cover the façade and bring out its features. The blue and red paint layers of the niche containing remains of two busts have been previously analyzed and found to consist of Egyptian blue and haematite respectively, in addition to gypsum (Shaer 1997: 121).

Sampling

Samples were taken for the purpose of studying the structure of the paint layers and in order to find if previously unknown paint remnants could be found (Shaer forthcoming a). These samples were taken from the painted plaster remnants of the niche with the red and blue colours, and from the "robe" dress of the bust in the niche. Additionally, several samples were taken from the area of the inscription in order to assess whether there were any remains of plaster or paint layers and their compositions. Table 2 provides a list of the samples analyzed.

Table 2. List of samples analysed from Tomb 633.

Sample	Provenance; Description
633-10	From the back wall of the niche with red colour; just above right bust; sample size: 5.5x1.5 mm, 1 mm thick
633-11	From the back wall of the niche; upper part; white plaster with red colour; sample size: 6x9 mm, 4 mm thick
633-12	From edge of niche at the corner with the façade; sample size: 5.5x2.5 mm, 1 mm thick
633-13	From the pink coloured plaster of the robe covering the right bust; sample size: 10x10 mm; up to 4 mm thick
633-14	From the plaster on the façade just below the niche on the left; sample size: 4x5 mm, up to 3 mm thick
633-16	From plaster representing a bolt, left of the inscription; several fragments, largest size: 2.5x3 mm, 1 mm thick
633-17	From the bottom part of the frame of the inscription; several fragments, largest size: 2x3 mm, 1 mm thick
633-18	Small fragment from an incised letter of the inscription; several fragments, largest size: 2x3 mm, 1.5 mm thick

Results of the Analysis

The façade of the tomb appears to have been once covered with a plaster layer as evident by the few remains under the niche (Fig. 15). This plaster is basically a gypsum plaster (633-14) with very few small quartz aggregates – as opposed to the gypsum plaster of the niche full of quartz aggregates. The right part of the sample shows the presence of some iron, which could mean that the surface had been painted with red. The plaster appears as though it were made of two types, a purely gypsum one with quartz aggregates and one with some lime as well as gypsum and containing calcite aggregates, with the lower part made of lime plaster. It thus seems that this layer consists of a lime/gypsum mix.

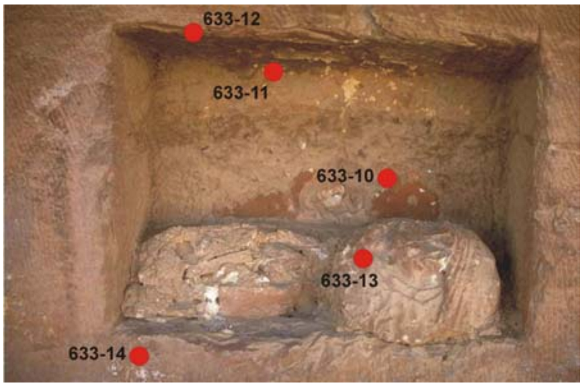


Figure 15. Tomb 633 sampling inside the niche.

For the red paint layer applied inside the rectangular niche (samples 633-10 and 633-12), a mixture containing red ochre was used. The whole paint layer is 10-40 µm thick. The paint layer was laid on top of a gypsum plaster layer (intonaco) containing a lot of quartz aggregates with a thickness of ca 450-800 µm under which is a support layer of lime plaster with aggregates (arriccio).

The underside of the ceiling of the niche has a blue colour in addition to the red, as does the top left side of the niche. In the latter case, a red paint layer was painted over the blue (sample 633-11). Here, the red layer is thicker (50-100 µm), and consists of a mixture of gypsum and haematite. This layer was painted over a blue one (50-120 µm) consisting of Egyptian blue pigment (cuprorivaite), over a preparation layer of gypsum plaster with quartz grains. This gypsum plaster layer contains potassium chloride (KCl) salt. The difference in thickness and pigment composition between this red layer and the above mentioned one covering the niche could mean that it was not contemporary with it, but was a later repainting of the blue.

Cross section analysis has also shown that the sculpture found inside the niche is made up of a dolomite stone (sample 633-13). The stone was first laid out with a support layer of gypsum plaster (1800 µm) containing small quartz grains, and painted over in layers (50-210 µm), as would be in a varnish, containing calcite and possibly iron rich ochre (Fe associated with Al, K and Si), alternating with layers rich in phosphorus (P) and magnesium (Mg). A pigment could not be identified. However, it is possible that the paint layers represent an application of a lake pigment with aluminium hydroxide, since this white substance is prepared from aluminium sulphate and potash, which would account for the presence of Al and K together in the sample. Also, calcium, iron, magnesium and phosphate can be encountered in applied madder lakes (Schweppe and Winter 1997: 131-132).

GC-MS analysis of the paint layer in sample 633-13 showed the presence of wax. FT-IR spectrometry of the same sample revealed the presence of gypsum, quartz, some weddellite, whevellite and traces of nitrates. Comparison of peaks as a result of analysis with toluene extract with peaks of paraffin wax showed them similar. Paraffin wax is a modern wax and hence it is highly improbable that it was used by the Nabataeans. However, it can be deduced that a mineral wax, such as ozocerite, could have been used.

Regarding the inscription itself (Fig. 16), which appears to have merely a very finely finished stone surface without any plaster or paint, was found to have originally been painted. It seems that the frame of the inscription was painted with a red ochre mixture with some lime (sample 633-17) as were the inscribed letters (sample 633-18). A particle of white apatite was detected in the sandstone substrate of sample 633-17, though unclear whether it is part of the sandstone or a penetration. This inscription represents a case of the direct application of paint on a very finely dressed stone surface. One tends to speculate the possibility of the whole inscription tablet being covered with a white lime plaster layer and afterwards the frame and inscribed letters painted red, giving a more pronounced inscription against the white homogeneous background than if it would have been against the sandstone background.

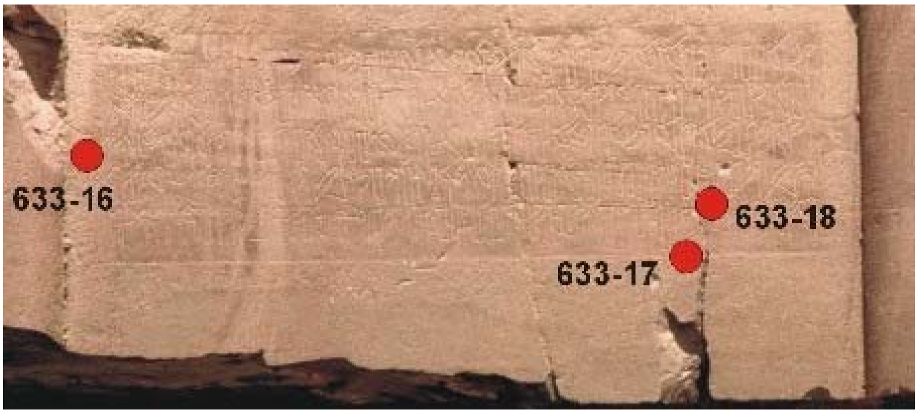


Figure 16. Tomb 633 sampling of the inscription tablet.

Moreover, the analysis of a sample (633-16) from the circular plaster remains to the left of the inscription showed the remains of pure iron directly attached to the sandstone surface. This implies that the 2 round circles on both sides of the tablet (Fig. 17) were originally sheets of iron metal placed directly on the stone that gave the impression of large circular bolts holding an inscription tablet on the façade. At a later stage, with the rusting of the metal, it was probably removed and a gypsum preparation layer (300-400 μm) was laid on top of it and painted over with yellow ochre. This repair was done simply and cheaply, and probably intended to give the impression of shiny metal bolts. As early as the beginning of the 19th century (during the years 1817 and 1818), Irby and Mangles (1985: 412) visited this monument and noted:

> "To return to the inscription; …there projects, from each of its ends, those wings in form of the blade of an axe, which are common both in the Roman and Greek tablets, and which would seem to have been in their origin, for the purpose of receiving screws or fastenings, … there is upon each side a stain of metal, which must be the effect of studs of bronze actually driven in, to give the whole tablet the appearance of a separate piece."

Figure 17. Circular shape in plaster to the right of the inscription.

Obviously the impression of the paint to Irby and Mangles seemed to be of bronze studs, as is the original intention of the Nabataeans. Figure 18 shows a hypothetical reconstruction of the inscription that is based of the results of analysis.

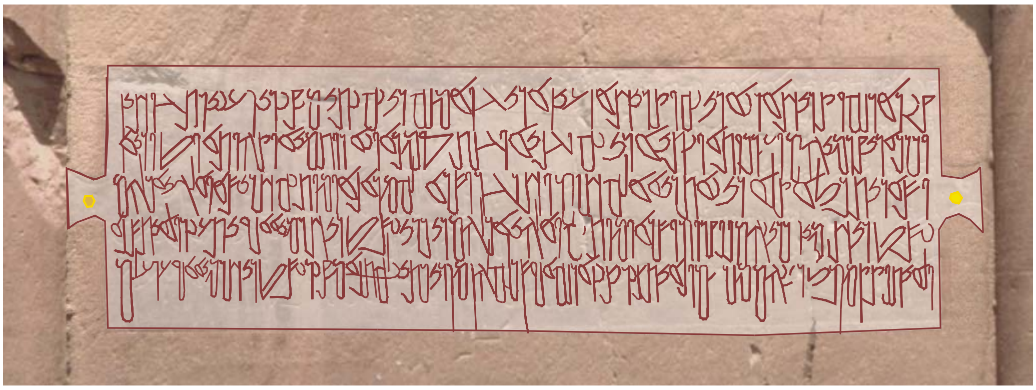


Figure 18. A reconstruction of the inscription on the façade of Tomb 633.

State of Preservation

The façade of Tomb 633 is in a very advanced state of deterioration that includes the presence of alveoli over relatively large areas and marking zones with high salinity, especially in the upper part of the façade. There is also a large crack that can be seen along the left part of the façade, which allows water seepage, in addition to structural cracks passing through the façade inscription lines and evident along the interior walls. Smaller cracks are present on many of the carved architectural features like capitals and cornices.

The highly deteriorated state of the façade of Tomb 633 is reflected in its decorative plaster remains. There is no façade-covering plaster except for the two detaching and fragile small patches evident directly under the niche, the two circles on either side of the inscription and what could be microscopically detected on the surface of the inscription tablet. The fragments found inside the niche are also detaching and can easily break. Soluble salts have been found in the cross sections in relatively high quantities. Sodium chloride could be seen in sample 633-10 in crystal form and is the result of the leaching out of salts from inside the rock and crystallizing on the surface. Potassium chloride could also be found in the painted plaster inside the niche (samples 633-11 and 633-12). Furthermore, the gypsum layer on the painted sculpture could be the result of sulphation. Nitrates have been detected in addition to whevellite and weddellite which are calcium oxalates that are also due to microbiological activities on the surface.

Conservation Recommendations

Scaffolding has been set in front of the façade of Tomb 633 in order to assess its weathering state and to conduct some conservation work that would help in preventing further deterioration of the façade. Of these measures, desalination and the filling of major alveoli is planned, in addition to the fixing of architectural elements by means of needles. The inscription has several cracks, and although it appears stable, a comprehensive structural study is needed before any plan for structural stabilization is set and implemented.

Due to the scarcity of the plaster remains, few conservation measures need to be implemented, yet such measures are necessary in order to help in preventing further deterioration and disintegration of this plaster. Of these measures is the cleaning, desalination and reattachment of the plaster edges covering the walls of the niche. Additionally, it is necessary to clean the surface of the remains of the sculpture and implement certain actions that would help to prevent rainwater from accumulating inside the niche.

5.1.3 Tomb 826

Tomb 826 is located in the area of the "Outer Siq" of Petra. It is a Pylon Tomb according to the tomb façade classification of Brünnow and Domaszewski (1904: 408). The façade measures ca 10.5x20 m, and consists of two rows of crowsteps, with each unit in the row comprising four steps. Below the upper set of crowsteps is a torus, as also evident above and below the lower set of crowsteps. To be noted is the absence of a stone carved fascia (the horizontal band that can be found usually below the torus on other façades in Petra) below any of the torus elements of this façade.

Nearly a quarter of the façade, representing its lower part, is eroded with no recognizable architectural features. The eroded entrance opening is ca 2x1.5 m, above which is a horizontal carved cavity in the rock where a doorway pediment in stone or in moulded stucco insets was once inserted. Additionally, the left part of the façade has carved cavities as well, and these also used to be filled with stone insets. Along the top of the façade is a carved water channel that had the function of draining rainwater coming down from the mountain face above, channelling it to the sides of the monument, thus preventing the water from seeping on the façade surface. At about 1.2 m below the lower torus, the façade was carved in a horizontal line and a ceramic water pipe was inserted, the remains of which are very few. This water pipe is evidently a later addition and is part of the water system running down the Siq and passing through other tombs as well. The water system is dated to after AD 50 (McKenzie 1990: 54, 110), and the façade of Tomb 826 was carved before the ceramic pipe was inserted. The interior of the monument consists of several loculi that were used for burial. Three loculi are found in the northern wall, four in the eastern wall and one in the southern wall.

Upon close inspection of the façade, substantial plaster and paint remains can be noted (Shaer forthcoming a; b). Several remains of a thin layer of white wash can be seen all over the façade. The architectural features, such as the two rows of crowsteps have thick plaster remains in between the steps (i.e. the recessed parts), with several remains still having a dark red colour and have the appearance of a fairly well polished surface (Fig. 19). The upper torus has just a few thin remains of plastering, while the two bottom ones have thick plaster remains and the remains of a yellow painted surface. Below the torus features are again thick plaster remains that protrude from the stone surface of the façade and in some cases is a clear cut horizontal edge, with instances of turquoise blue colour remains along the second torus (Fig. 23-24). This suggests that the fascia, i.e. the horizontal band found below the torus on many other façades, is in this case moulded in plaster and painted over, instead of it being carved from stone. The bottom fascia appears to have blue remains at its upper part, followed by dark red, similar to the painted surface between the crowsteps (Fig. 20). Below the bottom torus and fascia are the remains of a plaster layer suggesting another horizontal band, or fascia that is recessed with respect to the first horizontal band, and in that case, the fascia would be in two levels (Fig. 21).

The rest of the façade, comprising plain surfaces, has remains of the white layer of plaster, except in the middle of the façade where at ca 3.3 m below the bottom torus is a patch representing thicker plaster remains (Fig. 22).

Figure 19. Red paint between crowsteps.

Figure 20. Red and white paint on fascia.

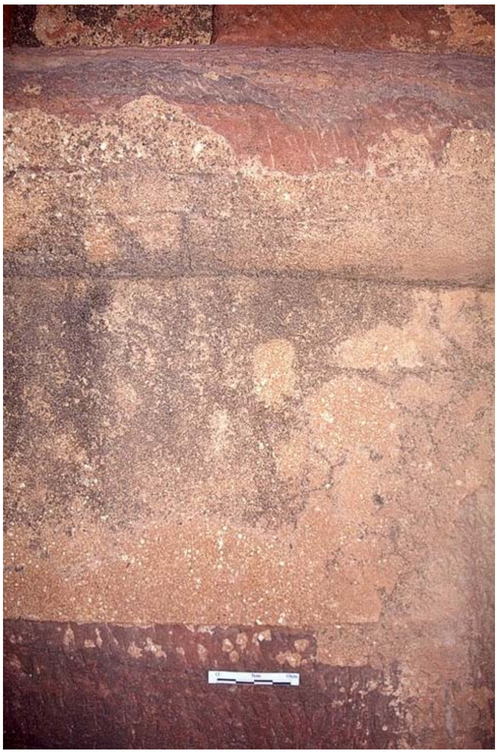


Figure 21. Remains of two horizontal bands.

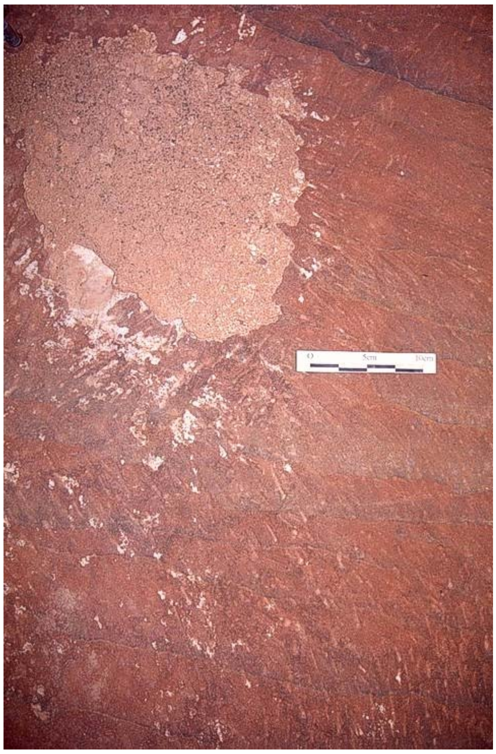


Figure 22. Plaster layer on the façade.

Figure 23. Blue paint on fascia below torus.

Figure 24. Detail of blue paint on fascia.

Several of the painted surfaces show horizontal marks hinting at the possible use of a metal polishing tool. Such marks are found on the red painted surfaces between the crowsteps, especially evident on the top left corner of the façade, as well as the blue painted surfaces. The bottom edge of the fascia is inclined at an angle, implying that the plasterers used a ruler at an angle of ca 45° angle. Also, the plaster along the edge of the torus and where the fascia begins is concave, showing that a rounded ruler was most probably used in order to create a well defined edge. Plaster and painted remains of the façade were mapped (Fig. 25), leading to an understanding regarding the façade renderings.

Figure 25. Mapping of plaster and paint remains on the façade of Tomb 826.

Sampling

Several samples were taken from the plaster remains of this façade in order to determine the structure of the plaster and paint layers, to analyze their composition, and to deduce the original appearance of the façade and the mode of plaster application. Table 3 provides the list of the samples and their provenance.

Table 3. List of samples analyzed from Tomb 826.

Sample	Provenance; Description
826-01	From the first set of crowsteps; area between the third and fourth set of steps from the right; has microbiological growth; several fragments, largest: 30x17 mm, 5 mm thick
826-02	From the first set of crowsteps; area between the first and second set of steps from the right; two layers and a red polished surface; 22x30 mm, 8 mm thick
826-03	From the horizontal band (fascia) below the upper torus; detached plaster; 20x23 mm up to 7 mm thick
826-04	From the horizontal band (fascia) below middle torus; two layers but no paint remains; 15x21 mm, 10 mm thick
826-05	From the middle torus; 17x20 mm, up to 5 mm thick
826-22	From the thin white "ground" layer on the surface of the stone; 5x4 mm, 1 mm thick
826-24	From white plaster at the top, above which would have been plaster and paint layers; 8x3 mm, 1 mm thick
826-31	From uppermost area between the first two sets of steps; has sandstone backing and red paint; 7.5x10 mm, up to 7 mm thick
826-32	From fascia below second torus; blue painted surface 6.5x9 mm, 7 mm thick
826-33	From the middle torus moulding; yellow paint on the original surface; 16x15 mm, up to 5 mm thick
826-42	From the plaster patch in the middle of the façade; 35x10 mm, 3 mm thick
826-46	From the white "ground" layer on the façade 2.5x1 mm, <1 mm thick
826-48	From single plaster of the second band of fascia below third torus; 12x7 mm, up to 2 mm thick
826-53	From fascia below second torus; red on blue; 3x1 mm, up to 2 mm thick
826-54	From plaster on second torus with sandstone backing; 10x7 mm, up to 2.5 mm thick

Results of the Analysis

Along with mapping the plaster and paint remains, samples were analyzed (Fig. 26), which helped in gaining knowledge of the façade's original appearance (Fig. 28).

Regarding the plaster layering of the façade, it appears that the plain surface and the protruding crowsteps were originally coated with a single layer of "fat" lime plaster (500-800 μm thick). Cross section analysis of two samples (826-22 and 826-46) showed that this plaster has several micro fissures due to its high lime content and lack of aggregate, thus resulting in its cracking due to shrinkage of the mortar mix. This layer seems to have been applied as a first coating, covering most parts of the façade, and afterwards the layers of lime plaster with aggregate and the paint layers were added. An example of this application is sample 826-24 which seems to be the ground layer applied between the first two sets of steps at the uppermost row of crowsteps, above which plaster and paint was added. This is found in samples 826-02 and 826-31. Parts of the torus elements had such a ground layer as well, upon which plaster and paint was applied (sample 826-54). However, this white wash is not present everywhere, and sometimes appears to have been laid following the plastering of some parts of the façade, such as on the surface below the middle fascia, where it does not continue under the plaster of that fascia, but stops at the edge.

Moving on to the architectural elements, in addition to the thin white layer, there seems to be 2 layers of lime plaster with many aggregates covering the recessed areas between the crowsteps, the torus elements, and the moulded fasciae. Each layer has a thickness of 3-5 mm, so that most often the total thickness of the plaster is 7-10 mm. In some instances in the analysis of cross sections (sample 826-31 from the area between the crowsteps), there seems to be a single plaster layer, rather than two layers, above the "fat" lime layer. It is possible that in certain instances the first layer was not meticulously laid out so as to cover every centimetre of the façade. Above the plaster, a paint layer was applied and polished over. Red was applied between the crowsteps, yellow on the torus and blue on the fascia. The fascia below the lowermost torus has red painted on the surface as does the few plaster remains of a single layer found below it (sample 826-48).

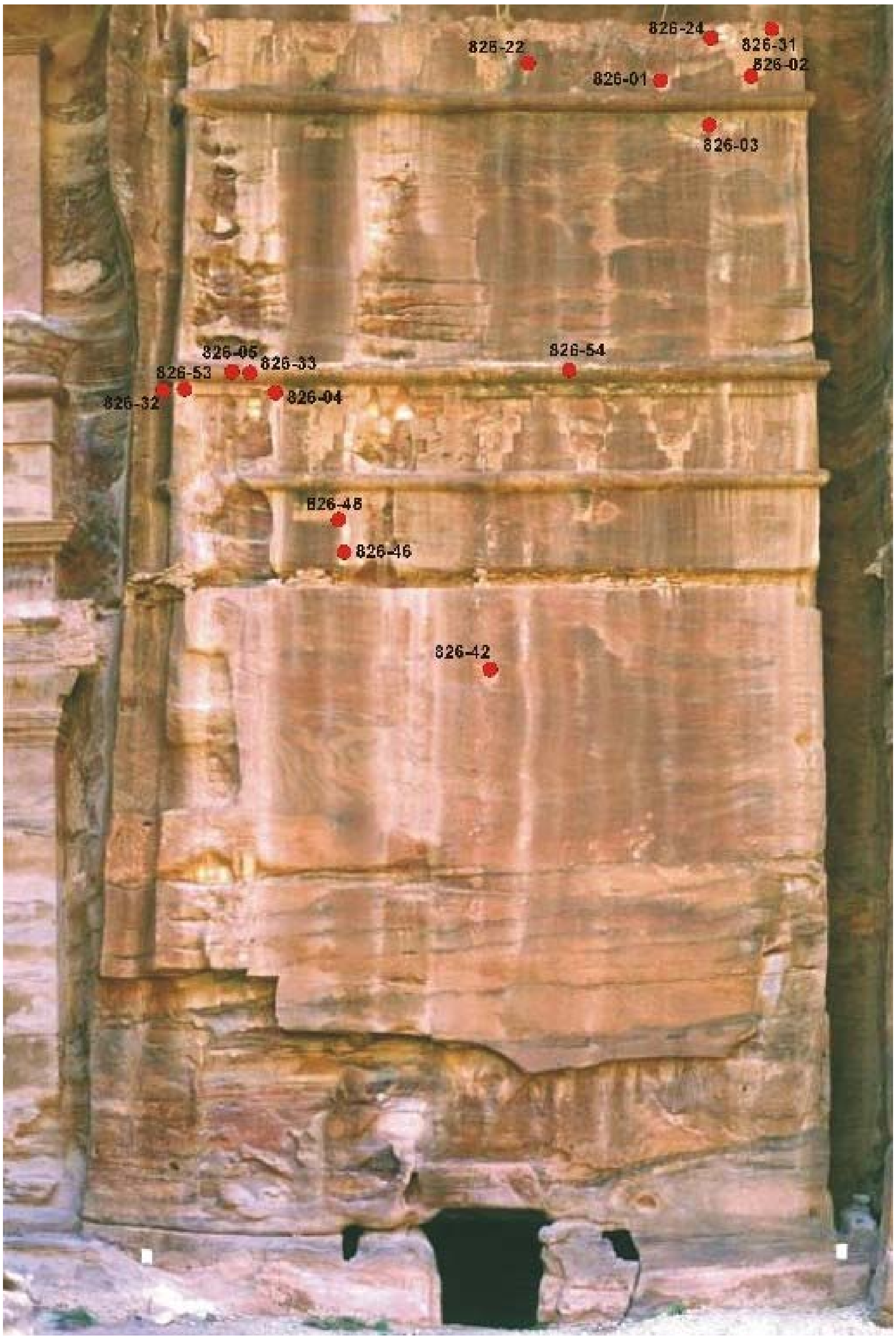


Figure 26. Sampling map of the façade of Tomb 826.

The dark red paint layer applied on the plaster between the crowsteps (samples 826-02 and 826-31) has haematite as the red pigment. This layer contains lime and is probably applied al fresco. Sample 826-31 shows application of the layers (Fig. 27), where first a ground layer of "fat" lime (ground) was applied directly on the sandstone (125-300 µm), followed by a layer of lime plaster (3500-4300 µm) with aggregates and finally the red paint layer of 60-90 µm. Also, barium sulphate ($BaSO_4$) is present on the highly polished surface and some inside the paint layer. The red paint on the few plaster fragments below the lowermost fascia (sample 826-48) is made of red ochre mixed with lime.

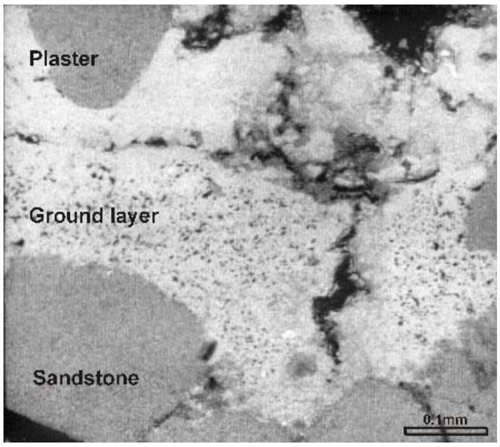


Figure 27. Lower part of sample 826-31, SEM photo, showing the application of the ground layer followed by the plaster layer.

The turquoise blue painted layer has a thickness of 75-100 µm, with the blue pigment being Egyptian blue (sample 826-32). Below the Egyptian blue layer are black particles of soot, the function of which would have been to provide a deeper colour tone, as a "veneda". Here, naturally, there is no lime present in the paint layer, as typically Egyptian blue does not work well with lime and cannot be used in a fresco technique. Alternatively, another binder would have been used in a secco/tempera technique. Another sample (826-53) from the same area was analyzed and showed a rather thick red layer above the blue painted a layer. Although iron (Fe) was detected within the layer, nevertheless the morphology of the layer implies that it is the result of dust accumulation rather than a red repainting.

As for the yellow layer (sample 826-33), the pigment used is yellow ochre. The layer contains lime which again implies a fresco application, and it also shows the presence of $BaSO_4$.

The results of analyzing 5 samples of plaster for binder/aggregate mass ratio measurement (samples 826-01, 826-02, 826-03, 826-04 and 826-05) have shown that this ratio is within the range of 1:0.5 and 1:1. The aggregates consist of quartz and fragments of rock from limestone, chert and sandstone. Any Calcite aggregates present could have also been dissolved in the acid mix along with the binder during this test, which might account for the relatively low amount of aggregate in some cases. Taking into consideration that about 20% of the aggregate might have been calcitic and thus dissolved with the binder (as found in the analysis of sand from the river bed – sample Sand 4), there would still be a high content of binder with respect to aggregate. This is quite different from recommendations of Pliny and Vitruvius. To be noted is the similarity of the B/A ratio of samples 826-01, 826-02 and 826-03, and the similarity of the B/A ratio of samples 826-04 and 816-05. This similarity is also reflected in the grain size distribution, whereby ca 52.6-61.7% of the aggregates in the former group are <500 µm, whereas in the latter group ca 77.5-79.1% of the aggregates are

<500 μm. Thus, it appears that although all of the samples are generally of a similar nature, there are at least two mixes of plaster prepared for the upper decorative architectural elements and for the middle ones, which vary in aggregate size and B/A ratio. Since these two mixes appear to have been both contemporary with the original façade surface finish, then the difference in mixes would be merely accidental, where the plasterers did not seem to adhere to a strict recipe for the plaster mixture nor for the aggregate size used.

From the plaster and colour remains on the façade, one can deduce that the three primary colours of red, blue and yellow have been used in addition to the white surfaces (Fig. 26). To be noted is the lack of secondary colours such as green, orange and pink on the exterior façade surface. The fresco technique was used to apply red and yellow colours by wetting the lime plaster and applying the paint layer above. $BaSO_4$ is clearly present and its origin could have been as an admixture or as part of the pigment. On the other hand, since Egyptian Blue doesn't work well in the fresco technique, the use of an organic binder is probable.

Moreover, the white "fat" lime layer on the façade, in addition to being a white coating of the façade's plain surfaces, was also a ground layer that was probably intended to help in closing the pores of the sandstone, and thus providing a uniform substrate surface for applying the plaster layer.

Finally, the plaster patch in the middle of the façade (sample 826-42) might have been probably a plaque (made of plaster), which comprised an inscription or dedication to the gods, or had the date, name of owner, or name of architect. Such rectangular plaques are found carved on the façades of Mada'in Saleh, which is a Nabataean site, situated in Saudi Arabia, with its monuments dated to the period spanning AD 1 to AD 76 (Jaussen and Savignac 1909; 1914).

On this façade we find the case where plaster was not used merely as a coating for the surface, but was also used to imitate architectural elements, such as the fasciae that are usually carved as part of the rock under the torus. Here, moulding it in plaster is much easier than carving it in stone, and additionally avoids failures that might occur in carving. Also the use of deep colours like red, blue and yellow on architectural elements helps to distinguish them from the plain façade surfaces and hence gives the impression that the façade is a set of constructed elements rather than one piece of carving on the mountain. This adds to the Nabataean concept of making their façades either set in the mountain or protruding out from it in order to give it a sense of separation from the natural rock.

State of Preservation

The bottom part of the façade of Tomb 826 is highly deteriorated. Original architectural features are unrecognizable in that area, and, additionally, stone parts have detached from the rock as a result of natural faults. Stone insets that were originally present along the left part of the façade and along the doorway are gone, while large alveoli, representing highly saline portions of the façade are evident along the left side. There, also weathering forms such as sanding and scaling are present. The façade has clearly lost a lot of its plaster and paint coating. There is also plaster detachment that is especially evident below the topmost torus, where substantial material has been lost between the plaster surface and the sandstone.

Even in places where the plaster does not appear loose, drill resistance measurements in two areas have in fact shown that the bonding between the plaster and the façade is rather weak. In some places, there is microbiological growth, especially evident on the plaster surfaces.

Figure 28. Hypothetical reconstruction of the façade of Tomb 826.

Conservation Recommendations
The façade of tomb 826 is currently undergoing conservation work. The top water channel has been cleaned of vegetation and debris, so as to allow water to drain from the sides of the façade again, rather than staying in open parts or flowing over the surface. Cleaning and desalination of the sandstone as well as filling the large alveoli in order to slow down the deterioration process is underway. The fixing of some stone parts at the bottom with steel needles is also planned. As for the plaster, it is recommended that reattachment of detached layers by grouting with lime mortar that is matching to the original should be done. Also, injections can be done for scaled and fragile layers of plaster. This can be conducted by an injection grout that is similar to the one used for fixing scales in the sandstone, i.e. a silica sol repair mortar of low viscosity (consisting of silica sol, water and a mineral mix). The cohesion of crumbling mortar can be increased by treatment with silicic acid ester with high deposition rates. These interventions have to be preceded by controlled applications on test areas.

5.1.4 Other Façades
Plaster and paint remains can also be seen on other tomb façades. These are often found on elevated places of the façade, which are not easily accessible even by using long ladders or by attempting to climb the mountain rocks in order to reach the plaster remains from the upper parts of the façades. The scaffolding in front of the façades of Tombs 633 and 826 permitted to obtain a variety of samples covering all the possible situations of the plaster and paint remains. Samples were taken from other tomb façades where it was permissible.

Tomb 827 (Fig. 29) is located adjacent to Tomb 826. It is also a pylon tomb and has some remains of plaster with red paint evident in the uppermost part constituting the crowsteps along the side wall (Fig. 30). The red paint layer was found to contain haematite as the red pigment mixed with lime, and applied al fresco (sample 827-02). Additionally, barium sulphate was found in the layer. The paint layer was applied over a coating of lime plaster with quartz aggregates and is ca 5 mm in thickness. Optical microscopy has shown the presence of microbiological infestation of the mortar.

Figure 29. Façade of Tomb 827.

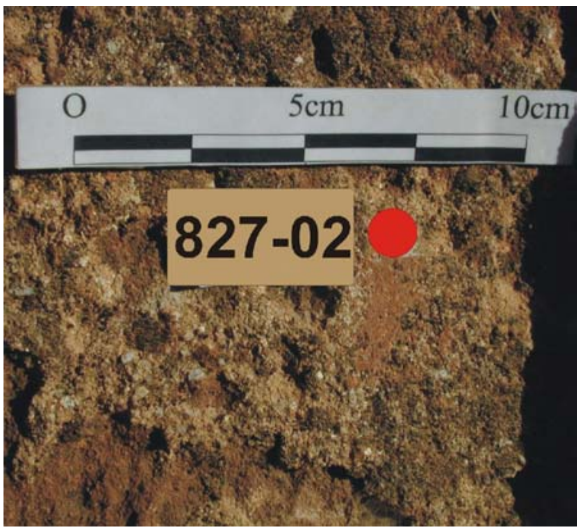


Figure 30. Sample 827-02 taken from the plaster.

Tomb 524 (Figs. 31-32), located in the area of Jabal al Mu'aysra al Gharbiyya, is perhaps the façade that has the most plaster still covering ca 35-40% of its surface. Red can be seen on the fascia below the torus of the cavetto cornice, while red and blue remains can be seen on the architrave below the classical cornice. Along the southern side wall of the monument, few remains of yellow painted plaster are found next to the big steps and possibly on the architrave. The only sample that could be obtained was from the top of the side wall (sample 524-01a) (Fig. 33). The yellow paint layer is composed of yellow ochre and calcite, implying a fresco technique of paint application. The paint layer is applied over a layer of 8-10 mm of lime plaster that has siliceous and calcareous aggregates of various sizes. The plaster layer appears to be in two layers, though without a distinct boundary; the upper one has more binder and less air voids. There is substantial microbiological growth especially evident in the upper part of the layer.

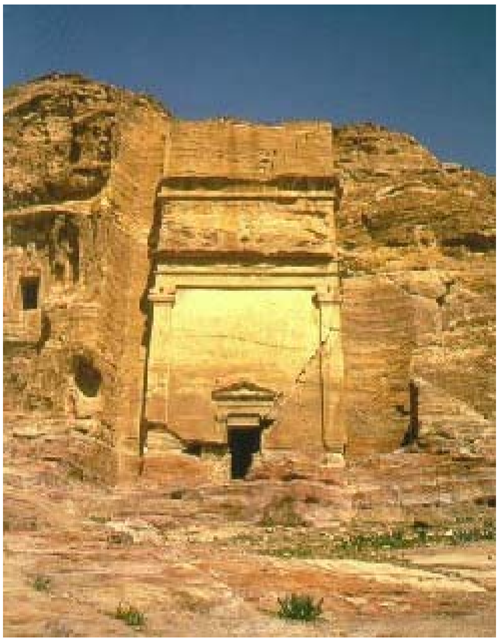


Figure 31. Façade of Tomb 524.

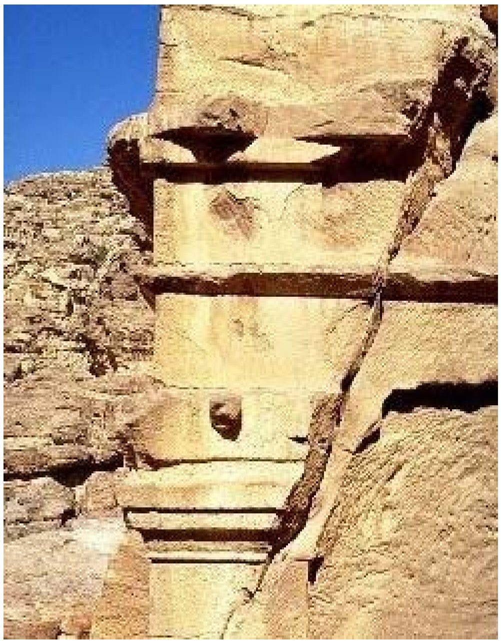


Figure 32. Side of Tomb 524 with plaster.

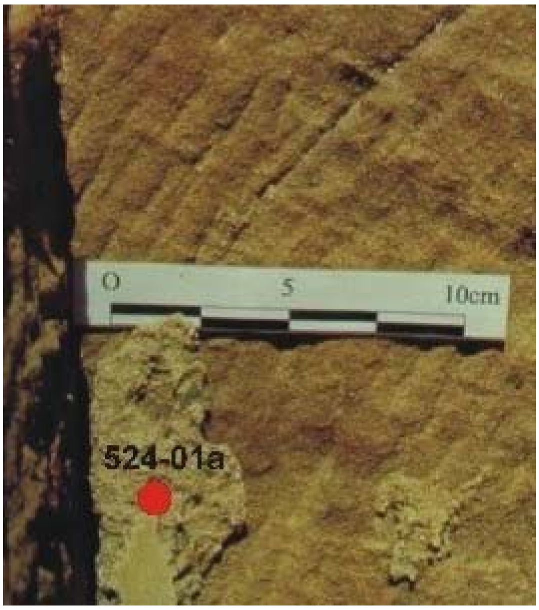


Figure 33. Sample taken from Tomb 524.

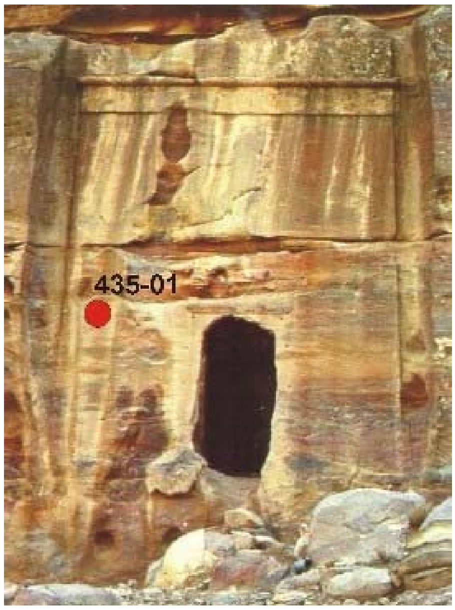


Figure 34. Façade of Tomb 435.

The façade of Tomb 435 (Fig. 34) is another pylon tomb that has evidence of red between the crowsteps and blue on the torus and fascia. These remains were too high to be reached by ladder and could not be collected by climbing the mountain. Nevertheless, a sample could be obtained from the thin white remains on the façade surface below the torus (sample 435-01). This showed that a fat lime wash was applied on the façade.

The Garden Temple (No. 244), located in the area of Wadi al-Farasa was also sampled (Fig. 35). This façade has four supports with two columns cut free. There are stucco remains on the left part of the façade moulded in the shape of ashlar masonry. The façade is approached by steps, and the interior consists of a vestibule and a chamber behind it. Sample 244-10 was collected from the stucco remains. Investigation of cross sections of this sample showed no evidence regarding the original surface of the stucco. The stucco is moulded out of lime mortar that contains much aggregate.

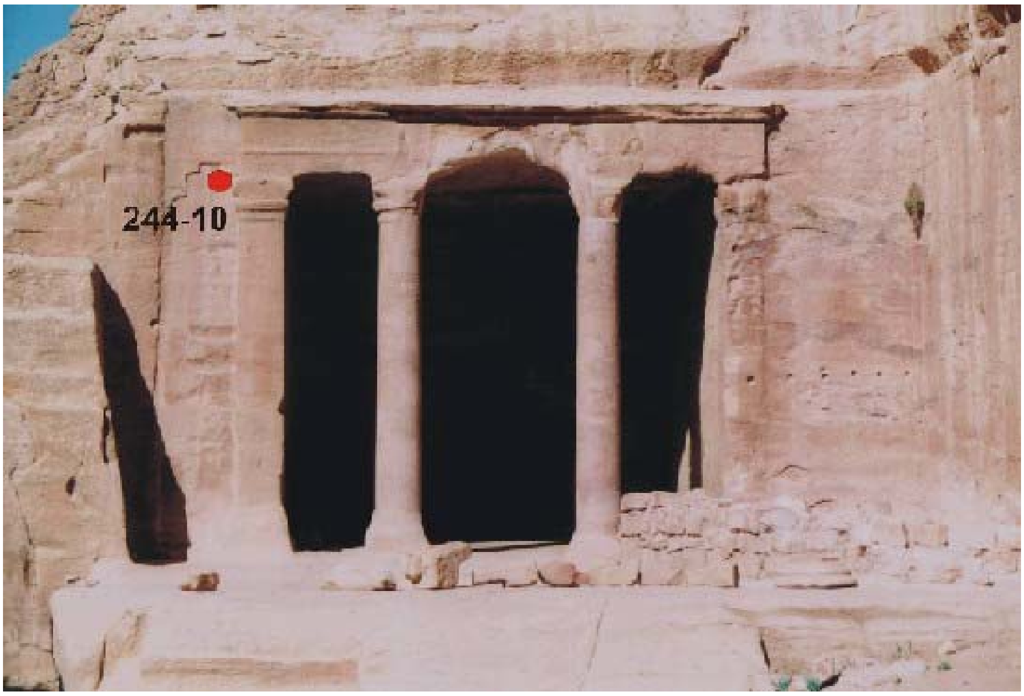


Figure 35. The Garden Temple (No. 244) with stucco remains in the form of ashlar masonry.

5.2 Rock Carved Chambers

5.2.1 Introduction

Rock carved chambers are numerous in Petra and the surrounding area. Many of these served functions such as triclinia – the dining area with benches on three sides – or as parts of dwellings. Some of them have remnants of plaster in one, two or three layers, in a succession ranging from coarse to fine textured mixes. Although only very few of these still retain painted remains, it nevertheless suggests that interior wall decoration was a common practice.

Many of these caves served as habitations for the local Bedul tribe until 1985, when they were settled in the nearby village of Umm Sayhoun. Consequently, many damages of the plasters and wall paintings are the result of functions carried out inside these chambers, such as the burning of fires and hence accumulation of soot on the walls.

5.5.2 Biclinium and painted room in Siq el Barid (No. 849)

One of the rock cut chambers along the southern side of Siq el-Barid is a biclinium, i.e. a dining hall with benches along two of its walls. It is higher than the street level, and is accessible through an opening in the mountain after reaching the top of a staircase. The biclinium is basically a room of 5x6.2 m, and has a vaulted recess accessible through its back wall. The back wall itself has remains of stucco in imitation of ashlars, while the ceiling of the alcove has a painting that is the only surviving example of Nabataean intricate painting and consisting of grape vines, flowers, various types of birds and cherubic figures (Figs. 36-38). Each of the interior walls of the recess has two carved niches.

Figure 36. Cherubic figure.

Figure 37. Painted fauna and flora.

This complex with its stucco and decorative painted plaster has been known to archaeologists since at least 1906. G. and A. Horsfield (1938: 21-24) have described it, as well as Tarrier (1988: 55-56), while Glueck (1956; 1965: Pl. 203-204) has provided a detailed description of the painting, and finds that it emphasizes the "joie de vivre" celebrated in Nabataean art, with the grape and vine depictions, the gods Pan and Eros and the sophisticated forms in the artistic translation of the Nabataean civilization (Glueck 1956: 19).

Figure 38. Part of the painted ceiling.

In many parts of the painting, although the original surface colour is lost, the original painting scheme can still be observed due to the faint grey traces of the drawing.

According to Zayadine (1987: 141-142), the painting is of Alexandrine influence and can be dated to the first half of the first century BC. Horsfield (1938: 21-24) dates it to the fourth or beginning of the third decade BC, while McKenzie (1990: 43, 52), dates it to the first half of the first century AD by grouping it with the Theatre, dated to that period, on the basis of the stone dressing of its rock cut walls. Glueck (1956: 21-23) compares this painting to a mosaic at Oudna, 25 km south of Tunis, dated to the last part of the first and beginning of the second century AD, and also to a painting at the entrance of the vault of the Catacomb of Domitilla in Rome, dated as well to the transition period between the first and second centuries AD. Based on this argument, Glueck dates the ceiling painting at al-Bayda to the end of the first or beginning of the second century AD.

Such ceiling decorations appear to have been popular in Pompeian Third Style of painting, of which is the painting of the vaulted ceiling of the Tomb of Pomponius Hylas on Via Latina in Rome dated to between AD 19 and 37, and, the paintings of the House of Orchard at Pompeii dated to AD 40-50 (Ling 1991: 65-66).

All such comparative examples can only prove that the mural painting of this biclinium is "part of a fairly long and widespread cultural and more specifically artistic tradition" (Glueck 1956: 22-23). Nevertheless, there is no reason to believe that the execution of such a painting was not executed by a Nabataean artist.

Sampling

Two samples were taken from the stucco applied in imitation of masonry, while all other samples were taken from the recessed alcove, representing the various colours. Table 4 gives a list of the samples taken and their provenance.

Table 4. List of samples analyzed from the biclinium and painted room.

Sample	Provenance; Description
849-10	From back wall of biclinium; stucco imitating masonry; original surface; soot; 8x3.5 mm, 3 mm thick
849-11	From back wall of biclinium; stucco imitating masonry; red surface; 6x2 mm, 1.5 mm
849-13	From west part of ceiling; leaf motif with 'pastel' green colour; 2x1 mm, 0.5 mm thick
849-14	From west part of ceiling; leaf motif with a brown colour; 1.5x0.5 mm, 0.5 mm
849-14a	From west part of ceiling; leaf motif with a brown colour; 2x1 mm, 1.5 mm thick
849-15	From west part of ceiling; grape motif of dark reddish; 2.5x3 mm, <0.5 mm thick
849-16	From west part of ceiling; vine scroll; grey colour ; 2x1 mm; <1 mm thick
849-17	From west part of ceiling; leaf motif of dark green colour; 2.5x0.5 mm, <0. 5mm thick
849-18	From west part of painted ceiling; blue outline around a painted face, probably helmet; 1x<0.5 mm, 1 mm thick
849-18a	From west part of ceiling; blue colour around a painted face, helmet (?); small particle
849-19	From plaster on the west wall below the stucco cornice; blue; 1x3 mm, 0.5 mm thick
849-20	From west part of ceiling; rosy/pink colour; probably armour; 4x2 mm,<0.5 mm thick
849-22	From the grey/white remnant of Bignonia; west part of ceiling; 3x2 mm, ca 200 μm
849-22a	From the grey/white remnant of Bignonia; west part of ceiling;1.3x1.2 mm, ca 350 μm
849-21	From east part of painted ceiling; leaf motif with grey surface; 4x2 mm; 0.5 mm thick
849-23	From east part of painted ceiling; white background; 2x2.5 mm,1 mm thick
849-24	From plaster of the western niche of the back wall of alcove; green; 8x3mm,5 mm thick
849-25	From grey/white remnant of Bignonia; west part of ceiling; 1.5x2 mm, ca 300 μm

Due to the richness and variation in colours, samples were taken to represent the various colour hues, in order to have an overview of the pigment palette at the time, and to get a better idea concerning the plaster behind the dark soot. Samples with the grey outlines of the drawing were taken in order to elucidate its composition. In sampling, care was taken in not destroying much the painted plaster, and hence very small particles with original surface were collected at broken out zones of the plaster. Thus, it was not possible to get samples representing the complete strata of layers with the sandstone substrate.

Figure 39. Sampling from the stucco covering the back wall of the biclinium.

Results of Analysis

Observation in optical microscopy, and analyses with Scanning Electron Microscopy (SEM) with Energy-Dispersive X-Ray Analysis (EDX) was conducted on the samples. The results were in some cases supported by X-Ray Diffraction analysis (Shaer forthcoming b).

Regarding the red paint of the stucco representing the joint in the ashlar masonry imitation (849-11) (Fig. 39), haematite was used mixed with gypsum. The layer is very fine, up to 60 µm, applied over a lime/gypsum plaster preparation layer of 35-65 µm that is in turn above a support layer of lime mortar with aggregates of about 0.5 cm thickness. The support layer is applied on top of two plaster layers of coarser texture. The one directly behind it is about 1-1.5 cm thick, while the one which is in contact with the sandstone is of varying thickness and coarser texture. Thus, there are three layers of lime plaster, applied successively from coarser to finer textured ones, followed by the intonaco and the paint layer.

Moving on to the painted ceiling, the green pigment used for some leaves (samples 849-13 and 849-17), seems to be atacamite with gypsum added to the paint mixture (Fig. 40). Microscopically, the green layer appears to be identical in the two samples, as a fine homogeneous pale green colour, rather than previously reported incidents in samples from other places where atacamite particles appear as round masses with dark centre as would be typical of the formation of synthetic salts (Scott 2002: 136). Hence, the atacamite found in this ceiling painting is probably not a deterioration product of other copper pigments, such as malachite, but was originally used as a pigment.

Figure 40. Sampling of the green painted leaves.

The green layer of sample 849-24 (Fig. 41), is of a different composition than the above mentioned one. The green layer here is up to 100 µm, and is composed of green earth mixed with particles of yellow ochre and Egyptian blue. Such a mixture gives a brighter green hue than that of green earth, which is further enhanced by including particles of soot in the gypsum preparation layer below.

Figure 41. Sampling of green inside niche.

Figure 42. Sampling of brown paint.

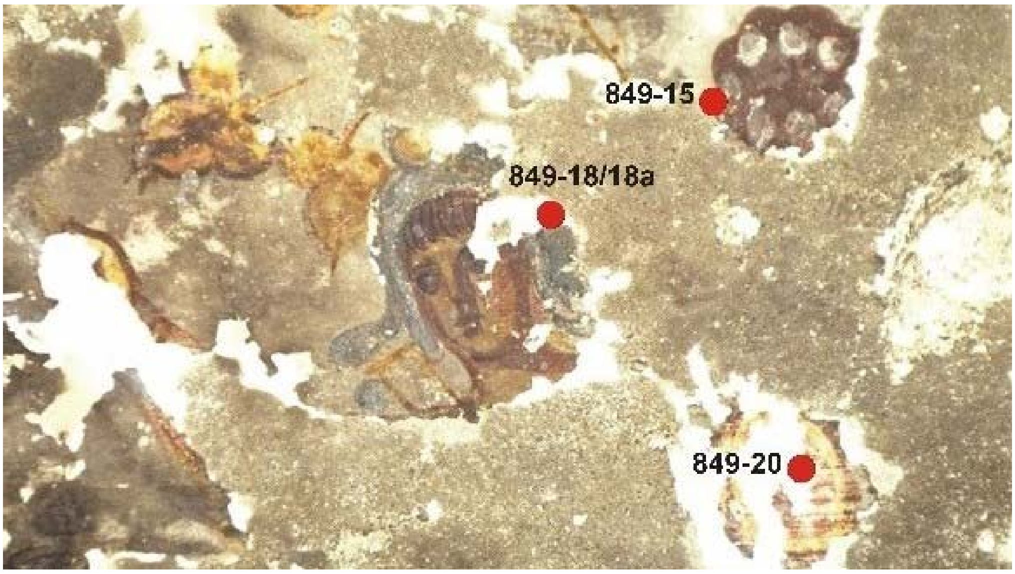


Figure 43. Sampling of blue and rosy/pink colours.

The blue pigment, as expected in all blue samples, was found to be Egyptian blue. Sample 849-18 from a grey blue motif painted around a face, and could be a representation of a helmet, was found to contain Egyptian blue over gypsum and a fine layer of red ochre with gypsum. The red ochre was probably used for painting the figure. The other blue sample (Fig. 44) came from the surface of the wall below a moulded stucco cornice (sample 849-19). The layer of Egyptian blue grains is applied in a rather thick layer of up to ca 225 μm.

