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PHNOM BAKHENG BRICK SHRINE CONSERVATION AND STABILIZATION WORKSHOP



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June 1 - 4, 2010

BRICK SHRINE CONSERVATION AND STABILIZATION WORKSHOP PACKET

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INTRODUCTION

In 1989 World Monuments Fund (WMF) was among the first international organizations to return to Angkor after decades of political strife and civil war. For the first ten years, Preah Khan was WMF's principal focus at Angkor and when WMF began taking on additional projects at other Angkor sites, some of the philosophy as well as methodologies developed at Preah Khan have stood as a sound model of approach.

One of WMF's guiding objectives has been the training local Khmer craftsmen and professionals. Over 20 years of work in the ancient city of Angkor has allowed WMF the opportunity to train over 150 Cambodian nationals in aspects of archeology, architectural conservation, preservation theory and philosophy, architecture, engineering, and conservation site management as well as the skills to implement and manage the work to sustain the effort. To reach this goal WMF has developed a close partnership with the APSARA National Authority as well as with Cambodian universities with programs in architecture, archaeology, and engineering. The end goal of this effort is to leave the day to day operations to the WMF Khmer staff. Today with almost 100 staff members in Cambodia, only two are not Khmer, bringing us closer to that goal. Today WMF is in close collaboration with the APSARA National Authority and has four ongoing projects in the ancient city of Angkor.

- **Churning of the Sea of Milk Gallery, Angkor Wat**

At Angkor Wat we are stabilizing and conserving the roof over one of the most important bas reliefs in South East Asia at the Churning of the Sea of Milk Gallery which is at the south east corner of the third enclosure.

- **Phnom Bakheng**

With support from the United States Department of State we have completed a master plan for Phnom Bakheng which is the first temple the Khmers built when they settled the area that we know today as Angkor. This work now continues into the implementation phase as WMF has begun the extremely large project of stabilizing and conserving the central temple.

- **Preah Khan**

WMF'S first project at Angkor. Initially, WMF conducted a series of annual field campaigns. The earliest interventions, starting in 1994, targeted the consolidation of the highest priority conditions. In addition the work focused on opening up the main hallways through the site providing the visitor with the striking size, symmetry and complexity of carved details. Yet sections of the site were left in a semi ruinous state to also help the visitor experience the overwhelming impact that the combination of nature and time have had on the site.

- **Ta Som**

WMF began conservation work at Ta Som in 1998. Over the past decade, work at Ta Som has included training Khmer workers and conservators on site and their work has made all four of the Temple's entrances accessible to the public. Four towers have been stabilized and debris has been removed. This improved presentation of the site's finely carved stone sculptures adds to the public's enjoyment of the site.

One of the largest and most complex projects WMF has embarked on in Cambodia is our current work at Phnom Bakheng. Phnom Bakheng is one of Angkor's oldest temples. It was built as a state temple between the late 9th and early 10th centuries, when King Yasovarman constructed it as the centerpiece of his new capital, Yasodharapura, later absorbed into Angkor. The first mountain-style temple built there, Phnom Bakheng represents Mount Meru, home of the Hindu gods. Despite its architectural and historical significance, the temple is popular today mainly for its panoramic view of Angkor Wat, particularly at sunset.

In 2004, international and local experts coordinated by WMF began surveying, analyzing, and planning for the conservation of the site, funded by a grant of \$550,000 from the U.S. State Department. Emergency measures were also taken to protect the site from further damage.

Based on the study's findings, in 2008 the State Department awarded WMF a second grant of nearly \$1 million to begin long-term conservation work. The list of the threats to the central temple are many yet the most significant are the façade walls and associated stone terrace shrines which make up the central temple. Although WMF carried out a survey of the site and stabilized locations in danger of collapse the current scope of work is focused on the most threatened area, the eastern façade of the main central temple. The size of the central temple is massive so even with a crew of more than 50 craftsmen along with the support of architects, engineers, archeologists, architectural conservators and supporting management WMF is scheduling 5 years for just the east façade, associated stone terrace shrines, and returns on the North and South Elevations.

However, there are many other threats to the site that cannot be overlooked. In collaboration with the APSARA National Authority as well as support from a grant from the Wilson Matching Fund the WMF has begun to focus limited attention on a number of these threats, one of which is the 44 endangered brick shrines that surround the base of the central temple. The first step was to carry out a survey of each of the existing brick shrines and document the structural stability of each. By doing this we were able to determine patterns of decay, severity of damage and prioritize the condition of each. (See addendum #1 Brick Shrine Conservation Stabilization Workshop Handbook for more detailed information).

As a result of the UNESCO Ad Hoc Committee of Expert's site visit to Phnom Bakheng in June 2009 and related discussions and recommendations for Phnom Bakheng discussed at the 18th ICC Technical Session, WMF had agreed to install temporary protection at two of the most severely decayed and structurally threatened brick shrines (G-5 and G-10). In addition, WMF has been encouraged and has now completed Phase 1 of the a brick shrine conservation and structural stabilization workshop in collaboration with the APSARA National Authority. (See attached Brick Shrine Conservation Stabilization Workshop Handbook for more detailed information).

The brick shrine conservation and stabilization workshop was carried out from June 1 – June 4th 2010. This work brought together UNESCO Ad Hoc Committee members, local experts, international experts who have had expertise in this subject at Angkor as well as international experts specializing in the field of brick monument stabilization and conservation who have never worked at Angkor before. The goal of this workshop was to review and prioritize the threats to the brick shrines at Phnom Bakheng and begin to develop potential repair options for the in situ structural stabilization and coordinated material conservation issues. The team made site visits to previously restored brick shrine sites within the Angkor Park and evaluated how previous techniques applied might or might not be of use at Phnom Bakheng.

WMF compiled an orientation handbook that was delivered to each of the workshop participating members a month before the start of the workshop, (see attached). The goal of this orientation handbook was to provide background information that would orient the participants to the challenges at hand so that participants would come to the workshop as prepared as possible.

The WMF hired a rapporteur (B. Alison Jean) who was present at each of the meetings and site visits that were part of the workshop. The important points from each of the meetings and site visits were recorded and careful notes were taken to document the discussions that took place. During the meetings notes were also taken to clarify discussion points and highlight important points. After the workshop the rapporteur pulled the important points together from each days work and documented this information in the attached "Workshop Minutes."

BRICK SHRINE CONSERVATION AND STABILIZATION WORKSHOP

June 1st - 4th 2010

Introduction

As a result of the UNESCO Ad Hoc Committee of Expert's site visit to Phnom Bakheng in June 2009 and related discussions and recommendations for Phnom Bakheng discussed at the 18th ICC Technical Session the WMF has agreed to install temporary protection at two of the most severely decayed and structurally threatened brick shrines (G-5 and G-10). In addition, WMF has been encouraged and has agreed to conduct a brick shrine conservation and structural stabilization workshop in collaboration with the APSARA National Authority. This workshop will include the UNESCO Ad Hoc Committee of Experts, select international Angkor colleagues, and invited international experts in the fields of:

- In-situ structural stabilization, and
- Conservation of brick, stone and pigmented stuccos.

The results of this workshop will advance the knowledge of brick shrine stabilization and conservation at Phnom Bakheng, specifically, as well as other threatened brick shrines throughout the ancient city of Angkor. The workshop will review successes and failures of methods previously used at Angkor and will result in potential options for structural repair and coordinated material conservation for each of the specific conditions found on G-5 and G-10, other brick shrines in varying conditions at Phnom Bakheng, as well as general conditions identified at other temple complexes within Angkor.

Agenda

Day 1: Tuesday, June 1st

9AM The Center for Khmer Studies
Wat Damnak, Siem Reap

Morning

- Greeting of workshop participants.
- Opening Remarks: H.E. Bun Narith, Director General, APSARA National Authority
- Introduction: Lisa Ackerman Executive Vice President, WMF & H.E. Ros Borath, Deputy Director General, APSARA National Authority
- Presentation of current scope of work at Phnom Bakheng and goals of the workshop. Introduction of workshop participants and their areas of expertise. Glenn Boornazian, Project Director, WMF

- Global view of the development of arches, domes and towers and the relationship to general structural threats to specific brick shrines at Phnom Bakheng and other brick shrines at temple complexes within ancient Angkor.
Giorgio Croci, UNESCO Ad Hoc Expert
- General conservation threats to the specific brick shrines at Angkor and introduction to previous attempts at stabilization and conservation.
Simon Warrack, ICCROM

LUNCH

Afternoon

Meet at the Center for Khmer Studies, bus to Phnom Bakheng. First stop at the APSARA Admissions Center to purchase passes to the Park.

- Site visit to Phnom Bakheng to review structural and material conditions at Brick Shrines

Day 2: Wednesday, June 2nd

8AM Meet bus at the Center for Khmer Studies

Morning - Site Visits, Presentations and Discussions.

Site Visit #1



Prasat Kravanh

Restored by the EFEO in the 1930's or 1940's

Tour led by: Pascal Royere, Manager, EFEO, Siem Reap, Cambodia

Site Visit #2



Pre Rup

Restored in the Late 1990's by Italian Team

Tour led by: Giorgio Croci, and Valter Santoro of IGeS.

Potential: site visit to brick kilns

LUNCH

Afternoon

Site Visit #3



Preah Ko

Restored in the Mid 1990's by the APSARA Authority

Tour led by: H.E. Ros Borath and Simon Warrack; Tan Sophal and Saray Kimhoul, Archaeologists, APSARA National Authority

Site Visit #4



Bakong

Review Conditions and Repair Options of Brick Shrines

Tour led by: H.E. Ros Borath and Simon Warrack; Heng Jeudi, Architect, APSARA National Authority

Bakong has both surrounding brick shrines and stone terrace shrines. Repairs to a section of one of the brick shrines are currently being completed by the APSARA National Authority. Possibly meet masonry conservation team.

Day 3: Thursday, June 3rd

9AM The Center for Khmer Studies

Morning

The team will meet as a group to review the materials, conditions, threats and priorities related to the conservation and stabilization of the brick shrines at Phnom Bakheng. The goal of these working sessions is to develop a holistic approach to the threats we have defined, review potential treatment options and decide on a course of action which may also include additional field and lab work as well as the implementation of pilot treatment programs to advance the fine tuning of potential final treatment options. Each of the groups might consider the following topics as a guide:

- Conservation Team: 1) examine and prioritize past and present mechanisms of material deterioration; 2) determine if any additional materials analysis, testing and or laboratory studies may be necessary; 3) design small scale pilot projects which will help fine tune final treatment options. 4) design preliminary treatment options.
- Structural Team: 1) examine and prioritize past and present mechanisms of structural failure; 2) determine if any additional laboratory testing, in situ investigations or monitoring may be necessary; 3) design potential small scale pilot projects which will help fine tune final treatment options; 4) design preliminary treatment options.

Afternoon

- Both teams meet to discuss overlapping issues and define potential treatment options.

Day 4: Friday, June 4th

9AM The Center for Khmer Studies

Morning and Afternoon

- Both teams meet to discuss overlapping issues and define final treatment options and next steps as required.

Closing Remarks.

