The Wall Paintings of Ahhichatragarh, Nagaur:

Report on the Investigations and Treatment Undertaken in February - March 2006 and Proposals for Future Conservation

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SUMMARY

Following the initial survey of the wall paintings undertaken by Stephanie Bogin (Courtauld Institute of Art) in September 2005, a five-week programme of diagnosis, recording and conservation work was undertaken in February – March 2006 by a Courtauld team in collaboration with the ICI Mehrangarh Art Conservation Centre (IMACC). This was followed by scientific examination of selected samples at the Courtauld Institute, and the production of the present report. Funding for the conservation programme was generously provided by the Helen Hamlyn Trust.

The conservation work on site included emergency measures such as the stabilisation of dangerously detached plaster, cleaning tests on a wide variety of different paintings, diagnosis of moisture and salts problems, and detailed documentation of deteriorating wall paintings. The results of this work are provided in the present report, and include emergency stabilisation of paintings on the exterior of the Hadi Rani Mahal and elsewhere, and successful cleaning trials on paintings of the Abha Mahal, Hadi Rani Mahal, and the Sheesh Mahal. Recommendations for further investigations and monitoring at the site are made in Section 7 of the report.

One of the main aims of the programme was to identify the most appropriate paintings on which to concentrate actual conservation treatment in the next few years, while investigations and testing on other paintings continues. The criteria employed included the relative importance of the paintings, the extent and nature of their deterioration, and the urgency and also feasibility of their treatment. On this basis, the paintings of the Sheesh Mahal – on both the interior and exterior – are recommended here for conservation treatment. Among the finest and most important at Nagaur, these paintings not only now require such treatment, but their appearance – and that of the building as a whole – would be considerably improved. Proposals for a comprehensive three-year conservation project on the Sheesh Mahal are therefore made in Section 8 of the report.

Acknowledgments

This phase of investigation and treatment could not have proceeded without the support of the Mehrangarh Museum Trust (MMT) and generous funding by the Helen Hamlyn Trust (UK). We are particularly indebted to Rao Raja Mahendra Singh (Chief Executive Officer, MMT) who oversaw all aspects of the on-site campaign.

We are also grateful for the collaboration of IMACC, especially Sunil Laghate (Acting Director) and Vikram Rathore Singh (Conservator). Minakshi Jain (Architect, Jain Associates) kindly discussed the architectural conservation of the site with us. On site, Surendra Harsh (Site Manager) tirelessly met our logistical needs throughout the phase.

At the Courtauld Institute, the Director, Dr. Deborah Swallow has afforded constant encouragement and support. Facilities for the follow-up scientific examination were provided by the Institute's Conservation of Wall Painting department, and we are extremely grateful to David Park (Director of the Department) and Sharon Cather for their consultation and advice throughout the phase. Through the auspices of the Department, optical mineralogy was undertaken by Dr C. Bläuer Böhm (Director of the Expert Center für Denkmalpflege, Zurich); consultation concerning the deterioration of the glass was kindly provided by Satoko Tanimoto (University College, London); and SEM / EDS analysis was undertaken at the Centre for Ultra-structural Imaging, King's College (University of London).

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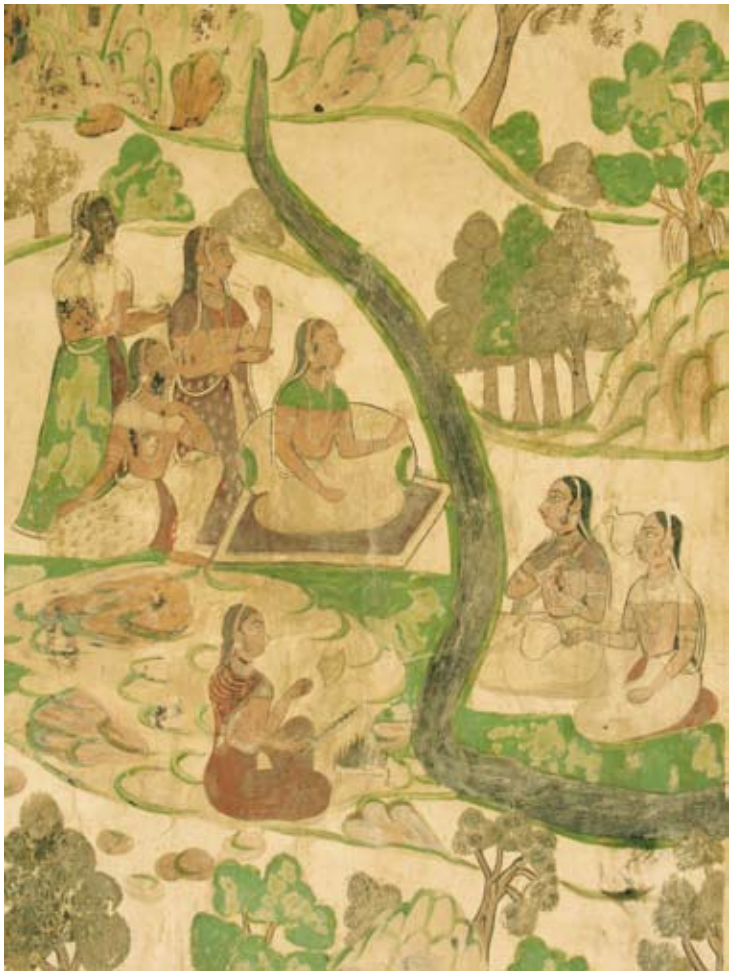
Note: All photographs by the authors
All plans generated from the site plan by Jain Associates

INTRODUCTION

The Ahhichatragarh complex is one of the finest and most extensive examples of Rajput-Mughal style architecture in the Marwar region of Rajasthan. Its many superb wall paintings, and its unique water system with pools and fountains, are further features distinguishing it as an exceptionally significant cultural monument in Rajasthan. After years of comparative neglect, considerable conservation efforts have been undertaken in recent years under the direction of the Mehrangarh Museum Trust (MMT), including an extensive programme of architectural conservation in 1998 – 2001 (Jain 2001), and the whole complex is now the focus of increasing study and attention.

Founded in the 4th century, Ahhichatragarh was modified by various rulers over the centuries, and much of its current appearance is attributable to Maharajah Bakht Singh, who undertook an extensive building campaign during his rule in 1725 – 1752. Extending over thirty-six acres, the four major palaces and sixty other buildings are constructed of sandstone and were originally rendered in lime plaster. Many of the wall paintings in the palaces and other buildings are also tentatively attributed to the period of Bakht Singh (Crill 1999:92), the only royal figure to base his court at Nagaur. The decorative programmes are extraordinarily widespread, occurring on both interior and exterior walls, ceilings and even floors (Bogin 2005). Often of very high quality, they include figurative subjects as well as decorative designs, and provide a wealth of historical information on the use of the palaces, manners of dress, as well as daily court life at Nagaur. In the most recent study of Indian wall painting, they are described as 'the finest murals of Marwar' (Seth 2006:325). Matching the quality of the painting is the richness of its materials, including organic colorants, gold leaf, and elaborate inlaid mirror-work. Of 'unmatchable' quality is the highly polished traditional ***kody*** lime plaster on which the paintings are executed, 'unique in… its smoothness and luster' (Jain 2001:40).



Left: view of the Hadi Rani Mahal and the Abha Mahal.
Above: detail of the paintings in the second-floor scheme of the Hadi Rani Mahal.

Following on from the recent architectural conservation work, it was recognised that a comprehensive survey was needed of the wall paintings and their present condition, and this was undertaken for the MMT in 2005. The resulting report (Bogin 2005) highlighted the varying – and in some cases alarming – condition of the paintings, noting causes of deterioration such as water infiltration, salt activity, and the deterioration of coatings applied in the past.

As a result of the recommendations in Bogin 2005, a phase of emergency treatment, further investigations, treatment-testing and documentation was commissioned by the MMT in February - March 2006. One of the chief aims of this phase was to establish clear priorities for the future conservation of the wall paintings. The work was funded by the Helen Hamlyn Trust (UK), and undertaken in collaboration with the ICI Mehrangarh Art Conservation Centre (IMACC). It was carried out by Stephanie Bogin, Charlotte Martin de Fonjaudran and Sibylla Tringham (Conservation of Wall Painting Department, Courtauld Institute of Art) with the assistance of Vikram Rathore Singh (IMACC). At the end of the phase, the results were discussed on site with Rao Raja Mahendra Singh (Director of MMT), Sunil Laghate (Acting Director of IMACC), and David Park (Director of the Courtauld's Conservation of Wall Painting Department). The results are presented here, together with the findings of the scientific analysis subsequently undertaken at the Courtauld Institute, and include both general recommendations and specific proposals for future conservation work.

Left: detail of the paintings in the vault of the Sheesh Mahal.
Above: examining the exterior paintings of the Hadi Rani Mahal, with Rao Raja Mahendra Singh (far left), Sunil Laghate (near left) and David Park (right), March 2006.

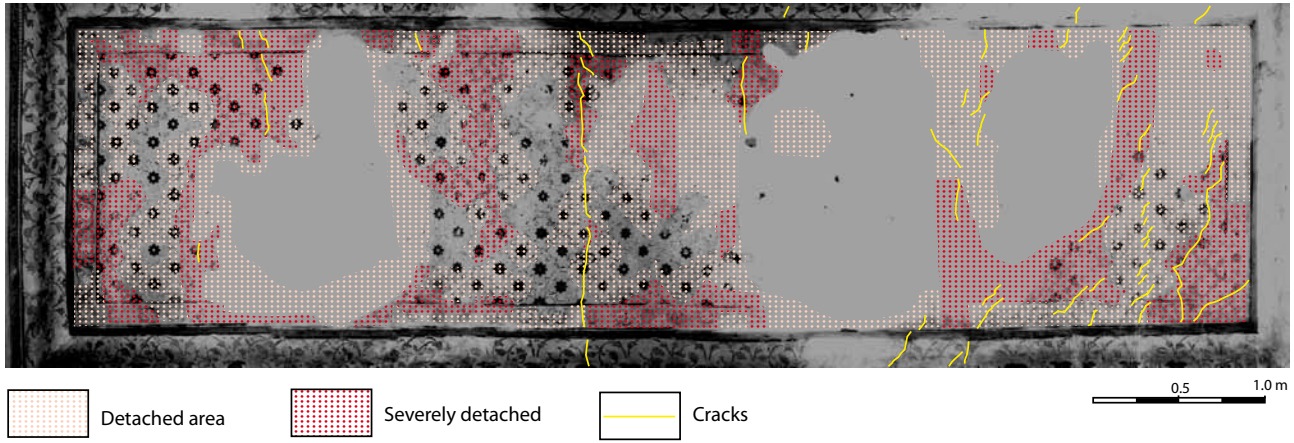
DOCUMENTATION

Documentation is an essential aspect of any conservation programme. Wong (2003) has defined its role in terms of both obligations (ethical and archival) and objectives (management, investigation, intervention, assessment, monitoring and maintenance). Documentation of wall paintings can be done in a variety of ways, such as visual glossaries, photographic monitoring, and written and graphic documentation. Details of the methods and results of the documentation are given in Appendix 2.

In the present phase a visual glossary of the condition of the wall paintings in the Sheesh Mahal was undertaken (Appendix 2a). It provides a significant tool for ongoing condition assessment, as well as for communication among members of the team. It is an important record for future consultation, since it illustrates the condition of the paintings prior to conservation treatment.

As part of the documentation component of this phase, a programme of photographic monitoring was developed with the IMACC team. Comparable photographs will be taken at four-month intervals over the next year at three locations in the Abha Mahal and Sheesh Mahal. This will allow assessment of changes across seasons, and takes advantage of the continuous access to the site of the IMACC team. Specific locations and images are provided in Appendix 2d.

Four documentation sessions were provided to the IMACC team to familiarise it with the use of the digital camera, the processes of creating a visual glossary and undertaking photographic monitoring, and to discuss the aims and objectives of documentation at the site. Written documentation of the IMACC sessions is provided in Appendix 2c.



Above: an example of graphic documentation showing areas of detached plaster on the mezzanine ceiling of the Bakht Singh Mahal (for full version see Appendix 2b).

Above: documentation of the detached plaster in the Bakht Singh Mahal being undertaken by Sibylla Tringham (Courtauld Institute).

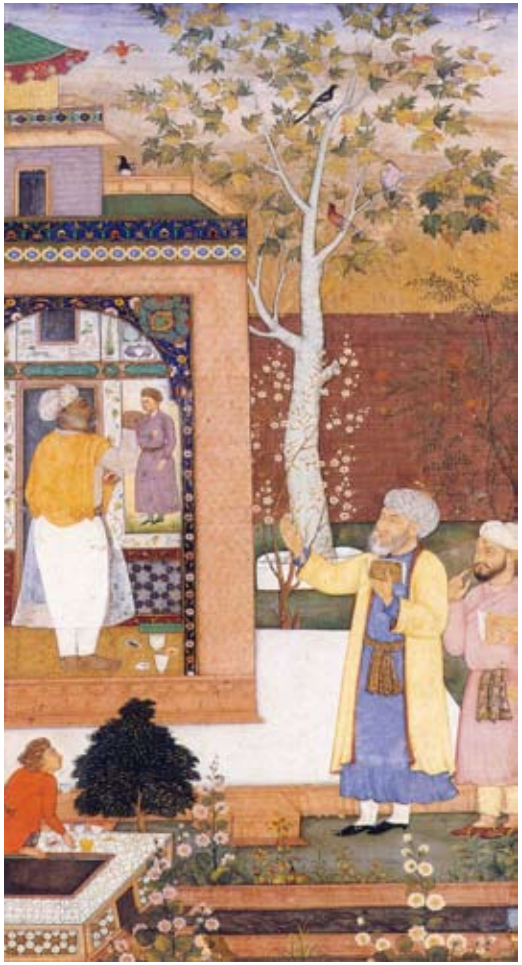
Diagnostic Investigations

Diagnostic investigations are essential for identifying and understanding causes of deterioration and their activation mechanisms. The results will inform decision-making concerning the most suitable conservation approach – whether preventive, passive or remedial. During this campaign, the following investigations were undertaken: examination of original technique, investigations of liquid moisture, and analysis of non-original materials including salts.

Original Technique

Investigations into original technique serve several purposes:

- to better understand the causes and-mechanisms of deterioration;
- to provide parameters for designing an appropriate conservation intervention;
- and to further our knowledge of painting techniques employed in the Rajput-Mughal murals.



Mughal miniature (c.1600-10) of an artist decorating a pavilion in a garden. Although somewhat earlier in date, this illustration shows a decorative scheme strikingly similar to those in the Sheesh Mahal and other buildings at Nagaur (after Stronge 2002, pl. 73).

Samples taken from the Abha Mahal, Akbari Mahal, and Hadi Rani Mahal were mounted in cross-sections and in dispersions and examined with polarised light microscopy. Selected cross-sections were also analysed using SEM-EDS (scanning electron microscopy with x-ray microanalysis). Sampling was designed to answer specific questions regarding the most important issues of deterioration. A more extensive study of the schemes may be appropriate before the implementation of a large-scale intervention.

A detailed presentation of the analytical results from this phase, associated in each case with the relevant building, is provided in Section 6. The most important findings may be summarised as follows.

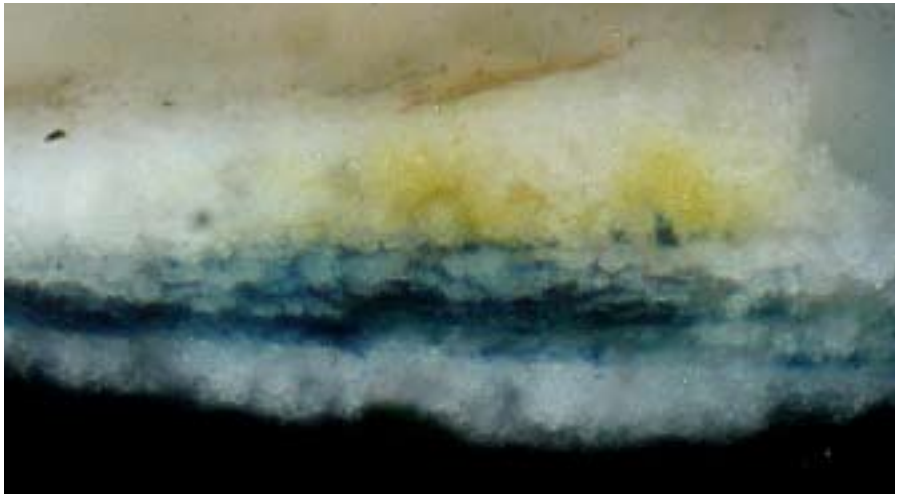
An extensive use of organic colorants was identified in the first-floor scheme of the Hadi Rani Mahal. In these paintings, the trees now alternate bright green (copper chloride) and beige, but analysis revealed that the latter colour is due to the fading of an organic yellow colorant applied over an organic blue layer (probably indigo), illustrated overleaf. A similar organic blue, mixed with lead white, also occurs in the floral border on the second floor of the Hadi Rani Mahal.

Comparative data on organic colorants in Indian wall painting is scarce, and their deterioration mechanisms are complex and not yet fully understood. Further research and in-situ observation are essential for the implementation of suitable remedial treatment and preventive conservation measures.

The dominant bright green pigment in the first-floor scheme of the Hadi Rani Mahal, and which is also present in many of the other schemes at Nagaur, has been identified as copper chloride (see figures overleaf). This has significant implications for remedial treatment, since it precludes the use of any alkaline materials in an intervention. Further analysis and research would be useful in relation to the use of this pigment in Rajput wall painting; to date, it has been identified (probably in the natural form paratacamite) in the murals at Gopi Nath temple, Parasrampura (Rajasthan) of 1742 (Seccaroni & Moioli 1995: 228), which also provide iconographical parallels to the Nagaur paintings.

Above: a section of the first-floor scheme of the Hadi Rani Mahal. The palette is predominantly bright green and beige, the latter the result of the fading of organic colorant.

Below: the cross-section shows a sample taken from the beige-coloured tree (similar to the one located above) from the first floor scheme in the Hadi Rani Mahal (Sample #3789), showing two layers of paint, yellow over blue (200x). The upper section of the yellow paint layer has faded, resulting in the present beige colour.

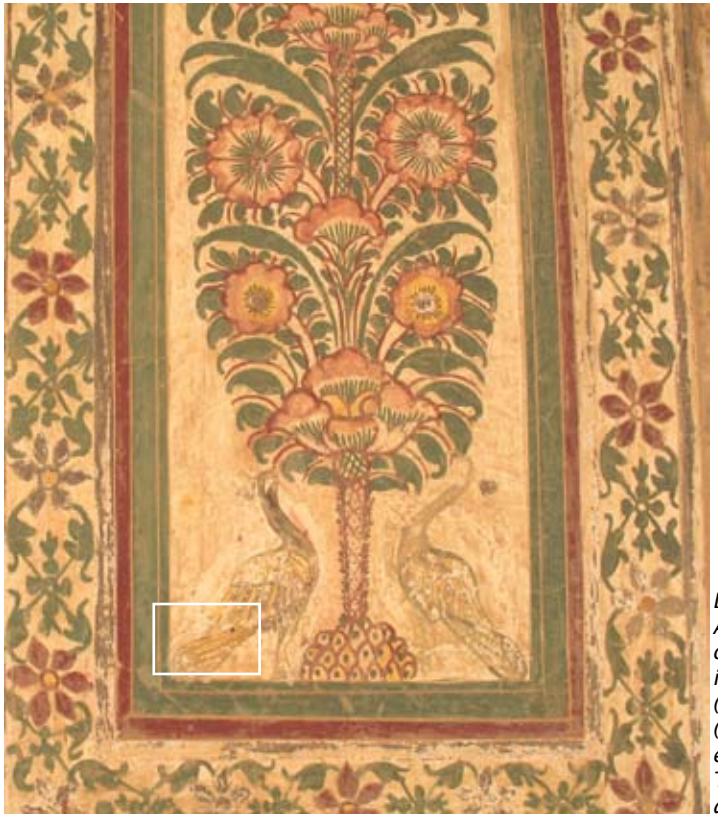


Right: cross-section of sample (Sample #3788, 200x) of the bright green trees in the Hadi Rani first-floor scheme, illustrated left). The pigment was identified as a copper chloride.

Right: the upper border in the second-floor scheme of the Hadi Rani Mahal is decorated with a floral motif.

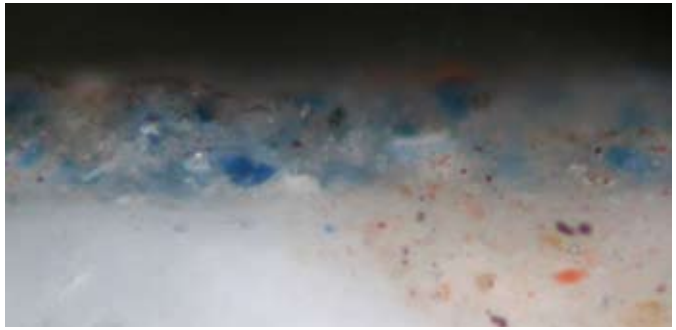
Right: cross-section from the border in the Hadi Rani Mahal (Sample # 3792, 200x) illustrated above, taken from the blue flower showing lead white mixed with indigo.

Although it had been hypothesised that the preferential loss of the yellow pigment on the exterior east wall of the Abha Mahal was due to the fading of an organic colorant, it has been shown that the pigment is yellow ochre and therefore not subject to fading (illustrated below). Deterioration might be related to the clay content of the earth pigment or to its binding medium, and exposure to extreme and fluctuating environmental parameters (temperature from direct sunlight, humidity and rain water).

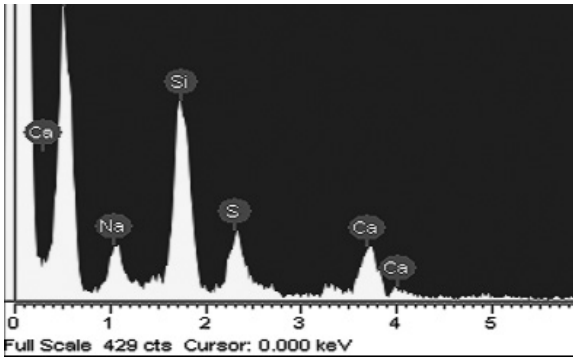


Left: the exterior of the Abha Mahal has few areas of yellow pigment remaining. Below left: cross-section (200x) of a yellow sample (Sample #3784) from the exterior of the Abha Mahal. The pigment was identified as yellow ochre.

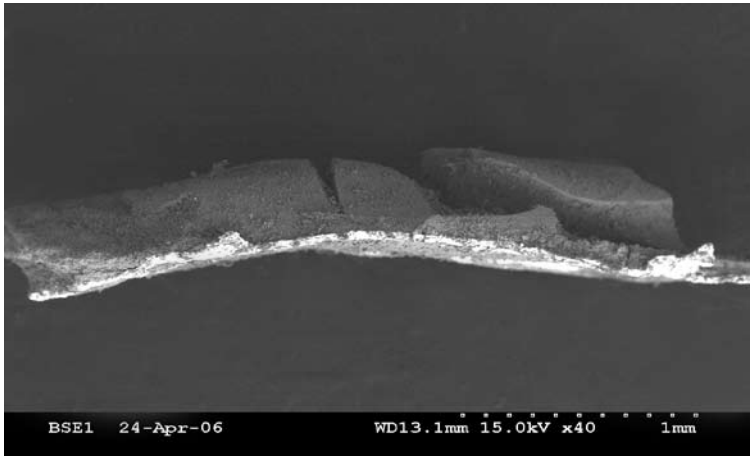
The inlaid mirror-work of the Sheesh Mahal is a fine example of the extensive use of glass so characteristic of Rajput interiors, and which surpasses its Mughal prototypes (Martinelli & Michell 2004:18). Despite the immense importance of such decoration in Rajasthan, it seems never to have been the subject of detailed scientific examination, though such analysis is essential for understanding its deterioration. Initial examination of the mirror-work of the Sheesh Mahal (elemental analysis by SEM-EDS) indicated that it is composed of sodium-based silica glass with a lead foil backing, and further research is needed to determine whether its deterioration is due to the leaching out of sodium and calcium (pers.comm. Satoko Tanimoto), see images overleaf. Analysis also showed that a glass-based pigment (probably smalt) was employed for the blue areas in the floral borders in the exterior paintings of the Sheesh Mahal, illustrated below.



Above and left: the exterior scheme of Sheesh Mahal retains an unaltered blue pigment which is probably smalt (Sample #3793, 200x).



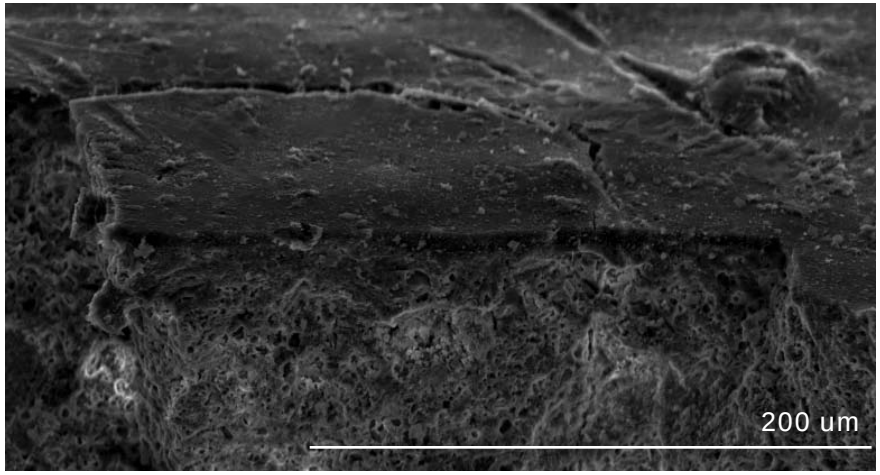
Left: the lower dado in the Sheesh Mahal is decorated with grey-blue inlaid mirror-work. The mirror is a sodium-based silica glass, (see EDS spectra of Sample #3806 above) with a lead foil backing. In the back-scattered SE micrograph (40x) of Sample #3806 below, the lead foil is imaged as the white layer.



Added materials

Synthetic coatings have been widely applied on the paintings at the site and are most notable on the interior of Hadi Rani Mahal and both the interior and exterior of Sheesh Mahal. Polyvinyl acetate is documented as having been applied on the interior of Sheesh Mahal (Agrawal 1989). Imaging with SEM confirmed the presence of a smooth polymer coating on these paintings of varying thickness (illustrated below). There may be additional undocumented and unidentified coating(s) and further characterisation of these material(s) is required to better define the scope for their removal.

Left: a niche in the Sheesh Mahal with discoloured, shiny coating.
Below: SE micrograph of Sample #3805 (250x) from the interior of the Sheesh Mahal before cleaning, showing a smooth amorphous coating above the lime plaster.



Liquid moisture investigations

Water infiltration, due to failures in the rainwater disposal system and/or historic pipes, has affected several structures causing staining, plaster and paint loss, and contributing to the activation of salt deterioration. The Sheesh Mahal (32), Bakht Singh Mahal (39), and Hammam (35) all exhibit moisture-related deterioration in the ceiling areas. Although the roofs were cleared of accumulated vegetation and repaired during the architectural conservation programme, the condition of some schemes and localised salt efflorescences warranted further investigation.

A liquid moisture assessment was therefore carried out in the Hamman (35) to determine if infiltration continues. Drilling core samples is necessarily invasive, so it was decided that an initial investigation in a single building was appropriate. The Hammam was chosen as representative of the types of deterioration associated with infiltration throughout the site, and because room 3 offered appropriate sampling locations. Details regarding the conclusions for the Hammam are given in section 6 and the full data are presented in Appendix 3c.

In summary, the results for this interior room (and adjacent corridor) demonstrated that the occurrence of liquid moisture within the walls is very irregular. On the north wall, samples taken at high level (1.95 and 3.00 m) were wet for the first 4 cm, corresponding to the obvious staining. By contrast, most samples taken at low level were dry.

These initial results suggest that, as anticipated, determining the current state of the liquid moisture in this complex structure will not be straightforward. There are indications that water ingress is not an active problem in the Hammam. However, the building should be monitored for evidence of change in the condition of the paintings and plaster which may indicate otherwise.

The north-east corner of the Hammam shows evidence of water infiltration: staining, plaster loss and salt efflorescence. This area was chosen as a sampling location for the liquid moisture investigations to determine if infiltration continues in the Hammam.

Salt analysis

Salts are a very common source of deterioration for wall paintings. Salt activity was observed in several areas of the Abha Mahal, the vault of the Sheesh Mahal, the domes of the Hammam, and on the upper north wall of the Krishna Temple. Investigating the types and distribution of the salts can help to identify their sources, and is necessary to understand the deterioration mechanisms and to consider treatment options.

Several types of sample were taken: surface efflorescences from both wall painting and plaster; repair materials used in the recent architectural conservation programme; water on the site; and the drilled core samples from the liquid moisture investigation. Analysis was principally of individual ions (sulfates, chlorides and nitrates), though for two salts the salt species were identified by means of optical mineralogy. Full results are provided in Appendix 3d.

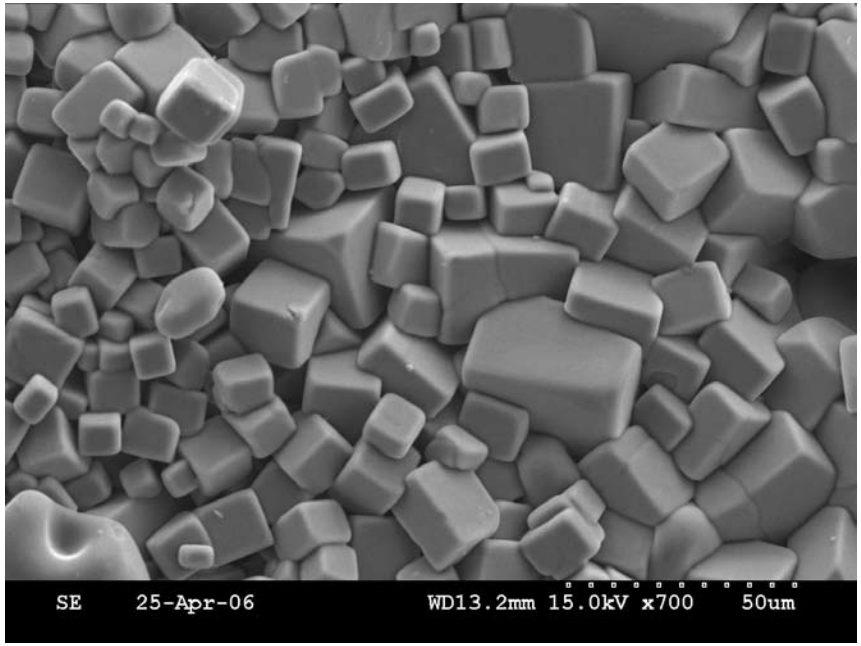
Two areas of salt efflorescence were identified as containing both sodium chloride (NaCl) and sodium nitrate ($NaNO_3$).[1] It should be stressed that because these two salts have a common ion (sodium), under different thermo-hygrometric conditions the same ions may crystallise as different salts (Sawdy 2003). Almost all other efflorescences contained both chloride and nitrate ions.