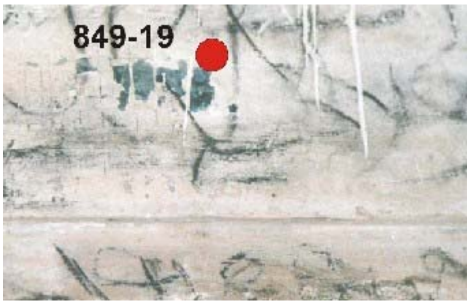


Figure 44. Blue sample 849-19.

Figure 45. Samples 849-22 and 849-22a.

Analyses of samples representing the white/greyish surface of the bignonia grandiflora flower (samples 849-22, 849-22a and 849-25) showed a fine layer of what appears to be aluminium hydroxide, with evidence of alum ($AlK(SO_4)$) in one of the samples. It is possible that in this case it was used as a white pigment to depict a white hue for the flower (Figs. 45-46), where also a brown/orange rendering is evident in the middle of the circular form.

Figure 46. Sample 849-25 from the greyish white area of the bignonia.

This transparent white aluminium hydroxide is often used as a substrate for dyes, and alum is reported as the source for it in classical times (Gettens and Stout 1966: 91-91). The fact that this material was detected in relation to the bignonia flower motif raises the question whether an organic pigment such as madder was also used, since the bignonia is a tubular flower that is often with a yellowish/orange colour. Additionally, magnesium (Mg) was detected in the three samples analyzed – often in relation with silicon – along with aluminium hydroxide, indicating that a magnesium bearing compound might have been used as well. Magnesium can be encountered as result of using madder lake (Schweppe and Winter 1997: 131), which could not be confirmed in this case. The gypsum intonaco layer is compacted and hints that the paint layer above was probably burnished causing its compaction below, or the gypsum was itself burnished to prepare for the paint layer. Under the aluminium hydroxide layer in sample 849-25, some parts of an orange layer are evident, and this probably related to the adjacent orange/brown painted stalks.

Analysis from the greyish/white painting background (sample 849-23) (Fig. 47) revealed a gypsum top layer above lime plaster, and is actually the same as the preparation layer underlying the painted surface.

The grey areas within the painting composition, which once represented bright colours (samples 849-16 and 849-21), consist of gypsum. GC-MS analysis carried out on sample 849-16 showed the presence of beeswax in the top layer. Beeswax was thus used as a binder, and it appears that the grey surfaces tracing the outlines of painted motifs represent remnants of this organic binder, while the pigments themselves have disappeared.

Figure 47. Sampling of grey background.

Clearly, the painting cannot be called a fresco. Analyses have proven that pigments were mixed with gypsum, rather than lime for application of the paint layer, and hence most probably gypsum was used as a binder and/or extender. In one instance beeswax was detected and hence it is certain that an organic binder was used. This paint layer is itself applied over a preparation layer (intonaco) made of gypsum and with a thickness lying within the range of 300-500 µm, over a support layer of lime mortar with aggregates (arriccio), followed by two other lime plaster layers with aggregates. The gypsum preparation layer would have been a dry surface by the time the paint layer was applied. Additionally, the paint layers were applied over each other to give a realistic depiction of these motifs which are borrowed from nature and to render them in shades, providing a three dimensional impression. It seems that paint layers were applied successively in a gradation from light to dark colours and finally the opaque outline of single motifs was drawn tracing the boundary. This can be especially noted for the yellow/brown stalks and vine leaves. One exception to this successive painting is where the light green vine leaves are concerned. Very few of the leaves with green colours have remained, which nevertheless show that all green leaves were painted after the yellow/brown ones had been painted and dried, evident by the relatively translucent nature of the green coloured leaves and their stems. Also, these green leaves are in a way "flat" motifs, and do not have an outline of their drawing.

State of Preservation

Although the painting covering the ceiling of the chamber's recess is a unique example of Nabataean artistic expression of natural subjects and is the primary attraction for visitors to Siq el-Barid, however, it is not well presented to the visitor and accessibility is rather difficult.

The stucco and painted plaster are not in a good state of preservation. Indeed, there is a substantial amount of plaster and paint detachment, in addition to many lost parts of the plaster. Also, many painted features have disappeared and in their place is a grey background revealing the original scheme, which represents leaves and stems. Green is the only colour whose remains could be found in some areas of the grey parts, and hence it appears that all these grey areas were once green painted motifs. This hypothesis is supported by the fact that very little painted green leaves have survived to balance the darker brown ones.

Soot covers most of the plaster as a result of fire burning by Bedouin habitation in the past. An assessment of the condition of the wall paintings of this chamber was conducted by Franchi and Pallecchi (1995), and it was concluded that nitrates and calcium sulphate have been formed as a result of the burning of fires and cooking.

Analysis of the samples has revealed the presence of soluble salts (sodium chloride), and some sulphates that causes further deterioration of the plaster layers, especially the more fragile paint layers. X-ray diffraction analysis of samples (849-11, 849-13 and 849-16) has shown the presence of the calcium oxalates, whevellite and weddellite, as has been also found by Franchi and Pallecchi (1995: 100).

Conservation Recommendations

It is recommended that conservation of this chamber and its recess should be done in a holistic approach. The site requires better presentation and interpretation, and improved accessibility.

Regarding plaster and paint conservation, the policy of minimal intervention should be considered. Cleaning of paint is necessary not only to show the original scheme, but also to remove the soot. Desalinization may be also required since salts can be harmful in the long term.

Methods of cleaning should be tested in order to find out the best method which does not harm the paint itself, whether by using poultices, mechanical cleaning or laser cleaning. Franchi and Pallecchi (1995: 103) have recommended using pads made of Japanese paper and containing a saturated solution of ammonium carbonate ($(NH_4)2CO_3$) and ethylenediaminetetracetic (EDTA), in order to absorb the soot layer, though they say that it would be necessary to first experiment with this method on site in order to determine the span of time required for the application of pads.

The use of ammonium carbonate and EDTA is in fact not recommended because of the ubiquitous presence of gypsum in and under the paint layer. Furthermore, the degradation of copper bearing pigments is to be expected.

Reattachment and consolidation of the plaster and paint layers should also be tried and observed prior to implementation. Filling in the lacunae is a necessary action that would help to prevent further loss of the plaster layers along the borders. The painting can be stabilized as it is, possibly by lime injection grouts and silicic compounds, and no additional plastering or painting is necessary, that might jeopardise the integrity and authenticity of the painting.

5.2.3 Rooms in Wadi as-Siyyagh

On the edge of Jabal umm Zaytuna, south of Wadi as-Siyyagh, is a set of rock carved rooms that have remains of decorative moulded stucco and painted plaster. Horsfield (1938: 18-19; Fig. 2), was the first to note these rooms that were later described by others (Nehmé 1997: 284; Zayadine 1987: 140) (Fig. 48). Perhaps, the most famous of these is a small inaccessible chamber (3x3m) with several wall paintings (Room "4" in Fig. 43). The paintings were first discovered in January of 1980 by N. Qadi and Cl. Vibert (Zayadine 1981: 355). The walls were all covered with mud and straw, and upon cleaning parts of them by a team from the Instituto del Restauro in Madrid (Zayadine 1987: 140), the decorative scheme was revealed. It seems that the upper part of the walls was decorated with a geometric pattern, while the lower part has a pattern of doorways framed by bands, with red and yellow doorway flaps. Above some of the doorways, is a cornice and sometimes a pediment.

According to Zayadine (1987: 140), the wall paintings are of Alexandrine influence and Nehmé (1997: 284) dates them back to the first century BC.

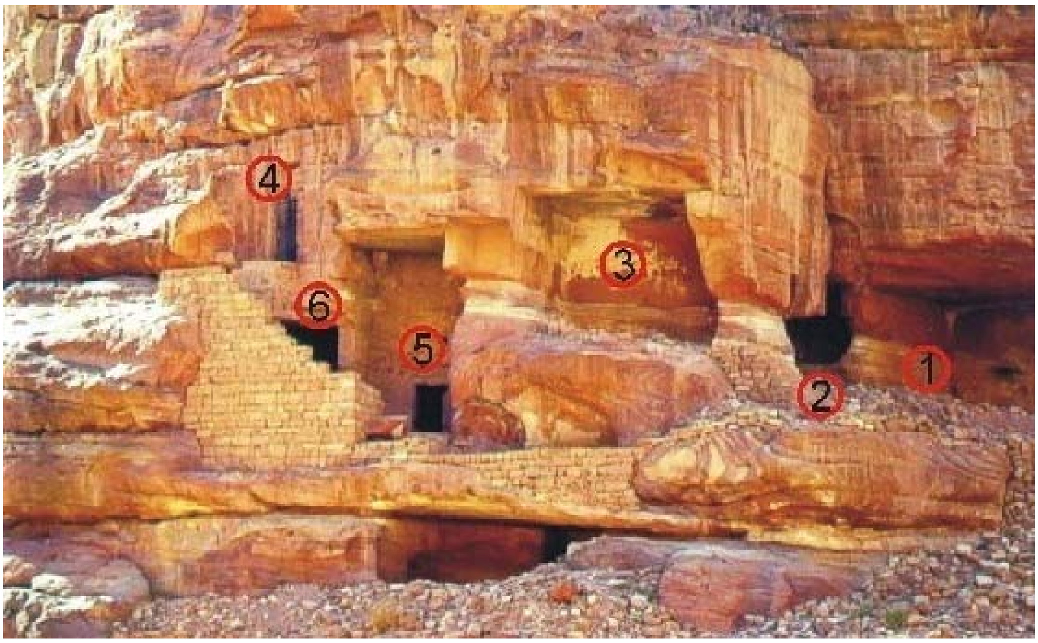


Figure 48. Complex of rooms along the northern edge of Wadi as-Siyyagh.

Sampling

Several samples were taken from the different chambers, representing the different painted surfaces, in order to find out about their composition and layer application. Sometimes very miniscule samples were taken from the painted surfaces of the richly decorated room (Room "4") in order not to destroy or threaten the stability of the layers. In the other chambers, the plaster was rather crumbly and falling apart in many places. Table 5 provides a list of the samples taken and their provenance and description.

Table 5. List of samples analyzed from the 3 rooms of the Wadi as-Siyyagh complex.

Sample	Provenance; Description
SIY-01	From the northern wall of room "1"; sample of 2 layers, 45x7mm, ca 10 mm thick
SIY-01a	From the northern wall of room "1"; outer layer, ca 5 mm thick
SIY-01b	From the northern wall of room "1"; inner layer, ca 5 mm thick
SIY-02	From the northern wall of room "1"; 35x20 mm; ca 7 mm thick
SIY-03	From the northern wall of room "1"; 32x15 mm; 5-7 mm thick
SIY-04	From lower part of northern wall of room "4" – pattern of doorways; red surface; 7x7 mm, 1 mm thick
SIY-05	From upper part of northern wall of room "4" – geometric pattern; first plaster layer; 5x2 mm, 2.5 mm thick
SIY-06	From upper part of northern wall of room "4" – geometric pattern; rosy/pink surface; 3x3 mm, 1 mm thick
SIY-08	From upper part of northern wall of room "4" – geometric pattern; dark red surface; 2x1 mm, 2 mm thick
SIY-09	From upper part of northern wall of room "4" – geometric pattern; white surface painting; 2x1 mm, 0.5 mm thick; 2x0.5 mm, ca 1 mm thick
SIY-12	From lower part of northern wall of room "4" – plaster layer below the one with colour; 1.5x1.5 mm; 0.5 mm thick
SIY-13	From lower part of northern wall of room "4" – pattern of doorways; blue surface; 7x6 mm, 2 mm thick
SIY-14	From lower part of northern wall of room "4" – pattern of doorways; rosy/pink surface; 2x1.5 mm, 1 mm thick
SIY-15	From lower part of northern wall of room "4" – pattern of doorways; green surface; 3x5 mm, 2 mm thick
SIY-16	From lower part of northern wall of room "4" – pattern of doorways; yellow surface; 4x3.5 mm, 1.5 mm thick
SIY-17	From lower part of northern wall of room "4" – pattern of doorways; black line; 4.5x4 mm, 2 mm
SIY-18	From lower part of northern wall of room "4" – pattern of doorways; blue surface; 2x1 mm, ca 0.7 mm thick
SIY-19	From upper part of northern wall of room "4" – geometric pattern; yellow surface; 2x2.5 mm, 0.5 mm thick
SIY-20	From upper part of northern wall of room "4" – geometric pattern; red surface; 2x1.5 mm, 0.5 mm thick
SIY-21	From upper part of northern wall of room "4"– geometric pattern; blue surface; 3x2 mm, 1 mm thick
SIY-22	From upper part of northern wall of room "4" – geometric pattern; red surface;
SIY-23	From upper part of northern wall of room "4" – geometric pattern; blue surface; 2x1.5, 1 mm thick
SIYAB-01	From the left niche of the western wall in room "3"; 4x1.5 mm, 1.5 mm thick
SIYAB-02	From the right niche of western wall in room "3"; 7x3 mm, 1 mm thick
SIYAB-04	From the ceiling of room "3"; 4x9.5 mm, 3.5 mm thick
SIYAB-05	From the rim of the oculus of the ceiling of room "3"; 6x4.5 mm, 2.5 mm thick
SIYAB-06	From the western wall of room "3"; 7x4 mm, 3.5 mm thick
SIYAB-07a	From western wall of room "3"; paint seems in several layers; 7x2 mm, 1 mm thick
SIYAB-08	From western wall of room "1"; green original surface; 2x2 mm, ca 1 mm thick
SIYAB-09	From northern wall of room "1"; green original surface; 10x5 mm, 1.5 mm thick
SIYAB-10	From northern wall of room "1"; red original surface; 5x2.5 mm, 1.5 mm thick

Results of Analysis

The upper wall painting in Room "4" represents a geometric pattern of squares, rotated squares and parallelograms. Red, yellow and green/blue colours fill the geometric pattern with white lines framing each geometric shape. Red squares are surrounded by a thick yellow frame, while red rotated squares are surrounded by green/blue parallelograms and green/blue rotated squares are surrounded by red/pink parallelograms (Fig. 49).

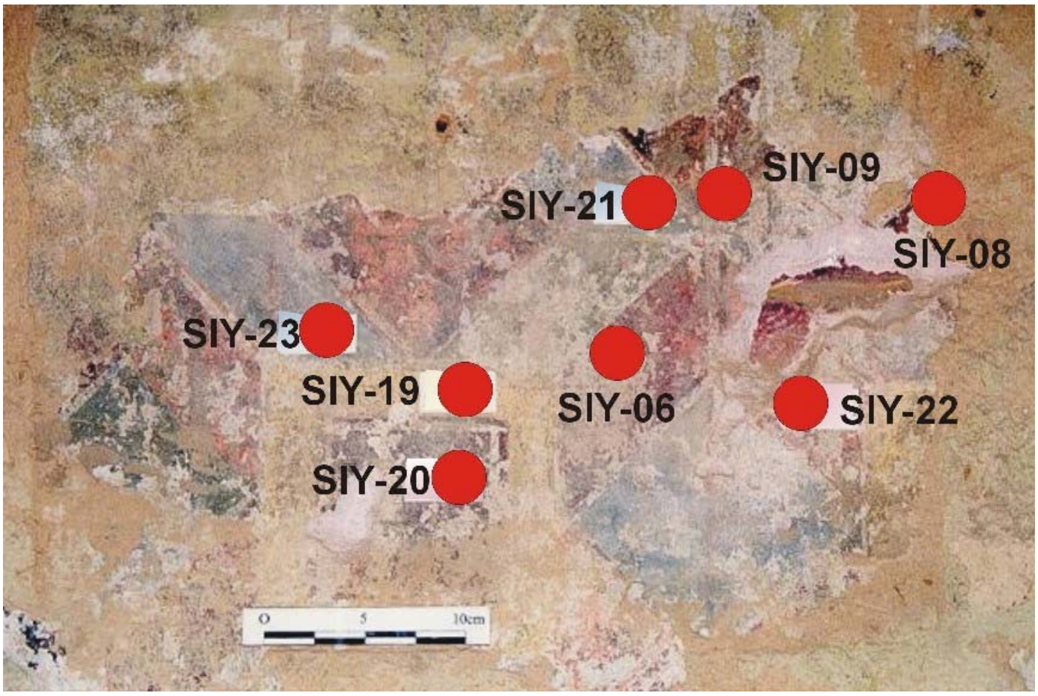


Figure 49. Sampling of upper painting of Room "4".

For the light red paint inside the parallelograms surrounding the blue square (samples SIY-06 and SIY-22), the pigment is made of red ochre, and in the case of SIY-22 the pigment is minium (Pb_3O_4) mixed with red ochre and some gypsum. The darker red tone filling the square (sample SIY-20) with yellow frame is also made up of red ochre and gypsum, applied over a preparation layer (intonaco) of gypsum, but here the ochre is mixed with some particles of black soot, giving it a darker hue. This red underlay is also found under the yellow frame (sample SIY-19) made up of yellow ochre. On the other hand, sample SIY-08, shows that haematite was used rather than ochre. Apparently, in this area the red painted layer was applied over a fresh gypsum layer, and hence a lighter tone of red can be seen. This can also be found in sample SIY-09, where the white border line was painted over the haematite red. In the latter sample we find that the gypsum layer is rather thick and contains aggregates. This support is also found in sample SIY-22. One tends to speculate in these cases whether in this area of the painting we have a fixing or retouching of the painting after it had been finished, as also the paint mixture varies with the presence of minium. The white line is of lime (SIY-09), and is a rather siliceous layer.

Analysis of samples from blue painted areas (SIY-21 and SIY-22), showed the use of Egyptian blue pigment, that has lost cohesion, over some black soot applied above the intonaco layer.

As for the painting in the lower parts of the walls (Fig. 50), the dark red colour of the doorways was achieved by using haematite (sample SIY-04), containing some barium sulphate, and was applied directly on a lime plaster with quartz aggregates. For the yellow doorway yellow ochre was used mixed with gypsum (SIY-16). For the blue panel (SIY-13), Egyptian blue was applied above a layer of black soot that is probably what gives it the deep blue colour. The other blue sample (SIY-18) was taken because it looked much paler with a more turquoise hue (Fig. 51). It turned out to be composed of Egyptian blue with gypsum, but here the soot particles are very few, and hence are not enough to give a dark deep tone to the blue colour. For the rosy or pinkish panel (SIY-14), haematite mixed with lime was used. The green bands (SIY-15) were coloured with a pigment made up of green earth mixed with some Egyptian blue particles applied over a preparation layer of gypsum (which appeared to blend with the pigment above). Carbon black was used as black pigment to paint the black strips.

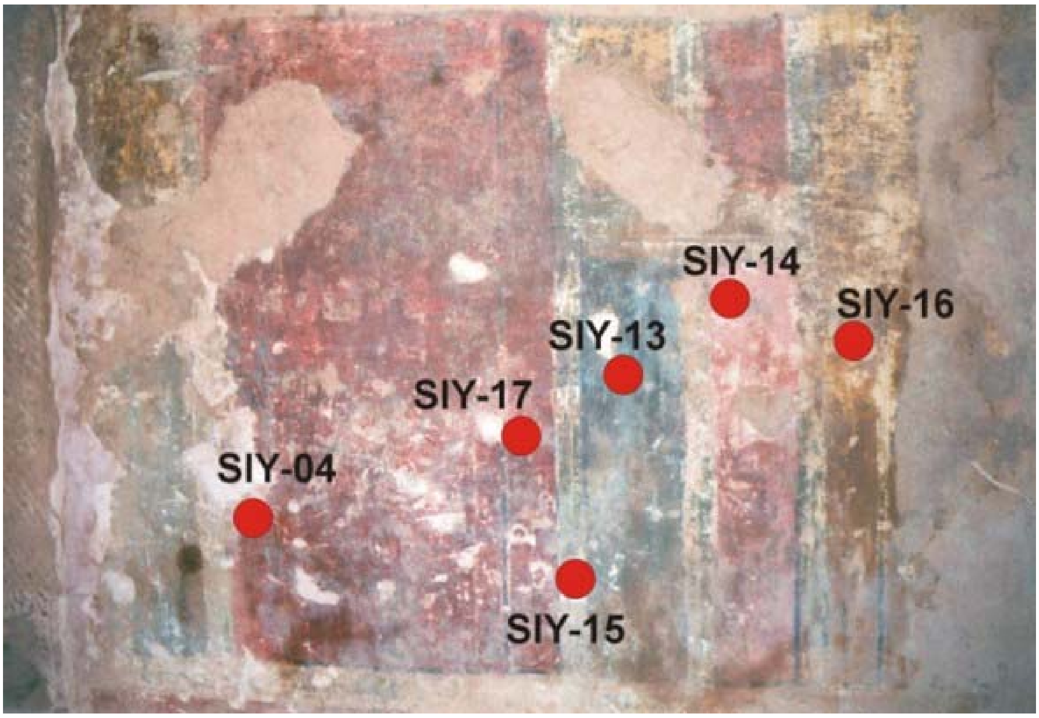


Figure 50. Sampling of lower painting of Room "4".

Figure 51. Turquoise blue sample from the lower painting.

Regarding the application of plaster layers in the painted room "4", again it can hardly be called a fresco since the pigment has not been mixed with lime (except for the pink sample SIY-14, which was clearly done with the aim to have a pinkish hue), and in the case of the upper painting there is a gypsum preparation layer below the painted surface.

It seems that in upper part, a thin layer of fat lime (sample SIY-05), up to 130 µm was applied over the sandstone walls, followed by 2 layers of lime plaster with aggregates, each 5-6 mm thick, over which the preparation layer (intonaco) of gypsum and the paint layer itself were applied. The whitewash and the two support layers continue behind the lower wall painting. It seems that there, another fat lime layer was painted over the upper support plaster layer (Fig. 52), made of lime and up to 175 µm in thickness (sample SIY-12). This support layer was in turn pecked over in order to receive a third lime plaster layer with aggregates (ca 5 mm thick), over which the painting of doorways was applied (Fig. 53). This obviously implies that the lower painting was painted sometime after the upper painting. To be noted is the fact that in the samples examined from the lower painting, no preparation layer (intonaco) was found underlying the final paint layer – other than in the green sample (SIY-15) – which again indicates a different technique of application from the upper painting. It is possible that sample SIY-15 belongs to a later repair, since it represents the only case where there is a gypsum ground in the lower zone.

Figure 52. Lower part of wall: 3 layers.

Figure 53. Lower part of wall: pecked layer.

Room "3" has some painted plaster remains, though very much deteriorated. The samples taken from the two niches in its west wall (SIYAB-01 and SIYAB-02) indicate that walls of the niches had been coated with a layer of fat lime (Fig. 54). Dust is evident, and there is no strong evidence to support the presence of pigment directly applied above. From the samples taken from the wall in between the two niches (SIYAB-06 and SIYAB-07a), it appears that the red paint layer was applied by mixing red ochre with gypsum over 2 successive layers of coarse and fine lime plaster.

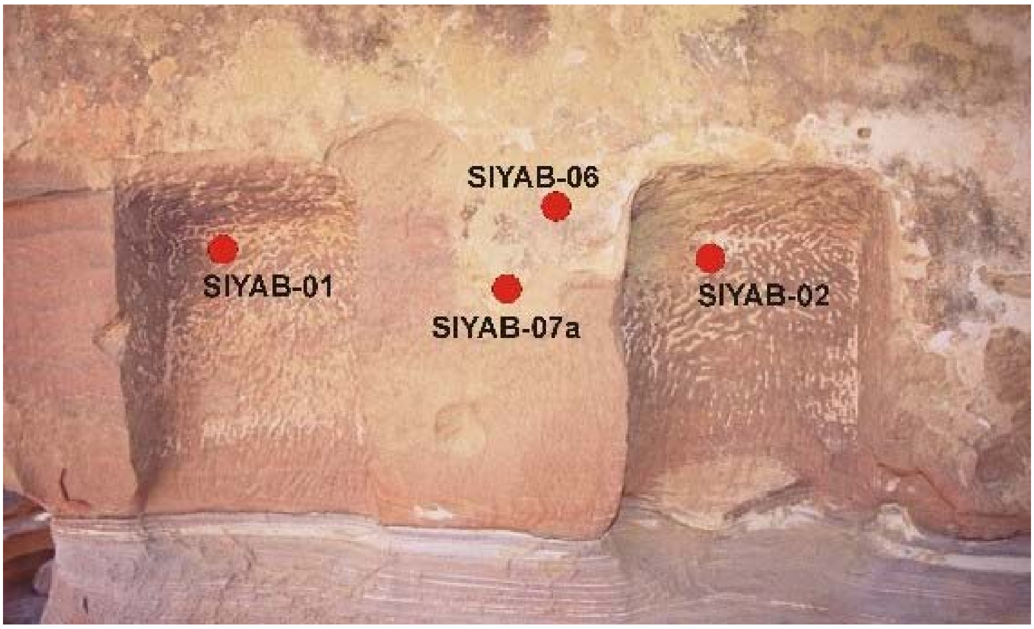


Figure 54. Sampling of west wall of Room "3".

The sample taken from the flat surface of the ceiling (SIYAB-04) (Fig. 55) showed that a fine lime wash was applied over a layer of lime plaster with aggregate, while the rim of the ceiling oculus (sample SIYAB-05) (Fig. 56), was most probably moulded in gypsum with siliceous aggregates, over which a preparation layer of gypsum (150-250 µm) was added and then painted over with a red ochre with gypsum.

Figure 55. Sampling of the ceiling edge.

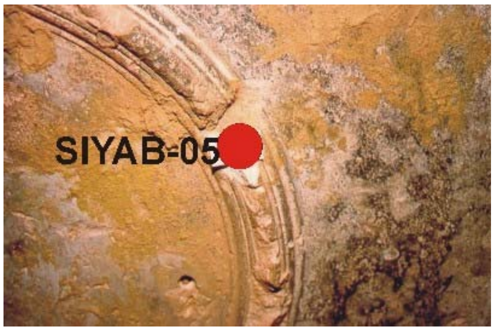


Figure 56. Sampling of the ceiling oculus.

Room "1" has painted plaster remains along its north and west walls. Additionally, there is at the top of the west wall of that room a single piece of moulded white stucco that gives an impression of what the decorative scheme might have looked like. The plastered walls have various successive layers, and it is somewhat difficult to distinguish which parts belonged to the same layer. Sometimes there is a succession of 4 layers over which the last painted layer with its preparation and support layers is laid. Mud and straw plaster is still evident in many parts overlaying the painted layers. In some parts, there is moulded stucco added above the painted layer, indicated that at least in the last stage of decoration the walls had a combination of wall painting and moulded stucco decoration. Investigation of the paint layers in this room indicated that they were applied above a preparation layer (intonaco) of gypsum over a support layer (arriccio) of lime plaster with aggregates. The green pigment used (SIYAB-08 and SIYAB-09) is a mix of Egyptian blue and yellow ochre. Although there appear to be some green particles in the paint layer, however neither green earth could be conclusively confirmed nor Egyptian green. The sample with red colour taken from the north wall of that room (sample SIYAB-10) revealed that there are two layers of paint, a brighter orange on a red paint layer applied over the preparation layer. The red turned out to be a mixture of red ochre, calcite with some gypsum, while the orange hue was achieved by mixing haematite and lead oxide (minium), with evidence of some traces of arsenic. It can be that the orange lead oxide was applied over red haematite to produce an orange colour because the texture of the two layers can be conceived as a single layer in the optical microscope photograph and in scanning electron microscopy.

The binder/aggregate ratio measurement of 4 samples in Room "1" (samples SIY-01a, SIY-01b, SIY-02 and SIY-03) (Figs. 57-59) has shown that this ratio ranges between 1:1.3 and 1:1.7. SIY-01a representing an outer layer has a B/A ratio of 1:1.3 and 2.45% of aggregates >1mm, while SIY-01b, representing the support plaster layer has 6.06% of aggregates >1mm. Thus, the support plaster layer is of a coarser quality, as would be expected and recommended by Pliny and Vitruvius. The ratio shows a rather high content of binder with respect to aggregate.

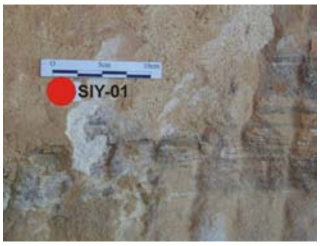


Figure 57. Sample SIY-01.

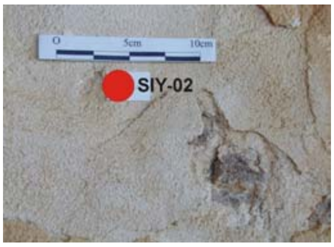


Figure 58. Sample SIY-02.

Figure 59. Sample Siy-03.

Therefore, we find that although none of the wall paintings analyzed falls within the realm of "buon fresco", they nevertheless, do not have much in common in terms of technology. Room "4" evidently has 2 wall paintings of different style (the upper geometric one gives an impression of a more elaborated painting than the lower one) and different application technique that could mean that it was built in two different times, or at least after the upper one was finished, work on the lower one was done by a different painter. Room "3" implies that a different technique of application was implemented, by using a preparation layer of lime rather than gypsum, yet the notion of having a layer of fat lime coating the sandstone before plaster application applies to both cases. Room "1" has at least at some point a similar method of applying paint layers to that of the upper wall painting of room "4", though in room "1" it would seem that there are two phases of application, or else it is a coincidence that the samples collected originally represented borders of different paint colour application, and hence we have a yellow over the green and an orange above the red.

State of Preservation

Most of the paintings in room "4" are still covered with a layer of mud and straw which had been applied by Bedouins who lived in those caves. This can also be noted in rooms "1" and "2". A lot of the painted plaster has detached and much of the plaster in rooms "1" and "3" has been lost or is extremely fragile and crumbling. In these two rooms, even the plaster that is still there has in many places faint or no traces of original painting. There is also a lot of soot covering the surfaces. In some cases it has penetrated deep into the paint and plaster layers (samples SIYAB-08, SIYAB-09 and SIYAB-10). There is also some sulphation (formation of gypsum) on some of the surfaces (samples SIYAB-09 and SIYAB-10), in addition to the soiling of the surfaces with dust and formation of substantial amounts of damage active soluble salts (mainly sodium chloride) that can be noted in all rooms.

X-ray diffraction analysis was conducted on some samples from room "4" revealing the presence of the two oxalates, whevellite and weddellite, and it is very possible that they might have originated from organic substances in the binder or the mud and straw layer. Franchi and Pallechi (1995: 101) have suggested that the presence of sodium chloride and potassium chloride in the painted surface and the mud coating may have been a result of the possible use of the room as a "salt store" in the past, and that salt is not a component of the sandstone of Petra, which is dated back to the Cambrian period. However, it is well known now that there is a lot of water and salts that is trapped in the sandstone of Petra. Upon the evaporation of water, salts migrate to the surface causing detachment and disintegration of the plaster.

Some conservation work was conducted on the paintings of Room "4" (Fig. 60). A team of specialists from the Instituto del Restauro in Madrid, began the cleaning and restoration of the murals in September of 1980 (Zayadine 1981: 355; 1987: 140). Apparently, parts of the paintings were cleaned from mud plaster and black soot, consolidation of some parts of the lower painting with the pattern of doorways was done, and lacunae were filled and painted over with pigments of matching colour to those of the original painting.

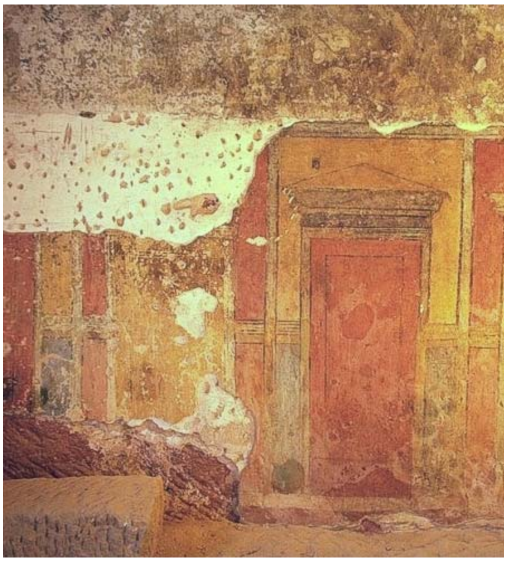


Figure 60. Restored part of the lower painting of the west wall of Room "4".

Conservation Recommendations

After obtaining the report of the previous conservation work, the methods and material used to conserve the wall painting in room "4" should be assessed in order to find out if it was the right approach in terms of materials and concept, or if different methods need to be investigated.

Removal of the layer of mud and straw and cleaning of black soot remains should be continued. This should be followed by the reattachment and consolidation of the paint and plaster layers.

5.2.4 House opposite the Theatre (no. 786)

A rock cut house lying opposite the main theatre of Petra and consisting of a central hall with six rooms around it (Fig. 61), has one of its rooms with remnants of painted plaster. It was first described by Horsfield (1938: 19-20), who mentions that the painted design of the plaster represented small arches in red and black.

Figure 61. View of the house complex lying opposite the theatre.

Along the western wall of the room with painted plaster, as well as parts of the northern and southern walls is a layer of white plaster of varying thickness (0.5-2 cm) which is pecked over, indicating that a second layer was added above it. Only at some corners and at the junction of the arch of the west wall and the ceiling, a few remains of an upper layer of plaster and paint depicting arches in red and yellow, with black have been preserved (Fig. 62).

Figure 62. Detail of painted arches along the western wall of the painted room.

Sampling

Some samples were taken from the few plaster remains (Figs. 63-65). Table 6 give the list of samples with their provenance and description.

Table 6. List of samples analyzed from the plaster layers.

Sample	Provenance; Description
786-10	From plaster layer of the south wall, 1cm thick with soot cover; 3.5x3 mm, 3 mm thick
786-11	From north wall; similar to 786-10; 20x25 mm; 8-10 mm thick
786-12	From the west wall ca 0.4 mm thick with original red surface; 7x2 mm, 1.5 mm thick
786-13	From edge of the north wall; 4x2.5 mm, 1.5 mm thick
786-14	From edge of vaulted ceiling; yellow surface; 2 fragments; largest is 7x3 mm, 2 mm thick.

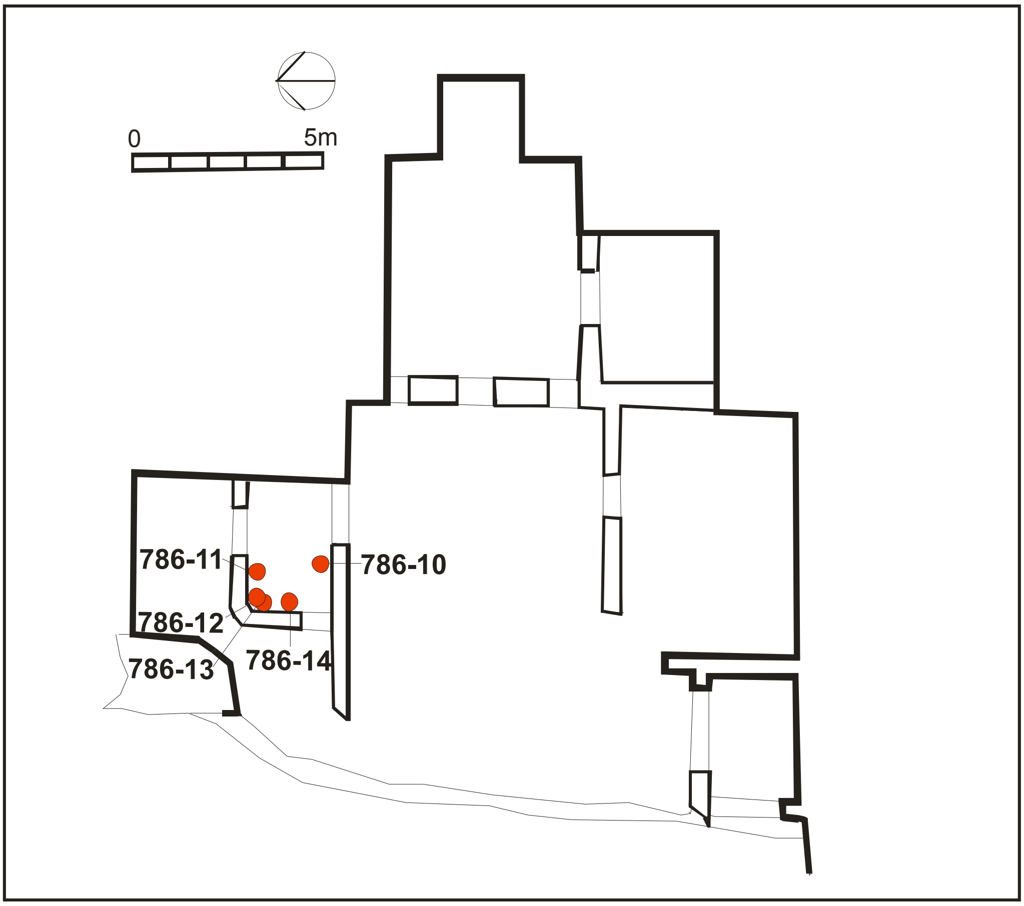


Figure 63. Plan of the house with sample location (plan after Horsfield 1938: Fig. 6).

Results of the Analysis

Examination of the samples with the optical microscope and the scanning electron microscope (SEM) with EDX showed that the red pigment applied to give the red colour is haematite that was mixed with some gypsum (sample 786-12) and the bright yellow paint is yellow ochre with gypsum (sample 786-14).

Figure 64. Sample 786-10 from the pecked layer.

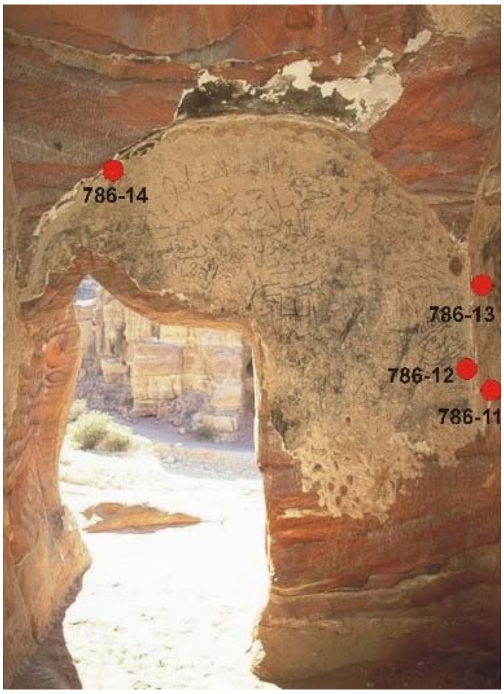


Figure 65. Sampling from the western and northern walls of the painted room.

Here, again, it is not the case of true fresco technique in painting. The paint layers, however, were applied above a preparation layer (intonaco) made of lime plaster with a thickness reaching up to 600 µm, laid over a support layer of lime mortar with aggregates (arriccio) of at least 4 mm thickness above the pecked surface of plaster. At the corner of the wall where it meets the ceiling the plaster thickness reaches 2 cm and over the ceiling it is 0.5-1 cm.

State of Preservation and Conservation Rescommendations

Although this house is easily accessible, nevertheless, there is no real emphasis on its importance in terms of being a tourist attraction. Also, the plaster and paint layers are in a very bad shape and only a few remains can still be seen. Soot covers the surfaces in addition to graffiti applied in black chalk. The plaster and paint layers, which have been infested with salts, are detaching. The easy accessibility increases the risk of further losses by vandalism. The borders of the plaster should be secured and the detached plaster areas grouted.

5.2.5 Wadi al-Farasa Triclinium (No. 235)

The triclinium is a rock cut chamber lying opposite the Tomb of the Roman Soldier. It has a plain exterior front façade with three entrances and a nearly square plan (11.14x11.33 m). The walls are decorated with engaged columns and niches. The benches are along three sides, parallel to the back and side walls. There is stucco adhering to the walls and the ceiling (McKenzie 1990: 149). Zayadine (1987: 132) gives this structure a probable date around the second half of the first century AD. McKenzie (1990: 149) dates it back to the first half of the first century AD.

Sampling

Sampling was relatively difficult since the few plaster remains are covered with black soot and have difficult accessibility. Table 7 gives the sample provenance and description and Figure 66 shows the location of samples collected.

Table 7. Samples from the plaster remains inside the triclinium.

Sample	Provenance; Description
235-10	From the frieze of the north part of east wall; 4x3.5 mm, 2 mm thick
235-11	From the inset stone moulding above the niche on the far left of the east wall; 8x1 mm, <0.5 mm thick
235-12	From the north wall, the bay between two columns above the top inset moulding of the niche; 7x3 mm, 2 mm thick.
235-13	From the east wall, the corona of the cornice at the east wall; 5x3 mm, ca 0.5 mm thick
235-14	From the east wall, an element of the cornice at the east wall; 3.5x2 mm, <0.5 mm thick
235-15	From the ceiling; 8x4 mm, 4 mm thick
235-16	From the frieze of the east wall; 9x3 mm, 6 mm thick
235-17	From the upper fascia of the architrave of the east wall above the niche and supports on the far right; 7x3.5 mm, 0.5 mm thick
235-18	From the lower fascia of the architrave of the east wall above the niche and supports on the far right; 3x2 mm, 1 mm thick
235-19	From the underside of the architrave above the bay between the columns in the south wall; red colour on the surface; 2x1.5 mm, 1 mm thick

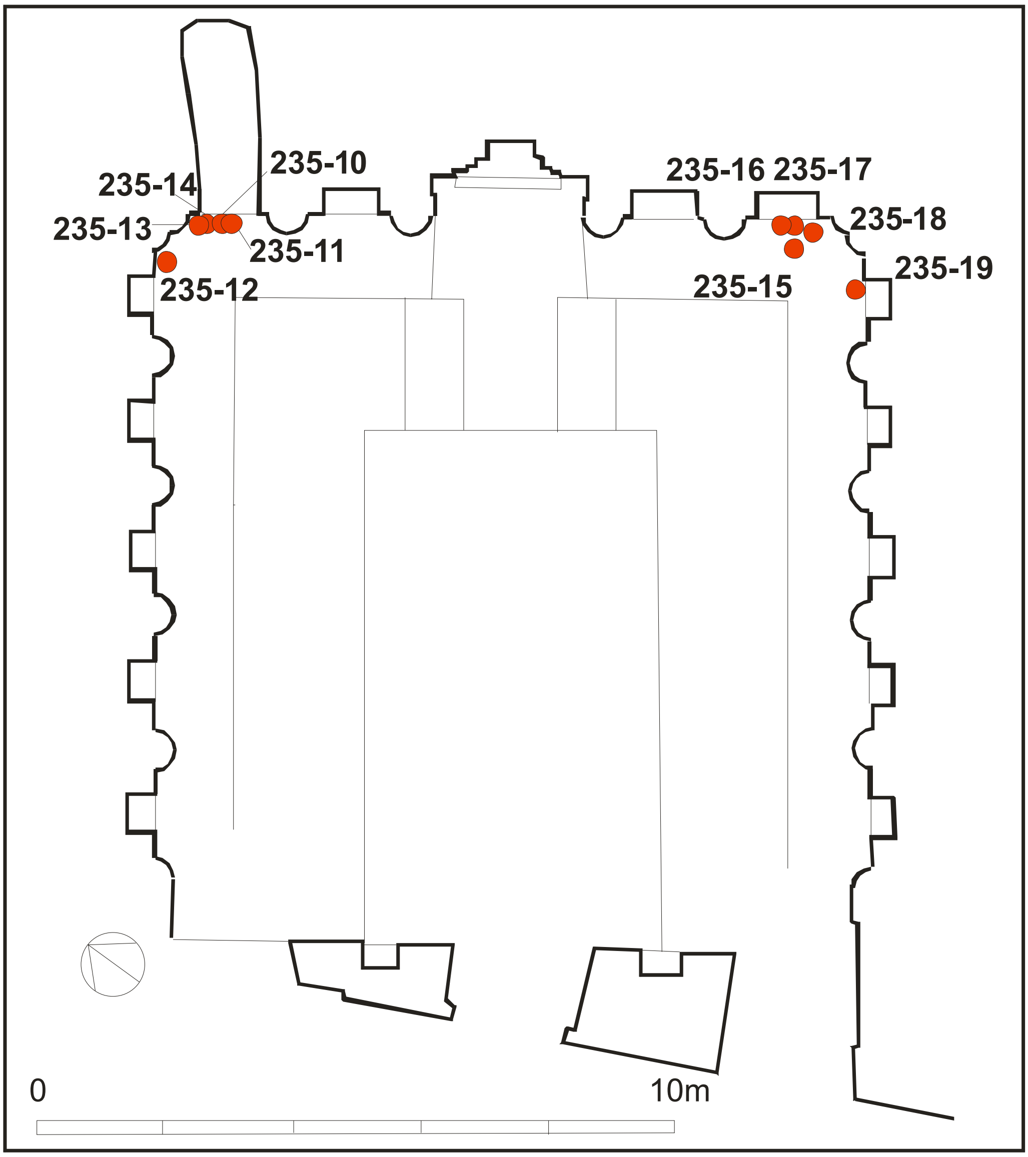


Figure 66. Plan of triclinium (235) with sampling (plan after McKenzie 1990: Pl. 104).

Results of the Analysis

All samples, except for 235-10 and 235-16 from the frieze and 235-14 from a cornice element have shown microscopically some remains of red particles. Sample 235-10 from the frieze (Fig. 67) has a top layer of white paint, which was found to be made of dolomitic lime applied over lime plaster with many aggregates. There are also $CaSO_4$ particle enrichment – possibly anhydrite – at the border between the lime paint and the plaster below. Sample 235-19 (Fig. 68), from the underside of the architrave has a 20-80 μm red layer composed of red ochre with gypsum. X-ray diffraction analysis of the plaster showed a presence of 90% quartz with the rest being calcite, anhydrite and gypsum. Sample 235-12 from the wall of the niche has also shown some red particles that could be the remains of a red layer. Samples 235-17 and 238-18 from the architrave similarly have particles of haematite with gypsum mixed with soot deposits. Sample 235-11 from the inset above one of the niches had some red particles, but the possibility of a pigment could not be confirmed. Apparently, the paint layer was applied over a preparation layer (intonaco) of gypsum of 200-250 μm and a support layer (arriccio) of lime/gypsum plaster with many quartz aggregates, and no consistency in the proportions.

Figure 67. Sample 235-10.

Figure 68. Sample 235-19.

X-ray diffraction analysis from a sample of the ceiling plaster (235-15) showed that it is a gypsum plaster.

Regarding the original appearance it can be deduced that the bay walls were painted red as well as the architrave with the two fasciae and at least part of the cornice. Apparently the architrave was originally white.

State of Preservation

The whole chamber is in a bad state of preservation, with the exterior west wall undergoing severe erosion. Any existing interior plaster remains are continuously detaching and breaking apart. Soot covers the surfaces of the plasters as a result of the burning of fires by previous human habitation. There is evidence of chloride salts, probably calcium or magnesium, in the plaster (samples 235-10, 235-11, 235-18 and 235-19).

Conservation Recommendations

It would not seem appropriate to preserve the plaster without a holistic approach to the conservation of the whole chamber. The interior of the room needs clearing in order to reach the floor level. Soot needs to be removed from the plaster as well as the sandstone surfaces. The plaster requires consolidation and reattachment, as do many flaking and scaling parts of the stone.

5.3 Freestanding Monuments

5.3.1 Introduction

Excavations at Petra are continuously revealing built structures that are helping tp provide a better idea regarding the whole planning of the city. Such structures include temples, public buildings as well as residential complexes. Additionally, these have distinctly shown substantial decorative painted remains. Perhaps, a very good example of a lavishly decorated residence is the so-called "Nabataean Mansion" at az-Zantur (Kolb 2001; Kolb, Gorgerat and Grawher 1999; Kolb and Keller 2000). There, decorative schemes in Masonry Style and illusionist painting can still be seen, and represent the use of two different, and usually not contemporaneous – Hellenistic and Augustan – styles together in a single building and dated to the first century AD.

5.3.2 Petra Great Temple

Excavations of the Petra Great Temple have been carried out since 1993 by archaeologists from Brown University (Joukowsky 1998: 9-11). It lies on the northern edge of al-Katute (Fig. 70), 895 m above sea level. The temple precinct is about 7560 m^2, and is composed of a monumental entrance (the propylaeum), the sacred area (lower temenous) and the upper temenous which comprises the temple itself (Joukowsky 1998: 11, 49). Until 1996, the site was called the "Petra Southern Temple" by its excavators, and in 1996 it was renamed as the "Great Temple" (Joukowsky 1998: 50).

The temple is 28x42.5 m (Fig. 71) and it is estimated that originally its height reached at least 18 m. The main approach to the temple is from the north, through a stairway leading from the lower temenous to a pronaos and into an area that is similar to a theatre, and has been called the "theatron". According to Joukowsky (1998: 11), the temple was built in the first century BC.

Figure 70. View of the Great Temple from the west part.

During the 1995 excavations of the Temple, the Pronaos columns were found with remains of red plaster on their drums (Joukowsky 1998: 88), and the 1.5 m high apsidal wall, upon which lies the Cavea of the Theatron, was found to be plastered (Joukowsky 1998: 120). The excavations of 1997 also showed that the walls of the West Corridor, built up to and behind the West Anta Pier had painted plaster with red, yellow, green and blue colours. Columns were also found with red and white plaster. All of the columns of the Temple building were covered with plaster and stucco. Some of these remains have a thickness of more than 0.1 m. There is also evidence of reapplication and redecoration. The lower parts of the interior colonnades have red plaster and at approximately 2 m it becomes fluted and white (Schluntz 1998a: 212). It seems from the archaeological evidence that the upper stucco decoration of the columns consisted of alternating convex flutes and borders of flattened ridges (Basile 1998: 194).

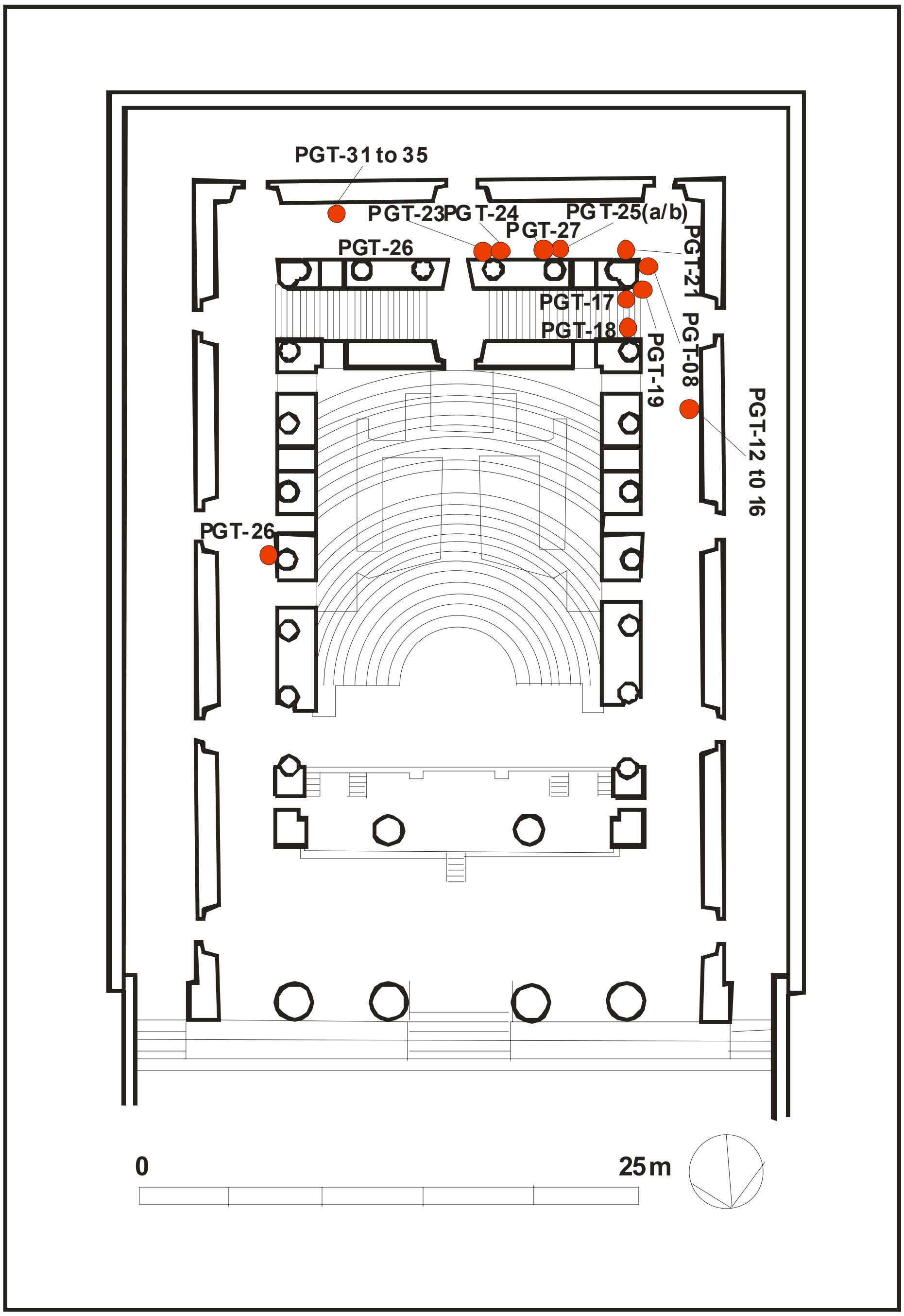


Figure 71. Plan of the Petra Great Temple with sample provenance (plan after Douglas Pitney, Loa P. Traxler and Paul C. Zimmerman in Joukowsky 1999: Fig. 7).

