FINAL REPORT

January 25, 2010 – March 22, 2010

ARCE Groundwater Lowering Response Project, Luxor

"Desalination and Conservation in the Hypostyle Hall, Karnak Temple"

Christie Pohl

The Egyptian Antiquities Conservation Project (EAC)
USAID Agreement No. 263-A-00-04-00018-00

Awarded to

THE AMERICAN RESEARCH CENTER IN EGYPT (ARCE)

Address: 8700 Crownhill Blvd. Suite 507, San Antonio, TX 78209 Tel: (210) 821-7000

by the

USAID Program Office of Productive Sector Development / Office of the Environment
USAID / Egypt

In collaboration with the United States Agency for International Development and the
Egyptian Ministry of State for Antiquities

American Research Center in Egypt (ARCE)
Desalination and Conservation in the Hypostyle Hall, Karnak Temple

Final Report: 2010 Field Season
Christie Pohl

Introduction and Summary of Work Completed from 25th January - 22nd March, 2010:

This report serves as the final documentation of the 2009-2010 desalination and conservation project that was completed on one side of the Northwest wall within the Hypostyle Hall in Karnak Temple. A previous progress report details the work that was completed from the start of my position as supervisor of the project (25th January - 22nd March, 2010). Results of the associated salt sampling and analyses are included, as well as a discussion of the outcome of three sessions of environmental monitoring conducted within the treated wall. The various steps of the desalination, conservation and mortar work are covered and the conclusion of the report includes recommendations for maintenance and future work, as well as an appendix of the salt testing data.

Fig. 1: One of the areas sampled and tested

Fig. 2: Thick salt crusts removed from a section of the wall

Fig. 3: The team desalinating and filling voids

Fig. 4: Preparing to make a batch of mortar

Salt Sampling and Associated Analyses: Merckoquant® Strip Testing and Conductivity Measurements:

In order to better understand the types of salts present in the Hypostyle Hall wall and the conditions within the sandstone, a research project was developed that involved analyses of multiple samples from the wall. The goal was to roughly determine the salt concentrations, the conductivity of the samples and how they relate in terms of their locations and the overall condition of the wall. The same 21 samples were used for both the Merckoquant® strip tests and the conductivity measurements.

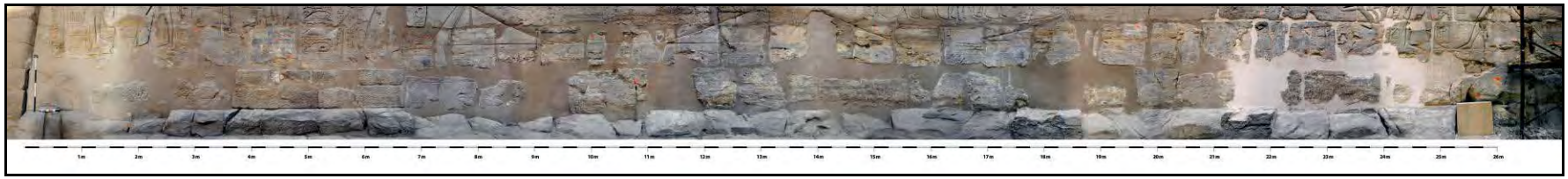


Fig. 5: Mosaic of photos of the portion of the Northwest wall where the samples were taken for the salt tests

The photograph above (figure 5) was patched together from multiple photos to give a sense of the length of the wall where the samples were taken. This represents 26 meters of the Northwest wall; the full length of the wall that was treated is approximately 35 meters. The following photos (figures 6-9) show this portion of the wall in four sections and the 21 sampled areas have been labeled on the photographs. Samples 18 and 21 were taken from areas inside a void towards the bottom of the wall and sample 19 was taken from one of the old bricks used to fill in the void.