Group Dinner - Location to be determined

PARTICIPANTS:

The APSARA National Authority

- H.E. Ros Borath, Deputy Director General
- Madame Mao Lao, Director of Department of Conservation of Monuments in the Angkor Park and Preventive Archaeology
- Tan Sophal, Archaeologist
- Saray Kimhoul, Archaeologist
- Heng Jeudi, Architect

World Monuments Fund

- Lisa Ackerman, Executive Vice President
- Glenn Boornazian, Project Director
- Konstanze von zur Muehlen, Project Manager
- Phally Cheam, Project Architect
- Bryse Gaboury, Engineer
- Bun Wat, Architect
- B. Alison Jean, Rapporteur
- Chiv Phirom, Engineer

U.S. Department of State

- John E. Johnson, Public Affairs Officer

UNESCO

- Giorgio Croci, UNESCO Ad Hoc Expert, Italy
- Dr. Kenichiro Hidaka, UNESCO Ad Hoc Expert, Japan
- Bun Hok LIM, NPO/CLT/PNP, Standing Secretariat of the ICC-Angkor, UNESCO, Phnom Penh

ICCROM

- Simon Warrack, Conservation Consultant

INTERNATIONAL EXPERTS WORKING AT ANGKOR

- Pascal Royere, Manager EFEO, Siem Reap
- Valter Santoro, IGeS, Italian Team

INTERNATIONAL EXPERTS VISITING FOR THE FIRST TIME

- John A. Fidler, RIBA FRICS Intl Assoc AIA, Staff Consultant and Practice Leader, Preservation Technology, Simpson Gumpertz & Heger
- Ian Hume, DIC, DiplConsAA, CEng, MIStructE, IHBC - Consulting Conservation Engineer
- Mara Landoni, Chief Field Architect of Lerici Foundation (Scientific University of "Politecnico di Milano") for Conservation and Restoration projects in Laos and Vietnam
- David Sleight, Specialist in the Conservation, Repair and related Craft Training for Historic Structures, David Sleight Conservation
- William B. Rose, Research Architect, Specialist in the field of environmental assessment, moisture management and control

WORKSHOP MINUTES

The important points from each of the meetings and site visits were recorded by a rapporteur (B. Alison Jean) who was hired by the WMF. This information has been compiled below as a record of each day.

Day: Tuesday, June 1
Session: Morning
Location: CKS

Participants:

Lisa Ackerman, Executive Vice President of WMF
Glenn Boornazian, Project Director of WMF Program in Angkor
H.E. Ros Borath, Deputy Director General of the APSARA National Authority
Phally Cham, Project Architect of WMF
Giorgio Croci, Engineer, UNESCO Ad Hoc Expert, Italy
John A. Fidler, RIBA FRICS Intl Assoc AIA, Staff Consultant and Practice Leader, Preservation Technology, Simpson Gumpertz & Heger
Bryse Gaboury, Engineer of WMF
Dr. Kenichiro Hidaka, UNESCO Ad Hoc Expert, Japan
Ian Hume, DIC, DiplConsAA, CEng, MIStructE, IHBC - Consulting Conservation Engineer
B. Alison Jean, Rapporteur of WMF
Mara Landoni, Chief Field Architect of Lerici Foundation (Scientific University of "Politecnico di Milano") for Conservation and Restoration projects in Laos and Vietnam
Madame Mao Lao, Director of Department of Preventive Archaeology and Monuments in the Angkor Park, APSARA National Authority
Lim Bun Hok, NPO/CLT/PNP, Standing Secretariat of the ICC-Angkor, UNESCO, Phnom Penh
Konstanze von zur Muehlen, Project Manager of WMF Program in Angkor
William B. Rose, Research Architect. Specialist in the field of environmental assessment, moisture management and control
Pascal Royere, Director of EFEO, Siem Reap
Valter Santoro, Project Director of IGeS, Italian Team
David Sleight, Specialist in the Conservation, Repair and related Craft Training for Historic Structures, David Sleight Conservation
Simon Warrack, Conservation Consultant of ICCROM
Bun Wat, Architect of WMF

Opening remarks by Glenn Boornazian (WMF), His Excellency Ros Borath (APSARA), and Lisa Ackerman (WMF) highlight the new professional partnership between World Monuments Fund (WMF) and APSARA. Workshop participants (see below) are welcomed.

H.E. Ros Borath described briefly the history of brick as a construction material in ancient Cambodia. The earliest brick buildings in Cambodia were constructed during the 5th century at the Funan archeological site, Oc Eo. Brick was chosen as the primary material for pre-Angkorian temples, such as Angkor Borei and Sambor Prei Kuk. At Angkor, brick temples were built during the 8th and 9th century, but sandstone replaced brick at the end of the 9th century until the middle of the 10th century. Brick resurfaced at this time and was used for buildings such as Pre Rup. It disappeared during the 12th century and resurfaced towards the end of the 13th century.

Even though brick was a popular construction material, our knowledge of the ancient way of producing bricks remains scant; no ancient brick kiln has been found to date. Brick maintenance and restoration pose more challenges than sandstone conservation, underscoring the timeliness and importance of this workshop.

Glenn provided an overview of WMF's Conservation Approach, using specific examples from WMF's work at Angkor Wat on the *Churning of the Sea of Milk* Gallery to highlight core principles. Assessing the previous work on the gallery conducted by the EFEO in the 1950's and an Indian team (ASI) in the 1980's convinced WMF of the importance of insuring that as much as possible all its work would be well documented. Furthermore, WMF practiced minimal intervention, such as continuing to use the original Khmer roof drainage channels. In order to minimize the need for long-term maintenance, WMF has erected a temporary walk-way around the gallery, along which signage and photographs educate tourists about the bas-reliefs and the conservation they are undergoing.

After reviewing WMF's Conservation Approach, Glenn delivered an overview of the temple of Phnom Bakheng. This site houses the brick shrines that are the focus of this workshop; 44 brick shrines surround the central temple. Over the years, a significant number of brick shrines have collapsed. Brick shrine G34 is considered to be in the best condition whereas G4, G5, and G10 have been identified as some of the shrines in the most serious condition; WMF has erected temporary protection of the latter three shrines as well as set up a conservation workshop on the premises.

Phnom Bakheng is a significantly earlier temple than Angkor Wat and is unique for its being built on top of a natural hill. The ancient Khmer builders shaved off the top 20% of the hill exposing the live rock interior. This live rock was carved to support the applied sandstone façade. When the EFEO rediscovered the site massive amounts of stone were found on the top terrace, which, it is believed, were the remains of a massive seated Buddha. In the 1920's the EFEO constructed large ramps which provided access to the upper section of the central shrine. We believe these ramps were used primarily to transport the remains of the seated Buddha to the base of the central shrine and then deposited on the hill's south side slope. Historic images show clearly that the temple was under tremendous amount of pressure caused by uncontrolled jungle overgrowth.

The ancient Khmer pitched all stone terraces of the central shrine for drainage reasons; today, however, many of the terrace stones are gone and the stone terrace shrines are sitting on the terrace and perimeter capstone. The stacked masonry of the stone terrace shrines has proven susceptible to cracks and collapse caused by water infiltration and movement caused by resulting erosion. WMF's approach is to return the sandstone terrace pavers to their original locations, placing them in their correct, original pitch while at the same time inserting a waterproof membrane properly detailed to prevent future water infiltration.

An earlier geotechnical survey carried out by a WMF consultant identified the mountain as relatively stable. Seismic activity was found to be none, and a review of the exposed live rock concluded that any fissures were localized and related to the presence of weaker inclusions. No displacement of bedrock substrate related to movement was identified.

The general threats to the overall site are many and will be addressed in a two phase Conservation Site Management Workshop beginning in February 2011. One interesting point however is the temple's high vantage point which attracts tourists, who primarily come to watch sunset; during peak season, as many as 4,000 tourists ascend upon Phnom Bakheng in a single evening. While technical challenges threaten the longevity of the temple, its sustainability is also greatly threatened by this concentrated influx of tourists, a capacity that the structure was never designed to withstand. Glenn, H. E. Ros Borath, and Lisa each reiterated the pressing need to regulate tourism more rigorously combined with a more concerted effort to educate tourists.

Professor Giorgio Croci presented his ideas of the "The Development of Arches, Domes, and Towers in Europe and Cambodia" and then sited his analysis of the failures WMF was facing with the brick shrines at Phnom Bakheng and how these conditions were similar to the condition of other brick shrines throughout the ancient city of Angkor. Professor Croci has been a UNESCO Ad Hoc Expert at Angkor representing the Italian Government since 1994 making him one of the longest serving UNESCO experts at Angkor. As a coordinator of an international group of

Experts, he prepared a document entitled Recommendations for the Conservation and Preservation of Angkor Monuments. From 1995 to 2005 he was the Chairman of the International Scientific Committee for Analysis and Restoration of Structures of Architectural Heritage at ICOMOS. At present he serves as the honorary chairman of this committee. He is also a UNESCO international expert for such sites as the Pyramid Plateau, Leaning Tower of Pisa, Axum etc.. Professor Croci presented on the pyramids, highlighting the structural problem between the interior's empty space and the outer walls, which columns can only partially address due to their height limitations. The architectural innovation of the arch expanded possibilities. An arch's bow shape and use of compression forces the flow of energy so that sliding between blocks is prevented. Arches above doorways reduce the amount of pressure by displacing the weight onto door-jambs rather than on the beam. Arches are often more stable than the buildings themselves, as evidenced by the fact that arches often remain intact even when buildings are destroyed over time or due to significant damage.

Some variations of the arch worth noting include that of the Domus Aurea from the 1st century ACE; this example proves that arches can be stable even if they are not continuous. The Hagia Sophia's dome was cited as an example of a weak arch because it was built on a square rather than cylindrical structure; each side of the square is an arch whose ends conjoin to form columns. Gothic cathedrals shifted away from using a curved shape for arches to using a triangular shape that allowed for lighter, less stiff walls. The bulbous shaped dome common on Islamic mosques is an illusion; the "real" dome structure is hidden behind the outer layer that gives it this shape.

At Angkor, arches are constructed from brick that has been stacked in horizontal layers; also known as a corbel arch. The behavior of the blocks is arch-like even though they do not take a curved form; the greater the inclination, the taller the structure. Stabilizing weights are an important feature of Angkorian arches. For example, the door to Angkor Thom utilizes the face of a Buddha in a stabilizing role to keep the correct angle of inclination. Collapsed arches at Angkor are often those that have lost their stabilizing weight on top. Furthermore, cracks often occur when the foundation is prevented from shifting as a unit.

Simon Warrack then spoke about general threats to Angkor's brick shrines, which include 1) danger to materials, 2) construction technique (foundation, jointing/bonding, carving), 3) climate (temperature/humidity change, rainfall/downwashing), 4) biological growth, and 5) previous restorations.

The ancient Khmer bonded the brick material in order to attempt to create monoliths, which were then carved; however, carving thins and weakens the brick because the dense outer layer or "fire skin" is removed and the softer more porous core exposed. Bricks were carved in great detail and later stuccoed and painted; the stucco takes on the appearance of sandstone and has acted as a protective layer.

Ironically, the thick forest overgrowth that covered many of the temples for centuries created a more stable micro-climate, in which there was a reduced amount of temperature variation. More stucco has been lost in recent years since the removal of this forest cover and exposure to higher variability in temperature and humidity. Plants take a greater toll on bricks than on stone because bricks offer a higher number of cracks and gaps.

Simon concluded his presentation by advocating for the "integrated approach" to conservation. Through integration, the conservation work remains invisible to the average visitor because choices made during reconstruction honor the original and do not make conjectures. Subtle details in how the surface has been treated transmit messages to other conservators about reconstruction materials and strategy.