Reassuringly, the repair materials used in the recent architectural conservation do not give cause for concern. Only two samples tested positive: one for sulfates (B1) and another for low levels of nitrates (B4).

By contrast, the three samples of site water (tap, tank and fountain) were all contaminated with sulfates, chlorides and nitrates. This water may well be the source of ions in the new repair materials. Clearly, this water should be treated before use on historic materials where it may cause future damage or other sources used.

Ion analysis of the drilled core samples from the Hammam is more complicated, and the present distribution of salt contamination is probably related to the sources and movement of the liquid water over time (perhaps over a considerable time). Sulfates were present in surface samples at several locations, while chlorides and especially nitrates also occur in depth. Once the salts are present, they have the potential to cause damage whenever they are

Above: area of salt efflorescence from Room 10, the Abha Mahal.
Below: SE micrograph (secondary electron, 700x) of salt sample (Sample # NAG05-26-11) from the area illustrated above in the Abha Mahal.



1 Optical mineralogy was kindly undertaken for the Courtauld Institute by Dr C. Bläuer Böhm, Director of the Expert Center für Denkmalpflege, Zurich.

dissolved and then recrystallise. Treatment options for salt-contaminated walls are limited, and all have disadvantages (Cather 2003).

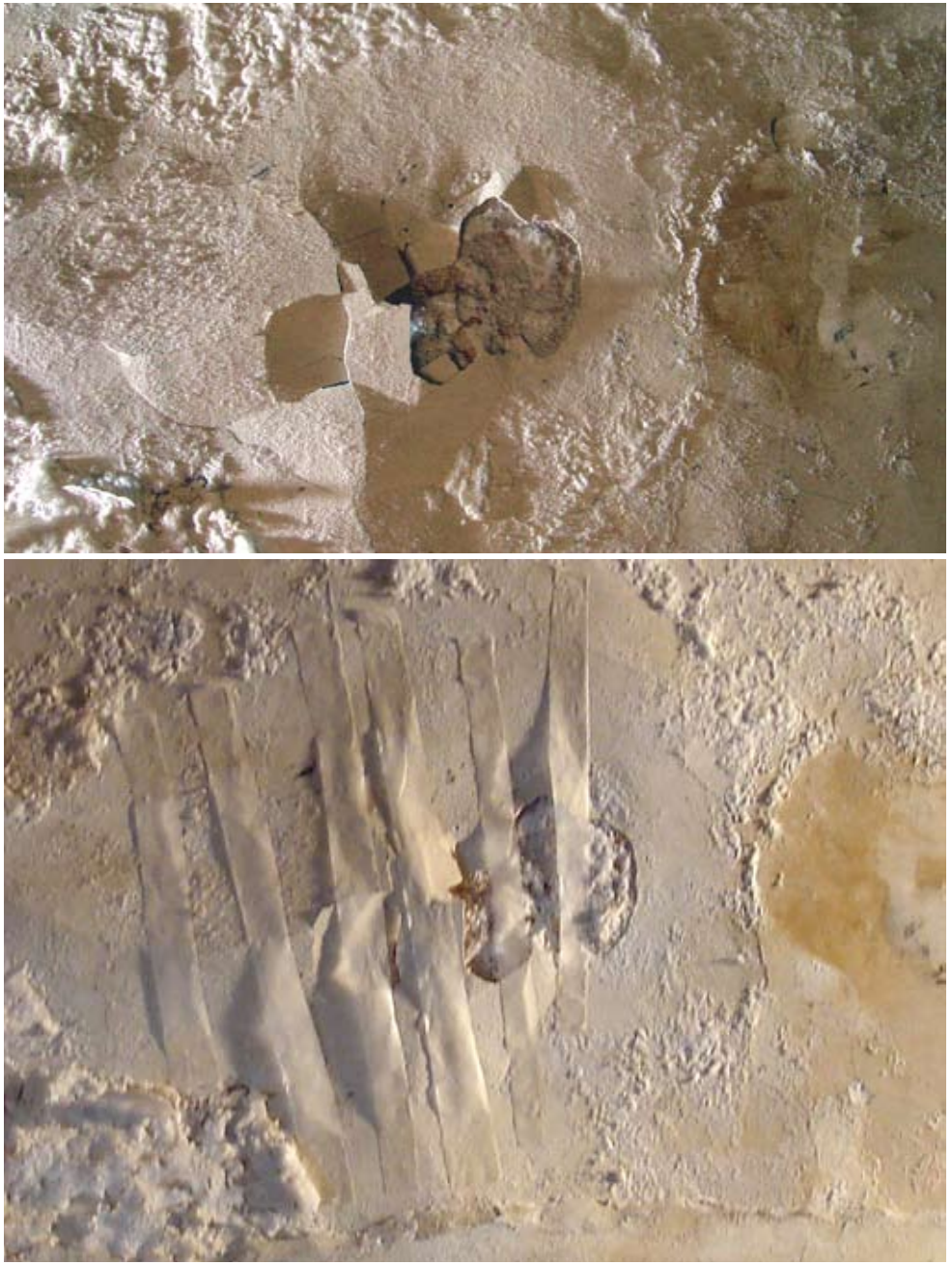
Salt contamination can have a number of possible sources: original and added materials; vegetation on the roofs (removed during the architectural conservation); historic use (water tanks) and failed drainage; contaminated water used for repairs; and ground water. In all cases, however, salt problems are activated by liquid water. Therefore, the emphasis should be on maintaining the buildings and their water disposal systems in good order.

A final aspect of potential salt deterioration should be considered. Some salts can dissolve by absorbing moisture from the air (deliquesce), including both of the salt species identified. Sodium chloride deliquesces when the relative humidity (RH) is about 75%, and sodium nitrate at about 73%. Although the RH was low during the investigations, it is possible that during the rainy season the salts may be activated by high RH. Photographic monitoring at regular intervals will help to understand the behaviour of the salts in different conditions, see Appendix 2d.

EMERGENCY STABILISATION

During this phase emergency treatment was carried out to provide interim stabilisation of areas considered to be at imminent risk of loss. Temporary facings were applied to localised areas of detached plaster on the north façade of Hadi Rani Mahal, the interior of Abha Mahal, and the interior courtyard of Sheesh Mahal. Performance criteria for this stabilisation included compatibility, durability over the anticipated time, resistance to biodeterioration, and complete removal of the temporary materials. Monitoring will be required to ensure that these measures are effective and it is desirable to implement a long-term approach to stabilising these areas as soon as possible.

Above: the fragmentary remains of a severely detached painting on the north facade of the Hadi Rani Mahal before facings were applied.



An area of severe detachment due to salts activity in room 10 of the Abha Mahal: before (above) and after temporary facings were applied (below).

Remedial Treatment Trials

A major component of the long-term conservation and presentation of the wall paintings at Nagaur involves stabilisation and aesthetic treatments. Before specific recommendations for these can be made, trials and assessments are required. Such interventions are guided by performance criteria (expectations of how the interventions will behave over time). General criteria, applicable to all interventions, include: preservation of significance; minimal intervention; knowledge of original materials, physical history and present condition, and of conservation materials and methods; retreatability/reversibility, stability and compatibility; appropriate health and safety measures; documentation.

At Nagaur, the large number of painting schemes, the virtual absence of information about their physical history, and similarly the lack of information on the painting technologies of this period and region, severely hamper the design of remedial interventions. Recognising these limitations, it was decided that assessed trials would be undertaken to address a variety of conditions considered representative of those encountered throughout the site. Trials were undertaken in three primary areas (Abha Mahal, Hadi Rani Mahal, and Sheesh Mahal) of:

- Cleaning: removal of non-original materials;
- Repairs: replacement of failed, harmful, or unsightly plaster repairs;
- Grouting: stabilisation of detached plaster by injection of an adhesive with bulking properties.

Left: a cleaning trial in Hadi Rani Mahal, first floor, after removal of a discoloured synthetic coating.
Above: a cleaning trial in the Sheesh Mahal on the central motif of the inlaid mirror-work, including removal of dirt deposition and lime residue.

Cleaning

The three trial locations were chosen to be representative of a range of cleaning problems, including the removal of dirt deposition, synthetic coatings, and lime residues.

Since cleaning is irreversible, the performance criteria focus on the choice and use of materials that are safe for the paintings, and include: specificity (cleaning materials should not adversely affect the original) and clearance (all materials must be removed). Recognising the need for a better understanding both of the original materials and the effects of the cleaning, several samples were taken before and after trials. They were examined using polarised light microscopy (PLM) and scanning electron microscopy (SEM) to assess the effects (see Section 6 and Appendix 3b).

At Nagaur a number of issues particularly complicate the cleaning. Although very little is known of the technology of these or similar paintings, it is clear that the painting materials are highly susceptible and include organic colorants, copper- and lead-based pigments, as well as inlaid mirrored glass. Some of these materials have already altered, most notably the lead pigments in the Sheesh Mahal, compromising what is possible in terms of cleaning results. In addition, past conservation materials, particularly an unevenly applied and now aged synthetic coating, pose further problems.

Nonetheless, several of the cleaning trials undertaken produced satisfactory results and it will be possible to begin the cleaning of the exterior of the Sheesh Mahal based on the success of trials carried out in the present phase. However, other areas present more challenging issues, requiring further trials with a wider array of cleaning materials.

Above: Stephanie Bogin (Courtauld Institute) applying a sorbent during cleaning trials to remove the heavy deposition of dirt which obscures the exterior scheme on the east facade of the Abha Mahal.

Repairs

Repairs of plaster losses have two important roles: they are necessary for stabilising adjacent plaster and they also have a significant aesthetic impact. At Nagaur, previous repairs have either failed, adversely affected the original (especially covering features such as the inlaid glass), or are unsightly and detract significantly from appreciation of the painting. A visual glossary was developed for recording their condition (see Appendix 2a), and trials were undertaken to assess alternative materials.

Performance criteria were set for assessing the trials, including: minimal shrinkage; similar thermal, hygral and mechanical behaviour to the original plaster; durability; absence of release of harmful ions; and appearance. Considering the diversity of the locations to be treated, several variables will have to be taken into account for the assessment, including: interior and exterior conditions; painted and unpainted areas; depth of losses; and cleaning level of surrounding painting.

Several repair formulations were developed, tests applied to a stone slab and assessed (see below). Those which best met the criteria were then applied in an area of unpainted plaster and a final selection made of two formulations. The first was applied in the first floor of Hadi Rani Mahal to losses in the dado of the east wall to replace bright white repairs from a previous intervention. The new repairs are both more sympathetic visually and more compatible. The second was used in the emergency stabilisation of the exterior scheme of Hadi Rani Mahal as an edging repair to replace previous unsightly and overlapping materials (see right). Monitoring these trials over the coming year will assist in the final selection of repair materials. Details of the trials are found in Appendix 5b.

Plaster tests used in the development and selection of a suitable repair material.

Above: an area of exposed detached plaster on the north facade of the Hadi Rani Mahal before (above) and after (below) the application of a trial edge repair.

Grouting

Grouting is a complex and irreversible stabilisation intervention involving the injection of an adhesive with bulking properties to address the failure of adhesion between layers of plaster and/or the support. At Nagaur, plaster detachment has been recorded in various areas (Appendix 2b), and it is expected that further condition assessments will indicate that the problem is widespread. Therefore, the need for grouting is anticipated and it seemed prudent to begin testing and assessment of locally available materials to allow a period of monitoring.

Much research has been done on grouting, particularly at the Courtauld Institute (Griffin 1999; Griffin 2004), to clarify the criteria for both performance and working properties and to develop materials testing. Performance criteria focus on compatibility and stability and include: minimal shrinkage; good adhesion; similar thermal, hygral and mechanical properties; absence of release of harmful ions; low density; and resistance to biodeterioration. A critical criterion is that of future retreatability.

Complications at Nagaur will include: grouting of ceiling plaster (where density issues are critical); presence of soluble salts (that can be mobilised by water-based grouts); and deformed plaster (requiring additional grouting materials and temporary support).

Development of a suitable grout was carried out in two phases; the first aimed to assess the suitability of locally available brick dust as a pozzolanic additive, comparing its performance to previously tested pozzolanas. The second was carried out in situ on unpainted plaster in Sheesh Mahal inner courtyard using the selected grout. Here, the nature of the delamination and its location within the stratigraphy seems representative of the plaster detachment encountered throughout the Fort, and its location is accessible for monitoring. Additionally, the inner courtyard has remains of paintings which until now have been largely overlooked due their poor condition and fragmentary state. During the intervention selected working properties were assessed, while performance characteristics (cohesion and adhesion over time, and stability) should be monitored.

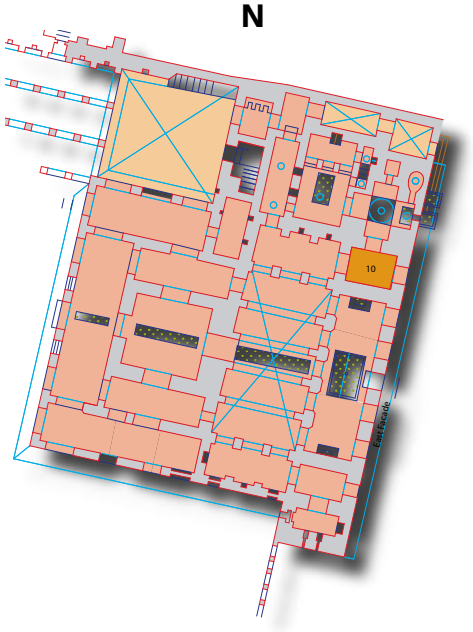
Overall the grout formulated as a result of the trials appears to be suitable. However, further testing and development will improve performance and working properties. Details on the assessment of selected grout materials is provided in Appendix 5c.

Above: Charlotte Martin de Fonjaudran (Courtauld Institute) demonstrates the grouting trials to Rao Raja Mahendra Singh (CEO, MMT) in the interior courtyard of the Sheesh Mahal.
Below: tests were undertaken to compare the pozzolanic performance of locally available brick dust

Overall site plan: palaces discussed in the following pages are outlined in black, the numbers on the plan and before each palace name on the following pages refer to the building number employed by the architectural conservator. These are provided to allow easy cross-referencing with Bogin 2005 and Jain 2001

ABHA MAHAL

The largest palace in the fort complex, the two-storeyed Abha Mahal has substantial internal and external painted decoration. The palace includes extensive water and air cooling systems, as well as a hammam. Its paintings appear to be of relatively late date, and there is evidence of extensive repainting in the interior. An account of the various schemes is provided by Bogin (2005:16-21). Study and treatment-testing during the present phase concentrated mainly on the exterior decoration of the east façade, which has not suffered from repainting, but which is now obscured by a thick uneven deposition of dirt, and at risk from environmental deterioration. Further study was also undertaken, however, of the salt-related deterioration of the paintings in room 10 of the palace (highlighted orange on the plan).



EXTERIOR

The exterior painting on the east façade of the Abha Mahal is covered in a thick uneven deposit of dirt. Loss has occurred at the base of the walls, and large vertical cracks occur in several locations. Detached plaster and earlier losses are often associated with these cracks. However, the plaster is generally stable, and the main issues are the visual disruption caused by the dirt and potential problems resulting from exposure to the weather. Recently, a temporary shelter was installed with the intention of directing rainfall away from the base of the wall. Before developing an approach for the conservation of the scheme, investigations and treatment trials were required to assess the inherent susceptibility of the original materials as well as to assess the feasibility of safely cleaning the painting. Additionally, requirements for appropriate long-term protection were considered.

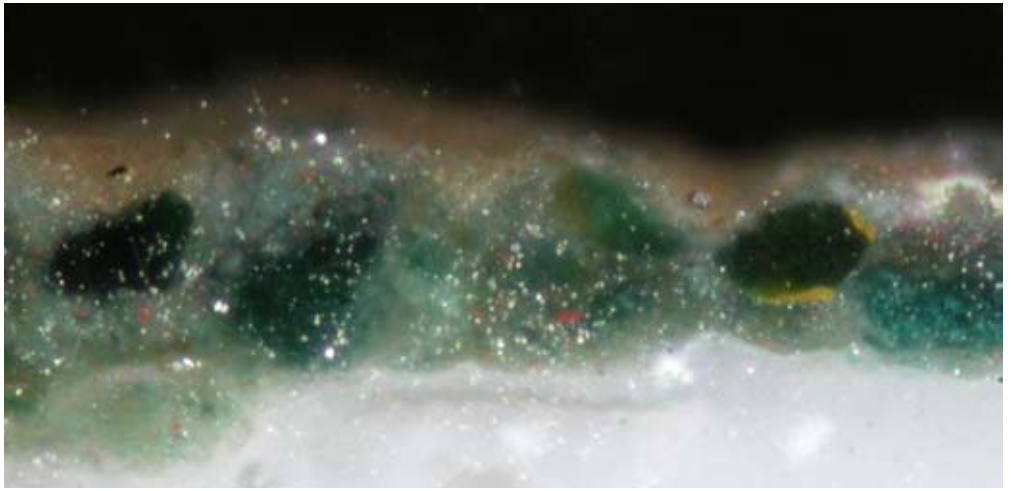
Left: view of the East facade of the Abha Mahal.
Above: the painting scheme on the East facade is obscured by a heavy deposition of dirt.

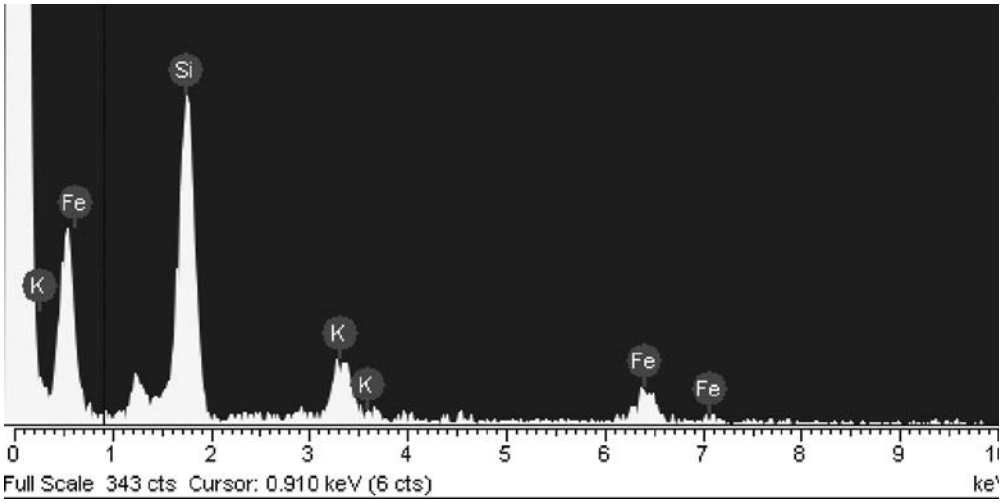
Diagnostic Investigations

Original Technique
The palette of the exterior scheme of the Abha Mahal is largely confined to red, green and black, though slightly water-sensitive these colours appear to be largely stable. However, there is also a bright yellow and given the occurrence of an organic yellow elsewhere at Nagaur (Bogin 2005:NN) and the possibility that cleaning would expose an organic colorant to further risk through fading, the yellow was sampled and analysed.

Two samples were taken from different locations (Samples #3784/#3785) and examined using polarised light microscopy (PLM), as well as scanning electron microscopy with energy dispersive x-ray analysis (SEM-EDS). The pigment was identified as yellow iron oxide (yellow ochre), rather than an organic colorant. It has a high clay content, suggesting that the ochre was of poor quality, and which may explain its preferential loss.

Examination of the green pigment (Samples #3802/#3803) with PLM and SEM-EDS identified it as green earth. Although sampling of the red and black pigments would also be desirable in the future, it does not appear that the exterior scheme includes any organic colorants which would be subject to further deterioration as a result of future cleaning.





Above: context of sampling location for sample #3802.
Centre: cross-section of sample #3802 (200x) showing large particles of green earth.
Below: EDS spectra showing iron (Fe) and silica (Si) content of sample #3802.

Treatment trials

Cleaning Trials
Cleaning trials were undertaken to assess the potential for safe removal of unevenly distributed surface dirt, which varies from a thick encrustation to a light deposit. Initial trials were carried out on a moderately soiled area. Of these, the most successful was a solution of ammonium bicarbonate applied in a cellulose sorbent over an intervention layer. This method was used to clean a larger area of heavy dirt (see image right) to assess the feasibility for such areas.

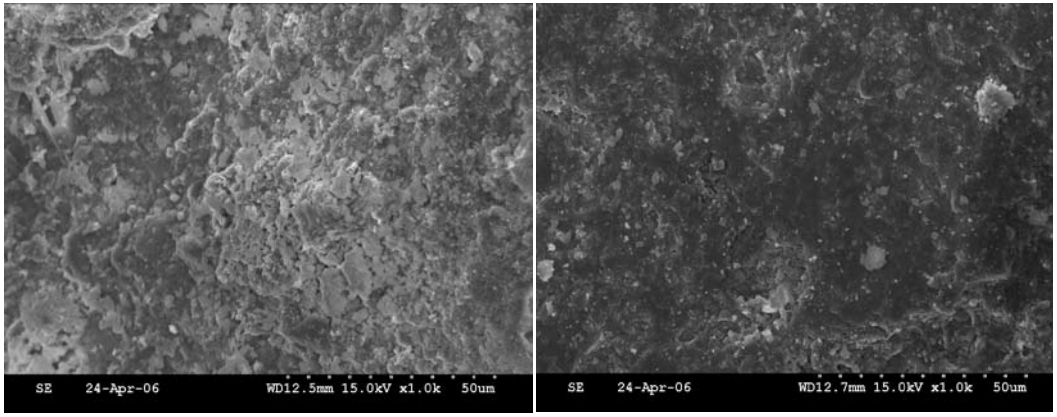
Samples (#3802/ #3803) were taken before and after cleaning and examined using SEM to assess results. Micrographs showing the area before and after cleaning at 1000 x magnification indicate that no damage was caused to the paint layer, and that removal of the dirt was successful (see images below).

Results
The trial made a substantial visible impact and indicated it will be possible to reveal the currently obscured scheme. Although these results were satisfactory, varying conditions will require adjustments. In addition, some mobilisation of the paint layer indicates that limiting exposure to water would be desirable. Moreover, because these paintings are external, some means of long-term protection needs also to be considered.

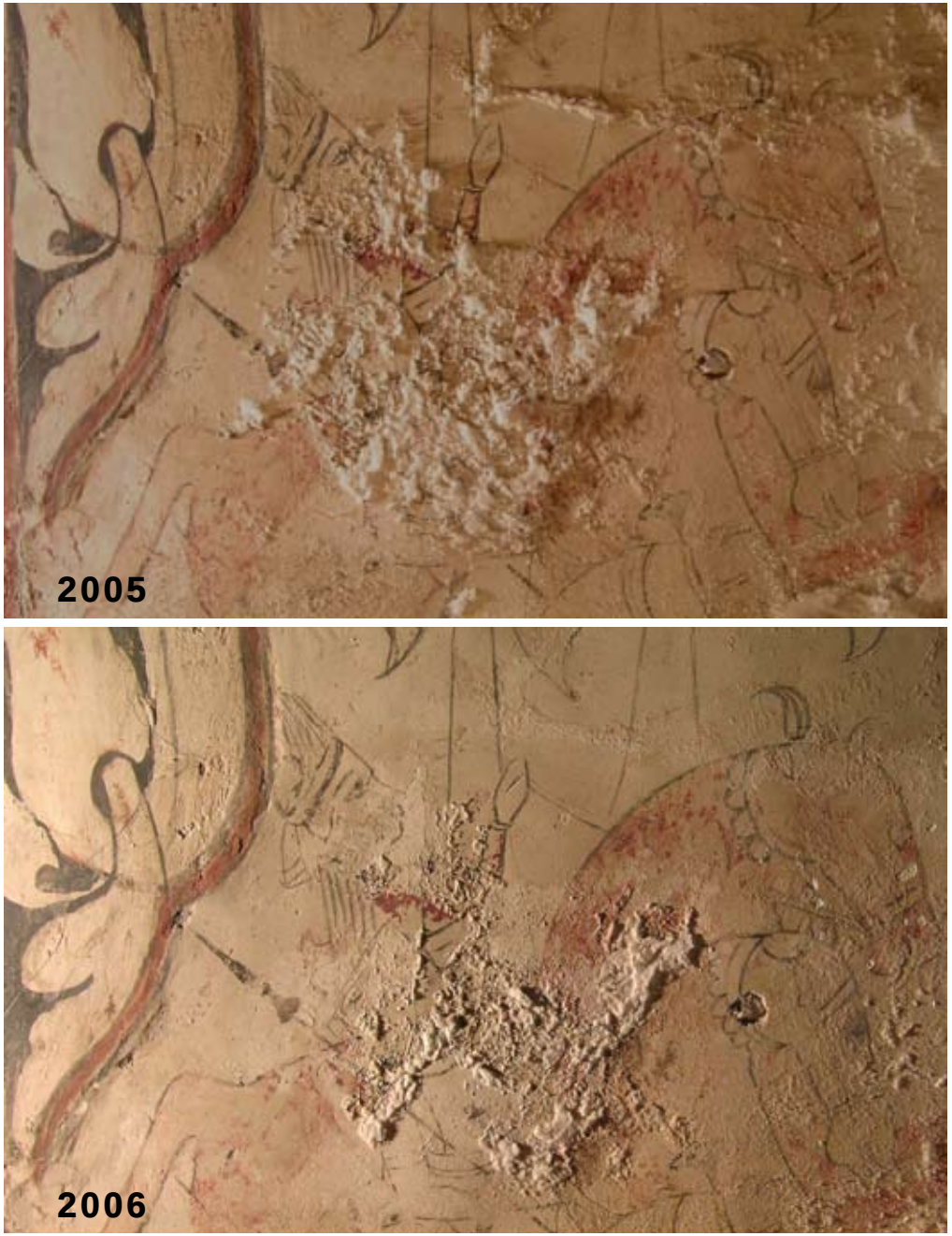
Recommendations

Investigation into original materials and treatment trials have indicated it would be possible to successfully clean this exterior scheme. However, since the intervention would primarily be intended to improve the legibility of the painting (which does not require major stabilisation), it is not currently a priority. Risks to the painting are largely environmental, and assessment of the current shelter and determination of long-term protection needs are instead priorities.

Therefore, a monitoring exercise has been put in place to assess the rate of redeposition of dirt, as well as the effect of the current shelter. Repeatable photographs of the cleaning trial window will be taken four times throughout the year, and the dirt deposited on the cleaned area will be examined. Additionally, observations will be made during periods of heavy rainfall to assess if the current shelter is successfully directing water away from the base of the wall.



Above: before (left) and after (right) cleaning on the exterior east facade of Abha Mahal.
Below: scanning electron micrographs (1000x) of sample # 3802 and #3803, showing the surface of the paintings before and after cleaning.



Above: an image of an area with salt-related deteriotation in Abha Mahal room 10 taken in September 2005, Below: an image of the same area in March 2006, showing loss due to ongoing salts activity.

INTERIOR

The interior of the Abha Mahal contains extensive painting on the walls and ceilings, and also some remains of painted floors. Their condition varies greatly and there is evidence of extensive repainting. The preliminary condition survey (Bogin 2005) highlighted the need for further investigation of ongoing deterioration, and the importance of suspending use of the historic water system, which was contributing to the deterioration. As a result the water system was suspended, and biodeterioration no longer appears to be a serious cause for concern. However, comparing photographs taken in September 2005 with the current condition, it is clear that salt-related deterioration is ongoing, causing loss of original material. Investigations were undertaken to characterise the salt activity, while emergency stabilisation was also undertaken, and a monitoring system devised.

DIAGNOSTIC INVESTIGATIONS

Salt Analysis

Investigations focused on Room 10, which has ongoing deterioration due to salt efflorescence. Sampling and analysis of the efflorescence, as well as profiling in depth (up to 6.2 cm) with microcores was carried out.

Results:

- Sodium chloride (NaCl, halite) and sodium nitrate ($NaNO_3$, nitratine) were identified by optical mineralogy
- Sodium chloride was also identified with SEM-EDS
- Chlorides and nitrates were found both in efflorescences and in depth

Comparing the condition in March 2006 with that in September 2005 demonstrated that significant changes to the distribution of efflorescences have occurred in the six-month period. This indicates the salts are active, since they can only be redistributed by dissolving and recrystallising. To monitor this, repeatable photographs (in normal and raking light) will be taken four times throughout the year, corresponding to seasonal change. In addition, acetate sheets were taped to the floor directly below the area of salt activity which will remain in place and catch falling efflorescences. These sheets will also be photographed to provide a record should any of the material be lost.

EMERGENCY STABILISATION

Localised areas of painting were at imminent risk of loss. An area of severely detached plaster was stabilised using temporary facings. Several strips of lens tissue (9 g/m^2) were applied (with Paraloid B72™ 5% in acetone) to span the area of detachment to provide support and to prevent further loss until long-term stabilisation can be undertaken.

RECOMMENDATIONS

The analysis of salts on the surface and in-depth in the interior of Abha Mahal has provided information needed to understand the complex mechanisms of deterioration. To further our understanding the following is recommended:

- A thorough examination of the roof and water drainage system to assess potential sources of liquid water infiltration.
- Continued monitoring of the area of salt activity is essential. Photographic monitoring should be continued by IMACC, and assessed in the next phase.
- Based on the monitoring an assessment of the microclimate in the interior should be made. The effects of the glass doors on the relative humidity in the room should also be considered.

Stabilisation should not be carried out until salt-related deterioration has been addressed, and until that time the temporary facings should be monitored.

BAKHT SINGH MAHAL

The tallest palace in the complex, the Bakht Singh Mahal includes a double-height entrance hall and mezzanine. Dating from the mid 18th century, it was the last of the major palaces to be built. The ground floor hall was decorated with floral motifs which are now largely obscured by limewash. Although the mezzanine retains a painted ceiling with a floral and geometric design, this scheme is in poor condition with much of the original gilding having been scraped away, and with staining due to infiltration. The most alarming issue is the detachment of the plaster from its support. For more information on the paintings, their physical history and present condition, see Bogin 2005: 30-31.