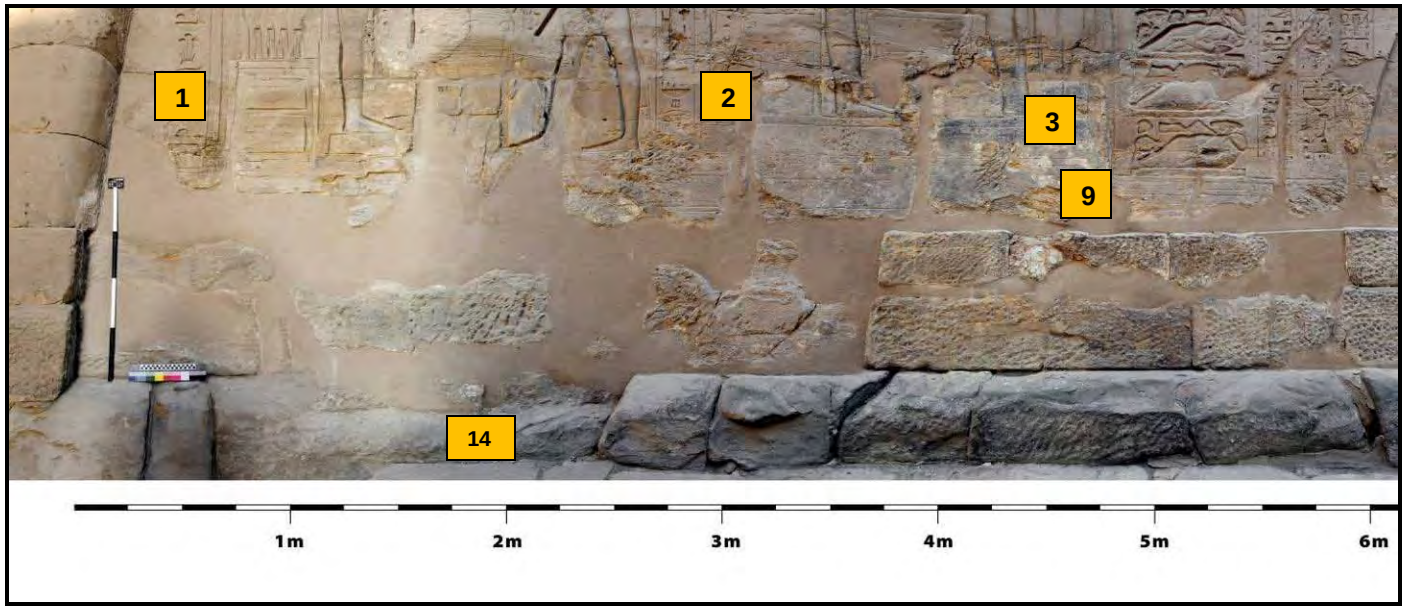


Fig. 6: Meters 1 - 6

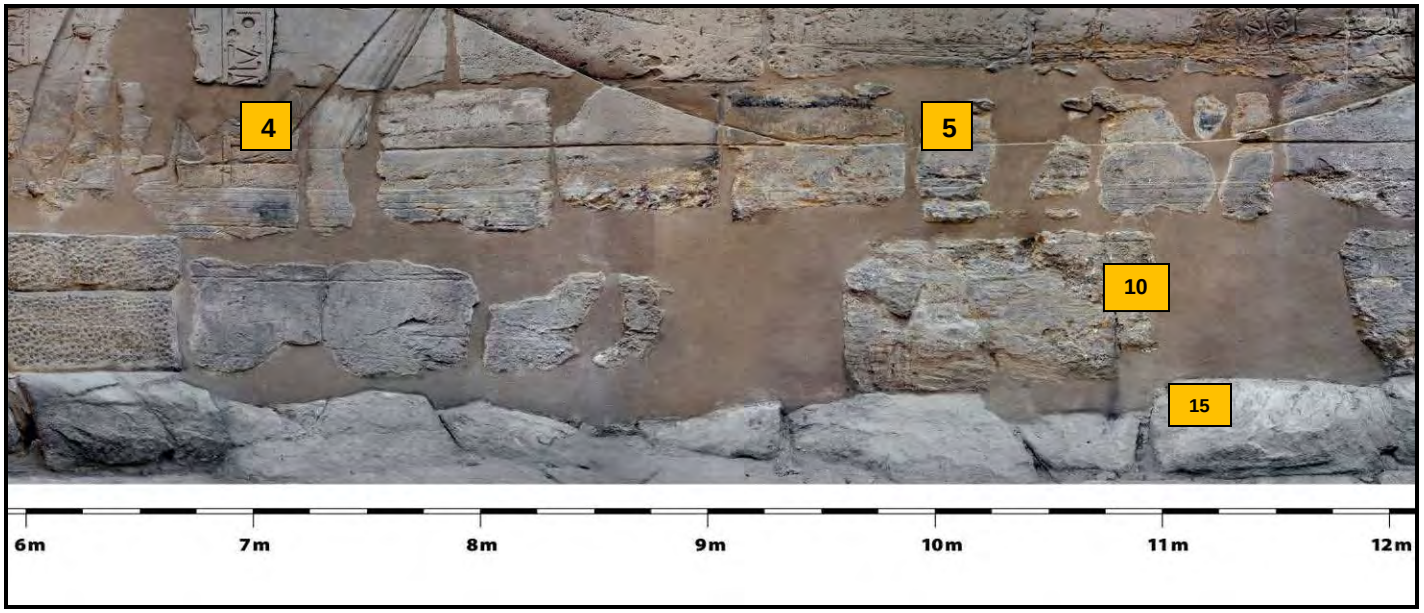


Fig. 7: Meters 6-12

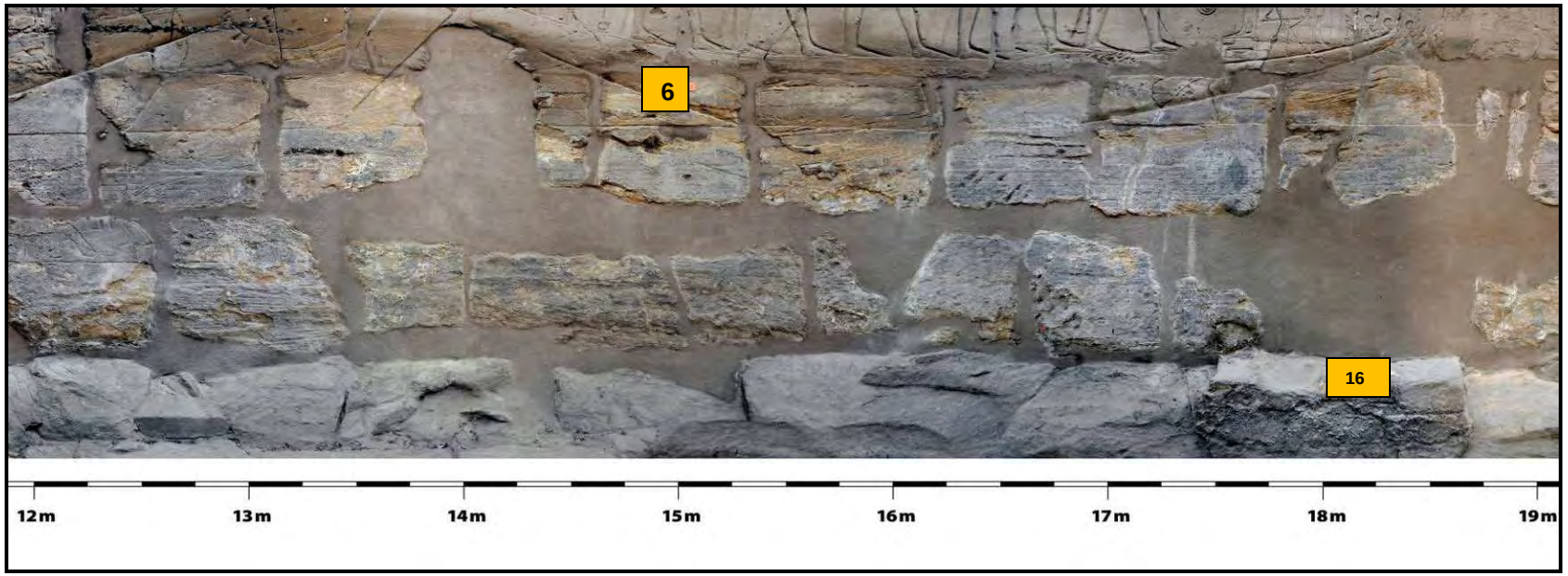


Fig. 8: Meters 12-19

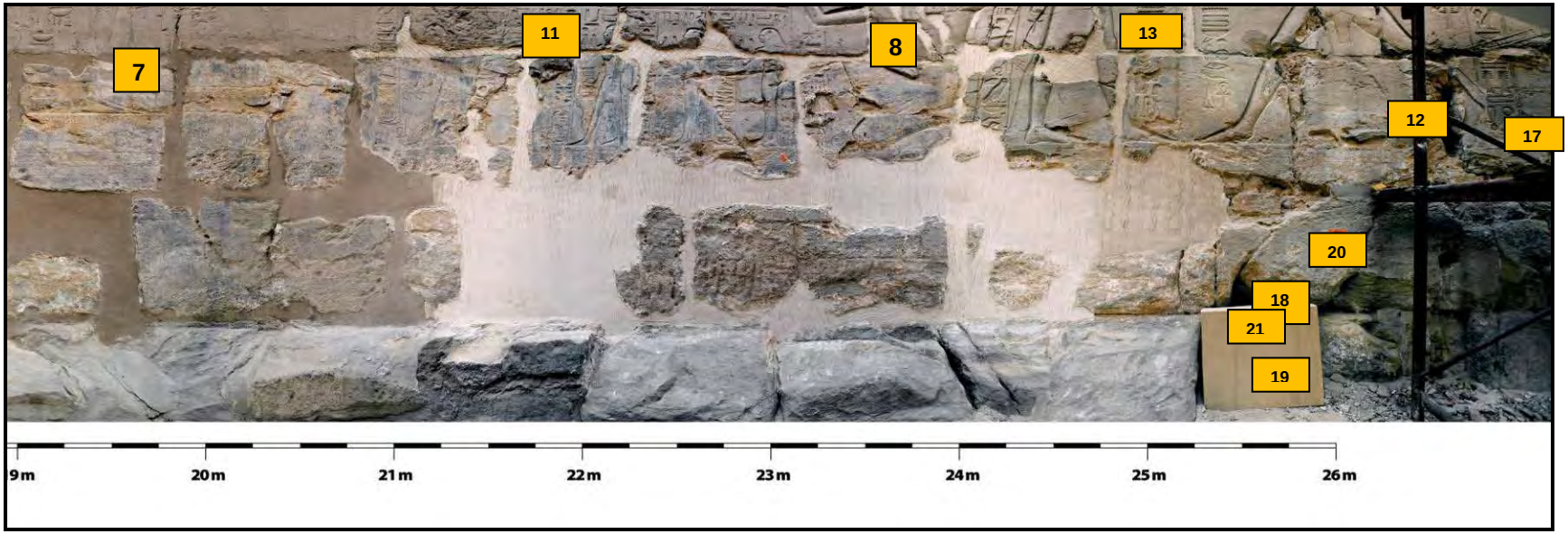


Fig. 9: Meters 19-26

Merckoquant® Strip Testing for Chlorides, Nitrates and Sulfates

The initial series of analyses involved testing of the 21 samples for chlorides, nitrates and sulfates using Merckoquant® test strips (Figure 10). The samples included salt from the wall surface, salt and hebba after successive applications in the same location, deteriorated sandstone, material from the base of the wall, part of an old brick fill and an unknown green material found behind a layer of mortar. Two samples of hebba, from different batches, were also sampled and designated as controls. To summarize, the data showed that, overall, the levels of nitrates are the lowest of the three. The primary source of nitrates is hypothesized to be in fertilizers that have been used in the surrounding area which then spread to the temple as a result of run-off. Chlorides are fairly consistent in concentration (0.0-5.00 mg/g) with the exception of samples 6-10 which contain higher levels. Sulfates are present the most overall, regardless of the concentrations found in the samples. Please refer to the January – March progress report for a more in-depth discussion of these results. However, a copy of the data from the strip tests has been included in Appendix A of this report. The six team members assisted with both the Merckoquant® strip testing and the conductivity measurements (Figure 11). These lab sessions gave the students valuable experience completing analyses used in conservation and the tests were directly connected to their field work in the Hypostyle Hall.

Fig. 10: The set-up for the strip testing

Fig. 11: Mohammed Ibrahim and Leuese preparing samples for the strip tests

Conductivity Testing

The next round of testing consisted of taking conductivity measurements of the same 21 samples, including additional samples from successive poultices, using a specialized meter. Conductivity measurements are based on the fact that pure water (containing no dissolved ionic salts) has a very low conductivity. As soluble salts are added, the water starts to conduct current and conductance is a direct function of the ion (salt) concentration. The idea behind this second round of analyses was to compare the salt concentrations in the samples to the results of the strip testing for chlorides, nitrates and sulfates. Some of the samples may have contained different types or combinations of salts and a second objective was to evaluate the conductivity measurements in relation to the position and height of the sampled areas on the wall. It was hypothesized that conductivity levels might be less in the samples taken from higher up on the wall since salts from the ground water and any salts from fertilization run-off would tend to decrease with height. However, some contaminant salts that are present in stone as a result of rising damp may be hygroscopic, or capable of absorbing moisture from the surrounding environment. This factor was one of the primary reasons for investigating the environmental conditions at various locations within the wall in order to get a better sense of the levels of humidity. This will be discussed further in the next section of this report.

The conductivity testing was completed over several lab sessions in April and May. Once again, I took the students in pairs to learn how to do the conductivity measurements. Madame Nahla, an SCA inspector assigned to observe the work in the Hypostyle Hall in March, also accompanied us to the lab and assisted with translation. The unit of measurement commonly used for conductivity is one millionth of a Siemen per centimeter (micro-Siemens per centimeter or µs/cm). When measuring more concentrated solutions, the units are expressed as milli-Siemens/cm (ms/cm).

1 Semen (S) = 1000 millisemens(ms) = 1,000,000 microsemens(µs)

Conductivity measurements are temperature dependent - the higher the temperature, the greater the electrical flow. All meters have either fixed or adjustable automatic temperature compensation referenced to a standard temperature which is typically 25°C.

The first instrument used for the testing was a PH-2603 combination meter, able to measure PH/mV/°C/EC/CF/TDS. The measurement range of this particular meter is 0.00~19.99ms/cm. First, the meter was calibrated using two different calibration solutions (figure 12). The 44 samples were weighed out in amounts of 1.00 gram or 0.50 grams, depending on the amount available for each sample. The samples were ground with a mortar and pestle, placed in a glass beaker and then 30 ml of distilled water (and 15 ml for the 0.50 gram samples) was added to the beaker to create a solution. After mixing the sample and water thoroughly, the electrode was submerged in the sample solution and the reading was allowed to stabilize before it was recorded (figure 13). The electrode and mortar and pestle were cleaned thoroughly after testing each sample.

Fig. 12: Calibrating the conductivity meter with Leuese, Nahla and Mariam

Fig. 13: Mariam taking a reading of one of the sample solutions

Mid-way through the testing, there were some problems with the conductivity meter. Sometimes the numbers would disappear suddenly and the meter would not show a reading in the ms/cm mode. I also questioned the results of a few of the samples as they were significantly higher than any of the other samples that were processed up to that point. I re-tested a few samples to see if the readings were consistent, and several showed different results from the first series of tests. Another suspicious occurrence was that several of the samples showed conductivity levels that were lower than the hebba controls. The latter served as a baseline for salt concentration and should have had the lowest readings of all the samples tested. After investigating the problem further, there were still some troubles with the meter functioning properly, so it was decided to use another meter which Magdi kindly lent us for the remainder of the testing. It was not possible to re-test every sample with the second meter due to the finite amount of each sample.

During the testing process and through multiple discussions with ARCE colleagues, it became apparent that the original design for the salt testing was flawed in a number of ways. I took over the testing mid-way through the sampling process and received eight samples that were taken by another individual in November 2009, prior to my arrival in Egypt. In order to produce reliable data, salt concentration needs to be measured and calculated according to surface area. The same surface area was not used for each of the samples and, overall, the amount of sample available for testing was insufficient. The minimal amount collected of each sample necessitated using 0.5 gram – 1.0 gram amounts for each test. This sample size is unlikely to reflect salt concentration accurately. A more scientifically sound method for this type of test would involve sampling over equivalent surface areas, followed by determining the salt concentration of an overall larger sample. Unfortunately, between the flaws in the project design

and the malfunctioning lab conductivity meter, the data produced is unreliable and cannot be interpreted. However, despite the inconclusive outcome of the testing, there was significant value in going through the tests with the students. Reliable data or not, they now have experience with testing for the presence and concentration of salts. Any future salt-related tests should be designed more thoroughly and precisely; if any work takes place on the Southwest wall of the Hypostyle Hall in the future, there is an opportunity to do additional testing prior to beginning any desalination and conservation work.

Environmental Monitoring: Measurements of Temperature and Relative Humidity (RH) within the Northwest Wall:

February Monitoring Session

After removing a cement fill and stack of bricks from a section of the wall in February, it was noticed that it was quite humid within the crevice (figure 14). There has been general concern about the levels of humidity within the walls, despite the ground watering lowering program that has been implemented on site. In order to better evaluate the environmental conditions inside of the wall, it was decided to monitor the temperature and relative humidity levels inside of the crevice for one week. The ambient conditions, just outside of the wall, were also monitored as a means of comparison.

Fig. 14: The crevice where the environmental readings were taken in February

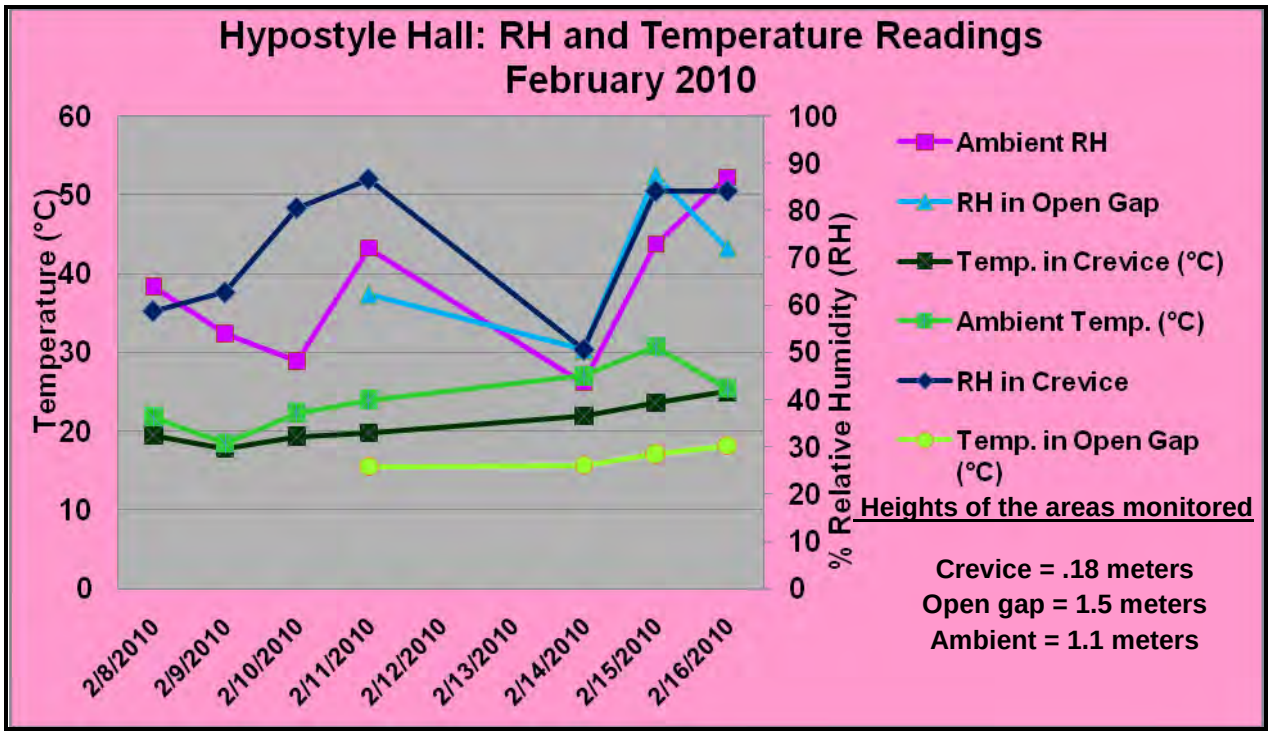
Fig. 15: The gap where additional readings were taken with the Tiny Tag® data logger

An open gap higher up on the wall (figure 15) was a later addition to the February monitoring session. This stage of the process was included in the previous progress report, but the following graph illustrates the results of this week of monitoring temperature and relative humidity.

Looking at the February graph, the RH ranged from 50-86% in the crevice, which is very high, and the open gap showed an RH range from 30-50%, a significant difference. The ambient RH showed a similar pattern in fluctuations as the RH in the crevice, but the RH in the latter was

higher overall. Both sets of temperature readings for the crevice and gap were lower than the ambient temperature readings.

It was necessary to further investigate the humidity levels within the wall to confirm that they were indeed as high as those from the crevice. Additional environmental monitoring was planned for sections further along the wall during the remainder of the season. The presence of soluble salts in the wall combined with fluctuating levels of humidity could potentially result in cycles of deliquescence and efflorescence. Humidity indicates saturation of the sandstone and the possibility of continued rising damp (despite the lowered water table) is a factor that must be explored.