Also, in the excavations behind the West Anta Wall, many decorative stucco fragments were found that include egg and tongue, and, egg and dart motifs, in addition to vegetal elements, painted cornices pieces and a stone capital fragment with traces of gold leaf (Joukowsky 1998: 121). Plaster was mostly found in small fragments with some of it still preserved on the walls, showing that the Exedrae were decorated in dark red, blue-green, yellow, black and orange. Archaeological excavations in the area of the Exedra recovered, aside from fragments of sandstone and limestone architectural elements, plaster fragments as well (Basile 1998: 200). A few samples of painted surfaces were analyzed (Corbeil and Helwig 1999).

The decorative elements recovered in the course of the excavation include a number of plaster repairs of capitals. Heavy pieces were held with wood or stone pegs. Sometimes the plaster repairs were found still coating the stone carved capitals. Some of the vegetal decoration was completely moulded in stucco. According to E. Schluntz (1998b: 229) this method was probably employed for capitals that were not easily seen.

Excavations in the summer of 2001 revealed a portion of painted stucco mouldings along the north face of the south corridor with geometric patterns and painted different hues of blue, as well as green, red and black colours.

Figure 72. Moulded rim going around one of the columns, below which is a yellow painted and polished surface, while above it is white fluting.

Within the scope of this study, further survey of painted plaster and stucco repairs was conducted (Shaer forthcoming c). From the very few remains that could be found, it was possible to add to the understanding of how the temple was decorated. It seems that the four columns along the northern entrance of the temple had a plaster coating that was painted in red, while the columns along the eastern, western and southern sides alternated between red and yellow, except for the middle two columns of the southern side which were both red. Along one of the columns it appeared that there are 6 layers of plaster, over which was the final layer of paint. These highly polished surfaces of red and yellow rise about 3 m above the column bases, and were probably meant to resemble marble with their polish. Afterwards there seems to have been a 2 cm thick rim going around each column and another 1 cm rim ca 10 cm higher and moulded in stucco above which the columns were white and fluted. The moulded stucco revealed a similarly fine surface with marks resembling those of a polisher.

Sampling

A number of samples were collected from this site. Some of the samples came from the fragments of painted plaster and stucco found during the excavations of the summer of 2001, while others were from the painted plasters on the western and southern walls as well as from column remains. Table 8 provides a list of the samples and their provenance.

Table 8. Samples of plaster taken from the Petra Great Temple.

Sample	Provenance; Description
PGT-03a	Excavated material; trench 79, locus 2; 2 layers of plaster of 5 cm total thickness; pink/rosy colour; sample is 4x3 mm, 2 mm thick
PGT-03b	Excavated material; trench 79, locus 2; 2 layers of plaster of 5 cm total thickness; white, green and dark red colours; sample is 6x2.5 mm, 3.5 mm thick
PGT-03b1	Excavated material; trench 79, locus 2; 2 layers of plaster of 5cm total thickness; green part taken from PGT-03b
PGT-03b2	Excavated material; trench 79, locus 2; 2 layers of plaster of 5 cm total thickness; white part taken from PGT-03b
PGT-03c	Excavated material; trench 79, locus 2; 2 layers of plaster of 5 cm total thickness; dark red colour;7x3 mm, 3.5 mm thick
PGT-08	West corridor, west of the southwestern column; the sample was collected from a heap of white powder found next to the column base, probably related to the a refurbishing phase of the temple
PGT-10a	Excavated material; trench 80, locus 2; located at corner of the temple next to the colonnaded street; 3 layers of plaster of ca 5.5cm total thickness; this sample from uppermost layer which is ca 0.7 cm thick with red colour; sample is 4x2.5 mm
PGT-10b	Excavated material; trench 80, locus 2; located at corner of the temple next to the colonnaded street; 3 layers of plaster of ca 5.5 cm total thickness; sample from middle layer, ca 1.8 cm thick with powdery red colour; sample is 5x3 mm, 5 mm thick
PGT-10c	Excavated material; trench 80, locus 2; located at corner of the temple next to the colonnaded street; 3 layers of plaster of ca 5.5 cm total thickness; sample is from lowermost layer, ca 2.8 cm thick with white surface; sample is 5x3 mm, 3 mm thick
PGT-11	From trench 79; moulded stucco with white surface; 5x3.5 mm,1.5 mm thick
PGT-12	From wall painting along the western wall of the west corridor; yellow colour; 4x3 mm, 3 mm thick
PGT-13	From wall painting along the western wall of the west corridor; pink/rosy colour; 5x3 mm, 2 mm thick
PGT-14	From wall painting along the western wall of the west corridor; dark red colour; 5x1.5 mm, 2.5 mm
PGT-15	From wall painting along the western wall of the west corridor; green colour; 5x3 mm, 2.5 mm thick
PGT-16	From wall painting along the western wall of the west corridor; dark red colour, framing the yellow area; 6x2 mm, 2 mm thick
PGT-17	From plaster of southwestern corner column of west corridor; red colour; 9x7 mm, 5 mm thick
PGT-18	From plaster of second column from the south, along the western corridor; yellow colour; 9x3 mm, 2 mm thick
PGT-19	From column base of southwestern corner column of west corridor; some red surface; 6x3 mm, 3 mm thick
PGT-21	From column base of southwestern corner column of west corridor; some red surface; 6x3 mm, 2 mm thick
PGT-23	From the faded white stucco of the 2cm rim of the west middle column of the south corridor; 7x2.5 mm, 3 mm thick
PGT-24	From the plaster of the west middle column of the south corridor with red surface over 2 different layers of plaster, a top white layer with very few visible aggregates and a bottom coarser beige layer; 10x5 mm, 4 mm thick
PGT-25	From the plaster of the west column of the south corridor with yellow surface over 2 different layers of plaster a top white layer with no visible aggregates and a bottom coarser beige layer; 10x7 mm, 6 mm thick
PGT-26	From the crenellation of the moulded stucco of the east middle column of the south corridor; 8x6,5, 2.5 mm thick
PGT-27	From the white stucco above the rim of the west column of the south corridor; 7x3 mm, 1.5 mm

Sample	Provenance; Description
PGT-31	From the painting of the stucco of the south wall; vertical band with bright green colour; 6x3 mm, 3 mm thick
PGT-31a	From painted stucco of the south wall; vertical band with bright green colour; 8x3 mm, 2.5 mm thick
PGT-32	From painted stucco of the south wall; dark blue surface; 13x7 mm, 4 mm thick
PGT-33	From painted stucco of the south wall; black painted lines; 3x2 mm, 1 mm thick
PGT-34	From painted stucco of the south wall; blue frame of panel; 11x5 mm, 2 mm thick
PGT-35	From painted stucco of the south wall; dark red frame of panel; 6.5x4.5 mm, 3 mm thick
PGT-36	From the plaster of the middle column of east corridor; red surface with brownish mortar; ca 2x1 cm, up to 1 cm thick

Results of the Analysis

Analysis of samples from a piece of painted plaster that had dark red, green, white and pink colours was conducted (samples PGT-03a, PGT-03b and PGT-03c) (Fig. 73). The pink colour was achieved by mixing a red pigment, possibly red ochre, with lime (PGT-03a); the white layer is made of calcite (PGT-03b); the green is made of green earth and is mixed with lime and has some Egyptian blue particles, while the dark red paint has haematite as the red pigment, and is again mixed with lime (PGT-03b). The paint layers are applied on a lime plaster mix with aggregates. The painting appears to have been applied in a lime secco manner as evidenced by the mix of lime with the pigments and applying it over lime plaster. It is not clear what type of pattern this decorative painting meant to achieve, but it appears that the dark red was applied after the green, which shows a technique of painting where the different areas of paint are applied successively one after the other rather than painting the bigger areas and afterwards going back to do the finer lines and divisions lines as in the painted room in Wadi as-Siyyagh.

Samples were analyzed from another excavated piece with three layers of different painted surfaces that give the impression of three phases of application (Fig. 74). The lowermost plaster layer (PGT-10c), representing the first phase of application, has a white layer (125 µm) that is made of calcite and applied over a lime plaster mix with aggregates. The second phase (PGT-10b) is composed of red plaster layer made of red ochre (70-120 µm) over a preparation layer (intonaco) of lime plaster with few aggregates and thickness of 1.5 mm, which in turn over a support layer (arriccio) of lime plaster with many quartz aggregates. The paint application in this layer is in secco as evident in the powdery character of the layer. The last phase of application (PGT-10a) is composed of a red paint layer made of red ochre and contains some lime, applied over a preparation layer, 1.2 mm thick, of lime plaster with few aggregates and a support layer of lime plaster with many quartz aggregates.

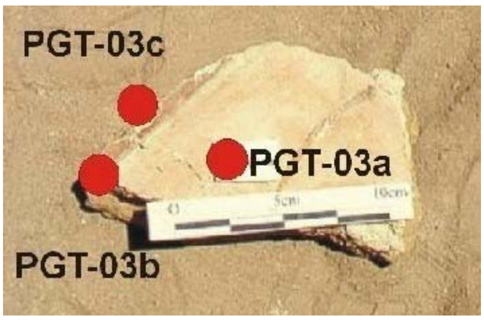


Figure 73. Sampling of painted plaster piece.

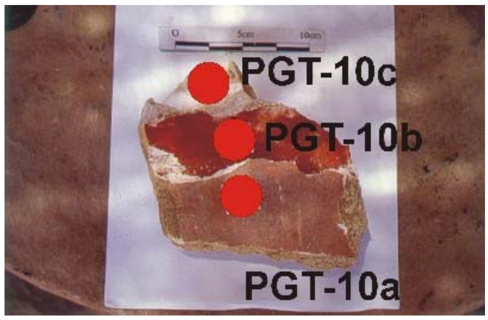


Figure 74. Three layers of plaster.

The sample taken from a piece of moulded stucco (sample PGT-11) (Fig. 75), was found to have calcium carbonate as the white pigment in the layer (100 µm thick). The white paint layer is applied over a layer of lime plaster containing many aggregates.

Figure 75. Sampling of the surface layer of white moulded stucco.

Moving on to the wall painting along the west wall of the west corridor (Fig. 76), several surface samples were collected representing the different paint layers, although the wall painting had already recently undergone conservation work.

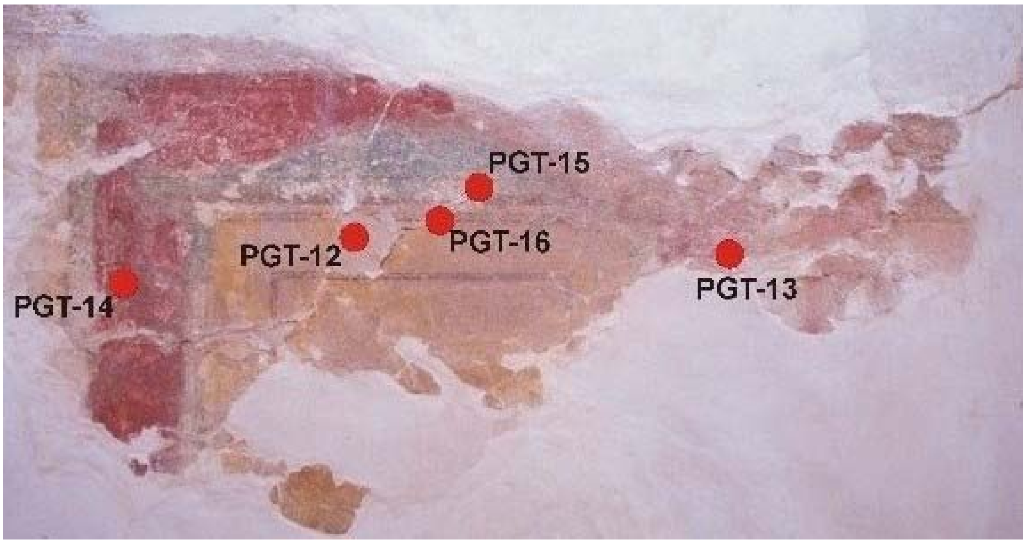


Figure 76. Sampling of wall painting along the west wall of the west corridor.

The yellow layer (PGT-12) constitutes yellow ochre, with gypsum in the layer. The pink layer (PGT-13) is made of lime with possibly a small amount of haematite and is mixed with some aggregates of quartz and dolomite, probably added to provide a lighter tone of pink. A black particle of bone black ($Ca_3(PO_4)_2$) was also detected in the layer. The red layer (PGT-14; PGT-16) is made of haematite with lime, and there is trace of gypsum in the layer. The green layer (PGT-15) appears to have been much disturbed, though it could contain green earth. There is gypsum in the layer. The disturbed sequence and thickness of the gypsum in the layer imply that its presence there is not original. From the analysis of red and pink samples, it appears that the fresco technique was the mode of application of the paint layers. The yellow and green samples have substantial amount of gypsum that might not necessarily have originally been there, but could be due to the sulphating action of the calcium carbonate. A substantial amount of silicon was detected and this is most probably due to the previous consolidation by silicic acid esters. The support for the paint layers is lime plaster mixed with sand aggregates.

Analysis of samples from the columns has shown that again the red paint (PGT-17 and PGT-24) is made up of haematite mixed with lime, while the yellow one is a mixture of yellow ochre with lime (PGT-18 and PGT-25).

The column bases were painted in similar colours to the shafts. The two samples (PGT-19 and PGT-21) (Fig. 77) taken from the base of one of the columns revealed that a layer of lime wash was applied directly over the stone surface of and painted then over with a layer of red ochre with lime. The column base is carved from a dolomite stone of very fine surface polish with marks showing that a kind of a metal scraper might have been used.

Figure 77. Sampling from the surface of the dolomite column base.

The application of red and yellow paint layers on the plaster of the columns along the southern side (PGT-24 and PGT-25) has shown that it was done on a preparation layer (intonaco) of lime mortar (calcite and dolomite) with ca 20% sand aggregate and not more than 3 mm thick, over a support layer (arriccio) of ca 75% sand aggregates. Thin section analysis of the mortar collected from one of the columns (sample PGT-36), showed that the aggregate is composed mainly of quartz with other rock fragments. There are also some few charcoal fragments and clay platelets that were probably introduced by the aggregate. In total, parts of these columns showed a 6 layer application preceding the painted polished surface, though unclear whether these were all originally applied or if they represent later reapplications.

Analysis of a sample from the white stucco flutes applied over the painted shafts (PGT-27) has shown that the surface of the moulded stucco was painted with a fat lime wash layer above a support of lime mortar with rounded quartz grains. The collar and rim moulded over the upper fluting and separating the flutes from the painted column shafts below were also made of lime mortar with aggregates, above which white gypsum was applied (sample PGT-23). This gypsum appears as a white paint over mortar with gypsum matrix and aggregates of quartz and some of $CaSO_4$, most probably anhydrite. It is possible that the flutes moulded in lime stucco, and brushed over with a fat lime wash were then coated with a gypsum plaster, probably at a later stage.

Regarding the painted stucco along the south corridor (Fig. 78), it appears that the bright green layer (PGT-31 and PGT-31a) has atacamite and malachite providing the green colour, below which is Egyptian blue with gypsum. The paint layer is applied over a preparation layer of gypsum mixed with some quartz grains and a thickness of 400-600 μm over a support layer of lime mortar with many quartz aggregates. It is most likely that atacamite is the green pigment applied over a layer of Egyptian blue, since the atacamite layer is too uniform and homogeneous to be considered as a deterioration product. The dark blue colour (PGT-32) was achieved by applying Egyptian blue over a carbon black layer of ca 200 μm, and a preparation layer of gypsum with quartz aggregates. This application of blue over a thick black layer to obtain a dark navy blue colour for the long strip is quite different from the blue achieved for the panel frame, where Egyptian blue was applied directly over plaster without carbon black. In the latter case the intended blue is of a very light hue. The relatively thick black layer made the blue appear as a dark navy blue. The black paint (PGT-33) is again carbon black, and possibly mixed with umber since both manganese and iron particles were detected. The red pigment used is red ochre mixed with gypsum, applied over the preparation layer of gypsum with quartz aggregates.

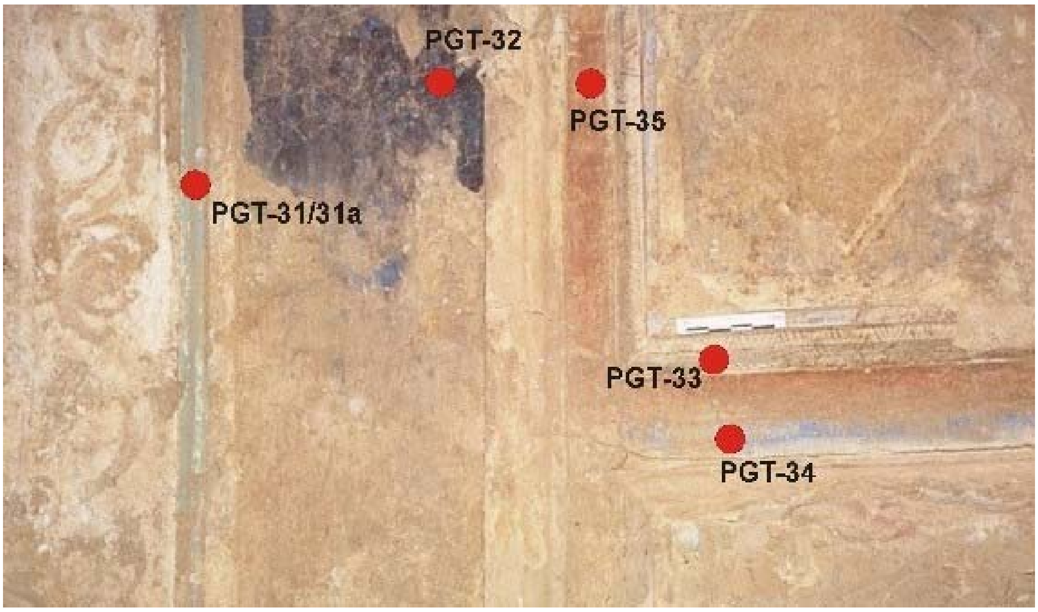


Figure 78. Sampling of the moulded stucco along the south corridor wall.

Therefore, we find that there are at least two major modes of paint application at the Great Temple. The first is the fresco technique, whereby the pigment is mixed with lime water and applied over a plaster layer of lime mixed with quartz aggregates, as found on the wall painting along the east face of the west corridor, and includes pigments compatible with lime. The second method is where the pigment is mixed with gypsum and applied al secco over a preparation layer of gypsum and quartz. This method characterizes the wall painted stucco along the north face of the south corridor wall. Lime based painting is also found on the columns and the excavated fragments except for one phase of painting on a fragment (PGT-10b).

Sample PGT-08 (Fig. 79) from a heap of powder found next to a column base was practically all dissolved in HCl, where only 11% of its original weight remained. It is clear that it is pure lime powder, with the remaining 11% made up of some sand and dirt residues. This lime was most probably left by the plasterers during one of the refurbishing phases of the temple.

Figure 79. Lime powder remains.

State of Preservation

The site has been undergoing conservation work that includes some restoration of the structure and the rebuilding of some parts, as well as the consolidation of the paint layers. Previous analysis of samples of painted plaster was done by the Canadian Conservation Institute (Corbeil and Helwig 1999). Conservation work was carried out on the painted plaster of the east face of the west corridor and some plaster and stucco still adhering to the columns. Newly excavated painted plaster on the north face of the south corridor wall appears very fragile. The main issue is that after excavation, these remains have become exposed to environmental factors like sun, wind and rain.

The samples retrieved from excavations (PGT-03 and PGT-10) have chloride salts. The painting on the east face of the west corridor has evidence of sulphation on the surface (e.g. PGT-12), while the painting along the north face of the south corridor has shown the presence of salts in nearly all samples analyzed.

Conservation Recommendations

It is recommended that an assessment of the already conserved wall painting should be carried out, in terms of materials, methods and extent of intervention. Tests that evaluate the strength of the mortar, its porosity and depth of the silicon penetration through the paint layer of the consolidants used might be of help in the evaluation. This is necessary before carrying out further conservation work at the southern corridor.

Additionally, discrete protective coverings for the paintings and means of draining rainwater from the tops of the walls are necessary preventive measures to minimise the impact of water on the stability of the plasters and paints.

5.3.3 Qasr el-Bint (no. 403)

Qasr el-Bint, located at the western end of the temenos gate, at the end of the colonnaded street and beneath the cliff of el-Habis, is the only freestanding stone built structure that, to a certain degree, withstood the effects of the earthquakes of AD 363 and 747, which brought the city of Petra to great destruction. The first to describe and record the monument was Kohl (1910), and was followed by Wright (1961). Excavations in and around the site began at the end of the 1960s and have continued at different intervals ever since then.

The plan of the temple is square shaped of ca 28 m sides, with a façade of four columns in antis through which one enters into a pronaos which in turn leads into a broad cella, or sacred area, through an arched doorway (Fig. 80). The adyton is divided into three parts with a central apse representing the Holy of Holies immediately facing the entrance and two compartments to its right and left sides. From the corners of the side rooms, stairways lead to upper mezzanines. In some parts, the walls are still standing up to 23 m in height (Wright 1961: 8-11). Archaeological evidence has shown that the roof used to be a pitched one that was originally a timber structure covered by roof tiles (Zayadine 1985: 243) rather than flat as suggested by Wright (1961:27-29). Complete detailed drawings of the plans and elevations of the temple were done by F. Larché (Zayadine 1985; 1987: 138).

The walls are built of massive sandstone blocks, with the length of a single block sometimes reaching ca 2 m. In between some of the stone courses are wooden planks. Parts of the eastern and southern exterior walls of the temple retain some remains of moulded stucco, as well as some of the interior walls. This was already observed and described by Kohl (1910: 15-20) (Fig. 75).

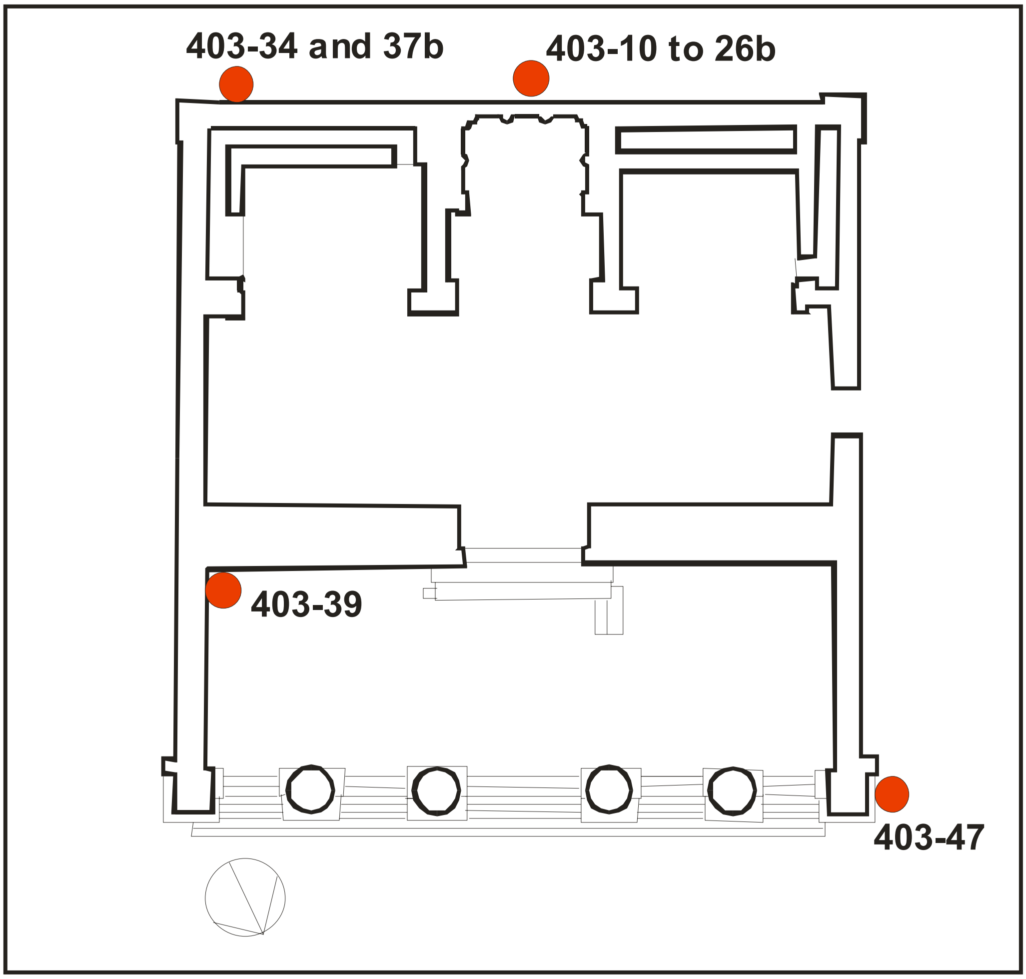


Figure 80. Plan of Qasr el-bint with the sample provenance (plan after F. Larché).

Figure 81. Southern façade of Qasr el-Bint with moulded stucco remains.

Along the eastern wall, the stucco pattern depicts a row of pilasters ca 2.65 m high, while that along the southern wall, in addition to the pattern of pilasters there are in the middle of the composition six pilasters with an architrave and a frieze of cupids holding garlands. At the top of the arrangement are a segmental pediment and a broken pediment arrangement (Zayadine 1985: 246). The pilasters, or vertical bands, are framed with an astragal, cyma reversa and fillet, as are the tops of these bands (McKenzie 1990: 137). Dentils are evident along the top moulded cornice, the entablature cornice, and the raking and curved cornices (McKenzie 1990: 137).

Excavation and clearance of the east compartment in 1983 revealed a large quantity of moulded stucco pieces which had a gold leaf covering (Zayadine 1985: 240). Cleaning of the stucco on the eastern wall revealed that the upper panel frieze had traces of blue paint, while a cleaning test with butylamine on the stucco at the south wall revealed yellow-ochre (Zayadine 1985: 247-248).

There seems to have been an earlier monument of unclear date that preceded Qasr el-Bint, as evident from clearance carried out in the northeastern anta, which yielded pieces of stucco that were probably used for the earlier building (Zayadine 1985: 248-249; 1987: 136). Parr (1967-8: 17) dates the temple to the time of Obodas III (30-9 BC) and McKenzie (1990: 34-35) give it a terminus ante quem of the first century AD. According to Zayadine (1985: 248-249) the exterior stucco revetment was most probably remodelled several times.

Sampling

Samples were collected from the moulded stucco revetment along the south façade (Figs. 80, 82 and 83), the western façade stucco plaque on the pilaster, and the interior of the temple. Table 9 provides a list of samples and their provenance.

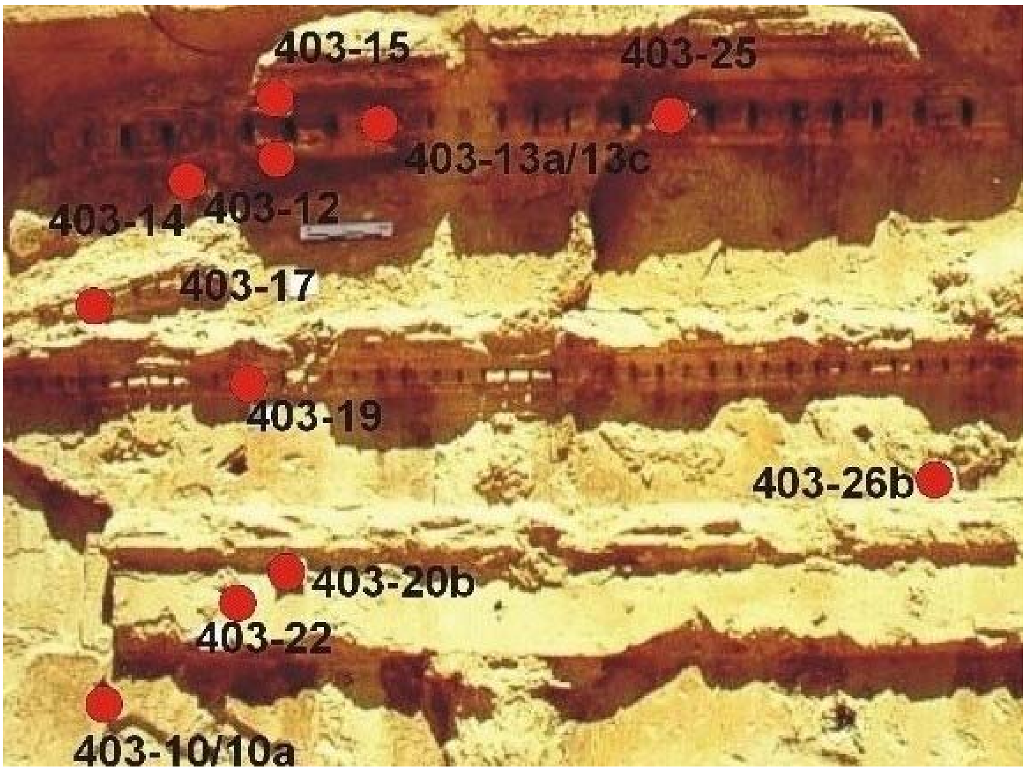


Figure 82. Sampling of the stucco of the southern façade.

Figure 83. Sampling of the stucco on the right side of the southern façade.

Table 9. List of Samples taken from Qasr el-Bint.

Sample	Provenance; Description
403-10	From the central pattern of the south wall; the flat plaster of the second bay, to the left of central panel; sample is 5x15 mm, 10 mm thick
403-10a	From the central pattern of the south wall; the flat plaster of the second bay, to the left of central panel; 2x1 mm, 1 mm thick
403-12	From the central pattern of the south wall; edge of rim below dentils of the top cornice moulding; 8x8 mm, 4 mm thick
403-13a	From the central pattern of the south wall; dentil surface of top cornice moulding; 9x8 mm, 7 mm thick
403-13c	From the central pattern of the south wall; dentil surface of top cornice moulding; 10x4.5 mm, <0.5 mm thick
403-14	From the central pattern of the south wall; plain plaster surface between top cornice moulding and raking cornice; 11x5 mm, 4 mm thick
403-15	From the central pattern of the south wall; moulding of top cornice above dentils; 3x2 mm, 1 mm thick
403-17	From the central pattern of the south wall; dentil of left raking cornice; 14x6 mm, 13 mm thick
403-19	From the central pattern of the south wall; dentil of curved cornice; 2 pieces, 5x4 mm, <0.5 mm thick
403-20b	From the central pattern of the south wall; added stucco on stucco architrave, possibly depicting vegetal scrolls pattern; 5x4 mm, 7 mm thick
403-22	From the central pattern of the south wall; stucco architrave; 5x5 mm, 5mm thick
403-25	From the central pattern of the south wall; dentil surface of top cornice moulding; 4.5x2.5 mm, 1 mm thick
403-26b	From the central pattern of the south wall; added stucco on stucco architrave, possibly depicting vegetal scrolls pattern (and cupids); 8x4 mm, 3mm thick
403-34	From the right side of the south wall; cyma reversa framing a panel above one of the vertical bands; 6x1.5 mm, 1.5 mm thick
403-37b	From the right side of the south wall; dentil element along the top cornice moulding; 3.5x5 mm, 3.5 mm thick
403-39	From the south east corner of the pronaos; plain plaster above moulded stucco; 8x4 mm, 4 mm thick
403-47	From the west exterior wall; stucco plaque on the anta; 8x5 mm, 4 mm thick

Results of the Analysis

Analysis of the samples has revealed a top coating of red dust covering the decorative moulded stucco. Although iron (Fe) has been detected in this top layer, however, its visual appearance is that of dust rather than a uniform paint layer. Surfaces of dentils of the central arrangement and top cornice that were analyzed (samples 403-13a; 403-13c; 403-17; 403-19; 403-25), have shown a top layer of red dust with gypsum over a layer of yellow ochre with gypsum and a gypsum preparation layer. There is a trace of a fine red line evident above the smooth edged yellow ochre in all of these four samples. Analysis of this red line in samples 403-19 and 403-25 showed that there are remains of gold, with impurities of silver (sample 403-25) and iron (samples 403-19 and 403-25), and there is also some gypsum and dust. The presence of iron could mean that it was intentionally added to the gold-silver alloy in order to give it a more reddish colour, balancing the pale tone of the alloy due to the presence of silver, as already noted at other sites (Ogden 2000: 163-164). It could also be that the iron is the product of using haematite for burnishing gold leaf or rather for burnishing the yellow ochre below, giving it a very straight edge. Another explanation to this phenomenon is that the red areas represent a "red bole" – i.e. a natural ferruginous aluminium silicate, similar to ochre and able of getting a high polish (Gettens and Stout 1966: 98) – applied as a ground for gilding. Colinart (2001: 1) mentions "red-coloured areas, which look like a glaze" accompanying the gilding of ancient Egyptian coffins, and explains the irregularity of the red areas as a phenomena of corrosion. In the case of Qasr el-Bint, the red is represented as a very fine line rather than irregular areas, and it would be highly improbable that it is a product of corrosion. Thus, the dentil mouldings were decorated with gold leaf applied over yellow ochre and gypsum of ca 50 μm thickness.

Regarding the plaster of the bays between the vertical bands in the central arrangement (samples 403-10 and 403-10a), and despite its dust cover, it has shown a yellow painted layer behind the dust. The yellow paint is made up of yellow ochre mixed with gypsum and containing some iron particles, applied over a gypsum preparation layer. Below this is a support layer of gypsum/lime plaster mixed with quartz aggregates. Sample 403-10a has some red particles, especially at the top part that looks like the red line found in the samples from the dentils. The yellow ochre layer is again uniform and has some vertical cracks as the ones of the dentils. Hence again, we have the case of a most probable gold leaf finish.

The sample from the decorative scroll in the architrave (sample 403-26b) also showed a reddish upper part of the yellow layer with some particles of the dark red ones found in the samples from the dentils. Thus, it is highly probable that this decoration was once coated with gold leaf as well. Another sample had only the red layer (sample 403-20b), and the one from the background (sample 403-22) had the dust and gypsum accumulation above a lime layer, which in turn was above a gypsum preparation layer. In the latter case, it is possible that initially this represented the white background for the scrolls, which was painted white with a white wash.

As for the regular arrangement of vertical bands, analysis from the surface of the frames of the panels above these bands (sample 403-34) revealed merely some dust above white gypsum plaster. While the dentils of the upper cornice (sample 403-37b) had only some dust and gypsum above gypsum plaster. The surface of the moulded stucco plaque of the west anta has a paint layer of red ochre with lime over a gypsum plaster with aggregates (sample 403-47).

As for the interior wall, a sample (403-39) showed that it consists of a top layer of gypsum and dust over a preparation layer of gypsum and a support layer of lime plaster with aggregates.

Hence, we find a difference in application of the interior plaster surface and the exterior moulded stucco. For the interior plaster a layer of lime plaster was first applied, upon which a gypsum plaster was laid. On the other hand, exterior stucco was moulded in a gypsum mix with aggregates, before the application of a preparation layer and paint. Moreover, it appears that gold leaf was used to cover dentils of the cornice, raking cornice and curved cornice in the central arrangement. No evidence has yet been found to support the argument that it was also used for cornice dentils along the entire wall. It is possible that the central arrangement was meant to stand out and shine more than the rest of the wall. Gold leaf was applied over a uniform layer of yellow ochre. Yellow appears to have been extensively used, as found on the bays between the vertical pilasters and on the architrave decoration.

State of Preservation

The whole temple building is in a bad state of preservation. The bottom parts of the walls have substantial erosion most probably due to the combined effect of salt and water. The sandstone blocks show a variety of weathering forms including sanding, flaking and scaling, in addition to many cracks and fissures of various sizes. The lime mortar that used to bind the sandstone blocks has greatly deteriorated. An investigation regarding the structural state of the building was conducted by Saffarini (1994). The study showed that strong earthquake tremors have affected the structure as evident by wide cracks along all of its four walls. While the tops of all walls have collapsed, the south wall is the most damaged, as is the southeast corner of the building. The south wall appears to be leaning outwards, which has in turn caused cracking of the interior adyton walls. Additionally, there is substantial salt efflorescence that is probably due to the reinforced concrete used.

The interior as well as the exterior stucco remains are in a very bad state of deterioration. Most of it has been irreversibly lost and in many parts pieces of stucco are continuously falling off. The originally painted surface is not visible anymore, and there is a lot of detachment from the sides.

There was partial reconstruction of the southeast corner of the temple by the Department of Antiquities in 1961-62, whereby sandstone blocks in addition to reinforced concrete were used in the restoration. In 1979-80 the doorjambs of the main entrance were restored. In 1984, some restoration work was conducted at the northeastern anta whereby 10 courses of stone were dismantled and rebuilt (Zayadine 1985: 246). During that time, the stucco along the eastern wall was consolidated as was the one along the south wall. The work included surface cleaning, injection of a solution of resin (Paraloid B72 in 5% of trichoroetane) and reattachment of detached edges of the stucco with a lime mortar (lime: sand = 1: 3). There were other conservation efforts since then, the last of which was a campaign initiated by UNESCO and funded by the Radisson SAS, whereby conservation work was conduced on the altar in front of the temple, mainly by grouting and repointing with a lime based mortar. The temple has been a priority for implementing a major conservation project that still waits funding.

Conservation Recommendations

Although all interventions on this monument should be done in accordance with a single conservation concept, nevertheless, there are some immediate steps that are needed and can be done. One of these is the consolidation and reattachment of the stucco that is detaching and ultimately breaking away.

5.3.4 Temple of the Winged Lions (No. 423)

The Temple of the Winged Lions is located along a slope lying north of the colonnaded street. It has been named after the sculpted lions with wings that were found decorating the capitals of the columns which were originally located in the vicinity of the temple's altar (Hammond 1996: 2). Electronic survey of the site was conducted in 1973 and excavations started in 1974, led by Philip Hammond (1975; 1977-8; 1996), and have continued since then to uncover the whole temple, and all adjoining rooms of the temple, including the residential quarters and workshops. The workshops consist of a Painter's workshop, a Metalworking workshop, a Marble workshop, an Oil workshop and a "Souvenir workshop". According to the excavator (Hammond 1996), the temple is dedicated to the female deity 'Allat.

The temple is oriented in a north-south direction and is approached from the south, the valley side. It has a porch (pronaos) which leads into the square cella (17.42x17.42 m), with engaged columns and deep niches decorating the side walls. The cella has an altar platform which rises 1.31 m above the floor of the cella and has steps on either side of its front (Hammond 1975: 20-22; 1977-8: 92-93; 1982: 233-234; 1996:19).

The interior decoration of the temple was done by plastering the walls. Extensive painted plaster and moulded stucco remains were found in the excavation, including plaster affixes and fragments of painted plaster and sculpture, as well as pots with original paint remains and several nails and tacks that were used in keying in the plaster (Hammond 1977-8).

Regarding the plastering, it was found that a coarser sand mortar was first applied on the walls, followed by a finer thinner coating that contains more gypsum (Hammond 1996: 24). It seems that sometimes another type of mortar can be found between the stone blocks of some walls, indicating that there was reinforcement of the walls at a later stage (Hammond 1996: 25). Application of decorative plaster was first done by having two layers of coarse plaster, attached to the wall with iron nails, followed by a finer plaster coating keyed by copper or sometimes small iron tacks. After that, the moulded or painted decoration was applied. In one application, two thin coats were first laid before the two thicker ones (Hammond 1996: 61-62). Sometimes stone carriers were used to hold stucco. Evidence of holes that show remains of plaster plugs or shows the impression of wooden plugs could be found, as well as lead plugs and iron ones that were bonded to the stone by lead (Hammond 1977-8: 83-87; 1996: 62).

It seems possible that moulded plasterwork was done by the use of templates, though apparently, if used, there must have been much latitude in execution since there is no exact uniformity in the mouldings (Hammond 1996: 60). Fragments of the ceiling plaster showed impressions of reed bundles that were used to hold the plaster of a most probable timber beamed roof (Hammond 1977-8: 90; 1982: 234).

Most of the decorative plasterwork and stucco were found collapsed as a result of the temple's destruction, and hence it is difficult to reconstruct the decorative scheme, but from what could be found intact, it appears that the scheme was rather close to the Pompeian Second Style, in addition to the First Style decoration (Hammond 1996: 61).

Previous investigation has shown that gilding was applied over a base of red or yellow paint (Hammond 1996: 64). According to Hammond (1996: 65-66), the red colours were found to contain cinnabar (HgS), or red lead (Pb_3O_4) with Fe_2O_3 and $Fe_2(SO_4)_3$. Yellow paint was ferric sulphate $Fe_2(SO_4)_3$, $Fe_2(SO_4)_3{\cdot}9H_2O$, and ferric oxalate $Fe_2(C_2O_4)_3$, while blue was achieved by using copper sulphate $CuSO_4$, although no copper sulphate pigments have been previously identified in ancient painting. Basic copper sulphates can be corrosion products of copper bearing minerals, but have also been detected as green pigments (Scott 2002: 165-166) rather than blue ones, and these are dated from the seventeenth century AD.

Some statistical analysis was conducted on the larger paint fragments. It was found that blue was the most extensively used colour on the mouldings and cornice elements (32%), followed by red (27%), while the other colours such as yellow, fuchsia, orange, purple and grey were much less extensively used (Hammond 1996: 67).

The "Painters' Workshop" was found in 1976 as a subterranean room adjacent to the west wall of the main temple building. The room is 8x(1.82-1.90) m with its entrance at the south end, and originally had five arches supporting the floor of the corridor above it. It seems that it was part of the original building plan, and was meant to be for activities related to the maintenance of the building (Hammond 1997-8: 87; 1996: 49-50).

An inscription found in the Marble Workshop and was apparently part of a panel that belonged once to the temple wall, is dated to "the fourth day of 'Ab, the 37th year of Aretas, King of the Nabataeans, who loves his people", which was translated to mean the 19th of August, AD 28, during the reign of Aretas IV. Assuming that the inscription was most probably affixed to the wall around the time of the completion of the temple, it therefore provides the date of the end of the construction of the temple (Hammond 1996: 5). The destruction of the temple has been absolutely dated by the excavator to the evening of the 19th of May, AD 363, i.e. as a result of the massive earthquake that occurred on that day.

Apparently, the temple decoration witnessed a remodelling stage as evidenced by painted plaster remains and stucco mouldings, especially around the column shafts. This remodelling has been attributed to a change in cultic or socio-political expressions, necessitating the replacement of "ritualistic" decoration with rather simpler decorative motifs, and according to the excavator, it most probably occurred during the reign of Malichus II (AD 40-70) (Hammond 1996: 11). The original surfaces of painted plaster were pecked over to receive a new coating, and fluted stucco surfaces of columns were coated with plain smooth plaster (Hammond 1977-8: 91). It seems that the "Painters' Workshop" is associated with this phase and was not used afterwards (Hammond 1996: 12).

Sampling

The temple was excavated some time ago and thus no plaster or moulded stucco remains could presently be found at the site. Hence, it was not possible to conduct any sampling of decorative wall surfaces in situ. Nevertheless, a few samples could be taken from objects on display in the Petra museum: namely from the paint remains in pots recovered from the "Painters' Workshop", and a piece of painted and gilded moulded stucco, all dated to the first century AD. Table 10 gives a list of the samples, their description and provenance.

Table 10. Samples taken from objects acquired from the Temple of Winged Lions.

Sample	Provenance; Description
423-01	Blue paint remains inside a small bowl, found in the "Painters' Workshop"; small sample fragment, ca 1 mm long
423-02	Black paint remains with grey/white parts inside a relatively larger bowl, found in the "Painters' Workshop"; 2x1 mm, 1 mm thick
423-03	Painted stucco moulding found inside the temple; from gilding of the egg and tongue motif; 2.5x1 mm, 1 mm thick
423-03a	Painted stucco moulding found inside the temple; from the gilding of the egg and tongue motif; 2x<0.5 mm; 1 mm thick

Results of the Analysis

The analysis of blue paint in one of the bowls (423-01) (Fig. 84) turned out to include cuprorivaite (Egyptian blue), with gypsum and quartz grains. The pigment that gives the blue colour is cuprorivaite. In order to detect the presence of organic material that might have been used as binder, FTIR analysis from water extract of the sample was conducted. Results only showed the presence of gypsum and nitrates, possibly potassium nitrate, since potassium as an element was also found in the SEM/EDX analysis. GC-MS analysis showed that the plant gum Tragacanth is present, and thus was used as a binder with the Egyptian blue pigment. The gypsum could, in this case, have been used as an extender. The black paint in another bowl (sample 423-02) is most probably a carbon black that is mixed with gypsum.

Figure 84. Sampling of pigment pots found in the painters' workshop.

Regarding the application of gold leaf (samples 423-03 and 423-03a) (Fig. 85), it appears that the gold leaf is laid directly over a gypsum layer. It is up to 40 µm thick and seems to be a mix of gold and iron. The iron, in contact with gypsum has caused some leaching and hence the yellow pigmentation of the upper part of the gypsum. In sample 423-03a, the iron is at the bottom part of the leaf, while the top is pure gold.

Figure 85. Sampling of a stucco surface covered with gold leaf from the Temple of Winged Lions.

State of Preservation

The temple has been exposed to weathering since the mid 1970s. Plants have grown at the site since then, and have been spreading their roots under the structure causing some damage to the stone tiles floors and column bases. No plaster or stucco is evident in situ. The museum samples analyzed have shown the presence of sodium chloride salt (423-02, 423-03 and 423-03a) and nitrates (423-01), while the gold leaf is obviously breaking and detaching.

Conservation Recommendations

A comprehensive assessment of the condition of the whole structure is required and ways of preservation need to be addressed. Biocides should be used to completely be able to get rid of the vegetation that continues to grow. The treatment has to be carefully chosen in order to avoid secondary damage frequently attributed to biocide application. Conservation of the paved floors, some columns drums and walls is necessary. These should be done with minimum intervention, and repointing mortar should match the original mortar as much as possible.

5.3.5 Staircase

A complex of buildings located to the south of the Arched Gate includes a circular room, a square room and a staircase. It is an underground construction, built of sandstone blocks. The circular room has a dome with a circular opening at the top. It is 5.12 m in diameter, with eight engaged half columns all around. Fragments of stucco mouldings were found inside the room (Khadija 1970: 200-201), some with red colour. There are still traces of plaster remains attached to the inside of the dome and the walls, including the half columns and niches. The square room is located adjacent to the circular one, and is entered from the latter's south wall. It also has a dome with a circular opening in its middle, and some remains of stucco on its interior walls.

A staircase building lies adjacent to the circular room, along its east side, with the stairway going around a square shaped post (Fig. 86). The connection between the staircase and the other rooms is not yet clear. The walls of the staircase have painted decorative stucco in panels of red and yellow bordered by ca 2.5 cm wide white borders. What can be hypothetically reconstructed is that at the bottom are 2 panels each with a white surrounding border, the border being level with the red and yellow areas. Above that is a diagonal field that protrudes from the pattern below ca 1cm and was most probably painted white, although it shows a rougher texture than the surface of the panels below. Above that is another white border.

Although the complex has been called a "Bath", with the circular domed room serving as a caldarium (Bachmann et al. 1921), yet Zayadine (1987: 137-139) doubts this theory, and says that it most likely served as part of a "palatial residence", since no traces of hypocausts or water pipes were found. He dates the complex back to the first half of the first century BC. McKenzie (1990: 41, 51) also dates it to the first century BC, i.e. later than Qasr el-Bint, but earlier than the Temple of the winged Lions. The stucco decoration of the staircase building is similar to the Pompeian First Style of decoration. According to Barbet (1995: 383; 389), this structure is dated to the end of the second century/beginning of the first century BC, while the domed room with the Second Style decoration is dated to the first century BC.

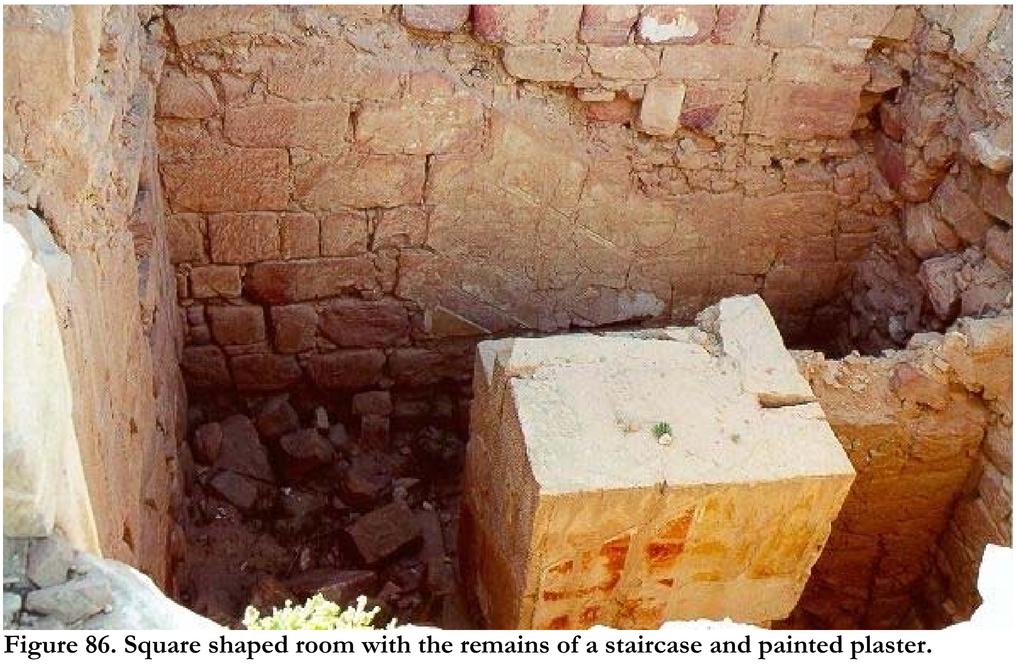


Figure 86. Square shaped room with the remains of a staircase and painted plaster.

Sampling

Samples were collected from the west wall of the room, and from the west and south walls of the central square post. The samples mainly represent areas of the plaster with an originally painted surface. Table 11 gives a list of the samples.

Table 11. List of samples from the stairway structure.

Sample	Provenance; Description
STA-01	From the west wall of staircase building; white inclined line; sample is 1.5x1 cm, 0.5 cm thick; white surface and support of white/beige mortar with fine aggregates (layer ca 0.4 cm) and 0.1 cm part of another layer of brownish/beige colour
STA-02	From the west wall of staircase building; yellow panel; sample is 0.4x0.3 cm, 0.2 cm thick, with yellow surface and mortar backing of white/beige mortar
STA-04	From the west wall of staircase building; white inclined line; sample is 1.5x1 cm, 0.5 cm thick; white painted surface and support of white/beige mortar with fine aggregates (layer ca 0.4 cm) and 0.1 cm of another layer of brownish/beige colour
STA-06	From the west side of the square post; plaster remains painted yellow; piece is 5x1.5 cm; has a white mortar backing that is up to 0.8 cm thick, followed by another mortar of brownish/beige colour and 0.5-1 cm thick.
STA-07	From the west side of the square post; upper part of plaster remains painted red; sample is in several fragments, biggest is 0.8x2 cm, with a red/brown surface (possibly a weathered surface) and two layers of plaster behind the first is ca 1cm thick brownish mortar (STA-07a) with aggregates and possibly fine straw and the second is ca 0.4-0.5 cm thick with white mortar with aggregates (STA-07b)
STA-08	From west side of staircase post; lower part of staircase remains painted red; sample is in several pieces, biggest is 1.5x2.5 cm, 0.5 cm thick with red surface and support of white mortar with aggregates
STA-09	From west side of staircase post; upper area of plaster remains from the spot of white/yellowish paint in the red field; sample is 0.7x0.8 cm, white surface with support mortar
STA-10b	From south side of staircase post; red at the border with white, where there is an incised line marking the edge between the red and the white areas; sample is 1.5x1.5 cm, red layer with support of white mortar with aggregates (0.5-1 cm thick), in some parts remains of another layer of brownish mortar (up to 0.3 mm)

Results of the Analysis

The yellow pigment used in the panel painting (samples STA-02 and STA-06) is yellow ochre mixed lime, it is 100-400 μm thick, while the red layer is made of red ochre mixed with gypsum (STA-08 and STA-10b), and is up to 240 μm thick. The white border (STA-01 and STA-04) was achieved by applying a white lime wash.