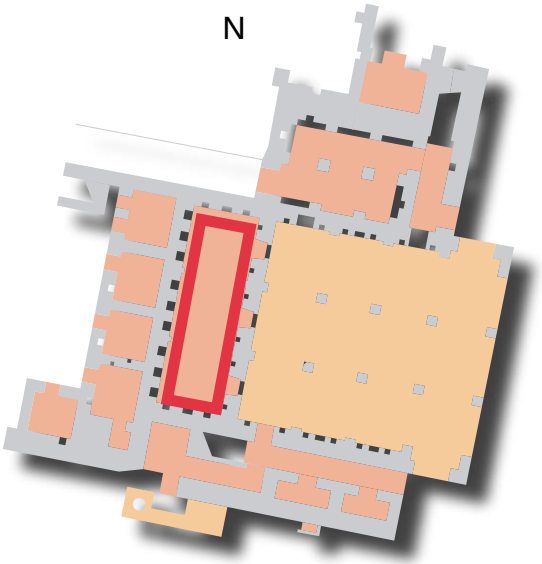
DIAGNOSTIC INVESTIGATIONS

Examination of the Mezzanine Ceiling

To assess the severity and extent of detached plaster on the mezzanine ceiling graphic documentation was carried out (see Appendix 2b).
Each section of the ceiling was categorised as either 'detached' or 'severely detached' assessed by means of gentle tapping. Each area was assessed by two conservators and the results were compared. While the method has some limitations it provides a suitable indication for risk assessment.

Results:

- A substantial portion of the original painted plaster on the ceiling has detached from the support.
- Large areas of the ceiling have repairs, and these seem to be attached, however edges adjacent to the original have started to separate from the support.
- Some large cracks are also present and often correspond to the most severely detached areas; these were also documented.



RECOMMENDATIONS

- Further investigation to assess whether the infiltration of liquid water is being prevented by the recent roof repairs is needed.
- The continued development of a grouting material which would be appropriate for use in this situation.
- The ceiling should be carefully monitored, and the need for a temporary support system considered during the next phase.

A general view of the mezzanine ceiling in the Bakht Singh Mahal

A general view of the North facade of Hadi Rani Mahal

HADI RANI MAHAL

The Hadi Rani Mahal is a three-storied palace which provided living quarters for the queens. It retains extensive wall paintings, with schemes on the ground, first and second floors, as well as on the exterior. It appears that all the paintings were executed in the same period, and their style closely resembles that of the Sheesh Mahal decoration. For further information on the various schemes, including their physical history and condition, see Bogin 2005:35-47. Together with treatment trials and emergency stabilisation, the following investigations were undertaken during the present phase.

Exterior

- emergency stabilisation
- repair trials

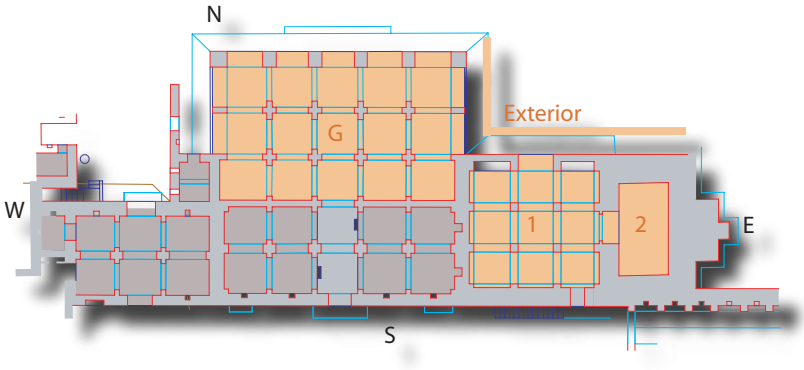
Ground Floor

- investigation of original technique
- investigation of non-original materials
- cleaning trials

First Floor

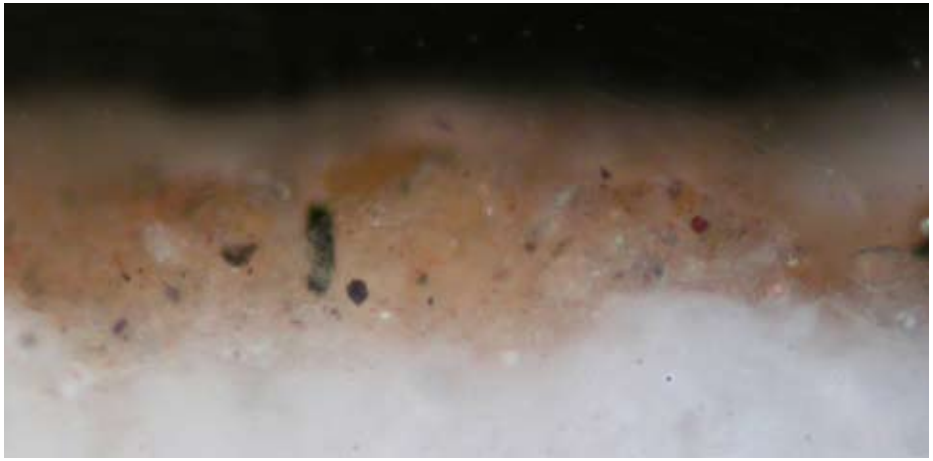
- investigation of original technique
- investigation of non-original materials (coating)
- cleaning trials
- repair trials

A summary of the results of these trials and investigations follows.



GROUND FLOOR

On the ground floor of the palace is an open reception hall divided into 15 square compartments by a series of arcades. The upper parts of the walls are painted with scenes of elephant battles, the cusped arches with foliate motifs, and the ceiling panels with winged figures with birds and musical instruments. The high quality of the paintings is obscured by accretions on the surface, as well as damage caused by water infiltration. Many of the pigments appear faded, possibly due to deterioration of organic colorants. Unsightly repairs to areas of loss often overlap the surface of the painted plaster. Based on observation with examination of samples with SEM, synthetic coatings such as those observed on the first and second floors of the palace and in the Sheesh Mahal do not appear to be present. However, the presence of non-original materials and their relationship to the original painting requires further characterisation.



Above: view of the ground floor of the Hadi Rani Mahal.
Right: cross-section of sample #3794 (200x) showing thick depostion on the surface of the plaster.

DIAGNOSTIC INVESTIGATIONS

Investigations on the ground floor of Hadi Rani Mahal focussed on characterising the unwanted non-original material which obscures the surface of the paintings. A sample was taken from a representative area and examined with PLM and SEM (Sample #3794). In addition, a sample was taken from a leaf of a tree in the paintings (Sample #3790), which had the appearance of a faded organic colorant.

RESULTS

- A thick uneven deposit is visible on the surface of the cross-section (see above), however further characterisation is needed.
- SEM examination confirmed that no synthetic coating (such as those found in Sheesh Mahal and the first floor of Hadi Rani Mahal) is present on the painting sampled on the ground floor.
- It proved impossible to identify the green with PLM, since no colour or pigment particles were visible in the sample. However, it may well be a faded organic colorant as identified in the first-floor scheme of the Hadi Rani Mahal, so further sampling is necessary.

TREATMENT TRIALS

Cleaning
Cleaning trials were carried out to assess the potential for the removal of the accretions which currently obscure the painting. Several cleaning systems were tested on different areas. Both aqueous and solvent systems were applied in a variety of sorbents and their impact on the original and unwanted non-original materials was visually assessed.

Results:

- Of the available cleaning systems none proved successful at removing the various surface deposits in a controllable, homogeneous way.
- Due to the nature of the original materials, aqueous systems are problematic.
- The application time needed for removal of the unwanted non-original materials could not be reconciled with the potential damage caused by mobilisation of the paint.

Above: detail of the ground floor scheme showing deposition and overlapping repair material on the surface of the painting.

Repair Removal
Preliminary trials were undertaken to assess the potential for the safe removal of unsympathetic repairs that overlap the painting. These were limited to small fills found in the painted areas of the upper walls, and can be characterised by their white appearance. Removal of the large plaster repairs at the base of the walls, which appear to be composed of a different material, was not addressed in this phase.

Results:

- The repairs were generally soft and easily removed without damage to the surrounding painting.
- Removal is potentially more problematic in areas of detachment, but this would need to be assessed on a case by case basis. Facings may be required before removal in such areas.

RECOMMENDATIONS

Currently, the cleaning of the ground floor scheme remains problematic. Further characterisation of the unwanted non-original material and its relationship to the original materials is needed.

- Further analysis of the non-original material on the surface and assessment of the nature of the interface between this material and the paint layer.
- Further characterisation of the original materials.
- Further trials using additional cleaning materials not available during the present phase should be undertaken.
- Trials to assess the feasibility/desirability of removal of the large plaster repairs on the lower walls are needed.

First Floor

The first floor houses a large room entirely covered with paintings, the scheme depicting the courtly life of the ladies who lived in the palace. The condition of the paintings is generally stable; however visual disruption has occurred as a result of the alteration of lead, the fading of organic colorants, and in some areas the deterioration of a synthetic coating applied in a previous intervention. Additionally, unsightly repairs create further disruption to the overall appearance of the paintings.

Diagnostic Investigations

Original Technique

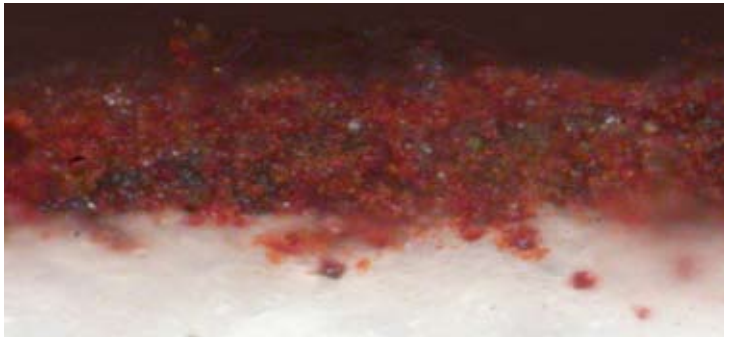
The palette of the first-floor scheme is dominated by a bright green pigment, subject to loss and flaking, and also found in many other paintings at Nagaur. The flesh areas of many of the figures has altered to brown or black, while there is also an extensive use of organic colorants throughout the scheme. Several samples were taken in order to clarify the nature of the alterations, and the paintings' susceptibility to future deterioration.

Results

The bright green pigment was identified as copper chloride (Sample #3788), applied in a thin layer with a high binder to pigment ratio which produces a glossy and at times translucent appearance. The alteration of the pink flesh tones to brown or black is due to the alteration of red lead (Sample #3786 / #3787).

The trees depicted in the scheme now alternate bright green (copper chloride) and beige. Examination of a cross-section (Sample #3789) revealed that the 'beige' is composed of two layers of organic colorants: a yellow colorant applied over a blue colorant to create green. The present beige appearance results from fading of the surface yellow layer.

A blue pigment employed on the first floor, which appeared to have darkened (Sample #3791), was examined with SEM-EDS. White lead was identified, but in examination of the cross-section with PLM no crystalline blue particles were visible, suggesting that the blue may comprise a fugitive indigo colorant in a lead white matrix. The darkening could be attributed to alteration of the lead white.



Above: figures from the first floor of the Hadi Rani Mahal with blackening due to alteration of red lead.
Below: a cross-section of sample #3787 (200x) showing partially altered red lead pigment particles.

Added Materials
Bands of dirt across the surface of the painting were noted in Bogin 2005: 42 and the possibility that these correspond to the application of a synthetic coating in a previous intervention was raised. Based on the documented application of PVAC in the Sheesh Mahal in 1989, as well as the similarity in its appearance and behaviour, it is suspected that a similar intervention was carried out in the Hadi Rani Mahal around that time. However, as there is no documentation of the intervention, sampling and analysis were required.

Results:

- A coating was visible on the surface of the painting in the examination of a cross-section (Sample #3788).
- The presence of a coating was confirmed with SEM examination (Sample #3796, see Appendix 3b).
- Further analysis is needed to characterise the material used.

TREATMENT TRIALS

Cleaning
Cleaning trials were undertaken to assess the potential for the removal of the coating which manifests as brown bands due to it becoming tacky and trapping dirt on the surface. The potential for the coating to become insoluble over time was also considered.

Results:

- Effective initial reduction of coating with acetone on cotton wool swabs.
- Removal of residual coating with longer application of acetone in a sorbent gel applied over an intervention layer.

The dirt trapped on the surface of the coating was successfully removed from both the painted and unpainted plaster. The incredibly smooth surface of the plaster allowed a homogeneous result. A sample was taken from an area which appeared to have residual coating to assess the cleaning method and was examined with SEM. This demonstrated that a fair amount of residual material remained on the surface after the cleaning in some areas. Further assessment of the level of cleaning and desired reduction of the coating is needed.

Above: dirt trapped on the surface of the coating prior to cleaning.
Below: the same area after cleaning.

Repairs
Trials for the removal of unsympathetic repairs and replacement with a compatible alternative were carried out on the dado panel of the east wall. Two shallow fills that had been applied in a previous intervention were carefully removed and replaced.

Results:

- Safe removal of the repair material was successful, with no damage to the surrounding areas.

- An appropriate repair material was developed (see section 5 for criteria) composed of compatible and locally available materials including lime, fine marble dust, fine sand, and a small quantity of yellow ochre.

- The new repairs have a more sympathetic appearance and blend into the surrounding painting.

RECOMMENDATIONS

There is potential to greatly improve the general appearance of the scheme through removal of the coating and replacement of the unsightly repairs. Some aspects of deterioration, such as pigment alteration (both organic and mineral) cannot be controlled. Further characterisation of the organic colorants would be informative, and potentially indicate the causes of deterioration.

- Further assessment of the effects of the cleaning method.

- It is recommended that the shutters remain closed when the room is not in use, to prevent direct sunlight and further deterioration of photosensitive organic colorants.

- At some stage an intervention to remove the coating is desirable, as other similar coatings demonstrate that deterioration will continue over time, and it could potentially become insoluble. At present, the negative effect of the coating is largely visual, and its removal is therefore not urgent.

HAMMAM

The Hammam is part of a group of enclosures west of the Sheesh Mahal believed to have been constructed in the same period as the main palace. The Hammam has three small domed chambers decorated with painted foliate and geometric motifs. Each of the chambers exhibits significant paint loss and evidence of historic water infiltration, as well as active plaster loss and salt efflorescence. (For further information, see Bogin 2005:48-49).

Above: Exterior of the Hammam.

Left: plan of the Hammam. The rooms are marked 1-4.

DIAGNOSTIC INVESTIGATIONS

A liquid moisture investigation was carried out to determine if infiltration continues to contribute to deterioration of the paintings in the Hammam or if the deterioration is activated by moisture from other sources. The Hammam is representative of the types of deterioration associated with infiltration throughout the site and room 3 offered appropriate sampling locations.

A liquid moisture investigation consists of sampling (drilled cores), gravimetric measurement of moisture content, and measurement of hygroscopic moisture absorption under controlled relative humidity conditions. For details on the methodology, sampling locations and sampling strategy see Appendix 3c.

Results

The following observations can be drawn from the data presented graphically in Appendix 3c. The results from ion analysis on the core samples are reported in Appendix 3d along with other salt analysis.

Moisture content

- Damp conditions were recorded at the surface of both locations A and B (with moisture content ranging between 8-14% of the dry mass of the samples).
- In the wall profile, there is a higher moisture content near the surface (typically in the plaster layer from 0 to 4 cm) than in depth.
- No clear vertical moisture distribution pattern was noted. At A3, the highest sampling location, the surface is damp, whilst at D2 taken at 2.40 m from the ground, the surface is relatively dry. The lower sample locations at B1 and A1 display opposite patterns, with a damp and dry surfaces respectively.
- The 'control' sample (C1) taken in an area with no evidence of water infiltration or salt efflorescence, is dry.

Potential hygroscopic moisture uptake

- Results for location A on potential hygroscopic moisture uptake under controlled relative humidity appears at first anomalous since A2 and A3 presented visible salt efflorescence. This might be explained by the prevalence of sulfates at these locations which typically absorb moisture at higher relative humidity than the one selected for the experimental set up.

- A slight hygroscopic moisture uptake was noted at location B with consistent values throughout the horizontal profile.
- Horizontal profile of recorded hygroscopic absorption at location D displays higher values that the actual moisture content but closely follow variation patterns according to each core samples.

Ion analysis of core samples

Overall, salt concentration is higher at the surface of the plaster than in-depth.

- Nitrates are present in all samples. In samples A1, C1, D1 and D2, nitrates are the only ions found in-depth.
- Sulfates are present in samples A2, A3, B1 and amounts are decreasing in depth. Sulfates are also present in samples C1 and D2 although limited to the surface.
- Chlorides are present in samples A2 and B1 and are limited to the surface of samples D1 and D2.
- Chlorides, nitrates and sulfates were present in samples A2 and B1. These locations also presented the highest concentrations of ions.

Discussion

- As the samples show higher moisture content at the plaster surface rather than in depth, infiltration from the roof does not appear to be active. During sampling detachment between the support, primary and secondary plaster layers was noted. This capillary break prevents liquid moisture moving from the support to the surface and further supports this conclusion
- The complete lack of moisture at the surface of samples A1 and C1 rules out condensation events as overall source of moisture.
- Salt efflorescence are localised and associated with other evidence of liquid water infiltration (staining, detachment). Furthermore the presence of chlorides and nitrates in depth indicate that liquid water is responsible for the transport of salt forming ions.
- Therefore, the moisture and analysed ions may be residual from historic, although recent liquid water infiltration. However, results from location B and D may illustrate the presence of alternative water sources such as drainage system or ground water.
- The potential participation of ambient humidity absorbed by hygroscopic salts and thus participating to the surface phenomenon remains unclear. The highest moisture content seems to correlate with relatively high level of salts (especially chlorides and nitrates) for location A2 and B1. However, external relative humidity during sampling was on average 32% (data obtained from www.weatherunderground.com). Although the internal climate of the Hammam was not recorded, close values are to be expected since both doors are often kept open for visitors. This would invalidate the theory of water vapour being responsible for the overall prevalence of moisture near the surface.

South wall of the Hammam showing brown staining and pigment loss in the dome area, and plaster loss at ground level. Sample B1 was taken from this wall.

Ideally, these investigations should be carried out when infiltration is more likely to occur for example during the monsoon season, however, these results remain a valid indication of moisture activity.

Recommendations

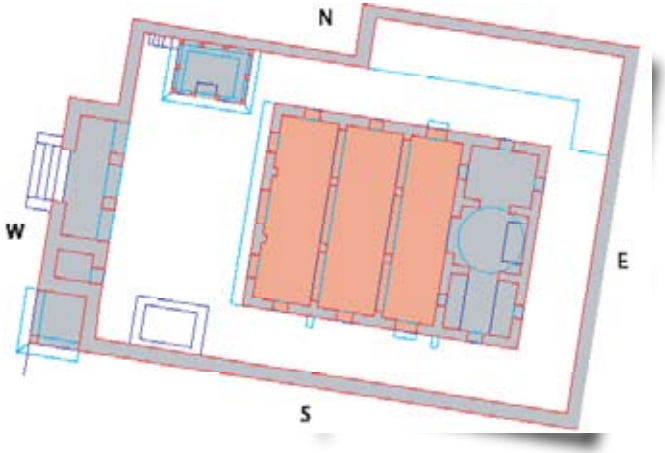
The investigations indicate that water ingress is not an active problem in the Hammam. However, the building will be monitored for evidence of change in the condition of the paintings and plaster which may indicate otherwise. The areas of high salt activity, especially sample location B1 needs to be noted in particular.

Plaster detachment was discovered during the investigations. Detachment is a risk for the paintings which needs to be assessed in more detail.

The core samples during hygroscopic moisture absorption measurement.

KRISHNA TEMPLE

The Krishna Temple is decorated with scenes from the life of Krishna and has recently been architecturally stabilised and a program of wall painting conservation has been undertaken. The wall paintings were uncovered and cleaned and are generally stable. Salt efflorescence was noted on the north wall in 2005 [Bogin 2005:50-52] and appears to be localised to repair material. The efflorescence was analysed to further our understanding of the phenomena.



Above: west facade of the Krishna Temple.
Left: plan of the Krishna Temple, the building is marked in pink.
Right: interior north wall of the Krishna Temple.

DIAGNOSTIC INVESTIGATIONS

For sampling locations, see Appendix 3d. Ion analysis conducted on salt efflorescence with Merckoquant™ strips shows the presence of nitrates and chlorides.

On site ion analysis with Merckoquant™ strips.

Sample type	#	Location	Ions		
			Sulfates	Chlorides	Nitrates
Efflorescence	C6	Interior north wall	-	-	x
Efflorescence	C7	Interior north wall, near repair	-	x	-

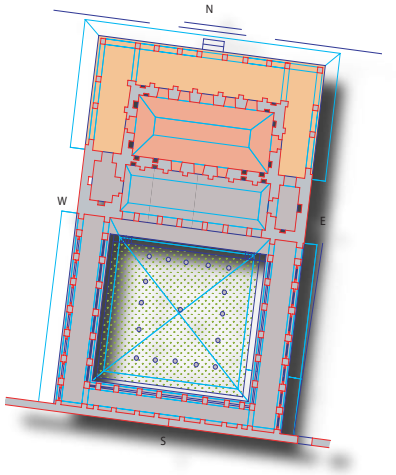
RECOMMENDATIONS

Currently, the salt deterioration is localised to a small area on the north wall, near to and on a repair material. As the salt activity is limited, further condition monitoring is recommended before assessing the need for more investigations or any intervention.

SHEESH MAHAL

Sheesh Mahal, sometimes called the Akbari Mahal, is one of the most important palaces in the complex, and retains extensive paintings of high quality on the outer veranda and in the interior hall. The latter depict scenes of courtly life and the vault contains an impressive scheme representing earth, water and heavens which is complemented by inlaid mirror-work. The outer veranda is a covered arcade which wraps around the north side of the palace and shelters an exterior wall painting scheme. The cusped arches are decorated with floral motifs and each pilaster is decorated with a woman offering flowers and other gifts. The precise date of the scheme is unknown but it is probable that all aspects of the decorative scheme date from the same period. In the late 1980s a programme of examination and conservation of the wall paintings was undertaken by INTACH (Agrawal 1989). For further information on the palace and its schemes, see Bogin 2005:22-25.

Above: exterior of Sheesh Mahal.
Right: plan of Sheesh Mahal.



VISUAL GLOSSARY OF CONDITION

A visual glossary of the condition of the wall paintings in the Sheesh Mahal was undertaken (Appendix 2a) which provides a significant tool for ongoing condition assessment, as well as for communication among members of the team. It is an important record for future consultation, since it illustrates the condition of the paintings prior to conservation treatment.

The interior and exterior exhibit similar types of damage and deterioration and thus are discussed together in this summary of the condition assessment.

- The plaster is unstable with areas of detachment and active loss. Significant historic loss has occurred in the vault area and loss may be continuing on the door jambs (although more assessment is necessary). The full extent and severity of the detachment has not been assessed. Widespread cracks in the plaster indicate further vulnerability, especially in the frieze area. In the ceiling of the exterior veranda, significant loss of plaster has occurred (and been repaired). There is also considerable plaster detachment in the interior courtyard.

- Discoloured coatings obscure the entire scheme compromising the visual integrity. On the eastern side of the south wall the coatings are especially thick and are associated with blistering and flaking of the paint layer.

- Salt activity is localised to the frieze area on the north wall where it is causing paint powdering and loss. No salt activity was observed on the exterior.

- Other previous interventions include plaster repairs which are inconsistently applied and failing in some areas.

- Inlaid mirror-work on the dado has suffered loss and damage extending to total destruction of the design through loss of the upper plaster layer. The dado plaster has accumulated dirt and excess lime deposits obscure the delicacy of the inlaid mirror-work as well as the grey-blue hue of the glass.

- The paint layer is generally stable with some areas of flaking, in particular the green. However, the colour scheme of the paintings has altered, both from conversion of lead pigments and fading of original pigments, affecting flesh tones most significantly. Blanching affects the paint layer on the exterior.

- There are minor surface deposits from bird and insect activity.

Above: a section of the upper register of the Sheesh Mahal, the left side before cleaning and the right side after cleaning. Removal of the darkened synthetic coating greatly improves the appearance of the paintings.

EXTERIOR

DIAGNOSTIC INVESTIGATIONS

Original Technique

Since analysis of the altered flesh areas had already been undertaken (Bogin 2005:23) and corresponds to this phenomena on the first floor of the Hadi Rani Mahal, examination in this phase focussed on the blue pigment in the exterior paintings, and on the extensive inlaid mirrorwork in the interior.

The blue employed in the floral borders of the exterior paintings provide one of the few areas of unaltered, stable blue pigment at Nagaur. Examination of dispersions with PLM revealed the use of a glass-based pigment, probably smalt (# 3793 see page 9). Further analysis would be desirable to confirm this finding.

Left: a plaster sample (width 3 cm) from the Sheesh Mahal showing a coarse lime plaster layer with large aggregates and brick particles, finer layer composed of brick powder and lime, and the uppermost fine polished lime and marble powder layer.

EMERGENCY STABILISATION

Facings of lens tissue (9 g/m^2) adhered with Paraloid B72™ (5% in acetone) were applied to localised areas of detached plaster on the interior courtyard of Sheesh Mahal. While a temporary measure, the lens tissue facings have successfully stabilised the detached plaster preventing further loss until long term stabilisation can be undertaken.

TREATMENT TRIALS

The entire exterior scheme has a brownish appearance due to discoloured coatings (see Visual Glossary) which are also visible in cross-section (see Bogin 2005:23). The coating on the upper register is suspected to be PVAC, as this material was also applied in the interior in the 1989 intervention and the appearance and behaviour are quite similar. PVAC becomes tacky in temperatures over 20°C thereby trapping dirt and is subject to cold flow (Horie 1990: 92), and it may also become insoluble over time, particularly in external contexts (Schwartzbaum 1988). The brown-coloured coating on the lower register is more matte and alters the appearance of the white kody plaster. There is no documentation recording any interventions to the exterior paintings.

Above and right: a figure from the exterior of Sheesh Mahal before cleaning. The painting is obscured by a discoloured coating which is particularly visible as drips and horizontal bands.

Above and left: the same figure after cleaning. Removal of the discoloured coating reveals many fine details previously obscured. The background is more homogeneous, the colours are clarified and the blanching on the figure's face is reduced.

DIAGNOSTIC INVESTIGATIONS

Original Technique

Visual examination of the inlaid mirror-work employed at dado level in the interior revealed aspects of its original technique. The support is a well finished plaster render onto which small curved pieces of glass were adhered with a coarse plaster. A fine lime plaster was then applied over the glass and the floral design transferred to the surface by pouncing through a template, illustrated right. This design was cut out while the plaster was still wet using a sharp implement to reveal the mirror.

The mirror-work is of a metallic grey-blue appearance. Elemental analysis of one sample (#3806) by SEM-EDS indicated that it is composed of sodium-based silica glass with a lead (Pb) foil backing. The lead component in the foil creates the grey coloration of the mirror, while the bluish effect is due to Rayleigh scattering (see Howard 1991). Lime residues on the glass which are clearly distinct from the original material suggest that the inlaid work may have been covered at some later stage. As a result, lime may have been absorbed by the glass, thus limiting the scope for its complete removal. As glass ages, calcium and sodium are also leached out making it brittle and porous, and further analysis of the manufacture, properties and deterioration of the mirror-work is required. (For images, see Diagnostic Investigations, p. 10).

Salt analysis

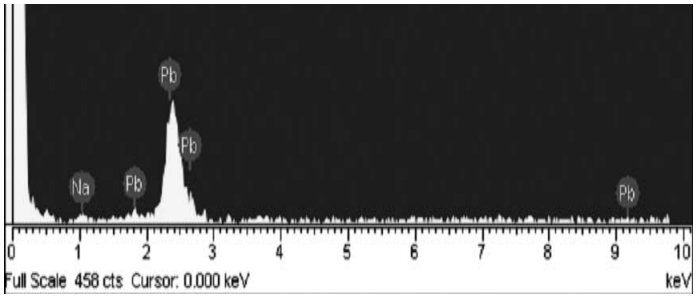
Results of on-site ion analysis with Merckoquant™ strips.

			Maximum ion concentration		
Sample type	Sample #	Location	Sulfates	Chlorides	Nitrates
Repair materials	B2	Roof	-	-	-
E ores-cence	C1	Interior north wall	-	✓	✓

Analysis by means of optical mineralogy and microchemical testing by Christine Blaüer Böhm identified sample NAG-32-15 (taken in 2005, same location as C1) as sodium chloride and sodium nitrate.

At Sheesh Mahal, the efflorescence corresponds to historic water infiltration, suggested by the brown staining and pigment loss associated with the area. While the new repair materials do not provide a source of potentially harmful ions, historic repairs and original materials may contribute. The new render on the vault addresses the problem of infiltration, however recent fills are failing which suggests continuing movement of water. To determine if the scheme is at risk from salt activity it is necessary to determine if water infiltration and salt efflorescence are active.

Right: pouncing marks are visible in some areas of the inlaid mirror-work. In this figure around the petals on the left of the flower and the left side of the main stem. After cleaning, some areas retain a white opaque residue which may be lime, visible on the central part of flower motif.

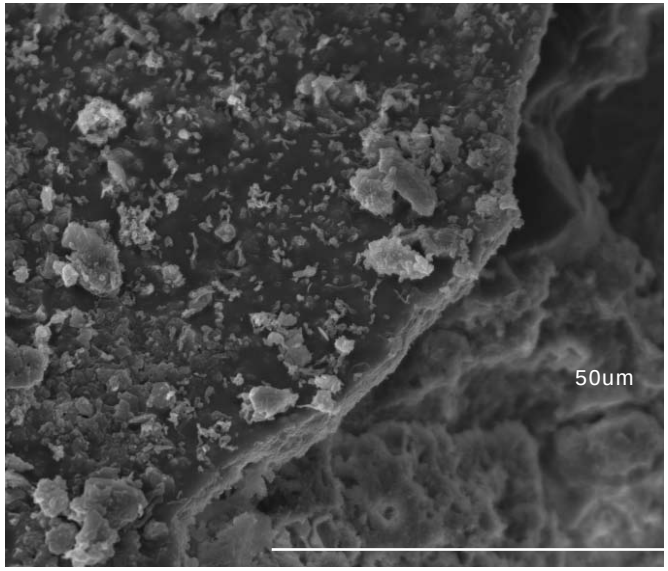


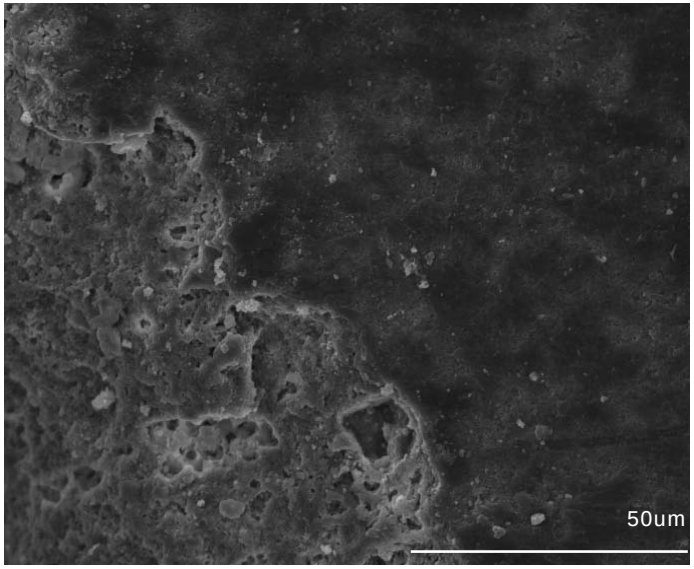
Right: SEM - EDS analysis of Sample #3806 showed that a lead foil backing creates the reflection and grey coloration of the mirror.