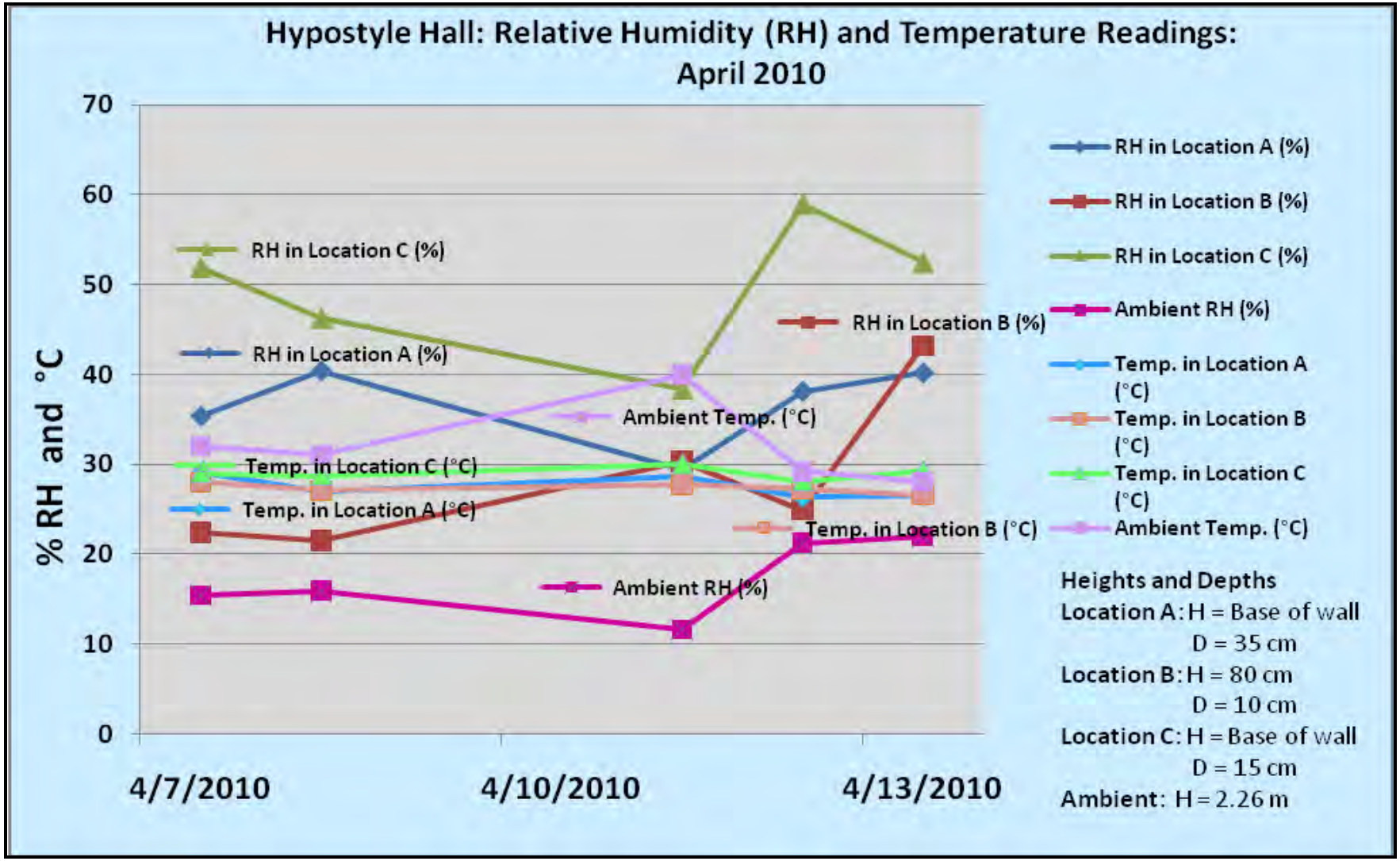
April and June Monitoring Sessions

As the desalination and conservation work progressed along the length of the Northwest wall, three additional areas suited for environmental monitoring were revealed (figures 16 and 17). The varying heights and depths of these locations would provide a better picture of the overall levels in temperature and humidity within the wall. To track any changes in the conditions over time, it was decided to complete a week of monitoring in April and a week of monitoring in June in the same 3 locations. As with the February session, ambient readings were also taken.

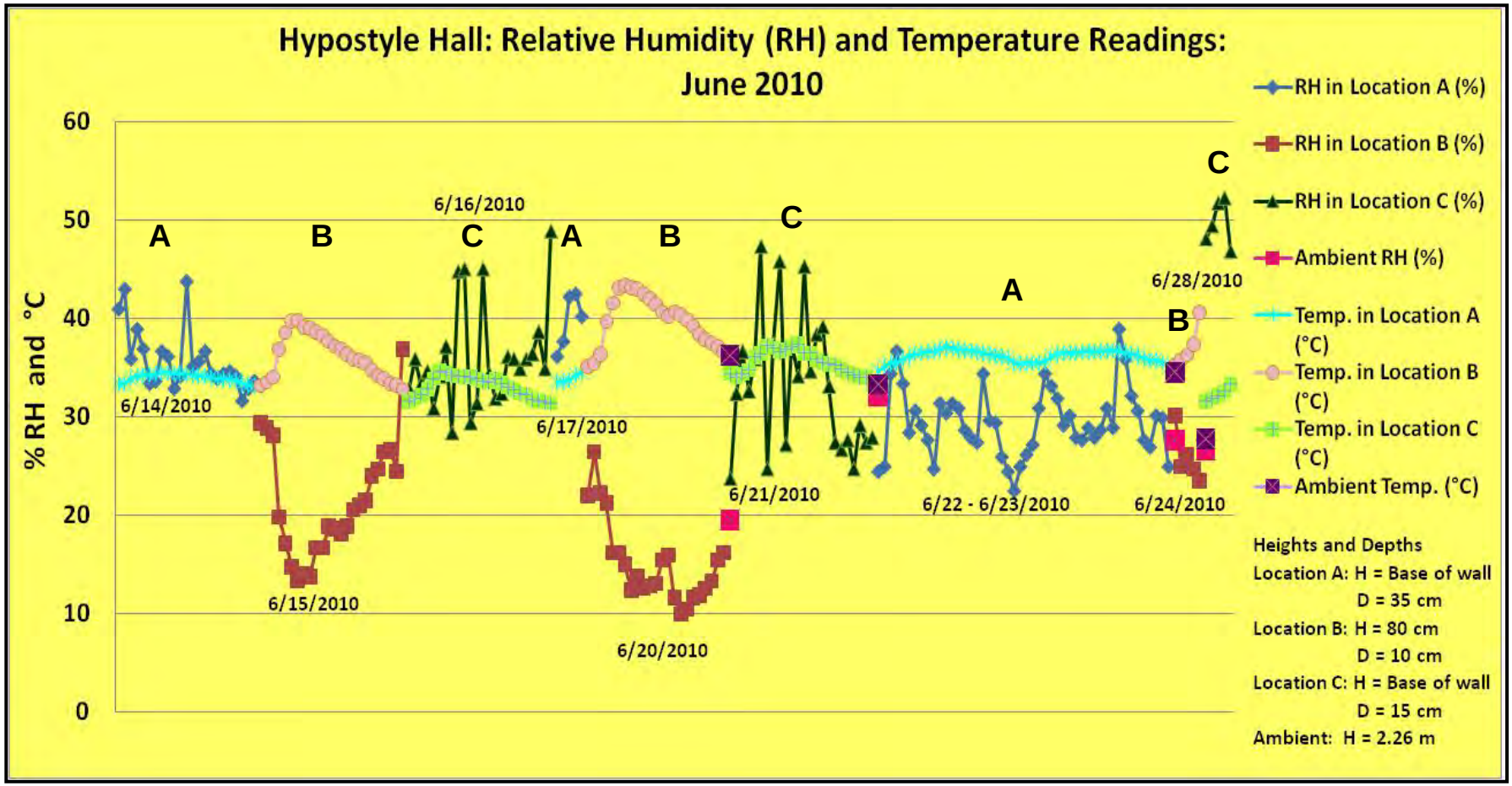
Fig. 16: Section of the wall showing two of the locations where monitoring was completed (A and B)

Fig. 17: Section of wall showing the third monitoring location (C)

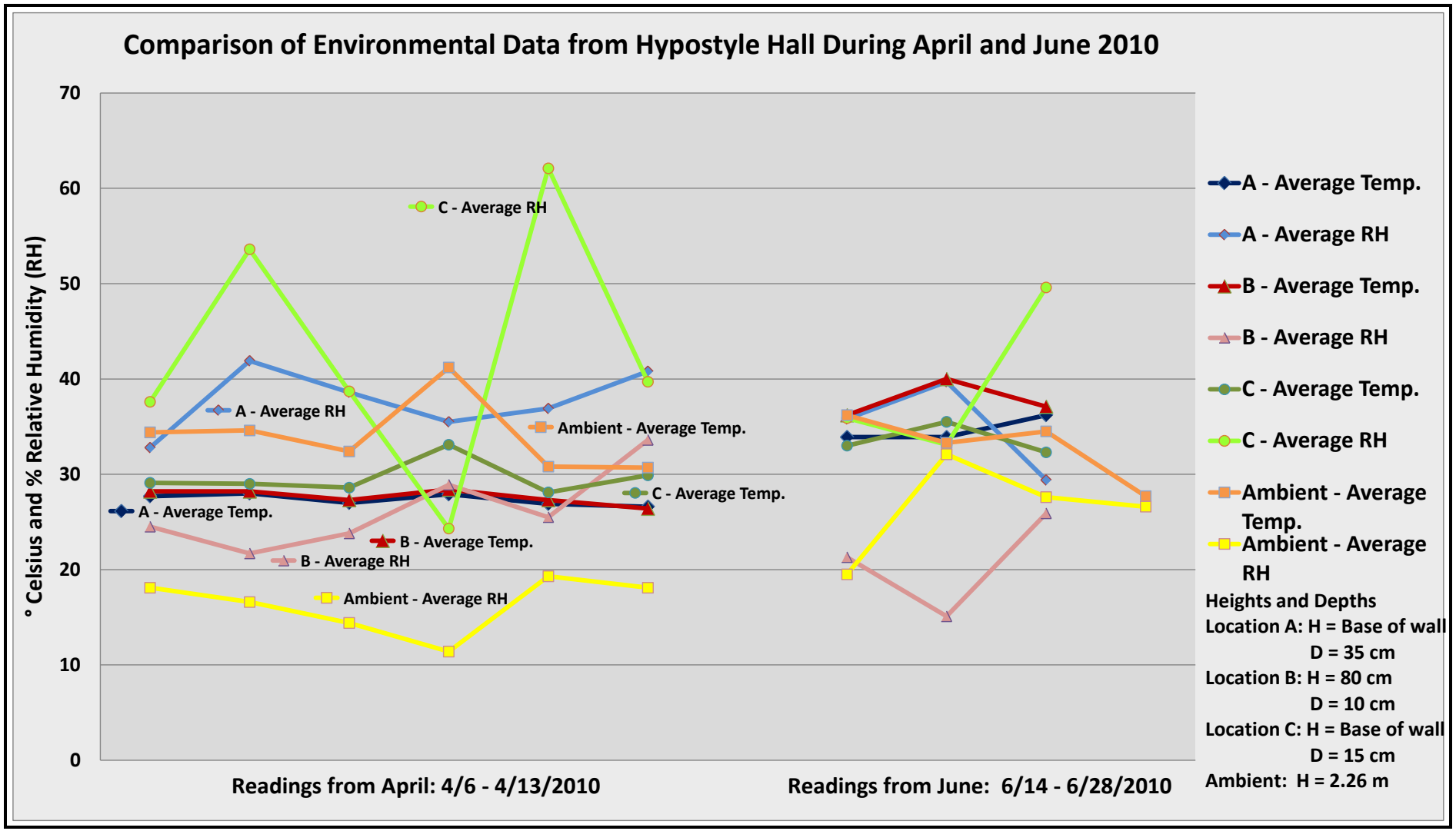
The following graphs show the results from a week of monitoring in April and a week of monitoring in June. A third graph compares the two sets of data using the average temperatures and RH levels for each day of monitoring. April and June's locations have been interpreted separately from February's as they were in different locations.



Note: The data logger was placed in each location for 1 hour during each work day from 4/7/2010 – 4/13/2010. The logger was programmed to take temperature and RH readings every 10 minutes.



Note: The data logger was placed in each location and rotated daily. Readings were taken every hour for a total of three days in each location (aside from A which had readings taken over four days). The reason for the different approach to the June monitoring was because the project in the Hypostyle Hall was completed at the end of May. The author was working in different areas of the site during June and was not able to come to the Hypostyle Hall every hour to rotate the Tiny Tag data logger. One reading of the ambient temperature and RH was taken on the mornings of the last four days of monitoring, before the data logger was placed in the appropriate location.


Comparison of Environmental Data from Hypostyle Hall During April and June 2010
° Celsius and % Relative Humidity (RH)
70
60
50
40
30
20
10
0
C - Average RH
A - Average RH
Ambient - Average Temp.
C - Average Temp.
A - Average Temp.
B - Average Temp.
B - Average RH
Ambient - Average RH
Readings from April: 4/6 - 4/13/2010
Readings from June: 6/14 - 6/28/2010
A - Average Temp.
A - Average RH
B - Average Temp.
B - Average RH
C - Average Temp.
C - Average RH
Ambient - Average Temp.
Ambient - Average RH
Heights and Depths
Location A: H = Base of wall
D = 35 cm
Location B: H = 80 cm
D = 10 cm
Location C: H = Base of wall
D = 15 cm
Ambient: H = 2.26 m

Discussion of Results

The April RH ranges in the four areas monitored were as follows: A - 30-40%; B – 20-45%; C – 37-60%; and ambient RH - 12-22%. The RH levels in all three locations were significantly higher than the ambient levels. Location C, at the base of the wall and a depth of 15 cm, had the highest RH readings of the three locations. Location A, also at the base of the wall and a depth of 35 cm was the second highest. Location B, the highest and shallowest of the areas monitored only showed one day where the RH levels were over 30%. The temperature ranges of A, B and C were all very similar (25-30°C) and the ambient temperature during the week in April was the highest overall (28-40°C). Because of the similar temperature readings in the three locations it is unlikely that temperature was having a marked effect on the RH levels within the wall.