Day: Tuesday, June 1
Session: Afternoon
Location: Phnom Bakheng

The group's first visit to Phnom Bakheng included observations of G34, G4, G5, G10, and the archeological trench dug by the APSARA National Authority team in collaboration with WMF. As the structure for this visit was loose, key questions posed and the responses they provoked have been summarized below.

Why did the ancient Khmer use/choose laterite?

There is a limited amount of information available to answer this question. However, current hypotheses include the fact that it is much quicker to build with laterite as compared to building with brick, which would require more material. It was noted that during the period in which Phnom Bakheng was built, there was an overall trend to move away from brick masonry towards stone.

Typical of Phnom Bakheng's brick shrines, a laterite foundation/platform is constructed that rests directly on the bedrock below; sandstone was used to surround the laterite platform and sandstone pavers were applied to the top. On top of these pavers, a shrine was built.

How is laterite quarried, and is new laterite good quality material?

The quality of laterite is far ranging, depending not only from which quarry it was taken but also from which layer within a quarry it was extracted. Builders often know to separate the layers of laterite for different uses, such as blocks needed for indoors versus outdoors construction.

There was some discrepancy as to when the best laterite can be quarried. At the quarry WMF Staff Phally and Konstanze have visited, the special time of year for quarrying is just before rainy season (March and April); in contrast, Mara noted that the opposite – just after rainy season – is practiced in the quarries she is familiar with in Vietnam.

Laterite is cured first to allow the softer material to drain out; after it has been cut out of the quarry, it is exposed to the sun to let it dry. The Japanese team has found that today's laterite is of less quality than that used by the ancient Khmer. Questions regarding how to separate good quality laterite from bad took place later in the workshop.

At G10, should the brickwork be consolidated prior to foundation stabilization? And what potential options are there?

The brick structure appears far more fragile than the foundation, which is more straightforward in terms of how to repair (see below). While vegetation is a concern, the main cause of stress on the bricks occurs in the middle, where debris and moisture have fallen into fissures, wedging the brickwork apart.

An alternate assessment cited the erosion of the substructure as the Central Temple as a significant problem. The force of the water, assisted by the steep slope to the ground level and the heavy rains, has caused major erosion of many of the surrounding brick shrines. Effective prevention of further erosion is a high priority.

During the consolidation of the brickwork, local stresses will be caused by this intervention; the approach should be interdisciplinary to mitigate this additional stress. While the theoretical model is to repair monuments in situ in the least intrusive way, sometimes it is important to consider ways to use selective disassembling to meet project goals.

One approach for stabilizing the foundation could be to provide temporary shoring that continues to support the laterite in place while digging down to the bedrock; then, underpinning installed.

Once the laterite was stabilized the shoring could be removed. Another approach could be adding shoring which would allow for exposing the laterite foundation as well as the bedrock. Then jacks could be used to assist in recovering the original foundation angle. Once the right angle was recovered new laterite could be used to infill missing sections.

It was noted that underpinning can be difficult if there is only a small space in which to work. It was suggested that glass telltales be installed in strategic locations and observed carefully during the progress of the work as these would indicate potential movement.

At G5, a question arose about the “ghost cuts” on the wall?

The current theory is that, in a later period, a roof structure was added to this (and other) brick shrines. The wood structures may relate to the later transition to Buddhism or relate to times the shrines may have been inhabited after the fall of the Angkorian empire. EFEO found traces of wood and pieces of Buddhist statues when excavating the terrace underneath in the 1920's.

Day: Wednesday, June 2
Session: Morning & Afternoon
Location: Site visits

Pascal Royere (EFEO) led a tour of Prasat Kravanh, whose interior, large-scale bas-reliefs in two of the brick shrines are unique in all of Angkor. When the French arrived during the 1950s, their major concern was that the opening walls would endanger the future survival of these bas-reliefs; the second major concern was the stabilization of towers. The towers sit on brick, and the brick goes down to a laterite pavement, much like at Preah Ko.

To conserve the bas-reliefs, the approach was to excavate portions of the walls, insert concrete pillars in the corners and concrete beams on top of the walls. Dismantling the entire wall was not an option because of the bas-reliefs. In general, the base of each wall has been replaced and the load bearing aspect of the walls altered.

New bricks of a slightly bigger dimension were chosen in order to distinguish them from the original; additionally, new bricks were stamped with “CA” (Conservation d’Angkor). It was observed that the new brickwork is better bonded than that of the original. A cement mortar was used between bricks.

The platforms were also dismantled and concrete slabs installed. With regards to waterproofing the structures, the French decided against building roofs, which would have cast shadows on the bas-reliefs. Because the hole at the top of the central shrine’s tower is relatively small, the French put in a piece of glass that allowed light to shine through but prevented water from entering; the glass was destroyed during the civil war.

Valter Santoro (IGeS) led a tour of Pre Rup, built about 50 years after Phnom Bakheng. The main problems encountered at these brick shrines by the Italian team included material decay, soil settlement, and deformation of foundations. As at Phnom Bakheng, those towers that are on the ground level have very different problems than those towers on the temple’s terraces. The stability of the ground-level towers is affected by rainfall and resulting wet soil. Additionally, the south side of the site is more affected by “subsidence”, or the variation of the behavior of the soil to the variation of water content.

Typical of stiff structures on unstable soil, the towers are divided by heavy, vertical cracks that put a great amount of stress on the corners; in turn, this stress causes a crushing effect on the brick in these locations which then affects the stability of some of the large decorative lintels at doorway openings specifically and the structure in general. The weight of some of the lintels has led to a structural imbalance; to counter this, the Italian team inserted stainless steel beams

And cables to prevent further tilting of the lintels. The presence of three false doors has contributed to the cracking.

The foundation is comprised of laterite blocks topped by a layer of sandstone. The core of the foundation is filled with sand (not compressed); the deformed shape of the towers is typical of a plastic fill under a rigid foundation. Furthermore, the behavior of the foundation relates to the hydraulic condition of the soil. Whereas the north side is independent, the south side, where there is less protection from sunshine, is strongly dependent on the hydraulic condition.

The restoration of the central tower (24 meters high) in 1998 consisted of underpinning the structure. The lower slab was pre-stressed in order to transfer the loads to the top layer of sandstone. Then, the concrete slab was connected to the foundation. Later, this approach was utilized at towers 1 and 3.

Major threats to the tower included its splitting into independent parts and losing the upper part. Through core-drilling the brick, rods were placed inside the walls at the top of the tower, after which the heads were capped; the rods are protected by electro-galvanization bar. The main crack was first filled with crushed brick and then injected with a mixture of lime, sand, crushed brick, and buffalo skin vegetable glue.

In the center of the tower, the team dug all the way down to the laterite (2.5 meters) in order to replace it with a cement slab followed by laterite. The concrete slab enlarges the base of the foundation, helping to spread the load. The foundation was enlarged more than 100%, which has halved the amount of pressure that the false doors must carry.

Simon Warrack (ICCROM), Tann Sophal (APSARA), and Sarary Kim Houl (APSARA) conducted the tour of Preah Ko, which is part of the pre-Angkorian Rolous Group and the earliest capital and royal sanctuary in the Angkor region. It has been discovered that there were several phases of building the brick shrines, beginning with their initial construction in all brick. Later, stone doors and lintels were added. Then, guardian figures were added and the platform was covered with stone and plinths were erected around the towers. Lastly, stucco was applied and painted.

The relative straightness of the towers here might be explained by their brick foundation; a solid brick platform extends down to the earth, under which is a layer of crushed laterite. The platform was consolidated with new brick because it was one of the main sources of water infiltration. When the team arrived, the platform was a pile of brick rubble, which allowed the rain to run underneath the towers. The repair work was complicated by the fact that the ancient Khmer had not planned any slope; the team had to slope the platform to insure gradual run off of water.

Regarding the conservation of decorative moldings, the philosophy has been to copy only what can be seen; there has been no attempt to recreate according to speculation. Towards the end of 2009, selected sandstone columns were worked on.

One of the most successful aspects of this project has been the handing over of it to the APSARA National Authority; accordingly, two members from ASPARA presented on the approach taken to consolidate Preah Ko's small corner tower. It is the only miniature shrine in all of Angkor to have survived, measuring about one meter tall.

Work on the miniature shrine began at the bottom and progressed upward layer by layer. The APSARA team removed the broken brick and replaced with new brick, using a lime mortar and fiberglass dowels. The mortar contained slaked lime, brick dust, sand, buffalo glue, and palm sugar; the lime comes from shells. The upper structure was tied with gauze bandage and PVA (20%) or rice husk to pre-consolidate the structure prior to disassembly of loose parts. It was necessary during this stage not to let the lime dry out, so a permanent water drip was used. After this, the second level of bricks was cleaned and broken bricks were replaced with new brick. New bricks were hand-chiseled in order to insure that they meet ancient dimensions; this process is

Quite time consuming and labor intensive – on average, a worker can complete two bricks in one day.

APSARA also conducted a tour of some of the brick shrines at the Bakong which was built just after Phnom Bakheng. One of the shrines at Bakong suffered the tragic shattering of a lintel as a result of a collapse during the 2009 typhoon. The team is currently working on replacing broken brick, primarily with fallen brick found on the premises of the temple. The second stage of conservation will focus on repairing the lintel and door-frame; to date, the lintel pieces have not yet been numbered. The team also plans to build a roof in order to protect the inside of the temple from rain as the work progresses.

Day: Thursday, June 3
Session: Morning
Location: CKS

John Fidler facilitated a round-table discussion specifically related to the restoration of brick shrines G5 and G10 at Phnom Bakheng and incorporating aspects of the repairs that were observed during day two. The goal of the discussion was to identify critical issues about the shrines and address questions about the foundation systems including the bedrock and laterite. Each component of the shrine was discussed to review the information that is known, to raise questions, and to identify additional research that needs to take place in order to make appropriate interventions. Correlations were made with other sites and tentative solutions were provided.

The discussion moved from the base of the brick shrine to top of the brick shrine beginning with the mountain formation and the bedrock. Within the first phase of WMF's project at Phnom Bakheng in 2005 a study of Phnom Bakheng that focused on geotechnical conditions, conservation aspects, and landscape interpretation was conducted. Geotechnical geologists looked at the plane that surrounds the area, the live rock/bedrock, which was shaped to serve as the foundation of the pyramid temple. The concern was whether or not there was any shifting going on. The report found that the bedrock mass was sound and stable. Some inclusions and fissures were identified but they were mostly localized. The team discussed how to work with the inherent features of the bedrock. It was decided that small loose bedrock pieces would be removed and where possible large bedrock pieces would be stabilized in place with the use of stainless steel rock bolts.

The team then discussed the effect that open fissures in the façade walls of the central temple and abutting bedrock are the areas in which water will collect and move, but it remains unknown where this water will exit. Pre Rup has a pitch that varies by at least 2 meters and a water table of 5 meters. The assumption is that the mountain drains water quickly, but at Pre Rup, only about 10% of the original drainage points still work. Water seepage affects the overall stability of the surrounding shrines. It is essential to better understand the impact of water runoff on the bearing capacity of G5 and G10. WMF pointed out that as a result of the conservation program on the central shrine all the terraces will be waterproofed. This will increase the concentration of water run off at the base of the central shrine. Development of large scale water management systems and an understanding of the pitch of the bedrock under the brick shrine was on track to be accomplished in the near future.

From here, the discussion moved on to laterite. Reiterations of similar queries from Day 1 about laterite underscore the importance of further research into this material. Laterite's variability, acting as both a stone and a soil, raises a multitude of questions about the quality of existing laterite as well as new laterite blocks. For example, the variations in laterite's inherent physical

markup should be better understood to determine if certain types of laterite will hold up longer than others and if orientation (bedding) when placed in a wall or a foundation will increase or decrease its useful life. A Japanese team (Sophia University) has done testing on laterite within their project of Rebuilding the Causeway at Angkor Wat and their work should be reviewed.