Right: salt efflorescence in the Sheesh Mahal has been identified as sodium chloride and sodium nitrate.

TREATMENT TRIALS

The treatment trials on the interior during the present phase addressed the thin discoloured coating which covers the entire painted scheme. This coating was applied during the 1989 intervention (Agrawal 1989). On the lower dado, trials to remove the dirt deposits and lime residues obscuring the inlaid mirror-work were undertaken.





Top: a niche from the interior of Sheesh Mahal before cleaning. The coating is shiny and discoloured.
Bottom: SE micrograph (secondary electron image) (1000x) of Sample # 3800 taken from an area similar to that illustrated above before cleaning. The surface coating has a soft and amorphous appearance in which dirt particles are embedded.

Top: the same niche after cleaning, the cleaned area within the white line. The coating was removed and the painted surface is matte. A yellow stain remains after cleaning.
Bottom: An SE micrograph (secondary electron image) (600x) of Sample #3801 taken from an areas similar to that illustrated above after cleaning. The dirt and amorphous coating have been removed.

- The heaviest lime residues were also removed from the edges of the glass without damage to the original plaster to clarify the delicate design and reveal the deep grey-blue colour of the mirror. The intransigent lime residues on the glass surface were not fully removed with tartaric acid. These residues, which are present on some, but not all, of the glass may be a result of lime absorption by the glass phase. Persistence with removal of these residues may not be appropriate to the aged glass although further investigation is needed.

RECOMMENDATIONS

See Section 8 below.

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS, MONITORING AND TRIALS

The recommendations made here are for further investigations at the site as a whole, to be undertaken simultaneously with the conservation treatment of the Sheesh Mahal proposed in Section 9.

Abha Mahal

Exterior

- o further assessment of necessity and feasibility of long-term protection
- o continued photographic monitoring of cleaning trial
- o monitoring of rainwater disposal

Interior

- o examination of the roof and water drainage system in area of salt activity.
- o continued photographic monitoring of salts
- o assessment of the effects of the glass doors on the microclimate

Bakht Singh Mahal

Mezzanine ceiling

- o monitoring of the condition
- o further investigation to verify that infiltration of liquid water is no longer an issue
- o continued development and testing of an appropriate grout material

Hadi Rani Mahal

Exterior

- o monitoring of emergency facings
- o assessment of repair trials

Ground Floor

- o further characterisation/analysis of the unwanted non-original material
- o further characterisation of the original materials
- o further cleaning trials
- o further repair removal trials
- o limewash trials

First Floor

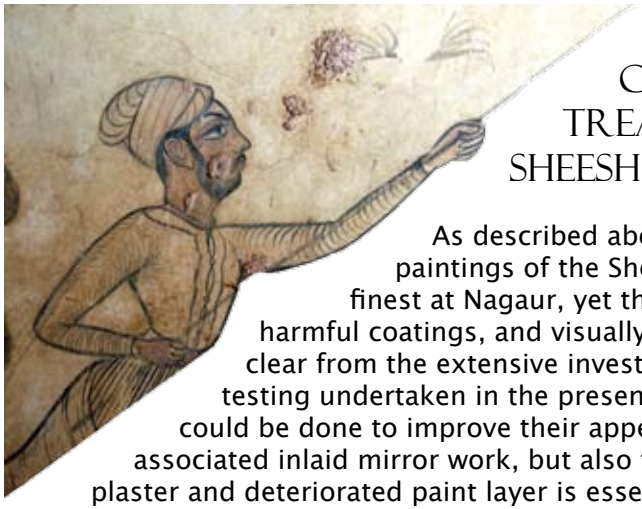
- o further analysis to characterise the coating
- o assessment of the cleaning trials

Hammam

- o condition monitoring

Krishna Temple

- o monitoring of salt activity



PROPOSALS FOR CONSERVATION TREATMENT OF THE SHEESH MAHAL

As described above (pp. 38–45) the paintings of the Sheesh Mahal are among the finest at Nagaur, yet they are obscured by dirt, harmful coatings, and visually distracting repairs. It is clear from the extensive investigations and treatment testing undertaken in the present phase not only that much could be done to improve their appearance, and that of the associated inlaid mirror work, but also that stabilisation of the plaster and deteriorated paint layer is essential. Conversion of the altered lead pigments in the flesh areas of the figures, however, would not be ethically acceptable.

There are strong reasons for proposing that remedial interventions to the wall paintings at Nagaur focus on the Sheesh Mahal. The building—with its elegant northern veranda, spacious vaulted hall, and internal fountain court—represents the epitome of the gracious courtly style at Nagaur, combining the best in the arts of architecture, painting and water features. Fully in line with the long-term goals of the MMT to restore a sense of the original elegance and integrity of the site while maintaining its historicity, a programme of treatment of the wall paintings and mirror work could helpfully demonstrate this potential.

From the point of view of the importance of the architecture and decoration this seems an obvious choice, but it may be surprising given that a major wall painting conservation programme was carried out on these paintings in the late 1980s (Agrawal 1989). Although since then the architecture has been stabilised (Jain 2001) the paintings have unfortunately seriously deteriorated. An undated but recent INTACH report notes of the Sheesh Mahal paintings that 'They were restored a few years back but they again need to be looked into,' and then proposes and costs 12 months' of treatment (INTACH nd:5–10).

Examinations by Bogin (2005:22–29) and during the current phase (Section 6 above) have demonstrated worrying ongoing problems. A responsible approach to long-term conservation certainly requires that further investigations and trials are undertaken so that the causes of the problems can be addressed and appropriate intervention methods designed, and these are proposed below. However, it is also clear that the aesthetic integrity of the architecture and its decoration is seriously compromised by past interventions. These, too, can and should be addressed.

In summary, the current conditions that cause concern for the safety of the wall paintings include: detachment of the painted plaster from the support; flaking and blistering of the paint layer; and losses due to ongoing salt activity. Aspects that adversely affect an appreciation of the paintings and their architectural setting include: coatings applied in the previous intervention that are uneven, discoloured, attract dirt, and are very possibly contributing to the flaking; and unsympathetic and diverse repairs that also extend over the exquisite mirror work and similarly may well be contributing to the deterioration of the glass.

A comprehensive programme of investigations and remedial interventions to be undertaken in three annual phases of eight weeks each is therefore proposed. This would include:

- INVESTIGATIONS: of the salt activity and its possible activation by ongoing infiltration; of the original painting technique and its susceptibility to deterioration and to potential conservation interventions; likewise, of the inlaid mirrored glass, an important feature of the Sheesh Mahal and of interior decoration in Rajasthan in this period; of the extent and severity of the detached and of the integrity of the previous repairs; and of the art-historical and technological context of the paintings and mirror glass;

- TREATMENT TRIALS AND ASSESSMENT: for removal of the coatings, which are multiple and present complex cleaning issues; for replacement of harmful and unsightly repairs and for architectural surface treatments intended to reassert its overall integrity; for stabilisation of the detached plaster (grouting) and flaking and blistering paint (readhesion); and for treatment of the salt contamination;

- **REMEDIAL INTERVENTIONS:** to stabilise the paintings and plaster; to replace failing, harmful and unsightly repairs; to clean the paintings, aiming for a result that is harmonious with the condition of the overall building; likewise, to treat unpainted areas to improve the overall presentation of the paintings and building.

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Damage

Cracks

Fissures or cracks in the plaster are widespread in the exterior scheme. Many cracks have been filled with a fine lime-based plaster.

Detachment

Loss of adhesion between the plaster layers and/or plaster and support. The extent of detachment has not been fully assessed.

Plaster Loss

Loss of plaster, both upper and secondary layers. Loss occurs in both painted and unpainted areas, and in upper and lower registers.

Deterioration

Pigment Alteration: to black

Alteration of pigments to black. This is the same phenomenon as that which occurs on the interior and is mostly associated with flesh tones. Some areas are fully altered, as in this example, in other locations more of the original colour remains.

Pigment alteration to black is probably related to the alteration of lead-based pigments.

Flaking Paint layer: general

Loss of adhesion between paint layers and/ or paint layers and upper plaster layer. Flaking occurs particularly on the layered paint in the figures' draperies.

Pigment alteration: loss of colour

Locations where there appears to be little visible pigmentation in the paint layer.

This phenomena is most common on the draperies and thought to be related to the fading of fugitive organic colourants.

Flaking Paint Layer: Green

Loss of adhesion between green paint layer and underlying layer. It is possibly due to the inherent susceptibility of the pigment and/or application method. The area illustrated shows characteristic cracking, lifting and loss of paint.

Deterioration

Ghost images

A negative image of a decorative motif which is surrounded by colour and/or dirt deposit or a discoloured coating.

It is not yet clear whether this may be due to fading of fugitive pigments or preferential loss.

Blanching

White patches on darker areas of paint. The black and brown passages are particularly affected.

Previous interventions

Coating on painted plaster

Light brown translucent and shiny coating. The coating is applied with wide horizontal brushstrokes and drips are often visible. The coating is applied to all plaster in the upper register on the exterior.

Coating on unpainted plaster

Brown coloured opaque coating with a blotcy, uneven and matte appearance. The coating is applied to all plaster on the lower register on the exterior.

Previous interventions

FILLS: SMALL

Smooth creamy-white plaster fills in small areas of loss on the walls and ceiling. The fills are mostly located on the upper register and frieze- and are similar in appearance to the large well finished fills in interior.

FILLS: SMALL

Putty coloured, rough plaster fills repair areas of loss on the walls and ceiling. These repairs are not widespread on the exterior.

FILLS: LARGE

Grey plaster fills in- large areas of loss on the ceiling. Over half of the exterior ceiling is lost and this type of repair was applied throughout.

CRACKED FILLS

Fissures or cracks affecting fills. They are possibly related to ongo- ing structural stresses or to the inherent susceptibility of the repair material.

Damage

PLASTER LOSS

Loss of plaster from stone support. Loss may affect all three layers of plaster. Large plaster losses have occured in the roof area, in the door jambs and on the south wall. Smaller areas of loss are also found in the painted scheme.

Loss may be associated with water infiltration, mechanical action and possibly the inherent susceptibility of the plaster and stresses imposed by structural failure.

Most areas of loss have been repaired, see Fills/ Repairs.

DETACHMENT

Loss of adhesion between plaster layers (shown here between the uppermost layer and secondary plaster layer), and/or between plaster and stone support.

The extent of detachment has not been fully assessed. Plaster detachment may be related to the inherent susceptibility of the plaster and support materials.

CRACKS

Fissures in the plaster. The cracks vary in size and width and the largest are generally distributed in the frieze area at the junction of the roof and walls, the corners of the building and on the walls.

Cracks may be associated with structural stresses in the building.

Some of the cracks were repaired with lime and marble dust plaster in the 1989 intervention (Agrawal 1989, 50).

STAINING

Light brown staining on the surface of the painting. The staining is located in the roof area, and may be associated with water infiltration.

During the 1989 intervention, the staining was reduced by application of ammonium bicarbonate and ammonium carbonate in a sorbent of carboxymethylcellulose.

Damage

Mirror Loss

Loss of inlaid mirror from the floral motifs in the dado area. Loss occurs on most motifs and appears to be associated with mechanical damage.

Plaster Loss on inlaid mirrors

Loss of plaster around the inlaid mirror motifs. Loss occurs in both upper and secondary plaster layers (in which the mirror is embedded) resulting in loss of design.

Plaster loss around the mirror work is widespread and may be related to mechanical damage.

Deterioration

Powdering Paint

Lack of cohesion in the paint layer resulting in loss. Powdering paint is localised to areas of salt efflorescence and is not widely distributed.

Flaking Paint

Detachment of the paint layer from the plaster, leading to loss. Flaking occurs mostly in the green paint layer and is prevalent in the green border between the walls and roof.

Deterioration

PIGMENT ALTERATION

A) Alteration of green paint layer to black. This type of alteration occurs on certain types of green such as the wine flasks and green border in the vault. This form of deterioration may be related to the mixing of lead white in the paint layer.


A

PIGMENT ALTERATION

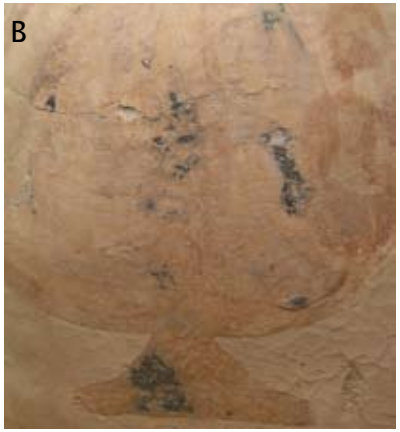
B) Alteration of pink paint layer to black. This alteration occurs in the wine flasks, draperies and also in the flesh tones (see E). The alteration occurs in most pink paint layers and may be related to use of lead white in paint layer.

C) Alteration or fading of swirling cloud shapes to translucent. The original colour is indeterminate but some areas appear to be blue.

D) Alteration of blue to black. This type of alteration is localised to the depiction of water in the paintings located in the roof.

E) Alteration of flesh tones to black/ grey. Alteration to black is widespread and occurs in most of the figures in the interior scheme. This type of alteration may be related to use of white or red lead in the paint layer, as in C.


D


B


C


E

Deterioration

Salt Efflorescence

Large white fluffy efflorescence, often forming sheets of crystals.

Salt efflorescence is only located on the north wall, in the roof scheme above the frieze.

Surface Deposits

Dirt

Homogeneous brown surface deposit. Dirt is most heavily and consistently deposited on the dado plaster around the inlaid mirrorwork.

Surface Deposits

Insect Nests

Multi-partioned casings patterns resulting from insect nesting. In some examples, the nest has fallen away leaving the shadow on the wall, as illustrated left. Insect nests are not common on the interior of the building.

Bird Excreta

Bird droppings which are found occasionally on the interior wall surface.

Previous Interventions

Fills/ Repairs: Tinted lime plaster

Lime-based plaster fills applied with recessed surface and tinted to match the colour of the plaster. These fills tend to be quite small and are present below the roof.

Application of these fills is referred to in the 1989 intervention.

Fills/ repairs: Dado Render/ Large fill

Larger lime-based fills applied in a technique replicating the original appearance. These fills are well-finished and neat. This type of fill is found in larger areas of loss in the dado, walls and on the ceiling.

Fills/ Repairs: Marble dust plaster

Fills in white lime-based material. Applied rapidly and often overlap the surface of the original plaster. These fills are small and present below the roof.

Fills/ Repairs: Loss

Loss of the uppermost fine white plaster occurs in the large fills. Loss of material occurs in fills in the roof and on the door jambs and may be related to continuing infiltration and mechanical abrasion respectively.

Previous Interventions

Attempted Reconversion

Trials to reconvert altered lead pigment from black to white. The trials are minimal.

Reconversion trials are recorded in the 1989 intervention but the methods are not specified.

Consolidation of powdering Paint

Recohesion of powdering paint by use of a consolidant. Some areas retain cotton wool on the surface. Consolidation is not extensive.

Repainting

Reintegration of losses in the paint layer. Repainting is poorly matched and often extends over the original paint.

Fill over inlaid mirror

Lime-based material filling the mirror work. The consistency and extent of the lime suggests that it was deliberately covered at some point. This filling material is distinct from the lime plaster creating the design.

Previous Interventions

Coatings: Thin

Thin, translucent, shiny coating on surface of entire interior scheme. In most places areas the coating has discoloured to brown.

During the 1989 intervention polyvinyl acetate was applied to the surface to readhere flakes and to provide a protective coating. (Agrawal 1989, 49).

Coatings: Thick and drippy

Brown, translucent and shiny coating applied thickly and unevely to the surface of the paintings. In some areas large drips are also present.

This type of coating is mostly found on the east side of the south wall.

Coatings: thick and bubbly

Brown, translucent and shiny coating applied to the surface of the paintings with associated bubbling and lifting of the paint layer.

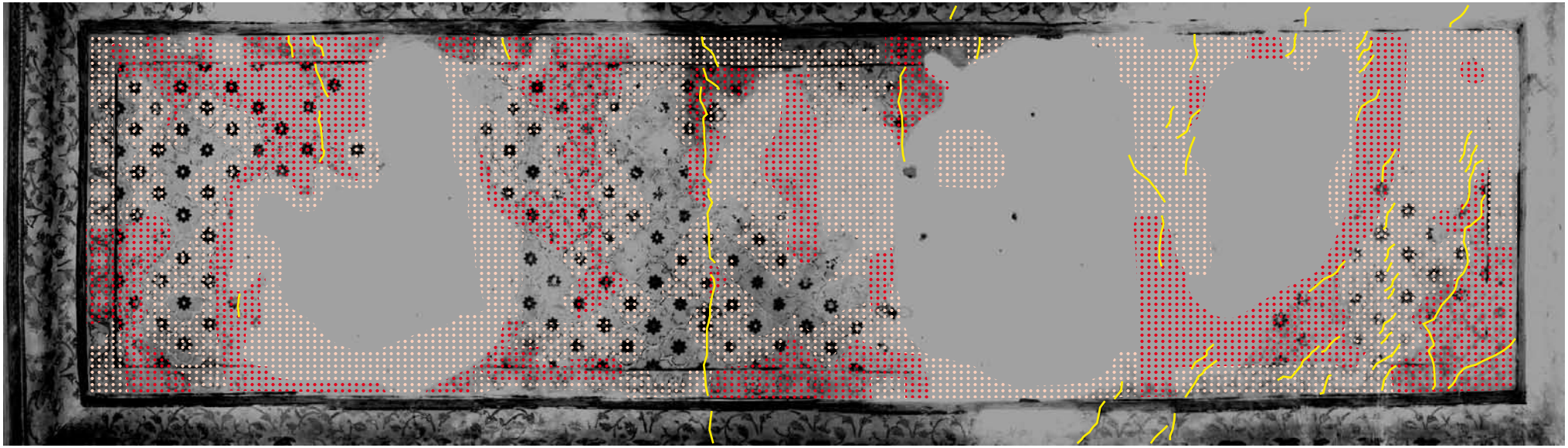
This type of deterioration is mostly found on the south wall, east side.

Coatings: Grey

Grey coloured coating applied patchily over the paintings' surface. This coating is widely distributed on the surface and is underneath the thin (PVAC) coating.

Graphic Documentation

Bakht Singh Mezzanine Level

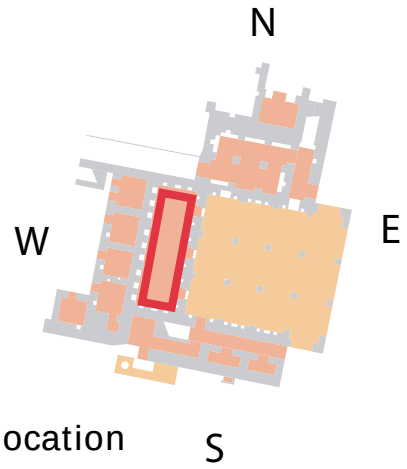


Detached area

Severely detached

Cracks

0.5 1.0 m



IMACC Documentation Sessions

Session I – 2006-03-03 – Introduction to Visual Glossary

A PowerPoint presentation was given to members of the IMACC team and illustrated the purpose and different components of a visual glossary recording aspects of original technique and condition of wall paintings.
The first floor of Hadi Rani Mahal was chosen for didactic purposes and the team guided trough the establishment of categories for photographic recording.
Basics of digital photography were also covered.

See Part I of PowerPoint document included in electronic format on the included CD and word document on categorisation of the condition of the wall paintings in the first floor of Hadi Rani Mahal

Session 2 and 3 – 2006-03-10/17 – Introduction to Photographic Monitoring

In the first session, a PowerPoint presentation was given to members of the IMACC team and illustrated the purpose and methodology of Photographic Monitoring. Basics of digital photography were covered with the newly acquired IMACC digital camera and didactic exercises set up to help understand the different capturing parameters. The second session was dedicated to the selection of different areas to be monitored for changes overtime. A first series of photographs was taken by the member of the IMACC team and recording on a proforma. A schedule was agreed for further photographic recording throughout the year.

See Part II of PowerPoint document included in electronic format on the included CD and word / excel documents on Basics of digital photography. For further details on Photographic monitoring and selected areas see excel document and Appendix 2d

Photographic Monitoring

Schedule-2006

Monitoring images should be taken within one week of the following dates:

1- March 23rd

2- June 23rd

3- September 23rd

4- December 23rd

Instructions

Images should be taken with the same frame and settings used for the March 23rd capture.
For each image a proforma should be filled out. Images should be downloaded, properly named, filed, and a back-up copy should be made on CD.

Please remember to consider the tips for imaging outlined in the document 'Photography Basics'.

Locations

(Note: For settings see proforma)

Location A: Abha Mahal (26), Interior, Room 10
Purpose of Monitoring: 1)To assess if the efflorescence changes in appearance during the year and 2) to determine if there is any loss of the salt efflorescence/crust

A1- Abha Mahal (26), Interior, Room 10, South Wall

Image: Context, normal light

A2- Abha Mahal (26), Interior, Room 10, South Wall (same frame as A1)

Image: Context, raking light
A3- Abha Mahal (26), Interior, Room 10, Floor below South Wall, Acetate Sheets

Location B: Abha Mahal (26), Exterior, East Façade
Purpose of monitoring: To assess rate of dirt deposition on cleaning trial

B1- Abha Mahal (26), Exterior, East Façade

Image: Context

B2- Abha Mahal (26), Exterior, East Façade

Image: Macro

Location C: Akbari Mahal (32), Interior, Vault
Purpose of monitoring: 1) To assess if loss of repair material is ongoing

CI- Akbari Mahal (32), Interior, Vault

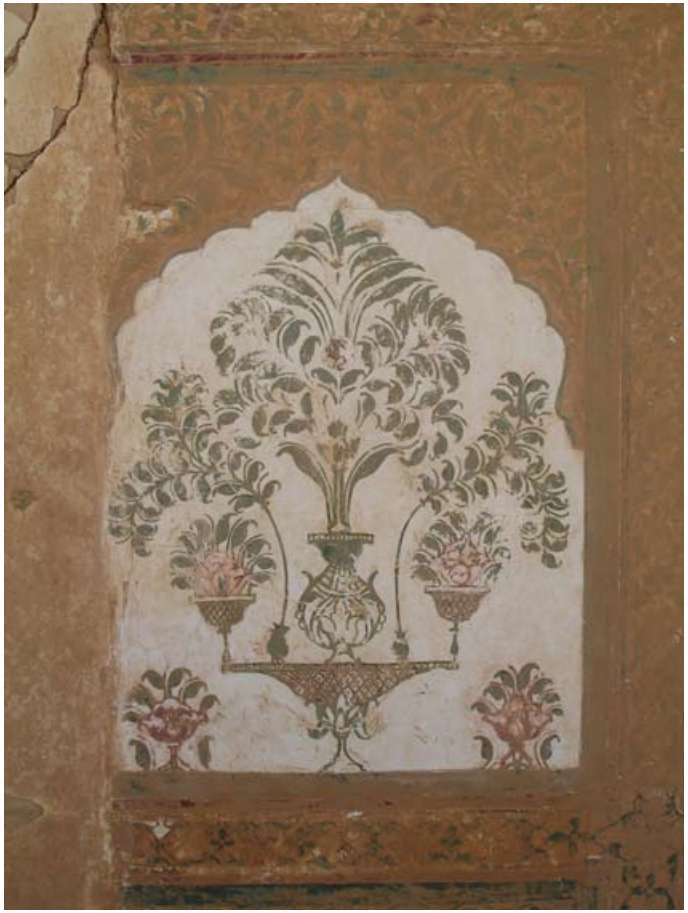
Image: Context, with flash

Above: Location A1

Above: Location A2

Above: Location A3

Above: Location C1



Above: Location B1

Above: Location B2

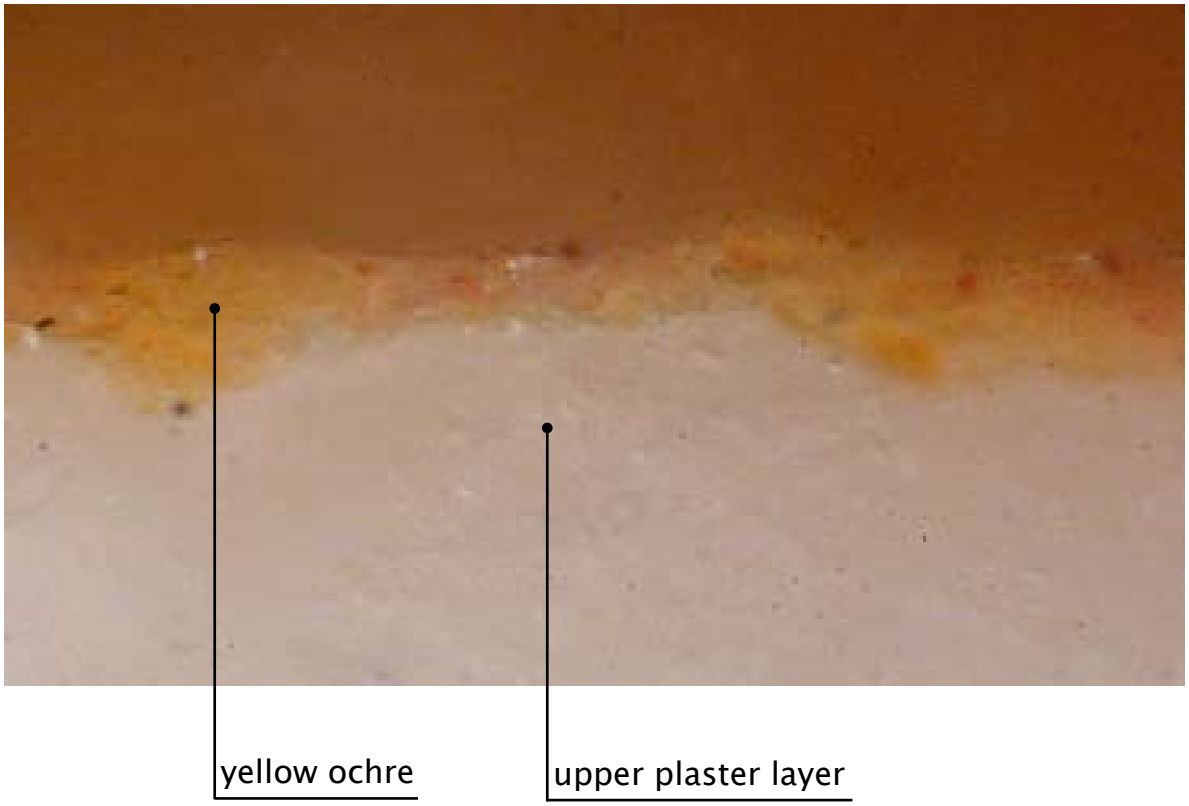
SAMPLING SUMMARY

Site Sample	CIA Sample #	Sample Description	Sample Location	Photo Reference	Cat-egory	Purpose of Sample	Intended Analysis
NAG06-26-S01	3784	golden yellow colour in flower pattern- area of loss with dirt on the surface- some flaking	26, ext. east façade H- 1.58m	NAG06-26-015	OT	id of yellow pigment, repaint (?), compare with NAG06-26-S02	☑ X-sec ☑ Dispersion ☑ MCT ☑SEM FTIR Other_____
NAG06-26-S02	3785	pale golden yellow, some flaking in adjacent area- faded in other areas	26, ext. east façade H- 2.3m	NAG06-26-016	OT	id of yellow pigment, fading of organic colorant(?), shelter(?), compare with NAG06-26-S02	☑X-sec ☑ Dispersion ☑ MCT SEM FTIR Other_____
NAG06-22-S03	3786	altered area- pink flesh tone to black near loss in hand- some blackening on surface	22, first floor, south wall H- 1.46m	NAG06-22-029	OT	id of stratigraphy and pigments in blackened flesh tone, extent of alteration	☑X-sec ☑ Dispersion ☑ MCT SEM FTIR Other_____
NAG06-22-S04	3787	altered area of pink flesh tone to black- all of surface is blackened	22, first floor, south wall H- 1.47m	NAG06-22-030	OT	id of stratigraphy and pigments in blackened flesh tone, extent of alteration	☑ X-sec ☑ Dispersion ☑ MCT ☑SEM FTIR Other_____
NAG06-22-S05	3788	bright green paint layer- high binder to pigment ratio(?), good condition, next to crack	22, first floor, north wall H- 2.42m	NAG06-22-031	OT	id of green pigment, mineral(?), flaking, compare with S06 & 07	☑ X-sec ☑ Dispersion ☑ MCT ☑SEM FTIR Other_____
NAG06-22-S06	3789	pale beige coloured tree, sample from near crack, thicker paint layer then other green	22, first floor, south wall H- 2.42m	NAG06-22-032	OT	id of green pigment, fading of organic colorant(?), compare with S05, S07	☑X-sec ☑ Dispersion ☑ MCT SEM FTIR Other_____
NAG06-22-S07	3790	near crack, possible white repair material on surface, faded green, organic colorant(?)	22, ground floor, south wall H- 2.37m	NAG06-22-037	OT	id of green pigment, fading of organic colorant(?), compare with S05, S06- include black outline over green- id for binding media	☑X-sec ☑ Dispersion ☑ MCT SEM FTIR Other_____
NAG06-22-S08	3791	near an area of filled loss, dark blue appearance with white 'wave' highlights	22, first floor, east wall H- 2.17m	NAG06-22-033	OT	id of blue pigment, possible foil(?), alteration to black(?)	☑X-sec ☑ Dispersion MCT SEM FTIR Other_____
NAG06-22-S09	3792	faded- partial fading of blue pigment from upper border w/ flower pattern, brittle paint layer	22, second floor, west wall H- 2.75m	NAG06-22-034	OT	id of blue pigment, fading of organic colorant(?)	☑ X-sec ☑ Dispersion ☑ MCT SEM FTIR Other_____
NAG06-32-S10	3793	stable 'unaltered' blue- near area of loss, cleaned area, good condition with some adj. flaking	32, ext., east wall H- 2.49m	NAG06-32-073	OT	id of blue pigment, stable unaltered area	☑ X-sec ☑ Dispersion ☑ MCT ☑SEM FTIR Other_____