The RH ranges in June were as follows: A – 22-45%; B – 10-37%; C – 24–53% and the ambient RH ranged from approximately 19-32%. The ambient RH was higher overall in June compared to April and all three locations had larger RH ranges during June's monitoring session. Locations B and C had lower maximum RH levels in June compared to the maximum readings in April. Perhaps the areas had dried out a bit over the two month period as a result of the voids being left open and not filled in immediately. However, there was still a significant amount of RH fluctuations in all three areas, more than 20 percentage points each. For the temperature readings, locations A and C (the deeper two of the three) showed similar results (~32-37°C). Compared to April, these readings were between 7 and 19° higher. The ambient temperature range (28-36°C) was similar to the ambient range in April, but this is not a very comprehensive figure as the June readings were only taken once a day, in the morning, when the temperatures were cooler.

To summarize the data averages from April and June, location C (at the bottom right-hand corner of the Northwest wall) had the highest RH levels overall and greatest fluctuations. The RH levels were reduced somewhat in June compared to April. Location A had the second highest average RH levels; these were slightly reduced overall in June compared to April. Location B had the lowest RH levels and this is logical as it was the highest up on the wall (80 cm) and the least deep (10 cm). The ambient RH increased in June. The ambient RH was significantly lower in April compared to the 3 locations and ambient readings in June. The ambient RH in June was higher than B, but lower than both A and C. This indicates the presence of moisture in the sandstone and air surrounding the areas that were monitored. The ambient temperature was the highest of all the temperature readings in April. The ambient temperature was similar to locations A and C in June.

The general conclusion is that moisture is present to varying extents within the wall and sandstone matrixes. It seems that more moisture is present overall in the lower sections of the

wall. Notable fluctuations are occurring with both RH and temperature and after analyzing the data, the RH fluctuations are not necessarily correlated to the levels or changes in temperature. Moisture and continuous rising damp is likely an issue in this particular wall and others on the site. This will need to be considered in relation to long-term maintenance and monitoring of the salts within the walls and on the surfaces of the monuments.

Analysis of Unknown Green and Brown Materials Discovered During Desalination:

During the desalination process, a fuzzy looking green material was revealed behind a thin layer of mortar above the crevice where the environmental monitoring took place in February. Additional spots were revealed with further desalination work in the same area (figures 18 and 19). A sample of this material was taken and tested during the salt analyses (see test-strip and conductivity sections – sample 20) and a few additional samples were taken so they could be analyzed further using the microscope in the lab.

Fig. 18: A section where the unknown green material was revealed

Fig. 19: Detail of the green material

Several dark brown/black spots on a sandstone block were also discovered on a lower section of the wall (figure 20). If the RH levels have historically been high in and around the wall, it would not be surprising for biological growth (e.g. mold) to occur in this environment. A sample of this material was also taken to determine if the material was biological growth or some sort of mineral inclusions in the sandstone. The dark brown/black material could represent iron inclusions, but it was necessary to look at both samples more carefully under the stereomicroscope.

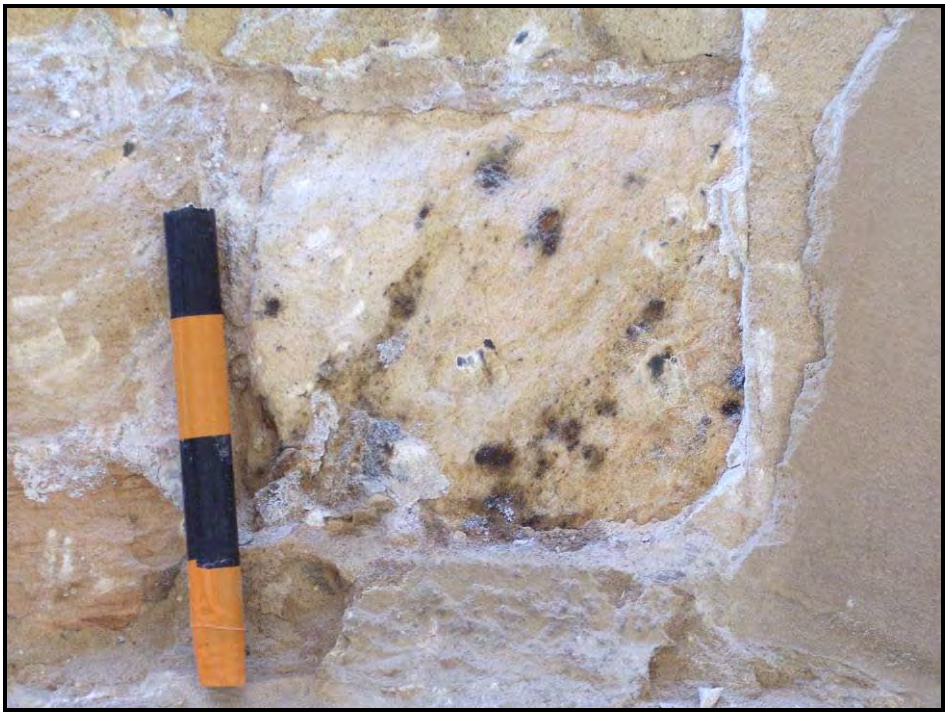
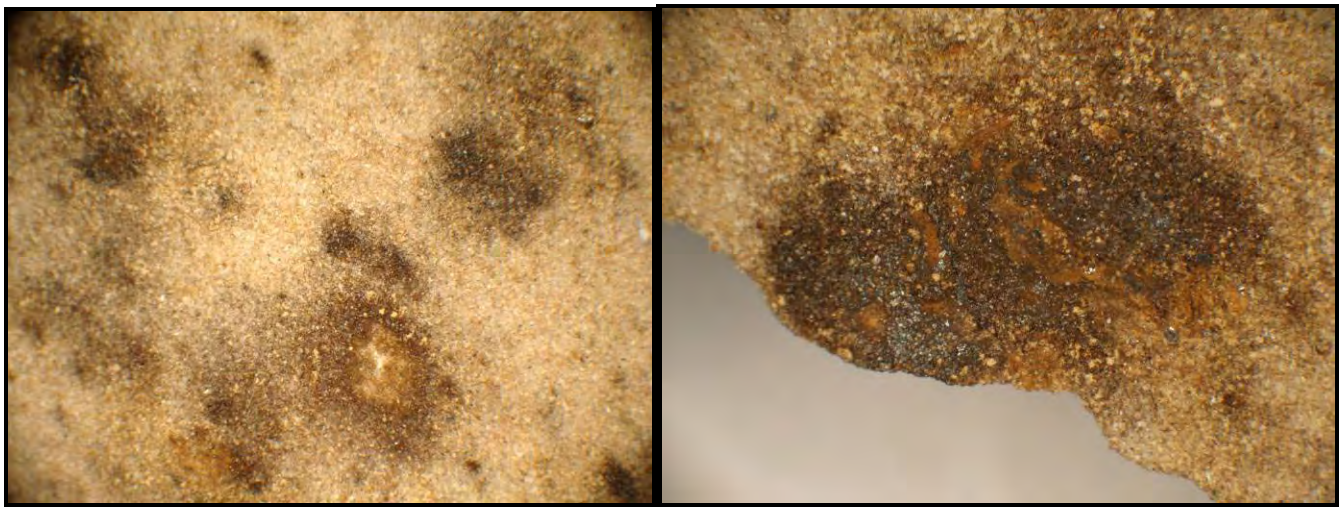


Fig. 20: The unknown brown/black spots *in situ* on a sandstone block

The samples were examined and photographed under the microscope towards the end of the project; both were determined to be mineral inclusions in the sandstone rather than mold or some other type of biological growth. The green material was clearly intermixed with sand particles and likely represents malachite, naturally existing copper carbonate, in the sandstone (figures 21 and 22).

Figs. 21 and 22: The green material as it appeared under the microscope



Figs. 23 and 24: The brownish-black material as it appeared under the microscope

Upon closer examination, the brownish-black material did not have a fuzzy look to it. Instead, the surface appeared smooth in some sections and, when looking under higher magnification, it was possible to see the orange-brown color which is indicative of the presence of iron. Iron inclusions have also been noted in other sandstone monuments on the Karnak site.

Desalination and Conservation Processes:

During April, the desalination process continued on the section of the wall that had the most severe damage from salt efflorescence, from approximately meter 21 through meter 30 (figures 25 and 26). First the salts were mechanically removed from the surface using hammers, chisels, and scalpels. Areas where extensive salts were present on the surface were treated with hebba poultices (figure 27) to try and remove additional salts below the sandstone surface. Please refer to the January – March progress report for further information on preparing the hebba for use. Some sections of the wall were poulticed with hebba two or three times in an attempt to remove as much salt as possible.

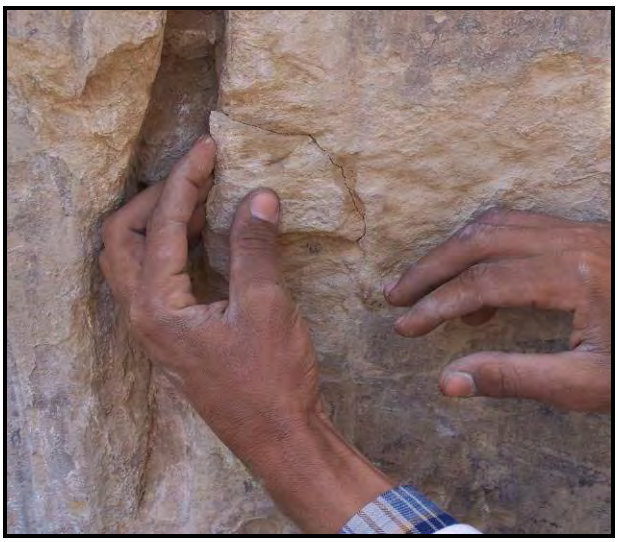
Figs. 25 and 26: A section of wall undergoing desalination and a detail showing extensive salt

Fig. 27: An area that was treated with several hebba poultices

Several areas of the surface were friable and in need of consolidation before any other treatment could take place. Medical syringes and needle attachments were used to inject the consolidant (a 3% w/v solution of Paraloid B44® in acetone) into the sandstone surface and into deeper gaps and cracks (figures 28 and 29).

Figs. 28 and 29: An area that required consolidation (left) and a detail of consolidant being injected with a syringe (right)

A few smaller fragments of the original wall were unstable or had become dislodged in the process of the desalination and fill removal work. The fragments were dry cleaned with brushes, consolidated (if necessary) and then re-attached using Araldite®, an epoxy adhesive (figures 30 and 31).



Figs. 30 and 31: Repairing a sandstone fragment

The area and crevice where the environmental monitoring was completed in February needed to be filled in with a material to replace the old brick from a previous restoration (figure 32). It was decided to use an extra sandstone block from another part of the site to fill in the gap and make the area flush with the surface of the surrounding wall (figure 33).

Fig. 32: The brick fill before removal

Fig. 33: Fitting the new sandstone block into the gap at the base of the wall

The sandstone block was chiseled to the size and shape needed and then imbedded into the ground at the base of the wall. Mortar was used to fill in the area surrounding the block and to secure it into position (figure 34).

Fig. 34: The sandstone block after securing with a first layer of mortar and giving the surface some texture

Sections of the wall treated prior to February 2010

There is on-going concern about additional salt efflorescence that might occur in the near or more distant future in the Hypostyle Hall. Despite the thorough desalination program, there were several areas where salts remained along the section of wall treated prior to February 2010. In other sections, there seemed to be recent efflorescence (i.e. since the beginning of the project in November 2009) on the surface. In response, the problem areas were marked and the team revisited these sections and completed additional treatment. Two additional applications of hebba were applied to the worst areas and mechanical cleaning was done on all of the tagged sections.

Removal of Old Cement Fills and Lime Mortar Work

All of the old cement fills below approximately two meters in elevation were removed. Many of the fills had failed in terms of support by separating from the surface of the original sandstone. Sections where this is the case sound hollow when tapped. Cement has a low porosity and is not a breathable material. Very often significant amounts of salt are trapped behind cement used in previous treatments. Cement is a stronger material than the sandstone and it is not a good match for long-term stone preservation. The idea behind the use of lime mortar is that it is more similar to sandstone and, therefore, should serve as a sacrificial material so the salt damage occurs to the mortar and not just the original sandstone.

Cement removal requires tapping out the fills with hammers and chisels while being careful to avoid damaging or removing fragments of the original sandstone (figures 35 and 36). The cement removal on the Northwest wall occurred simultaneously with the desalination and other conservation work. Once the cement was removed, additional mechanical cleaning was completed to expose the original sandstone surface.