Figure 87. Sampling of the west wall.

Figure 88. Sampling of the middle post.

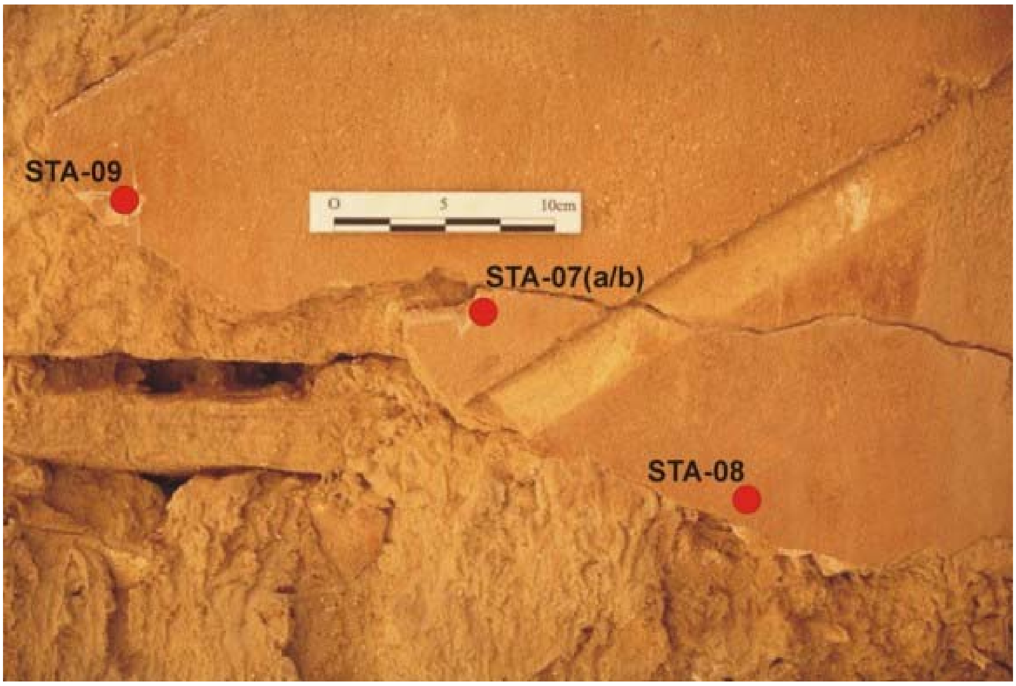


Figure 89. Sampling of the middle post.

Figure 90. Sample from the middle post.

The application of the paint layers (as investigation of sample STA-01 of the white border shows) appears to have been done above a preparation layer (intonaco) of lime mortar with aggregates and ca 0.4-0.6 cm thick, and a support layer (arriccio) of lime mortar with coarse aggregates 0.2-0.3 cm. All of these layers are applied over another 0.5 cm scratch coat of gypsum mortar with few aggregates.

The red and yellow fields with their white borders have the same plastering level, but appear to have had an incised line going all along, marking the separation between the different colours. Also, it seems that the plastering of these panels was done with the help of a long ruler or template edge that has a concave shape, thus providing a straight edge for the panels. The panels were afterwards painted in the secco technique. The upper protruding inclined fields were then added after the lower panels had become dry. Thus, we find that the plastering of the panels was done in parts and the protruding edge provides a clear connection. The white surface of the upper protruding plaster is made of lime (STA-09), which was applied over a preparation layer of gypsum mortar, up to 1 cm thick, and a support of lime mortar, up to 0.4-0.5 cm thick. X-ray diffraction analysis has shown that while the lime mortar contains ca 37% quartz, the gypsum mortar above contains ca 62% quartz, thus accounting for the brownish colour of the gypsum mortar.

An explanation regarding why the coarser gypsum plaster was used as an intonaco in the upper panels cannot be conclusively reached. It is possible that these protruding panels were originally moulded and afterwards fixed when the stucco had dried and hence gypsum was used for moulding. Still, no clear reason can be conceived regarding why so much aggregate was used for a gypsum moulding. It is possible that the protruding panel was originally meant to have a coarser texture than the panels below.

State of Preservation
The staircase room is a subterranean built structure and currently has an open exposed roof. The floor is not completely cleared and debris is continuously falling inside. In some parts, the masonry walls appear quite loose, and, there is disintegration of the mortar that used to bind the stone blocks. The plaster panels are detaching and its colours are fading. The washing of rain on the originally painted surfaces is very evident. These surfaces have a lot of accumulation of dirt. There is evidence of salts (STA-06; STA-08), and sulphation (STA-09).

Conservation Recommendations
Conducting interior conservation work would be futile without providing some kind of protection at the top which is completely exposed, i.e. having a protective roof. Ideally, the room should be dealt with along with the whole area south of the arched gate, with proper excavation and a single conservation concept. Until then, the chamber should be preserved and protected from the weathering elements, particularly rain. The interior needs to be cleared, and the walls consolidated with the repointing of joints. The plaster surfaces should be cleaned with the reattachment of the layers.

5.3.6 Main Theatre (No. 161)
The Main Theatre of Petra is located in the centre of the city (Fig. 91). It was excavated by P. Hammond and the Department of Antiquities in 1962-1963. The theatre consists of forty five rows of seats carved in the natural rock, and can accommodate 70,000 to 10,000 people. The orchestra was cut into the bedrock as well, while the stage and scenae frons are freestanding structures. The two orchestra entrances have vaulted ceilings built of sandstone blocks (Hammond 1965: 28-38). According to Hammond (1965: 38-51), the stage front originally had apsidal niches framed by pillars that were later blocked up. Hammond (1965: 65) dates the initial construction of the theatre to the reign of Aretas IV, between 4 BC and AD 27, while McKenzie (1990: 143) dates it to the first century AD.

Figure 91. The Main Theatre in Petra.

Sampling

One sample (THE-01) was taken from the plaster lining the interior of the southernmost niche constructed in the stage area. It was collected from the south wall of that niche. It is ca 2x2.5 cm, with a thickness of 1-1.5 cm, and has the original top surface. It is composed of an upper 1.5-2 mm layer of white plaster (sample THE-01a) and a 1 cm thick layer of pale pink lower plaster with scarcely visible aggregates (sample THE-01b).

Figure 92. Location of sample THE-01.

Results of the Analysis

Analyses carried out on sample THE-01 (Fig. 92) included SEM/EDX, thin section analysis, XRD and FT-IR. The sample is made up of three layers, a top layer, and two plaster layers. The top layer (ca 200 µm) appears as an encrustation and is actually a carbonate layer with an isotropic phase of halite/sylvite salt precipitation and gypsum precipitation in a crack parallel to surface.

The upper plaster layer (ca 1.5 mm) consists of lime as the binder with very few quartz grains and other rock fragments. Lime lumps are also present and there is gypsum precipitation in some pores. This layer has some cracks perpendicular to the surface. The lower plaster is also made of lime and contains lime lumps, with sub-rounded to rounded aggregates of large and small sizes and consisting of quartz and rock fragments. This layer appears to be divided into two sub-layers. To be noted is the possible evidence of a hydraulic reaction around an elongated fragment, since it is surrounded by a reaction zone of carbonate. Additionally, there are clay platelets which are probably kaolinite or metakaolinte.

State of Preservation

The theatre has been undergoing much erosion and there is need for access and visitor management which can help in minimising anthropogenic and environmental impact. Paradise (1999; undated) conducted a study on sandstone weathering at the theatre, and found that weathering depends on increased solar flux, aspect and variations in rock matrix, whereby weathering rates increase with increased calcite and matrix to particle ratio, while it decreases with an increased concentration of ferrous iron, and the associated increase in matrix density.

The few remains of plaster lining are badly deteriorated and detached, as are what has remained of the marble facing many of its walls.

Conservation Recommendations

In the 1960s parts of the stage and scenae frons underwent some conservation work. Before executing any major intervention at the theatre, a well studied plan for execution is required, taking into consideration all the previous work that was done, and implementing proper visitor management.

6. CONCLUSIONS: NABATAEAN RENDERRING AND PAINTING

6.1 Introduction

From the above analyses and discussion, it can be concluded that the Nabataean pigments were ones that could be found or manufactured in the region and at the same time were common pigments of the time. Natural earth pigments like red, yellow and green were extensively used. Artificially manufactured Egyptian blue was also a very common pigment in the present analyses, which is expected, considering the popularity of this pigment in both, ancient Egypt and the classical world. Such pigments were found to have been used in Roman wall paintings in Cyprus (Kakouli 1997), Pompeii and Rome (Ling 1991: 207-209) and Roman sites in Switzerland (Béarat 1997). Pigments founds in Acre, dated to between the third and second centuries BC (Segal and Porat 1997: 86-89), are similar to those found in Petra, consisting of red ochre with traces of arsenic, yellow ochre, cuprorivaite, celadonite, charcoal and calcite. Similarly, pigments of wall paintings found at the Roman Thermes in Spain are also similar to the Petra pigments and include calcium carbonate, red ochre, yellow ochre and carbon black (Moreno et al. 1997: 299). To a certain extent, the green pigment atacamite was used, but much less so was red lead oxide. These pigments hint at a wider palette used by the Nabataeans at Petra. Tables 12 and 13 summarize the findings concerning the paint layers analyzed for the different structures. Analysis of a number of samples for organic binders or waxes showed that a variety of media were used: tragacanth gum, beeswax, and possibly a mineral wax.

Table 12. The interior renderings analyzed for the various structures.

Monument	Date	Colour	Paint Layer	Technique	Preparation (intonaco)	Support (arriccio)
Biclinium 849	First half of first century BC	Blue	Egyptian blue	Secco	Gypsum plaster	Lime plaster with aggregates
		Brown	Haematite with black particles mixed with gypsum	Secco	Gypsum plaster	Lime plaster with aggregates
		Green	Atacamite with gypsum	Secco	Gypsum plaster	Lime plaster with aggregates
			Green earth with yellow ochre and Egyptian blue mixed with gypsum	Secco	Gypsum plaster; has soot black particles	Lime plaster with aggregates
		Colour gone/ grey		Secco/ beeswax	Gypsum plaster	Lime plaster with aggregates
		Pink	Haematite; gypsum in the layer	Secco	Gypsum plaster	Lime plaster with aggregates
		Red	Haematite with gypsum	Secco	Gypsum plaster/ Lime plaster	Lime plaster with aggregates
		White	Aluminium hydroxide	Secco	Gypsum plaster	Lime plaster with aggregates
		Yellow	Yellow ochre with gypsum	Secco	Gypsum plaster	Lime plaster with aggregates

Monument	Date	Colour	Paint Layer	Technique	Preparation (intonaco)	Support (arriccio)
Wadi as-Siyyagh room (1)		Green	Egyptian blue, yellow ochre and green earth (?), with gypsum	Secco	Gypsum plaster with black soot particles	Lime plaster with aggregates
		Orange	Minium with haematite (and trace realgar?), calcite and some gypsum			
		Red	Red ochre, calcite and some gypsum	Secco	Gypsum plaster with black soot	Lime plaster with aggregates
		Yellow	Yellow ochre and gypsum			
Wadi as-Siyyagh room (3)		Red	Red ochre with gypsum	Secco	Fine lime plaster with aggregates	Coarse lime plaster with aggregates
			Red ochre with gypsum (ceiling)	Secco	Gypsum plaster	Moulded gypsum
		White	Lime (ceiling)		Lime plaster with aggregates	
Wadi as-Siyyagh room (4)/ upper painting	First century BC	Blue	Egyptian blue, black soot below blue layer	Secco	Gypsum plaster	Lime plaster with aggregates
		Red	Red ochre with gypsum	Secco	Gypsum plaster	Lime plaster with aggregates
			Haematite with gypsum	Secco	Gypsum plaster	Lime plaster with aggregates
			Minium with red ochre and gypsum	Secco	Gypsum plaster with aggregates	
		White	Lime	Secco	Gypsum plaster	Lime plaster with aggregates
		Yellow	Yellow ochre with gypsum	Secco	Gypsum plaster	Lime plaster with aggregates
Wadi as-Siyyagh room (4)/ lower painting	First century BC	Black	Soot, most probably carbon black	Secco	Lime plaster with aggregates	
		Blue	Egyptian blue, black soot below blue layer	Secco	Lime plaster with aggregates	
		Green	Green earth with Egyptian blue particles and gypsum	Secco	Gypsum plaster	Lime plaster with aggregates
		Pink	Haematite with lime	Secco	Lime plaster with aggregates	
		Red	Haematite with gypsum	Secco	Lime plaster with aggregates	
		Yellow	Yellow ochre with gypsum	Secco	Lime plaster with aggregates	

Monument	Date	Colour	Paint Layer	Technique	Preparation (intonaco)	Support (arriccio)
House opposite theatre 786		Red	Haematite with gypsum	Secco	Lime plaster	Lime plaster with aggregates
		Yellow	Yellow ochre with gypsum	Secco	Lime plaster	Lime plaster with aggregates
Triclinium 235	First century AD	Red	Red ochre with gypsum	Secco	Gypsum plaster	Gypsum/ lime plaster with aggregates
		White	Lime	Secco	Lime/ gypsum (?) plaster	
Qasr el-Bint 403	Terminus ante quem first century AD or reign of Obodas (30-9BC)	Red	Red ochre with gypsum	Secco	Gypsum plaster	Lime plaster with aggregates
Petra Great Temple	First century BC	Black	Carbon black with gypsum; possibly with umber	Secco	Gypsum with some aggregates	Lime plaster with aggregates
		Blue	Egyptian blue			
		Dark blue	Egyptian blue,thick layer of carbon black below blue	Secco	Gypsum with some aggregates	Lime plaster with aggregates
		Green	Green earth with lime	Fresco	Lime plaster with aggregates	
			Green earth; there is some gypsum?		Lime plaster with aggregates	
			Atacamite (with malachite) over Egyptian blue	Secco	Gypsum with some aggregates	Lime plaster with aggregates
		Pink	Lime with red ochre; sometimes with added aggregates	Fresco	Lime plaster with aggregates	
		Red	Haematite with lime	Fresco	Lime plaster with few aggregates	Lime plaster with a lot of aggregates
			Red ochre with lime	Fresco	Lime wash	Dolomite stone
			Red ochre with gypsum	Secco	Gypsum with some aggregates	Lime plaster with aggregates
			Red ochre			
		White	Gypsum		Fat lime	Lime stucco
		Yellow	Yellow ochre		Lime plaster aggregates	
			Yellow ochre with lime	Fresco	Lime plaster with few aggregates	Lime plaster with a lot of aggregates
Temple of the Winged Lions	AD40-70	Blue		Secco, gum trgacanth		
		Gold leaf	Gold with iron impurities		Gypsum	

Monument	Date	Colour	Paint Layer	Technique	Preparation (intonaco)	Support (arriccio)
Staircase building	First or second century BC	Red	Red ochre with gypsum	Secco	Lime plaster with few aggregates	Lime plaster with aggregates
		Yellow	Yellow ochre		Lime plaster with few aggregates	Lime plaster with aggregates
		White	Lime	Fresco	Lime plaster with few aggregates/ or gypsum plaster with aggregates	Lime plaster with aggregates

Table 13. The exterior renderings analyzed for the various structures.

Monument	Date	Colour	Paint Layer	Technique	Preparation (intonaco)	Support (arriccio)
Tomb 633	AD 40-70	Blue	Egyptian blue		Gypsum plaster with aggregates	
		Red	Red ochre		Gypsum plaster with aggregates	Lime plaster with aggregates
			Haematite with gypsum	Secco		
			Red ochre with gypsum	Secco	Gypsum plaster with aggregates	
			Red ochre with gypsum	Secco	Façade sandstone	
			Lake?	Secco/wax		
		Yellow	Yellow ochre		Gypsum plaster with aggregates	
		Iron sheet			Façade sandstone	
Tomb 826	Before the water system that was constructed after AD50	Blue	Egyptian blue, some soot applied under blue layer		Lime plaster with aggregates	
		Red	Haematite with lime	Fresco/The surface appears to have been polished	Lime plaster with aggregates	Fat lime layer over sandstone
			Red ochre with lime		Lime plaster with aggregates	
		Yellow	Yellow ochre with lime	Fresco/ surfaced polished	Lime plaster with aggregates	

Monument	Date	Colour	Paint Layer	Technique	Preparation (intonaco)	Support (arriccio)
Tomb 827		Red	Haematite with lime	Fresco/ surface polished, barium sulphate	Lime plaster with aggregates	
Tomb 524		Yellow	Yellow ochre with lime	Fresco/ surface polished	Lime plaster with aggregates	
Qasr el-Bint 403	Terminus ante quem first century AD or reign of Obodas (30-9BC)	Gold leaf	Gold has impurities of silver and iron		Yellow ochre with gypsum	Gypsum plaster over gypsum/lime plaster with aggregates
		Red	Red ochre with gypsum	Secco		
		Red	Red ochre with lime		Gypsum plaster with aggregates	
		White	Lime		Gypsum plaster	

6.2 Nabataean Paints and Pigments

What follows is a compilation of pigments that were found to have been used in Petra. They are presented according to their colours, which are listed in alphabetical order.

Black

Black was used in interior wall paintings as stripes or to mark borders between the different colour fields or decorative features. Carbon black was invariably used as the pigment, mixed with gypsum, as also found in the paint bowl retrieved from the Temple of the Winged Lions. There is a case where possibly umber was used with carbon black, giving a brownish tone. Black was sometimes used under blue and green pigments to give a darker hue of the colour.

Blue

Blue was a very popular colour that was used on the interior decorative wall paintings as well as on the exterior façades. Egyptian blue was the only blue pigment used, mixed with gypsum and applied in the secco technique. This mix of pigment with gypsum was also found in a bowl inside the painters' room of the Temple of the Winged Lions. Different shades of blue could be achieved by having a black layer (carbon black) below the blue one; the more dense the black layer, the darker the tone of the blue would appear. Such a technique was also found at a Roman site in Cyprus where black pyrolosite was used as an intermediate layer for blue and green pigments (Kakouli 1997: 139).

Brown

The only source of brown painting that was found and analyzed in the course of the present study is from the painted ceiling in Siq el-Barid (No. 849). The sample was collected from the realistic depiction of vine stalks, superimposed over yellow, giving a three dimensional depiction and play in light and shade. For achieving the brown colour in this case, haematite was mixed with black soot particles and gypsum.

Green

Green was found to have been used in interior wall painting, and has not yet been noted on exterior façades. Different compositions of green pigment were used to achieve the various shades of green, sometimes within the same room. To be noted is the use of atacamite, a basic copper chloride ($Cu_2Cl(OH)_3$) that has been previously described as a degradation of blue pigment (Lee and Quirke 2000: 112) or other copper bearing minerals. In the samples analyzed it appears as a rather cohesive layer of well defined surface which implies that it has been originally applied. Atacamite was used in painting the green leaves of the painted ceiling of the biclinium (No. 849) where it was applied over a gypsum preparation layer. At the Great Temple this pigment showed also the presence of malachite and was applied over Egyptian blue. The visual effect is of a rather bright intensive green colour.

Green earth was encountered in the samples more than atacamite. It was used either alone as a pigment, mixed with either gypsum or lime, or had other pigments as additions to it. It was sometimes mixed with Egyptian blue and yellow ochre to give a brighter hue of the green earth. In one case, it was found that a mix of Egyptian blue and yellow ochre was used giving a rather green colour, with no concrete evidence of an accompanying green pigment, and hence it is possible that the green colour was achieved by mixing blue and yellow pigments, as already noted in other sites of the ancient world (Forbes 1965b: 230; Grissom 1986: 143; Lucas and Harris 1999: 345; Rozenberg 1997: 69).

Orange

A single example of an orange paint layer was found in a sample from the interior wall of one of the rooms in Wadi as-Siyyagh. It appeared to be a mixture of haematite and minium (with possible traces of realgar). Nevertheless, orange does not seem to have been widely used.

Pink

Pink, of a rather rosy colour, was encountered only in interior decorative paintings, though in limited painted areas. The pigments used are either haematite or red ochre, mixed with lime to produce the lighter pink hue. In one case, in the pink paint layer in the ceiling painting of the biclinium (No. 849), no lime was added, while gypsum appears to be present within the layer.

Red

The application of red colour appears to have been quite widespread within the Nabataean decorative renders, whether in the interior wall paintings or the exterior plastered façades. Dark, deep red colours were favoured and when used, the paint layers appear to have been very well polished. These colour hues are especially noted on exterior renderings. Both, haematite and red ochre were extensively used and were mixed either with lime – sometimes applied as fresco – or with gypsum. A red paint layer in the lower painting of room 4 in Wadi as-Siyyagh was found to contain a mixture of minium and red ochre with gypsum. There, the preparation layer appeared different from the preparation layer of the surrounding area, and hence might be a repair of the wall painting, with minium being used in this area. Hammond (1996: 65) adds to these pigments cinnabar (HgS), which however, was not detected in any of the pigments analyzed within the scope of the present study.

White
White was often used in painting stripes and dividing fields of colour. For that, lime paint appears to have been extensively used. Aluminium hydroxide was also found as a layer in one of the sampled paintings, sometimes with an unexplained magnesium presence. It is possible that aluminium hydroxide was used as a white pigment or in some cases as a substrate for madder or other type of pigment. No calcium sulphate was found to have been used in the samples of white paint analyzed.

Yellow
Yellow was another very extensively used colour for interior as well as exterior paint decorations. Yellow ochre was the only yellow pigment found, and it was mixed either with gypsum or with lime, sometimes applied al fresco.

Gold Leaf
The application of gold leaf appears to have been very widely spread in Petra. Fragments of moulded stucco with remains of gold leaf have been found in the excavations of the Petra Great Temple, the Temple of the Winged Lions, a dump at Qasr el-Bint and the so-called "mansion" at az-Zantur. Investigations carried out at the samples from the decorative stucco along the south wall of Qasr el-Bint has shown that at least parts of this stucco decoration was covered with gold leaf, namely the dentils and bays between the stucco pilasters. The investigations carried out on these samples and the samples with gold leaf from the Temple of the Winged Lions have shown two modes of application. At Qasr el-Bint gold is applied over a preparation layer of yellow ochre on gypsum, and possibly with a very fine "red bole" in between. At the Temple of the Winged Lions (No. 423) it was directly applied over gypsum, although Hammond (1996: 64) mentions that at this Temple gilding was applied above a base of red or yellow paint. In both types of applications analyzed, the gold is not completely pure, whereby in the former there are impurities of silver and iron, while in the latter there are only iron impurities. According to Ogden (2000: 163), much of the ancient gold was found to contain iron in trace levels, and, it has been noted that a reddish hue of gold could be obtained by intentionally adding a small portion of iron to gold.

Iron Sheeting
One example of the use of iron sheeting as an external render was found during the investigations on the surfaces of Tomb 633. There, iron metal was placed over the sandstone along the circular shapes on both sides of the inscription to give the impression of original metal bolts. At a later stage, this was substituted by painting with yellow ochre, most probably due to the poor durability of iron on external façades.

6.3 Materials and Methods in the Application of Renders
Architectural paint supports in Petra include both, stone and plastered wall surfaces. Samples could not be collected from well represented stone supports, such as the façades of al-Khaznah and the Palace Tomb, however, the samples from the façade inscription of Tomb 633 showed the application of red ochre possibly over a lime wash above the sandstone. Moreover, it seems that dolomite stone was used in the fine carving of architectural elements and sculptures, such as the column bases of the Great Temple and the sculptured bust of Tomb 633. Due to the very fine surface finish, only a fine wash layer was needed before the paint

application; in the case of the Great Temple the wash is made from lime, while in the case of Tomb 633 it is a gypsum one.

For the tomb façades, samples from three investigated tombs (Tomb 826, Tomb 827 and Tomb 524) showed similar applications of polished fresco paint layers applied over lime plaster with aggregates – sometimes in two layers. Analysis of the mass ratio of binder to aggregate showed that it varied between 1:0.5 and 1:1.0. This result, although implying a low proportion of aggregate, and although there might have been calcitic aggregates which would have dissolved with the binder (ca 20% of aggregate according to the analysis of natural sand), nevertheless, the amount of binder would still be high.

Lumps of lime have been noted on this façade plaster as well as on other plaster mixes. The presence of these lime lumps implies that a dry slaking process was used rather than wet slaking with surplus of water and long term aging in pits. Dry slaking involves mixing wet sand with quicklime in layers and adding just enough water (+ an extra 5-7%) to slake it. To be noted is that these mortars are usually hard, and it could be due to this method of slaking.

Tomb 633 had a different application whereby gypsum or gypsum/lime plaster was used. Gypsum mortar could be encountered often, and has been mostly used with siliceous or anhydrite aggregates. The advantage in producing gypsum mortar lies in the fact that it requires a lower temperature in preparation than lime, and hence it requires less wood for burning.

Regarding the interior painted plasters, two modes of application could be noted. The first is in having a support of lime plaster followed by another layer of finer quality. The second method is in the application of a preparation layer of gypsum plaster over the lime plaster with aggregates. In the "painted room" of Wadi as-Siyyagh the two methods could be found in two different paintings, and thus most probably implying that the two paintings were not executed at the same time.

The binder/aggregate ratio measurements calculated for the plaster present in Room "1" in Wadi as-Siyyagh, showed a value ranging between 1:1.3 to 1:1.7, with the coarser layer (B/A ratio=1:1.7) being the support for the finer layer (B/A ratio=1:1.3). The support layer contains ca 6% of aggregates >1mm, while the top plaster layer contains only 2.5% of aggregates >1mm, reflecting a bottom coarse layer and a top finer one. The high content of the binder in many of the lime plasters in Petra (found to be between 1: 0.5 and 1: 1.7) is similar to Roman mortars in Germany with ratios ranging between 1: 0.5 and 1: 1.5 (Auras 1997: 23).

Grain size distribution analysis of the samples showed the aggregates to be quite similar to the natural sand collected from the riverbeds. Nevertheless, the distributions are not in agreement with the "Fuller" line. The grains appear to be well sorted, lacking finer aggregates, and hence they must have been washed well before use.

Regarding the replastering of walls, the originally applied wall coatings were first pecked over and then a thin layer of fat lime was painted over in order to prepare the surface for reapplication. This fat lime layer is very often found also directly applied as wash on the sandstone surface, whether interior or exterior, as either a coating on its own or as a ground layer before plastering. Such a coating would serve the purpose of filling the sandstone pores and making the surface more smooth and ready for receiving a plaster layer.

From the samples analyzed, it can be deduced that there was no single method employed in Petra in the application of paint layers, even within a single structure. It seems that the fresco technique was sometimes used, i.e. by mixing the pigments with lime and applying it on damp lime plaster. Additionally, the secco method was often used. It consists of mixing the pigment with gypsum or lime and applying it on a surface that would have been dry, such as a gypsum plaster layer. In some cases, where neither lime nor gypsum could be identified within the paint layer, it is then assumed that an organic binder must have been employed, and hence another secco method of application. Naturally, not all pigments go well with the fresco technique, as Pliny suggested, and therefore the other methods were employed. In many cases, a thin gypsum layer was applied just before the paint layer, and it could be the layer known as "gesso". Gesso – which means gypsum in Italian – is defined as "any aqueous, white priming or ground material that is used to prepare wooden panels or other supports for painting or gilding" (Gettens and Stout 1966: 115). Although the term is mainly used by Italian painters denoting a mixture of glue and gypsum, it nevertheless can be used in the present context to represent the gypsum layer upon which the paint layer was applied.

The gypsum present in the painting layers could have had the function of a binder, or an extender when an organic binder is present. The origin of barium sulphate found in some of the paint layers, mainly with haematite and red ochre pigments, is unclear. This natural mineral can be used as an extender and is known to remain unaffected by light and heat (Gettens and Stout 1966: 96), and hence would have been an ideal extender to be used in the exterior paint layers in Petra.

Regarding organic binding media used in tempera, few results were achieved in the binding media analyses, which nevertheless show that a variety of organic binding media was used. Gum tragacanth, beeswax and another wax, which appears similar to mineral wax upon analysis, have been detected.

The method of "encausting", i.e. painting with wax, mentioned by Pliny and described by Vitruvius, might have been actually applied in Petra. Analysis of the surface of the remains of a sculpted bust on the façade of Tomb 633 (sample 633-13), revealed the presence of a wax (with FTIR peaks similar to Paraffin wax), which could also imply a mineral wax such as Ozocerite. Moreover, this wax is known to harden with time and has a higher capacity for shrinkage than beeswax (Masschelein-Kleiner 1995: 42). This phenomenon of shrinkage is in accordance with the observed surface of the sculpture in question, that shows micro-fissuring and hardness not encountered on the surface of other painted surfaces.

Several painted surfaces in Petra retain a well polished surface appearing as though the surface has been worked horizontally with a polishing tool. Notable examples of this phenomenon are the painted surfaces of Tomb 826, Tomb 524 and the columns of the Great Temple. It is possible that a metal scraper was used for pressing and smoothing the painted surface. According to Ling (1991: 201), slight indentations on the surface of Roman fresco paintings reveal how the surface was worked with a "blunt tool" so that extra lime water was squeezed out for fixing the pigments. This could well be the case in the well burnished surfaces of the monuments in Petra. The compacted upper part of the gypsum intonaco applied in the rendering of the biclinium ceiling (No. 849), again implies that either the painting was burnished or the intonaco was flattened in preparation for applying the paint layer.

Moreover, pointed tools must have also been used, since the separation of borders of colour was done by making an incised line. This practice of using a pointed instrument had the purpose of providing guide lines for the painter (Ling 1991: 203). These are evident on the paintings of the stairway room, as also are rulers and templates. Moreover, it is quite clear in Petra that for holding stucco mouldings several wooden pegs were used inside regularly spaced holes, in addition to iron nails and tacks (Fig. 93). The façade of Tomb 825 has three holes regularly spaced in a row: one with a wooden piece, and another filled with mortar with a square hole in the middle (Fig. 94). This implies that in this case of stucco application, a wooden piece was inserted in the carved hole that was then filled with mortar, and afterwards a nail was hammered in, probably of iron (Shaer 2000: 141).

Figure 93. Qasr el-Bint, holes with wood.

Figure 94. Tomb 825, holes on the façade.

6.4 Provenance of the Materials

Raw materials used in the preparation of plasters, support and paint preparation layers, in addition to the paint layers themselves, can be found in abundance in Petra and its immediate surroundings. In the mixing of plasters, the use of gypsum/anhydrite, lime, dolomitic limestone, and quartz is extensive. All of these basic ingredients could be easily obtained. Limestone is found in the nearby Wadi abu 'Ullayqah and Jabal Umm Sayhoun and could be brought by the Nabataeans (Albright 1953: 19). Comparison of sand collected from several river beds within Petra, Wadi al-Mataha, Wadi Musa, Wadi abu 'Ullayqah and Wadi as-Siyyagh, showed that they all come from the sandstone formations of Petra and are very similar. The sand is highly quartzite with uneven grain size distribution, generally angular or sub-angular to rounded, some with the characteristic pink or yellow colour, and contains a certain amount of rock fragments, mainly of calcite origin. Analysis of sand from Wadi al-Mataha (Sand 4) showed that it consists of 20% calcite aggregates, while comparison of its grain size distribution revealed that it is similar to that of aggregates used in the mixtures of lime plasters. Additionally, these aggregates also contain rock fragments and calcite grains, and very often had quartz grains similar to those found in river beds. Hence, it seems plausible that for the preparation of lime plaster, aggregates were collected from the nearest river beds and often mixed with pure lime, and in some cases with dolomitic lime.

Dolomite could be easily brought from the area lying west of Petra, i.e. Wadi 'Arabah, Wadi Feinan and Wadi Dana, in addition to Bir Madhkur to the northwest (Bender 1974: 47). Also, raw gypsum deposits can be found in the region close to Petra, and could be obtained from the area between al-Karak and Dhra', lying to the north, as well as in the area lying to the west of the road crossing Wadi al-Mujib (Bender 1974: 168).

Taking into consideration the local availability of raw materials necessary for the production of a variety of mortar types, it would seem logical to assume that the process of lime burning and mortar preparation was done locally and within the area of Petra. However, only a single circular structure was found which can be considered as a lime kiln (Fig. 95), though of unclear date and found in association with Ottoman pottery sherds (Frosén et al. 1999: 399). This structure was first documented during the 1998 survey of the area west of Jabal Harun by a team from the Finnish Jabal Harun Project. The structure (Site 24) is a circular building, ca 5.2 m in diameter and of 1.2 m minimum depth. An opening along its west side was probably the place through which air was blown into the kiln. Some chunks of lime can be found inside the structure, and there is limestone in the surrounding area, thus indicating its function as a lime kiln. However, no charcoal remains were found, and there is not much evidence of lime burning, except perhaps in the lower part.

Figure 95. A circular structure that appears to be a lime kiln.

Regarding the Nabataean goods and products, Strabo (XVI; iv; 26), in his book of"Geography" provides the following description:

> "…especially in the case of those that are native products, as, for example, gold and silver and most of the aromatics, whereas brass and iron, as also purple garb, syntax, crocus, costaria, embossed works, paintings, and moulded works are not produced in their country."

In fact, and contrary to Strabo's statement, there are several copper and iron mines in the vicinity of Petra that were extensively mined in ancient times, particularly during the Nabataean period. Haematite can be found within the sandstone of Petra, as for example in figure 96, where it has been identified along the path leading up to al-Dayr monument.

Figure 96. Haematite ores within the sandstone.

Archaeological excavations have revealed a large quantity of haematite, malachite and lumps of red and yellow ochre at the pre-pottery B Neolithic site of al-Bayda (Kirkbride 1966: 53) (Fig. 97), and thus the $8^{th}/7^{th}$ millennium BC appears to mark the first use of copper in Jordan.

Figure 97. Neolithic site at al-Bayda, north of Petra.

Egyptian blue is the only artificially synthesized pigment found that was surely extensively used. The presence of several copper mines in the surroundings of Petra that were mined during Nabataean times indicates the possibility that Egyptian blue was manufactured in the area. The area of Wadi ‘Arabah, lying along the stretch between the Dead Sea and the Red Sea, west of Petra, is considered as the main copper mining area in this region. It has been suggested that since Petra was in the middle of the copper mining area, such mines might have played a role in the city's economy (Muhly 1943: 215).

Copper mining sites are located in the area of Wadi ‘Arabah and include Khirbat Nahas, Khirbat Gheweibeh and Khirbat Jariyeh that were mined during the Iron Age, with no evidence of their exploitation during the Nabataean period according to Glueck (1940: 69-70). Very well-known by now, are the copper ores of Wadi Faynan, lying west of Petra. The area of Wadi Faynan is considered as the richest in the area of Wadi ‘Arabah in copper ores, and it seems that metallurgy started there already during the Chalcolithic period (Hauptmann 1989: 119), and continued during the Early and Middle Bronze Ages, the Iron Age, Nabataean, Roman, Byzantine and Islamic periods (Glueck 1940: 68-70).

Two types of mineralizations could be distinguished at Faynan: the stratigraphically higher one is found in joints and faults of Cambrian sandstones, and the lower one is connected with dolomite-limestone-shale. The ores from the sandstone consist of malachite, chalcocite, (par)-atacamite, so called tile ore' (a mix of malachite and iron hydroxide) and copper silicates, while ores from the dolomite-limestone-shale units consist of malachite and chryscolla, with fibrous copper silicates replacing malachite (Hauptmann 1989: 120-121). Investigations carried out on copper metallurgy in Chalcolithic times, has shown that there was metal production from pure pieces of malachite, (par)-atacamite with cuprite, chalcocite and copper silicates. Some pieces of blue planchite ($Cu_8[(OH)_2Si_4O_{11}]_2 \cdot H_2O$) were also found (Hauptmann 1989: 122). Haematite is also found to an extent in Wadi ‘Arabah.

Another nearby copper mining site is at Umm el-‘Amad, which lies about 8 km to the northwest of Faynan. The mine was cut into the sandstone cliff and consists of cupriferous sandstone speckled with iron oxide (Glueck 1940: 70-71). Other sites in Wadi ‘Arabah with evidence of copper smelting and mining are Ghadyan and Mene'iyeh, the latter being a large centre located about 38 km northwest of ‘Aqaba (Glueck 1940: 75-77).

Of major interest to the present context is the site of es-Sabrah, lying about 7 km to the south/southwest of Petra, along Wadi Sabrah, that was a major copper mining and smelting site exploited by the Nabataeans. The sandstone cliffs located about 1 km west of the site are cupriferous. Glueck (1940: 74) has noted that some of the buildings on the north side of Wadi Sabrah, and located close to a small theatre, functioned for the industry of large scale copper smelting (Fig. 98).

Figure 98. The theatre in Wadi Sabrah, close to a copper smelting site.

Indeed, walking south towards this valley, several features were encountered and sampled, giving results that proved the area as a possible source of raw materials for pigments. At the beginning of the descent to the valley, a couple of mounds can be seen, one of green clayish veins within white sandstone and contains alternating layers of brown clay-like earth (SAB1) (Fig. 99), and another mound (SAB2) of earthy colours of brown, reddish brown and yellow (Fig. 100). Going further south and to the right side of the valley, outcrops of white sandstone with green veins could be noted (SAB5). At the southern end before the valley turns to the right is a cavity in the rocky sandstone with layers, of green, brownish yellow and black veins (SAB3) (Fig. 101). Also, the copper smelting installations mentioned by Glueck could be seen. There, at the bottom of some unexcavated structures, abundant charcoal, burnt soil and pieces of metal slag could be found in addition to Nabataean fine ware pottery, implying a Nabataean copper mining site (Fig. 102). The site additionally provided haematite, and several pieces of iron attached to sandstone could be collected along the valley.

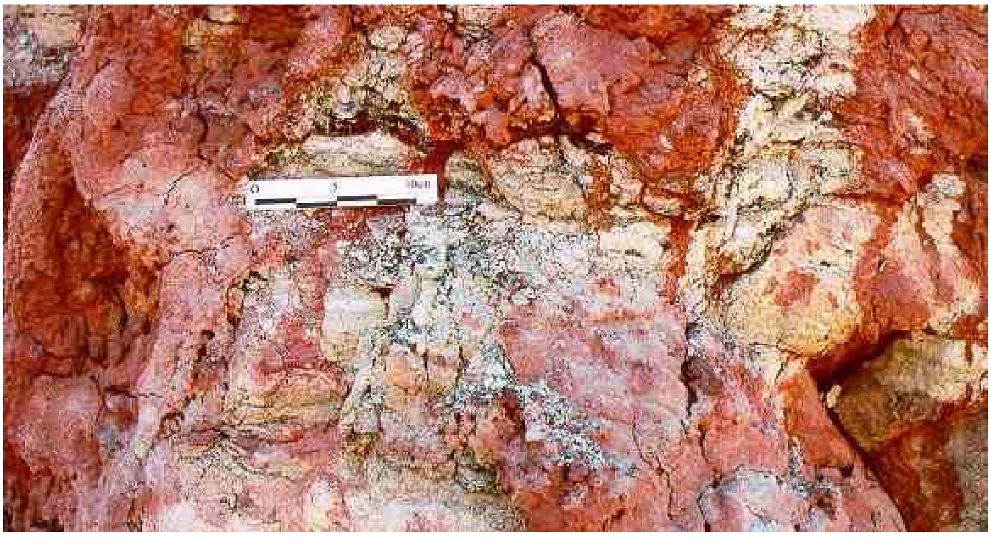


Figure 99. Mound of green clayish veins alternating with brown clay-like veins (SAB1).

Figure 100. Brown, red and yellow veins (SAB2).

X-ray diffraction analysis of a green sample from SAB1 (sample SAB1-02a), revealed the presence of quartz and glauconite, and hence the site could be the source of green earth, while the brown from SAB2 (sample SAB2-01), appeared to contain sodium iron oxide silicate, haematite and quartz (Figs. 103-104).

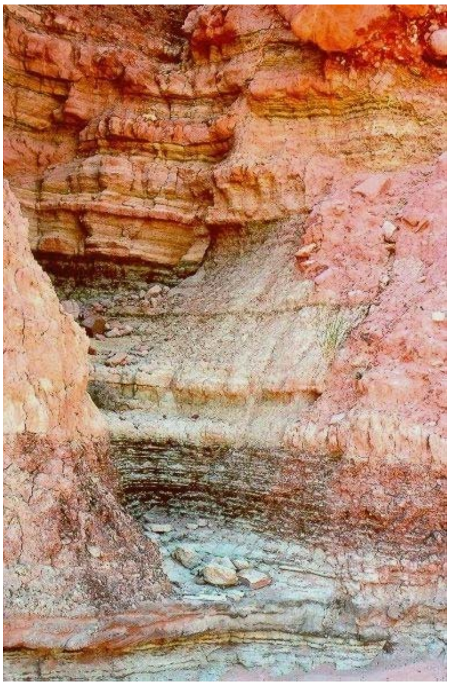


Figure 101. Green, brown and black layers.

Figure 102. Copper smelting site.

Figure 103. SAB1-02a.

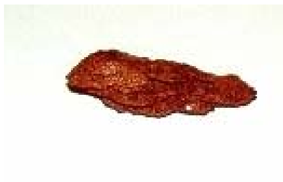


Figure 104. SAB2-01.

Moreover, green veins in the white sandstone – samples SAB5-01 from SAB5 (Fig. 105) and SAB4-01 from the copper smelting site – apparently contain atacamite and malachite in addition to quartz. This evidently proves the presence of atacamite in its natural form, and hence further justifies the argument that its presence in green painted layers is not as a degradation of other copper bearing pigments, but rather as an original one. Moreover, its natural association with malachite, as also found in sample analysis, is a further proof that it was brought from the site itself.

Figure 105. Sample SAB5-01.

Figure 106. Sample SAB6-06.

Furthermore, two yellow samples of limonite were collected from Wadi Sabrah (SAB6-01 and SAB6-06) and upon analysis proved to contain quartz, kaolinite, and goethite, with SAB6-06 (Fig. 106) having additionally haematite. By comparing these constituents to yellow samples analyzed, it proves that the yellow pigment was actually supplied by such limonite veins.

Analysis of gold leaf samples has shown that the gold used was not completely pure, and contained silver alloy and iron impurities. Thus, even if the gold to be used had undergone a refining process, it seems that it was not totally refined. It can only be speculated that the gold used in Petra was brought from the regions close to Nabataea or places that are along the trade routes passing through Petra. Strabo (XVI; iv; 22) mentions that the Nabataeans exchanged aromatics and precious stones in exchange for gold and silver. Rich sources of gold deposits are found in Egypt, along the Red Sea coast and the Nubian desert, which in Hellenistic times was controlled by the Ptolmies who ruled in Egypt after the death of Alexander (Painter 1991: 136-137). Some of the Aegean islands and the coasts of Thrace and Macedonia provided a main source of gold for the Greek and Hellenistic world, as did the area of Asia Minor, Afghanistan, Turkestan and India (Painter 1991: 136-137).

Gum tragacanth is produced from the leguminous shrubs of the genus *Astragalus*. Several species of this plant, including *A. gummifer* and *A. gossypinus* which are considered as the best in producing the gum (Newman and Serpico 2000: 478) are found in Jordan, Syria and Lebanon, among other species found in south Jordan's high region to the east of Petra and stretching from Jabal el-'Ata Ita northeast of al-Shawbak and all way to the south to Jabal Khalal (Baierle 1993: 63-66; Beilage 6b).

Although not detected, yet it is possible that also *gum Arabic*, produced from the *Acacia* trees, was used. Several species of *Acacia* trees can be found along the desert area of Wadi Arabah, to the west and northwest of Petra, these being *Acacia raddiana*, *Acacia tortilis* and *Acacia gerrardii* (Baierle 1993: 110), and hence it would be reasonable to assume that the Nabataeans extracted and used the gum from these trees, especially as it was common practice at the time, especially in Egypt (Newman and Serpico 2000: 476-477).

As previously mentioned, ozocerite could have been the source of a wax used on the paint layer of the sculptural bust at Tomb 633. Ozocerite occurs in the bituminous deposits from the Miocene age, and is extracted by melting bituminous earth in boiling water. Upon boiling, the wax floats to the surface and therefore can be separated and used (Masschelein-Kleiner 1995: 42). Hence, if such a mineral wax was used, it could very well be one that is extracted from bitumen, since bitumen occurs at the Dead Sea, and its extraction and importance for Nabataean trade with Egypt is well attested (Hammond 1973: 67).

Bitumen from the Dead Sea was sold to the Egyptians for use in embalming and waterproofing boats. The method of extracting bitumen is mentioned by Hieronymus of Cardia (Diodorus XIX, 98-100) who describes how bitumen would occasionally appear as a block of mass on the surface of the Dead Sea. Bitumen was also found at ancient sites where it was used as an adhesive or even as a binding mortar.

6.5 Concluding Remarks

Within the scope of the present study, it has been proven that painting and gilding were of vital relevance to Nabataean architectural surfaces. True, many walls and façades show plastering remains, however, on close and scientific inspection of cross sections, it was found that many of the plastered surfaces that appear quite bare had originally paint, or even gold leaf remains. Notable examples of this are the southern façade of Qasr el Bint (403) and the inscription tablet of Turkmaniyya (Tomb 633). All of this evidence points out to a colourfully decorated city set against a background of natural sandstone rock surroundings.

The pigments used were ones identified by classical writers like Theophrastus, Dioscorides, Vitruvius and Pliny, and includes those that were popular at the time, in addition to readily available raw materials, such as we find in the use of atacamite. Although there is a basic colour palette used by the Nabateans that includes pigments that were brought from the surrounding areas, still there is a certain peculiarity in the use of the different colours for the different functional uses of the surfaces.

Colours other than primary ones, i.e. red, blue and yellow have not yet been detected on any single rock carved tomb façade in Petra, while interior mural paintings include additionally different hues of green, pink, orange, brown and black. For the red, blue and yellow paint layers, red ochre and haematite, Egyptian blue and yellow ochre were respectively used. According to Pliny (XXXV; XIII-XXIX), these pigments were considered rather cheap at the time. Their price in Petra wouldn't have been more expensive, since the raw materials could be found locally. The use of cheaper, easily accessible pigments, especially on exterior façades, would appear logical, considering that relatively large surfaces were coated, which were exposed to weathering elements. Also, from the samples investigated, gilding seems to be a feature of public buildings, and particularly temples, and has been used on moulded stuccowork, rather than wall paintings.

Red, blue and yellow are also the three main colours that were used to decorate the architectural elements of ancient Greek tombs, such as the Prince's Tomb at Vergina and the Great Tomb at Lefkadia (Ling and Prag 2000: 201), and are a reminder of the restricted palette mentioned by Pliny (XXXV; XXXII). On the other hand, the styles of interior mural paintings in Petra are reminiscent of Roman painting styles known from Pompeii and other sites, such as the Masonry Style (known in First Style Pompeian painting and goes back to the times of classical Greece), the Second Style and the Third Style. However, it is difficult to date such paintings in Petra according to such styles, since in many cases they can be found simultaneously decorating the same structure, such as at az-Zantur (Kolb 2001: 445).

It appears that there are strong connections between Petra and the classical world in terms of artistic expression. The Second Style of painting seems to have been influenced by the court art of the Hellenistic monarchy, especially that of the Ptolmies of Egypt (Perkins and Claridge 1979: 98), while it has been suggested that in fact Macedonian art and architecture influenced Alexandrian forms (Haddad 1998: 161-171). Strong Alexandrian influences can also be seen in Petra as well as the Second Style paintings in Pompeii (McKenzie 1990). Hence, it can be concluded that Hellenistic elements, especially those found in Alexandrian forms influenced much of the Nabataean decorative arts, yet these were used in new ways along with styles that became also popular in Roman painting, as also already noted regarding the mansion of az-Zantur (Kolb 2001: 445)

Moreover, although there is very little knowledge on the meaning of different colours to the Nabataeans, yet it can be suggested that such meanings are not very different from ones existing in other contemporary cultures. While, Pliny (IX; XXXVI) writes about the high regard for the purple colour during his time, when it was the colour worn by the highest ranked officers Strabo (XVI; iv; 26) similarly mentions that the Nabataean kings dressed in purple.

To be noted is the fact that evidence of possible repainting or repair of existing paint layers is found only in very few cases, and none on the exterior tomb façades. Evidence of the reapplication of wall plasters can be seen in the interior chambers with pecked over surfaces. However, with regards to exterior painted plaster and stucco, it is possible that often the whole structure, including support, preparation and paint layers was removed to be replaced by newer decorative surfaces. Such an argument is supported by evidence from Qasr el-Bint, whereby in the course of excavation, a dump had been identified, consisting of painted and gilded moulded stucco that was replaced at some stage.

Moreover, different applications of paint support layers have been found, and this could either mean different schools for mural painting application or different periods of execution. At this point, such hypotheses cannot be conclusively proved, although evidence in the painted room in Wadi as-Siyyagh has shown that two different techniques were used for two paintings that were probably executed at two different times.

The techniques and materials used in Petra were rather common elsewhere during the period in question, nevertheless, there are some distinguishable peculiarities for Petra. Of these, is the fat lime coating often applied as a first layer that implies the Nabataean knowledge of the sandstone and its fragility and porosity. The polishing of paint layers was done to a rather high level. Waxing might have been employed, and if a mineral wax was used, then most probably it was also brought from a nearby area, such as the bitumen of the Dead Sea, the industrial product, which the Nabataeans were so famously known for.

Even though it seems that there were certain set procedures and norms in the execution of wall plastering and painting, yet there was still freedom and individuality in implementation. This is evidenced in some variations in applications that could be due to the individual craftsman's method of working, and can be noted in the use of different mixes within a single work with an overall concept. However, major changes in the technological aspects of the application of paint layers could signal chronologically different periods.

Further studies on wall paintings and retrieved stucco pieces that are continuously being uncovered in Petra will add to the understanding of Nabataean painting technology. Also, studying the renders of many more façade, which could not be achieved within the scope of this research, is crucial as such remains are fragile and are at risk of being lost. Results on organic binding media that were revealed in the course of this study, present an important and interesting direction for further conservation science research. Finally, a comprehensive research on Nabataean painting from an art historical point of view is necessary. By correlating art historical and architectural studies with those relating to painting technology it might be possible to arrive at more accurate dating and classification of monuments in Petra according to building periods.

7. PETRA: SITE CONSERVATION

7.1 Introduction

Tourism is regarded as one of Jordan's most important resources. Although the country boasts a large number of sites that are considered as major attractions for tourism, Petra remains the number one site that is frequented by most. The number of visitors to Petra increased from about 100,000 in 1990 to nearly 500,000 in the year 2000. The nearby village of Wadi Musa has a variety of hotels, which have dramatically increased in number since 1981 from one hotel to a total of 65. *The National Geographic Traveler*, in its special issue celebrating its 15th anniversary published its list of "50 places of a lifetime", which included Petra under the category of "World Wonders".

Petra was inscribed on the list of World Heritage Sites in 1985 (UNESCO 1985). In its Ninth Ordinary Session, the World Heritage Committee agreed to include Petra on the list based on the criteria C (i), (iii) and (iv) of the World Heritage Convention, i.e.:

> "i. represent a masterpiece of human creative genius";
> "iii. bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared" and
> "iv. be an outstanding example of a type of building or architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history"
> (World Heritage Committee, UNESCO, Operational Guidelines of the World Heritage Convention, Paris, 1972).

Thus, Petra came to be recognized for its "outstanding universal value".