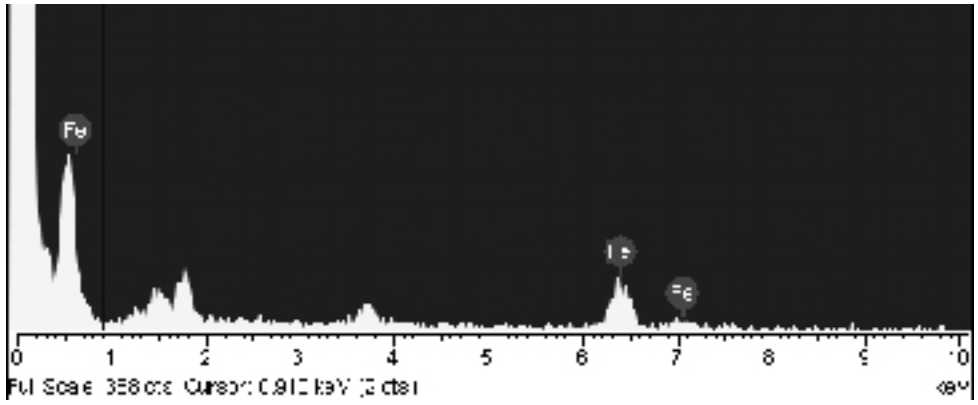
NAG06-22-S11	3794	area of damage- possibly white repair on surface, grouted in prev. int.?	22, ground floor, south wall H- 2.97m	NAG06-22-036	AM	characterisation of coating and dirt deposition (to assess cleaning potential)- large sample needed	☑ X-sec Dispersion MCT ☑SEM FTIR Other_____
NAG06-26-S12	3795	plaster w/ coating in area of detachment near loss, saturated surface	26, int., room 10, west wall H- 1.56m	NAG06-26-017	AM	characterisation of coating, previous intervention(?), cleaning potential, salts	☑ X-sec Dispersion MCT ☑SEM FTIR Other_____
NAG06-22-S13	3796	area of residual PVAC in plaster background, near loss	22, first floor, west wall	NAG06-32-035	AM	characterisation of surface residue after removal of PVAC coating (drips)	X-sec Dispersion MCT SEM FTIR Other_____
NAG06-32-S14	3797	ochre coloured coating over plaster on lower register near a loss- area w/ fine cracks	32, ext., east wall H- 1.55m	NAG06-32-074	AM	characterisation of ochre coloured coating on lower register, cleaning potential	☑X-sec Dispersion ☑ MCT SEM FTIR Other_____
NAG06-32-S15	3798	paint layer- brown over black (woman's dress), before cleaning trial	32, ext., south wall	NAG06-32-004	TA	before cleaning- assessment of impact of cleaning with acetone swab	☑X-sec Dispersion MCT ☑SEM FTIR Other_____
NAG06-32-S16	3799	paint layer- brown over black (woman's dress), after cleaning trial	32, ext., south wall	NAG06-32-004	TA	after cleaning- assessment of impact of cleaning with acetone swab	☑ X-sec Dispersion MCT ☑SEM FTIR Other_____
NAG06-32-S17	3800	faded area on wine flask w/ grey patchy deposit on surface, next to a loss, before cleaning	32, int., north wall 2.05m	NAG06-32-75	TA	before cleaning, removal of PVAC, trial assessment, safety of cleaning 'faded' pigments	☑X-sec Dispersion MCT ☑SEM FTIR Other_____
NAG06-32-S18	3801	as above- after cleaning compare w/ S17	32, int., north wall 2.05m	NAG06-32-75	TA	after cleaning- as above	☑X-sec Dispersion MCT ☑SEM FTIR Other_____
NAG06-26-S19	3802	green paint layer under thick deposition of dirt, near area of loss	26, ext. east façade H- 0.31m	NAG06-	TA	before cleaning- characterisation of dirt deposit and assess the effect of cleaning- compare w/ S20	☑ X-sec Dispersion MCT ☑SEM FTIR Other_____
NAG06-26-S20	3803	green paint layer after cleaning trial, near area of loss, some residual dirt on the surface	26, ext. east façade H- 0.31m	NAG06-26-002	TA	after cleaning- to assess the effect of cleaning on the green pigment	☑ X-sec ☑ Dispersion MCT ☑SEM FTIR Other_____
NAG06-32-S21	3804	heavy area of ochre coloured coating over the plaster on lower register- fine cracks	32, ext., west wall	NAG06-	AM	characterisation of ochre coloured coating on lower register, assessment of cleaning potential	☑X-sec ☑ Dispersion ☑ MCT SEM FTIR Other_____
NAG06-32-S22	3805	area of grey deposit/coating in niche, near crack	32, int., north wall H- 2.0m	NAG06-	AM	characterisation of grey coloured coating, assessment of cleaning potential	☑ X-sec ☑ Dispersion ☑ MCT ☑SEM FTIR Other_____
NAG06-32-S23	3806	area of damaged inlaid mirror-work on dado, some lime on surface (crushed)	32, int., west wall H- 0.52m	NAG06-32-076	OT	examination/analysis of glass used for inlaid mirrorwork- Satoko? potential for removing lime from surface	X-sec ☑ Dispersion MCT ☑SEM FTIR Other__*Satoko?*_____

Context of sampling location

Sampling location

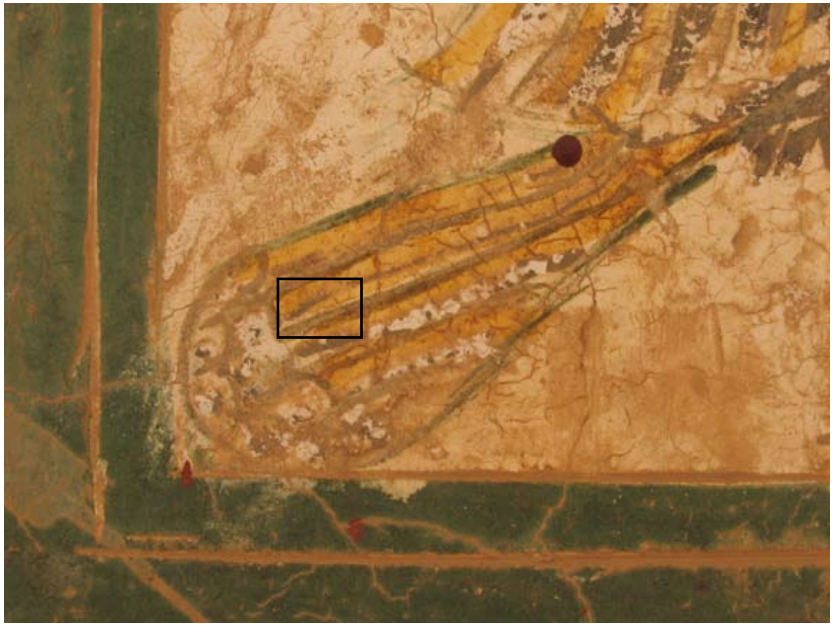


Cross-section of sample 3784 (photographed at 200x) taken from a yellow flower on the east facade of the Abha Mahal. The cross-section shows a medium rich layer of yellow ochre and the upper plaster layer. Below an EDS spectrum shows peaks for iron (Fe).

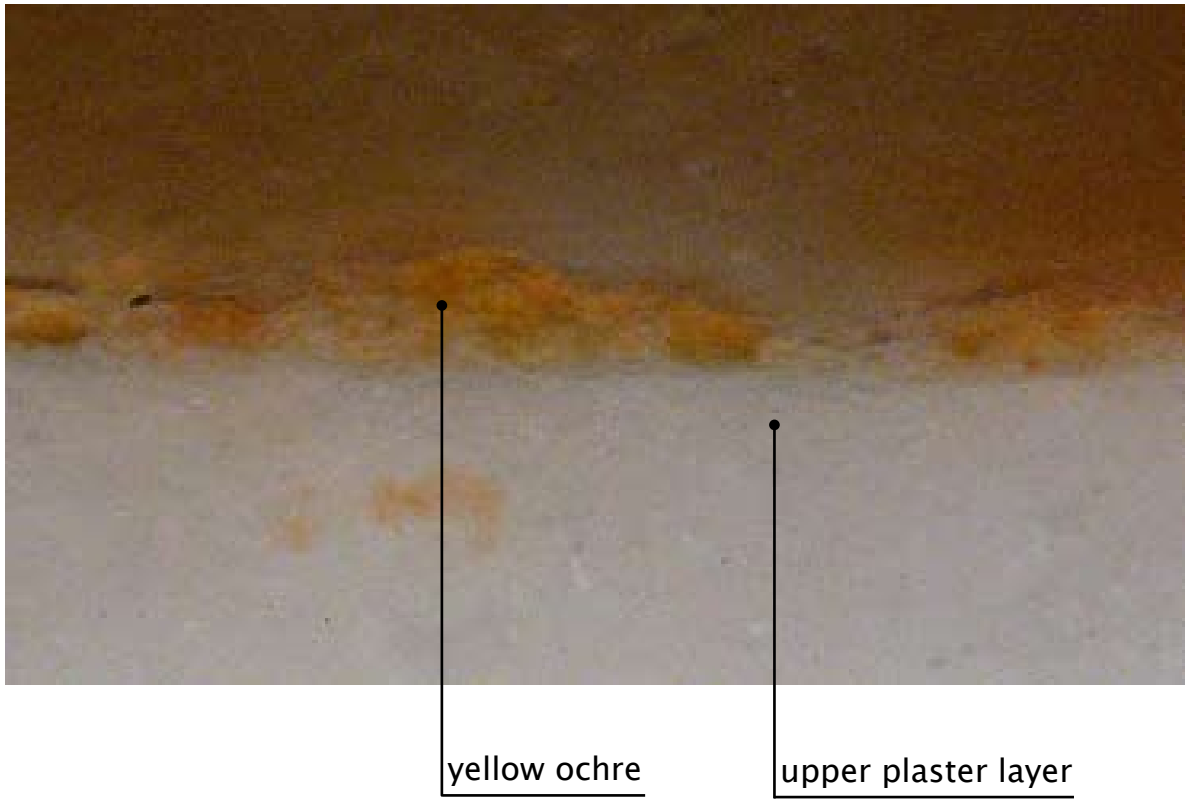


Sample 3785

Context of sampling location



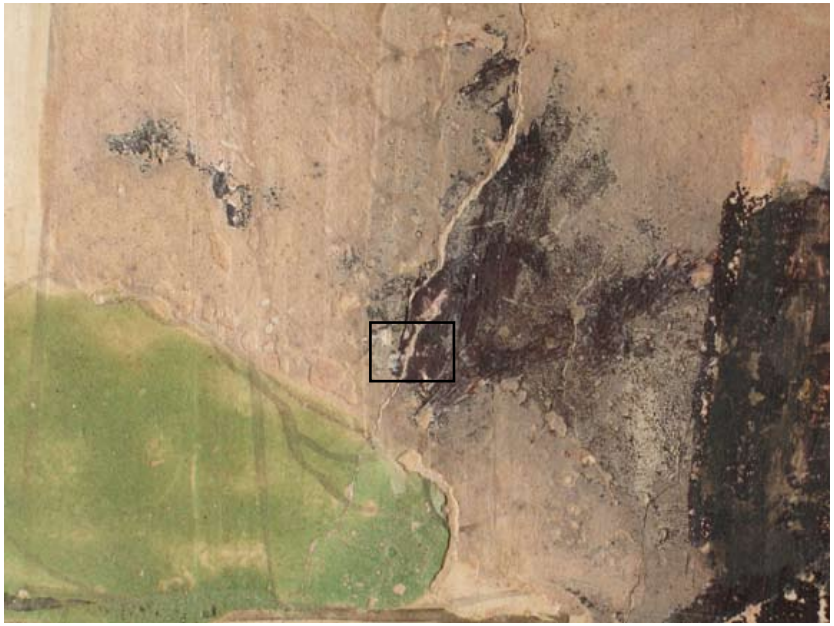
Sampling location



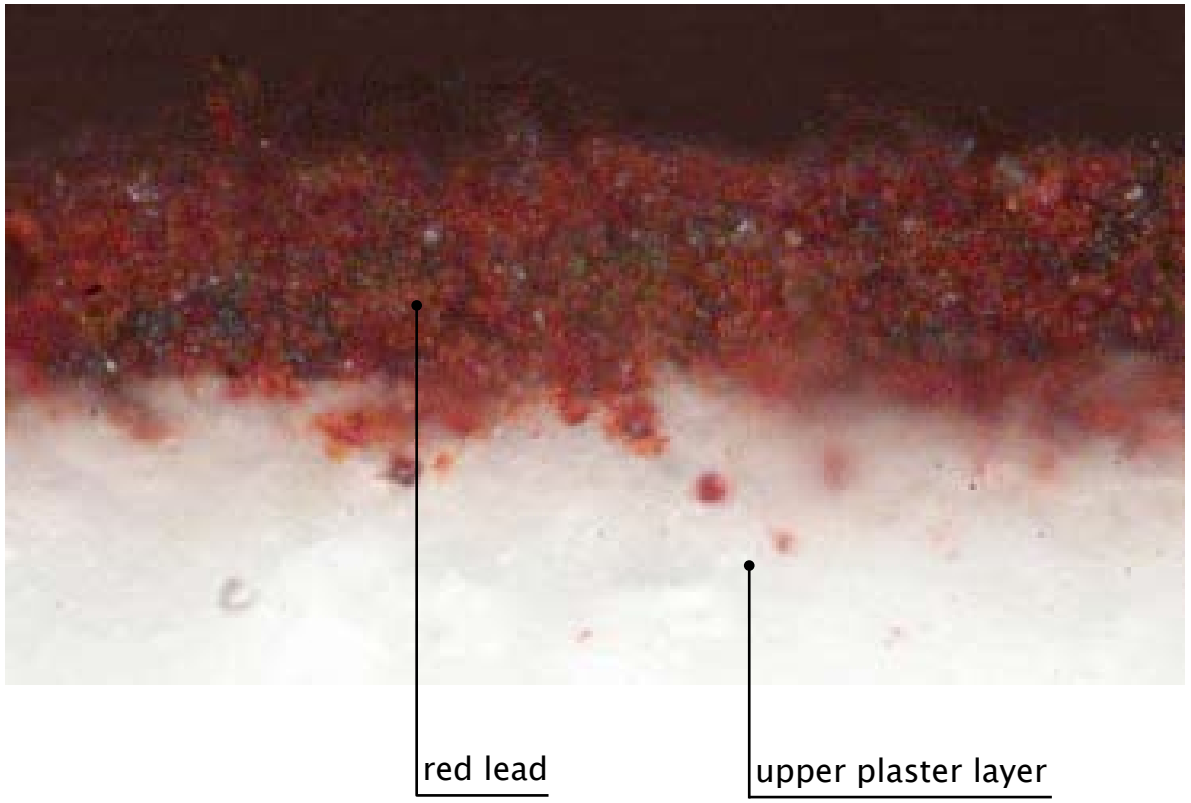
Cross-section of sample 3785 (photographed at 200x) taken from a peacock's tail on the east facade of the Abha Mahal. The cross-section shows a medium rich layer of yellow ochre and the upper plaster layer.

Sample 3787

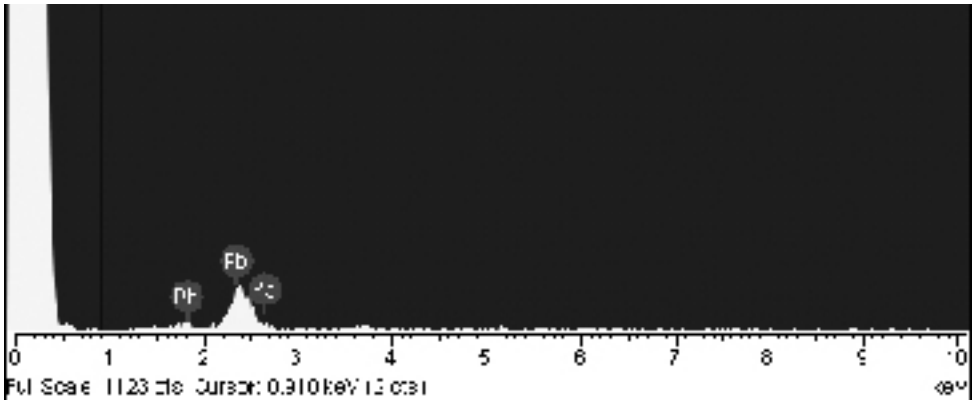
Context of sampling location



Sampling location



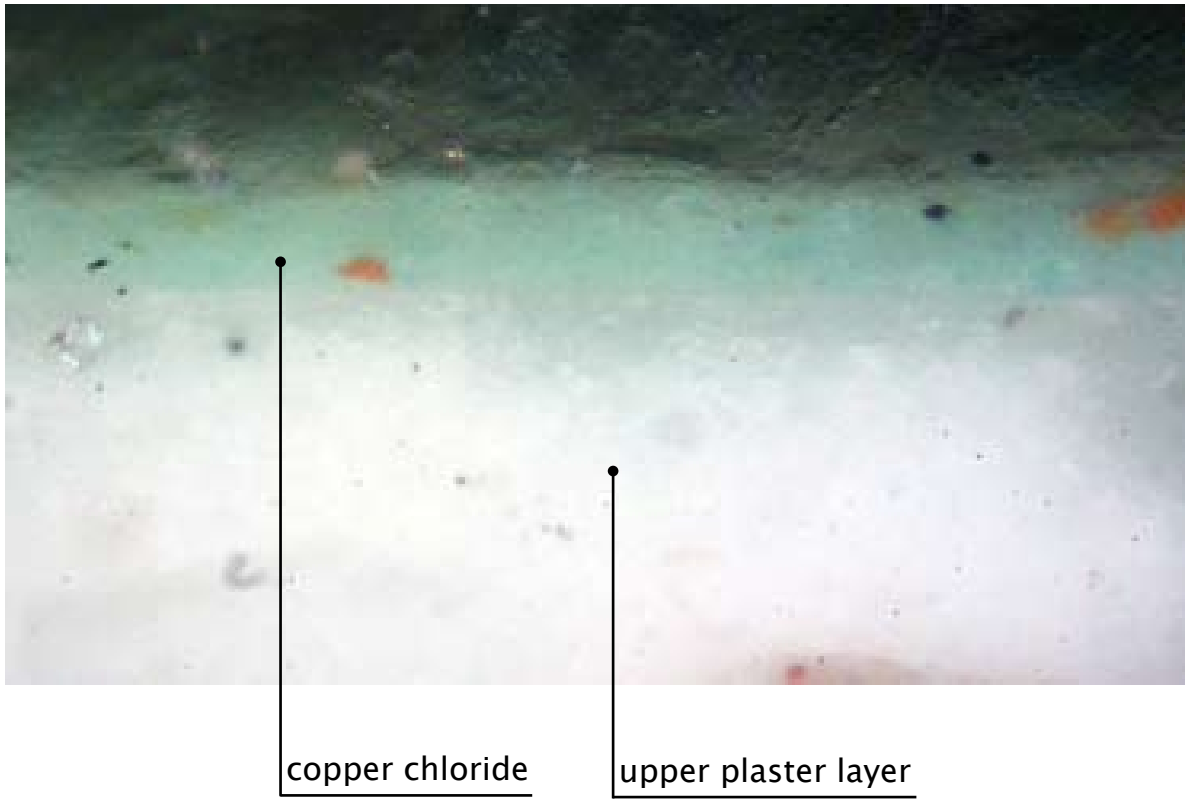
Cross-section of sample 3787 (photographed at 200x) taken from an area of altered flesh tone on the south wall of the first floor of the Hadi Rani Mahal. The cross-section shows a layer of red lead with dark particles of altered pigment. Below an EDS spectrum shows peaks for lead (Pb).



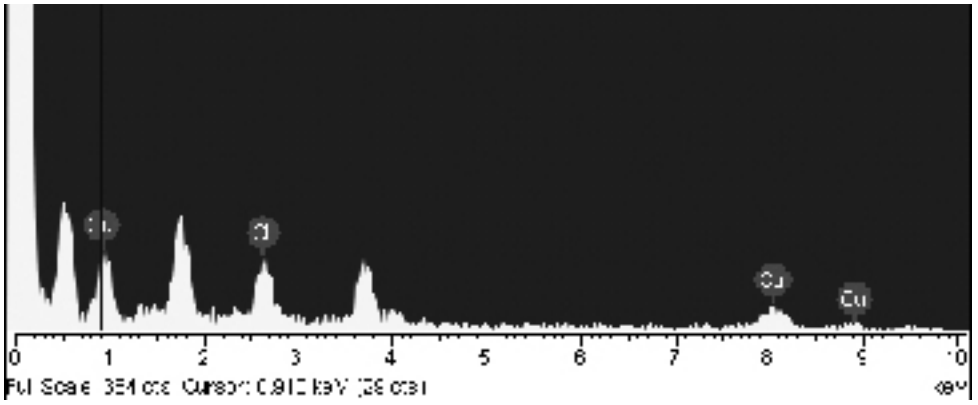
Sample 3788

Context of sampling location

Sampling location



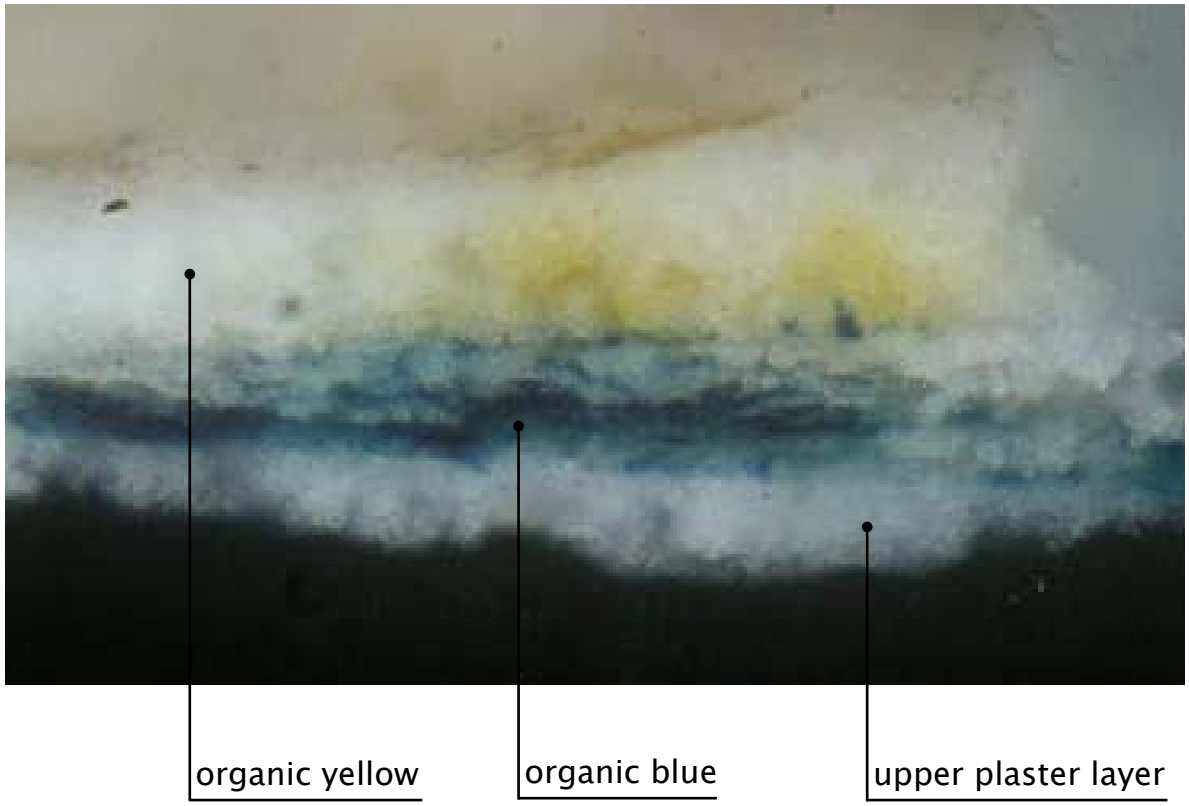
Cross-section of sample 3788 (photographed at 200x) taken from a bright green tree on the north wall of the first floor of the Hadi Rani Mahal. The cross-section shows a medium rich layer of copper chloride green. Below an EDS spectrum shows peaks for copper and chloride.



Sample 3789

Context of sampling location

Sampling location

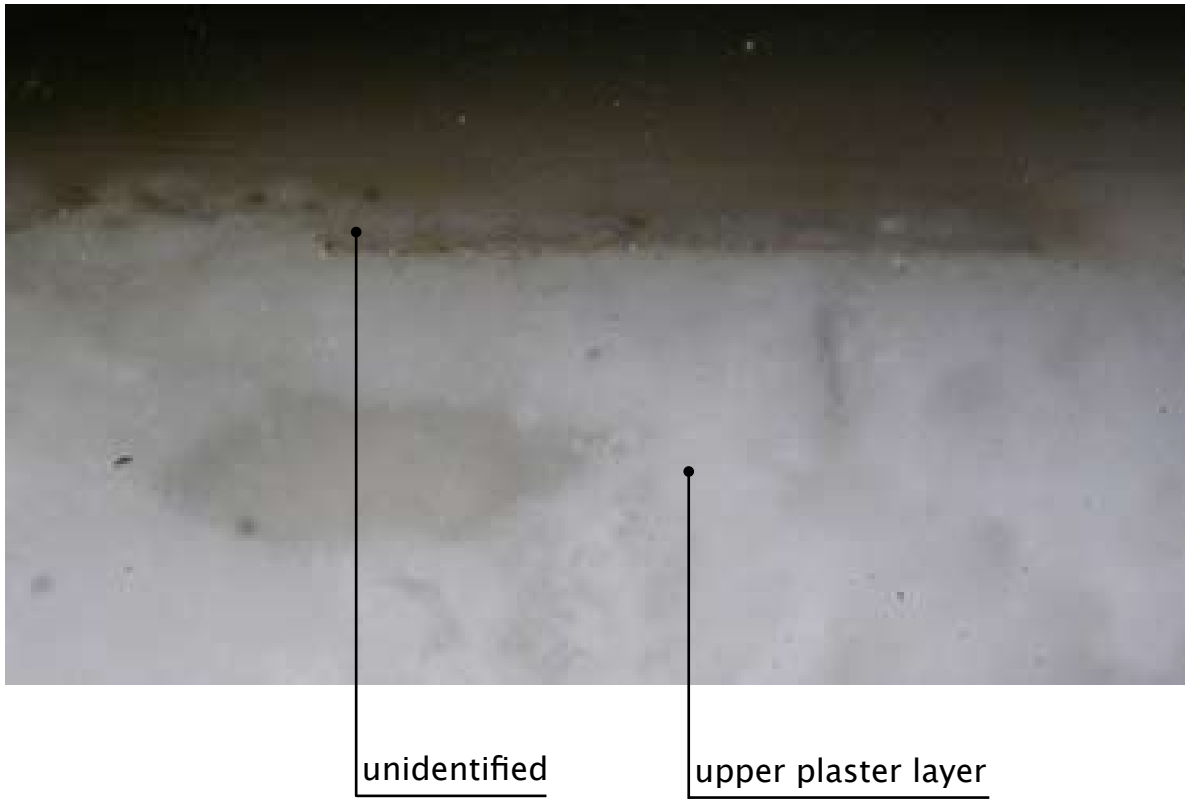


Cross-section of sample 3789 (photographed at 200x) taken from an altered beige-coloured tree on the south wall of the first floor of the Hadi Rani Mahal. The cross-section shows a layer of organic yellow over a layer of organic blue. Both organic colorants are fugitive resulting in the present beige appearance, instead of the intended green.

Sample 3790

Context of sampling location

Sampling location

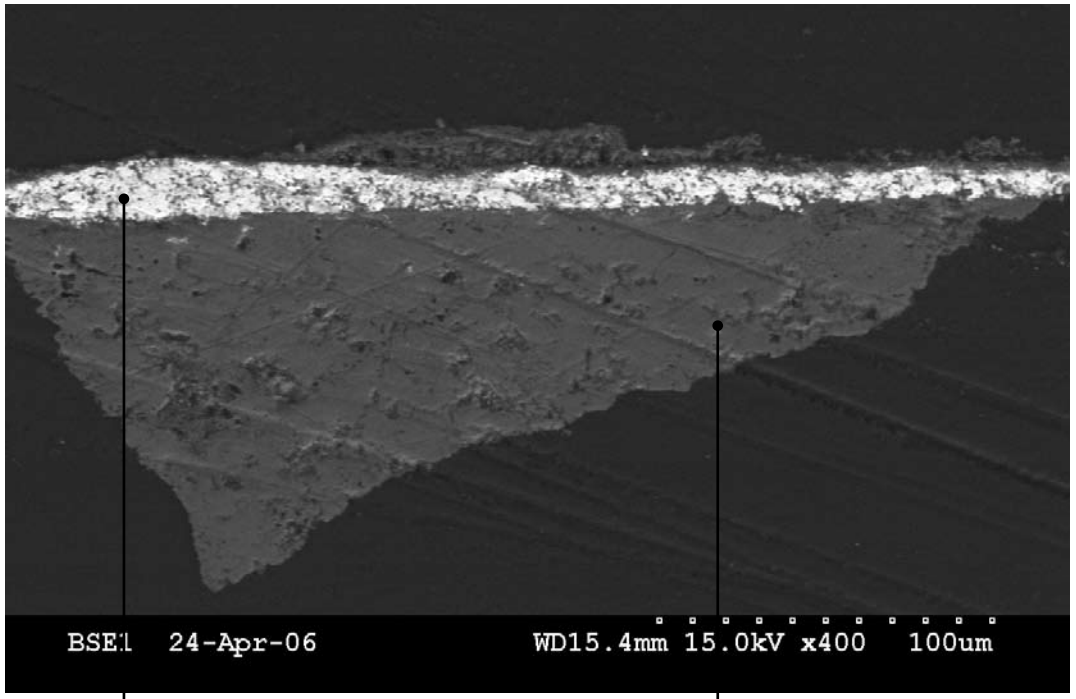


Cross-section of sample 3790 (photographed at 100x) taken from a faded palm tree on the south wall of the ground floor of the Hadi Rani Mahal. It was not possible to identify the paint layer with PLM since no colour or pigment particles were visible in the sample. However, it may well be a fugitive organic colorant as seen in sample 3789. Further sampling and analysis is needed for identifcation.