Figs. 35 and 36: The team removing cement fills (left) and cement fragments after removal (right)

During April and early May the team continued to remove the old cement and mortar, including a very large patch at the end of the wall (figures 37 and 38).

Fig. 37: Mohammed Ibrahim removing the large cement fill at the end of the NW wall

Fig. 38: The large fill area after removing most of the old cement and mortar

Once the removal of the old fills and the mechanical cleaning were complete, the areas of loss were filled with two layers of lime mortar. The recipes for the lime mortar layers are as follows:

> **<u>Layer 1</u>: 3 parts sand: 1 part lime**
>
> **<u>Layer 2</u>: 2 parts sand: 1 part lime: 0.5 parts fine sandstone (earth pigments are used in the second layer to achieve an appropriate color)**

The wall is first wet using a spray bottle and then the mortar is applied to the deepest voids in the wall. The first layer is scored on the surface in order to achieve good adhesion with the second layer of mortar. The first layer is allowed to dry, typically over a few days time. The second layer, tinted with pigment, is then applied and the surface smoothed. The new mortar fills are left at a level that is slightly lower than the original sandstone wall so that there is no question as to which sections are original and which are modern additions.

During the first half of the season, an SCA team came to complete the mortaring in the Hypostyle Hall. Some of the students helped minimally with preparing the mortar on-site, but up until the end of March they had not been directly involved with applying either of the layers (figure 39).

Fig. 39: An SCA team applying mortar to the Northwest wall in February

I felt strongly that the students should be involved in the mortar work and that the only way to learn how to make and apply the mortar properly was to do these tasks and practice the techniques. It would also behoove the project in terms of scheduling as the students could complete the mortar work as needed rather than working around the SCA team's schedule. I discussed this issue with ARCE staff at the end of March and it was agreed to involve the students in the mortar work. The necessary mortaring supplies were acquired including sand,

lime, fine sandstone in a variety of colors and earth pigments. The SCA management at Karnak preferred for their team to do the second layer of mortaring. Understandably, there was concern about the finished product of the mortar work in the Hypostyle Hall because it is a high traffic area and a very popular section of the site. After several discussions and meetings between ARCE and SCA staff, a compromise was reached whereby the team would prepare and apply both layers of mortar beginning in April, but that Amr Abdu (employed by the SCA and very skilled in mortar work) would provide guidance on preparing the mortar, creating an appropriate pigment recipe for the second layer and offer tips for achieving a good surface finish.

First Layer Mortar Work

The mortar preparation area was set-up outside of the Hypostyle Hall, next to our supply and storage area. The first step involved measuring out three parts sand (figure 40) followed by one part lime. The lime was pushed through a metal and wood sieve (figure 41) to remove any stones, larger chunks of lime or any other debris. The sand and paste-like lime was thoroughly mixed together in a wheelbarrow (figure 42).

Fig. 40: Measuring out sand for the first layer of mortar

Fig. 41: Sieving the lime into the wheelbarrow

Fig. 42: Mixing the sand and lime together

After spraying the area to be filled with distilled water, the voids were filled in part-way with the first layer mixture (figure 43). The surface was then scored while the mortar was still wet (figure 44).

Fig. 43: Mohammed Ali and Ashraf applying a first layer of mortar

Fig. 44: Scoring the surface of the mortar

In some areas, the voids were quite deep and it was necessary to bulk out the first layer of mortar for additional support. Fragments of sandstone were used in these areas and they were imbedded in the first layer while it was still wet (figure 45).

Fig. 45: A section of fill where the first layer was bulked out with pieces of sandstone

The quality of the mortar improves the longer the material is slaked and the slower it dries *in situ*. In order to prevent the first layer of mortar from drying out too quickly, large sheets of plastic were secured to the top of the scaffolding and draped over the wall after mortar application and scoring of the surface (figures 46 and 47).

Figs. 46 and 47: Sections of the wall were covered in plastic to slow down the mortar drying process

Appearance of Additional Salts during the Mortar Work

In mid-April, while the team was applying new lime mortar in the large fill area at the end of the wall, additional salts appeared in several areas just to the left of the large fill. The efflorescence was quite noticeable and occurred suddenly over the course of a few days (figure 48). These areas had already been mechanically cleaned and hebba had been applied once. A first layer of mortar was applied in the smaller gaps around this section and it may be that the water in the mortar activated some of the soluble salts still remaining inside the wall. These sections were poulticed again with hebba and another round of mechanical cleaning was completed.

The appearance of additional salts raises the concern that, in general, too much water is being used in the lime mortar mixture. This seems to be a common mistake made in mortar preparation, since it is applied and mixed more easily with additional water. Sometimes with very good quality lime it may not even be necessary to add water. High quality lime is not a reality in Egypt, but I was aware of this tendency during the project and the team tried to use as little as possible in the preparation of mortar batches. Regardless of whether an ample or

Fig. 48: A section of wall showing additional salt efflorescence that appeared after desalination

minimal amount of water is used in the mortar; even a small amount could activate the soluble salts within the wall, causing efflorescence. The use of a cement mixer to prepare mortar has been discussed amongst ARCE staff and this method is planned for the 2010-2011 season. Instead of using a wheelbarrow, a cement mixer will make batch preparation easier and allow for more consistency. It will also reduce the tendency to use too much water. However, proper preparation techniques must also be a part of the field school curriculum and demonstration sessions prior to beginning projects will be implemented next season.

Concerns about the appearance of additional salts after desalination treatment will be discussed further in the '*Recommendations for Maintenance and Future Desalination Work*' section of this report.

Test Patches for the Second Layer of Mortar

Prior to making and applying the second layer of mortar, it was decided to do several test patches using different recipes and proportions of earth pigments. This would enable the team to see which combination might best match the previously patched sections. Five test patches were created and applied directly to the wall next to the area that was most recently completed by the SCA team (figure 49). The five recipes are listed below:

1). **2 sand*: 1 lime: 1 sandstone: 1 g. titan buff: 1 g. burnt sienna**

2). **2 sand*: 1 lime: 1 sandstone: 1 g. titan buff: 1 g. raw umber**

* Note: There is typically three parts sand in both the first and second layers of mortar, but there was a miscommunication in regards to the proportions of sand used prior to my arrival, so test patches one and two were made with only two parts sand.

3). **3 sand: 1 lime: 1 sandstone: 0.5 g. raw umber: 0.5 g. raw sienna: 0.5 g burnt sienna: 1 g. titan buff**

4). **3 sand: 1 lime: 1 sandstone: 0.5 g. raw sienna: 0.5 g. titan buff: 0.25 g. raw umber**

5). **3 sand: 1 lime: 1 sandstone: 0.5 g. raw sienna: 1 g. titan buff: 0.25 g. raw umber: 0.25 g g. burnt sienna**

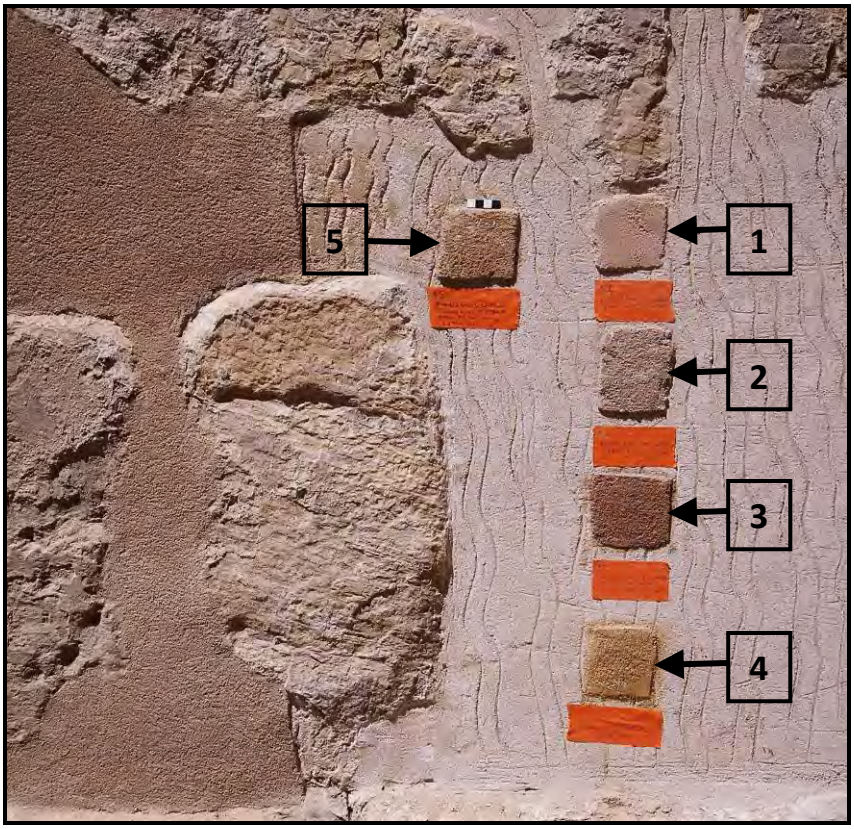


Fig. 49: The five test patches for the second layer of mortar

A batch of second layer dry mix was given to the team by the SCA to use on the wall; this mixture was supposedly the same recipe that had been used by the SCA on the previously mortared sections of the Northwest wall. However, prior to applying this mixture, it was decided to do a larger test patch directly next to the completed second layer (figure 50) to check the consistency in color. The following is the recipe for the second layer dry mix from the SCA:

150 kg. sand: 75 kg. lime: 200 g. brown: 700 g. yellow ochre: 40 g. black: 50 g. red ochre

Fig. 50: The section of wall treated earlier in the season (to the left of the line) and the larger test patch of the mixture from the SCA (to the right of the line)

This larger test patch appeared to be a bit too red (e.g. too much burnt sienna) and the sand granules were smaller than the previously filled section, so it also had a different texture.

Second Layer Mortar Work

During the latter part of April, Amr Abdu began to advise the team on a recipe for the second layer of mortar and also guided the team on application and smoothing techniques (figures 51 and 52). While the team was applying the first layer of mortar, the SCA began a project on the columns in the Hypostyle Hall that abut the Northwest wall. This involved removing old cement fills and replacing them with new lime mortar. It was logical to replicate (as best as possible) the

recipe the SCA was using on the columns for overall consistency in the texture and color of the mortar work.

Figs. 51 and 52: Ashraf and Mohammed Ali working with Amr Abdu (left) and Christie working on applying the second layer of mortar to a section of the wall (right)

On April 29th, the team accompanied Amr Abdu to the area next to Khonsu Temple where mortar preparation takes place. The SCA staff showed us the cement mixer and other materials used for mortar work. We then went to the French lab where large amounts of the dry pigments are stored and there is also a scale for weighing out the different proportions. The following is the recipe that was used for the mortar patches that were being applied to the columns in the Hypostyle Hall. This is also the recipe that the team adopted for use on the Northwest wall. The cement, lime and sand were measured using a 1 kg. metal container and the pigments were measured on the scale in the French lab:

2 white cement: 2 lime: 7 sand: 700 g. yellow ochre: 200 g. brown: 40 g. black: 50 g red ochre: 16 g. sand: 4 g. white cement

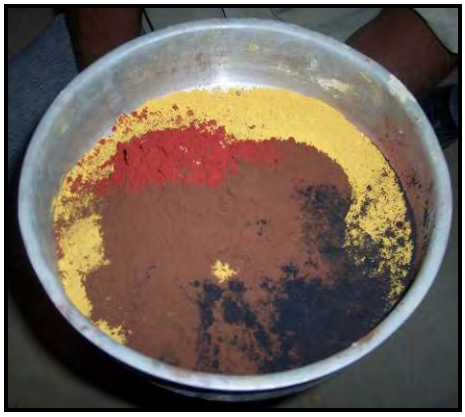


Fig. 53: Earth pigments for a batch of mortar

Fig. 54: The team working with two SCA employees to prepare the dry mixture of a second layer of mortar

The team helped with the measuring (figure 53) and mixing processes (figure 54); the entire batch was then transported to our work area outside the Hypostyle Hall. Future batches were weighed and prepared in the same fashion in our work area (figures 55 and 56).

Fig. 55: Adding the earth pigments to the dry mortar mixture

Fig. 56: After mixing the pigments into the dry batch

The four male team members noticeably improved their mortar application skills over the course of the project (figure 57). There is a way of smoothing the surface which improves with practice. Amr Abdu also introduced us to a few different tools (e.g. different shaped brushes, trowels and sponges) which were helpful, particularly for second layer application and smoothing. It was rewarding to see their skills improve and the team also vocalized that they were very much enjoying the mortar work. Some of the areas of loss on the wall required modeling of the

Fig. 57: From left – Hamdi, Mohammed Ibrahim, Ashraf and Mohammed Ali work on smoothing and modeling figure outlines in the second layer of mortar

second layer of mortar to re-create parts of figures. This was a challenging task, but was also great experience for the entire team. The fine shaping and sculpting of these areas was a nice contrast to the desalination, conservation work and filling large areas of loss (figure 58).