The area of Petra that was declared a protected site in 1993 is 264 km^2, while the whole Petra Region is, however, nearly 1000 km^2 and includes the surrounding areas and urban centres. Until 1985, the local Bdoul tribe were living inside the rock cut caves and monuments of Petra. They were moved to a nearby village, Umm Sayhoun, where dwellings were constructed to accommodate them. The housing plan for the Bdoul did not take into consideration the natural increase in families, that the village has grown beyond original plans, and even so, many are still having accommodation at the site.

According to the Antiquities' Law, the protection and conservation of all archaeological sites (pre-AD 1700 sites), lies within the responsibility of the Department of Antiquities. Nevertheless, numerous national and international archaeological and conservation missions, universities and institutions have been working closely with the Department of Antiquities, in conducting archaeological surveys, excavations and conservation projects.

In 1989, the Petra National Trust, a Jordanian non-governmental organization was established to "preserve the environment, antiquities, and cultural heritage of the Petra region", and has carried several projects in Petra since then. Of these, was a project to survey the Nabataean hydraulic systems, with funds from the bilateral agreement between the governments of Switzerland and Jordan, followed by another project that aimed at recovery and consolidation of the pavement of al-Siq at the site entrance as well as flash flood control.

Petra was included in 1998, 2000 and 2002 in the *List of 100 most Endangered Sites* that is issued every other year by the World Monuments Watch. The World Monuments Watch is a program of the World Monuments Fund, an organization that aims to identify and preserve the world's cultural heritage which is in danger. This was the basis of a partnership that was established between the Petra National Trust and the World Monuments Fund that resulted in the provision of several grants for projects executed by the Petra National Trust.

Realizing the importance of the site of Petra with all the values that it encompasses, cultural and socio-economic, conservation of the site is of highest priority not only in solving immediate conservation problems, but also for the long term sustainability of the site as a cultural resource. Comprehensive site management of Petra, with all its components of site interpretation, tourism management, conservation and monitoring of monuments, should ideally be implemented.

This issue was recognized, to some extent, already by the late 1960s, when the United States National Park Service prepared the first Master Plan for the management of the Petra National Park, with funding from USAID. This plan dealt with issues such as the preservation of the site and tourism development.

In 1991, UNESCO sent a mission to Jordan in order to identify problems at the site and suggest projects. This was followed by a second mission in 1992, and another one in 1994 that resulted in the preparation of a Management Plan for the Petra National Park (UNESCO 1994). A third study was conducted in 1996 by another team from the United States entitled "Management Analysis and Recommendations for the Petra World Heritage Site".

The final study dealing with the management of Petra was done in the year 2000, when the United States National Park Service, upon signing a memorandum of agreement with the Ministry of Tourism of Antiquities for upgrading the management structure of Petra, prepared a draft Operational Plan for the newly established Petra Archaeological Park. This plan was reviewed by the Ministry of Tourism and Antiquities and some of the stakeholders, upon which some of its items were reformulated. The Operational Plan includes the park's organizational structure, operating procedures and standards, required facilities and equipment, a "Conservation Guide", general policy planning and a schedule of implementation. All of these items have been broadly stated, and now a complete and detailed management plan needs to be set and implemented.

During that time, and specifically in 1995, the Petra Regional Planning Council was established to help in the protection of the site and in preventing external threats, such as for example in executing a wastewater network in order to protect the archaeological park. It is also concerned with developing the local communities and tourism as a major contributor to the economy. A comprehensive study was done by Dar al-Handasa called "Petra Priority Action Plan", and includes social, touristic and economic aspects. Several other projects were also conducted that include infrastructure, environmental protection, rehabilitation and reconstruction of cultural heritage sites and beautification projects. The Petra region includes the areas of Wadi Musa, Taybeh, Umm Sayhoun, Edlagha, al-Bayda and Rajef. The population of the whole region is about 30,000. In 2001, the Petra Regional Planning Council became an independent Petra Region Authority.

The World Bank's Second Tourism Development Project, with and estimated project cost of 44$ mill. had 22$ mill. allocated for Petra, with emphasis on physical planning and infrastructure, development, environmental management, site enhancement and visitor management in the Petra sanctuary.

Several surveys and studies have been carried out at the archaeological site. To be noted is the survey and mapping conducted by the Hashemite University which now consists of a database of some 2750 monuments, with 1000 still to be included. The database, which is linked to GIS maps, includes the monument number, type and general condition for each monument. Such an archive can be the basis for further developing conservation and site management plans.

There have been specific conservation projects which are mainly conducted by archaeological teams excavating specific sites, such as the Great Temple and the Byzantine Cathedral, where excavation, conservation and sheltering was conducted by teams from the American Center for Oriental Research (ACOR).

Due to the lack of long term plans, policies and established procedures to safeguard the unique monuments of Petra, a project was initiated in November 1993 in order to help in providing the necessary tools, expertise and infrastructure required to address such needs. The main goal of the Petra Stone Preservation project was to give assistance to the Jordanian Government in establishing the Conservation and Restoration Centre in Petra (CARCIP).

Thus, the Conservation and Restoration Center in Petra was established in the years 1993-2002 with the support of the German government (through GTZ) in the form of technical assistance to the Department of Antiquities of Jordan. The Center has been established under the Department of Antiquities. Envisaged as the nucleus for an institution addressing the conservation and restoration needs of monuments on a nationwide basis, CARCIP is to carry out its mission as being the technical arm that will render support to the newly established Petra Archaeological Park and will fulfill its mission in the following areas:

- Supporting the Petra Archaeological Park in establishing conservation plans and policies for the site, so as to assure regular maintenance and appropriate conservation measures.
- Supporting the Petra Archaeological Park in setting up and implementing management plans and policies (including excavations and permitting).
- Documentation and evaluation of the state of preservation of monuments, and maintenance of an archive that includes all relevant information regarding the inventory of monuments and their state of preservation.
- Planning and carrying out conservation and restoration work according to internationally known and accepted procedures.
- Coordinating all conservation projects and ensuring that they are conducted according to conservation and management plans of the center.

- Designing, coordinating and implementing training in various aspects of conservation work by cooperating with national and international organizations.
- Promoting awareness regarding the importance of the protection of the cultural heritage, and the appropriate tools and methods.

A conservation strategy is required for the site which would include management policies that can be considered as preventive care and long term preservation policies. The strategy would also consist of management and conservation guidelines, a methodology for conservation, general conservation principles and a prioritized list of monuments and sites that require conservation. Additionally, the strategy should include a monitoring system for continuous review and updating of the strategy and the priorities stated.

7.2 Weathering and Conservation

Efforts to preserve the monuments in Petra and ensure its adequate presentation to the visitor started already in 1958. The weathered and partly non-existent column of al-Khaznah was restored as well as the other existing columns next to it. Restoration of this very famous rock hewn façade of Petra was done with procedures that are considered unacceptable today, such as the use of Portland cement, but were at the time rather popular. Nevertheless, ultrasonic measurements of two of the repaired columns indicated that the interior parts of the columns have a homogeneous strength profile, while the exposed surfaces are rather weathered and require consolidation (Simon 2000).

Regarding the issue of sandstone weathering in Petra, scientists at Yarmouk University were the first to point out the problem, and in 1982 they decided to examine it and to look into the possibility of providing solutions. They worked on it with the collaboration of B. Fitzner of the Geological Institute at the University of Aachen (RWTH). The working group "Natural Stones and Weathering" at the Geological Institute has carried out studies focusing on the registration and evaluation of damages at the monuments, including a lithostratigraphic classification and analyses of petrographical properties, and the characterization and quantification of the weathering state of monuments (Fitzner and Heinrichs 1998; Heinrichs and Fitzner 1999; 2000a; 2000b).

Moreover, Paradise (1999), in analyzing the weathering of the theatre in Petra, concluded that weathering was due to variations in rock matrix, as well as to aspect and the related annular solar flux. The Natural Resources Authority of the Ministry of Energy and Mineral Resources conducted some research on the sandstone of Petra, its geotechnical and engineering properties, lithology, faulting and causes of erosion weathering (Barjous and Jaser 1988).

In 1992 the Electicité de France (EDF) began a study related to the hydrology of the area, and in collaboration with the University of Nancy carried out some experiments on samples taken from the Palace Tomb in order to determine the degree of weathering of the rock walls. They devised a method for consolidating and water proofing the walls, though no implementation of these plans is envisaged.

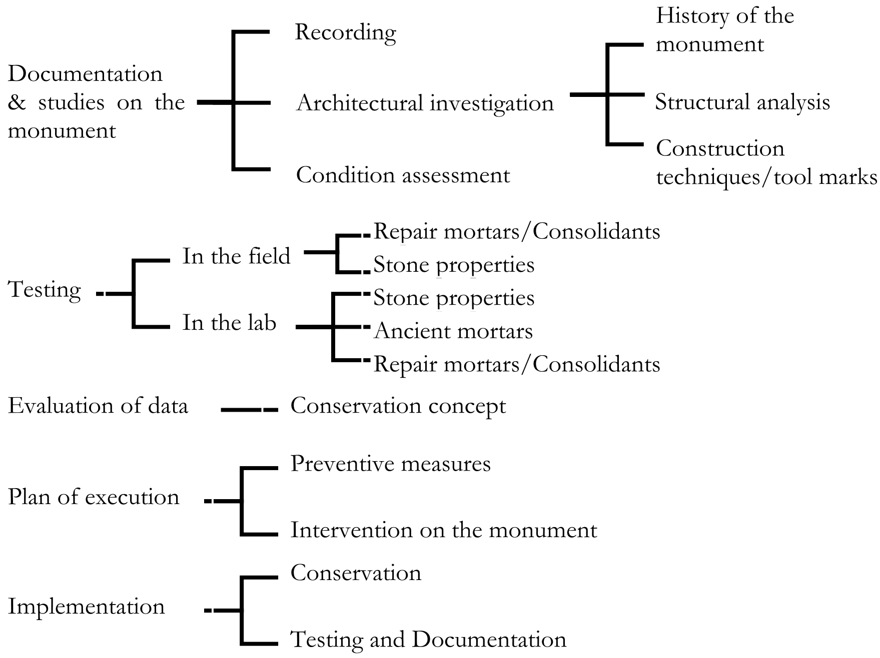
The above mentioned Petra Stone Preservation project was concerned with establishing a methodology for the conservation of the façades in Petra, which was adopted for the first time on one of the monuments, namely Tomb 825 (*Tomb of the Fourteen Graves*). Similarly, it is being implemented on another monument, Tomb 826, and should be carried out on all monuments to be restored. It includes procedures that are internationally accepted and used in the preparation and execution of conservation measures for such a World Heritage Site.

One of the aspects that needed to be investigated relates to the types of weathering forms that can be encountered on the sandstone surfaces of the Petra monuments. After researching into the different lists of weathering forms established by international norms and certain case studies, and particularly those published by Fitzner and Heinrichs (1992; 1994), and after a general inspection of the types of weathering forms found on the monuments of Petra, a list of weathering types was compiled, which includes only those weathering forms that are peculiar to the site. The weathering types are classified into five categories and have been chosen to suit the purpose of the project in terms of weathering forms, diagnosis and treatability. The five categories of weathering types are:

1. Detachment of stone material (sanding, flaking, scaling and exfoliation)
2. Loss of stone material (pitting, alveolar weathering, outbreaks, spalling, backweathering, washouts, missing insets)
3. Formation of deposits on the stone surface (salt efflorescence, surface crusts, salt crusts, microbiological deterioration, vegetation, insect colonization, soot, bird droppings, graffiti, soiling)
4. Cracking (Cracks, joints, faults)
5. Deterioration in mortar and plaster (plaster detachment, mortar disintegration, mortar infestation)

Along with trying to understand the weathering forms in Petra, an attempt to learn more about the sandstone formations at the site, as well as its reaction to various treatments, was also necessary. The stone was tested for its water uptake, water vapour permeability, porosity, strength and salt content. A test field for various testing procedures was designed at an ancient quarry in Petra (Kühlenthal, Kaiser and Fischer 2000). There, a silica sol based repair mortar (Snethlage 2000) was tested on the rock, in order to determine its compatibility and suitability with the sandstone, and, to observe its long and short term impact on the appearance. Various consolidants were also tested and evaluated in the laboratory in order to assess their suitability for use at the sandstone monuments of Petra (al-Saad 2000).

After the above mentioned investigations and preparations were done, a methodology for working on the conservation of the monuments was developed by the project, and its implementation was begun on Tomb 825. This methodology can be summarized in the following diagram:



Recording and documentation of a monument is the first step that should be done before any type of investigation is to begin. Architectural investigation is the result of the close observation of all features of a monument that leads to a better understanding of the building in terms of its history, construction techniques and ancient materials that were used.

A detailed mapping of the weathering forms which are found on the facade is then conducted. This helps in assessing the general condition of the monument and in understanding its state of deterioration. In addition to the previously mentioned tests, additional investigation of the actual rock from which the monument was carved is done. Again, properties such as mineral components, water uptake, water vapour permeability, porosity, strength and salt content are determined. When all of the preparatory work is done and the tests are finalized, the conservation concept can be established and the measures to be executed can be decided upon according to the different weathering forms.

For any execution measure, the principles of minimum intervention, compatibility and retreatablility have to be observed. Practical measures that can be done on a single facade include the removal and cleaning of deposits, filling and patching of mortar, mortar injection, adding protective mortar copings, and adding stone insets. As a general rule, the only measures that will be taken are ones that result in minimizing further damage that can occur on a monument. Filling cavities with a repair mortar for example, stops the accumulation of water which usually accelerates the deterioration process. Also, adding a protective mortar coping which is slightly sloped on architectural elements such as cornices helps in draining away rainwater from the facades. Finally, the addition of stone blocks where there are missing insets shall only be done where such a reconstruction will help in preventing further damage of the facade.

The mortar used for filling cavities is a silica sol repair mortar that is a mix of the natural sand of Petra, very fine sand, a mineral mix and silica sol which is basically an SiO_2 compound dispersed in water. A "wash" of similar properties, but of a very dilute nature was also developed and used for the injection of surface scales. The procedure of application involves first cleaning the surface and desalination, applying a silicic acid ester with a brush, followed by the "wash", and finally filling in the mortar (Kühlenthal 2000).

Continuous maintenance is crucial to safeguarding the monuments of Petra. Therefore, it is worth noting that the restoration of a single façade does not imply the end of the preservation effort, but rather a prospect for a continuous monitoring.

The conservation of plaster and stucco should follow a similar methodology, but of course with different treatments. There have been single projects for the conservation of plasters and stucco, but no comprehensive planning was ever set for that. As a first step, previous procedures which have been implemented need to be assessed and evaluated in terms of the materials used and methods of consolidation. Accurate documentation with drawings and photographs is necessary before any intervention. This should be followed by an assessment of the occurring damages, such as the presence of salts and soot, the detachment of plaster and paint layers, and microbiological growth. Analysis of original materials and the testing of new materials should be conducted. Treatment trials for cleaning, reattachment and consolidation should also be done. Tests for cleaning can include mechanical cleaning, laser cleaning and cleaning by poultices. Trials of plaster reattachment with a plaster that is similar to the original used should be done. Consolidation with silicic acid esters should be also tried first, and evaluated in the long term.

Again, the principles of minimum intervention and compatibility should be adhered to. The filling of lacuna and repainting should be done only when necessary to preserve the integrity of a painting without sacrificing its authenticity.

8. APPENDICES

8.1 List of the Analyzed Samples

Table 14 provides a list of the samples collected and analyzed, the questions of interest which prompted their collection and the methods of analysis for each sample.

Table 14. List of samples analyzed.

No.	Sample	Questions	Methods
1	235-10	Structure and constituents	Optical microscopy; SEM/EDX
2	235-11	Structure and constituents	Optical microscopy; SEM/EDX
3	235-12	Structure of layers; if paint layers present	Optical microscopy
4	235-13	Structure of layers; if paint layers present	Optical microscopy
5	235-14	Structure of layers; if paint layers present	Optical microscopy
6	235-15	Mortar constituents	XRD
7	235-16	Structure of layers; if paint layers present	Optical microscopy
8	235-17	Structure and constituents	Optical microscopy; SEM/EDX
9	235-18	Structure and constituents	Optical microscopy; SEM/EDX
10	235-19	Pigment and mortar constituents; Presence of organic binding media; structure of layers	XRD; XRF; GC-MS (no result); Optical microscopy; SEM/EDX
11	244-10	Structure of layers; if paint layers present	Optical microscopy; HCl dissolution to identify binder
12	403-10	Structure and constituents	Optical microscopy; SEM/EDX
13	403-10a	Structure of layers; if paint layers present	Optical microscopy
14	403-12	Structure of layers; if paint layers present	Optical microscopy
15	403-13a	Structure and constituents	Optical microscopy; SEM/EDX
16	403-13c	Structure; if paint layers present	Optical microscopy
17	403-14	Structure and constituents	Optical microscopy; SEM/EDX
18	403-15	Structure of layers; if paint layers present	Optical microscopy
19	403-17	Structure of layers; if paint layers present	Optical microscopy
20	403-19	Structure and constituents	Optical microscopy; SEM/EDX
21	403-20b	Structure of layers; if paint layers present	Optical microscopy
22	403-22	Structure and constituents	Optical microscopy; SEM/EDX
23	403-25	Structure and constituents	Optical microscopy; SEM/EDX
24	403-26b	Structure of layers; if paint layers present	Optical microscopy
25	403-34	Structure and constituents	Optical microscopy; SEM/EDX
26	403-37b	Structure and constituents	Optical microscopy; SEM/EDX
27	403-39	Structure and constituents	Optical microscopy; SEM/EDX
28	403-47	Structure and constituents	Optical microscopy; SEM/EDX
29	423-01	Nature and structure of pigment and any organic binding media	XRD; FT-IR; GC-MS; Optical microscopy; SEM/EDX
30	423-02	Nature and structure of pigment and any organic binding media	XRD; FT-IR; Optical microscopy; SEM/EDX

No.	Sample	Questions	Methods
31	423-03	Structure and constituents	Optical microscopy; SEM/EDX
32	423-03a	Structure and constituents	Optical microscopy; SEM/EDX
33	435-01	Structure of layers; if paint layers present	Optical microscopy
34	524-01a	Pigment and mortar constituents and qualities; structure of layers	XRD; FT-IR; Thin section; Optical microscopy; SEM/EDX
35	633-10	Structure and constituents	Optical microscopy; SEM/EDX; GC-MS (no result)
36	633-11	Structure and constituents	Optical microscopy; SEM/EDX
37	633-12	Structure and constituents	Optical microscopy; SEM/EDX
38	633-13	Pigment layers and any organic binding media or wax; structure of layers	XRD; XRF; FT-IR; GC-MS; Optical microscopy; SEM/EDX
39	633-14	Structure and constituents	Optical microscopy; SEM/EDX
40	633-16	Structure and constituents	Optical microscopy; SEM/EDX
41	633-17	Structure and constituents	Optical microscopy; SEM/EDX
42	633-18	Structure and constituents	Optical microscopy; SEM/EDX
43	786-10	Structure of layers; if paint layers present	Optical microscopy
44	786-11	Mortar constituents	B/A ratio; GSD
45	786-12	Structure and constituents	Optical microscopy; SEM/EDX
46	786-13	Structure of layers; if paint layers present	Optical microscopy
47	786-14	Pigment constituents; structure	XRD; XRF; Optical microscopy; SEM/EDX
48	826-01	Mortar constituents	XRD; B/A ratio; GSD
49	826-02	Mortar constituents; structure of layers	B/A ratio; GSD; Optical microscopy; SEM/EDX
50	826-03	Mortar constituents	B/A ratio; GSD
51	826-04	Mortar constituents	B/A ratio; GSD
52	826-05	Mortar constituents and qualities	XRD; FT-IR; B/A ratio; GSD; Thin section
53	826-22	Mortar constituents; structure of layers	XRD; Optical microscopy; SEM/EDX
54	826-24	Structure and constituents	Optical microscopy; SEM/EDX
55	826-31	Structure and constituents	Optical microscopy; SEM/EDX
56	826-32	Structure and constituents	Optical microscopy; SEM/EDX
57	826-33	Structure and constituents	Optical microscopy; SEM/EDX
58	826-42	Mortar constituents	XRD
59	826-46	Structure and constituents	Optical microscopy; SEM/EDX
60	826-48	Structure and constituents	Optical microscopy; SEM/EDX
61	826-53	Structure and constituents	Optical microscopy; SEM/EDX
62	826-54	Structure of layers; if paint layers present	Optical microscopy; GC-Ms (no result)
63	827-02	Structure and constituents	Optical microscopy; SEM/EDX
64	849-10	Structure; if paint layers present	Optical microscopy
65	849-11	Pigment constituents; structure of layers	XRD; XRF; Optical microscopy; SEM/EDX; GC-MS (no result)
66	849-13	Pigment constituents; structure of layers	XRD; Optical microscopy; SEM/EDX
67	849-14	Structure of layers	Optical microscopy
68	849-14a	Structure and constituents	Optical microscopy; SEM/EDX
69	849-15	Structure and constituents	Optical microscopy; SEM/EDX
70	849-16	Presence of organic binding media; Structure and constituents	XRD; GC-MS; Optical microscopy; SEM/EDX
71	849-17	Structure and constituents	Optical microscopy; SEM/EDX

No.	Sample	Questions	Methods
72	849-18	Structure and constituents	Optical microscopy; SEM/EDX
73	849-18a	Structure of layers; if paint layers present	Optical microscopy
74	849-19	Structure of layers; if paint layers present	Optical microscopy
75	849-20	Structure and constituents	Optical microscopy; SEM/EDX
76	849-21	Presence of organic binding media	XRD; GC-MS (no result)
77	849-22	Structure and constituents	Optical microscopy; SEM/EDX
78	849-22a	Structure and constituents	Optical microscopy; SEM/EDX; GC-MS (no result)
79	849-23	Structure and constituents	Optical microscopy; SEM/EDX
80	849-24	Presence of organic binding media; Structure and constituents	XRD; GC-MS (no result); Optical microscopy; SEM/EDX
81	849-25	Structure and constituents	Optical microscopy; SEM/EDX
82	PGT-03a	Pigment constituents; structure of layers	XRD; Optical microscopy; SEM/EDX
83	PGT-03b	Structure and constituents	Optical microscopy; SEM/EDX
84	PGT-03b1	Pigment constituents	XRD
85	PGT-03b2	Pigment constituents	XRD
86	PGT-03c	Pigment constituents; structure of layers	XRD; Optical microscopy; SEM/EDX
87	PGT-08	Constituents	B/A ratio measurement procedure
88	PGT-10a	Structure and constituents	Optical microscopy; SEM/EDX
89	PGT-10b	Structure and constituents	Optical microscopy; SEM/EDX
90	PGT-10c	Structure and constituents	Optical microscopy; SEM/EDX
91	PGT-11	Structure and constituents	Optical microscopy; SEM/EDX
92	PGT-12	Structure and constituents	Optical microscopy; SEM/EDX
93	PGT-13	Presence of organic binding media; Structure and constituents	GC-MS (no result); Optical microscopy; SEM/EDX
94	PGT-14	Structure and constituents	Optical microscopy; SEM/EDX
95	PGT-15	Structure and constituents	Optical microscopy; SEM/EDX
96	PGT-16	Structure and constituents	Optical microscopy; SEM/EDX
97	PGT-17	Structure and constituents	Optical microscopy; SEM/EDX
98	PGT-18	Structure and constituents	Optical microscopy; SEM/EDX
99	PGT-19	Structure and constituents	Optical microscopy; SEM/EDX
100	PGT-21	Structure	Optical microscopy
101	PGT-23	Structure and constituents	Optical microscopy; SEM/EDX
102	PGT-24	Structure and constituents	Optical microscopy; SEM/EDX
103	PGT-25	Pigment constituents; structure of the layers	XRD; Optical microscopy; SEM/EDX
104	PGT-25a	Mortar constituents	XRD
105	PGT-25b	Mortar constituents	XRD
106	PGT-26	Structure of layers	Optical microscopy
107	PGT-27	Structure and constituents	Optical microscopy; SEM/EDX
107	PGT-31	Presence of organic binding media; Structure and constituents	GC-MS (no result); Optical microscopy; SEM/EDX
109	PGT-31a	Pigment constituents; structure of layers	XRD; FT-IR; Optical microscopy; SEM/EDX
110	PGT-32	Presence of organic binding media; structure and constituents	GC-MS (no result); Optical microscopy; SEM/EDX
111	PGT-33	Structure and constituents	Optical microscopy; SEM/EDX
112	PGT-34	Structure of layers	Optical microscopy
113	PGT-35	Structure and constituents	Optical microscopy; SEM/EDX

No.	Sample	Questions	Methods
114	PGT-36	Mortar constituents and qualities	XRD; FTIR; Thin section
115	SAB1-02a	Constituents; if sample could identify a provenance for pigment	XRD
116	SAB2-01	Constituents; if sample could identify a provenance for pigment	XRD
117	SAB4-01	Constituents; if sample could identify a provenance for pigment	XRD
118	SAB5-01	Constituents; if sample could identify a provenance for pigment	XRD
119	SAB6-01	Constituents; if sample could identify a provenance for pigment	XRD
120	SAB6-06	Constituents; if sample could identify a provenance for pigment	XRD
121	Sand 4	Proportion of calcitic aggregate in the sand; aggregate distribution	B/A ratio measurement procedure; GSD
122	SIY-01a	Mortar constituents	B/A ratio; GSD
123	SIY-01b	Mortar constituents	B/A ratio; GSD
124	SIY-02	Mortar constituents	B/A ratio; GSD
125	SIY-03	Mortar constituents	B/A ratio; GSD
126	SIY-04	Structure and constituents	Optical microscopy; SEM/EDX
127	SIY-05	Structure and constituents	Optical microscopy; SEM/EDX
128	SIY-06	Structure and constituents	Optical microscopy; SEM/EDX
129	SIY-08	Structure and constituents	Optical microscopy; SEM/EDX
130	SIY-09	Structure and constituents	Optical microscopy; SEM/EDX
131	SIY-12	Structure and constituents	Optical microscopy; SEM/EDX
132	SIY-13	Pigment constituents; structure of the layers	XRD; XRF; Optical microscopy; SEM/EDX
133	SIY-14	Structure and constituents	Optical microscopy; SEM/EDX
134	SIY-15	Structure and constituents	Optical microscopy; SEM/EDX
135	SIY-16	Pigment constituents; ; structure of the layers	XRD; XRD; Optical microscopy; SEM/EDX
136	SIY-17	Pigment constituents; structure of the layers	XRD; XRD; Optical microscopy; SEM/EDX
137	SIY-18	Pigment constituents; structure of the layers	XRD; XRD; Optical microscopy; SEM/EDX
138	SIY-19	Structure and constituents	Optical microscopy; SEM/EDX
139	SIY-20	Structure and constituents	Optical microscopy; SEM/EDX
140	SIY-21	Structure of layers	Optical microscopy
141	SIY-22	Structure and constituents	Optical microscopy; SEM/EDX
142	SIY-23	Structure of layers	Optical microscopy
143	SIYAB-01	Structure and constituents	Optical microscopy; SEM/EDX
144	SIYAB-02	Structure and constituents	Optical microscopy; SEM/EDX
145	SIYAB-04	Structure and constituents	Optical microscopy; SEM/EDX
146	SIYAB-05	Structure and constituents	Optical microscopy; SEM/EDX
147	SIYAB-06	Structure and constituents	Optical microscopy; SEM/EDX
148	SIYAB-07a	Structure and constituents	Optical microscopy; SEM/EDX
149	SIYAB-08	Structure and constituents	Optical microscopy; SEM/EDX
150	SIYAB-09	Structure and constituents	Optical microscopy; SEM/EDX
151	SIYAB-10	Structure and constituents	Optical microscopy; SEM/EDX
152	STA-01	Structure of layers	Optical microscopy
153	STA-02	Structure and constituents	Optical microscopy; SEM/EDX

No.	Sample	Questions	Methods
154	STA-04	Structure of layers	Optical microscopy
155	STA-06	Mortar constituents and qualities; structure of layers	Thin section; Optical microscopy
156	STA-06a	Mortar constituents	XRD; FT-IR
157	STA-06b	Mortar constituents	XRD; FT-IR
158	STA-07	Structure of layers	Optical microscopy
159	STA-08	Structure and constituents	Optical microscopy; SEM/EDX
160	STA-09	Structure and constituents	Optical microscopy; SEM/EDX
161	STA-10b	Structure and constituents	Optical microscopy; SEM/EDX
162	THE-01	Mortar constituents and qualities; structure of layers; if any pigments present	Thin section; Optical microscopy; SEM/EDX
163	THE-01a	Mortar constituents	XRD; FT-IR
164	THE-01b	Mortar constituents	XRD-FT-IR

8.2 X-ray Diffraction, X-ray Fluorescence, FT-IR Spectrometry and GC-MS Analysis

The following is a listing of the results of sample analysis by means of x-ray diffraction, x-ray fluorescence, FT-IR spectrometry and GC-MS spectrometry. The samples are listed in an ascending order. Table 15 provides the analysis of plaster samples, while Table 16 gives the analysis of samples from the original surface layers. Table 17 lists x-ray diffraction analysis results of samples from Wadi Sabrah. Underlined components represent the major minerals/elements, while those in brackets represent traces.

Table 15: Analysis of samples for plaster constituents.

Sample no.	XRD	FT-IR
235-15	anhydrite (50%); gypsum (24%); calcite (24%); (quartz (2%))	
235-19	quartz (90%); calcite (5%); anhydrite (3%); (Gypsum (<1%)); (kaolinite (<1%)); (bassanite: $CaSO_4.0.5H_2O$ (<1%))	
524-01a	quartz; calcite	calcite; quartz
633-14	anhydrite; quartz; gypsum; (kaolinite : $Al_2Si_2O_5(OH)_4$); (bassanite); (whevellite : $CaC_2O_4{\cdot}H_2O$)	
826-01	quartz; calcite; kaolinite; (ferroan dolomite: Ca(Mg, Fe) $(CO_3)_2$)	
826-05	quartz; calcite; dolomite	calcite; quartz; silicates; gypsum
826-22	quartz; calcite; kaolinite	
826-42	quartz; calcite; ferroan dolomite; (kaolinite); (K-feldspar)	
PGT-25a	calcite (59%); dolomite (12%); quartz (19%); (albite (<1%))	
PGT-25b	quartz (75%); calcite (20%); (dolomite (<4%)); (kaolinite (<1%))	
PGT-36	quartz; gypsum; calcite; magnetite	quartz; calcite
STA-06a	quartz; gypsum; calcite	gypsum; calcite; silicates
STA-06b	quartz; (calcite)	calcite; quartz
STA-07a	quartz (62%); gypsum (26%); (calcite (5%)); (kaolinite (3%)); (dolomite (4%))	
STA-07b	calcite (54%); quartz (37%); (dolomite (7%)); (kaolinite (1%)); (gypsum (1%))	
THE-01a	quartz; calcite	quartz; calcite; silicates
THE-01b	calcite; quartz; gypsum; haematite; halite	calcite;aragonite; quartz; silicates; nitrates

Table 16. Analysis of samples for pigment and organic binder identification.

Sample no.	XRD	XRF	FT-IR	GC-MS
235-19 red	quartz; gypsum; calcite; (anhydrite); (whevellite); (kaolinite)	Ca; Fe; S; (Si)		
423-01 blue	cuprorivaite; gypsum; quartz; cristobalite: SiO_2		gypsum; nitrates	Tragacanth; 0.95 correlation
633-13 red	Quartz; whevellite; weddellite:$C_2CaO_4{\cdot}2.25H_2O$; gypsum; bassanite; kaolinite; haematite(?)	Ca;Fe;S;(K); (Si);(P);(Ba)	Gypsum; nitrate; Paraffin wax – in toluene extract	Wax; siloxanes on GCMS
786-14 yellow	quartz; calcite; gypsum; kaolinite; whevellite; weddellite; (haematite)	Ca;S;(Fe);(K); (Al)		
849-11 red	quartz; kaolinite; gypsum; calcite; weddellite; (haematite); (whevellite)	Ca;S;(Fe);(Si)		
849-13 green	anhydrite; gypsum; whevellite; atacamite; malachite (?); (quartz)			
849-16 grey	anhydrite; gypsum; whevellite; (quartz)			Beeswax on M-station; siloxanes and wax on GC-MS
849-21 grey			nitrates; calcite; gypsum	
PGT-03a red/rosy	calcite; ferroan dolomite; quartz; (gypsum); (kaolonite); (haematite); (jurbanite: $AlSO_4OH{*}5H_2O$?)			
PGT-03b1 green	calcite; quartz; ferroan dolomite; cuprorivaite; kaolinite; (muscovite: $KAl_2Si_3AlO_{10}(OH)_2$)			
PGT-03b2 white	calcite; ferroan dolomite; quartz; kaolinite; (gypsum); (K-feldspar)			
PGT-03c red above green	calcite; quartz; gypsum; cuprorivaite; kaolinite; haematite; (muscovite)			
PGT-25 yellow	calcite; dolomite; quartz; halite; kaolinite; allophan: $Al_2O_3{\cdot}2SiO_2{\cdot}3H_2O$; goethite ($FeO(OH)$)	Ca; (Cl); (Fe)		
PGT-31a green	Chlorapatite: $Ca_5Cl(PO_4)_3$; gypsum; malachite; atacamite; cuprorivaite; quartz; kaolinite		gypsum; nitrates	
SIY-13 blue	calcite; cuprorivaite; quartz; gypsum; ferroan dolomite; (weddellite); (kaolinite)	Ca;(Cu);(Fe); (K)(Si)		
SIY-16 yellow	calcite;dolomite; quartz; (kaolinite); (weddellite)			
SIY-17 black	calcite; kaolinite; weddellite; (quartz); (dolomite); (muscovite)			
SIY-18 blue	cuprorivaite; calcite; quartz; (ferroan dolomite)			

Table 17. Analysis of samples from Wadi Sabrah

Sample no.	XRD
SAB1-02a green	quartz; glauconite
SAB2-01 brown	quartz; sodium iron oxide silicate ($NaFeO_2$.1Si0.05/$NaFeO_2$ 0.05SiO_2)(?); haematite
SAB4-01 green	quartz; malachite; atacamite
SAB5-01 green	quartz; atacamite; malachite
SAB6-01 yellow	quartz; goethite; kaolinite
SAB6-06 yellow	quartz; kaolinite; haematite/goethite(?)

8.3 Binder/Aggregate Ratio Measurement and Grain Size Distribution

Table 18 provides the results of the analyses for binder/aggregates ratio measurements (by volume) of the samples analyzed, after transforming the mass ratio calculated into a volume ratio (B/A(VP)). Table 19 provides the data on the non-mortar samples subjected to similar tests. These are followed by the relative grain size distribution (GSD) for each sample analyzed.

Binder/Aggregate Ratio Measurements

Table 18. Binder/Aggregate Ratio Measurements.

Sample No.	Input (g)	Result (g)	Binder (g)	B_O (M%)	B_M (M%)	o	m	B/A (VP)
786-11	19.556	10.745	8.811	37.76	45.05	1: 1.7	1: 1.2	1: 0.7
826-01	16.969	10.26	6.709	32.61	39.54	1: 2.1	1: 1.5	1: 0.8
826-02	8.379	5.263	3.116	30.46	37.19	1: 2.3	1: 1.7	1: 0.9
826-03	25.655	16.662	8.993	28.54	35.05	1: 2.5	1: 1.9	1: 1.0
826-04	18.085	9.045	9.04	42.52	49.99	1: 1.4	1: 1.0	1: 0.6
826-05	43.729	21.316	22.413	43.76	51.25	1: 1.3	1: 1.0	1: 0.5
SIY-01a	7.19	4.985	2.205	24.66	30.67	1: 3.1	1: 2.3	1: 1.3
SIY-01b	6.726	5.062	1.664	19.57	24.74	1: 4.1	1: 3.0	1: 1.7
SIY-02	7.884	5.519	2.365	24.08	30.00	1: 3.2	1: 2.3	1: 1.3
SIY-03	12.311	8.54	3.771	24.63	30.63	1: 3.1	1: 2.3	1: 1.3

Table 19. Analysis Results for Samples PGT-08 and Sand 4

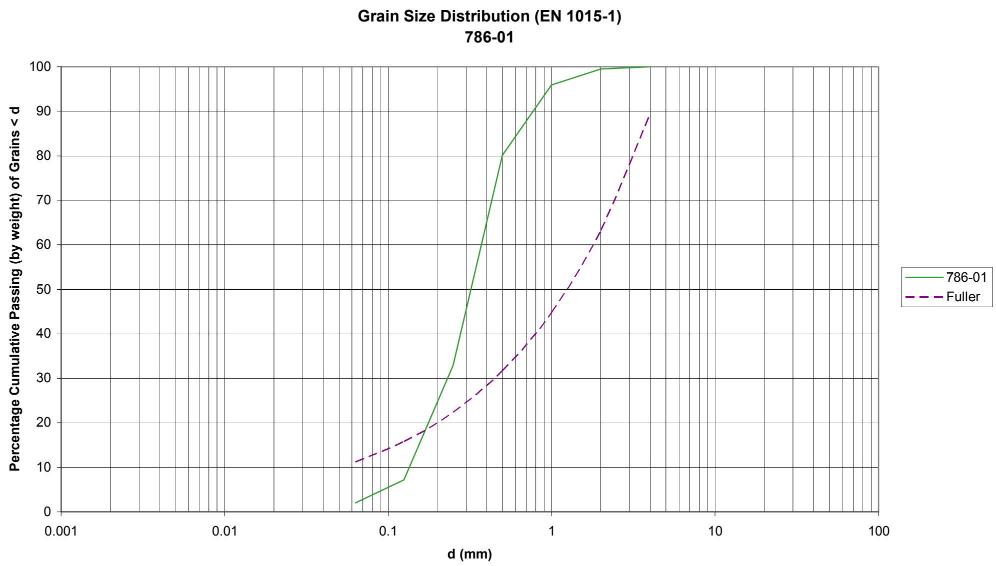
Sample No.	Input (g)	Result Weight (g)	Dissolved Weight (g)	Result
PGT-08	4.647	0.512	4.135	Pure lime
Sand 4	10.336	8.288	2.048	Calcite=19.8%

Grain Size Distribution of Samples

786-11
Diameter size of biggest grain = 5 mm

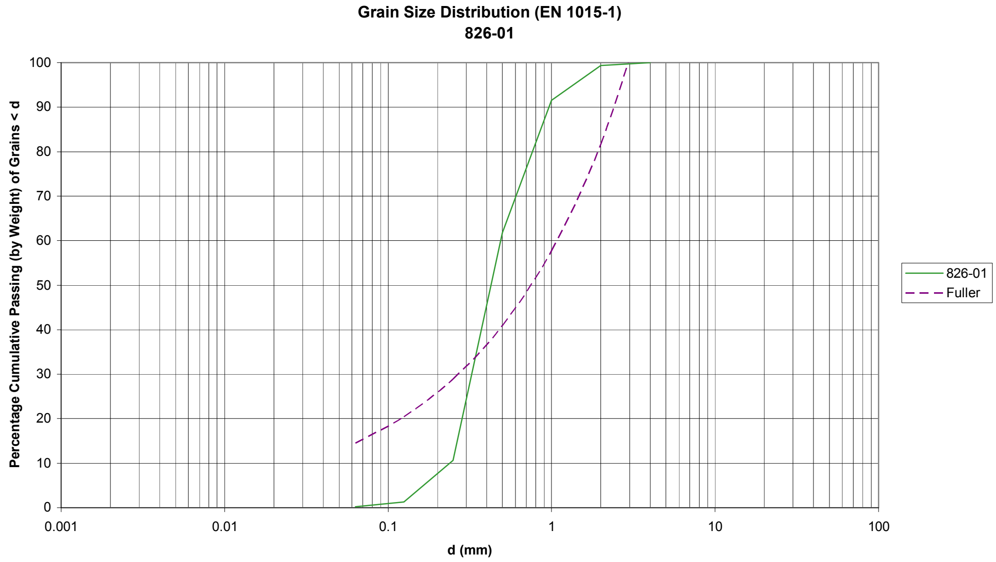
Sieve Size	Percentage Aggregate
0	2.00
63μm	5.20
125μm	25.67
250μm	47.26
500μm	15.78
1000μm	3.62
2000μm	0.47
4000μm	0

Sieve Size	Cumulative Passing Aggregate
0	
< 63μm	2.00
< 125μm	7.20
< 250μm	32.87
< 500μm	80.13
< 1000μm	95.91
< 2000μm	99.53
< 4000μm	100



826-01
Diameter size of biggest grain = 3 mm

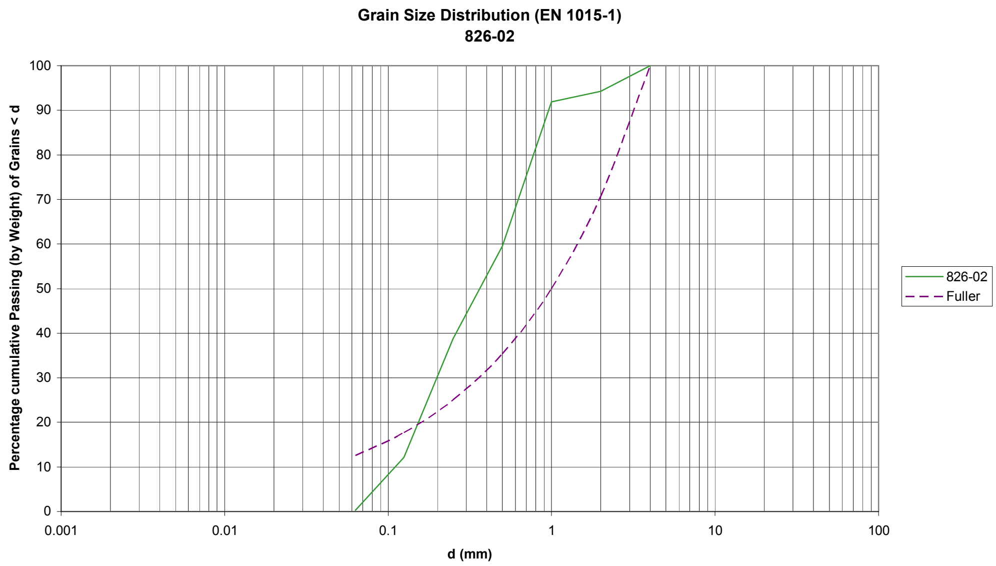
Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	0.21		0	
63µm	1.10		< 63µm	0.21
125µm	9.35		< 125µm	1.31
250µm	51.10		< 250µm	10.66
500µm	29.78		< 500µm	61.76
1000µm	7.84		< 1000µm	91.54
2000µm	0.62		< 2000µm	99.38
4000µm	0		< 4000µm	100



826-02
Diameter size of biggest grain = 4 mm

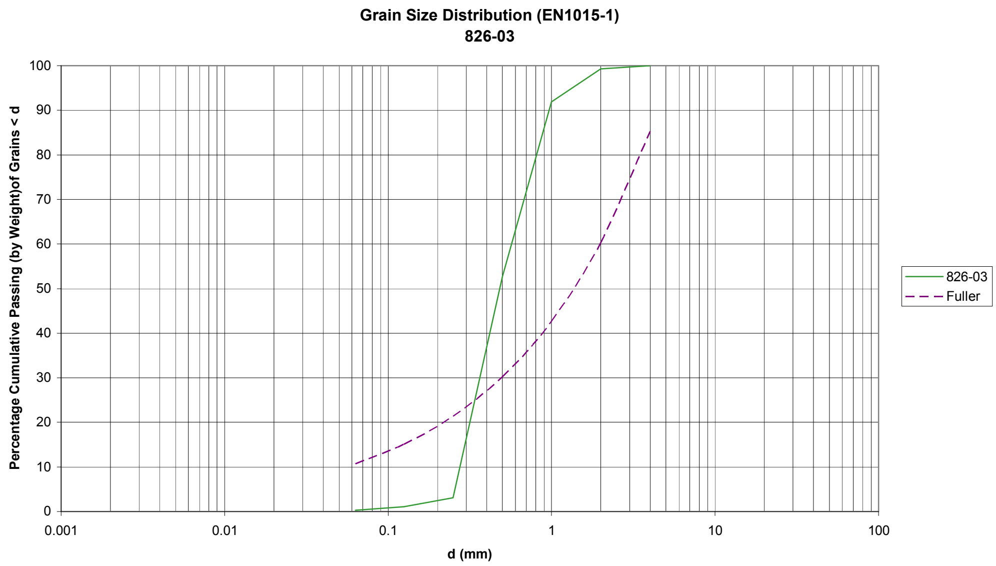
Sieve Size	Percentage Aggregate
0	0.29
63μm	11.81
125μm	26.67
250μm	20.76
500μm	32.38
1000μm	2.38
2000μm	5.71
4000μm	0

Sieve Size	Cumulative Passing Aggregate
0	
< 63μm	0.29
< 125μm	12.10
< 250μm	38.77
< 500μm	59.53
< 1000μm	91.91
< 2000μm	94.29
< 4000μm	100



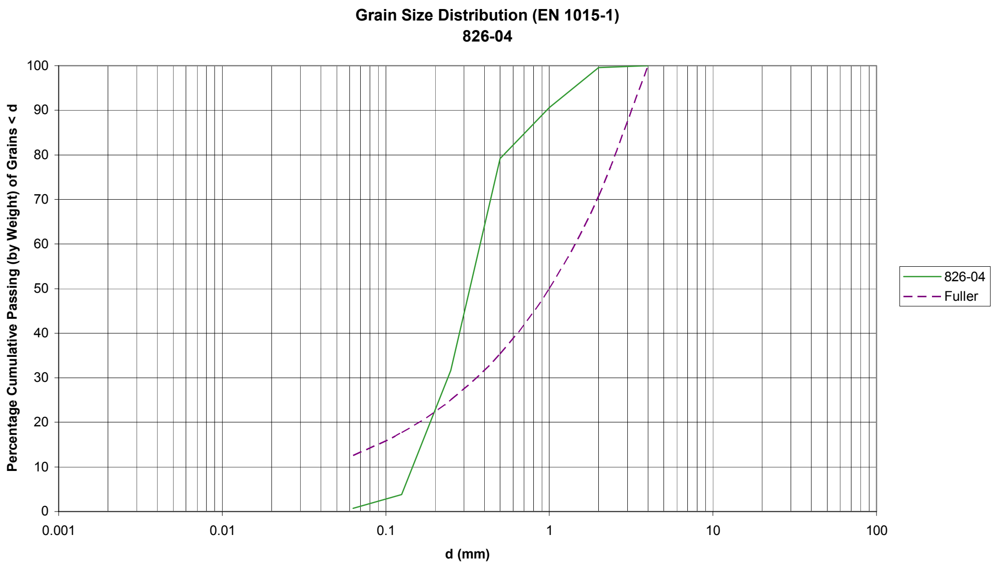
826-03
Diameter size of biggest grain = 5.5 mm

Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	0.32		0	
63μm	0.78		< 63μm	0.32
125μm	1.97		< 125μm	1.10
250μm	49.58		< 250μm	3.07
500μm	39.27		< 500μm	52.65
1000μm	7.34		< 1000μm	91.92
2000μm	0.74		< 2000μm	99.26
4000μm	0		< 4000μm	100



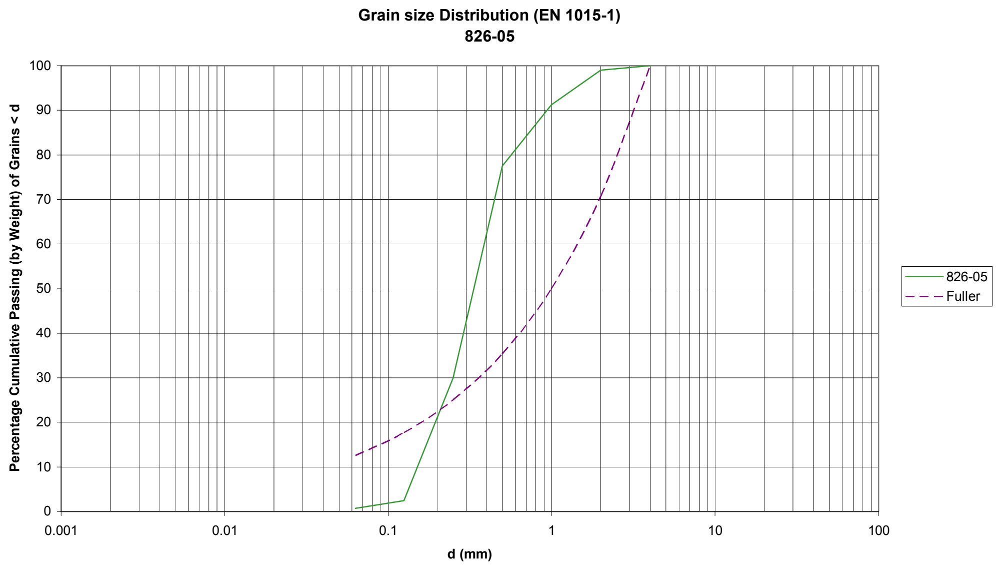
826-04
Diameter size of biggest grain = 4 mm

Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	0.74		0	
63μm	3.10		< 63μm	0.74
125μm	27.80		< 125μm	3.84
250μm	47.55		< 250μm	31.64
500μm	11.39		< 500μm	79.19
1000μm	8.98		< 1000μm	90.58
2000μm	0.44		< 2000μm	99.56
4000μm	0		< 4000μm	100



826-05
Diameter size of biggest grain = 4 mm

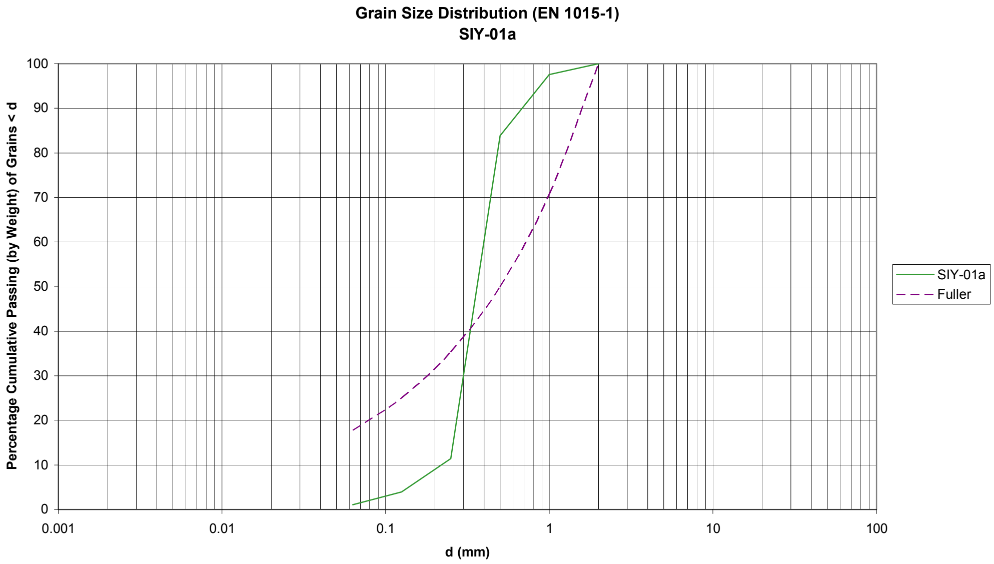
Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	0.70		0	
63μm	1.72		< 63μm	0.70
125μm	27.52		< 125μm	2.42
250μm	47.59		< 250μm	29.94
500μm	13.68		< 500μm	77.53
1000μm	7.79		< 1000μm	91.21
2000μm	1.00		< 2000μm	99.00
4000μm	0		< 4000μm	100