Understanding the decay phenomena of laterite is key to informing the conservation decisions. A statistical study of how laterite behaves in the field and why certain blocks decay and others do not would help to inform decisions regarding the selection of new materials and the repair of the existing material.

There is evidence of migration of minerals in the laterite over time and oxide staining on sandstone, likely through water shedding and runoff. Although most minerals are not water soluble, they can still migrate.

There is no clear information currently about the porosity of laterite as well as its compressive strength. Because laterite is so variable in its properties it was recommended that tests be carried out on new material, old material, cured, and uncured laterite to provide results that represent the range of conditions associated with laterite. Data could be collected from various nearby sites to increase the body of knowledge. Techniques such as ultrasound and resistance drilling testing were also suggested. Due to the variation in laterite it was recommended that WMF find an expert laterite quarrier with whom it can work closely to find the best possible material.

WMF and the APSARA Authority agreed that further understanding of laterite is in order and will begin to think about next steps. A discussion of the testing followed to address which tests should be conducted and what questions and concerns need to be addressed. A set of guidelines for testing and the identification of conditions for the tests have to be outlined as well.

-It was agreed that a literature review would be the best place to start so as to build on the testing and research that has already begun. The literature review should be specific and focus on laterite in the region.

-Sample preparation was identified as critical. Good and decayed material should be tested simultaneously and consideration should be given to the curing, aging process, testing of new and ancient material, laterite that is filled with loose material versus laterite that is void of loose material, as well as testing wet and dry conditions.

-Sample size is a critical component too and consideration should be given to the shape such as cubes or cylinders.

-Compression testing, measuring the plastic limit; and how the results of the tests relate to the way the stone is taken out of the quarry and oriented.

-Water absorption testing.

-Petrography to determine porosity and pore size distribution, mineral sensitivities and mobility of oxides.

Through the discussion of testing, various other issues were discussed. The complexities of introducing new laterite were raised in relation to bonding or keying it to the existing laterite. It is not clear if there is a bonding pattern present and if the laterite can indeed be bonded or if it should be dry stacked. This issue is not just structural but should emerge out of the philosophy that dictates the brick shrine conservation approach. The condition of the laterite platform at G10 was discussed and concern was raised about the nature of the deformations and whether they are cyclical or progressive. It is generally believed that the disaggregation of the laterite at the perimeter at G10 is a result of water undercutting the stone, however the condition of the blocks and bedrock under the shrine are unknown and there is a possibility of water infiltration. Radar

was mentioned as a possible detection tool but is affected by moisture and might not be successful in the damp Cambodian climate.

Above ground, there is evidence of various salts present on the brickwork of G10. Identification of the salts might inform where the water is coming from. An in depth study of the salts was recommended.

In terms of the brick superstructure, there are deformations and destruction apparent in brickwork. Tree trunk and roots are buried in the walls. Cracks allow debris to fall inside risking wedging which can cause further damage. If the foundations are not actively moving anymore than the vertical cracks only need to be protected from water infiltration and debris. If the movement is active, movement would have to be constrained in order to stabilize the structure. Grout was suggested as a fill for the cracks to allow them to repel water while remaining breathable. Recessing the grout is an aesthetic option that would protect the crack while allowing it to be seen. Glass tell tales could be used to monitor any movement in the structure and have the advantage of providing an instant response to movement.

Another concern about stabilization is the fragile tops of the shrines. At Preah Ko, the shrines were wrapped and consolidated however it is not recommended at Phnom Bakheng because it obstructs a clear view of the structure making it difficult to detect what is happening below the wrapping.

It was decided to address some of the questions regarding the tops of the shrines again during a site visit. Each structure is different and would have to be treated individually. The use of resin as a water repellent to shed water was raised. More investigation into this approach is necessary.

New bricks used in reconstruction were discussed briefly as well. Currently rain is absorbed into the building and the water held by the bricks increases the load on the structure. The new bricks respond differently than the old bricks. There is no color change between new bricks that are wet and new bricks that are dry. The new bricks also attract different kinds of biological growth, although the difference in appearance evened out over time. It is important to know what the firing temperatures of the new bricks are.

Day: Friday, June 4
Session: Morning
Location: CKS

John Fidler orchestrated a recap of Thursday afternoon's follow-up visit to G10 and G5 at Phnom Bakheng, addressing some of the questions that had been raised the previous day as well as new questions based on observations made on site.

The discussion at G10 was focused on the laterite foundation, followed by a discussion of the brickwork above.

At G10, the archeological excavations revealed that on the north side of the shrine, the laterite sits directly on top of the bedrock whereas on the south side the laterite sits on top of a fill layer of laterite and stone particles. Cylindrical holes found, are presumed to be former post-holes.

On the west-side laterite boundary wall, there was a discernable striation pattern to the surface of the laterite; however, the decayed material that was recessed from the surface by approximately 75mm did not show evidence of this pattern. This discrepancy may be significant for future considerations about the placement of new laterite and the impact on its decay mechanisms and longevity. Petrography will be required to confirm.

To address the deterioration conditions on the southwest corner where the laterite meets the sandstone the laterite could be recorded, numbered, dismantled, and rebuilt with new laterite blocks. This would require underpinning the structure. The goal in rebuilding the laterite should be to achieve some horizontality in bonding the stones. Currently, the laterite is not sufficiently bonded; achieving structural integrity between the old and new laterite is necessary. One suggestion was to use rock bolts. It was recommended that the new laterite be stepped away from the monument in order to direct the force of the weight.

At the West Elevation of G10, beams currently hinder the effective insertion of new laterite blocks; it was suggested that beams be substituted with jacks or individual posts to accommodate the new laterite and spread the load from sandstone blocks or a laterite pillar.

The question of how to finish the new laterite was raised. The old laterite is weathered and sloped while the new blocks have a hard edge. The face of the new blocks could be softened to visually integrate the new and old blocks.

At the brick masonry, there is unconsolidated loose material at the top of the shrine, as well as a fissure in the corner of two perpendicular walls, caused by a tree. Prior to addressing the deteriorated laterite, the top section of the masonry walls should be constrained by tying opposing faces to one another to stabilize the monument during underpinning. One half to one meter of brickwork could be dismantled and the top tree root removed. In order to insert the laterite blocks under the sandstone, it is necessary to pack and stress the joints so the load can be transferred to the laterite, away from the sandstone. A pocket to accommodate the jack system will be necessary.

An alternative approach would be the use of folding wedges. The potential for straightening some of the walls after the fissures have been cleaned was also discussed; fissures should be filled with a bonding material that can keep vegetation and water out.

The floor at the center of the shrine is level and appears in good condition. From an interior vantage point, most of the wall planes are nearly vertical unlike the exterior.

There was some discussion about which corner of the shrine is best to begin work on – with the most precipitous or with the easiest corner; there is value in having some “practice” with an easier corner prior to tackling a more complex corner.

Once the foundations are stabilized, fissures can be cleaned and filled with inert material that has flexural strength, will bond with the substrate and keep water and debris out of the cracks. Visually the fissures could be represented with recessed filling material.

At G5, the cracks in the wall caused by tree trunks were focused on. Due to the fragility of these walls, it was recommended that pins are used in order to maintain the physical integrity of the wall and to avoid the wall face from shearing off as it is stabilized. The tops of the walls appear very loose and the material could be recorded, numbered, dismantled, and stored safely prior to addressing the underpinning. Once the wall gets rebuilt, a gentle sloping profile could be created to better shed water.

John Fidler shared some relevant examples of a range of techniques used in various conservation projects by English Heritage. A commonly used device in the UK to connect loose bricks to the wall is the helifix anchor. A pilot hole is drilled in the masonry, into which a stainless steel helifix with sharp edges is drilled at an angle, creating its own “worm” hole. This is a dry connection and the steel is ductile, allowing for some movement of the material. Pins are placed in opposed directions to lock the masonry and are nearly impossible to pull out.

Mara then presented her work at My Son, a Hindu temple complex in central Vietnam. Two of the buildings use laterite as foundations as well as the enclosing wall and foundation. The elevations are in brick. Various brick shapes are used here such as triangular, trapezoidal, and square shapes to minimize movement especially at the corners. The trapezoidal bricks were used as wedges because walls were built from the edge inwards. The square bricks appear to shift the joints. Brick compression tests revealed that bricks with the original joint are continuous whereas bricks without the joint test as non-continuous. Mara and her team have had success with dismantling bricks, cleaning, and reassembling them with resin. According to a resin test, organic material was noted in the original joints. The natural resin appears similar but not exactly the same as the resin they are using today. The tree where the resin comes from produces resin after 50 years with 1 ½ to 2 kilos of resin per year.

Termites were raised as an extensive problem that demands attention during the conservation. According to H. E. Ros Borath, Exterra has been experimented with on small surface areas. Borates are being used at Preak Khan as more of a preventative measure. Philosophically, APSARA aims to avoid environmental pollution; additionally, Buddhist culture is resistant to killing any living matter.

Nests created by the termites on the brick shrines are quite strong and can act as support systems for the temples due to their concrete-like strength. Removal of the nests risks destabilization of the structure and may create new opportunities for water to enter.

The risk that termites pose to trees is also of concern due to the large number of trees on the site and the damage that falling branches could do to the structures. A forestry survey is important to understand the condition of the trees.

Surface Finishes were briefly mentioned in relation to the conservation of the other shrine elements. Concern was raised over the impact that conservation treatments for structural repairs might have on the more delicate finishes, in particular with the introduction of water or potentially salt laden materials. When selecting treatments, consideration should be given to the possible effects on the finishes.

The use of new bricks and the reuse of old bricks were discussed as well. There were problems with the new bricks that were used recently. They were uneven and bowed and had to be cut to fit. It was suggested that reducing the firing temperature might help keep them the same and provide a similar absorption rate to the old bricks. The question of whether or not it was necessary to use new bricks was raised. There are lots of miscellaneous bricks lying around the site that could be incorporated. In addition, the aesthetic of the new bricks have a flat appearance and a different texture than the old bricks.

The team summarized the final objectives and conclusions as follows:

The ground conditions and water run off below the shrines are fundamental in terms of the potential deterioration of the shrines above.

Laterite: Understanding laterite is key to making future conservation decisions for the shrines.

- A review of existing research should be conducted.
- Conduct tests on a variety of laterite (old, new, cured, uncured, dry, wet).
- Understand decay mechanisms, particularly at the perimeter edge.
- Understand the properties of new and old blocks.
- Communicate with the quartier to determine of appropriate selection and installation of new blocks.
- Determine whether the new laterite blocks should appear new or should be softened for a weathered appearance.
- Folding wedges or jacks can be used for underpinning.
- The original bonding pattern should be retained for continuity.

Water Management:

- Observations and monitoring/testing are necessary to understand the path that water takes and the locations of ingress and egress.

Brick Walls:

- Stabilization of the brick walls and delaminating skin can be achieved with containment straps to hold the structure together during underpinning.
- Outer skin of brick is peeling away-helefix anchors recommended to connect the skin to the body of the wall.
- Shear cracks caused by root systems are making the walls unstable-stabilization of the structure is necessary prior to removal.
- Crack fills should have bond and flexural strength, be permeable and able to keep plants and debris out. Recessing the crack fills was discussed for aesthetic purposes.
- After underpinning, tie rods or cables can be used to make fundamental corrections at the corners.
- The top of the walls are loose, friable and permeable to water ingress-the loose material may be documented, numbered and dismantled. When it is rebuilt, a sloping profile should be created to shed water.