Fig. 58: A section of the wall which required modeling parts of figures in the second layer

There were several challenges encountered during the second layer application process. The most difficult things included creating an absolutely smooth surface in all areas, making sure the mortar was built up and consistent in relation to the remaining original sandstone and achieving consistency in the color of the second layer of mortar when several different batches were required for the fills. Sometimes we made a large batch of mortar in our wheelbarrow and other days we used the large metal bowls to make smaller batches. One section that was completed appeared patchy and four different color variations were visible the next day (figure 59). The previous day we had all worked independently using the metal bowls for the mortar and the four patchy sections corresponded to the number of bowls of mortar we applied to the wall. There were several possible reasons for the color variation. Perhaps the batch of mortar was not mixed well enough (this was the batch that was prepared by Abdu and the team the previous week), or the color was altered depending on what bowl was used. It was also possible that some residual material from inside the bowls came off into the mix each time the mortar was placed inside.

Fig. 59: A section showing a color difference and inconsistencies in the surface texture

This patchy section was not an acceptable finished product, so we tried a few different techniques to even out the color and surface appearance. The SCA mortar teams sometimes use a dilute “wash” of mortar and water in order to even out the color and surface texture. We observed the workmen doing this on some of the columns in the Hypostyle Hall. There are some areas of new mortar work which also appear to be slightly different colors, so this seems to be a challenge that is not unique to the team, but rather a wide-ranging challenge with second layer color differences. We tried using a wash on the problematic section of the wall, however this did not seem to improve the appearance much or reduce the multiple color variations.

Ornella, one of the conservators working for the French mission, came by to visit one day and suggested we try using a screed (a square, flat stick of wood) to smooth out the surface of the mortar after it has been allowed to set and dry for a few minutes. The team was able to acquire several of these for smoothing the second layer and they were very helpful for achieving a more uniform and consistent surface.

We also tried removing a few millimeters of the second layer in the areas where there were color differences and surface inconsistencies. After taking down the surface with a small serrated jeweler’s saw, a thin layer of additional mortar was applied and then smoothed down with the small saw. A test area using this method seemed to mask the color difference and the

new mortar applied matched better with the surrounding mortar. This technique also helped to eliminate some of the small spots on the surface that were flatter than the textured surface of the mortar. The team also tried using some sand paper to flatten and smooth out the surface in the problematic areas. This was not as successful as the previously described technique and also created dust that settled into the second layer.

Despite the slight improvements after trying these methods, I was still not happy overall with the seven-eight meter section to the left of the large fill. After discussing the situation with the team, as well as ARCE and SCA staff, it was decided to remove the second layer entirely from this section and re-do it with one large batch of mortar (figures 60 and 61).

Figs. 60 and 61: The team re-mortaring the section where there were issues with the look and color of the second layer

In May, after finishing their work with the Talatat project, Claire and Lindsay came to assist the team with the work in the Hypostyle Hall. Their participation was helpful in terms of keeping us on schedule and having some additional hands to assist us with the large fill. As Lindsay is planning to attend a graduate conservation program in the near future, she was able to gain some additional fieldwork experience, involving very different tasks from the Talatat project.

Figs. 62 and 63: Claire (left) and Lindsay (right) helping with the mortar work

Our last major challenge was to fill the large void at the end of the wall (figures 64 and 65) and to have this as smooth and as consistent in color as possible. To reduce the likelihood of color differences a double batch of mortar was made and the goal was to try and complete the second layer mortar application in one work day.

Fig. 64: The section at the end of the wall after removing the old cement fill and before applying any new mortar

Fig. 65: Part of the fill after the first layer of mortar was applied

In order to achieve this, all four of the men, Lindsay, Claire and I worked on the fill. By this stage we had worked out a method whereby someone would work on applying the second layer of mortar and another person would follow behind and work on smoothing the surface after it had a bit of time to set. This set-up worked well, so we used the same approach on the large fill, only the work moved from top to bottom instead of left to right (figures 66 and 67).

Fig. 66: Mohammed Ibrahim and Mohammed Ali begin applying the second layer

Fig. 67: Hamdi and Claire continue by smoothing the surface with screeds

We also had some assistance towards the end of the day from Adel, one of the SCA workmen who is very skilled and fast at mortar work. This helped to ensure that we finished the fill in one day (figure 68).

Fig. 68: The fill after applying and smoothing the second layer of mortar

Finishing Touches, Cleaning and Inventorying Supplies

After the second layer of mortar had been applied to all of the areas of loss on the wall there were a few small spots that required a bit more mortar and finishing around the edges. We checked the entire length of the wall to be sure that there were not any areas that required further desalination. The entire base was then thoroughly cleaned and all of the remaining rubble, debris and dirt were removed from the work area.

Once the work was complete, all of the tools were cleaned, organized and transported back to the lab. The tools and supplies from the Hypostyle Hall project and the Talatat project were incorporated into the general collection and the inventory lists for the lab and store rooms were updated. The store room in the lab building was also cleaned and organized. Some of the larger equipment that was not being used was moved to the additional storage facility next to ARCE's headquarters in Luxor. The project and associated tasks were completed a few days ahead of schedule on May 27th, 2010.

The following photograph (figure 69) shows the entire length of the wall after treatment was complete. Due to the large size and length of the wall, this mosaic of photos is followed by larger size photos of the wall, divided into sections (figures 70-75).

Fig. 69: A mosaic of photographs, taken by ARCE photographer Owen Murray, showing the entire Northwest wall after treatment