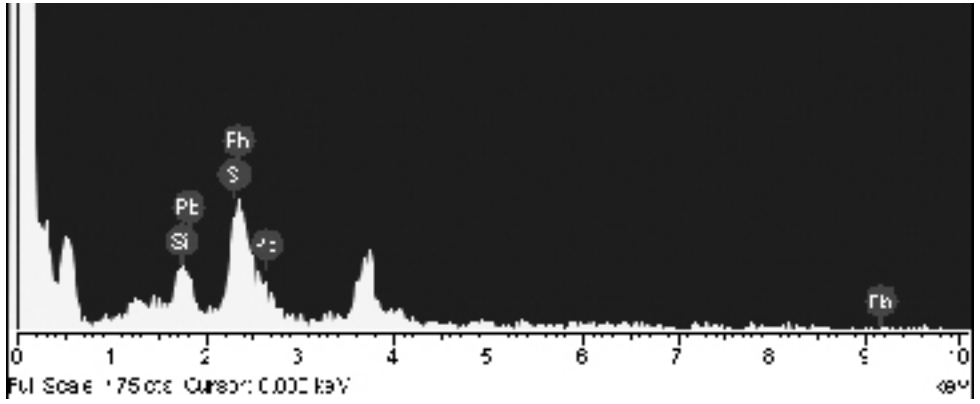
Sample 3791

Context of sampling location

Sampling location



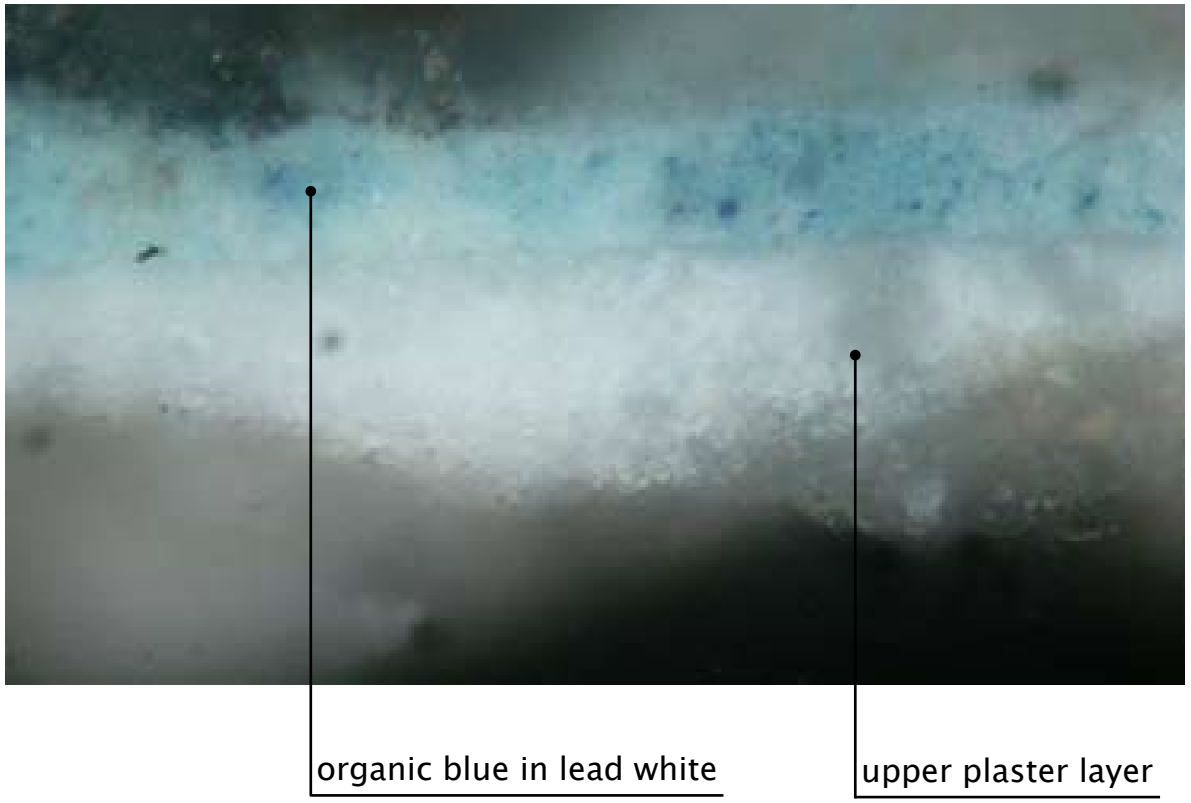
Back-scattered electron image of a cross-section of sample 3791 (photographed at 400x) taken from the river on the east wall of the first floor of the Hadi Rani Mahal. The bright white layer is lead white, identified with SEM-EDS. In PLM no crystalline blue particles were visible, suggesting that the blue may comprise a fugitive organic blue colorant in a lead white matrix, as seen in sample 3792. Below an EDS spectrum shows peaks for lead.



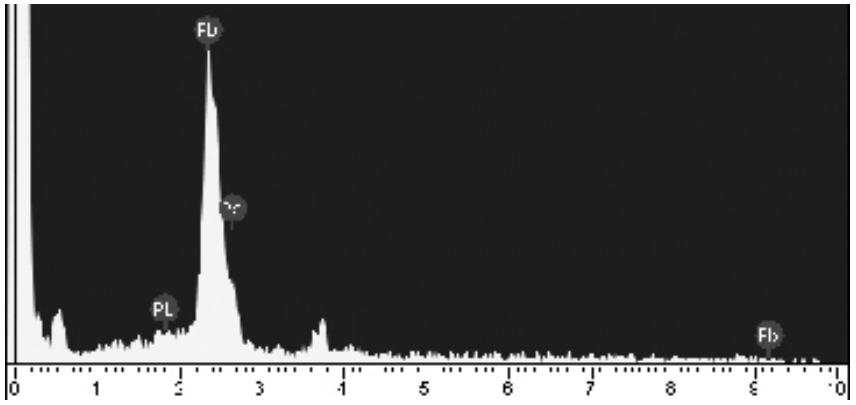
Sample 3792

Context of sampling location

Sampling location



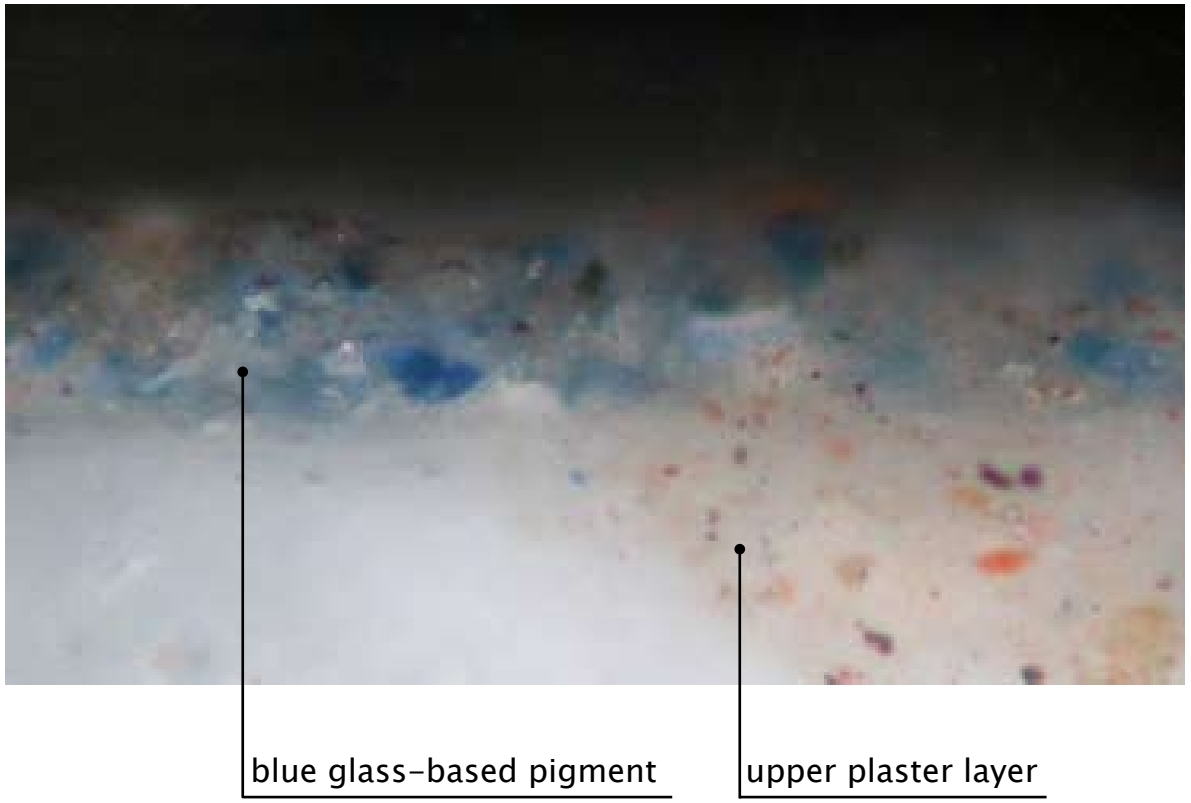
Cross-section of sample 3792 (photographed at 100x) taken from the blue flower on the upper border of the west wall of the second floor of the Hadi Rani Mahal. The cross-section shows a layer of fugitive organic blue (probably indigo) in a lead white matrix. Below an EDS spectrum shows peaks for lead.



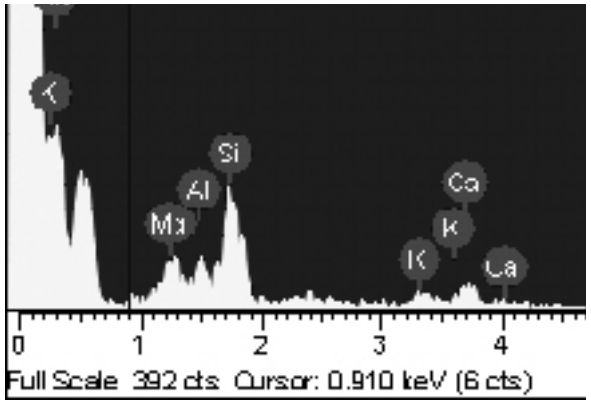
Sample 3793

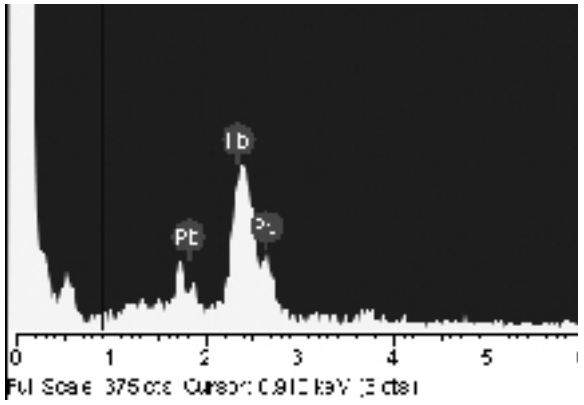
Context of sampling location

Sampling location

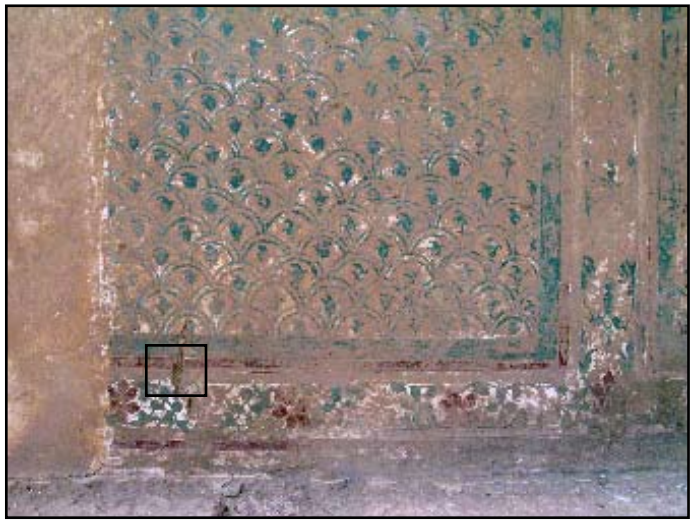


Cross-section of sample 3793 (photographed at 200x) taken from the blue flower on the east wall of the exterior of the Sheesh Mahal. The cross-section shows a blue glass-based pigment (probably smalt) in a lead white matrix. Below EDS spectra show peaks for silica



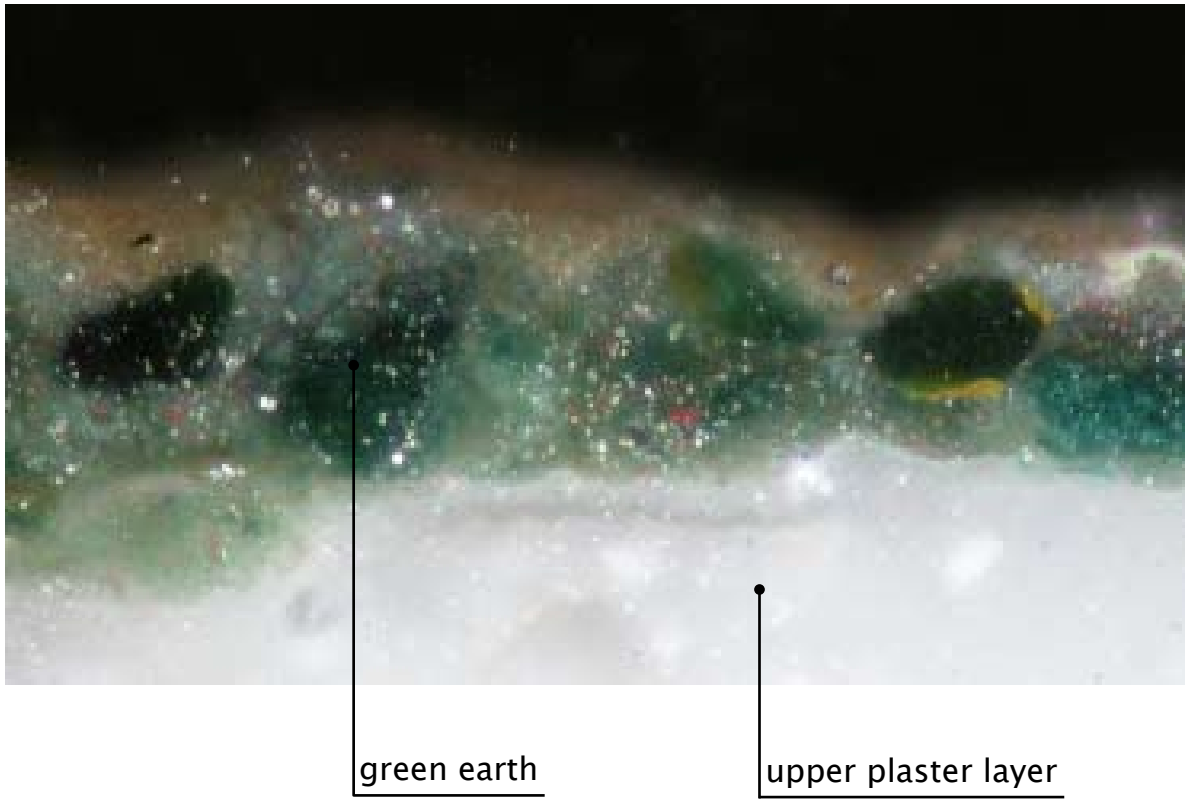


Sample 3802

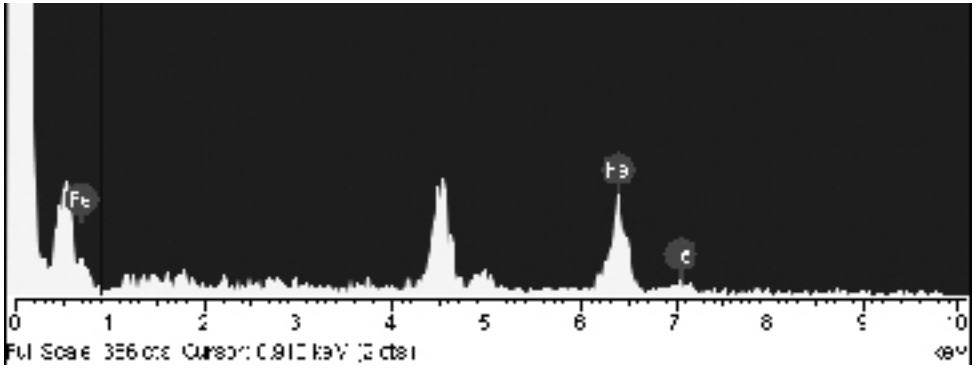


Context of sampling location

Sampling location



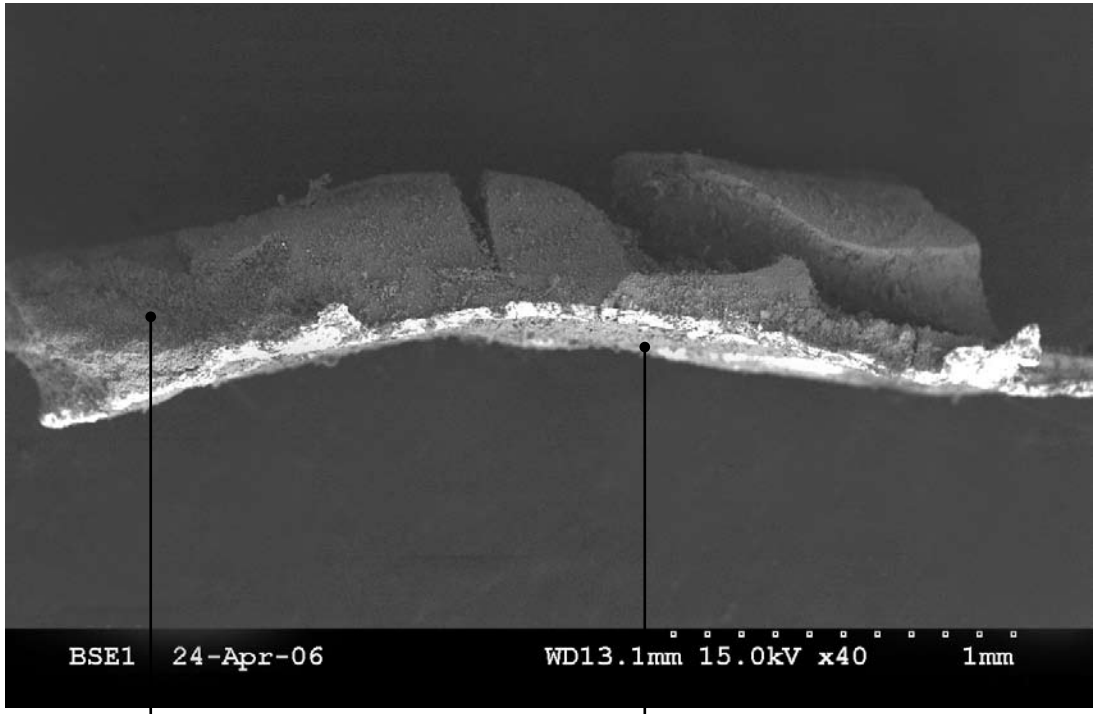
Cross-section of sample 3802 (photographed at 200x) taken from the green flower border on the east facade of the Hadi Rani Mahal. The cross-section shows large particles of green earth. Below an EDS spectrum shows peaks for iron (Fe).



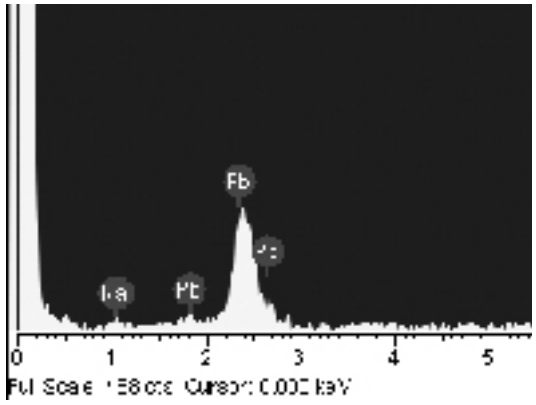
Sample 3806

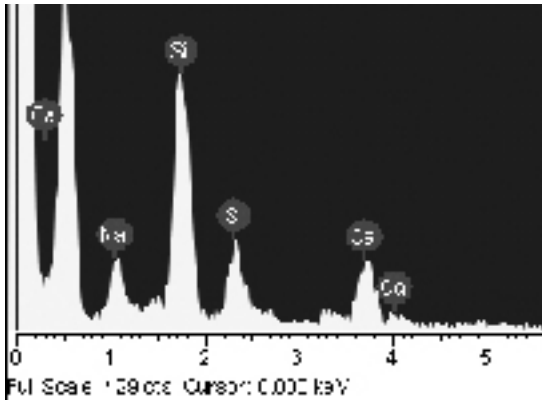
Context of sampling location

Sampling location



Back-scattered electron micrograph of sample 3806 (photographed at 40x) taken from the inlaid mirror-work on the dado of the west wall of the Sheesh Mahal. Elemental analysis by SEM / EDS identified the sample as a sodium-based silica glass with a lead foil backing. Below EDS spectra show peaks for lead and silica.

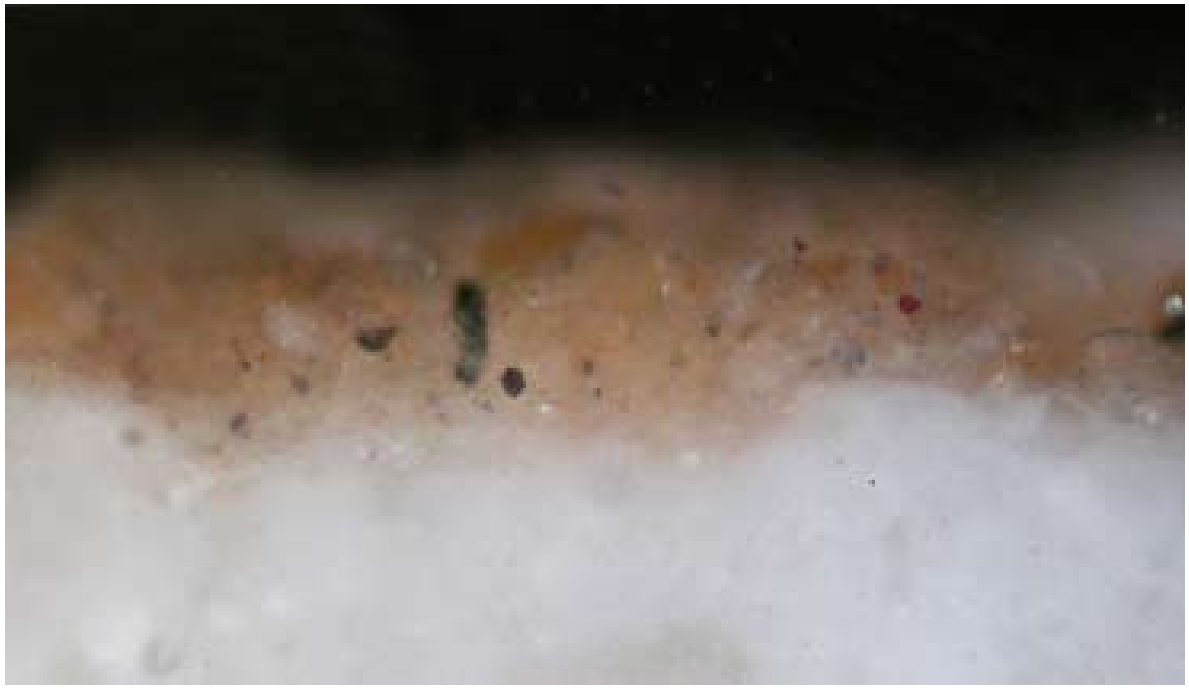




Sample 3794

Context of sampling location

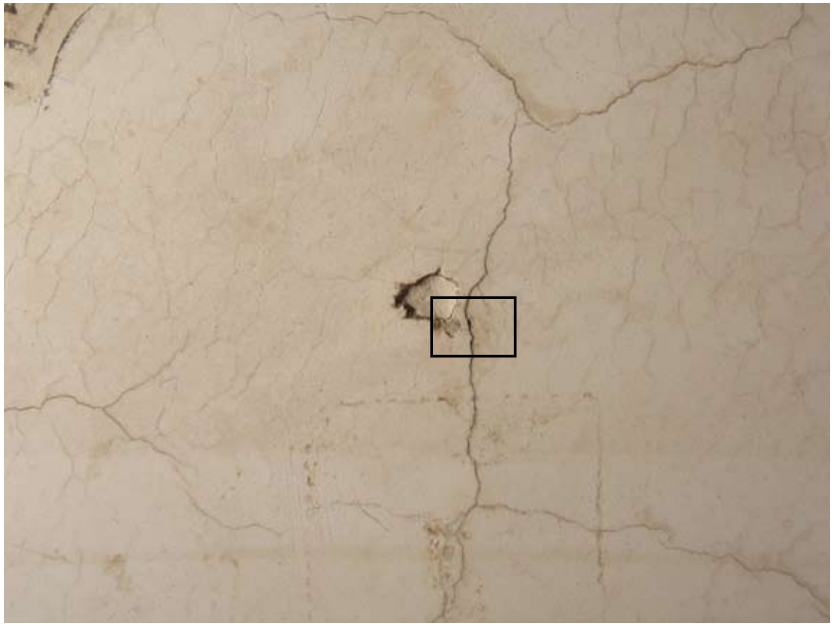
Sampling location



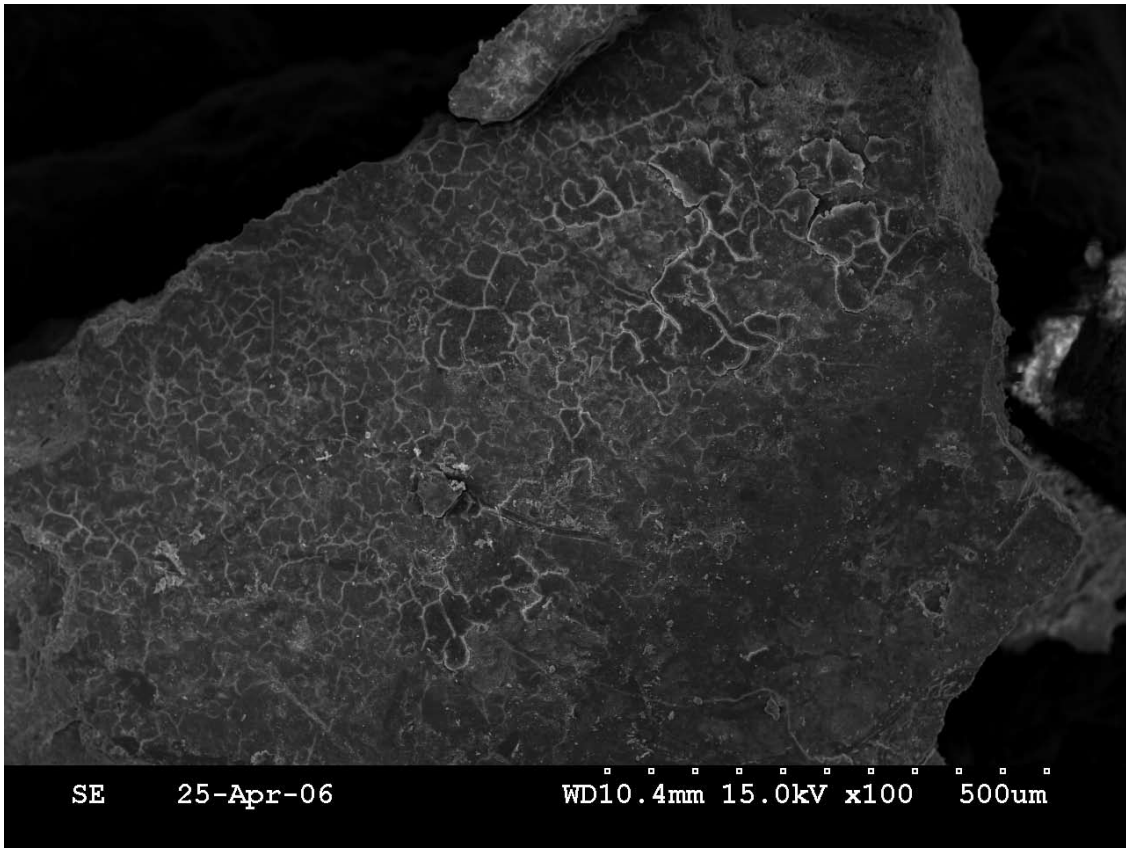
Cross-section of sample 3794 (photographed at 200x) showing the upper plaster layer taken from the south wall of the ground floor of the Hadi Rani Mahal. The cross-section shows a deposition on the surface of the plaster. Further characterisation of this unwanted material is required.

Sample 3796

Context of sampling location



Sampling location



Scanning electron micrograph of sample 3796 (photographed at 100x). The image shows residual synthetic coating after cleaning trials. The residue is characterised by dark saturated patches on the surface of the plaster.

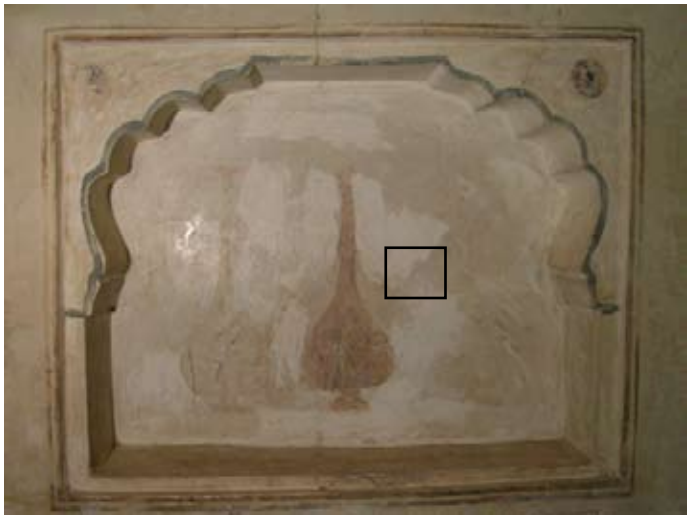
Sample 3804

Context of sampling location

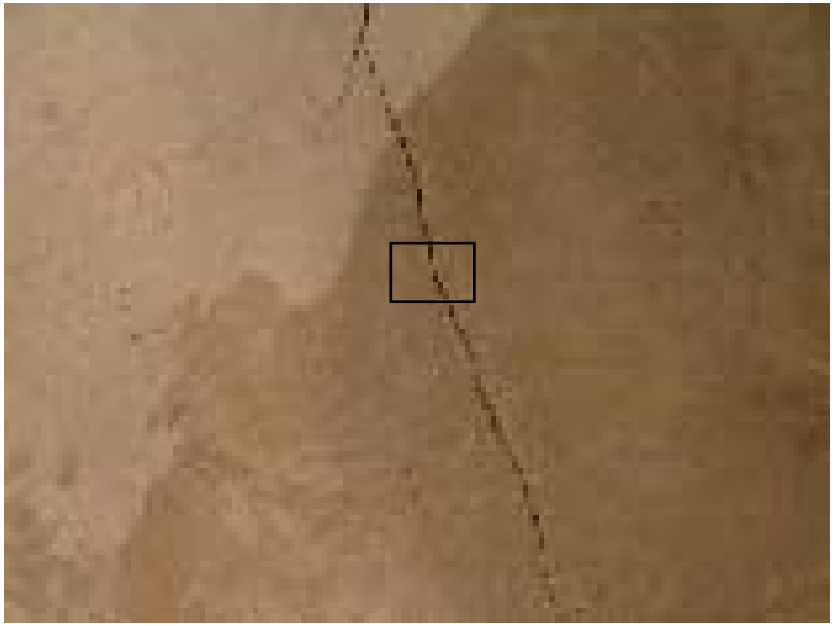
Cross-section of sample 3804 (photographed at 100x) showing the upper plaster layer taken from the west wall of the exterior of the Sheesh Mahal. The cross-section shows a translucent coating on the surface of the plaster.