New and Old Bricks:

- There is a dramatic contrast in porosity between the new and old bricks.
- Historic bricks need to be understood to select replacement bricks.
- Communication with the brick maker is critical for quality control and the development of appropriate replacement bricks.

Resin:

- Need to understand what kind of resin is found between the bricks and determine if resin produced by local trees can be used.
- Study the use of resin as a water repellent.

Surface Finishes:

- The fragility of the finishes in relation to salts and water will determine the brick treatments such as the use of grouts, fills and adhesives.

Termites:

- There are cultural and biological issues associated with the use of borates.
- The removal of termite nests may result in the destabilization of the structure.
- A study of the surrounding trees is important to understand their condition and potential threat to the shrines due to falling branches.

Underpinning:

- Vertical underpinning of the sandstone platform may be necessary to replace and reset the laterite blocks.
- The new laterite should be built out and away from the platform so structural forces can be directed to the bedrock.
- Rock anchors can be used.

Trials and Mock-Ups:

- Trials and mock-ups demonstrating techniques should be undertaken for testing and to train craftspeople.

Next Steps:

- Examine and prioritize past and present mechanisms of structural and material deterioration

- Determine the type of analysis, testing, and monitoring that may be necessary to target the decay mechanisms identified.
 - A literature review of relevant research and testing in nearby areas should be conducted and correlations made between other sites.
 - The standardization of testing techniques between other WMF sites should be conducted.
 - The testing program should be streamlined.
- Discuss overlapping issues for structural and material conservation, impacts and management
- Discuss potential treatment options
- Design small scale pilot projects (mock-ups) to help refine and determine final treatment options.

Since the initial June 2010 workshop reported on the points made above, a great deal of testing, literature review and site survey and investigation work has taken place. In February 2011 a pilot phase implementation program was carried out under the direction of Professor Giorgio Croci. The results of this work will be reported on in an upcoming report.

Background to the Conservation and Restoration of Brick Shrines at Angkor

Simon Warrack – ICCROM

Background

The monuments at Angkor are justifiably renowned for the extra-ordinary art and architecture that has been achieved by the Ancient Khmer builders in stone, but the brick temples and shrines are also of high artistic and historic value even though they, perhaps, lie in the shadow of their stone-built cousins.

The earliest Khmer temples, which date from as early as the 6th Century AD, were built in brick, while sandstone was included mainly for the decorative elements, doorways and windows. Pre- Angkorian sites such as Sambor Pre Kuk and early temples in the area to the North of the Tonle Sap, such as Ak Yum and Prasat Trapeang Phong and later Preah Ko, were built of tightly bonded brick and it was only as quarrying and carving techniques developed that the temples began to be built from entirely from stone.

Building Techniques and Materials

The objective of the early Khmer builder who was using brick was to create a very solid structure that behaved almost as if it were a monolith and to this end they created razor thin joints which were tightly bound together. The bricks were certainly rubbed together vigorously by the mason so as to eliminate any irregularities and binder was added at the same time. Great care that was taken to ensure strong adhesion between the bricks but less attention was paid to the laying of inter-related bonds between courses. There was no use of radiating arch or vaulting (a tradition also carried through to the stone monuments) and nearly all bricks were laid horizontally resulting in the characteristic corbelled openings.

Once the towers were built and the bricks had been laid, the carvers would start to decorate the structures by carving the bricks, so again the concept of treating the structure as a monolith returns (See Fig. 1). However the carving of bricks poses inherent problems due to the removal of the fire layer and the exposure of the weaker and more permeable core, particularly in the case of bricks that have been fired at low temperatures. This would have meant that even a few years after construction some of the bricks would have shown signs of decay and loss.

It is probable that the stucco at Preah Ko was applied to cover the fact that the bricks were already falling off and thus not only to improve the decoration of the temples but also to protect them. This can be deduced by the fact that there are traces of red paint on the original brick surface, so it is reasonable to assume that the first phase saw the temples painted with a smooth red layer which began to look bad when the bricks started to decay and fall off. The builders then chipped all the surfaces and applied several layers of intricately carved stucco which of course served to beautify the temple but also to protect the weakening brick from the elements. It is hard to date the application of the stucco and there is still work to be done on this.

There have been some archaeological finds of ancient ceramic kilns but there is much less evidence regarding the manufacture of ancient bricks. However, the physical parameters for the firing of clay are constant and since there are many traditional brick kilns in use in Dam Dek about 25 kilometres to the East of Angkor (Fig. 2) it is not unreasonable to suppose that there are similarities between these and those used in Angkorian times in the region.

If bricks are fired at temperatures lower than 750°C oxidation does not occur and the clay is merely dehydrated which means they are more permeable and friable. This is the case in some of the brick temples at Angkor (such as Bat Chum and parts of Preah Ko), while others are of much better quality which would suggest that there was not always a constant understanding of the importance of high and constant temperatures during the firing.

There is a need for more research on the composition of Khmer bricks and more specifically on the nature of the binders that were used by the ancient builders of the brick temples in Cambodia. It is

clear that the bricks were bonded together with a very fine binder but there is still debate between conservation scientists and archaeologists working in the region as to the precise composition of this binder. While Rodolfo Lunsford Lujan working at Preah Ko between 1994 and 1996 with the Royal Angkor Foundation concludes¹ that the mortar was lime-based, more recent research at the brick sanctuaries of My Son in Vietnam, by the Politecnico of Milan, has produced quite different results showing a greater emphasis on organic components.

While it is, of course, quite possible that one method was used by the Khmer at Preah Ko and another by the Chams in My Son, the scientific research in this field needs to be extended and integrated if a true understanding of Khmer brick building is to be achieved.

Archaeological and Conservation Background

It is perhaps understandable that when early conservators and architects began working at Angkor their primary focus was on the greater stone temples and the smaller less imposing brick shrines were not given the same attention. It is also true that the consolidation and strengthening of a decaying brick structure poses more complex problems than that of a sandstone structure where the blocks are bigger and usually much stronger thus requiring, in those early years, in the eyes of those architects and engineers, nothing more than reassembly on a strong foundation. However, the difference between the importance that the early European conservators attached to brick shrines, compared to their approach to stone structures, is worth noting.

A summary of work carried out in the 20th Century on brick structures in the Angkor Region is included in Table 1.

More Recent Conservation Programmes

Other interventions that have been carried out on brick towers include the Preah Ko Project, which was carried out by the Royal Angkor Foundation between 1994 and 1996 and was then taken over by the German Apsara Conservation Project² in 1997, and subsequently handed over to the APSARA National Authority. Also the Pre Rup Project, which was carried out by IGeS³ in collaboration with the APSARA National Authority.

These two projects faced very different issues. On the one hand, the Preah Ko Project was concerned more with material decay and detachment of decorative elements on towers where structural issues were not predominant, while on the other hand the work at Pre Rup was concerned almost exclusively with structural and engineering issues and much less with materials and decorated surfaces.

It is perhaps here that lays the key to the future of conservation of brick structures in the region. It is also perhaps here that we find the keynote for this symposium. The coming together of conservators, architects, archaeologists and engineers to discuss and develop working methodologies that will generate a more integrated approach to the conservation of brick towers.

¹ Royal Angkor Foundation – Brick and Stucco Conservators Final Report 1994, Appendix A, Results of Laboratory Analysis.

² German Apsara Conservation Project – Directed by Prof. Dr. Hans Leisen of the University of Applied Science Cologne, funded by the Government of the Federal Republic of Germany.

³ IGeS – Ingegneria Geotecnica e Strutturale, Rome.



Figure 1: Carved brick at Preah Ko Temple.



Figure 2: A brick kiln in Dam Dek.

Table 1

Name of Temple	Date	Name of King	Restorations
Sambor Pre Kuk	616 - 635	Isanavarman I	
Ak Yum	7 th Century		Trouve' 1932 - 1935
Prasat Trapeang Phong	7 th Century		
Preah Ko	879	Indravarman I	Trouve' 1932 RAF 1994 – 1996 GACP 1997 – 1999
Bakong	881	Indravarman I	Henri Marchal 1931 Glaize 1936 - 1943
Phnom Bakheng	889-910	Yashovarman	H. Marchal 1919 – 1930 Goloboeuw (Research) 1931 – 1934
Lolei	893	Yashovarman	
Prasat Bei	10 th Century		H. Marchal 1919
Prasat Neang Khmao	10 th Century		
Prasat Kravanh	921	Harshavarman	H. Marchal 1929 – 1931 G. Trouve' 1935 B.P. Groslier 1962 - 1966
Koh Ker	928	Jayavarman IV	Research by Parmentier
Baksei Chamkrong	947	Harshavarman	H. Marchal 1919
Prasat Bat Tchum	953	Built by Minister of Rajendravarman	
East Mebon	953	Rajendravarman	H. Marchal and M. Glaize 1935 - 1939
Pre Rup	961	Rajendravarman	H. Marchal and G. Trouve' 1930 – 1935 IGeS 1995 - 2002

History of Conservation at Phnom Bakheng

Claude Jacques, *École pratique des Hautes Etudes, Paris*

We move now to the year 1860, when Henri Mouhot discovered the monument: the Khmers seemed to have abandoned in part the immense site of the former capitals; only the temple of Angkor Wat, flanked by its two pagodas, remained really alive. On the Bakheng's esplanade, there was only one Vietnamese pagoda, of which monks became the guardians of the Buddhapada, dug on the esplanade, in the middle of the eastern causeway. For Mouhot, the monument was above all a viewpoint, which he praised at length. We can moreover suppose that it was what he was brought there to see. Alas, things have changed little, and it is sad to have to report that a monument of such value is today used as a stepping stone!

The history of the discovery and research of Phnom Bakheng is exemplary for it shows the difficulty in understanding an ancient monument about which we know almost nothing from the beginning. The first obligation of those who work to highlight it should be to exalt its symbolism and aesthetics, while admitting that it can also be used to admire a landscape, in fact less interesting than what is often described. Mouhot shows in passing a rather bad estimation of distances, which indicates that he was walking through the forest on winding paths, without perspective: "Two miles and a half north of Angkor-Wat, on the path that leads to the city, a temple was established at the summit of Mount Ba-Kheng, about one hundred meters high." Further, he adds: "Six or seven kilometers northwest of the temple [of the Bakheng], lay the ruins of Ongkor Thorn, (the) former capital."

Soon after, in June 1866, Angkor was visited by the expedition led by Doudart de Lagrée; on his part, Francis Gamier, assistant to the commandant, describes thus the top of the pyramid: "At the center of the superior terrace is a base of about 1 meter high, having 30 meters in the north and south direction, 31.50 meters east and west. It was on this base that the towers that overlook the surrounding land were elevated. Their examination enables one to recognize that there were three towers, facing east, and that the middle one must have been the most considerable. From the summit of these ruins, the view is ravishing: at the feet of the spectator stretches the moving dome of the forest, whose waves and indefinable murmurs come up to him."⁴²

The travelers who were to follow would not bring much to these first descriptions, with the same questions about the central temple and the same false answers. The Ecole française d'Extrême-Orient (EFEO) took charge of Angkor's preservation at the beginning of 1908. A few preliminary research works on Phnom Bakheng in 1911 are surely mentioned, but nothing of importance. Jean Commaille, the first curator, describes the monument in good place in his *Guide*: "The temple of the Phnom Bak-Keng," he writes, "was elevated on a pyramidal base comprised of five superposed terraces. Of the temple itself we can say nothing, for it no longer exists. It disappeared for the most part in a deep cavity that can be seen by leaning above the heap of fallen rocks and that enables one to believe that the builders had dug a vast crypt under the sanctuary, for we must dismiss the hypothesis of a subsidence (of the ground) at a location where the rock is, that is to say, *á fleur de peau* (quite close to the ground)."⁴³ In order to enjoy the view, tourists start to climb up the hill, and that is why the EFEO had two trails—still in use today—created in 1919 or 1920, which provide an easier ascent than did the old eastern stairway.