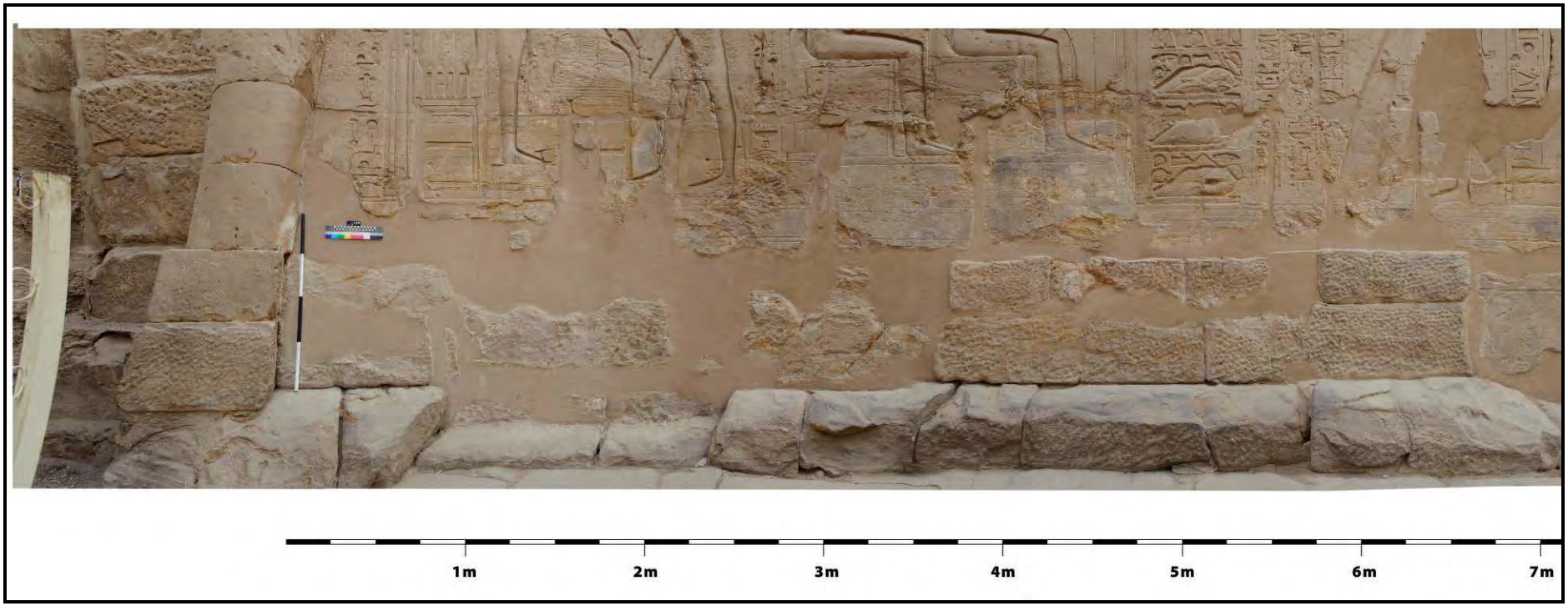


Fig. 70: The first 7 meters of the Northwest wall, after treatment

Fig. 71: Meters 7-14 after treatment

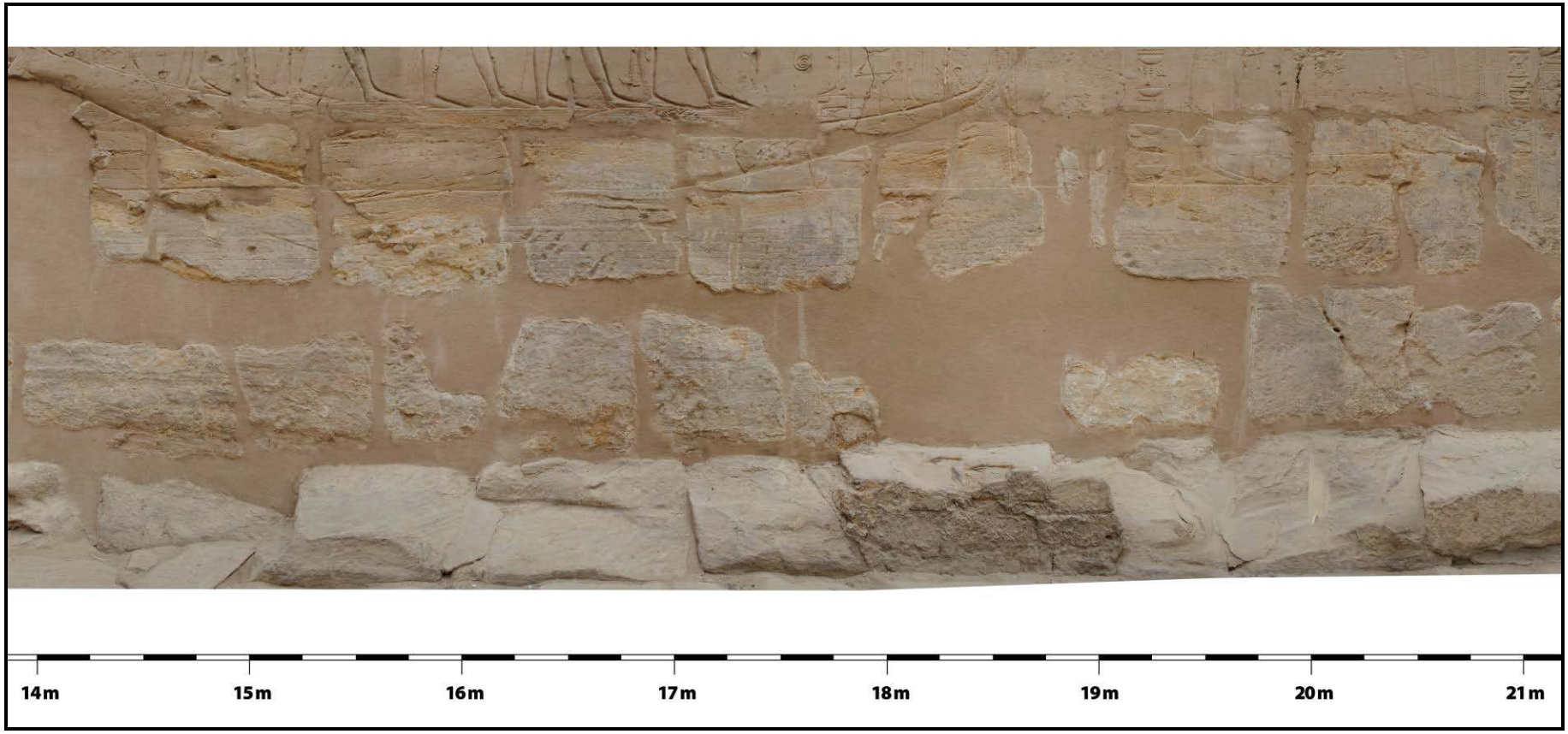


Fig. 72: Meters 14-21 after treatment

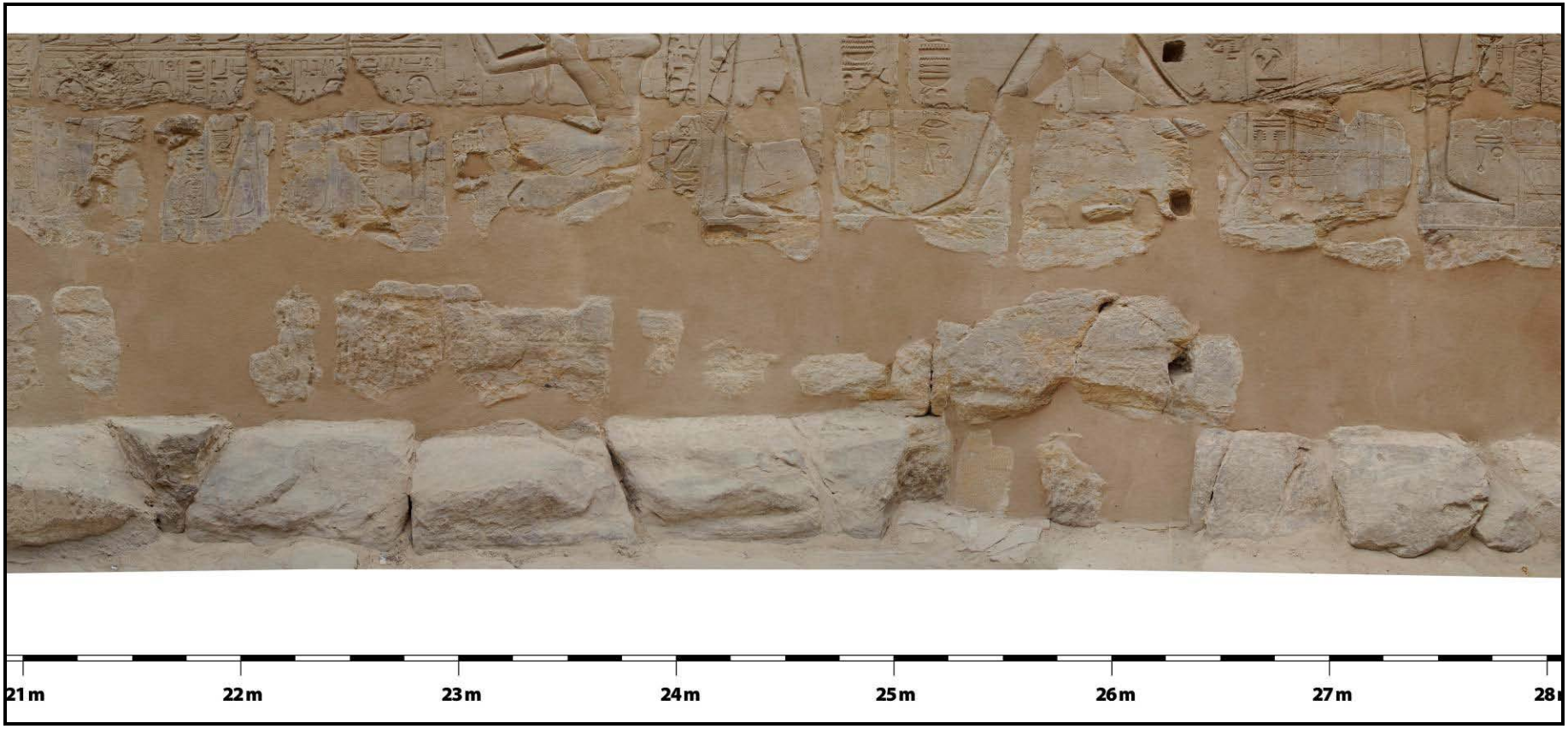


Fig. 73: Meters 21-28 after treatment

Fig. 74: Meters 28-33 after treatment

Fig. 75: Meters 33-37 after treatment

Other Related Activities

Coins Discovered in the Wall during Cement Removal

On March 15th, five coins were discovered behind a chunk of old fill towards the bottom of the wall (figure 76). After superficial cleaning they were determined to be relatively modern (figure 77) and Cyrillic writing was visible on a few. The space behind where the coins were found was

Figs. 76 and 77: The five coins discovered behind an old cement fill at the base of the wall

actually a deep gap in the wall. After putting a tape measure in this gap, it was determined to be approximately 90-100 cm deep. This was an ideal place to do some additional environmental monitoring and this gap ended up being area A during the April and June monitoring sessions. The coins were incorporated into the teaching collection of objects for the Karnak conservation lab and field school.

Condition Reporting and Condition/Damage Mapping

The two female members of the Hypostyle Hall team, Mariam and Leuese, were involved in all of the project activities, aside from applying mortar to the areas of loss. They both felt more comfortable and better equipped to do the necessary condition reporting and damage mapping of the Northwest wall rather than the mortar work. While the men worked on applying the mortar, Mariam and Leuese completed the condition reports and damage maps of the six registers (figure 78).

Although no work was completed on the Southwest wall during the 2009-2010 season, and work is not planned for next season, there was some additional time left in May after completing the documentation of the Northwest wall. I had Miriam and Leuese work on the condition reports for the seven registers of the Southwest wall (figure 79), as this will allow a future team to be a step ahead with before treatment documentation. Miriam and Leuese managed to finish the condition

reports for all seven registers of the Southwest wall by the end of the project (May 27th, 2010). The reports were given to Amel at the end of the season for proof-reading and editing.

Fig. 78: Leuese works on a damage map of the Northwest wall

Fig. 79: Leuese and Mariam working on the condition reports for the Southwest wall

The Creation of a Lime Slaking Program and Preparation Area outside the Karnak Lab

There is a significant amount of mortar work that occurs in the Hypostyle Hall and many other areas around the site. As a result of the demand for a large amount of lime and a desire to implement more quality control of the mortar, a lime slaking program was developed in cooperation with John Shearman, Elsa Bourguignon, Reis Mahmoud and his team of workers.

Elsa provided advice on the preparation and storage of the lime and the idea was to create an on-going program, where batches of lime created in April and May could be ready in the fall, at the beginning of the next season. During the fall, additional lime could be prepared and stored for use later in the season. Once mortar has been slaked, it is best to wait at least six months before using it; the longer lime is stored, the better the properties of the material. Lime mortar which is then applied to a wall as a fill material needs about three months to cure properly.

ARCE staff discussed creating a lime mortar preparation area outside, adjacent to the back of the Karnak conservation lab (figure 80). Here there was enough space for a preparation and storage area without it being visible to visitors to the site. This space also allowed for access to supplies, electricity and water. One of the other goals was to design the area for demonstrations and hands-on lime preparation training for the field school students.

Fig. 80: The lime preparation area at the back of the conservation lab

Fig. 81: One of the metal tanks for lime slaking

After discussing plans with Reis Mahmoud, he created two large galvanized metal tanks (one meter x two meters x one meter) for slaking large batches of lime (figure 81). A heat resistant

Fig. 82: The exothermic reaction between the lime and water

Fig. 83: Reis Mahmoud and his team preparing a large batch of lime

container was necessary for the slaking process, as the initial contact between lime and water creates a powerful and potentially dangerous exothermic reaction (figure 82). After a few days the lime cools and it is mixed thoroughly with the water. Large stones and any other debris are removed from the mixture. The lime from the tanks can then be transferred to plastic barrels for longer-term storage; however, prior to this transfer the lime is pushed through increasingly smaller sieves to remove larger particles and any non-reactive lime. The resulting material should be a smooth paste and remain submerged in water throughout the storage period.

250 bags of lime and sixteen large plastic tanks were purchased in May and the lime preparation continued over the summer (figure 83). There are also plans for extensive mortar work in Luxor Temple during the 2010-2011 season and several of the large plastic lime barrels will be transported to the site for filling areas of loss on columns.

Recommendations for Maintenance and Future Desalination Work

- **Regular monitoring of the Northwest wall for the appearance of additional salt efflorescence**

There is on-going concern about additional salt efflorescence that might occur in the near or more distant future in the Hypostyle Hall, even after the completion of a thorough desalination program. There were several problematic areas along the Northwest wall, in terms of remaining salts, which had to be treated numerous times. It should be stressed that this type of desalination program is not a one-time “cure” or fix for salts that have caused such significant damage. Even after lowering the ground water significantly, mechanically cleaning the surface and poulticing with hebba, soluble salts remain within the sandstone. From the environmental monitoring sessions, it is clear that there are still rather high levels of humidity and RH fluctuations occurring within the wall. This combination is likely to result in cycles of deliquescence and efflorescence of the soluble salts. Another factor is the thickness of the wall; even with multiple poultices, it is impossible to reach all of the salt contained within the sandstone blocks. It is important that all stakeholders understand the reality of the situation and the need for regular monitoring of the previously desalinated areas. If efflorescence does occur in the future, then the same desalination methods that have been employed in the past can be used to re-treat the affected areas. Any one of the group of students who worked on the Hypostyle Hall 2009-2010 project can provide guidance on the desalination methods and are capable of completing any necessary treatment.

- **Regular cleaning of the surface and base of the Northwest wall**

The Northwest wall is an area that is frequently visited by tour guides and tourist groups. As a result, rubbish and other debris such as bird feathers and dust tend to accumulate on the surface and along the base of the wall. To keep the area looking tidy, it should be cleaned and swept regularly. The stones on the ground in front of the wall should also be monitored for

stability. Approximately three weeks after the project ended, I went to check the area and a few of the stones surrounding one of the metal posts had become dislodged.

- **Desalination and conservation of the Southwest wall in the Hypostyle Hall**

There may be a possibility to treat the Southwest wall in the future, perhaps while ARCE is involved with work in Karnak, or perhaps additional work will be completed by SCA teams. Condition reports were completed for all registers of the Southwest wall during May 2010. These are in the format developed for the field school in previous seasons. The reports are in Arabic and include historical background information and explanations of the scenes depicted on the wall. There are plans to change the format of the condition reports for the 2010-2011 season. They will be more standardized, concise and will include both English and Arabic descriptions. It is recommended that the new condition report forms be completed on the Southwest wall and these can be filed with the older versions. Condition maps have not yet been completed for the Southwest wall. As of the 2010-2011 season, the methods for doing the condition maps will also be changing, so any future mapping can mimic the new method using transparent overlays and a color-coded condition key.

Future desalination and conservation work on the Southwest wall can follow the treatment process that was completed on the Northwest wall: mechanical removal and cleaning of salts from the surface; removal of old cement fills; poulticing areas containing significant amounts of salt with hebba; mechanically cleaning (and solvent cleaning only if necessary) the dried hebba; consolidation and repair work where needed; preparation and application of lime mortar to replace the old cement fills, tinting the second layer with earth pigments.

- **Repeat salt sampling and testing with another set of samples from the Southwest wall**

If additional salt testing is desired or needed in the future, a new set of samples could be taken from the Southwest wall and then analyzed. Learning from this season's sampling process, it is recommended to use a more precise method for calculating the concentration of salts. The sizes of the sample squares should all be the same and documented with a scale. If a known amount of salt or a salt mixture is dissolved in a known volume of water, then it is possible to calculate the salt concentration per cm^2. It is also recommended that a few samples be taken from the same sandstone blocks to be able to compare the salt concentrations from areas in close proximity.

It would also be best if the same individual takes all the samples and completes the analyses for consistency reasons. This past season, Mohammed Hussein took eight of the samples prior to my arrival and I took the remainder. Even slight differences in methods and information recorded can impact the reliability of this type of study. Some material from each of the 21 samples used for this initial study have been reserved in case there is a need for re-testing or use in another form of analyses. These samples are stored in the office in the Karnak

conservation lab. Considering the problems that were encountered with the conductivity meter, it would be best to acquire a new one which produces more reliable data.

There was not time this season to complete another test for salt concentration in addition to the Merckoquant® strip tests and conductivity measurements. In the future an additional technique, such as hygroscopic moisture content (HMC) measurement, could be incorporated into a study. Some contaminant salts which can be present as a result of rising dampness may be hygroscopic, or capable of absorbing moisture from the surrounding environment. Soluble chlorides and nitrates are often present in ground water and may be present as result of long-term rising damp. The HMC technique Involves taking a sample about thumb size, weighing it, drying it in an oven, weighing it again then taking the hygroscopic measurements.

- **Environmental monitoring at points within the Southwest wall**

The results of the environmental monitoring this season proved to be very useful for evaluating the levels and changes in temperature and relative humidity. It would be interesting to complete similar monitoring sessions at locations within the Southwest wall and compare these to the results from the Northwest wall. A monitor could be placed in a few locations where there are gaps in the wall, at a variety of heights, and the data could be recorded every few months throughout the season.

- **Continuation of the lime slaking and lime preparation program**

The lime slaking and lime preparation program that was established at the end of the 2009-2010 season should continue and be monitored by both ARCE staff, Reis Mahmoud and his team. If further mortar work occurs on the Southwest wall in the Hypostyle Hall, the same recipes for the mortar layers on the Northwest wall should be followed (see pages 25 and 32 for the recipes). A cement mixer should be used to mix the mortar ingredients, whenever possible, to be sure the particles are thoroughly mixed together.

Elsa Bourguignon has developed quality control guidelines and field testing suggestions for ARCE's various activities in Luxor and Karnak. Any guidelines pertaining to the preparation and/or application of mortar should be incorporated into any relevant future project.