SIY-01a
Diameter size of biggest grain = 2 mm

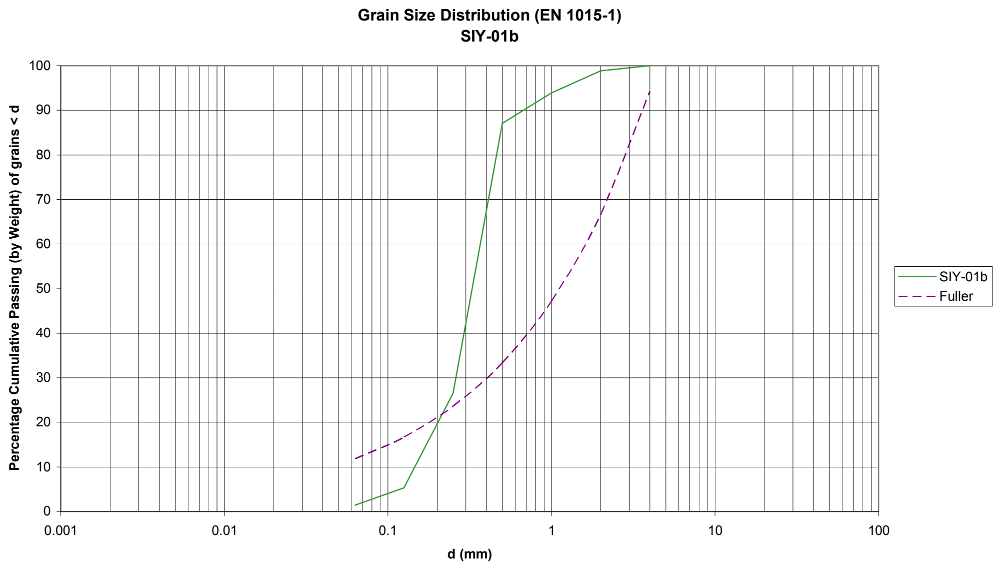
Sieve Size	Percentage Aggregate
0	1.11
63μm	2.82
125μm	7.49
250μm	72.46
500μm	13.66
1000μm	2.46
2000μm	0
4000μm	0

Sieve Size	Cumulative Passing Aggregate
0	
< 63μm	1.11
< 125μm	3.93
< 250μm	11.42
< 500μm	83.88
< 1000μm	97.54
< 2000μm	100
< 4000μm	100



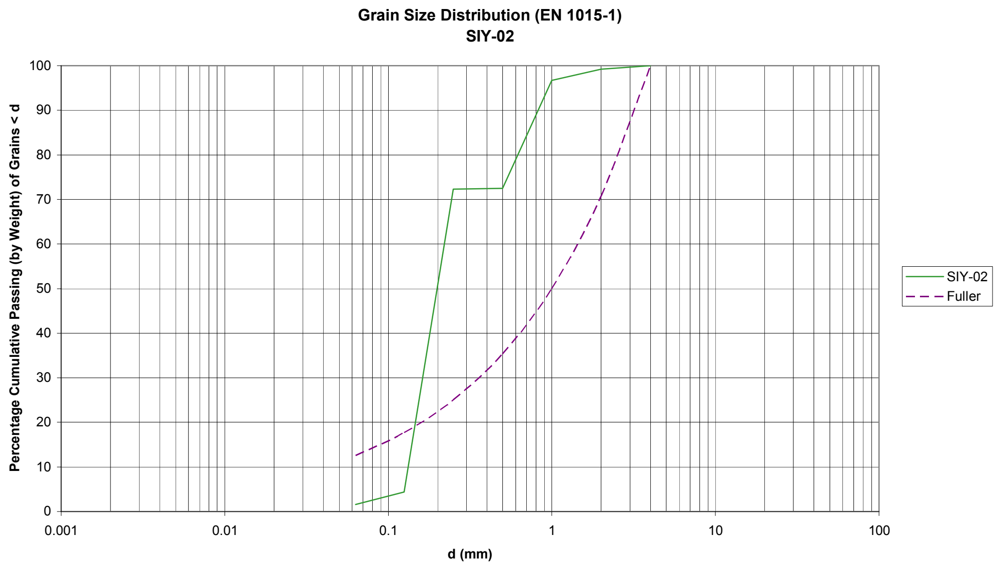
SIY-01b
Diameter size of biggest grain = 4.5 mm

Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	1.46		0	
63μm	3.82		< 63μm	1.46
125μm	21.24		< 125μm	5.28
250μm	60.56		< 250μm	26.52
500μm	6.85		< 500μm	87.08
1000μm	4.95		< 1000μm	93.93
2000μm	1.12		< 2000μm	98.88
4000μm	0		< 4000μm	100



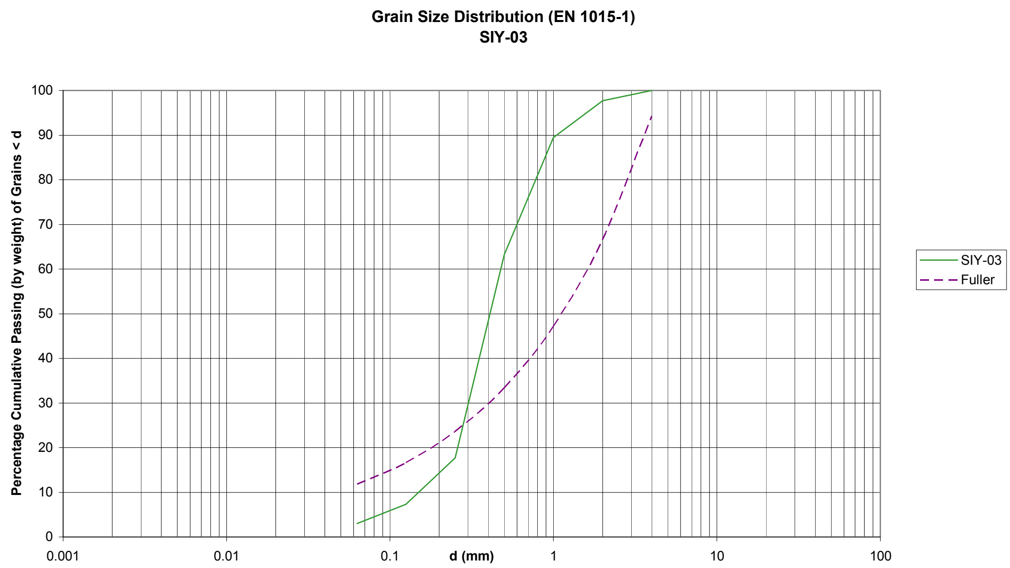
SIY-02
Diameter size of biggest grain = 4 mm

Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	1.56		0	
63μm	2.84		< 63μm	1.56
125μm	67.89		< 125μm	4.4
250μm	0.18		< 250μm	72.29
500μm	24.24		< 500μm	72.47
1000μm	2.47		< 1000μm	96.71
2000μm	0.82		< 2000μm	99.18
4000μm	0		< 4000μm	100



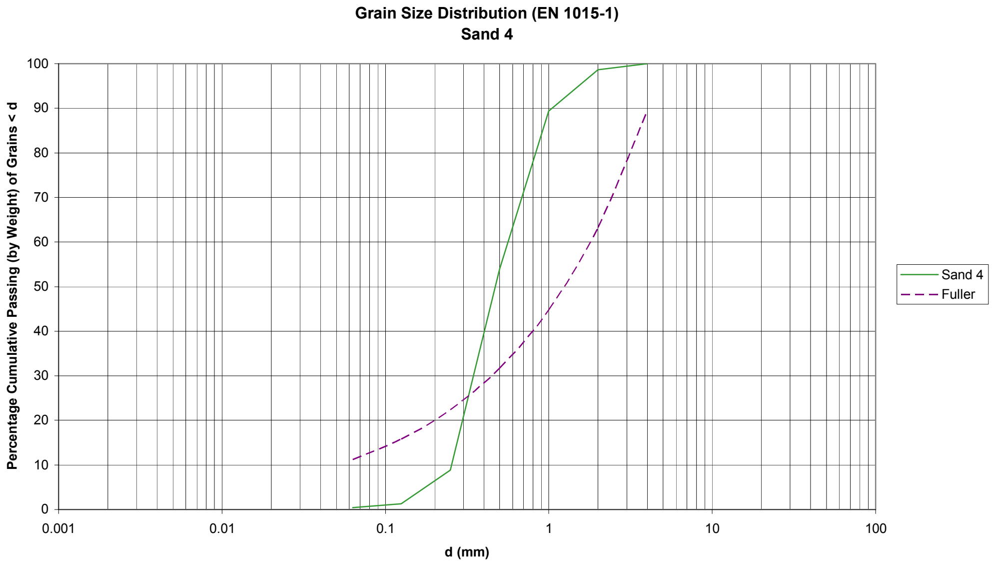
SIY-03
Diameter size of biggest grain = 4.5 mm

Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	3.04		0	
63μm	4.26		< 63μm	3.04
125μm	10.40		< 125μm	7.30
250μm	45.56		< 250μm	17.70
500μm	26.17		< 500μm	63.26
1000μm	8.29		< 1000μm	89.43
2000μm	2.28		< 2000μm	97.72
4000μm	0		< 4000μm	100



Sand 4
Diameter size of biggest grain = 4 mm

Sieve Size	Percentage Aggregate		Sieve Size	Cumulative Passing Aggregate
0	0.44		0	
63μm	0.82		< 63μm	0.44
125μm	7.57		< 125μm	1.26
250μm	45.10		< 250μm	8.83
500μm	35.45		< 500μm	53.93
1000μm	9.29		< 1000μm	89.38
2000μm	1.33		< 2000μm	98.67
4000μm	0		< 4000μm	100

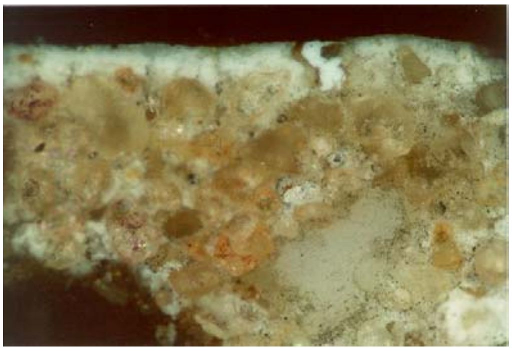


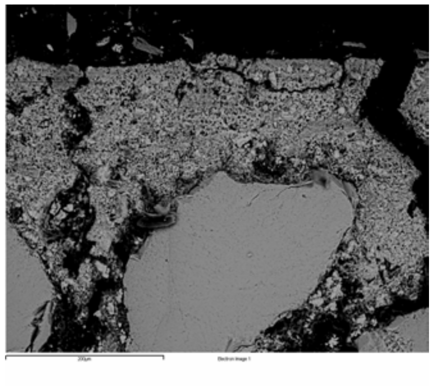
8.4 Microscopic Observations, Scanning Electron Microscopy and Thin Sections

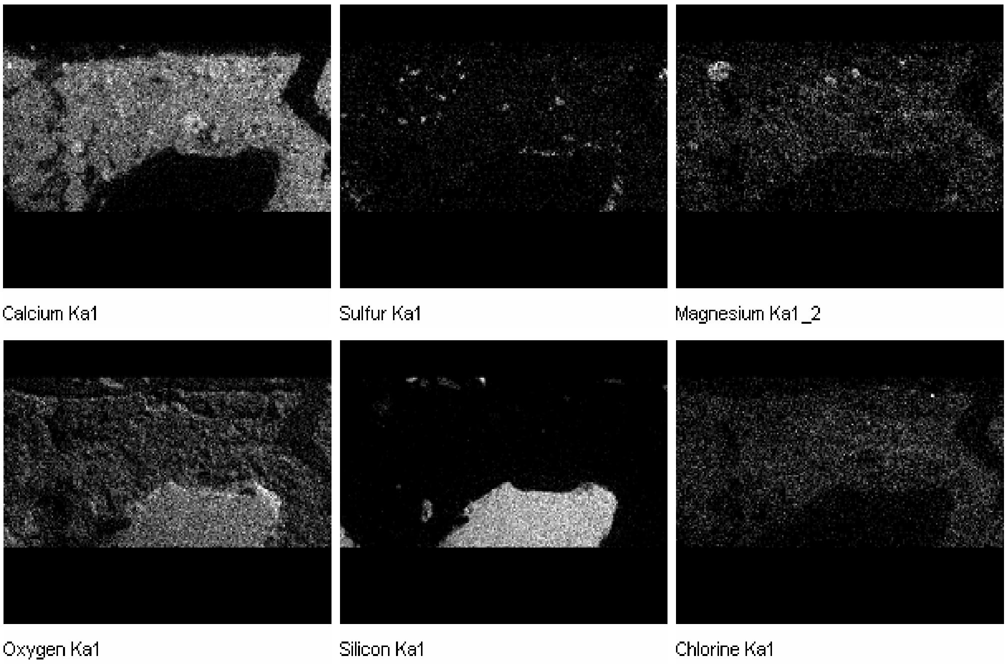
This section includes the results of microscopic observations and scanning electron microscopy (with EDX) analyses. Each sample is accompanied by at least a microscopic photograph and a table of its description, analysis results and interpretation. The sequence of samples is in an ascending order. Major elements are underlined, and trace elements are in brackets.

Thin sections were prepared for some of the samples. These were analyzed under the polarising microscope in transmitted light. The results of this analysis are also presented in this section.

Sample no.: 235-10

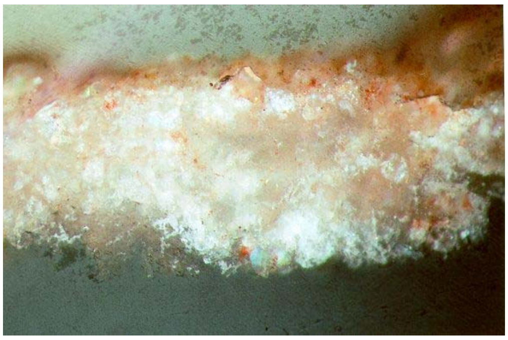






Layer	Thickness	Description	Elements	Interpretation
1	Up to 100µm	Red	Si; (Mg)	Siliceous dust
2	10µm	Grey	Ca; Cl; Si; Mg; (S)	Lime paint; possibly magnesium or calcium chloride; possibly lime sinter
3	100-200µm	White	Ca; S; Cl; Mg; Si	Same layer as 2; some ($CaSO_4$) particles (might be anhydrite) at the border with 4; possibly magnesium or calcium chloride
4	>2000µm	Beige with a lot of aggregates	Ca; Si; Mg; S; Cl; (Al);	Lime plaster (dolomitic) with siliceous aggregates, as support layer; possibly magnesium or calcium chloride

Sample no.: 235-11



Layer	Thickness	Description	Elements	Interpretation
1	Up to 100µm	Red particles	Si; S; Ca; Al; (Cl); (K); (Mg)	Possibly remains of red layer
2	200-500µm	White, some red particles		Gypsum with quartz aggregates

Sample no.: 235-12

Layer	Thickness	Description	Elements	Interpretation
1	50µm	Red and some yellow particles		
2	30-70µm	White		
3	>1500µm	White/pinkish with aggregates		

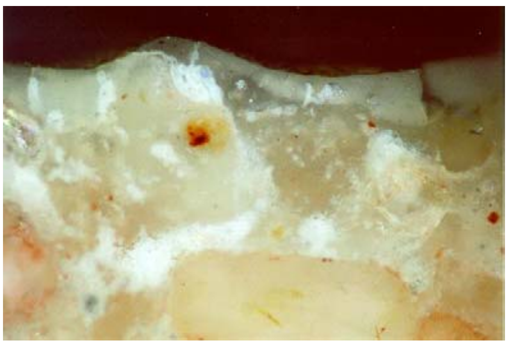
Sample no.: 235-13

Layer	Thickness	Description	Elements	Interpretation
1		Red particles		
2	30-100μm	White/greyish		
3	>550μm	White; some aggregates		

Sample no.: 235-14

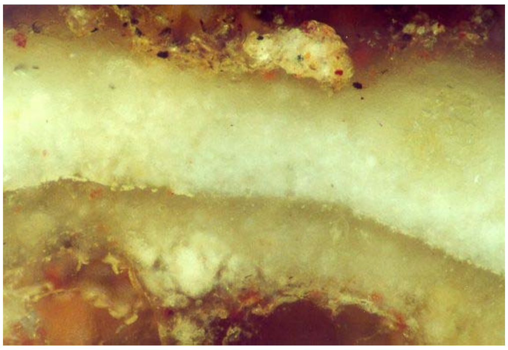
Layer	Thickness	Description	Elements	Interpretation
1	Up to 50μm	Soot		
2	>350μm	White with vertical cracks		

Sample no.: 235-16



Layer	Thickness	Description	Elements	Interpretation
1	50-150μm	White with vertical cracks		
2	>800μm	White/pink with some aggregates		

Sample no.: 235-17

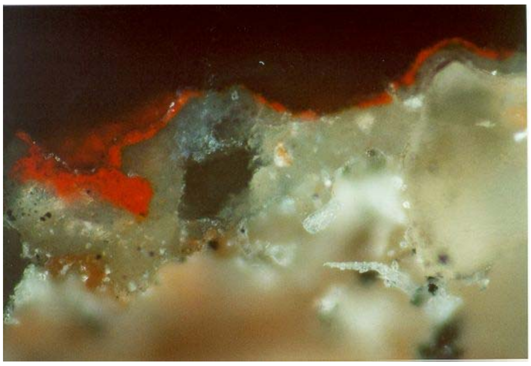


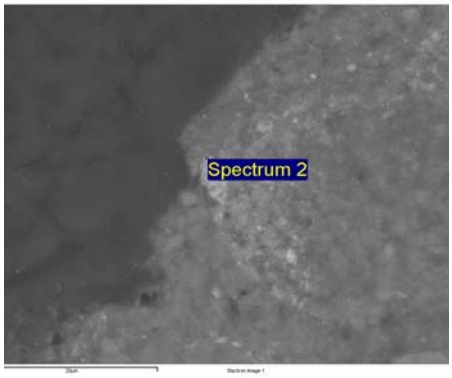
Layer	Thickness	Description	Elements	Interpretation
1		Black, red, yellow and white particles	Si; Ca; S; Al; (Fe); (K); (Mg)	Dust, soot and particles of red ochre
2	60-250µm	White	Ca; S; (Si); (Mg)	Gyosum
3	50-170µm	White/beige	Ca; S; (Si); (Al)	Gypsum
4	>500µm	Red stone backing	Si	Sandstone

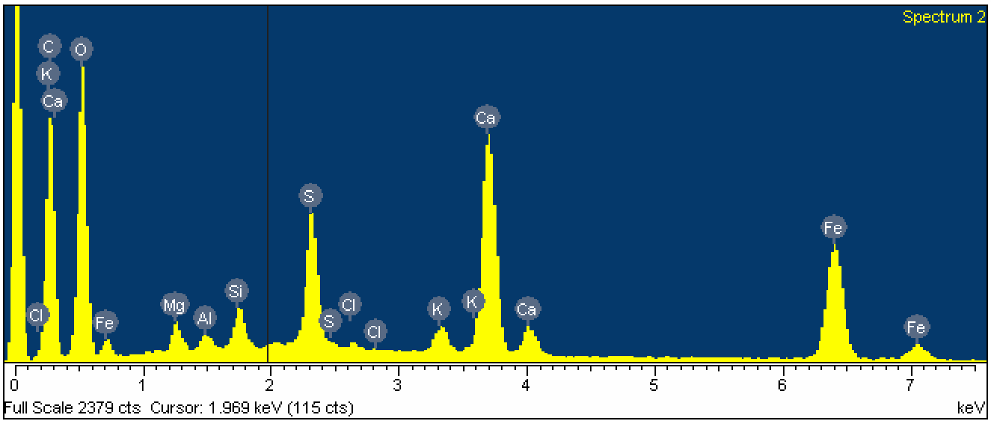
Sample no.: 235-18

Layer	Thickness	Description	Elements	Interpretation
1	40-1200µm	Black and brown particles; red layer remains	Si; Ca; S; Al; (K); (Fe); (Mg)	Red ochre layer remains; soot and dust
2	40-400µm	White	Ca; S; (Si); (Mg); (Cl)	Gypsum
3	520-1200µm	Red stone backing	Si	Sandstone

Sample no.: 235-19

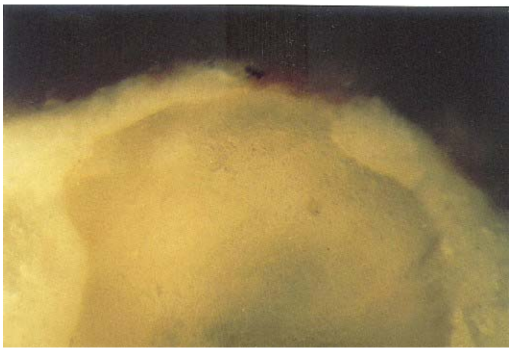






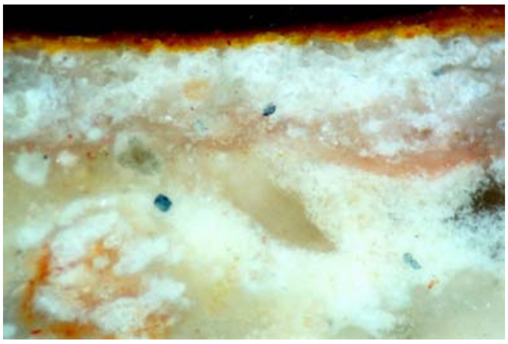
Layer	Thickness	Description	Elements	Interpretation
1	20-80µm	Red	Ca; S; Si; Al; Mg; (Fe); (P)	Red ochre with gypsum
2	40-200µm	White	Ca; S; Si; Mg; (Al); (Cl); (P)	Gypsum plaster as preparation layer
3	>3000µm	Beige with aggregates	Si; Ca; S; (Mg); (Cl); (Al)	Gypsum plaster with a lot of quartz aggregates

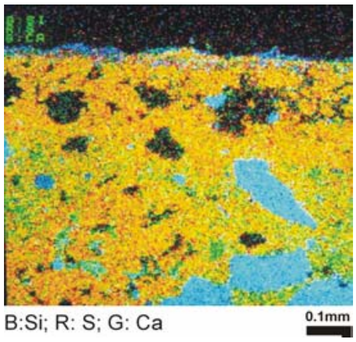
Sample no.: 244-10



Layer	Thickness	Description	Elements	Interpretation
1	10-30µm	Red with few black particles		
2	>6000µm	White plaster with many aggregates		

Sample no.: 403-10



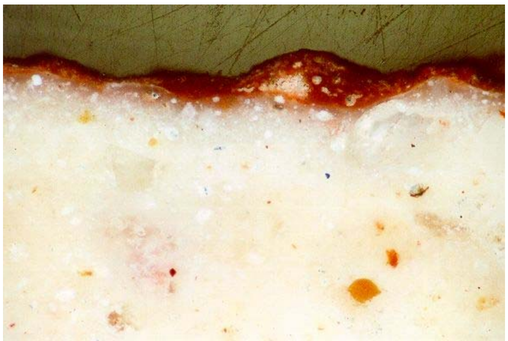


Layer	Thickness	Description	Elements	Interpretation
1	5-50µm	Red	Ca; Si; S; (Al); (Fe); (K)	Dust layer (with Si and Al present)
2	15µm	Yellow		Pigment is yellow ochre, mixed with gypsum; there is also haematite (Fe_2O_3)
3	90-150µm	White plaster layer		Gypsum plaster
4	15-20µm	Thin pinkish/white		Gypsum plaster with some lime – can be considered as part of layer 5
5	>200µ	White/pinkish plaster layer with aggregates		Gypsum/lime plaster (gypsum predominant), with angular quartz grains

Sample no.: 403-10a

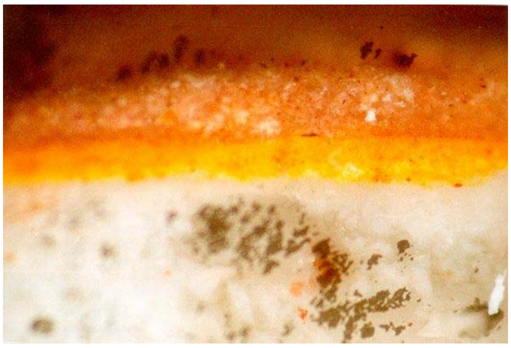
Layer	Thickness	Description	Elements	Interpretation
1	Up to 50µm	Red		
2	6µm	Dark red line		
3	15µm	Yellow with vertical cracks		
4	180µm	White plaster layer		
5	>600µm	White/beige with aggregates		

Sample no.: 403-12



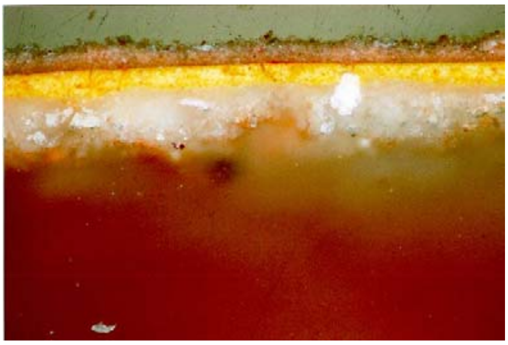
Layer	Thickness	Description	Elements	Interpretation
1	30-550µm	Red		
2	>1500µm	White/pinkish, with some red and yellow particles		

Sample no.: 403-13a



Layer	Thickness	Description	Elements	Interpretation
1	60-110µm	Red/whitish	<u>Ca</u>; <u>S</u>; <u>Si</u>; Al; (Fe); (K); (Mg); (Cl); (P)	Red ochre with gypsum
2	2-5µm	Fine red /blackish line in some parts		
3	50µm	Yellow	<u>Ca</u>; <u>S</u>; Si; Al; (Fe); (K); (P); (Mg)	Yellow ochre with gypsum
4	>800µm	White with some aggregates	<u>Ca</u>; <u>S</u>; Si; (Al);(Mg)	Gypsum

Sample no.: 403-13c

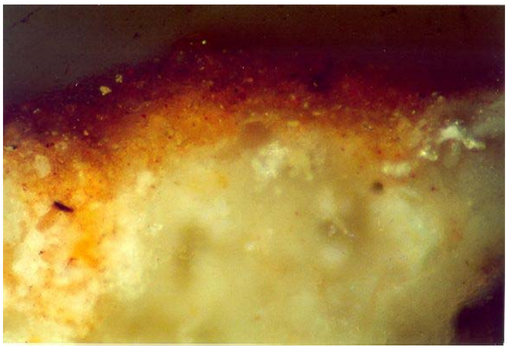


Layer	Thickness	Description	Elements	Interpretation
1	50-150µm	Reddish/white		
2	2-5µm	Dark red fine line in some parts		
3	10-150µm	Yellow with vertical cracks		
4	200-2000µm	white		

Sample no.: 403-14

Layer	Thickness	Description	Elements	Interpretation
1	Up to 850µm	Reddish white layer	<u>Ca</u>; <u>S</u>; Si; Al; (Mg); (K); (Fe)	Gypsum with dust
2	50-100µm	Red		
3	>3000µm	White/pinkish plaster with aggregates	<u>Si</u>; <u>Ca</u>; S; (Al); (Cl); (Mg); (Na)	Gypsum

Sample no.: 403-15

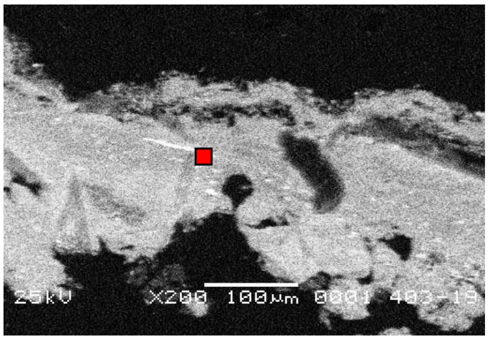


Layer	Thickness	Description	Elements	Interpretation
1	30-300µm	Red		
2	>600µm	White with aggregates		

Sample no.: 403-17

Layer	Thickness	Description	Elements	Interpretation
1	100-230µm	Reddish/white		
2	5-20µm	Fine dark red line in some places		
3	70-100µm	Yellow		
4	270-360µm	Red		
5	>300µm	White		

Sample no.: 403-19



Layer	Thickness	Description	Elements	Interpretation
1	20-200μm	Reddish white	Si; Ca; S; Al; (Mg); (K); (Fe)	Gypsum with dust
2	3μm	Dark red line in some parts (marked above)	Ca; S; Au; (Ag); (Fe); (Si); (Al)	Remains of gold leaf that has impurities of silver and iron
3	30-50μm	Yellow	Ca; S; Si; Al; Fe; K	Yellow ochre with gypsum
4	>250μm	White	Ca; S; (P)	Gypsum

Sample no.: 403-20b

Layer	Thickness	Description	Elements	Interpretation
1	20-100μm	Red		
2	>3500μm	white		

Sample no.: 403-22

Layer	Thickness	Description	Elements	Interpretation
1	20-100µm	Red	Ca; S; Si; Al; (K); (Fe)	Dust with gypsum
2	>2500µm	White/beige with aggregates at the top is some yellow	Ca; S ; Si; Al; (Fe); (K); (Mg)	Gypsum/lime plaster with quartz aggregates and some red ochre penetration at the top

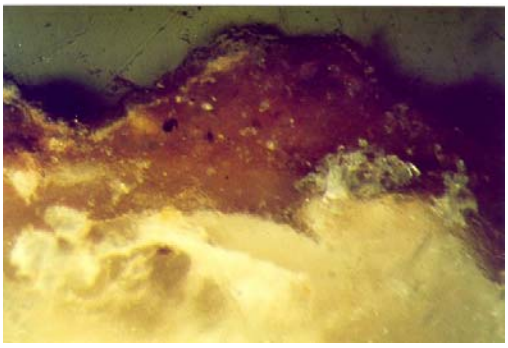
Sample no.: 403-25

Layer	Thickness	Description	Elements	Interpretation
1	10-30µm	Yellow	Si; Ca; S; Al; Fe; K; (Mg)	Yellow ochre with gypsum
2	30-150µm	White	Ca; S; (Si); (Al); (Mg); (K)	Gypsum
3	30-250µm	Red and has dark and bright particles	Bright particles: Si; Al; Au; Fe; Mg; Ca; (K); (S) ; Dark particles: Ca ; S ; Si ; Al ; (Fe) ; (K) ; (Ti) ; (Mg)	Dust penetration through the gypsum plaster (layers 2 and 4 were originally a single layer); the bright particles are remains of gold leaf that would have once covered the surface (gold contains some iron); dark particles probably titano-magnetite
4	>1200µm	White	Ca; S	Gypsum

Sample no.: 403-26b

Layer	Thickness	Description	Elements	Interpretation
1	30-120µm	Red		
2	70-100µm	Dark yellow with a lot of red particles		
3	>2750µm	White		

Sample no.: 403-34



Layer	Thickness	Description	Elements	Interpretation
1	50-200µm	Red	Ca; S; Si; Al; (K); (Cl); (Mg)	Dust with gypsum
2	>1500µm	White	Ca; S; Si	Gypsum

Sample no.: 403-37b

Layer	Thickness	Description	Elements	Interpretation
1	50-750µm	Red with red and black particles	Ca; S; Si; Al; (P); (K); (Fe)	Some dust with gypsum and perhaps apatite
2	>200µm	White	Ca; S; Si	Gypsum

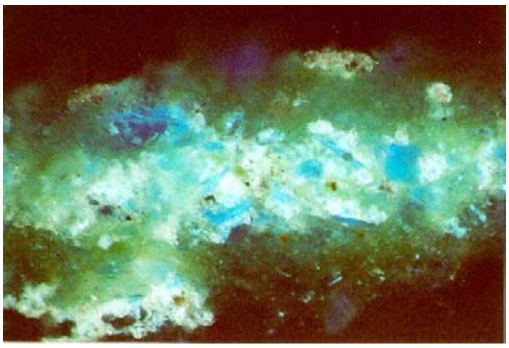
Sample no.: 403-39

Layer	Thickness	Description	Elements	Interpretation
1	40-300µm	Red	Ca; Si; S; Al; (K); (Fe)	Gypsum with some dust
2		White/beige with aggregates; green biogenic layer running through	At top: Ca; S; (Si); (Al); (Mg) At bottom: Ca; Si; (Al)	Lime mortar with aggregates of rounded and angular quartz grains; top with gypsum/anhydrite probably related to paint layer

Sample no.: 403-47

Layer	Thickness	Description	Elements	Interpretation
1	70-1000µm	Red	Si; Ca; Al; Fe; K; (Mg)	Lime mixed with red ochre
2	>4000µm	White with aggregates	Ca; S; Si	Gypsum/anhydrite plaster with aggregates

Sample no.: 423-01

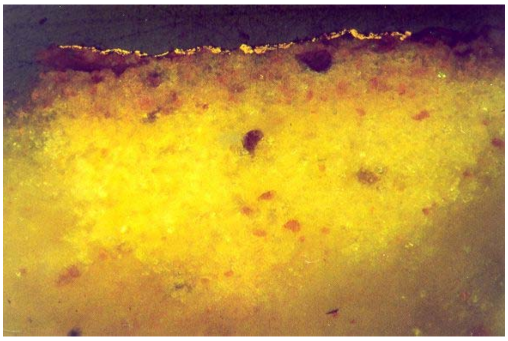


Layer	Thickness	Description	Elements	Interpretation
1	80-350µm	Blue particles mixed with white in between	Blue: Si; Ca; Cu; (Al) White : Si ; Ca; S; Cu; (Al); (Mg) Some grains: Si	Particles of cuprorivaite mixed with gypsum and quartz sand

Sample no.: 423-02

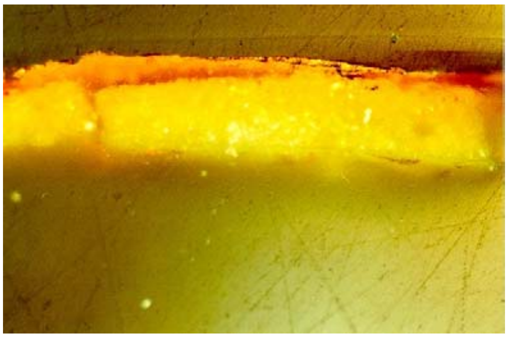
Layer	Thickness	Description	Elements	Interpretation
1	100-580µm	Black	Ca; S; Si; (K); (P); (Al)	Carbon black and gypsum
2	300-650µm	Beige/creamy	Ca; S; (Si); (P); (Al); (Mg); (Na)	Gypsum
3		White	Ca; S; (Si);(P); (Al); (Na)	
4		Grey	Ca; S; (Si); (P)	

Sample no.: 423-03



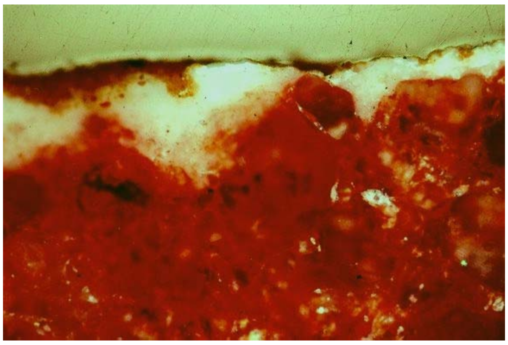
Layer	Thickness	Description	Elements	Interpretation
1	1-10µm	Gold	Au; Fe; (Si); (Al)	Gold leaf is enriched with iron
2	70-100µm	Yellow	Ca; S; Fe; Al; (P); (Si); (Mg); (na); (Cl); the very top part: Fe; (Ca); (S); (Si)	Gypsum that has iron leaching from the gold above; also has NaCl salt; this layer is originally part of layer 3
3	>300µm	White with some yellow	Ca; S; (Al); (Si); (P); (Fe); (Mg)	Gypsum with some residue from the iron

Sample no.: 423-03a



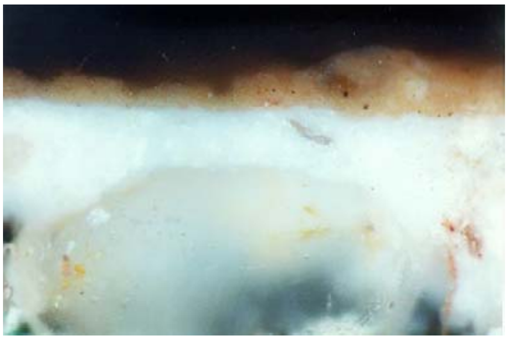
Layer	Thickness	Description	Elements	Interpretation
1	5-40μm	Gold; the bottom part is of a grey metal colour	Top: Au Middle: Au; (Fe) Bottom: Fe; Au; (Ca); (Al)	Gold leaf at the topmost is of pure gold; at the bottom is iron rich
2	90-180μm	Yellow of various gradations from dark to light	Ca; S; Fe; (Si); (Al)	Gypsum that has iron leaching from the gold above; this layer is originally part of layer 3
3	>140μm	White	Ca; S; (P); (Si); (Al); (K); (Mg); (Cl); (Na)	Gypsum with some salts - NaCl

Sample no.: 435-01



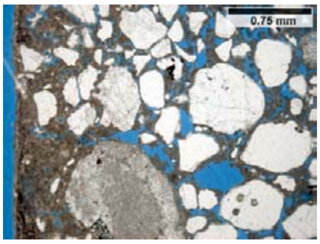
Layer	Thickness	Description	Elements	Interpretation
1	10-170μm	Red/orange		
2	50-350μm	White		
3	>3000μm	Red stone backing		

Sample no.: 524-01a

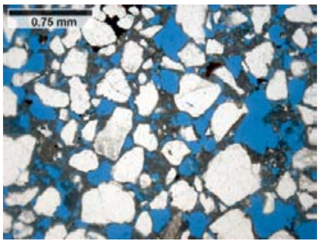


Layer	Thickness	Description	Elements	Interpretation
1	30-200µm	Dull yellow	Ca; Si; Al; (Fe); (K); (P); (Mg)	Yellow ochre with lime
2	>2600µm	White/pale pink plaster with aggregates; green biogenic growth within the plaster	Ca; Si; (P); (Al); (Mg)	Lime plaster with calcite and quartz aggregates of various sizes

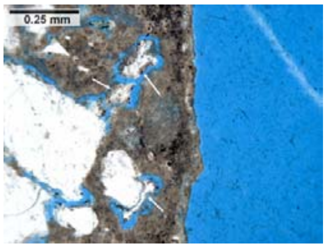
Thin Section



Sample with compacted surface layer



Texture of non-compacted layer with many air voids



Precipitation of a phase with low birefringence in pores

Components

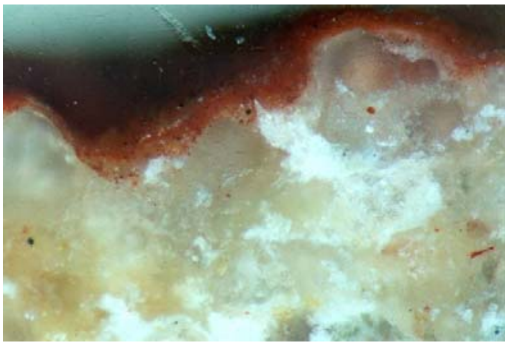
Aggregate: quartz; carbonate; rock fragments (polycrystalline quartz and sandstone); binder: carbonate; compacted surface has precipitation with low birefringence (gypsum or apatite).

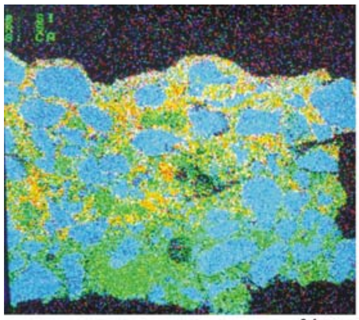
Texture

Orientation: Sample with original surface consists of two layers with no distinctive boundaries; the surface layer (0.5-1 mm) exhibiting a crust (50 µm) and a compacted layer underneath.

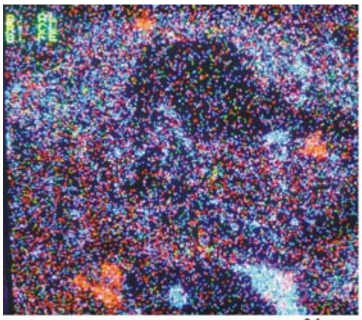
Structure: The only difference between the two layers is the binder content; in the surface layer it is higher and the amount of air voids are lower; aggregates are sub-rounded to rounded, smaller aggregates are more subangular; moderately sorted; moderate amount of binder in the lower layer with a very high amount of air voids and interstitial pores; direct grain-grain contacts are rare.

Sample no.: 633-10

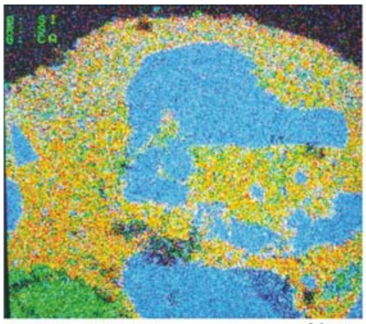




B: Si; R: S; G:Ca 0.4mm



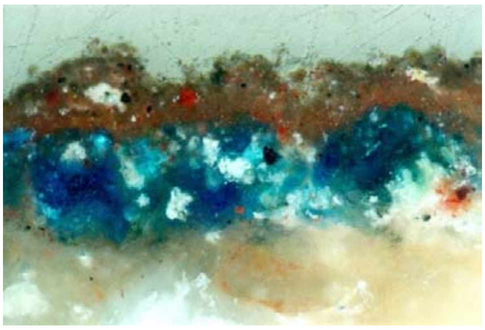
B: Al; R: Cl; G:Fe 0.1 mm

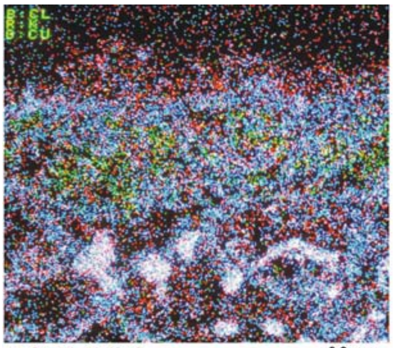


B: Si; R: S; G:Ca 0.1 mm

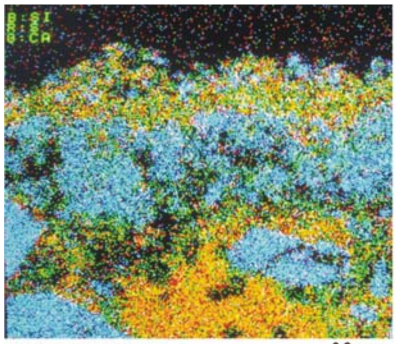
Layer	Thickness	Description	Elements	Interpretation
1	10-40μm	Red	Si; Ca; S; (Al); (Cl); (K); (Mg); (Na); (Fe)	Very siliceous layer of gypsum with Al, and very little iron (Fe); if present, the pigment comes from red ochre; there is sodium chloride salt (NaCl) in the plaster and the surface
2	150-250μm	White plaster with aggregates		Gypsum plaster with rounded quartz grains
3	300-450μm	White plaster with aggregates		Lime/gypsum plaster with rounded quartz grains
4	>450μm	White plaster with aggregates		Lime plaster with rounded quartz grains

Sample no.: 633-11





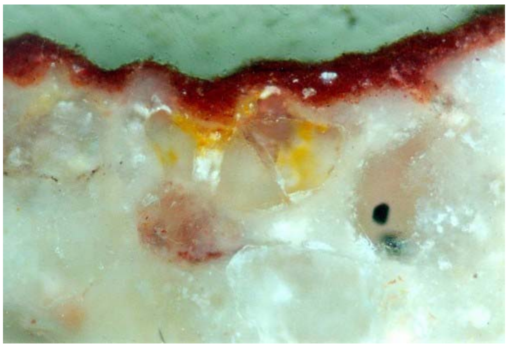
B: Cl; R: K; G:Cu 0.2 mm

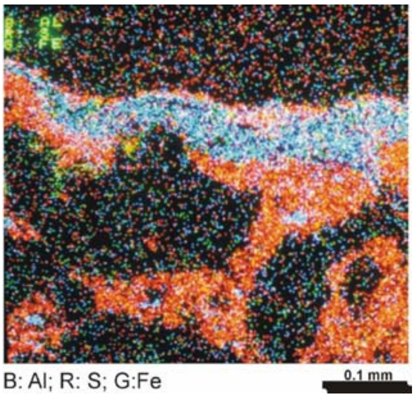


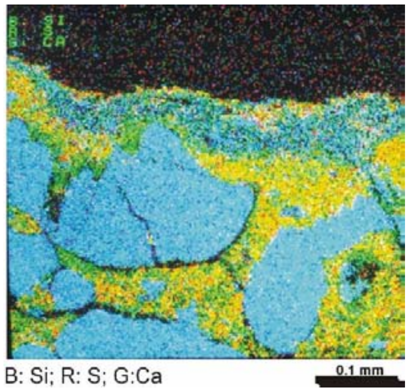
B: Si; R: S; G:Ca 0.2 mm

Layer	Thickness	Description	Elements	Interpretation
1	50-100µm	Red	Si, Ca; Cl; S; (K); (Al); (Mg); (Cu)	Layer made of gypsum with haematite particles; there is an iron particle that contains titanium (Ti)
2	50-120µm	Blue		The blue pigment is Egyptian Blue (cuprorivaite)
3	›350µm	White plaster layer with aggregates		Gypsum palster with some quartz aggregates; there is potassium chloride (KCl) in the mortar

Sample no.: 633-12

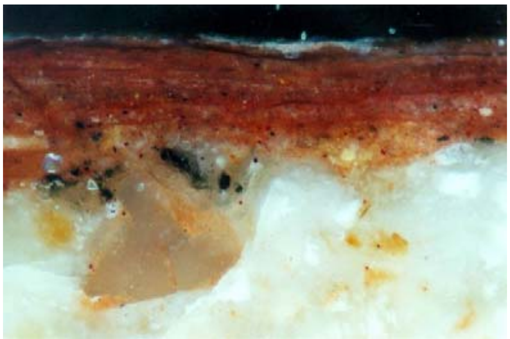






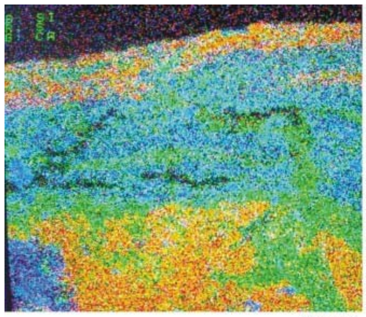
Layer	Thickness	Description	Elements	Interpretation
1	30µm	Red	Si; Ca; S; (Cl); (Al); (K); (Fe); (Mg)	Red ochre was used as the pigment for the red layer; there is a thin gypsum layer at the top
2	>350µ	White with aggregates		Gypsum plaster with a lot of quartz angular and rounded aggregates; some potassium chloride (KCl) in the gypsum plaster

Sample no.: 633-13



B: Al; R: P; G:Ca 0.05 mm

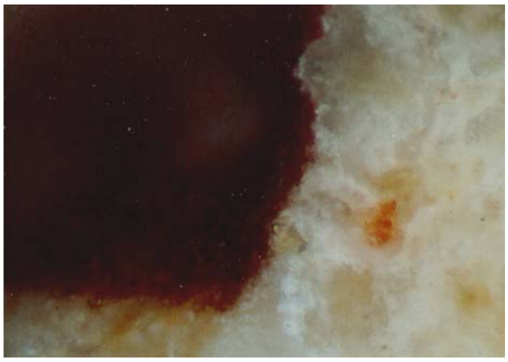
B:Mg; R: K; G:Fe 0.05 mm



B:Si; R: S; G:K 0.05 mm

Layer	Thickness	Description	Elements		Interpretation
1	10-30µm	Red	Ca; Si; S; Mg; (Al); (P); (K); (Cl); (Fe)		A gypsum layer
2	50-210µ	Red multi-layered		Si; Ca; P; Al; Mg; (Cl); (K); Fe	Alternating layers of calcite and Fe (and associated with Al, Si, K) on the one hand, and phosphorus with magnesium on the other (P and Mg); it might be possible that the paint layer is composed of a lake consisting of Al(OH$_3$) and possibly madder
3	1800µm	White plaster layer with aggregates			Gypsum plaster containing some small quartz aggregates
4	>500µm	Stone backing		Ca; Mg; Si	Dolomite stone, with calcite grains bound by siliceous material

Sample no.: 633-14

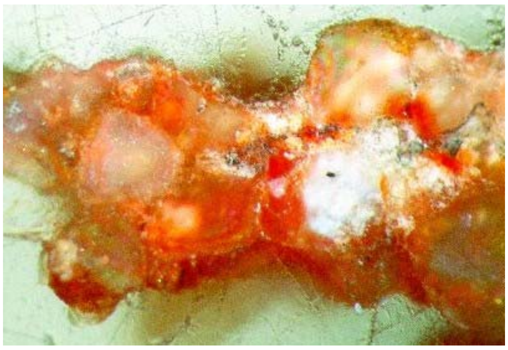


Layer	Thickness	Description	Elements	Interpretation
1	20-70µm	Red	Ca; S; Si; (Al); (K); (Fe);(Mg)	On the right part of the section, the layer contains some red ochre, indicating that it was a red painted layer
2	340-2400µm	White plaster layer with few aggregates		Gypsum plaster with some few small quartz grains; to the right, the gypsum appears different with calcite aggregates including a dolomite grain. The potassium (K) present is associated with silicon (Si) and aluminium (Al), indicating feldspar grains
3	>250µm	Stone backing		Façade sandstone

Sample no.: 633-16

Layer	Thickness	Description	Elements		Interpretation
1	70-120µm	Red	Si; S; Ca; (Al); (Fe); (K)		Dust layer; very siliceous and containing gypsum
2	10µm	Yellow			Yellow ochre used as the pigment
3	300-400µm	White with very few aggregate			Gypsum plaster with very few quartz aggregates
4	max.15µm	Remnants of a metal with some blue particles		Fe	Remains of iron sheet that had been directly fixed to the sandstone
5	>250m	Stone backing			Façade sandstone

Sample no.: 633-17

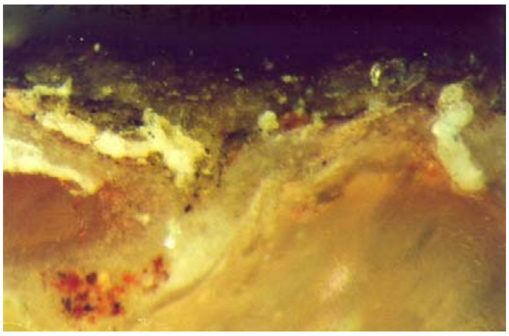


Layer	Thickness	Description	Elements	Interpretation
1	10-60µm	Red	Si; (Al); (Ca); (Fe); (P); (S)	Red ochre with some lime
2	>300µm	Stone backing		Façade sandstone made of rounded quartz grains. There is probably apatite ($Ca_3(PO_4)_2$) (white), that is present as part of the sandstone or as a penetration

Sample no.: 633-18

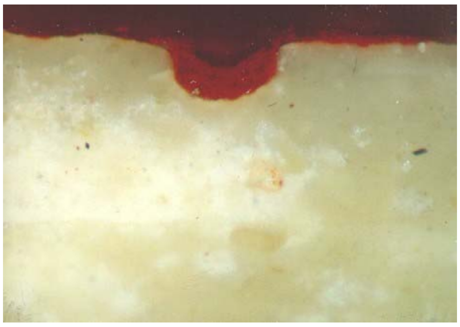
Layer	Thickness	Description	Elements	Interpretation
1	5-25µm	Red	Si; (Ca); (S); (K); (Fe)	Pigment used is red ochre; gypsum is present in layer
2	15-85µm	White plaster layer with no aggregates		Lime plaster layer that appears to have covered the sandstone in order to even out the surface
3	>500µm	Stone backing		Façade sandstone made of angular and rounded quartz grains, bonded by calcite

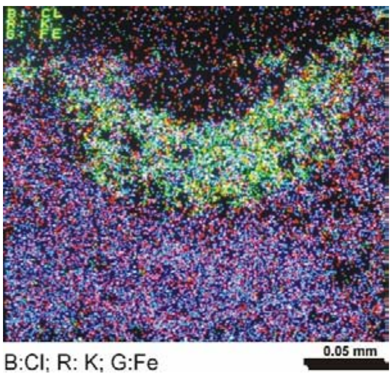
Sample no.: 786-10



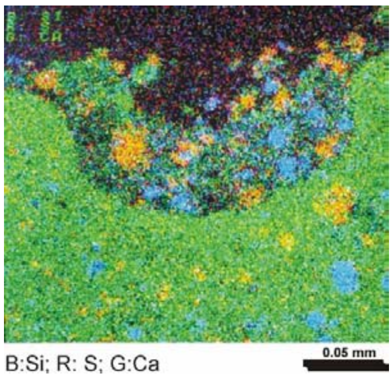
Layer	Thickness	Description	Elements	Interpretation
1	20-40µm	Black		
2	60-80µm	White/greyish		
3	>600µm	White/beige with aggregates		

Sample no.: 786-12





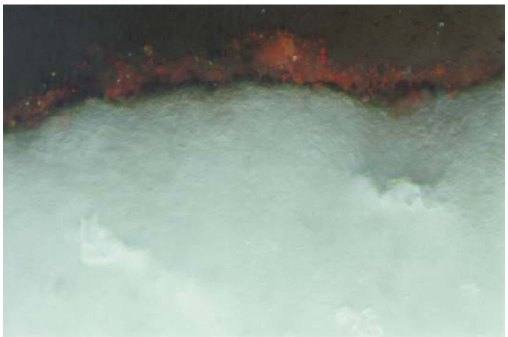
B:Cl; R: K; G:Fe



B:Si; R: S; G:Ca

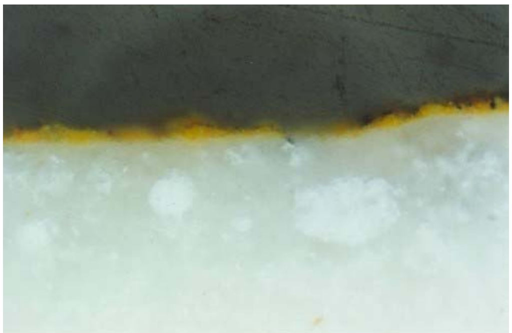
Layer	Thickness	Description	Elements	Interpretation
1	15µm (65µm in the cavity filling)	Red	Ca; Si; (Cl); (K); (S); (Al); (Mg); (Fe)	Haematite was used for the red pigment; the layer also contains gypsum and potassium chloride
2	450-600µm	Fine white plaster		Lime plaster
3	›1000µm	Coarse white plaster		Lime plaster with a lot of angular quartz aggregates

Sample no.: 786-13



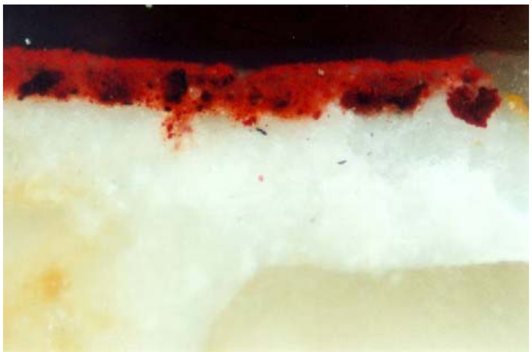
Layer	Thickness	Description	Elements	Interpretation
1	4-10µm	Red particles on the surface		
2	10-30µm	Black soot		
3	260-350µm	Fine white plaster		
4	›500µm	Coarse white/beige plaster		

Sample no.: 786-14



Layer	Thickness	Description	Elements	Interpretation
1		Soot (not a continuous layer)		
2	5-10µm	Remnants of a bright yellow layer	Ca; Fe; Al; Si; (S); (Cl); (K)	Yellow ochre was used as pigment, with gypsum
3	250-350µm	Fine white plaster		Lime plaster layer with no aggregates
4	>400µm	Coarse white plaster		Lime plaster with many quartz aggregates

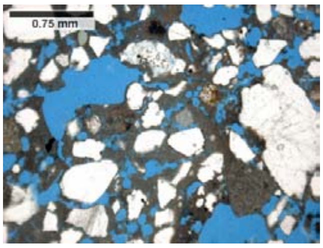
Sample no.: 826-02



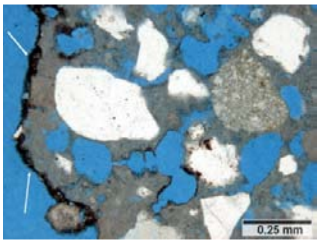
Layer	Thickness	Description	Elements	Interpretation
1	20-30µm	dark red uniform layer	Fe; Si	Pigment is haematite (Fe_2O_3)
2	>100µm	white	Ca; Si	Plaster layer has lime as the binder with quartz aggregates

Sample no.: 826-05

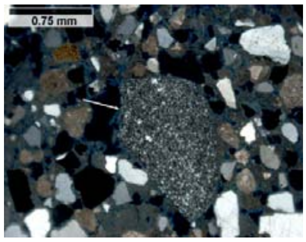
Thin Section



Texture of plaster with many air voids



Dust deposits on the original surface of the plaster (arrows)



Rounded chert aggregate

Components

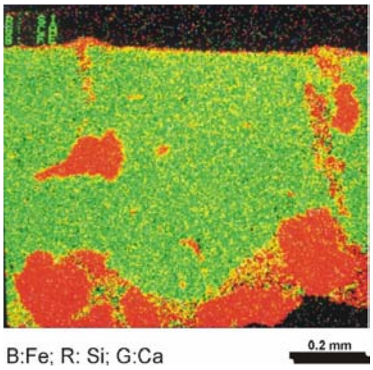
Aggregates: quartz; rock fragments (chert, limestone, sandstone, polycrystalline quartz); carbonate; opaque phases; binder: carbonate, lumps of lime.