In the year 1920, however, one still wondered about what the Khmers had tried doing with the massive stone blocks that covered the last terrace. Henri Parmentier notes that "the temple's pyramid, maybe with the hill itself, underwent a movement of subsidence in the southeast corner; it caused the ruin of some of the small pavilions that were on the steps and seems to have compromised the solidity of the central sanctuary built with a studied hardness not ordinary for the Khmers."⁴⁴ Therefore he explains that the four doors of the central sanctuary "were closed by the construction of a huge belt of masonry that offered outside a sort of facing and was executed with care, using sandstone blocks." He adds further: "The whole excavation will have to be done with great caution; the establishment of this belt is not explained in

a precise way yet, and we don't know if, as it is likely, the catastrophe that it appears to be, has happened or is still to be feared."

The work of the Ecole française d'Extreme-Orient on the temple of Phnom Bakheng, led by Parmentier and Marchal, would not really start until November 1922; it would last for the first half of the work, until October 1925. They excavated principally the central mass and, at the same time, the small sanctuaries constructed around the pyramid, mostly collapsed and partly hidden under a heavy heap of earth. The task was considerable and the credits were meager. Previously, in December 1920, Parmentier had dug an east-west passage through the central solid mass, fashioned to be able to penetrate directly in the tower, which was accessible until then only from its top, using a ladder. It was during this excavation that the Arab stele, previously mentioned, was discovered.

Charged with clearing the central mass of its vegetation and noting that this work would have to be done repeatedly because of the layer of humus that had settled over the centuries, Marchal decided in 1922 to remove the ground and the conglomeration of stone blocks which enclosed the tower "in order to avoid the return of this uncontrolled vegetation which made it dangerous to climb over the heap of fallen rocks to arrive at the top." It was then, and after a few months of work, realized that this considerable stone mass actually constituted the base of a monumental statue of a sitting Buddha, unfinished.

"At the Phnom Bakheng, the excavation of the pyramid which rises at the top of the monument made it possible to recognize a work analogous to the construction of the sleeping Buddha of the Baphuon. Here, the Cambodians of the late period tried to raise on this formidable throne a gigantic seated Buddha. It was never carved and undoubtedly even the mass of the torso was not built. The intention however is recognizable with the layout in the shape of opposite lotus cushions; it [the base] draws the shape of a large heart, which usually supports figures with crossed legs. Thus it explains the strange accumulation of material at the multiple crampons that, in such an odd way, surrounded the central sanctuary with four bays. Under this mass the four small corner *prasats* disappeared: a part of the western face of the northeast *prasat* was preserved in the mass of the legs of the Buddha."⁴⁵ The first photographs of the entirely excavated central sanctuary date back to April 1924. One was then able to understand that the platform on top of the pyramid carried five towers in quincunx arrangement of which remain, apart from the central sanctuary, only vestiges, still visible, from the northeast tower.

During this time, the excavation began of numerous smaller brick temples at the foot of the pyramid and the smaller sandstone temples on the steps, work also considerable even if it proved less rich in surprises. Work began again from 1929 until the end of 1931, then, more episodically, until 1935. Work consisted of excavating the small sanctuaries surrounding the foot of the pyramid from the enormous mass of earth that had accumulated; some of these sanctuaries gave the impression of having been voluntarily destroyed, without its being possible to propose a date.

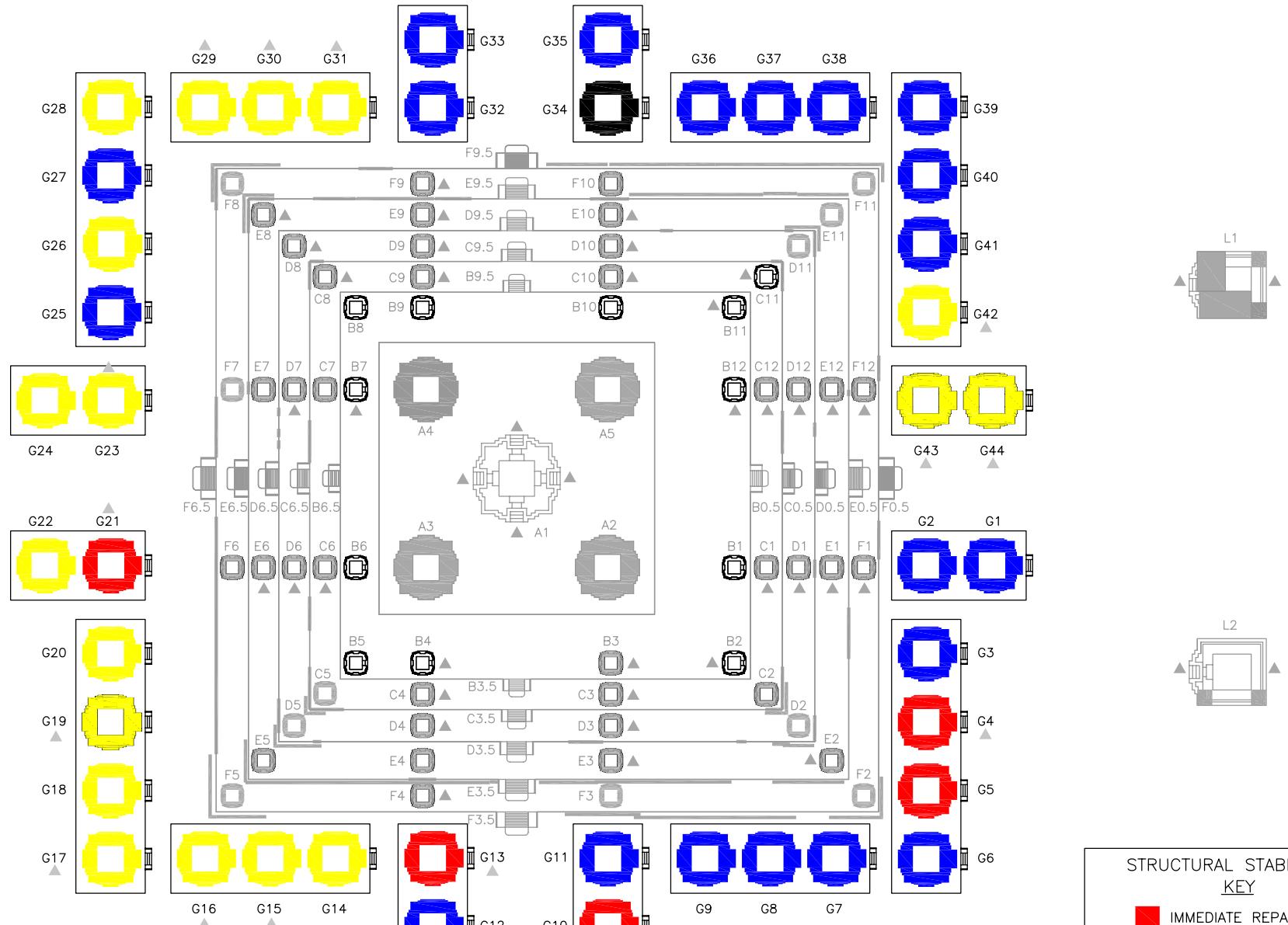
At the same time, one consolidated or one restored, when able, where it was necessary. It was during this period that the work of Victor Goloubew made it possible to place the monument in history. In association with Henri Marchal, he then made a good number of excavations and surveys in the city that he believed surrounded the hill of the Phnom Bakheng: even if the conclusions he drew have been revealed to be erroneous, all of this work was not useless; it brought to light numerous urban structures belonging to the following centuries.

In 1948, Marchal, then more than seventy-two years old, returned to Angkor to replace the curator Lagisquet; he remained the head of conservation until June 1949, before taking a definitive retirement to Siem Reap, where he died in April 1970. Aside from various works, notably on the small sanctuaries of the pyramid, he sought, without much success, alas, to find the stones of the corner *prasat* of the upper platform—particularly on the hillsides where, in the 1920s, he had the blocks of stone from the central mass discarded. It would undoubtedly be important to find these stones, if only to know if the five principle temples could be restored, at least in part.

Jean Laur had to intervene in (second part of) 1956 following the collapse of the southern wall from the first terrace. In July 1959, he noted new damage on the first tower north of the central staircase, on the western side of the first terrace. He then had to be content with stabilizing it before withdrawing from the conservation.

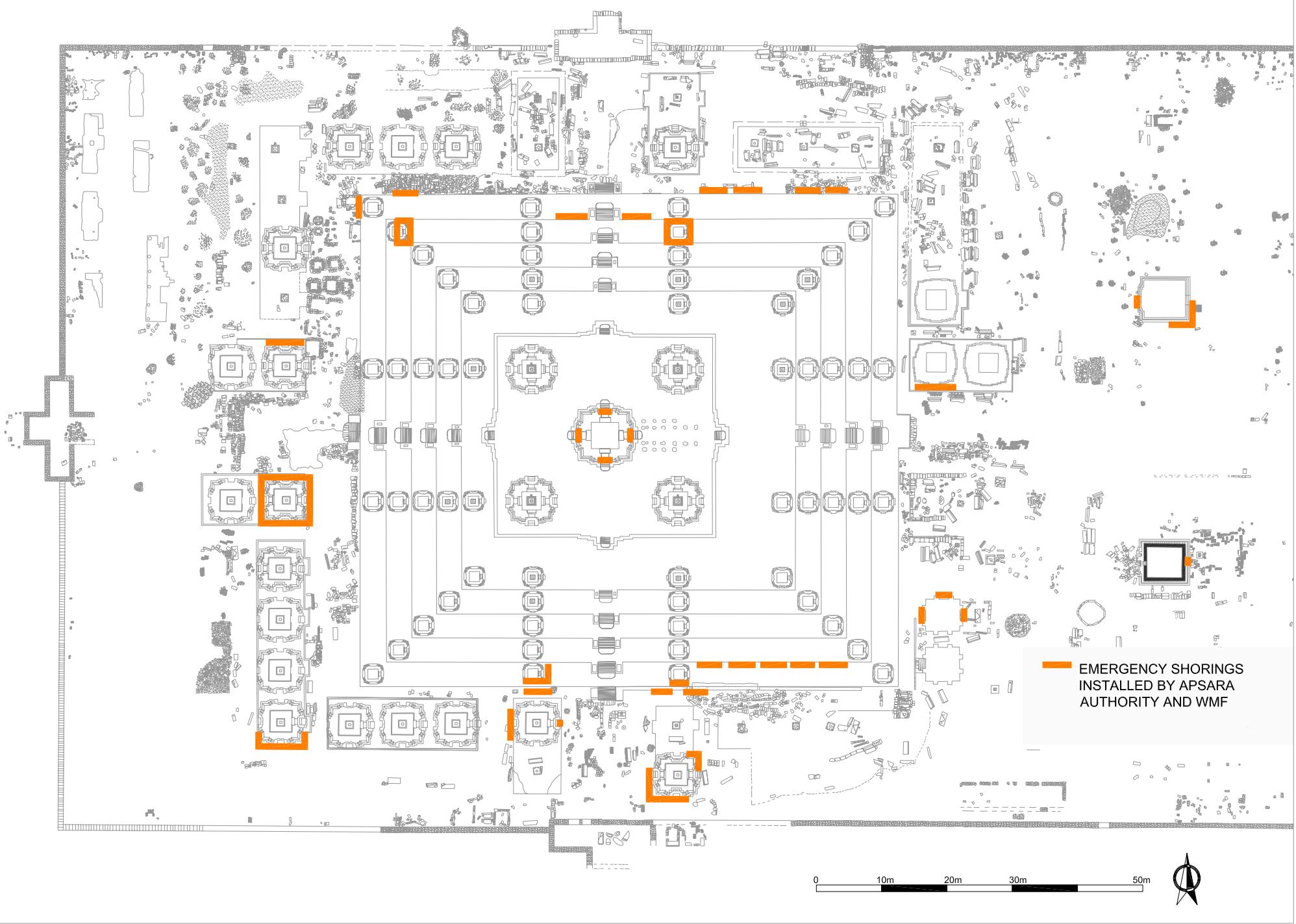
Rocks again fell at the beginning of the 1960s: Bernard-Philippe Groslier notes that it would be necessary to make a serious restoration, but he did not include it in an already full program. He settled with some clearing and installation on the northern staircase in 1969, following the restoration of the temples established at the bottom of the hill. However, it is necessary to note the large study of the monument made by Dumarcay, who published the plans of the temple in 1972.⁴⁶