Appendix A: Results of the Merckoquant® Strip Testing

Location								Test strip concentration (mg/L)						Concentration in sample (mg/g)					
Sample Point	Sample #	Height from base (m)	Distance from SW corner (m)	Type	Date sampled	Weight (g)	Water added (ml)	Chlorides (Cl^-)		Nitrates (NO_3^-)		Sulfates (SO_4^{2-})		Chlorides (Cl^-)		Nitrates (NO_3^-)		Sulfates (SO_4^{2-})	
								Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	1	1.50	0.35	Surface before poulticing	early Nov. 2009	1	10	500	500		10	200	400	5.00	5.00	0.00	0.10	2.00	4.00
2	1	1.54	2.20	Surface before poulticing	early Nov. 2009	1	10	500	500	25	50		200	5.00	5.00	0.25	0.50	0.00	2.00
	2	1.54	2.20	1st poultice (salted)	2/4/2010	0.25	2.5	500	500	25	50	200	400	5.00	5.00	0.25	0.50	2.00	4.00
	3	1.54	2.20	2nd poultice (salted)	2/9/2010	1	10	500	500		10		200	5.00	5.00	0.00	0.10	0.00	2.00
	4	1.54	2.20	3rd poultice (salted)	3/15/2010	1	10	500	1000		10		200	5.00	10.00	0.00	0.10	0.00	2.00
3	1	1.38	5.00	Surface before poulticing	early Nov. 2009	1	10	0	500	50	100	400	800	0.00	5.00	0.50	1.00	4.00	8.00
	2	1.38	5.00	1st poultice (salted)	2/4/2010	1	10	500	500		10	800	1200	5.00	5.00	0.00	0.10	8.00	12.00
	3	1.38	5.00	2nd poultice (salted)	2/9/2010	1	10	500	500		10	400	800	5.00	5.00	0.00	0.10	4.00	8.00
	4	1.38	5.00	3rd poultice (salted)	3/15/2010	1	10	0	500		10		200	0.00	5.00	0.00	0.10	0.00	2.00
4	1	1.54	8.03	Surface before poulticing	early Nov. 2009	1	10	500	500	100	250		200	5.00	5.00	1.00	2.50	0.00	2.00
5	1a	1.53	11.24	Surface before poulticing	early Nov. 2009	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		1.25		0.05		8.00
	1b	1.53	11.24	Surface before poulticing	early Nov. 2010	1	10	500	500		10	1600		5.00	5.00	0.00	0.10	16.00	0.00
	2	1.53	11.24	1st poultice (salted)	2/4/2010	1	10	500	500		10	400	800	5.00	5.00	0.00	0.10	4.00	8.00
	3	1.53	11.24	2nd poultice (salted)	2/9/2010	1	10	0	500		10		200	0.00	5.00	0.00	0.10	0.00	2.00
	4	1.53	11.24	3rd poultice (salted)	3/15/2010	1	10	0	500		10		200	0.00	5.00	0.00	0.10	0.00	2.00
6	1a	1.73	18.90	Surface before poulticing	early Nov. 2009	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		15.00		1.25		8.00
	1b	1.73	18.90	Surface before poulticing	early Nov. 2010	0.5	5	1500	2000	250	500	1220	1600	15.00	20.00	2.50	5.00	12.20	16.00
7	1a	1.64	21.95	Surface before poulticing	early Nov. 2009	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		10.00		1.25		8.00
	1b	1.64	21.95	Surface before poulticing	early Nov. 2010	1	10	1500	2000	50	100	1200	1600	15.00	20.00	0.50	1.00	12.00	16.00
8	1a	1.90	25.30	Surface before poulticing	early Nov. 2009	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		15.00		1.25		8.00

	1b	1.90	25.30	Surface before poulticing	early Nov. 2010	1	10	1000	1500	250	500	1600		10.00	15.00	2.50	5.00	16.00	0.00
9	1a	0.96	5.22	Surface before poulticing	1/31/2010	0.75	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		15.00		1.25		8.00
	1b	0.96	5.22	Surface before poulticing	2/1/2010	0.1	1	1000	1500	50	100	800	1200	10.00	15.00	0.50	1.00	8.00	12.00
10	1a	0.64	16.62	Surface before poulticing	1/31/2010	0.53	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		5.00		0.00		4.00
	1b	0.64	16.62	Surface before poulticing	2/1/2010	0.1	10	500	500	10	25	800	1200	50.00	50.00	1.00	2.50	80.00	120.00
	2	0.64	16.62	1st poultice (salted)	2/2/2010	1	10		0		10		200	0.00	0.00	0.00	0.10	0.00	2.00
	3	0.64	16.62	2nd poultice (salted)	2/9/2010	1	10	500	500		10	800	1200	5.00	5.00	0.00	0.10	8.00	12.00
	4	0.64	16.62	3rd poultice (salted)	3/15/2010	1	10		500		10		200		5.00	0.00	0.10		2.00
11	1a	1.74	24.20	Surface before poulticing	1/31/2010	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		10.00		1.875		1.00
	1b	1.74	24.20	Surface before poulticing	2/1/2010	0.5	5	500	1000	250	500	800	1200	5.00	10.00	2.50	5.00	8.00	12.00
12	1a	1.16	27.30	Surface before poulticing	1/31/2010	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		15.00		1.875		8.00
	1b	1.16	27.30	Surface before poulticing	2/1/2010	0.1	1	500	1000	100	250	400	800	5.00	10.00	1.00	2.50	4.00	8.00
13	1a	1.30	25.75	Surface before poulticing	1/31/2010	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		2.50		0.00		4.00
	1b	1.30	25.75	Surface before poulticing	2/1/2010	1	10	500	500		10	1200	1600	5.00	5.00	0.00	0.10	12.00	16.00
	2	1.30	25.75	1st poultice (salted)	2/2/2010	1	10	500	500		10	800	1200	5.00	5.00	0.00	0.10	8.00	12.00
	3	1.30	25.75	2nd poultice (salted)	2/11/2010	1	10	0	500		10	200	400	0.00	5.00	0.00	0.10	2.00	4.00
14	1a	0.18	0.5	Surface before poulticing	1/31/2010	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		2.50		0.125		0.125
	1b	1.18	0.5	Surface before poulticing	2/1/2010	1	10	500	500		10		200	5.00	5.00	0.00	0.10	0.00	2.00
	2	0.18	0.5	1st poultice (salted)	2/9/2010	1	10	500	500		10	400	800	5.00	5.00	0.00	0.10	4.00	8.00
	3	0.18	0.5	2nd poultice (salted)	2/11/2010	1	10	0	500		10	200	400	0.00	5.00	0.00	0.10	2.00	4.00
15	1a	0.21	10.60	Surface before poulticing	2/1/2010	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		5.00		0.50		2.00
	1b	0.21	10.60	Surface before poulticing	2/2/2010	1	10	500	1000	25	50	400	800	5.00	10.00	0.25	0.50	4.00	8.00
16	1a	0.41	23.57	Surface before poulticing	2/1/2010	1	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		2.50		0.125		6.00
	1b	0.41	23.57	Surface before poulticing	2/2/2010	1	10	500	1000	25	50	800	1200	5.00	10.00	0.25	0.50	8.00	12.00

	2	0.41	23.57	1st poultice (salted)	2/9/2010	1	10	500	500	10	10	400	800	5.00	5.00	0.10	0.10	4.00	8.00
	3	0.41	23.57	2nd poultice (salted)	2/11/2010	1	10	500	500	10	10	400	800	5.00	5.00	0.10	0.10	4.00	8.00
17	1	0.95	30.10	Surface before poulticing	2/2/2010	1	10	500	500		10	800	1200	5.00	5.00	0.00	0.10	8.00	12.00
18	1	0.18	28.44	Surface before poulticing	2/2/2010	1	10		0		10	1600		0.00	0.00	0.00	0.10	16.00	0.00
19	1	0.00	28.44	Surface before poulticing	2/4/2010	1	10		0	10	10		200	0.00	0.00	0.10	0.10	0.00	2.00
20	1	0.45	28.84	Surface before poulticing/ Unknown green material	2/4/2010	1	10	0	500	10	25	1600		0.00	5.00	0.10	0.25	16.00	0.00
21	1	0.15	28.27	Surface Salt (thick crust)	2/7/2010	1	10		0		0	1200	1600	0.00	0.00	0.00	0.00	12.00	16.00
Hebba	1	n.a.	n.a.	Control unsalted	1/31/2010	1	10		0		10		200	0.00	0.00	0.00	0.10	0.00	2.00
	2	n.a.	n.a.	Control unsalted	2/4/2010	1	10	500	500		10		200	5.00	5.00	0.00	0.10	0.00	2.00

Appendix B: Results of the Conductivity Measurements

Sample Point	Sample #	Height from base (m)	Distance from SW corner (m)	Type	Date sampled	Sampler	Weight (g)	Water added (mL)	ms/cm	µs/cm
1	1	1.50	0.35	Surface before poulticing	early Nov. 2009	MH	1	30	1.32	1.32E+03
2	1	1.54	2.20	Surface before poulticing	early Nov. 2009	MH	1	30	0.59	590
	2	1.54	2.20	1st poultice (salted)	2/4/2010	CP	1	30	0.8	800
	3	1.54	2.20	2nd poultice (salted)	2/9/2010	CP	1	30	0.68	680
	4	1.54	2.20	3rd poultice (salted)	3/15/2010	CP	1	30	0.72	720
3	1	1.38	5.00	Surface before poulticing	early Nov. 2009	MH	1	30	1.95	1.95E+03
	2	1.38	5.00	1st poultice (salted)	2/4/2010	CP	1	30	0.95	950
	3	1.38	5.00	2nd poultice (salted)	2/9/2010	CP	1	30	0.64	640
	4	1.38	5.00	3rd poultice (salted)	3/15/2010	CP	1	30	0.88	880
4	1	1.54	8.03	Surface before poulticing	early Nov. 2009	MH	1	30	1.89	1.89E+03
5	1	1.53	11.24	Surface before poulticing	early Nov. 2009	MH	0.5	15	2.11	2.11E+03
	2	1.53	11.24	1st poultice (salted)	2/4/2010	CP	1	30	0.74	740
	3	1.53	11.24	2nd poultice (salted)	2/9/2010	CP	1	30	0.78	780
	4	1.53	11.24	3rd poultice (salted)	3/15/2010	CP	1	30	0.46	460
6	1	1.73	18.90	Surface before poulticing	early Nov. 2009	MH	0.25	15	19.36	1.94E+04
7	1	1.64	21.95	Surface before poulticing	early Nov. 2009	MH	0.5	15	11.5	1.15 E+4
8	1	1.90	25.30	Surface before poulticing	early Nov. 2009	MH	1	30	10.11 (2nd reading on 4/11/10 was 15.28 ms/cm)	1.01E+04
9	1	0.96	5.22	Surface before poulticing	2/1/2010	CP	0.5	15	8.65	8.65E+03
10	1	0.64	16.62	Surface before poulticing	2/1/2010	CP	0.5	15	1.88	1.88E+03
	2	0.64	16.62	1st poultice (salted)	2/2/2010	CP	1	30	0.53	530
	3	0.64	16.62	2nd poultice (salted)	2/9/2010	CP	1	30	0.64	640
	4	0.64	16.62	3rd poultice (salted)	3/15/2010	CP	1	30	0.74	740
11	1	1.74	24.20	Surface before poulticing	2/1/2010	CP	0.5	15	5.82	5.82E+03
12	1	1.16	27.30	Surface before poulticing	2/1/2010	CP	0.5	15	6.59	6.59E+03
13	1	1.30	25.75	Surface before poulticing	2/1/2010	CP	1	30	2.04	2,040
	2	1.30	25.75	1st poultice (salted)	2/2/2010	CP	1	30	2.56	2,560
	3	1.30	25.75	2nd poultice (salted)	2/11/2010	CP	1	30	1.07	1,070
	4	1.30	25.75	3rd poultice (salted)	3/15/2010	CP	1	30	0.65	650

14	1	1.18	0.5	Surface before poulticing	2/1/2010	CP	1	30	1.03	1.03 E+3
	2	0.18	0.5	1st poultice (salted)	2/9/2010	CP	1	30	0.6	600
	3	0.18	0.5	2nd poultice (salted)	2/11/2010	CP	1	30	0.72	720
	4	0.18	0.5	3rd poultice (salted)	3/15/2010	CP	1	30	1.63	1,630
15	1	0.21	10.60	Surface before poulticing	2/2/2010	CP	1	30	1.26	1.26 E+3
16	1	0.41	23.57	Surface before poulticing	2/2/2010	CP	1	30	2.52	1.88E+03
	2	0.41	23.57	1st poultice (salted)	2/9/2010	CP	1	30	0.91	910
	3	0.41	23.57	2nd poultice (salted)	2/11/2010	CP	1	30	1.71	1.71E+03
	4	0.41	23.57	3rd poultice (salted)	3/15/2010	CP	1	30	0.87	870
17	1	0.95	30.10	Surface before poulticing	2/2/2010	CP	1	30	2.77	2.77 E+3
18	1	0.18	28.44	Surface before poulticing	2/2/2010	CP	1	30	2.8	2.80 E+3
19	1	0.00	28.44	Surface of a brick used as fill	2/4/2010	CP	1	30	0.41	410
20	1	0.45	28.84	Surface before poulticing/Unknown green material	2/4/2010	CP	0.5	15	3.03	3.03E+03
21	1	0.15	28.27	Surface Salt (thick crust)	2/7/2010	CP	1	30	2.4	2.40E+03
Hebba	1	n.a.	n.a.	Control unsalted	1/31/2010	CP	1	30	1	1.00E+03
	2	n.a.	n.a.	Control unsalted	2/4/2010	CP	1	30	0.66	660