Texture

Orientation: original surface layer indicated by a thin dust layer; surface not completely flat but undulated; particles are randomly oriented.

Structure: Aggregate subangular to rounded; moderately sorted; moderate amount of binder; few direct grain-grain contacts; high amount of air voids of various sizes, low amount of interstitial pores.

Sample no.: 826-22

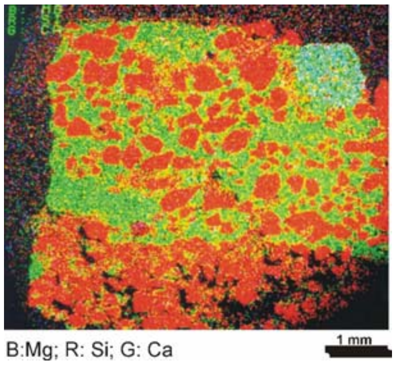


Layer	Thickness	Description	Elements	Interpretation
1	10-40µm	Red layer on the surface	Ca; Si;(Al);(Mg); (K); (S); (Cl)	Surface dust, since there are no elements that would indicate a red pigment such as iron (Fe)
2	500-800µm	White with very few aggregates; penetration of the surface is of red colour		The plaster is of very "fat" lime, with dust penetrating the vertical cracks that must have occurred due to shrinkage of the plaster
3	>350µm	Stone backing		Façade sandstone with rounded quartz grains

Sample no.: 826-24

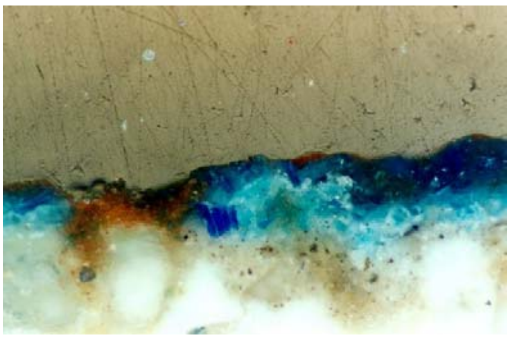
Layer	Thickness	Description	Elements	Interpretation
1	250-600µm	White/beige with some brownish dust penetration in a top horizontal crack	Ca; Si; (Al); (S)	Lime plaster with no aggregates; dust particles penetrated
2	>450µ	Stone backing		Sandstone with mainly angular quartz grains

Sample no.: 826-31



Layer	Thickness	Description	Elements	Interpretation
1	60-90µm	Dark red; uniform	Ca; Si; Fe; (Mg); (S); (Ba); (Zn)	Haematite with lime; with a top surface layer of barium sulphate (5µm); some of it inside the layer
2	3500-4300µ	White with aggregates	Ca; Si; Mg	Lime plaster with a lot of angular and quartz aggregates of varying sizes; to the right of the sample is a dolomite aggregate
3	125-300µm	White with vertical cracks going through the layer and a horizontal crack separating it from layer 2	Ca; (Mg)	Plaster layer of “fat” lime with cracks due to shrinkage caused by the fat lime

Sample no.: 826-32



<table>
<tr><th>Layer</th><th>Thickness</th><th>Description</th><th colspan="2">Elements</th><th>Interpretation</th></tr>
<tr><td>1</td><td>5-15µm</td><td>Red that looks like dust</td><td rowspan="4">Si; Ca; (Cu); (Mg); (Al)</td><td rowspan="2">Si; Ca; Cu</td><td>Dust layer on the surface</td></tr>
<tr><td>2</td><td>75-100µm</td><td>Blue</td><td>The pigment used is Egyptian blue (cuprorivaite)</td></tr>
<tr><td>3</td><td>25-75µm</td><td>Black particles</td><td></td><td>Some kind of soot (carbon black)</td></tr>
<tr><td>4</td><td>>200µm</td><td>White with aggregates</td><td></td><td>Lime plaster with angular quartz aggregates</td></tr>
</table>

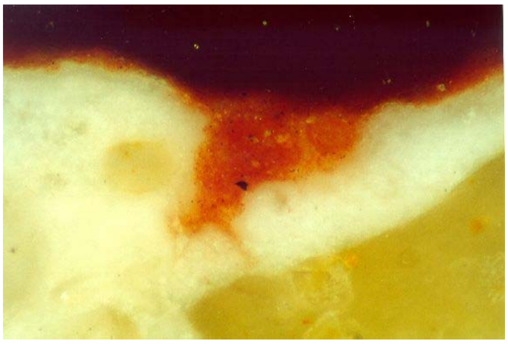
Sample no.: 826-33

Layer	Thickness	Description	Elements	Interpretation
1	20-50μm	Yellow	Ca; Si; (Al); (Mg); (Fe); (S); (Ba)	Yellow ochre with lime, and barium sulphate ($BaSO_4$) in the layer
2	>900μm	White with a lot of aggregates and biogenic growth		Lime plaster with rounded and angular quartz aggregates, and one dolomite grain evident

Sample no.: 826-46

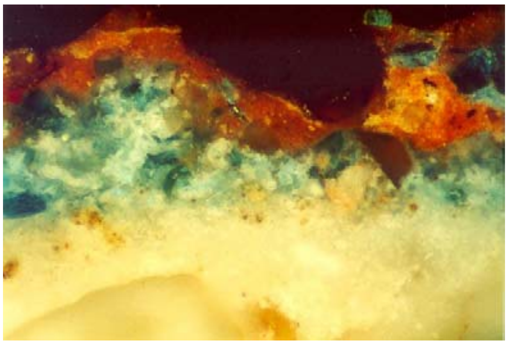
Layer	Thickness	Description	Elements	Interpretation
1	Up to 10μm	Red that appears like dust going through cracks in 2		
2	230-550μm	White with green biogenic growth		
3	90μm	Stone backing		

Sample no.: 826-48



Layer	Thickness	Description	Elements	Interpretation
1	Up to 100µm	Red	Si; Ca; Al; Mg; Ba; S; Fe; (K)	Red ochre with lime, there is barium sulphate
2	>2000µm	White with a lot of aggregates	Ca; Si; (S); (Al); (Mg)	Lime plaster

Sample no.: 826-53

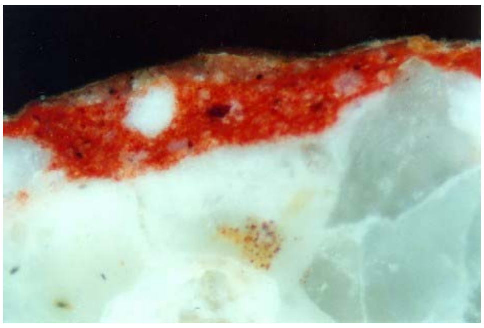


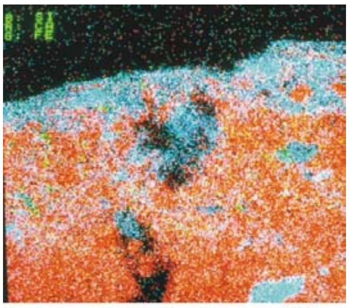
Layer	Thickness	Description	Elements	Interpretation
1	10-120µm	Red	Si; Ca; (Cu); (Fe); (K); (S); (Al); (Mg)	Dust mixed with some cuprorivaite from the layer below
2	50-150µm	Blue	Ca; Si; Cu	Cuprorivaite
3	30-120µm	White with brown/black particles	Ca; Si; Al; (Mg); (K)	Lime with a kind of soot (carbon black particles)
4	>200µm	White with aggregates	Ca; Si; (Mg); (Al)	Lime plaster with aggregates

Sample no.: 826-54

Layer	Thickness	Description	Elements	Interpretation
1	Up to 200µm	Black		
2	Up to 300µm	Red		
3	400-850µm	White with aggregates		
4	80-100µm	White		
5	>2000µm	Stone backing		

Sample no.: 827-02





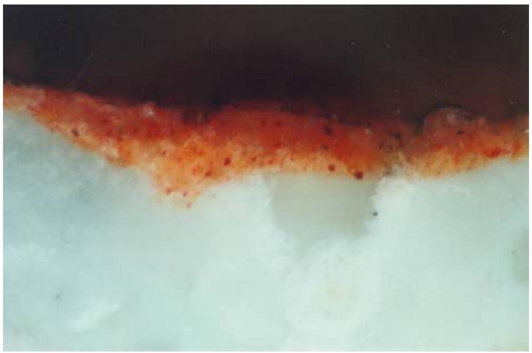
B:Si; R: Ca; G: Fe 0.02 mm

Layer	Thickness	Description	Elements	Interpretation
1	Varying thickness, max.50µm	Red; layer contains some aggregates	Si; Ca; (Al); (Mg); (S); (Ba); (Fe); (K)	Haematite was used as the pigment; the layer contains lime-seems like a fresco-and there is barium sulphate; dust is evident on the surface
2	>1000µm	White plaster with coarse aggregates		Lime plaster with quartz aggregates as the ground layer

Sample no.: 849-10

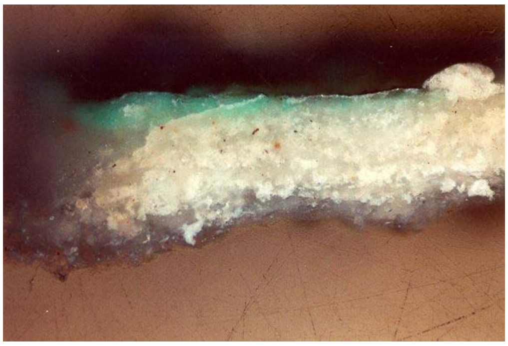
Layer	Thickness	Description	Elements	Interpretation
1	50-70µm	Black		
2	>150µm	White (with red particle)		

Sample no.: 849-11



Layer	Thickness	Description	Elements	Interpretation
1	5-10µm	Black	Si; Ca; (Al); (S); (P); (Fe)	Layer of soot and dust
2	10-60µm	Red with a darker hue as a top layer		Haematite was used as the pigment, mixed with gypsum/anhydrite; there is also some calcite and a grain of apatite ($Ca_3(PO_4)_2$),
3	35-65µm	White		Lime plaster with some gypsum/anhydrite, and without aggregates
4	>1500µm	White with aggregates		Lime plaster with angular quartz grains; the lime sinter layer is evident

Sample no.: 849-13

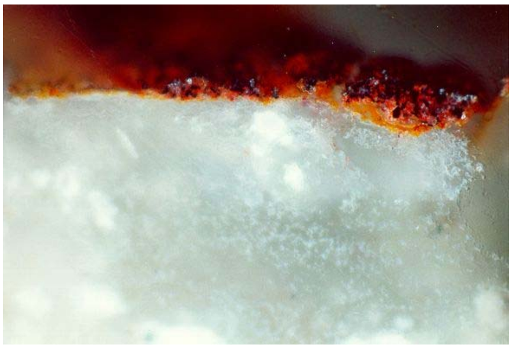


Layer	Thickness	Description	Elements	Interpretation
1	<10µm	Black		Soot
2	20-180µm	Light green	Ca; Cl; S; (Si); (Cu); (Al); (Mg); (P)	Atacamite with gypsum
3	>700µm	White plaster	Ca; S; (Si); (Al); (P)	Gypsum

Sample no.: 849-14

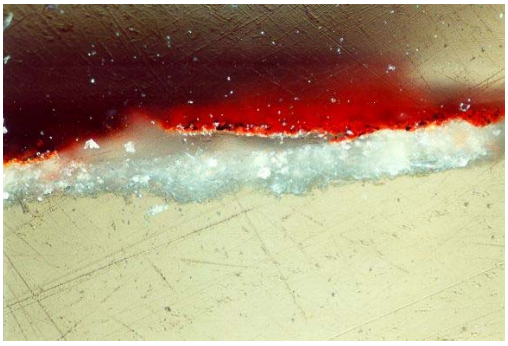
Layer	Thickness	Description	Elements	Interpretation
1	20µm	Yellow/brown		
2	220-300µm	White		
3	>300µm	Beige/white plaster with aggregates		

Sample no.: 849-14a



Layer	Thickness	Description	Elements	Interpretation
1	10-60µm	Red/orange mixed with black particles	Ca; S; Si; Fe; Al; (Mg); (K); (Cl); (Na)	Haematite and soot particles; NaCl salt in the layer
2	10-20µm	Bright yellow	Ca; S; (P); (Si); (Fe)	Possibly yellow ochre
3	200-300µm	White plaster	Ca; S; (P); (Si)	Gypsum/anhydrite
4	>1000µm	Beige/white plaster with aggregates	Ca; Si; (Al); (Cl); (Mg); (S)	Lime plaster with aggregates

Sample no.: 849-15



Layer	**Thickness**	**Description**	**Elements**	**Interpretation**
1	10-15µm	Red with black particles	Ca; S; Fe; (Si); (Al); (Mg); (P)	Haematite with gypsum
2	>150µm	White plaster	Ca; S; (Si); (Al); (P)	Gypsum

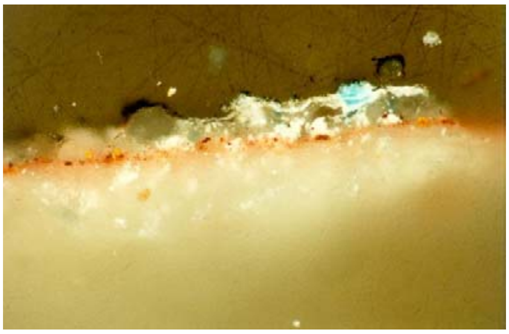
Sample no.: 849-16

Layer	Thickness	Description	Elements	Interpretation
1	10-20µm	Dark soot		
2	30-50µm	Grey with a transparent line running through it	Ca; S; (P); (Si); (Mg); (Al)	Gypsum
3	>500µm	White plaster	Ca; S; (P); (Al)	Gypsum

Sample no.: 849-17

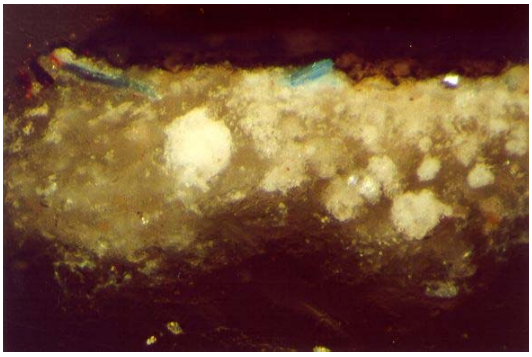
Layer	Thickness	Description	Elements	Interpretation
1	Up to 15µm	Black	Ca; Cl; Cu; S; (P); (Si)	Soot
2	Up to 30µm	Light green	Ca; Sn; Cu; Cl; (S); (P); (Si)	Atacamite with gypsum
3	>270µm	White plaster	Ca; S; (P); (Si)	Gypsum

Sample no.: 849-18



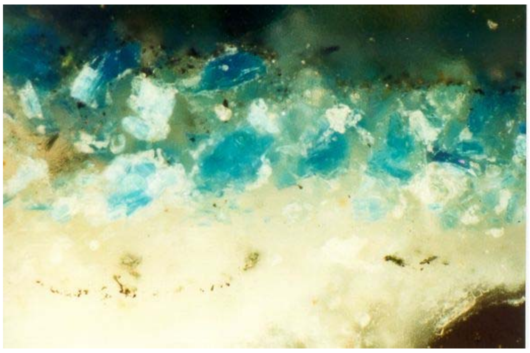
Layer	Thickness	Description	Elements	Interpretation
1	Up to 20μm	Black		
2	Grain up to 45μm thick	Blue	Si; Ca; Cu	Cuprorivaite
3	25-65μm	Transparent	Si; Ca; S; Al; (Mg); (Cl); (K)	Gypsum was probably the adhesive layer or binder for the blue pigment
4	Up to 20μm	Red	Al; Ca; S; Fe; Si; K; (Cl); (Mg); (P)	Red ochre with gypsum
5	>130μm	White plaster	Ca; S; (P); (Si); (Al)	Gypsum

Sample no.: 849-18a



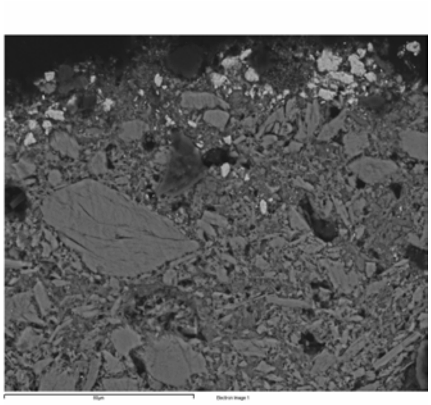
Layer	Thickness	Description	Elements	Interpretation
1	Up to 40μm	Black (soot)		
2	Grains up to 20μm thick	Blue particles; remains of red layer to left		
3	>200μm	White		

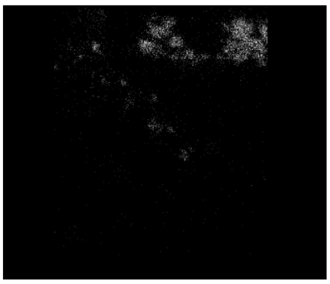
Sample no.: 849-19



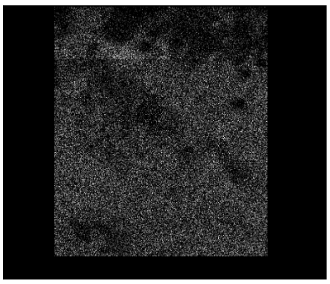
Layer	Thickness	Description	Elements	Interpretation
1	Up to 15µm	Black soot		
2	120-225µm	Blue		
3	100-200µm	White plaster		
4	>350µm	Beige/white plaster with aggregates		

Sample no.: 849-20

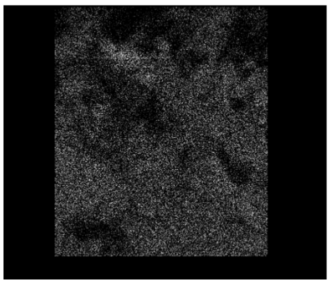




Iron Ka1



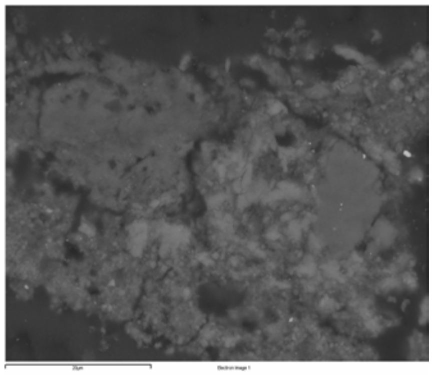
Calcium Ka1

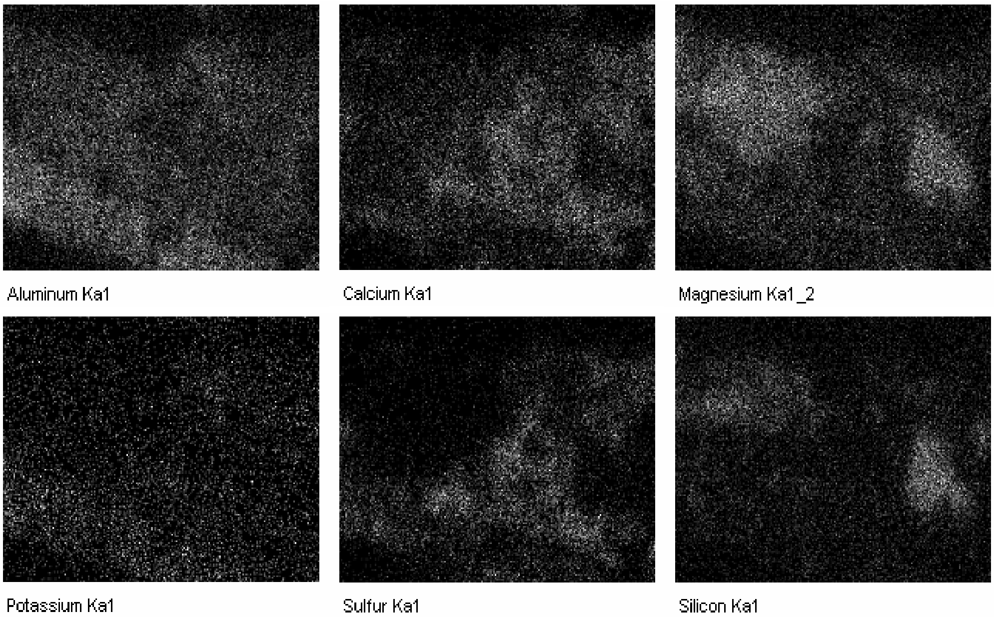


Sulphur Ka1

Layer	Thickness	Description	Elements	Interpretation
1	30-70µm	Red with black particles at the top (soot)	Fe; Ca; S; (Si); (Al); (K)	Haematite particles over gypsum
2	>300µm	White plaster	Ca; S; (Fe)	Gypsum plaster with $CaSO_4$ crystals

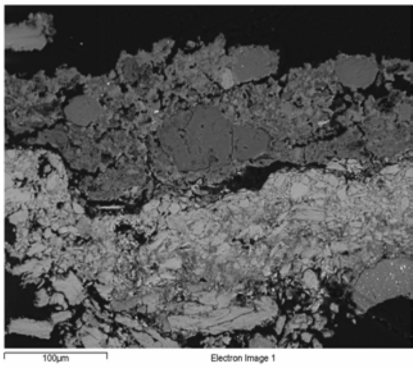
Sample no.: 849-22

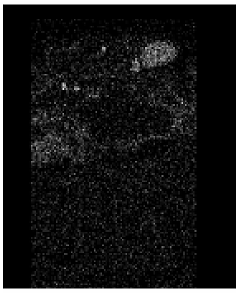




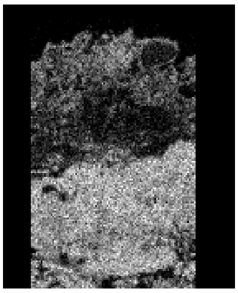
Layer	Thickness	Description	Elements	Interpretation
1		Black	Si; Al	Soot
2	50-100µm	White	Si; Ca; Mg; Al; Cl; S; (K); (Ba)	$Al(OH_3)$, possibly as white pigment; some gypsum and $BaSO_4$ traces; unclear Mg origin
3	>100µm	White	Ca; S; (Si); (Al);	Gypsum plaster

Sample no.: 849-22a

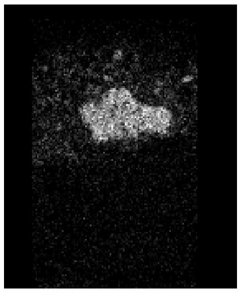




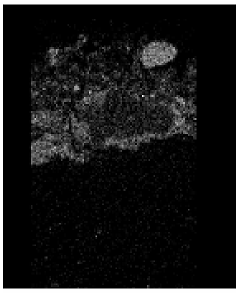
Potassium Ka1



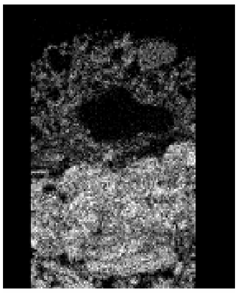
Calcium Ka1



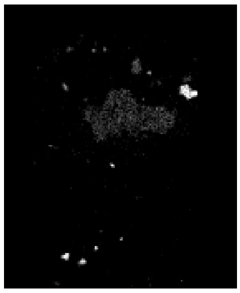
Magnesium Ka1-2



Aluminum Ka1



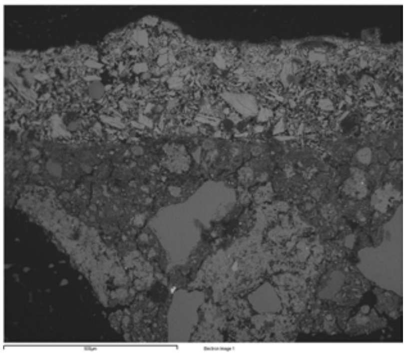
Sulfur Ka1

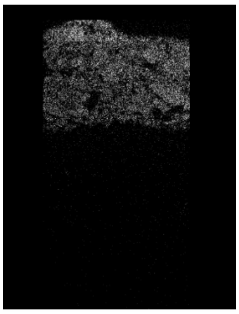


Silicon Ka1

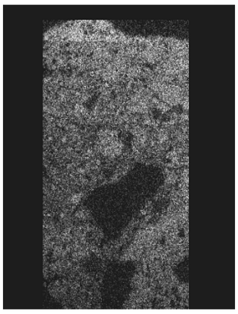
Layer	Thickness	Description	Elements	Interpretation
1	Up to 15µm	Black		Soot
2	80-100µm	Grey/white	Mg; Al; Cl; K; (Si); (Ca); (S)	$Al(OH_3)$; with the presence of a particle of $KAl(SO_4)_2$ (alum); dolomitic particle
3	>250µm	White; red particle	Ca; S	Gypsum plaster

Sample no.: 849-23

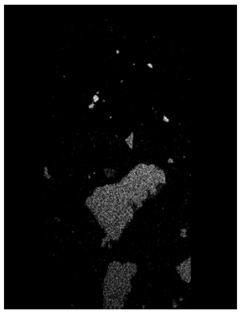




Sulphur Ka1



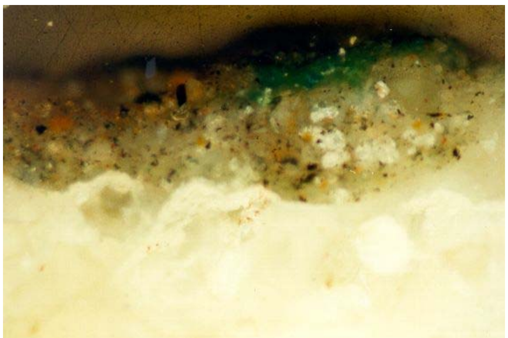
Calcium Ka1



Silicon Ka1

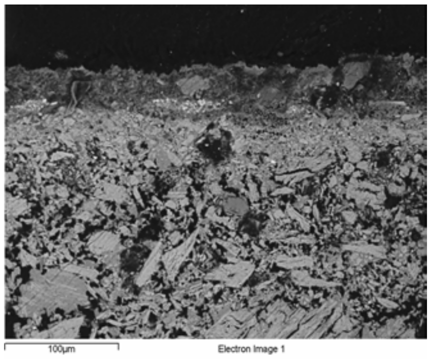
Layer	Thickness	Description	Elements	Interpretation
1	300µm	white	Ca; S; (Si); (Mg)	Gypsum
2	>600µm	White/beige with aggregates	Ca; Si; (Al)	Lime plaster with aggregates

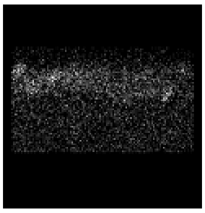
Sample no.: 849-24



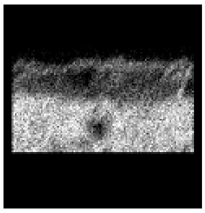
Layer	Thickness	Description	Elements	Interpretation
1	Up to 10µm	Some black		Soot
2	Up to 100µm	Green with yellow and blue particles	Ca; Si; S; (Al);(K); (Fe); (Mg); (Cl); (Na); blue particle area: Si; Ca; (S); (Mg); (Cu); (Fe); (K); (Al); (Cl)	Green earth with yellow ochre, Egyptian blue and gypsum
3	150-300µm	White with black particles	Ca; S; (Si); (Cl); (Al); (Mg)	Gypsum
4	>1500µm	Beige/white plaster with aggregates	Si; Ca; (Cl); (Al); (S); (Mg); (Fe); (Na)	Lime mortar with aggregates

Sample no.: 849-25

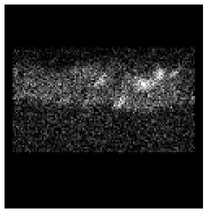




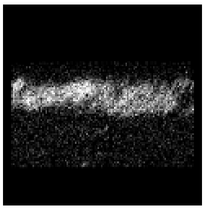
Potassium Ka1



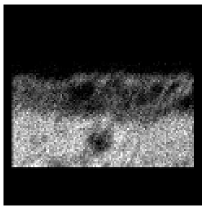
Calcium Ka1



Magnesium Ka1



Aluminum Ka1

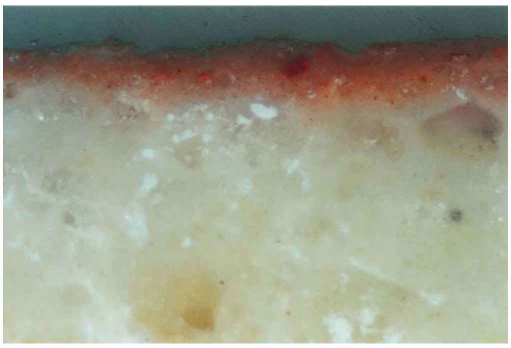


Sulphur Ka1

Iron Ka1

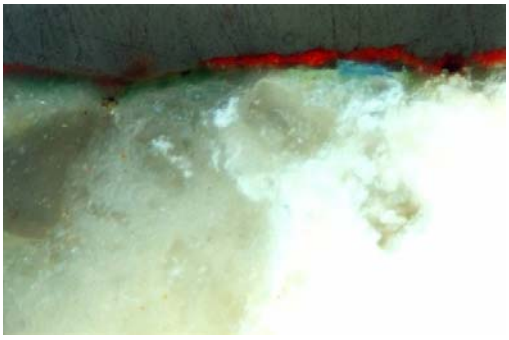
Layer	Thickness	Description	Elements	Interpretation
1	Up to 10µm	Black		Soot
2	30-50µm	White/Grey	Mg; Al; K; Cl; (Si); (Ca);(S)	Al(OH$_3$); unclear origin of Mg; some gypsum
3	Up to 15µm	Orange areas	Fe	Haematite
4	>300µm	White	Ca;S	Gypsum

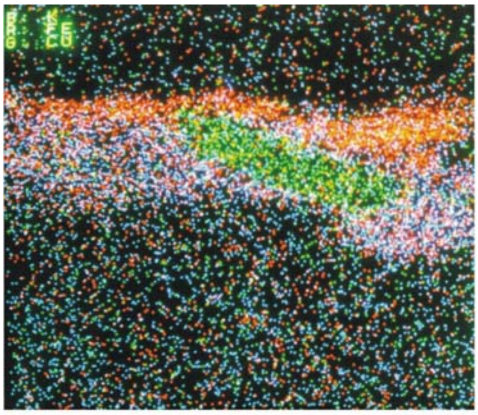
Sample no.: PGT-03a



Layer	Thickness	Description	Elements	Interpretation
1	60-100µm	Light red/rosy	Ca; Mg; Si; S; (Cl); (K); (Fe); (P)	Red ochre with lime, might be fresco; gypsum on the surface, possibly a sulphate contamination
2	>140µm	White/beige plaster layer		Lime plaster; quartz aggregates and dolomite

Sample no.: PGT-03b

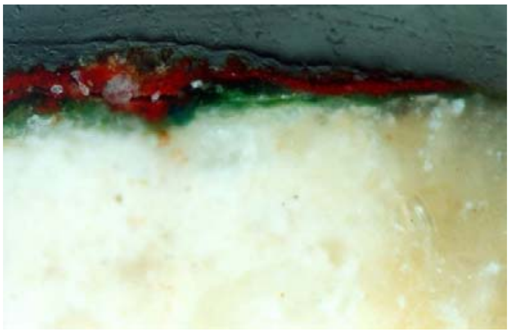


B: K, R: Fe; G: Cu 0.02 mm

Layer	Thickness	Description	Elements		Interpretation
1	5-15µm	White discontinuous layer	Ca; Si; Mg; S; Fe; (Al); (K); (Cl); (Cu)		Superficial layer of gypsum, due to sulphate contamination
2	a. 5-10µm b. 15µm c. 40-50µm	Sequence of 3 colours on the surface: a. red b. light green (with a blue particle) c. white (with some remnants of green and some black particles		a. Si; Ca; Fe; K; (S); (Al); (Mg)	a. Haematite was used for the pigment, and is mixed with lime, appears as a fresco b. Green earth used as pigment, mixed with lime, appears as a fresco; blue particle is cuprorivaite c. Lime layer ($CaCO_3$), used as white coloured layer
3	a. 15-80µm b. 200-250µm	a. green layer b. white layer		a. Si; Ca; K; Al; Mg; Fe; S; Cl	a. green earth used as pigment, mixed with lime, appearing like a fresco b. Lime layer ($CaCO_3$)
4	>240µm	a. white plaster layer			a. lime plaster with few aggregates

Sample no.: PGT-03c

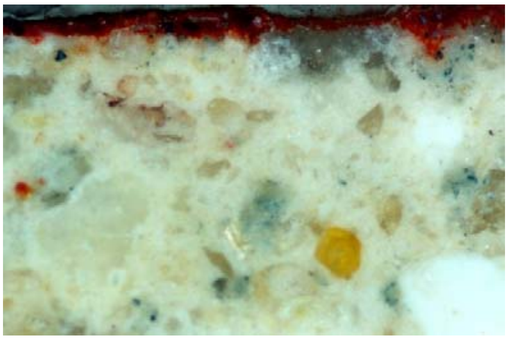


Layer	Thickness	Description	Elements	Interpretation
1	15-50µm	Dark red		
2	15-30µm	Green		
3	>200µm	White		

Sample no.: PGT-10a

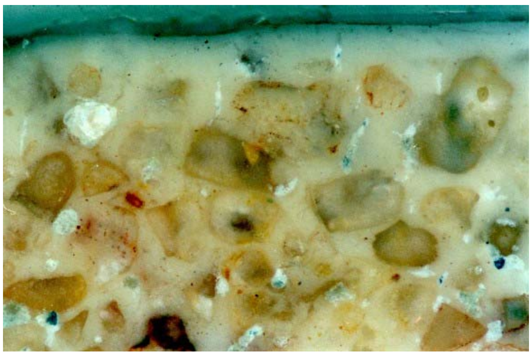
Layer	Thickness	Description	Elements	Interpretation
1		Some surface dust	Si; Ca; (Fe); (Al); (Mg); (S); (Cl); (K)	
2	5-30µm	Red		Red ochre was used as the pigment; calcite in the layer
3	1200µm	Fine white plaster layer with few aggregates		Lime plaster with few quartz aggregates
4	>1600µm	Coarse white plaster layer with many aggregates		Lime plaster with a lot of quartz aggregates

Sample no.: PGT-10b



Layer	Thickness	Description	Elements	Interpretation
1	70-120µm	Red	Si; Ca; (Mg); (Fe); (Al); (S); (Cl); (K)	Red ochre was used as the pigment
2	1500µm	Fine grained white plaster		Lime plaster with a few aggregates of quartz, and one dolomite aggregate is evident
3	>1500µm	Coarse grained white plaster layer		Lime plaster with a lot of quartz aggregates

Sample no.: PGT-10c

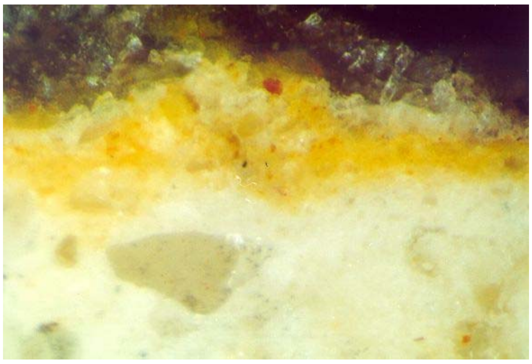


Layer	Thickness	Description	Elements	Interpretation
1	125µm	White plaster layer	Si; Ca; (Al)	Layer of lime ($CaCO_3$)
2	>800µm	White plaster layer full of aggregates		Lime plaster with a lot of quartz aggregates

Sample no.: PGT-11

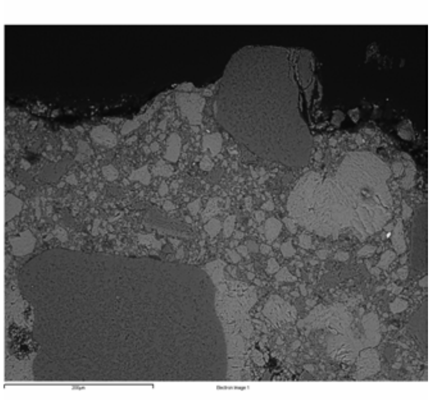
Layer	Thickness	Description	Elements	Interpretation
1	100µm	White plaster	Si; Ca	Layer of white lime ($CaCO_3$)
2	>1200µm	White plaster with aggregates		Lime plaster with a lot of quartz aggregates

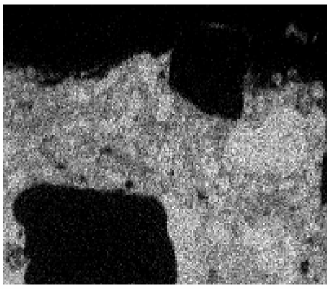
Sample no.: PGT-12



Layer	Thickness	Description	Elements	Interpretation
1	40-160µm	White/ transparent	Ca; S; (Si)	Gypsum
2	40-120µm	Yellow	Si; Ca; S; (Fe); (Al); (Fe); (K)	Yellow ochre; there is gypsum
3	>2400µm	White with a lot of aggregates	Ca; Si; (S)	Lime plaster with quartz aggregates

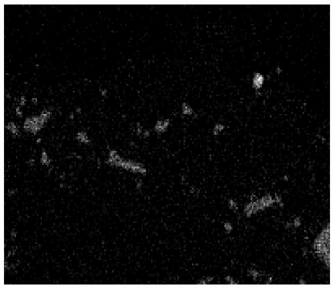
Sample no.: PGT-13





Calcium Ka1

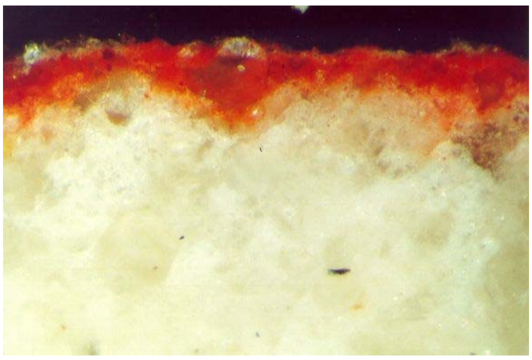
Silicon Ka1



Magnesium Ka1

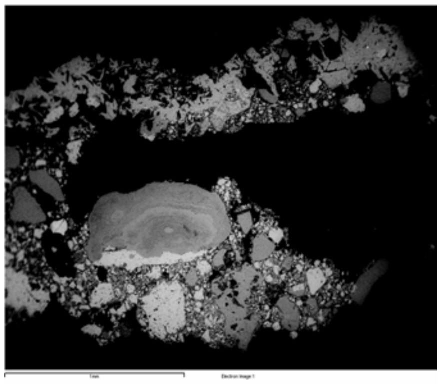
Layer	Thickness	Description	Elements	Interpretation
1	10-30µm	White	Ca;Si; (S); (Al); (Mg);(Fe)	Gypsum
2	30-250µm	Pink/rosy and contains some aggregates		Haematite with calcite as binder and aggregate, quartz and some dolomite; black particle is bone black ($Ca(PO_4)_2$)
3	>1400µm	White plaster with aggregates		Lime plaster with quartz aggregates

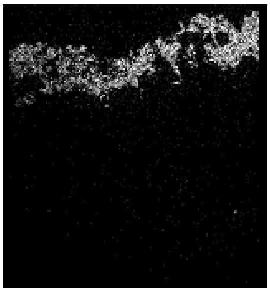
Sample no.: PGT-14



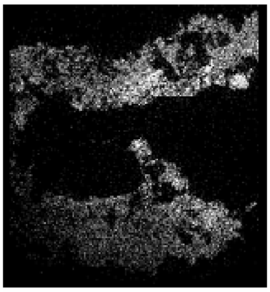
Layer	Thickness	Description	Elements	Interpretation
1	40-80µm	Dark red	Ca; Si; Fe; (S); (Al); (Mg); (Cl)	Haematite with lime; some gypsum traces
2	>2800µm	White plaster with aggregates	Ca; Si; (Mg)	Lime plaster with quartz aggregates, probably a dolomite one

Sample no.: PGT-15

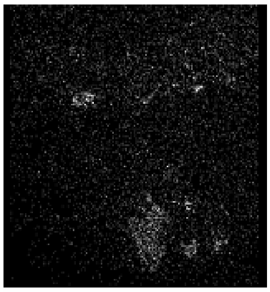




Sulphur Ka1



Calcium Ka1



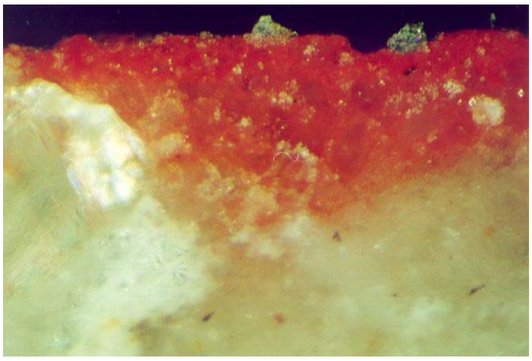
Magnesium Ka1

Layer	Thickness	Description	Elements	Interpretation
1	Up to 400µm	Green layer with white; red in some places	Si; Ca; K; Fe; S; Al; Mg	Possible green earth; the white is gypsum; red could not be verified; disturbed sequence and thickness of gypsum imply that it's not original
2	>1600µm	White/beige with aggregates	Ca; Si	Lime mortar with aggregates

Sample no.: PGT-16

Layer	Thickness	Description	Elements	Interpretation
1	10-50µm	Red	Si; Ca; Fe; Mg; (S); (K); (Al)	Haematite with lime, appears as fresco
2	10-40µm	Yellow		Yellow is due to contact of haematite with lime
3	>1400µm	White with aggregates	Ca; Si; (Mg); (Al); (S)	Lime plaster; quartz, calcite and dolomite aggregates

Sample no.: PGT-17

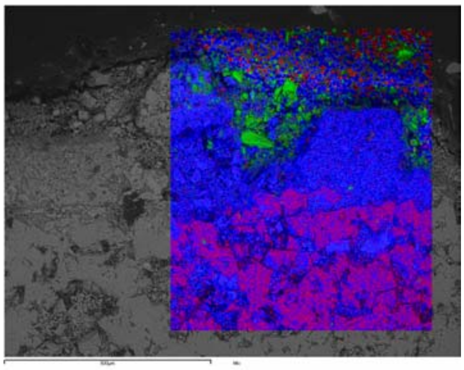


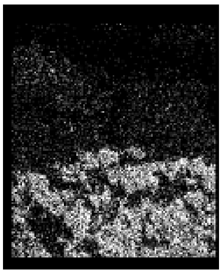
Layer	Thickness	Description	Elements	Interpretation
1	20-200µm	Red; top appears as a polished edge	Ca; Fe; Cl; Na; (K); (Si); (S); (Mg)	Haematite with lime; there is a lot of NaCl
2	>4800µm	White/beige with aggregates	Ca; Si; (Mg); (Cl)	Lime plaster with mainly quartz aggregates; NaCl is present

Sample no.: PGT-18

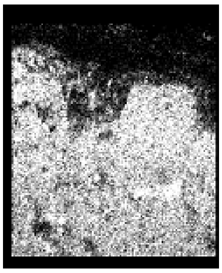
Layer	Thickness	Description	Elements	Interpretation
1	20-140µm	Yellow	Ca; Si; K; (Cl); (Fe); (Mg); (Al)	Yellow ochre with lime
2	>1400µm	White with aggregates	Ca; Si; Cl; K; (Mg); (Na); (Al)	Lime plaster with aggregates

Sample no.: PGT-19

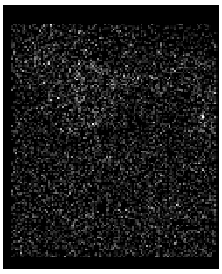




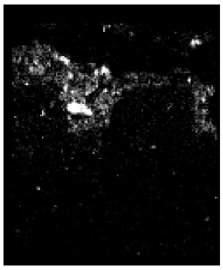
Magnesium Ka1-2



Calcium Ka1



Iron Ka1



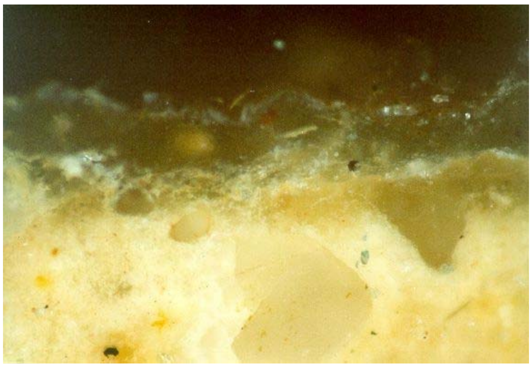
Silicon Ka1

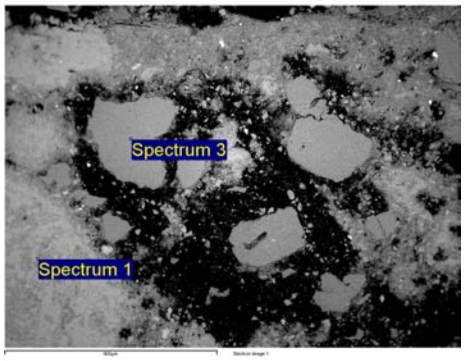
Layer	Thickness	Description	Elements	Interpretation
1	50-300µm	Red	Ca; Si; (Fe)	Red ochre with lime
2	70-250µm	white	Ca; (S)	Lime wash with some gypsum
3	>600µm	Stone backing	Ca; Si; Mg	Dolomite stone

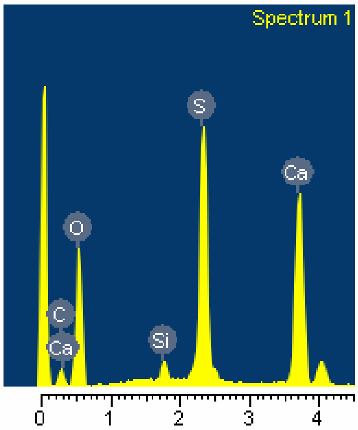
Sample no.: PGT-21

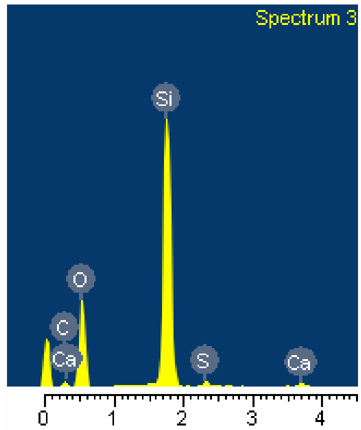
Layer	Thickness	Description	Elements	Interpretation
1	5-140µm	Red		
2	>2mm	Beige/white with sometimes white patches		

Sample no.: PGT-23



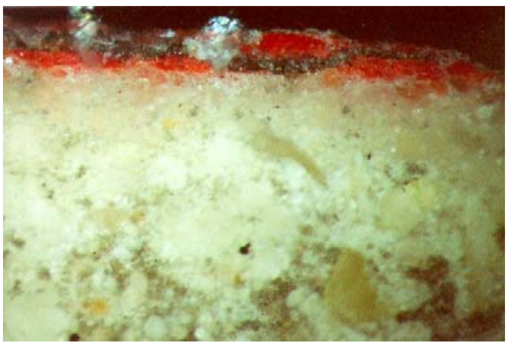






Layer	Thickness	Description	Elements	Interpretation
1		Red particles		
2	100-150µm	white	Ca; S; (Si)	Gypsum
3	>2700µm	Beige plaster with aggregates of different sizes	Ca; S; Si	Gypsum matrix with $CaSO_4$ (anhydrite) and quartz aggregates