To my knowledge, the first work that was made on the monument of Phnom Bakheng since the end of the serious events of Cambodia was clearing the undergrowth, carried out around 1994 at the request of a Japanese Buddhist congregation, under the direction of Ung Vong. Various studies were made there since, in particular by the APSARA Authority, up until those of the World Monuments Fund, currently underway. Important consolidation work and essential restoration has become urgent, and it is hoped that it will soon begin. However, much research will still be necessary to understand the history of Phnom Bakheng, which is far from having delivered all that one would want to know.



STRUCTURAL STABILIZATION
KEY

- IMMEDIATE REPAIRS
- DEFERRED REPAIRS
- COLLAPSED
- NO STRUCTURAL REPAIRS



Existing Conditions of Brick Shrines at Phnom Bakheng

Architecture

Phnom Bakheng is one of the three temple complexes in the greater Angkor region that are built on top of natural hills. Phnom Bakheng presents a unique example where the rock was carved to accommodate the pyramid shape of the main sandstone temple, which provides the structure with a solid foundation. The central temple pyramid is constructed by sandstone blocks that are embedded into the natural rock (bedrock). Laterite is used as fill-in material to level uneven areas in the bedrock. At the surrounding temple complex, the bedrock was graded to a plain platform which provides the base for the brick shrines. The brick shrines are constructed on platforms made of stacked laterite blocks that sit directly on the bedrock. The platforms are encased in sand stone blocks. The brick shrines are built up with several layers of sandstone blocks that form the base and floor at the interior. The walls and vaults (false-vault, a typical architectural feature in Khmer temples) are generally made of three rows of bricks. The brick masonry is executed with very fine to almost no joints. The shrines are open at the east west axis by two sandstone doors. At the north and south side there are blind doors made of sandstone. Further sandstone elements are employed at door colonnettes, pilasters, lintels, and steps. There are remains of colored plaster at interior walls of two brick shrines which suggests that all interior walls were decorated with colored plaster in the original condition.



Fig. 1: Brick Shrine G34



Fig 2: Brick shrine platform showing laterite foundation and sandstone encasement

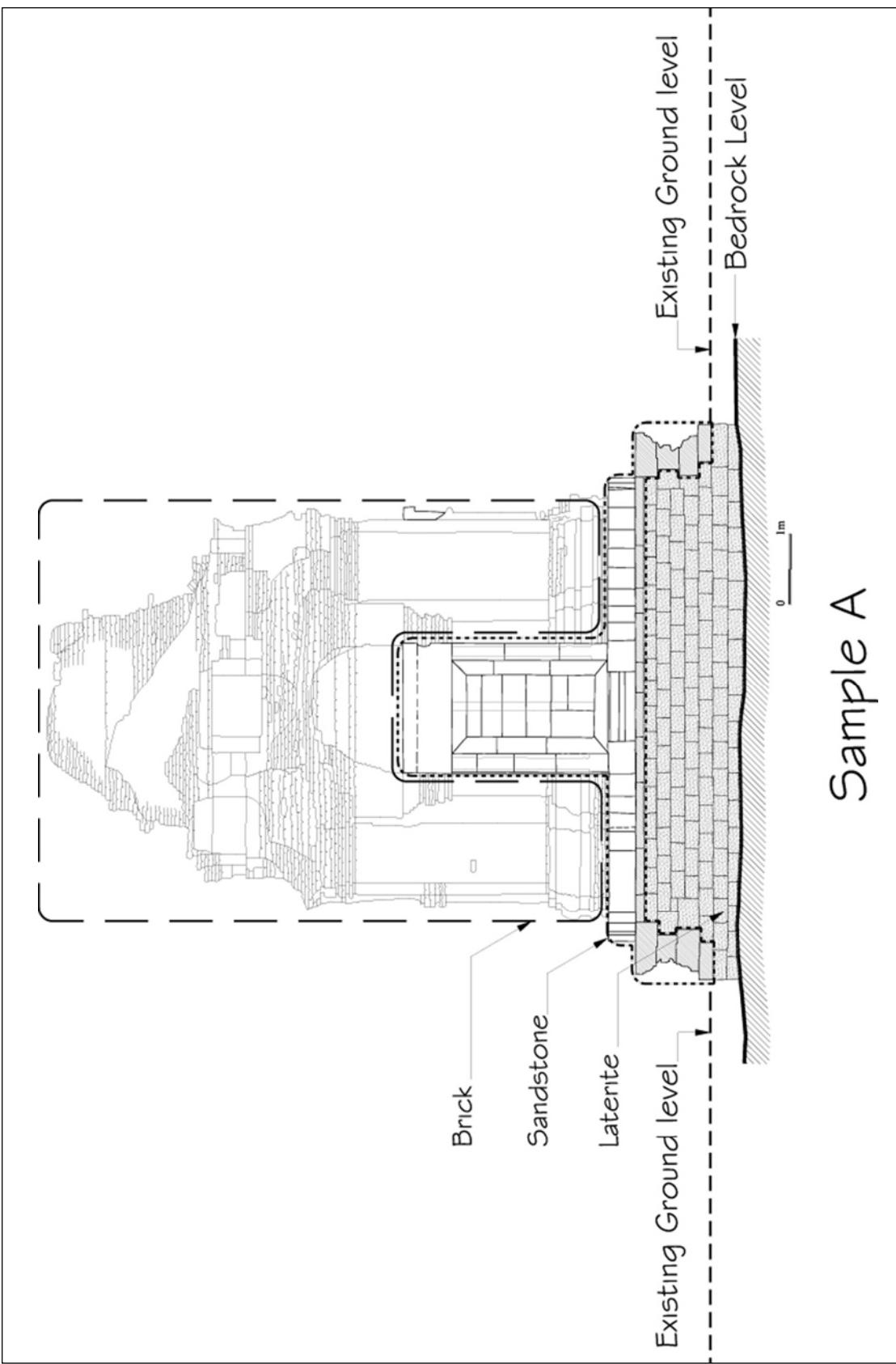


Fig. 3: Cross section of brick shrine with foundation

Structural Condition

There are forty-four brick shrines at Phnom Bakheng that encircle the central sandstone temple pyramid of which more than half (twenty-five) are fully or partially collapsed. Six of the remaining shrines require immediate attention and only four are preserved in structural sound condition.

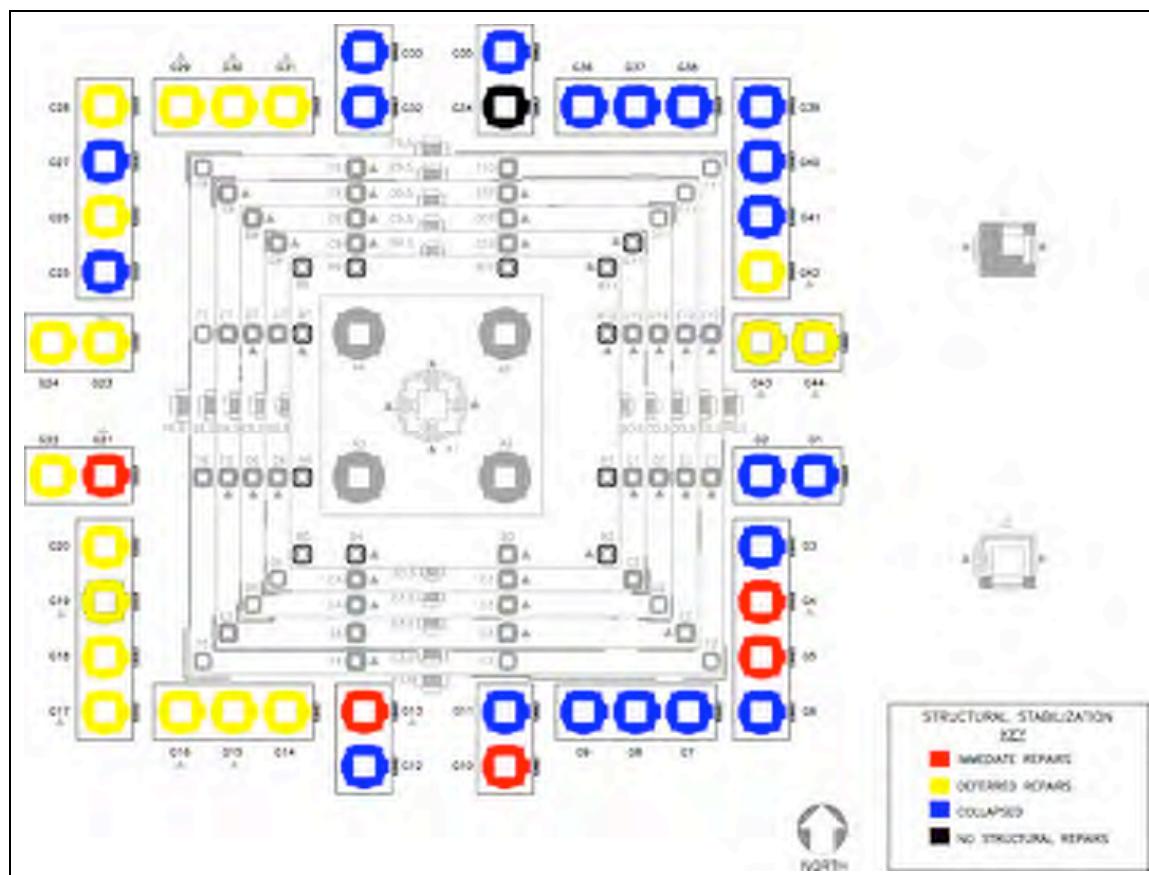


Fig 4: Structural risk map

The combination of severe weather conditions with extreme heat, heavy rainfalls and occasional storms, vegetation encroachment, and partial improper building techniques have led to deterioration of the materials and caused destabilization of the structures. The major threat to the structure is posed by uncontrolled water runoff of the main temple pyramid, which has led to undermining of the surrounding brick shrines and resulted in failure of most of their foundations. This typical decay pattern shows especially in shrines where the encased sandstone blocks of the platforms have either fallen off or have been removed, leaving the laterite block foundation exposed to the elements. During heavy monsoon rains that occur from June to October every year, large volumes of water drain from the main temple past the brick shrine platforms which leads to accelerated deterioration of the exposed laterite blocks, and results in undermining of the shrines. As a result of failed foundations, brick walls cracked especially near corners and along joints where bricks are insufficiently interlocked. Consequently, wall sections and roofs collapsed leaving walls open and exposed to rainwater that enters into the masonry and

accelerates water induced deterioration of bricks, mortars and plasters. Open gaps give place to uncontrolled growth of vegetation and soil deposits by termites which additionally creates physical stress to the structures and has contributed to the damage. Despite the sound bedrock foundation, lacking of a well performing drainage system at Phnom Bakheng has ultimately led to considerable loss of brick shrine structures over time.