Sampling location

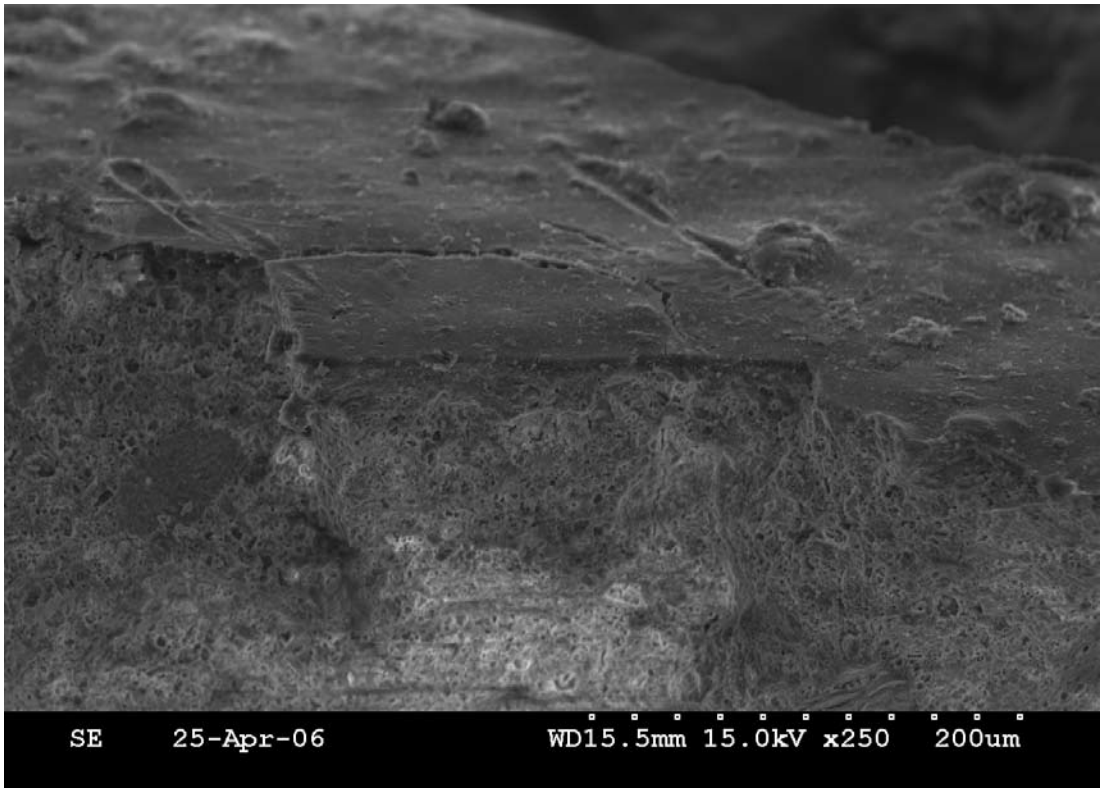
Sample 3805



Context of sampling location



Sampling location

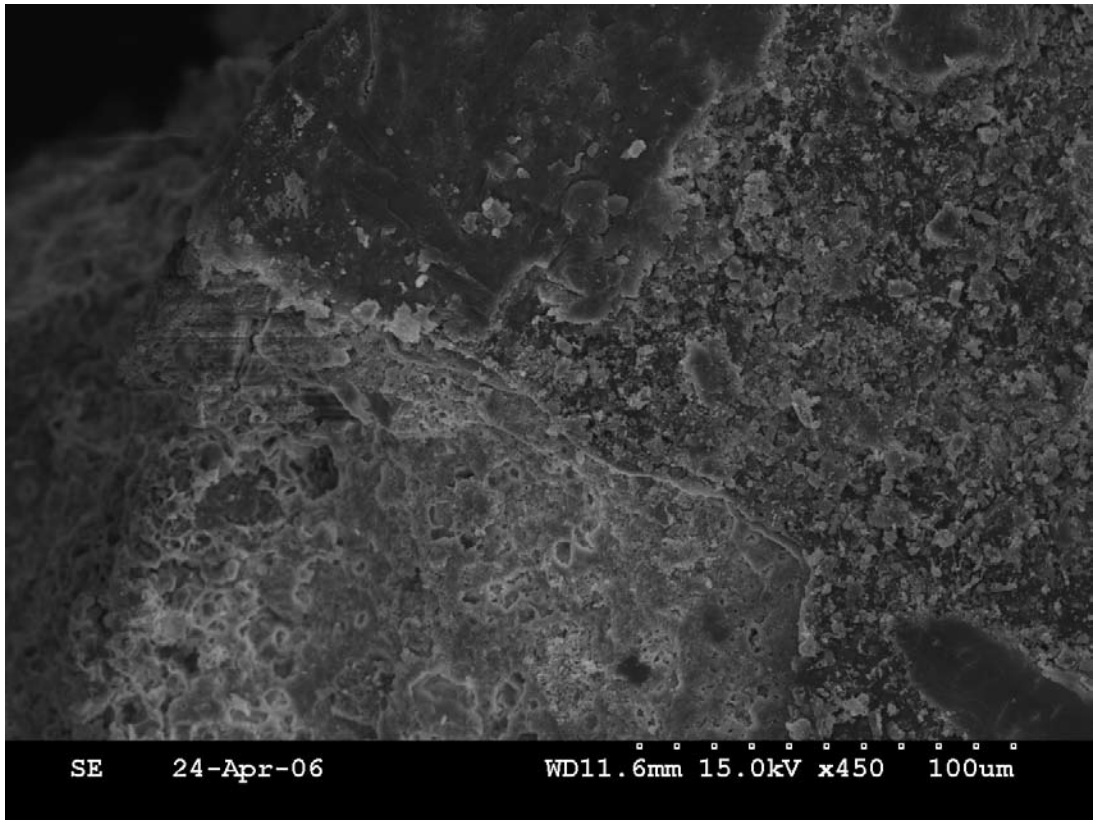


Scanning electron micrograph of sample 3805 (photographed at 250x). The image shows a smooth coating on the surface of the upper plaster layer (also visible as a dinstinct layer in cross-section). The interface between the coating and the plaster layer is distinct, and the unwanted material does not appear to have penetrated into the pore structure.

Sample 3800

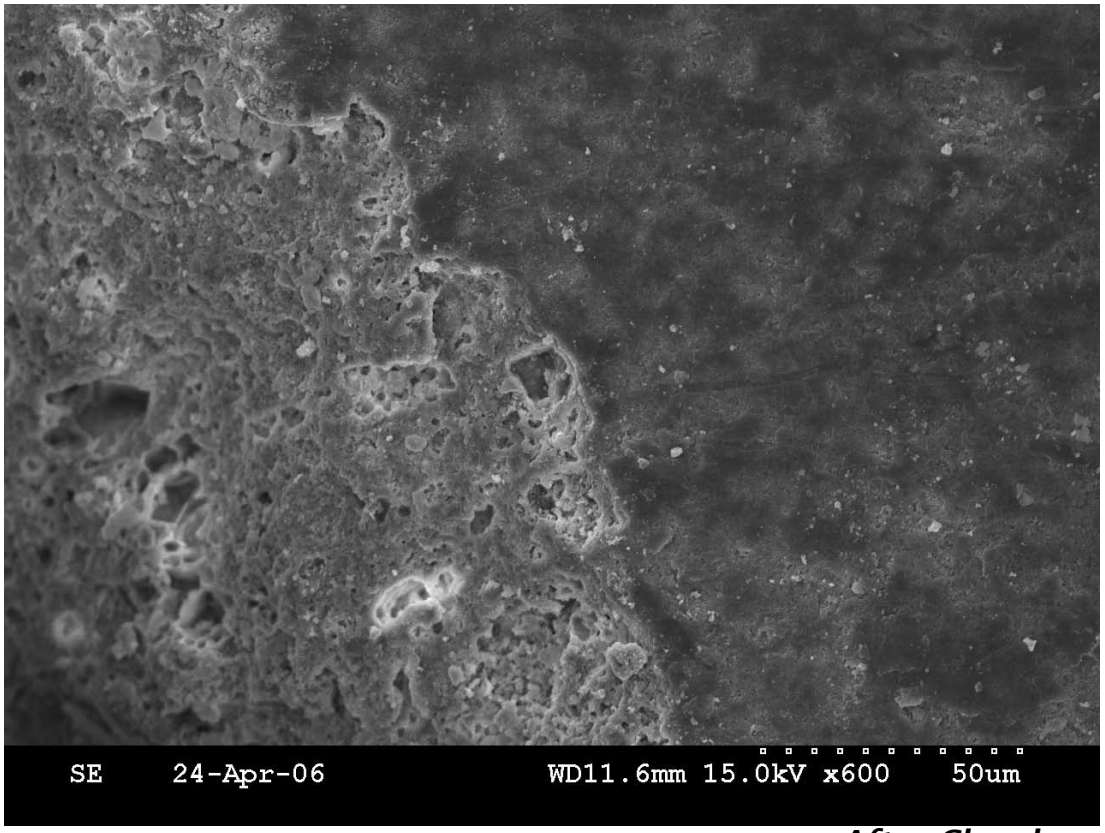
Context of sampling location

Sampling location



Before Cleaning

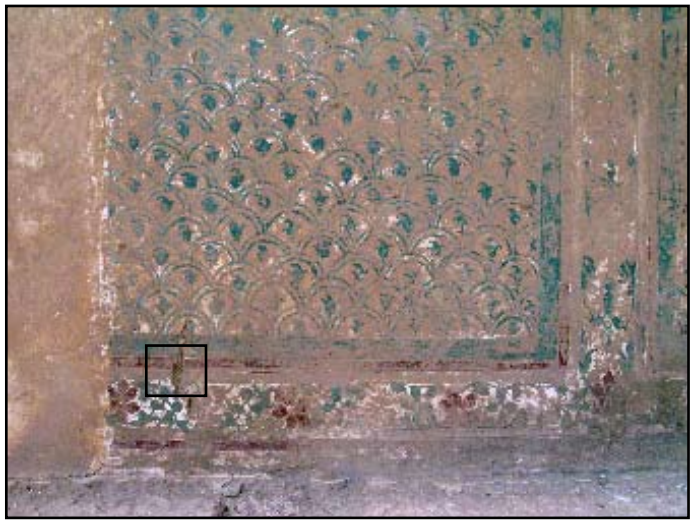
Sample 3801



After Cleaning

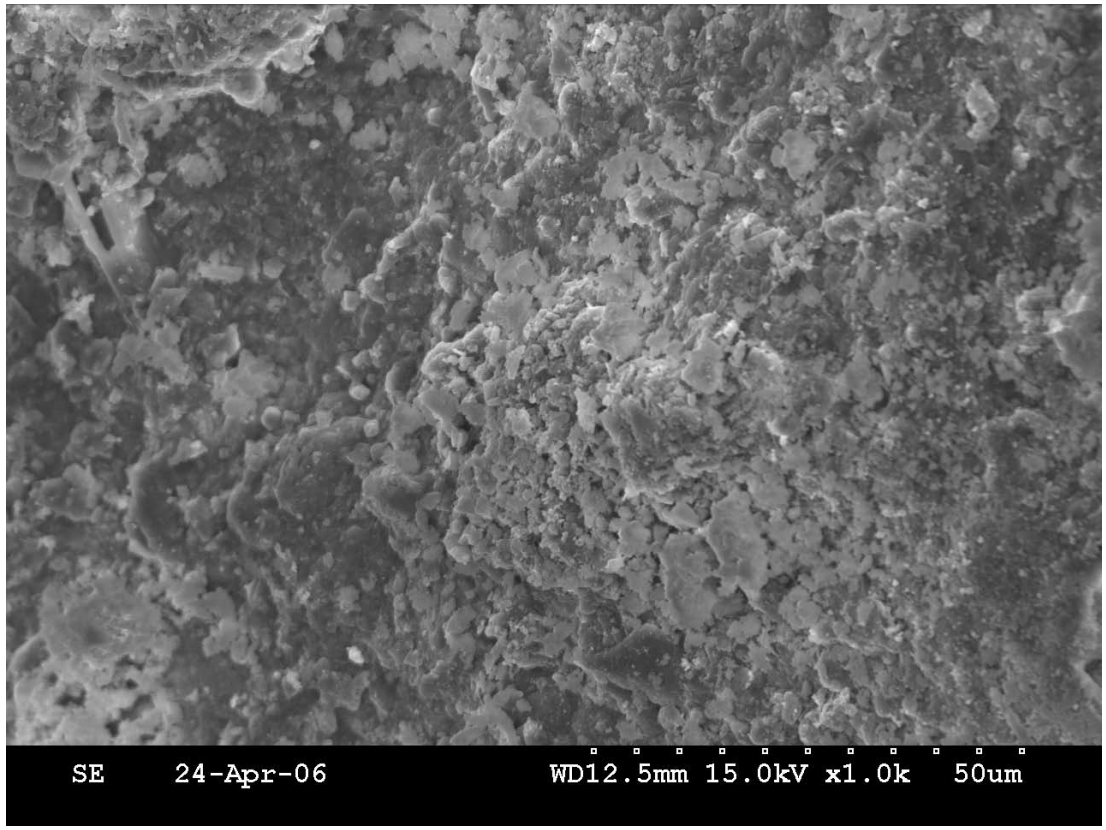
Scanning electron micrographs of samples 3800 and 3801 showing the surface of the painting before and after cleaning trials. The samples were taken from the upper plaster layer in a niche on the north wall of the Sheesh Mahal. The before trial micrograph (left) shows the presence of a smooth coating (probably PVAC) contrasting with the rough surface of the upper plaster layer beneath. Residue of a non-original material (either PVAC or the uncharacterised material seen in sample 3805) can be observed in the after trial micrograph, which is characterised by a smooth surface with dark mottling.

Sample 3802



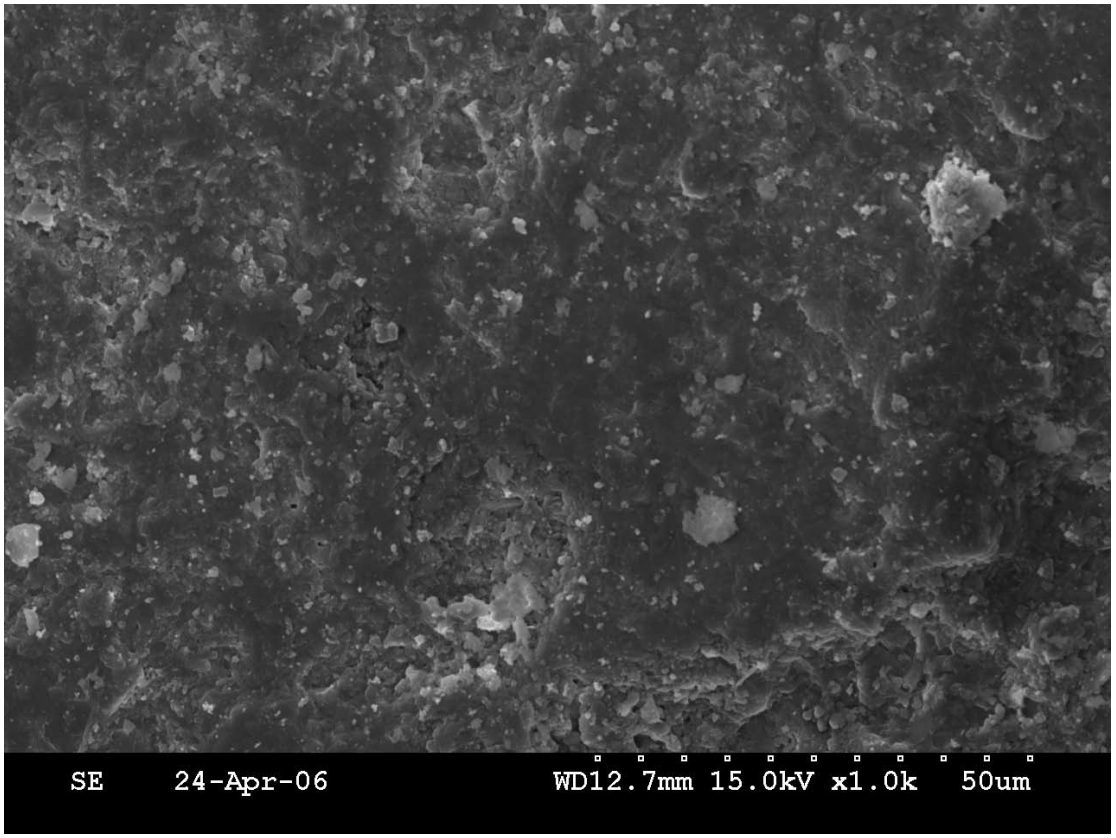
Context of sampling location

Sampling location



Before Cleaning

Sample 3803



After Cleaning

Scanning electron micrographs of samples 3802 and 3803 showing the surface of the painting before and after cleaning trials. The samples were taken from the green flower border on the east facade of the Hadi Rani Mahal. The thick dirt depostion is visible in the before cleaning micrograph and is characterised by abundant loosely packed particulate matter on the surface of the paint layer. While some of this depostion is still visible in the after cleaning micrograph it has been dramatically reduced. The surface of the paint layer does not appear to have been adversely affected by the cleaning trial (no visible cracks or evidence of mechanical damage).

Liquid moisture investigation: Hammam

Methodology

A liquid moisture investigation has several components:
sampling (drilled cores)
gravimetric measurement of moisture content
measurement of hygroscopic moisture uptake

Core sampling
Drilled core samples were taken from the North, South and West walls of the hammam and in the corridor outside the hammam. Where possible, a vertical profile was established for sample locations in order to assess the moisture content of the substrate according to height. Sampling location was determined by the condition of the substrate and locations causing the least risk and disruption to the plaster.

Cores were drilled up to 16 cm, average sample depth was 14 cm. This limit was imposed by the diameter (1.2 cm) and length of the drill (30 cm) which were chosen to minimize the visual alterations to the painting. Samples were drilled at approximately 3 cm depths, or at changes in the stratigraphy in order to establish a horizontal profile.

Gravimetric measurements of moisture content
Each sample obtained was weighed on-site using a standard laboratory balance (d= 0.01g). The wet weight was recorded and the samples oven-dried until they reached constant weight (when the weight change within 24 hours is smaller than 0.1% of the weight of the sample). The moisture content of the samples was calculated as a percentage of their dry masses.

Hygroscopic moisture uptake
On returning to the lab, samples were oven-dried at 30°C until they reached constant weight again, and placed in air tight containers of constant relative humidity obtained by concentrated salt solutions. Atmospheres of approximately 55% RH and 75% RH were maintained using a saturated solution of calcium nitrate ($Ca(NO_3)_2.4H_2O$), and potassium nitrate (KNO_3) respectively.

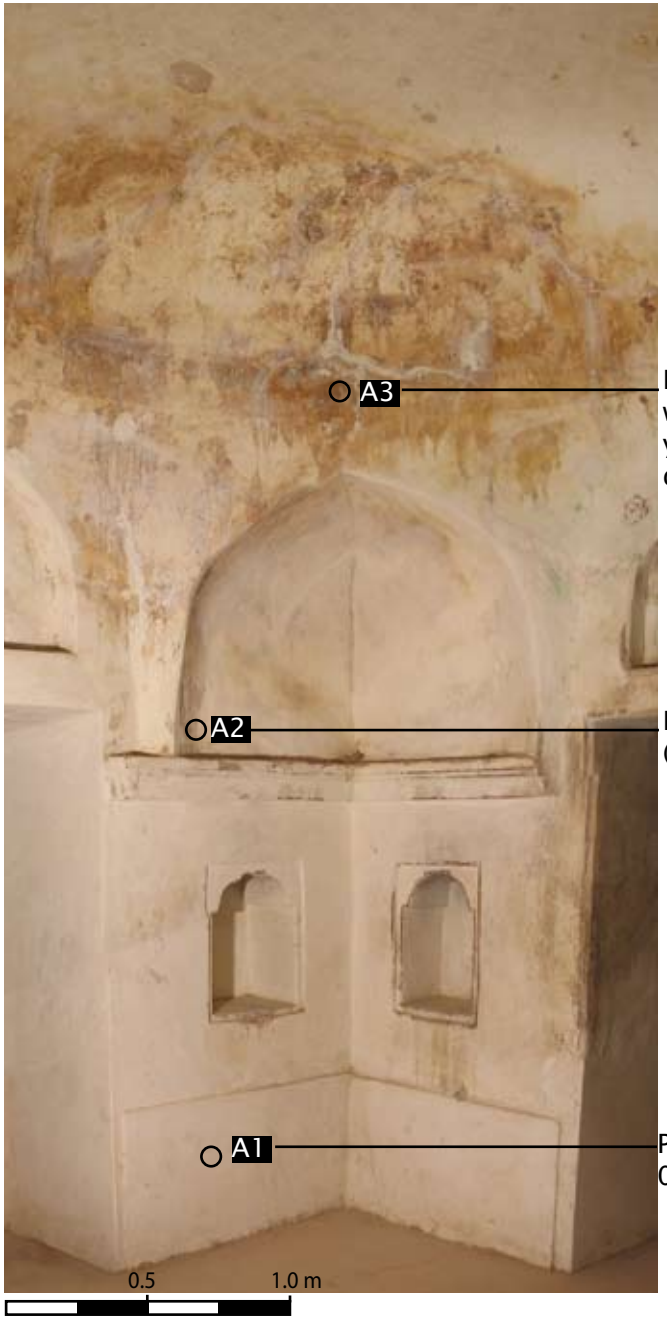
Absorption measurements were obtained by weighing the samples after they reached constant weight at each RH. The mean value of the sample weights were used as final data. The hygroscopic moisture content is given as a % of the dry weight.

Sampling strategy

Widespread plaster detachment and the need to reduce surface disruption restricted possible sampling locations. Location of core samples and sampling strategy are summarised in the table below.

Location/ profile	Sample height	Aims and description of sample area.
A	A1: 0.34 m A2: 1.95 m A3: 3.00 m	To establish horizontal and vertical profile of the moisture content of the north wall. Locations A2 and A3 exhibit deterioration or staining which may result from moisture movement.
B	B1: 0.24 m	To establish horizontal profile of the moisture content of the south wall. The sample location exhibits plaster loss and detachment and salt efflorescence.
C	C1: 1.15 m	Control location on interior wall where moisture content is anticipated to be low. The area is stable and in good condition.
D	D1: 1.24 m D2: 2.40 m	To establish horizontal and vertical profile of the moisture content of the west wall in the corridor outside the hammam rooms. This location is underneath a historic water tank. D1 exhibits salt efflorescence and loss of repair plaster, D2 is stable.

RESULTS



A3 — Loss in original plaster; whole area is stained yellow. Some plaster detachment. (H: 3.00 m)

A2 — Loss in original plaster. (H: 1.95 m)

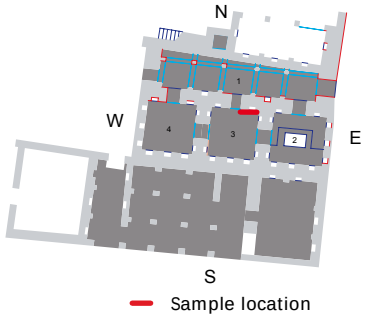
A1 — Plaster. (H: 0.34 m)

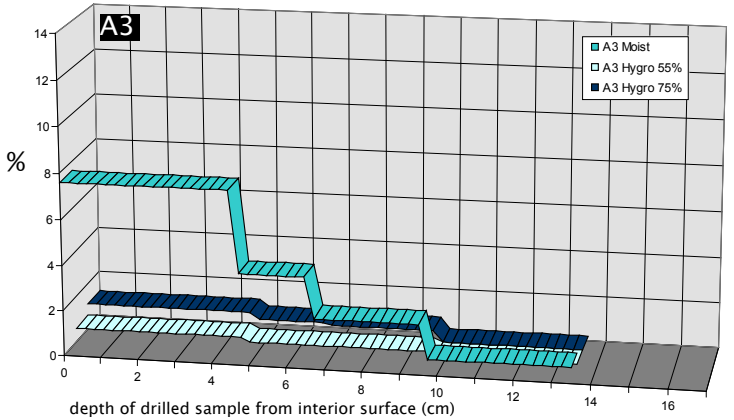
Key

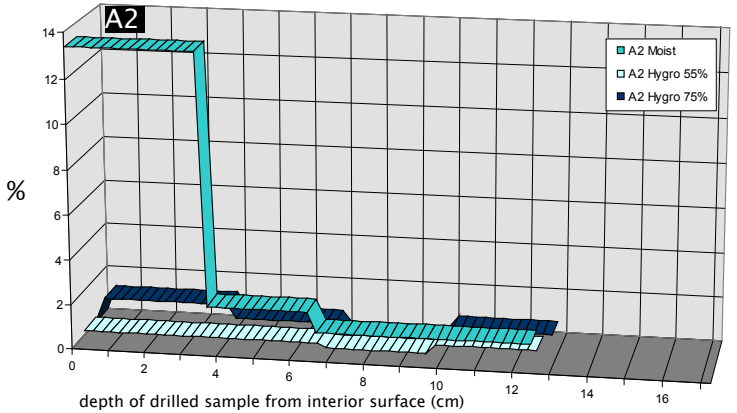
Moist: Total moisture content (% of dry weight)

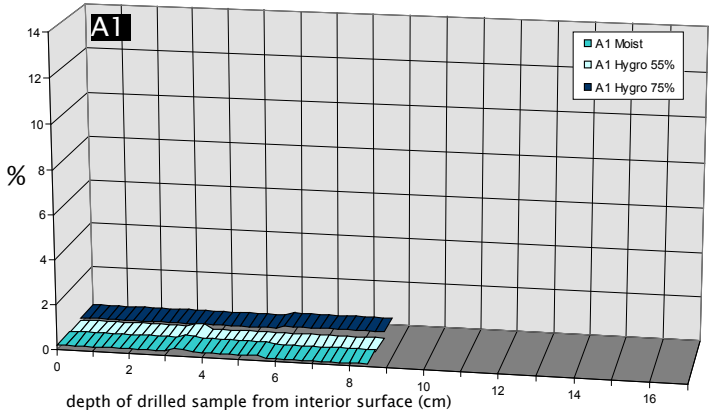
Hygro 55%: Potential hygroscopic moisture content (% of dry weight) at 55% RH

Hygro 75%: Potential hygroscopic moisture content (% of dry weight) at 75% RH

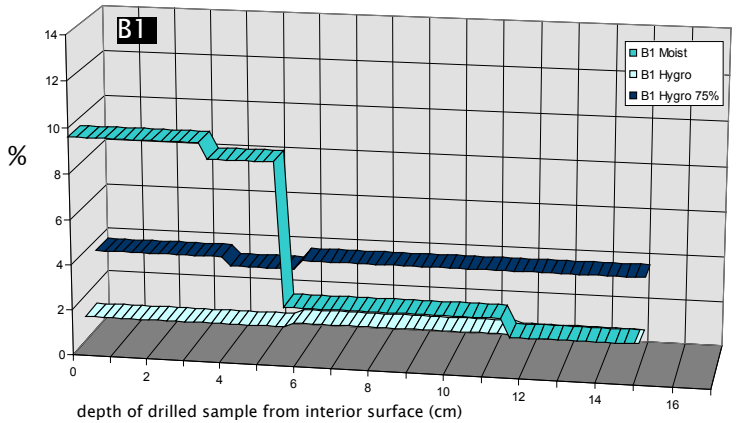








Loss in original plaster; some salt effloresence (H: 0.24 m)

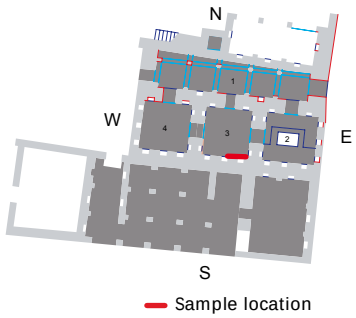


Key

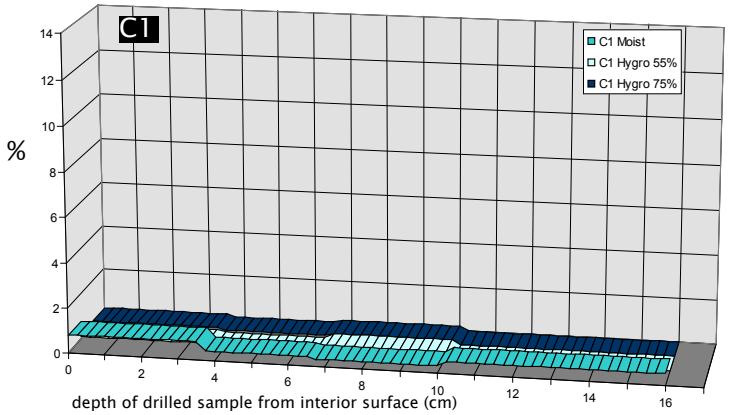
Moist: Total moisture content (% of dry weight)

Hygro 55%: Potential hygroscopic moisture content (% of dry weight) at 55% RH

Hygro 75%: Potential hygroscopic moisture content (% of dry weight) at 75% RH



Loss in original plaster.
(H: 1.15 m)