Sample no.: PGT-24

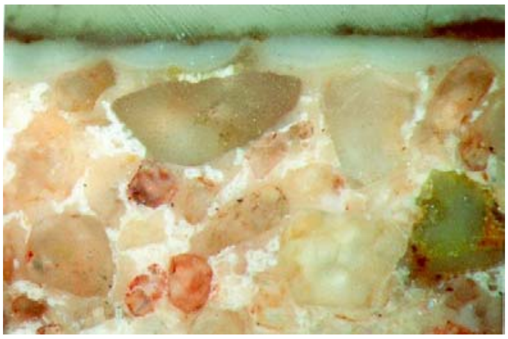


Layer	Thickness	Description	Elements	Interpretation
1	120-240µm	Red; horizontal crack	<u>Ca</u>; Fe; (Si); (Mg); (Al)	Haematite and lime; looks like fresco; Al and Si maybe associated with dust
2	1400-1600µm	White plaster; few aggregates	<u>Ca</u>; Si; (Mg)	Lime plaster
3	>500µm	Beige/white plaster; many aggregates	<u>Si</u>; <u>Ca</u>; (Mg); (Cl)	Lime plaster with aggregates

Sample no.: PGT-25

Layer	Thickness	Description	Elements	Interpretation
1	100-200µm	Yellow	Ca; Si; Fe; (Al); (Mg); (K); (Cl); (S)	Yellow ochre with lime
2	2500-3000µm	White plaster with few small aggregates	Ca; (P); (Si); (S); (Mg)	Lime plaster
3	>3000µm	Beige/white plaster with aggregates	Si; Ca; (Mg); (Cl); (S)	Lime plaster with quartz aggregates

Sample no.: PGT-26

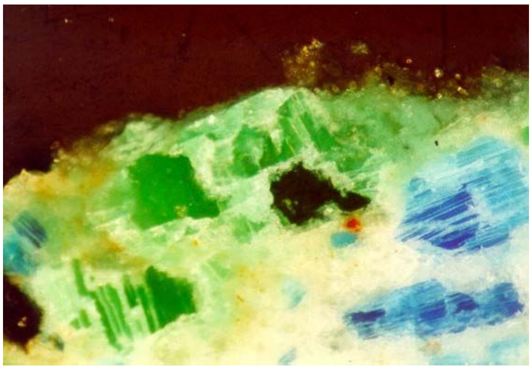


Layer	Thickness	Description	Elements	Interpretation
1	Up to 80µm	Red		
2	100-600µm	white		
3	>2200µm	White/pinkish with a lot of aggregates		

Sample no.: PGT-27

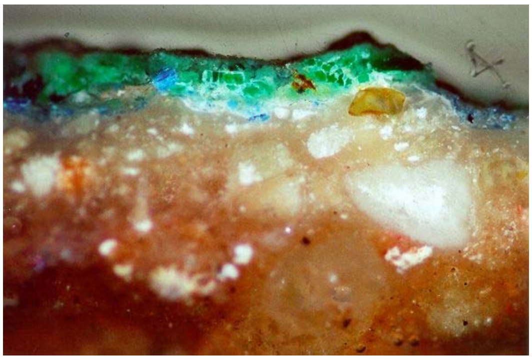
Layer	Thickness	Description	Elements	Interpretation
1	Up to 120µm	Red	Si; (Al)	Dust
2	100-300µm	White	Ca	Lime plaster
3	>1400µm	White with many rounded aggregates	Si; Ca	Lime plaster with quartz aggregates

Sample no.: PGT-31



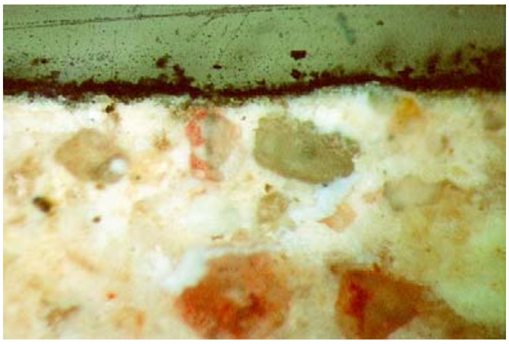
Layer	Thickness	Description	Elements	Interpretation
1	120-240µm	Green, part of particles with fibrous structure, other part as homogeneous green	Green fibrous particles: Cu Green homogeneous layer: Cl; Cu; (Ca); (S)	Malachite represented by distinctive individual particles with atacamite at the upper part
2	120-320µm	Blue particles of fibrous structure with white in between	Blue: Si; Ca; Cu; (Cl) White: Ca; S; Si; (Cl); (P); (Al); (Cu)	Cuprorivaite (Egyptian blue) with gypsum
3	400-600µm	White plaster with some aggregates	Ca; S; (Si); (Al)	Gypsum with quartz aggregates
4	>1350µm	Beige plaster full of aggregates	Ca; S; (Si); (Al)	Gypsum plaster with aggregates

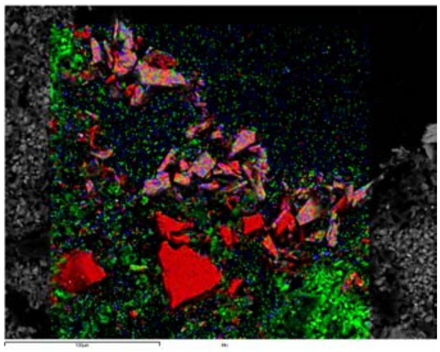
Sample no.: PGT-31a

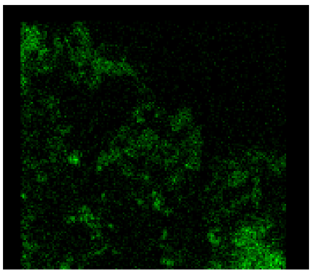


Layer	Thickness	Description	Elements	Interpretation
1	70-230µm	Green; upper layer is mainly homogeneous; lower has green fibrous particles		
2	80-100µm	Blue particles with some white		
3	360-720µm	Beige with aggregates		
4	>800µm	Brown with aggregates		

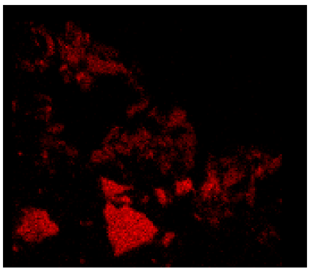
Sample no.: PGT-32



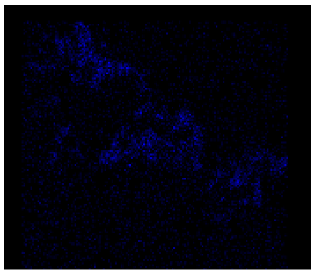




Calcium Ka1



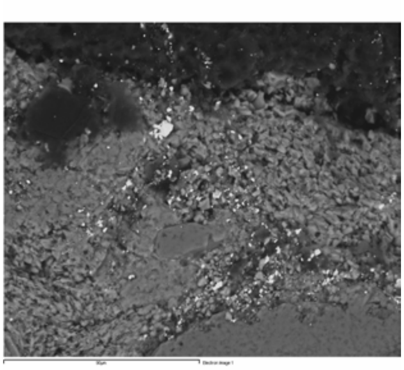
Silicon Ka1

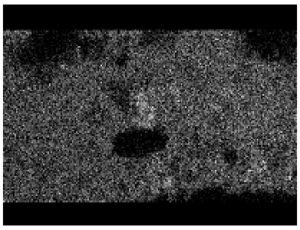


Copper Ka1

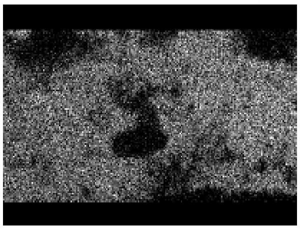
Layer	Thickness	Description	Elements	Interpretation
1		Blue particles	Si; Ca; Cu; S	Cuprorivaite
2	40-200µm	Black	Si; Ca; (Cl); (Al); (Mg); (K); (Fe); (Cu)	Carbon black
3	>1400µm	Beige/pinkish with aggregates	S; Ca; Si; (Al)	Gypsum plaster with quartz aggregates

Sample no.: PGT-33

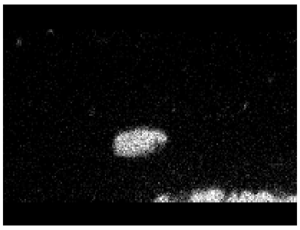




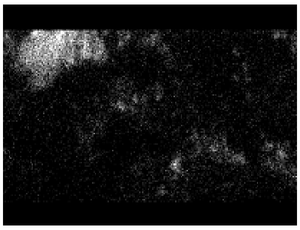
Calcium Ka1



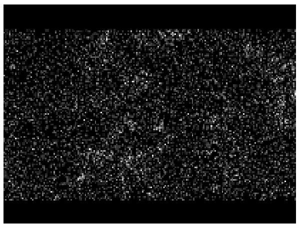
Sulphur Ka1



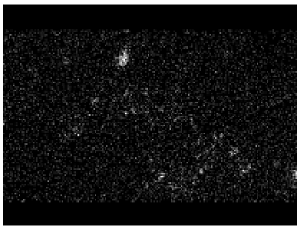
Silicon Ka1



Carbon Ka1



Manganese Ka1



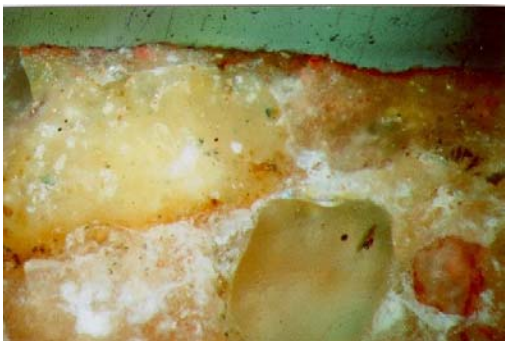
Barium Ka1

Layer	Thickness	Description	Elements	Interpretation
1		Black/brown	Si; Ca; Na; Cl; S; K; Al; Mg; (Mn); (Fe)	Mainly carbon black; few Mn and Fe particles (perhaps umber); NaCl salt
2	>300µm	Beige mortar with aggregates	S; Ca; (Si); (Ba); (Cl); (Al)	Gypsum; some quartz aggregates; considerable traces of $BaSO_4$

Sample no.: PGT-34

Layer	Thickness	Description	Elements	Interpretation
1		Blue particles		
2	>1500µm	Red/brown plaster; aggregates		

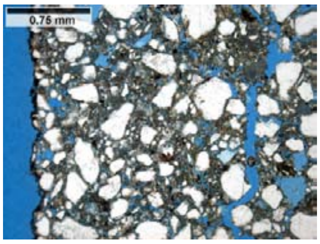
Sample no.: PGT-35



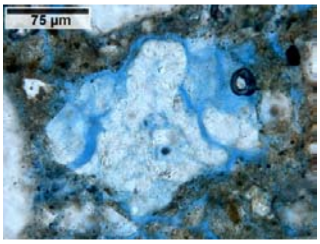
Layer	Thickness	Description	Elements	Interpretation
1	10-20µm	Red	Si; S; Ca; (Al); (Mg); (Cl); (K); (Fe); (Na)	Red ochre and gypsum
2	>3000µm	Beige/white plaster with aggregates	Si; Ca; S; (Al); (Mg)	Gypsum plaster with quartz aggregates and some calcite

Sample no.: PGT-36

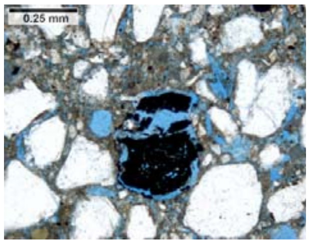
Thin Section



Texture of sample with original surface



Stacked platelets of kaolinite



One of the few charcoal fragments

Components

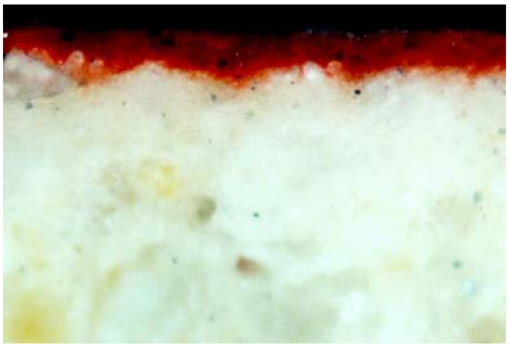
Aggregate: quartz; rock fragments (sandstone, polycrystalline quartz, sometimes with pockets of kaolinite); carbonate; few fragments of charcoal; binder: carbonate; lime lumps; kaolinite or meta-kaolinite (low birefrigence, stacked platelets), might have been introduced by the aggregate.

Texture

Orientation: Particle randomly oriented; two cracks running parallel through the sample; on one side of the section original pigmented surface visible; no layering obvious.

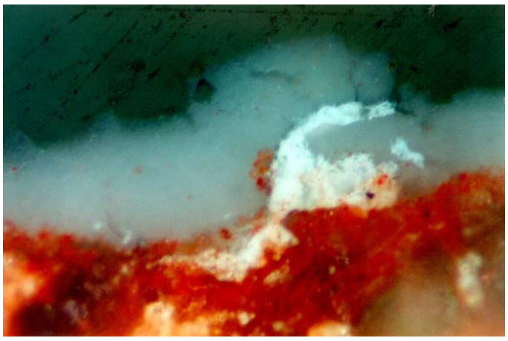
Structure: Aggregate subangular to rounded; poorly to moderately sorted, higher amount of small aggregate; moderate content of binder; low amount of air voids, many interstitial pores.

Sample no.: SIY-04



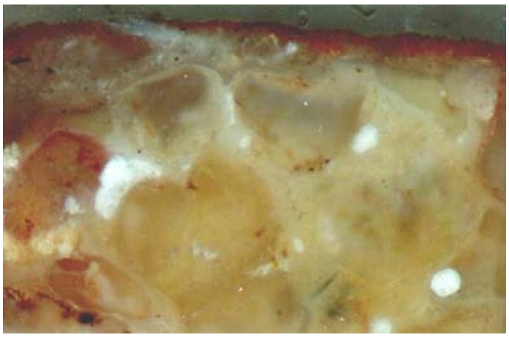
Layer	Thickness	Description	Elements	Interpretation
1	30-55µm	Red	Ca; Si; Fe; Mg; S; Na; (Ba); (K)	Haematite as pigment; the layer contains $BaSO_4$
2	>600µm	White with aggregates	Ca; Si	Lime plaster with quartz aggregates

Sample no.: SIY-05



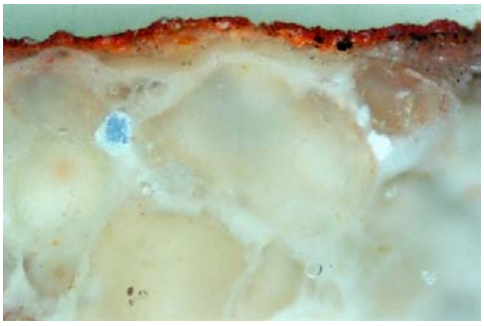
Layer	Thickness	Description	Elements	Interpretation
1	50-130µm	White	Si; Ca; Al	Pure lime layer
2	>400µm	Stone backing		Façade sandstone, made of quartz grains

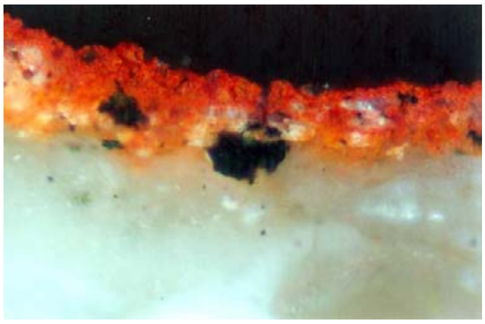
Sample no.: SIY-06

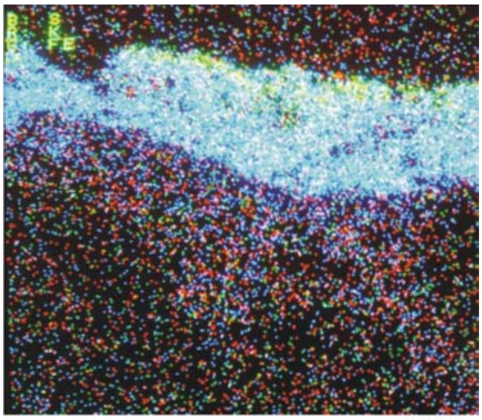


Layer	Thickness	Description	Elements	Interpretation
1	10-20µm	light red/rosy	Si; Ca; S; (Al); (K); (Fe)	Red ochre and gypsum
2	20-60µm	White		Gypsum as ground layer
3	>300µm	White plaster with aggregates		Lime plaster; angular quartz grains

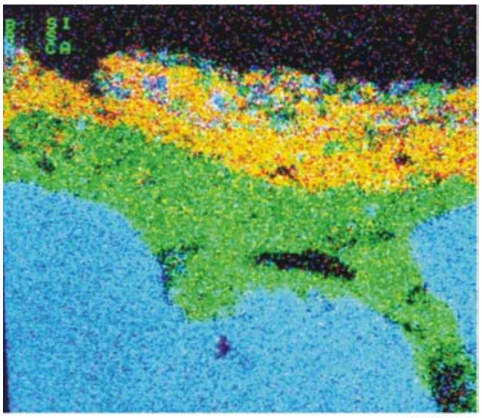
Sample no.: SIY-08







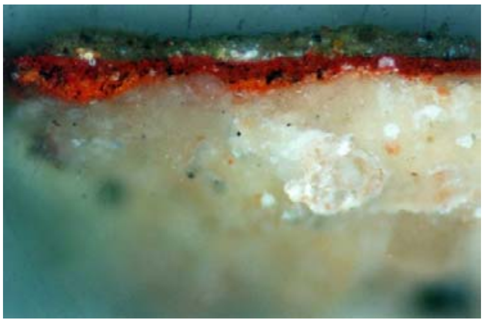
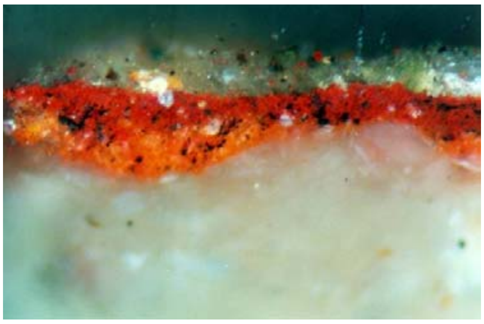
B: S; R: K; G: Fe — 0.05 mm



B: Si; R: S; G: Ca — 0.05 mm

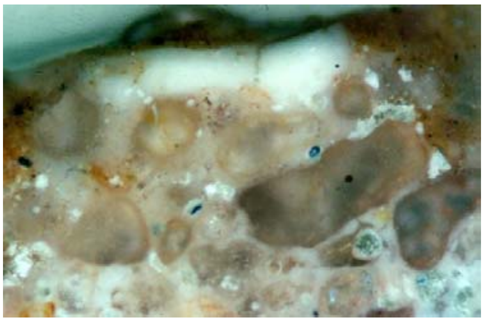
Layer	Thickness	Description	Elements		Interpretation
1	20-70µm	Red with its bottom part being of lighter red (orange)	Si; Ca; (S); (Fe)	top: <u>Fe</u>; <u>Ca</u>; S; Si; Al; (K); (Mg); bottom: <u>S</u>; <u>Ca</u>; Si; Al; (K); (Mg)	Haematite was used as the pigment; the lighter red tone comes from the mix with gypsum
2	15-40µm	White layer			Lime plaster without aggregate
3	>700µm	White plaster with coarse aggregates			Lime plaster with quartz aggregates-lime sinter layer at the top is evident

Sample no.: SIY-09

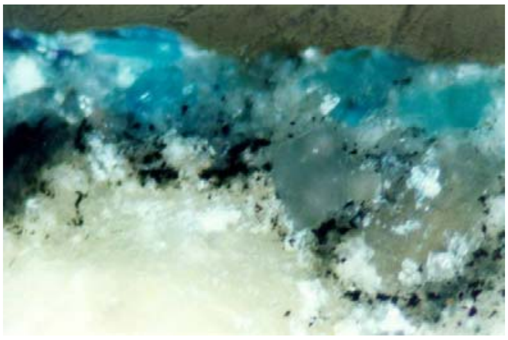
Layer	Thickness	Description	Elements	Interpretation
1	15-25µm	White layer	Si; Ca; Al; (K); (Fe); (S); (Mg)	Very siliceous layer with Al and Si, containing calcite
2	20-50µm (top part= 10-30µm; bottom part= 10-30µm	Red that appears in two layers, the top being dark red and the bottom is lighter orange	Top: Si; Fe; Al; Ca; (Mg); (S); (K) Bottom: Si; S; Ca; Al; Fe; (Mg); (K)	Haematite was used as the pigment, with gypsum in the layer
3	>600µm	White plaster with aggregates	S; Ca; (Si); (Al)	Gypsum plaster with some aggregates

Sample no.: SIY-12



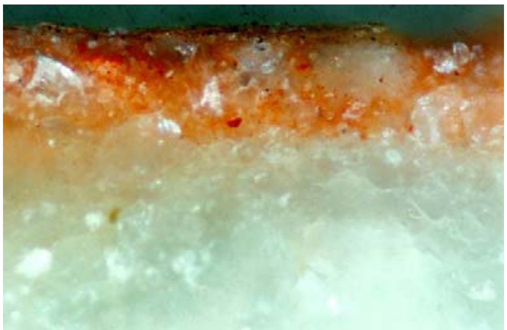
<table>
<tr><th>Layer</th><th>Thickness</th><th>Description</th><th colspan="2">Elements</th><th>Interpretation</th></tr>
<tr><td>1</td><td>20-30µm</td><td>Dust layer</td><td rowspan="3">Si; Ca; (Cl); (Al); (S); (K); (Na)</td><td></td><td>Siliceous layer of dust</td></tr>
<tr><td>2</td><td>100-175µm</td><td>White plaster layer</td><td>Cl; Ca; Na; (Si); (Al); (K); (S)</td><td>“Fat” lime layer ($CaCO_3$); there is a lot of NaCl salt in the layer</td></tr>
<tr><td>2</td><td>>800µm</td><td>White plaster with aggregates</td><td></td><td>Lime plaster with rounded and angular quartz grains</td></tr>
</table>

Sample no.: SIY-13



Layer	Thickness	Description	Elements	Interpretation
1	50-70µm	Blue	Si; Ca; Cu	Cuprorivaite (Egyptian blue) was used as blue pigment
2	50µm	Layer with black particles	Ca; (Mg); (Al); (Si)	Some charred material, or a kind of soot
3	>100µm	White plaster with aggregates	Ca; Si; (Al); (Mg)	Lime mortar with quartz aggregates, and possibly a dolomite one

Sample no.: SIY-14



Layer	Thickness	Description	Elements	Interpretation
1	10-20µm	Surface dust	Ca; Si; (S); (K); (Cl); (Al); (Mg); (Fe); (P)	Surface dust with a lot of Si
2	70-80µm	Light red/rose		Haematite was used as the pigment, mixed with lime
3	>400µm	White with few visible aggregates		Lime plaster layer with few aggregates

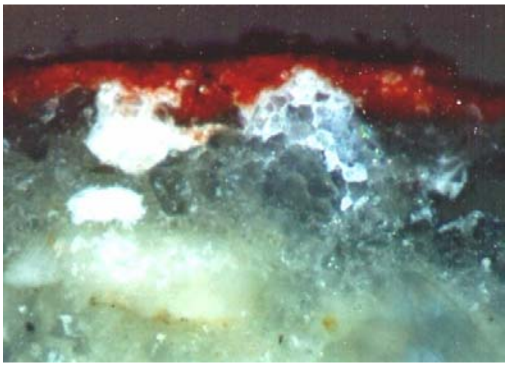
Sample no.: SIY-15

Layer	Thickness	Description	Elements	Interpretation
1	5µm	Red layer of surface dust	Si; Al	Surface dust
2	30-40µm	Green layer with 2 blue particles of fibrous structure	Ca; S; Si; (K); (Al); (Fe); (Mg); (Na); (Cl); (Cu)	Green earth was used as the pigment; blue particles are Egyptian blue
3	25-60µm	Whitish/green	Ca; S; (Si)	Gypsum; probably a repair since this layer is different from paint layer ground of surrounding samples
4	>800µm	White with aggregates	Ca; Si; (Mg)	Lime mortar with a lot of quartz aggregates

Sample no.: SIY-16

Layer	Thickness	Description	Elements	Interpretation
1	10µm	Red particles	Si; Al	Dust on the surface
2	40-60µm	Yellow	Ca; Si; Al; (Fe); (K); (S); (Na); (Cl)	Yellow ochre is the pigment, and is mixed with some gypsum; there is NaCl salt in the layer
3	>750µm	White with aggregates	Ca; Si; Mg	Lime plaster with quartz and calcite aggregates – some being dolomite

Sample no.: SIY-17

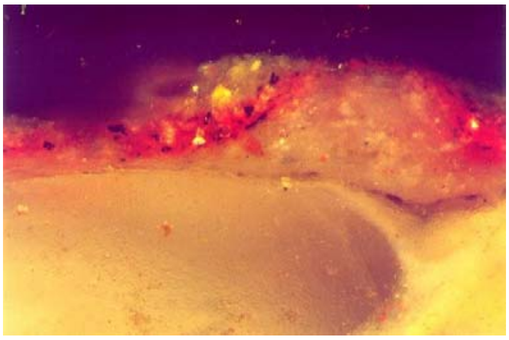


Layer	Thickness	Description	Elements	Interpretation
1	10-25μm	Black	Ca; Si; (Al); (Mg); (S); (Fe); (K); (Cl)	Most probably carbon black
2	30-50μm	Red		Haematite, with some red ochre as the pigment, with some gypsum in the layer
3	>250μm	White plaster layer		Lime plaster with aggregates

Sample no.: SIY-18

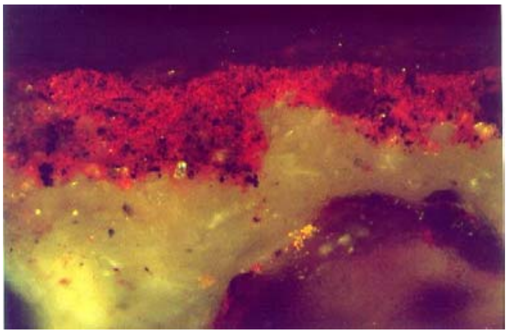
Layer	Thickness	Description	Elements	Interpretation
1	50μm	Light blue	Ca; Si; (S); (Cl); (K); (Fe); (Al); (Mg); (Cu)	Egyptian blue was used as the pigment; there is gypsum in the layer
2		Some black particles as a non-continuous layer		Some kind of soot particles
3	25x80μm	Red particle		Particle of haematite
4	>200μm	White plaster with aggregates		Lime plaster with aggregates of calcite and quartz

Sample no.: SIY-19



Layer	Thickness	Description	Elements	Interpretation
1	20-50µm	Yellow	Si; Fe; Al; Ca; S; (K)	Yellow ochre; gypsum
2	20-50µm	Red with black particles	Ca; S; Si; Al; Fe; (Mg); (K)	Red ochre and gypsum
3	30-130µm	White	Ca; S; Si	gypsum
4	800µm	White with aggregates	Si; Ca; (S)	Lime plaster with aggregates

Sample no.: SIY-20

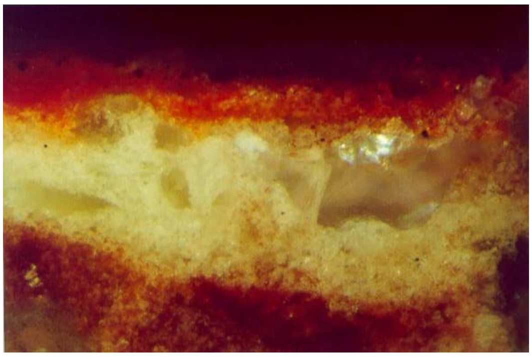


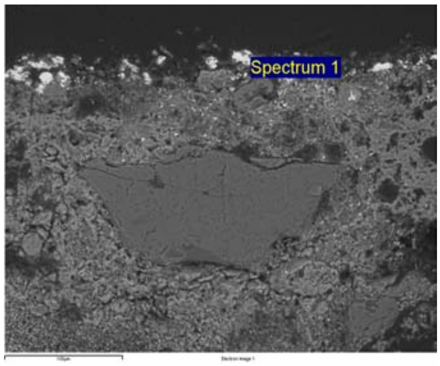
Layer	Thickness	Description	Elements	Interpretation
1	50-160µm	Dark red with black particles	Ca; S; Fe; Al; (K); (Cl); (Mg); (Na)	Red ochre and gypsum; NaCl present
2	>500µm	White with one aggregate evident	Ca; S	Gypsum with a quartz aggregate

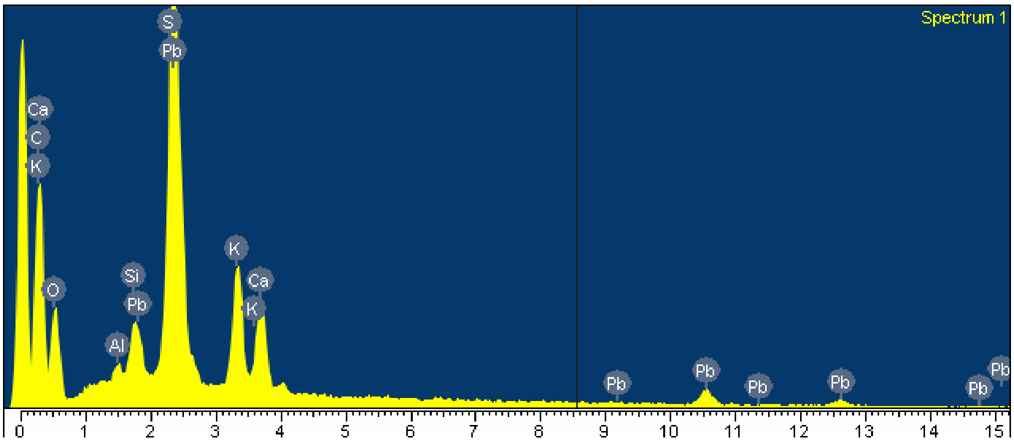
Sample no.: SIY-21

Layer	Thickness	Description	Elements	Interpretation
1		Pale blue particles		
2	Up to 30µm	Black		
3	100-150µm	White		
4	>800µm	White with aggregates		

Sample no.: SIY-22





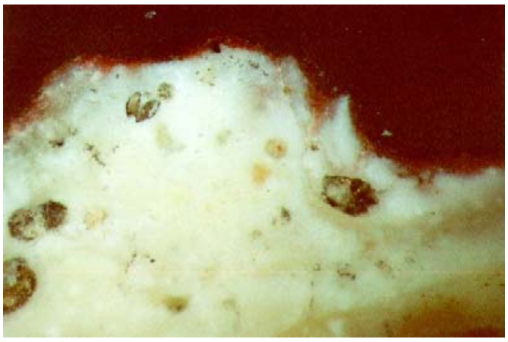


Layer	Thickness	Description	Elements	Interpretation
1	40-60µm	Red	S; Pb; K; Ca; Si; Al; (Fe)	Red ochre and minium (Pb_3O_4) with gypsum
2	50-750µm	White, sometimes brownish plaster with aggregates	Ca; S; K; Si; Cl; (Al); (Mg); (Na)	Gypsum plaster with aggregates
3	>120µm	Sandstone		

Sample no.: SIY-23

Layer	Thickness	Description	Elements	Interpretation
1	20µm	Blue		
2	Up to 15µm	Black		
3	40-100µm	White		
	>800µm	White; aggregates		

Sample no.: SIY-AB01



Layer	Thickness	Description	Elements	Interpretation
1	20-130µm	Red	Ca; Cl; S; (Si); (Mg); (K)	Gypsum and dust
2	>2000µm	White/beige	Ca; Cl; (K); (S); (Mg); (Na)	Lime plaster; NaCl salt

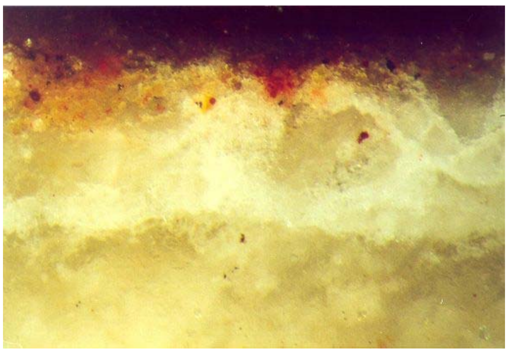
Sample no.: SIY-AB02

Layer	Thickness	Description	Elements	Interpretation
1	Up to 50µm	Red/brown	Ca; S; Si; Cl; (K); (Al); (Mg); (Fe)	Ochre and gypsum; some chloride
2	>1100µm	White with few aggregates	Ca; Cl; (Na);(K); (S); (Si)(Mg);(Al)	Lime plaster ; contains NaCl salt

Sample no.: SIY-AB04

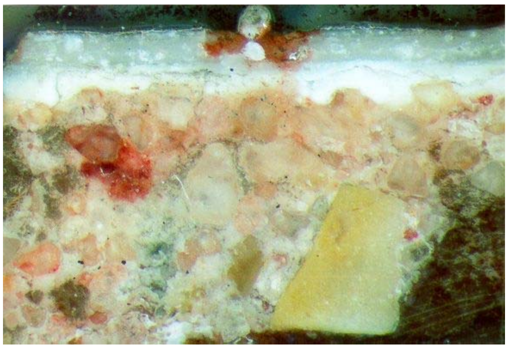
Layer	Thickness	Description	Elements	Interpretation
1	40-280µm	White with some red particles at the top	Ca; (Si)	Lime wash with surface dust
2	>3000µm	Pinkish/beige plaster with aggregates	Si; Ca; (Cl); (S); (K)	Lime plaster with quartz aggregates

Sample no.: SIY-AB05



Layer	Thickness	Description	Elements	Interpretation
1	Up to 100µm	Light red/brownish	Si; Al	Surface dust
2	10-40µm	Dark red	Si; Ca; Al; S; Fe; K; (Cl); (Mg); (Ba)	Red ochre with gypsum; some barium sulphate
3	150-250µm	White	Ca; S; (Si)	Gypsum preparation layer
4	>2000µm	White plaster with aggregates	Ca; S; Si; (Cl); (Al); (K)	Gypsum with quartz aggregates

Sample no.: SIY-AB06

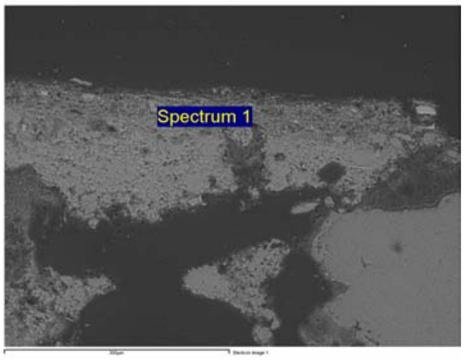


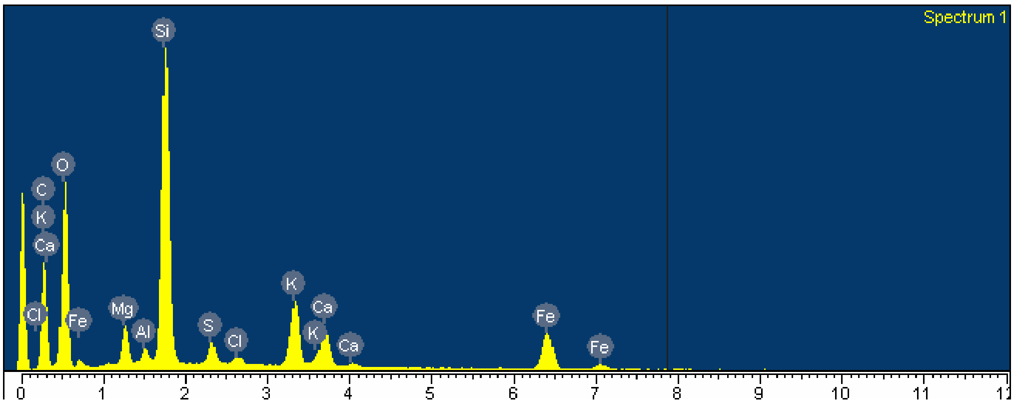
Layer	Thickness	Description	Elements	Interpretation
1	20µm; in the middle it is 100µm	Red/brownish	Ca; S; Si; Al; (Fe); (K); (Mg)	Remains of red ochre with gypsum
2	10-40µm	White; somewhat transparent	Ca; S; (Cl); (K); (Mg); (Na)	Gypsum plaster; there is sodium chloride salt in the layer
3	150-250µm	White; appears as two layers	Ca; Cl; (S); (Si); (Mg); (Na)	Layer of fat lime, with sodium chloride and some sulphates
4	>2000µm	Pinkish plaster with aggregates	Si; Ca; Cl; (S) ; (Al); (K) ; (Mg) ; (Na)	Lime plaster with angular to subangular quartz aggregates; a dolomite one is also found

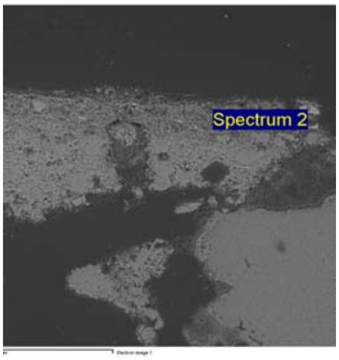
Sample no.: SIY-AB07a

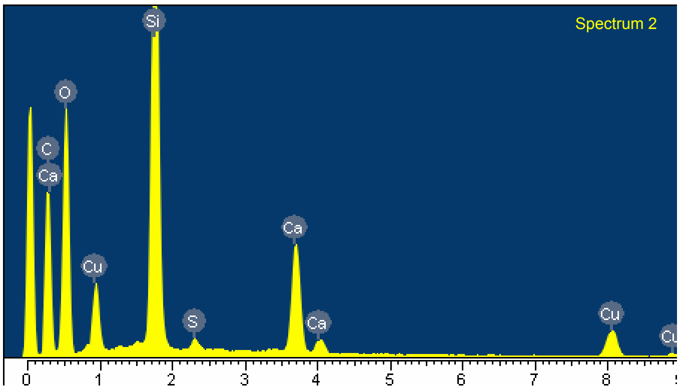
Layer	Thickness	Description	Elements	Interpretation
1	Red: 15-30µm; Orange/yellow: 10-70µm	Red with an orange/yellow hue at the bottom/black particle is evident	Red: Ca; S; Si; Al; Fe; Cl; Mg; (K) Orange/yellow: Ca; Si; S; Al; Fe; Cl; (Mg); (K) Black: Ca;Fe; P; (Cl); (Si); (Al)	Red ochre with gypsum; the orange/yellow hue is due to its fusion with the white layer below
3	330-410µm	White with few aggregates	Ca; (Si); (Al); (K)	Lime plaster with few quartz aggregates
4	>360µm	White plaster with aggregates	Ca; Si; (Cl); (Al); (K); (Mg)	Lime plaster with quartz aggregates

Sample no.: SIY-AB08



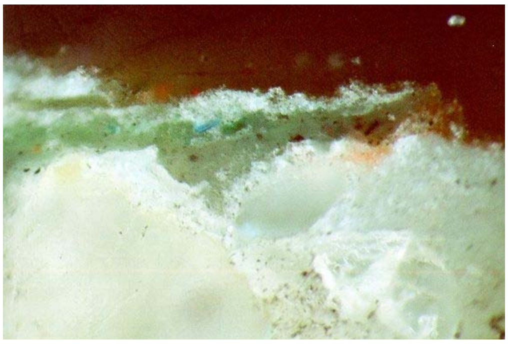






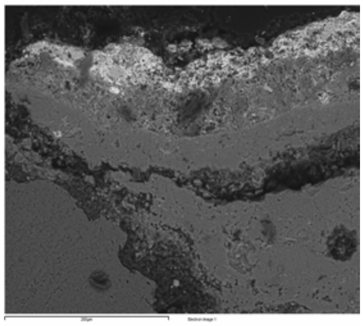
Layer	Thickness	Description	Elements	Interpretation
1	10-50µm	Yellow with yellow particles	Si; Ca; S; Al; Fe; (K); (Mg)	Yellow ochre with gypsum
2	30-50µm	Green layer, with green, blue and yellow particles	Green area: Si; Ca; S; Al; Mg; Fe; K; (Cu);blue: Si; Ca; Cu; yellow particles: Ca; Si; Al; Mg; (K); (S); (Fe); green particles: Si; Ca; Cu	Green is a mix of yellow ochre and Egyptian blue and possibly green earth (unclear)
3	30-70µm	White/grey; with black particles	Ca; S; Si; Al; (Mg); (K)	Gypsum plaster
4	>2000µm	White plaster with aggregates	Si; Ca; (Mg); (Al); (Na); (Cl)	Lime plaster with a lot of mainly rounded, quartz aggregates; salt is present

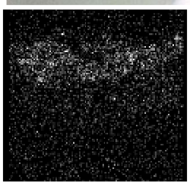
Sample no.: SIY-AB09



Layer	Thickness	Description	Elements	Interpretation
1	Up to 70µm	Red	S; Al; Ca; K; (Si); (Cl); (Mg);(Na)	Gypsum, dust and sodium chloride salt
2	50-100µm	Light green; few green particles; a blue particle	Green : Si; Ca; (Cl); S; (Al); (K); (Fe) ; (Mg); (Na)	blue is cuprorivaite; possible green earth (unclear); NaCl salt
3	10-50µm - reached 250µm	White/grey; with black particles	Ca; S; (Si)	Gypsum plaster
4	>1200µm	White plaster; many aggregates	Si; Ca; (Cl); (S); (Al); (K); (Na); (Mg)	Lime plaster; mainly rounded quartz aggregates; salt is present

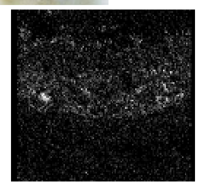
Sample no.: SIY-AB10





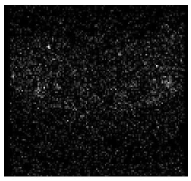
Lead La1

Arsenic La1-2



Aluminium Ka1

Iron Ka1



Potassium Ka1

Layer	Thickness	Description	Elements	Interpretation
1	Up to 70µm	White/ transparent	Ca, S, Si, (Al), (Fe)	Gypsum and some dust
2	40-100µm	Orange	Ca, S, Fe, Pb, (Si), (Cl), (Mg), (K), (Al); (As)	Lead oxide (minium) with haematite and traces of As (possibly realgar), calcite and some gypsum
3	20-60µm	Red	Si, Ca, S, Fe, Al, (K), (Mg)	Red ochre with calcite and some gypsum
4	20-300µm	White/grey with black particles	Ca, S, Si	Gypsum plaster
5	>600µm	White plaster with aggregates	Ca, Si, Cl, (Al), (Mg), (S)	Lime plaster with quartz aggregates

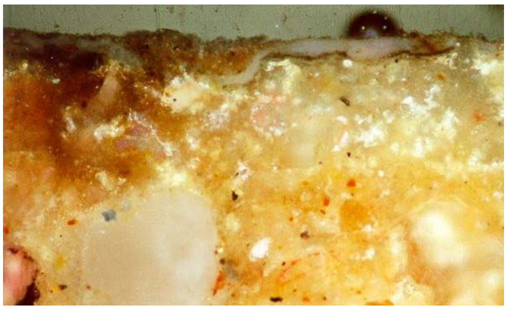
Sample no.: STA-01

Layer	Thickness	Description	Elements	Interpretation
1	80-600µm	Red		
2	40-280µm	White		
3	3500µm	Pinkish white with aggregates		
4	ca. 120µm	White		

Sample no.: STA-02

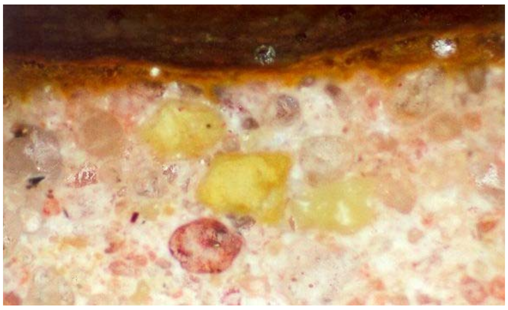
Layer	Thickness	Description	Elements	Interpretation
1	100-400µm	Yellow/reddish in some parts	Ca; Mg; Si; (Al); (Fe)	Yellow ochre with lime made of dolomite stone
2	>1400µm	White with a lot of aggregates	Ca; Si;(Mg); (Al)	Lime plaster with quartz aggregates

Sample no.: STA-04



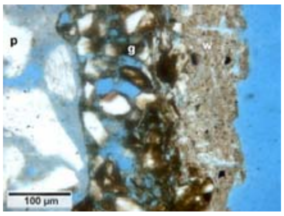
Layer	Thickness	Description	Elements	Interpretation
1	Up to 100µm	Red/brownish		
2	30-50µm	White		
3	>700µm	Beige; with aggregates		

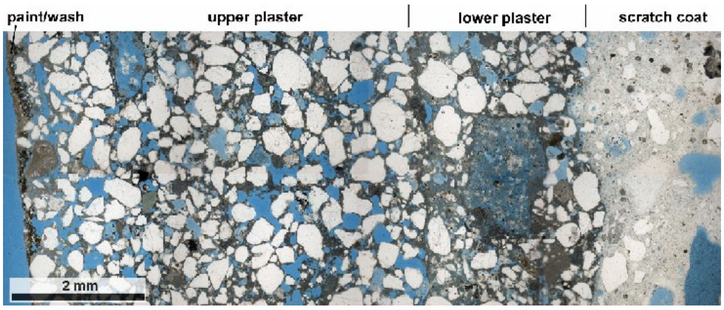
Sample no.: STA-06



Layer	Thickness	Description	Elements	Interpretation
1	100-400µm	Dark yellow		
2	6mm	Pinkish/yellow, pink aggregates		
3	2-2.5mm	Pinkish beige with aggregates		
4	5-9mm	Dark beige; many aggregates		

Thin Section





Components

Paint layer (w): consists of finely dispersed carbonate; *ground layer (g)*: consists of small siliceous and carbonate aggregate and finely dispersed iron oxide/hydroxide, clay (?) (ochre); *upper plaster (p)*: aggregate: quartz; rock fragments (polycrystalline quartz); carbonate; binder: carbonate; few lime lumps; isotrope phase (cubic salt or hydrate phase?); gypsum (very few); *lower plaster*: aggregate: as upper plaster; binder: carbonate; few lime lumps; isotrope phase (cubic salt or hydrate phase?); *scratch coat*: aggregate: quartz; rock fragments; carbonate; binder: gypsum; carbonate; lumps of lime and gypsum

Texture

Orientation: consists of four layers: *paint layer* with a brownish ground (ca. 150 µm), *upper plaster* (6.0 mm), *lower plaster* (2.5 mm) and a *scratch coat*; all particles randomly oriented.

Structure: *upper plaster*: aggregate subangular to rounded; poorly to moderately sorted; moderate amount of binder; high amount of air voids and interstitial pores; rare grain-grain contact; *lower plaster*: aggregate subangular to rounded; poorly to moderately sorted; moderate amount of binder but higher than in upper plaster; high amount of air voids and lower amount of interstitial pores; rare grain-grain contact; *scratch coat*: aggregate subangular to subrounded; moderately sorted, very high amount of binder; moderate amount of air voids and almost no interstitial pores; no grain-grain contacts.

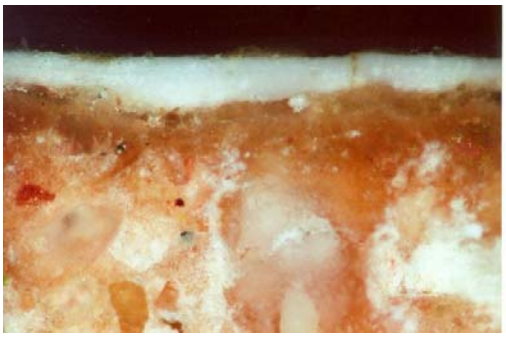
Sample no.: STA-07

Layer	Thickness	Description	Elements	Interpretation
1	Up to 150µm	Brownish not uniform layer, dust		
2	8-10mm	Reddish brown plaster with aggregates		
3	>3mm	White plaster with aggregates		

Sample no.: STA-08

Layer	Thickness	Description	Elements	Interpretation
1	40-140µm	White	Ca; Si; (S); (Cl); (Al); (P)	Lime layer with sand and possibly apatite
2	30-140µm	Red	Ca; S; Si; (Al); (Fe); (K)	Red ochre and gypsum
3	4.5-5mm	Beige/pinkish plaster with aggregates	Ca; Si; (S); (Cl); (Al); (Mg)	Lime plaster with aggregates
4	>5mm	Beige/brownish plaster with aggregates	Ca; Si; (Al); (Mg)	Lime plaster with aggregates

Sample no.: STA-09



Layer	Thickness	Description	Elements	Interpretation
1	20-60µm	Light red/brownish	Ca; S; Si; (Al)	Gypsum with dust
2	100-140µm	White with vertical crack	Ca; (S)	Pure lime, with trace of gypsum
3	>3200µm	Reddish brown plaster with many aggregates	Ca; S; Si; (Al); (Fe)	Gypsum with quartz aggregates

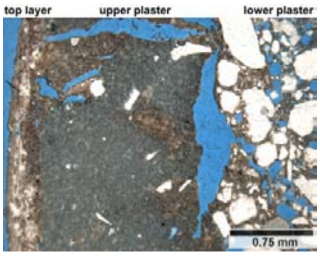
Sample no.: STA-10b

Layer	Thickness	Description	Elements	Interpretation
1	40-240µm	Red	Ca; S; Si; Al; Fe	Red ochre with gypsum and some quartz grains
2	>1mm	White/pinkish with many aggregates	Ca; Si; Al; (Mg)	Lime mortar with quartz aggregates, and a dolomite one is found

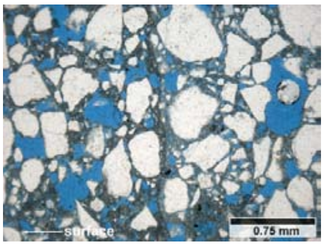
Sample no.: THE-01

Layer	Thickness	Description	Elements	Interpretation
1	100-200µm	Reddish white	Ca; Si; (Si); (Cl); (K); (Na)	Dust at top; followed by sulphate and calcite crust due to contamination
2	1000-1500µm	Fine white plaster		Lime plaster with much NaCl; gypsum at the top
3	>1000mm	Coarse white plaster		Lime plaster; many quartz aggregates of various sizes

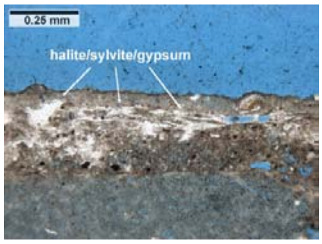
Thin Section



Sequence of layers in sample; cracks in the top layer; crack in the upper plaster is perpendicular to the surface.



Boundary between the two sublayers of lower plaster; high amount of air voids and interstitial pores.



Halite/sylvite precipitations, intergrown with gypsum in a crack of the top layer.

Components:

Uppermost layer: carbonate; isotropic phase as precipitation in cracks, probably a cubic salt (halite/sylvite); gypsum is precipitated in crack parallel to surface, intergrown with isotropic phase; *upper plaster*: aggregate: quartz; carbonate; few rock fragments; binder: carbonate; lime lumps; gypsum as reprecipitation in few pores; *lower plaster*: aggregate: quartz; rock fragments (polycrystalline quartz); one large isotropic, elongated fragment that might be a product of a hydraulic reaction since it is surrounded by a reaction zone of carbonate; binder: carbonate, lime lumps; larger plate-like crystallites of a clay, probably kaolinite or metakaolinite.

Texture

Orientation: sample has three layers, *uppermost* layer (ca 200 µm), represents original surface; *upper plaster* (1.5 mm) and *lower plaster*; the lower plaster contains two sublayers with evident boundary; uppermost layer has many small cracks parallel to surface, filled by isotropic salt (halite/sylvite); upper plaster with few cracks perpendicular to the surface.

Structure: *upper plaster*: scarce aggregates; subangular to subrounded; moderately sorted; very high binder content; few air voids and interstitial pores; *lower plaster*: large aggregates, subrounded to rounded, small aggregates are very angular and often elongated; poorly to moderately sorted; moderate binder content; high amount of air voids and interstitial pores; high amount of very fine aggregates.

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