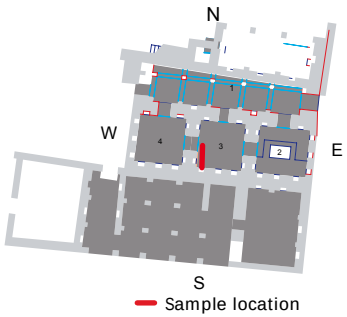


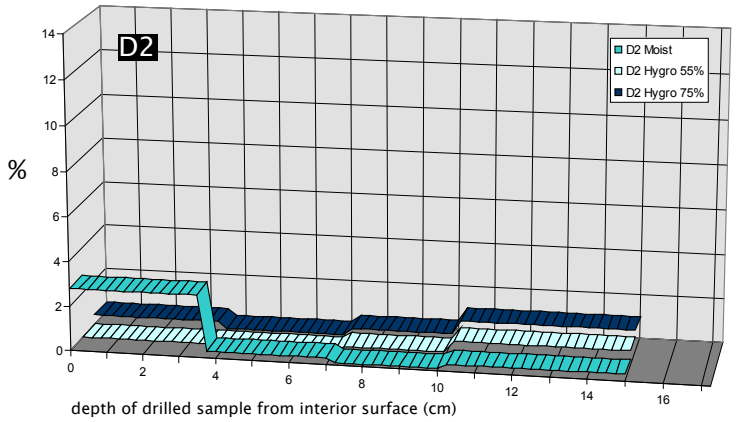
Key

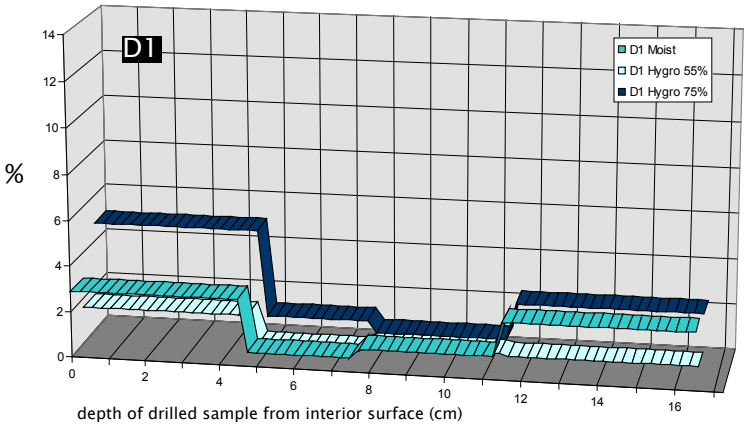
Moist: Total moisture content (% of dry weight)

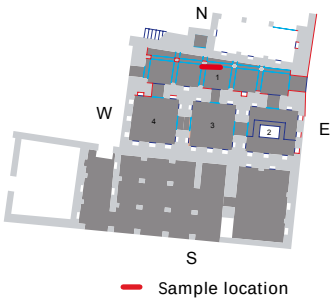
Hygro 55%: Potential hygroscopic moisture content (% of dry weight) at 55% RH

Hygro 75%: Potential hygroscopic moisture content (% of dry weight) at 75% RH









Key

Moist: Total moisture content (% of dry weight)

Hygro 55%: Potential hygroscopic moisture content (% of dry weight) at 55% RH

Hygro 75%: Potential hygroscopic moisture content (% of dry weight) at 75% RH

LOCATIONS AND RESULTS OF SALT ANALYSIS

Salt Efflorescence

Sample#	Location	Sulphates	Chlorides	Nitrates	Method
C1	Akbari Mahal [32] north wall	–		□	Merck
NAG-32-11	Akbari Mahal [32] north wall	–	sodium chloride (NaCl, halite)	sodium nitrate ($NaNO_3$, nitratine)	PLM
C2	Hammam [35] corridor	–	□	□	Merck
C3	Hammam [35] corridor	–	□	□	Merck
C5	Abha Mahal [26] room 10	–	□	□	Merck
NAG-26-11	Abha Mahal [26] room 10	–	sodium chloride (NaCl, halite)	sodium nitrate ($NaNO_3$, nitratine)	PLM/ SEM-EDS
C6	Krishna Temple [12] north wall	–	–	□	Merck
C7	Krishna Temple [12] north wall	–	□	–	Merck
C8	Abha Mahal [26] hammam	–	□	□	Merck

Core samples

	Abha Mahal [32] Room 10				
E1	Height=0.35 m Depth=0-6.2 cm	–	□	□	Merck
E2	Height=1.55 m Depth=0-2.7 cm	□	□	□	Merck
	Hammam [35] Room 3				
(Core) A1	Height=0.34 m Depth=0-8.5 cm	–	–	□	Merck
(Core) A2	Height=1.95 m Depth=0-12.5 cm	□	□	□	Merck
(Core) A3	Height=3 m Depth=0-13.5 cm	□	–	□	Merck
(Core) B1	Height=0.24 m Depth=0-15.0 cm	□	□	□	Merck
(Core) C1	Height=1.15 m Depth=0-16.0 cm	–(□)	–	□	Merck
	Hammam [35] corridor				
(Core) D1	Height=1.24 m Depth=0-15.0 cm	–	–(□)	□	Merck
(Core) D2	Height=2.40 m Depth=0-15 cm	–(□)	–	□	Merck

Repair materials

B1	Ground resurfacing plaster	□	–	–	Merck
B2	Akbari Mahal [32] roof.	–	–	–	Merck
B3	Hammam [35] roof	–	–	–	Merck
B4	Abha Mahal [26] roof	–	–	□	Merck

Site water

A1	Tap water	□	□	□	Merck
A2	Water from tank, used in resurfacing	□	□	□	Merck
A3	Water in fountain	□	□	□	Merck

□ presence of ions – no ion presence (□) small quantities of ions present at the surface.

Salt Efflorescence

Sample: C1

Sample location: Akbari Mahal [32], north wall, above door level. Localised area of heavy salt efflorescence forming sheets or clusters. Previously sampled by S Bogin (NAG05-32-15).

Sample #	Weight/g	deionised H_20/ ml	pH	buffer
C4	0.05	20	6.5	n/a

Results

Sample #	Ions present		
	Sulfates	Chlorides	Nitrates
C4	-	x	x

Methodology of ion analysis with Merckoquant™ strips.

Each sample was immersed in room-temperature deionised water in a solid: water ratio of 1:20, gently agitated, and left for 30 minutes at normal room temperature to bring the ions into solution. The pH of each solution was measured to ensure that levels lay within the parameters required for accurate results. If necessary, the solution was buffered with tartaric acid. Measurements using the test strips were repeated after 24 and 48 hours to ensure complete dissolution of the less soluble ions.

Salt Efflorescence

Sample: C2

Sample location: Hamman [35], corridor, north wall. Area of heavy salt efflorescence on the 2nd plaster layer, hard crust.

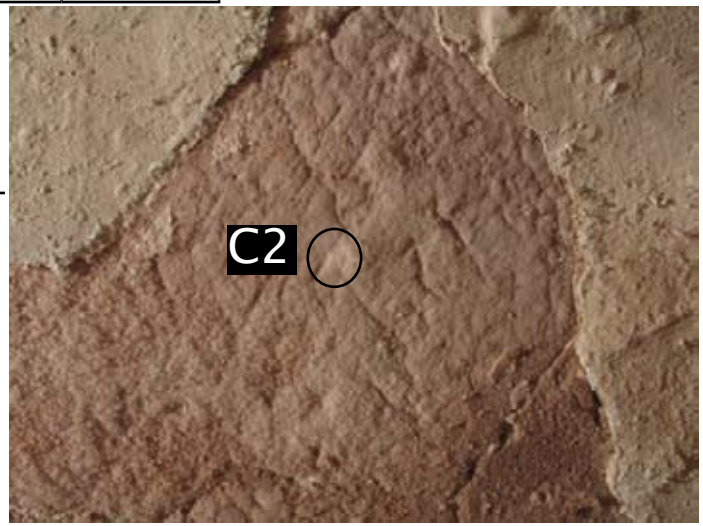
Sample: C3

Sample location: Hamman [35], corridor, north wall. Area of heavy salt efflorescence on the 3rd plaster layer, fluffy appearance.

Results

Sample #	Ions present		
	Sulfates	Chlorides	Nitrates
C2	–	x	x
C3	–	x	x

Sample #	Weight/g	deionised H_2O/ ml	pH	buffer
C2	0.05	20	7	n/a
C3	0.05	20	7	n/a



Salt Efflorescence

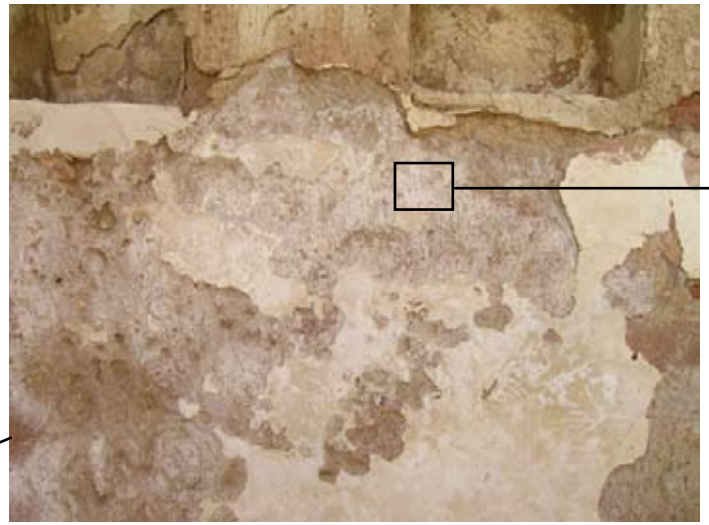
Sample: C4

Sample location: Hamman [35], exterior, north wall.
Area of heavy salt efflorescence forming sheets and clusters, previously sampled by SB (NAG05-26-11).

Sample #	Weight/g	deionised H_2O/ ml	pH	buffer
C4	0.02	10	6.5	n/a

Results

Sample #	Ions present		
	Sulfates	Chlorides	Nitrates
C4	-	x	x



Salt Efflorescence

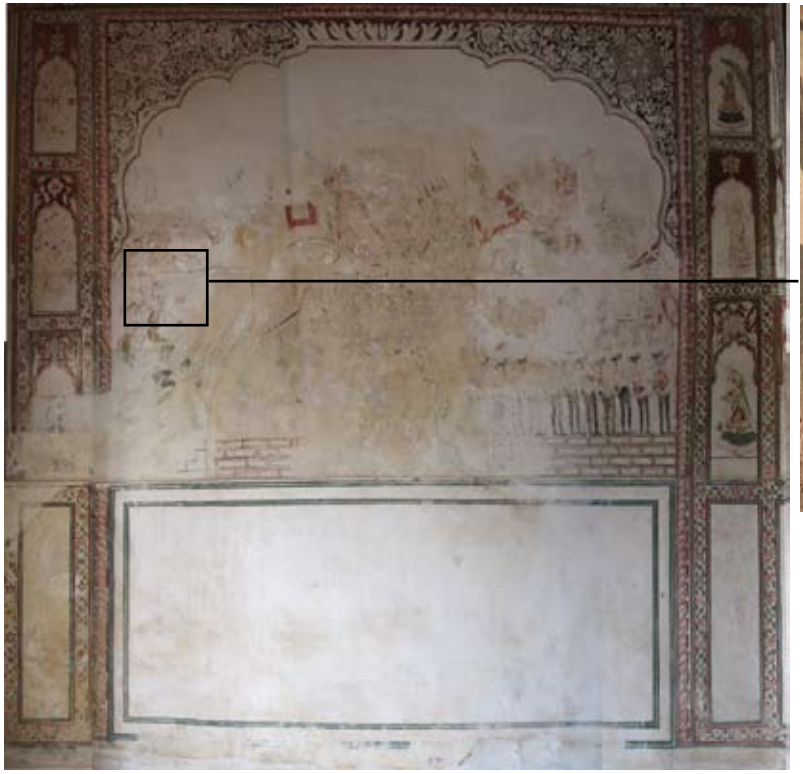
Sample: C5

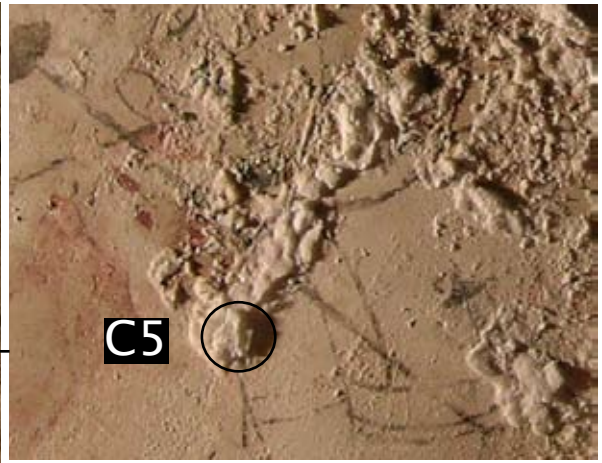
Sample location: Abha Mahal [26], room 10, west wall, localised area of heavy salt efflorescence forming sheets and clusters. Previously sampled by SB (NAG05-26-11).

Sample #	Weight/g	deionised H_2O/ ml	pH	buffer
C5	<0.01	10	6.5	n/a

Results

Sample #	Ions present		
	Sulfates	Chlorides	Nitrates
C5	-	x	x





Salt Efflorescence

Sample: C6

Sample location: Krishna Temple [12], north wall, above cornice level. Area of localised salt activity, salt efflorescence characterised by a powdery appearance.

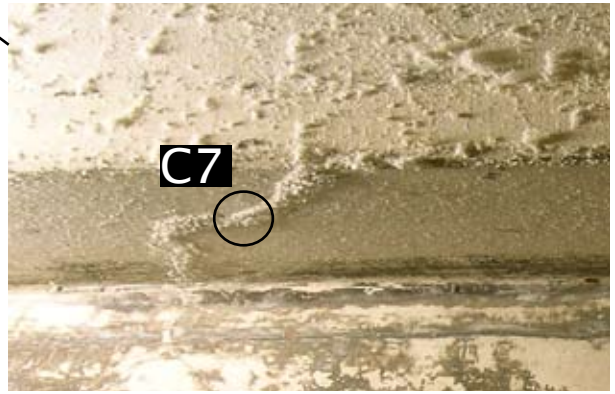
Sample: C7

Sample location: Krishna Temple [12], north wall, above cornice level. Area of localised salt activity near repair.

Sample #	Weight/g	deionised H_20/ ml	pH	buffer
C6	<0.01	10	6.5	n/a
C7	<0.01	10	7	n/a

Results

Sample #	Ions present		
	Sulfates	Chlorides	Nitrates
C6	-	-	x
C7	-	x	-



Salt Efflorescence

Sample: C8

Sample location: Abha Mahal [26], Hammam, section near vertical water fountain. Area of heavy salt efflorescence with thick crust appearance.

Sample #	Weight/g	deionised H_20/ ml	pH	buffer
C8	<0.01	10	6.5	n/a

Results

Sample #	Ions present		
	Sulfates	Chlorides	Nitrates
C8	–	x	–

Core samples

Sample: E1

Sample location: Abha Mahal [26], room 10, north wall, height: 0.35 m. Plaster repair associated with salt activity.

Results

Sam-ple #	Depth /cm	Weight/ g	water/ ml	pH	buffer	Maximum ion concentration (mg/ l)		
						Sulfates	Chlorides	Nitrates
E1a	0.0-0.2	0.25	5	6.5	n/a	0	1000	500
E1b	0.2-0.7	0.25	5	6.5	n/a	0	500-1000	500
E1c	0.7-1.2	0.25	5	6.5	n/a	0	1500	500
E1d	1.2-2.2	0.25	5	6.5	n/a	0	1000	500
E1e	2.2-4.2	0.25	5	6.5	n/a	0	1000	500
E1f	4.2-6.2	0.25	5	6.5	n/a	0	500-1000	500

CORE SAMPLES

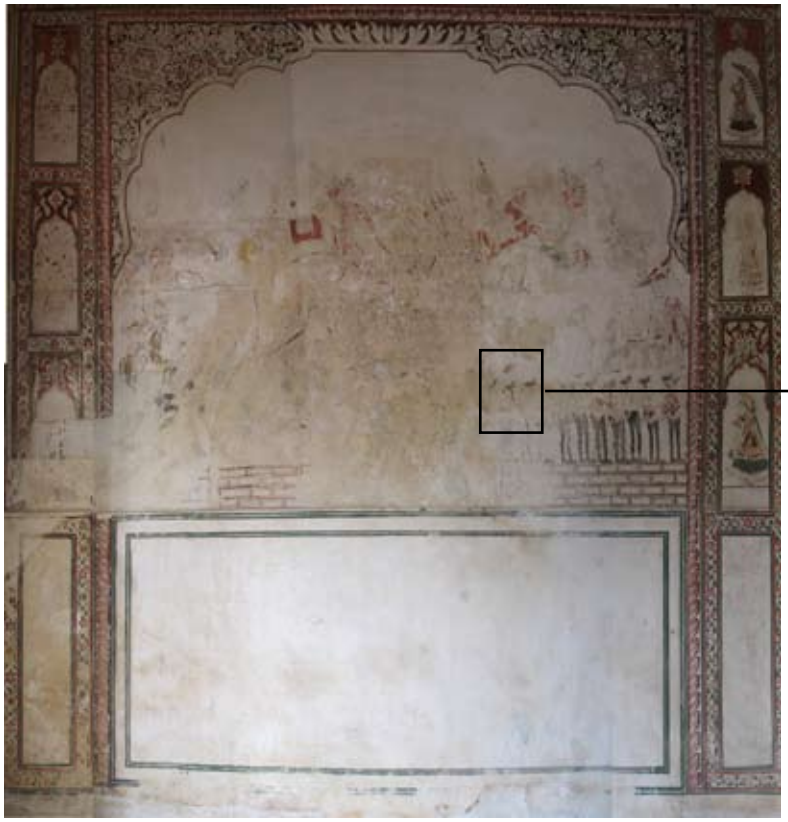
Sample: E2

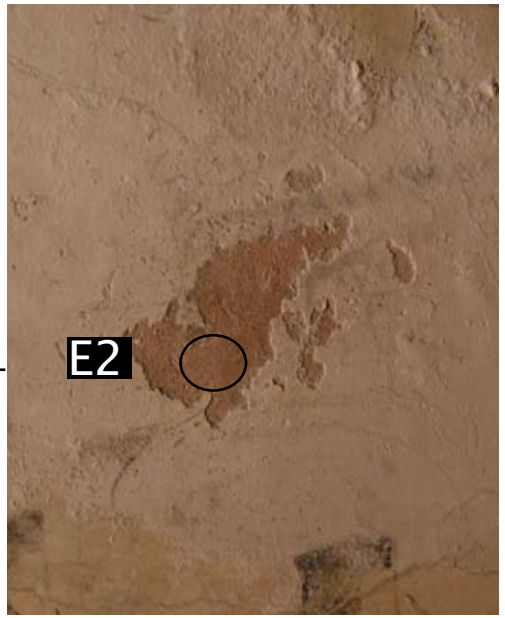
Sample location: Abha Mahal [26], room 10, north wall, height: 1.55 m. Plaster repair associated with salt activity

Results

Sam-ple #	Depth	Weight/ g	water/ ml	pH	buffer	Maximum ion concentration (mg/ l)		
						Sulfates*	Chlorides	Nitrates*
E2a	0.0-0.2	0.25	5	7	n/a	1600	2000	500
E2b	0.2-0.7	0.25	5	7	n/a	800	1500-2000	500
E2c	0.7-1.2	0.25	5	7	n/a	800	1000	500
E2d	1.2-2.2	0.25	5	7	n/a	800	1000	500
E2e	2.2-2.7	0.25	5	7.5	n/a	0	500	500

* Nitrites were present during the first set of measurements. Nitrites were not present during subsequent tests, probably due to to their rapid conversion to nitrates. The presence of nitrites suggests an active contamination source. The presence of nitrites can also produce a false positive result for sulphates but no sulphates were present in NAG05-26-11 during microchemical tests and the sulphate results here should be disregarded.





Core samples

Samples: (Core) A1–A3
Sample location: Hammam [35], room 3, north wall (see below).

Results

Sample #	Depth /cm	Weight/ g	water/ ml	pH	buffer	Maximum ion concentration (mg/ l)		
						Sulfates	Chlorides	Nitrates
A1a	0.0–3.0	0.5	10	7	n/a	0	0	100
A1b	3.0–3.5	0.5	10	7	n/a	0	0	100
A1c	3.5–5.5	0.5	10	7	n/a	0	0	100
A1d	5.5–8.5	0.5	10	7	n/a	0	0	100
A2a	0.0–3.5	0.5	10	7	n/a	1600	1600	100
A2b	3.5–6.5	0.5	10	7	n/a	1600	0–500	100
A2c	6.5–9.5	0.5	10	7	n/a	1200	0–500	100
A2d	9.5–12.5	0.5	10	7	n/a	over 1200	0	100
A3a	0.0–4.5	0.5	10	7	n/a	1600	0	100
A3b	4.5–6.5	0.5	10	7	n/a	over 1200	0	100
A3c	6.5–9.5	0.5	10	7	n/a	over 800	0	50
A3d	9.5–13.5	0.5	10	7	n/a	over 400	0	25

Sample: A1
Sample location: Hammam [35], room 3, north wall, height: 0.34 m. Repair plaster.
Sample: A2
Sample location: Hammam [35], room 3, north wall, height: 1.95 m. Loss in original plaster.
Sample: A3
Sample location: Hammam [35], room 3, north wall, height: 3 m. Loss in original plaster; whole area is stained yellow.

Core samples

Sample: (Core) B1

Sample location: Hammam [35], room 3, south wall, height: 0.24 m. Loss in original plaster in area of salt activity.

Results

Sample #	Depth /cm	Weight/ g	water/ ml	pH	buffer	Maximum ion concentration (mg/ l)		
						Sulfates	Chlorides	Nitrates
B1a	0.0–3.5	0.5	10	7	n/a	1600	0–500	500
B1b	3.5–5.5	0.5	10	7	n/a	1600	0–500	500
B1c	5.5–11.5	0.5	10	7	n/a	1200	0–500	500
B1d	11.5–15.0	0.5	10	7	n/a	800	0–500	500

Core samples

Sample: (Core) C1

Sample location: Hammam [35], room 3, west wall, height: 1.15 m

Results

Sam-ple #	Depth /cm	Weight/ g	water/ ml	pH	buffer	Maximum ion concentration (mg/ l)		
						Sulfates	Chlorides	Nitrates
C1a	0-3.5	0.5	10	7	n/a	over 400	0	25
C1b	3.5-6.5	0.5	10	7	n/a	0	0	10
C1c	6.5-10	0.5	10	7	n/a	0	0	10
C1d	10-16	0.5	10	7	n/a	0	0	10

Core samples

Samples: (Core) D1–D2
Sample location: Hammam [35], corridor, north wall (see below).

Results

Sam-ple #	Depth /cm	Weight/ g	water/ ml	pH	buffer	Maximum ion concentration (mg/ l)		
						Sulfates	Chlorides	Nitrates
D1a	0.0–3.5	0.5	10	7	n/a	0	500	500
D1b	3.5–5.5	0.5	10	7	n/a	0	0	250
D1c	5.5–11.5	0.5	10	7	n/a	0	0	250
D1d	11.5–15	0.5	10	7	n/a	0	0	250
D2a	0.0–3.5	0.5	10	7	n/a	over 800	0	50
D2b	3.5–7.0	0.5	10	7	n/a	0	0	50
D2c	7.0–10.0	0.5	10	7	n/a	0	0	50
D2d	10.0–15.0	0.5	10	7	n/a	0	0	50

Sample: D1
Sample location: Hammam, corridor, north wall, height: 1.24 m. Loss in repair plaster. Salt efflorescence on surface.

Sample: D2
Sample location: Hammam, corridor, north wall, height: 2.40 m. Repair plaster.

Repair Materials

Sample: B2

Sample location: Akbari Mahal [32] roof, area above painting presenting salt efflorescence (sample C1).

Weight/g	deionised H20/ ml	pH	buffer
0.4	8	6	n/a

Results

Maximum ion concentration (mg/ l)		
Sulfates	Chlorides	Nitrates
0	0	0

Repair Materials

Sample: B3

Sample location: Hammam [35], roof, area above corridor presenting salt efflorescence (samples C2, C3, C4).

Sample #	Weight/g	deionised H20/ ml	pH	buffer
B3	0.6	12	6.5	n/a

Results

Maximum ion concentration (mg/ l)		
Sulfates	Chlorides	Nitrates
0	0	0

Repair Materials

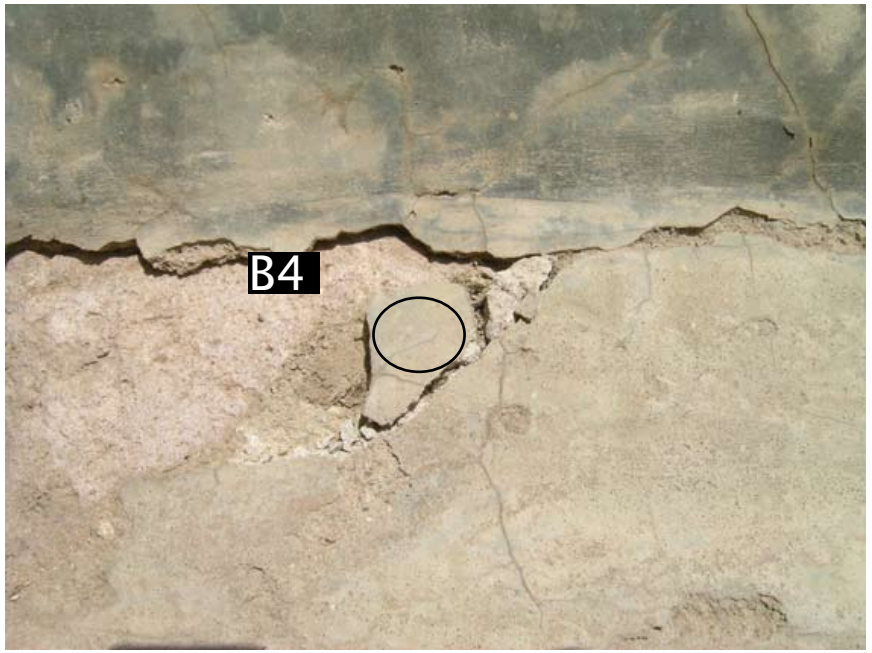
Sample: B4

Sample location: Abha Mahal [26], roof, water tank above the Hammam.

Sample #	Weight/g	deionised H20/ ml	pH	buffer
B4	0.7	14	6	n/a

Results

Maximum ion concentration (mg/ l)		
Sulfates	Chlorides	Nitrates
0	0	50



Repair Materials

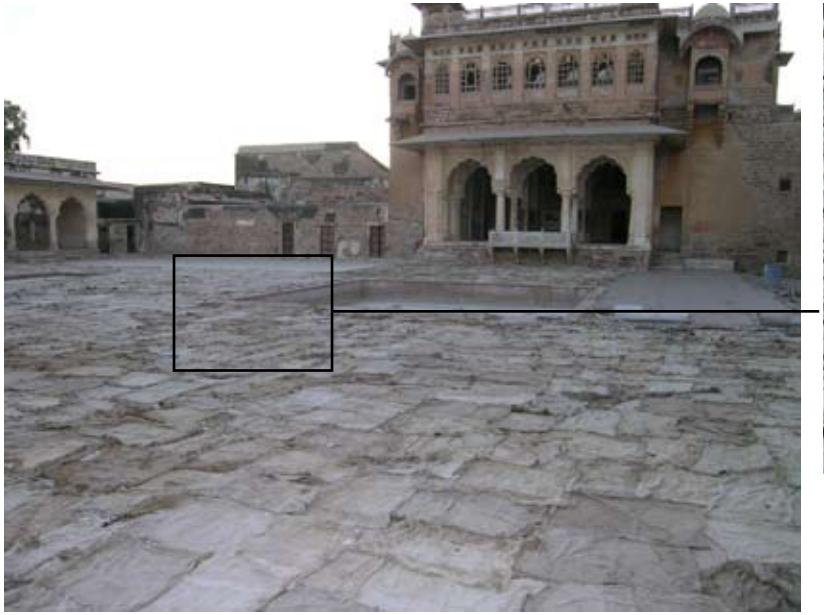
Sample: B1

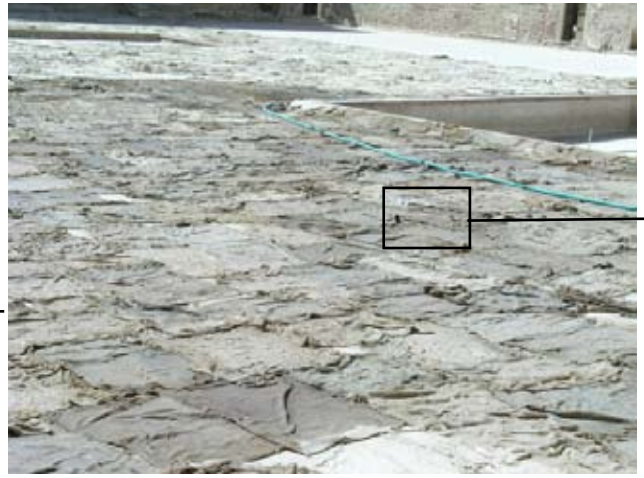
Sample location: Plaster used for resurfacing ground in front of Hadi Rani and Bakht Singh Mahal (to compare with A2 water used to mix plaster).

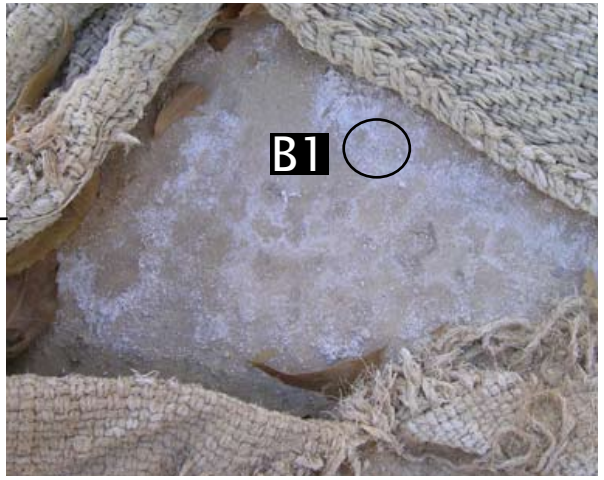
Weight/g	deionised H20/ ml	pH	buffer
1	20	6	tartaric acid

Results

Maximum ion concentration (mg/ l)		
Sulfates	Chlorides	Nitrates
1200	0	0







Site Water

Sample: A1
Sample location: Tap water (living quarters bathroom).
Sample: A2
Sample location: Water transported in tank and used to spray lime-based render material on courtyard in front of Hadi Rani Mahal and Bakht Singh Mahal.
Sample: A3
Sample location: Water from fountain opposite Bakht Singh.

Results

Sample #	Weight/ g	water/ ml	pH	buffer	Maximum ion concentration (mg/ l)		
					Sulfates	Chlorides	Nitrates
A1	5	n/a	7	n/a	1600	500	50
A2	5	n/a	5	n/a	1600	1000	250-500
A3	5	n/a	7	n/a	1600	1000	250-500

A2

A3