Fig 5: G10 bird-eyes view



Fig 6: G10 typical crack at corner where interlocking is missing



Fig 7: G5 Crack in brick with tree

Materials Condition

The brick shrines were constructed under employment of three material types:

- Laterite, which is a red residual soil formed by the leaching of silica and by enrichment with aluminum and iron oxides, used especially in humid climates. In Angkor temples laterite is commonly used for foundations and enclosure walls. At the brick shrines at Phnom Bakheng laterite blocks are used for foundations of platforms that sit directly on top of the natural rock. The average size of one laterite block is 64cm x 36cm x 24cm.
- Sandstone from local quarries of different varieties with high content of clay minerals. In brick shrines, sandstone is typically used for the base, interior floors, doors, lintels, and steps. In addition, sandstone blocks are used for encasement of laterite foundations. The average size of one sandstone block is 69cm x 39cm x 24cm.
- Bricks are used for walls and vaults. Units vary in size. The average size of one brick is 11-17cm x ~ 4.5cm x ~ 26cm.

The materials used at the brick shrines are in different state of preservation.

Where laterite is exposed to the elements it is heavily deteriorated and has lost its bearing capacity as supportive foundation material. In locations where laterite is covered by sandstone it is well preserved and structurally intact.



Fig 8: G10 SW corner - deteriorated laterite



Fig 9: G10 NE corner – freestanding sandstone door

In comparison to laterite and brick, most of the sandstone elements are well preserved based on its greater resistance to physical stress and water induced deterioration. As a result there are examples where sandstone elements are preserved whereas the rest of the shrine has collapsed. Decay in sandstone concentrates at the base and in upper areas of doorframes and adjacent pilasters. Weathering in these locations has led to exfoliation and scaling and in some areas resulted in loss of material. The occurrence of salt crusts near weathered areas suggests salt-water induced deterioration processes. There is little microbiological deposit and some lichens, especially in protected and horizontal areas where water can accumulate.



Fig 10: Deteriorated sandstone at base of door



Fig 11: Lichens on sandstone at doorframe

The majority of bricks are in moderate to good condition. In locations where structural damage occurred, bricks are heavily damaged and have lost their structural bearing capacity, which has often led to loss of larger sections of walls and roofs. In addition, there is crumbling disintegration and exfoliation on surfaces that are exposed to heavy weathering, for example on superimposed architectural features like cornices. The surfaces of straight walls are generally in good condition. Microbiological growth is located where water accumulates and mainly occurs in a black biofilm.



Fig 12: Deterioration in brick



Fig 13: Structural damage in brick



Fig 14: Detail of structural damage

More information about materials conditions, and forms and extent of decay can be found in the mapping and glossary.

Existing Condition of brick shrine G5 and G10

Shrines G5 and G10 were chosen to be the focus of this workshop because they combine structural and material conservation problems. Both shrines are exemplary for existing conditions of brick shrines at Phnom Bakheng.

Brick Shrine G5

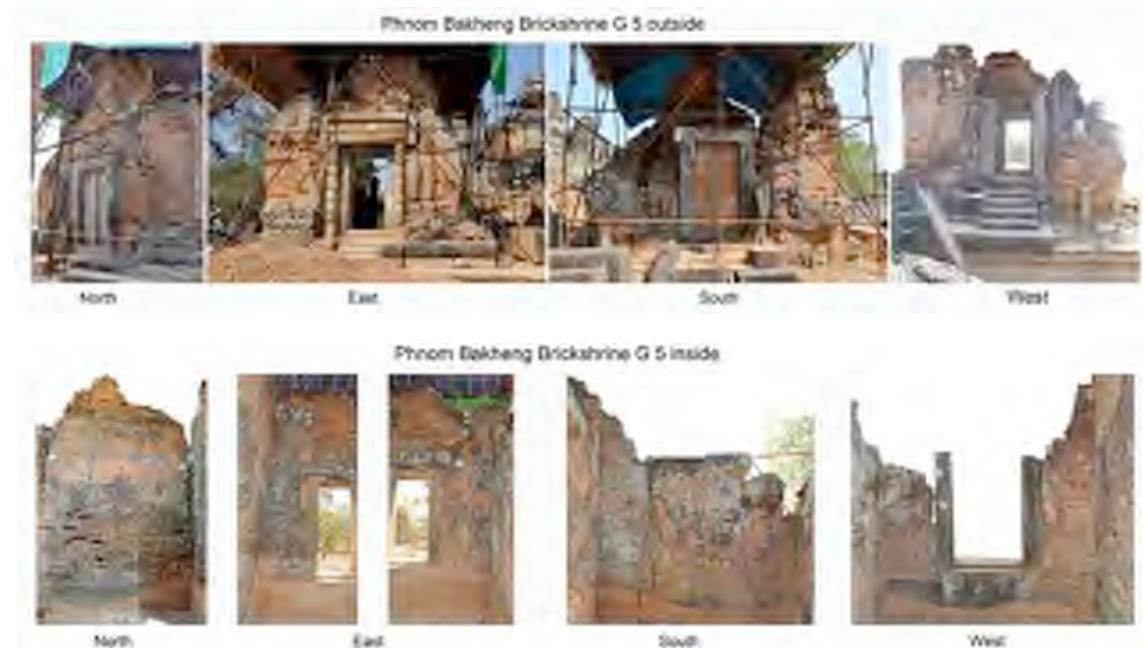


Fig 15: G5 - elevations

Brick shrine G5 is located within a soil ramp that was kept by the EFEO during their restoration and excavation campaign in 1911-1929, most likely to ease material transport to the upper terraces of the main temple. This accumulation of debris and soil has acted as an additional support for the foundation of the brick shrine and left it in structurally decent condition. In addition, several concrete columns were installed by EFEO during their restoration campaign at the southwest and southeast corners, which aided to preserve G5 in relatively sound structural condition.

The majority of the brick walls above the doorway height are missing and the remaining walls are in bad condition. The north wall is relatively intact and contains the largest amount of remaining bricks. It carries some of the few remaining colored plaster at interior walls of brick shrines in Phnom Bakheng. The plaster is in decent condition with partial loss due to vegetation growth and deteriorating brickwork, and is subject to microbiological growth. On top of this wall sits a large mass of structurally unstable brickwork that is in danger of collapse, hence poses a threat to the intact wall with plaster remains underneath.



Fig 16: G4 and G5 - bird eyes view



Fig 17: G5 - SW corner

There are vertical cracks that run through the entire height of the remaining walls at each elevation and upper corners are missing, which leaves walls yawning open. Gaps give space to vegetation and accumulation of soil, as there is a tree root in the north elevation.

With the removal of the soil ramp which is part of the conservation efforts of the central temple pyramid, supporting soil is currently being removed which poses new challenges to the structural consolidation of the brick shrine. The removal also changes the microclimate bricks were exposed to during past decades, which must be considered in regards to material conservation.



Fig 18: G5 – North wall with colored plaster



Fig 19: G5 - Concrete columns installed by EFEO

Brick Shrine G10



Fig 20: G10 - elevations

The majority of sandstone platform encasement of brick shrine G10 is missing, which has left the laterite blocks exposed to the elements. As a result the laterite foundation has deteriorated to the point that sandstone blocks of the base of the shrine are undermined and destabilized. Several units have dislodged leaving the corners in danger of collapse. The southwest corner is in very bad condition and remaining sandstone blocks are currently being held in place by a pipe scaffolding shoring and wooden props. At the northeast corner, several sandstone blocks fell out of place during a large rain storm in 2009. These blocks were replaced and are currently shored with wood supports.



Fig 21: G10 - deteriorated laterite foundation



Fig 22: Cracks in brick at G10

The southeast corner of G10 was excavated during the beginning of 2010 to confirm that the laterite foundation is sitting directly on the bedrock. The excavation confirmed that the laterite, while deteriorated at the exposed surfaces, is in relatively good condition and does sit directly on the bedrock.



Fig 23: excavated laterite foundation sitting directly on bedrock

The entire brick wall at the east elevation has collapsed, as has half of the north and parts of the south, leaving the sandstone door almost free standing. Remains of walls show vertical cracks and are cut open, which allows water to enter into the masonry and promotes deterioration.

In order to address stated issues in the short term, structural shoring has been installed and temporarily roofs have been set up at both shrines.

Glossary

The glossary shall serve to give examples and to provide definitions for each category of the classification system used for the condition survey. Here specified categories interrelate to the key used in the mappings.

Four subcategories were identified:

Materials – includes materials that are to be found at the brick shrines

Decay – includes forms of decay of the different materials

Deposits – includes all superficial deposits on bricks and sandstone elements as well as vegetation

Structural damage – includes all forms of decay that pose a risk to the structural condition of the shrines

Materials



Brick

All walls made of brick, each wall consists of 3 units of varying size
Length: 11-17 cm
Height: ~ 4,5 cm
Depth: ~ 26 cm

Photo:

G5, North wall, exterior



Laterite

A red residual soil formed by the leaching of silica and by enrichment with aluminum and iron oxides, especially in humid climates. Used for foundations of platforms that sit directly on top of the natural rock.

Glossary



Sandstone

Used for platforms, stairs, doorframes, lintel, doors, and columns

Photo:
G10, South side, exterior



Sandstone

Photo:
G5, North, doorframe, exterior



Colored plaster

Applied at interior walls

Photo:
G5, North wall, interior



Concrete (previous intervention)

Reinforcements that origin from restoration intervention by EFEO (Ecole Francaise d'Extreme Orient) in 1911 to 1929.

Photo:
G5, South West corner, exterior

Decay

Brick - Decay

- a) Brick deterioration
- b) Loss of brick material
- c) Loss of brick material due to insect colonization



a) Brick deterioration includes exfoliation left, and crumbly disintegration right

Photo: G10, West wall, exterior



b) Loss of brick material due to heavy deterioration and structural failure

Photo: G10, North wall, exterior



b) Loss of brick material due to vandalism or later renovations

Photo: G10, South wall, interior



c) Loss of brick material due to insect colonization

Photo: G5, North wall, interior

Sandstone - Decay

- d) Sandstone deterioration:
Exfoliation
Scale
- e) Loss of sandstone material



d) Exfoliation of sandstone.

Photo: G10, doorframe, East, exterior



d) Scale of sandstone

Photo: G5, doorstep, East, exterior



e) loss of material due to heavy deterioration

Photo: G10, doorframe, North, exterior

Laterite - Decay

- f) Laterite deterioration



f) Laterite deterioration

Photo: G10, South

Deposits



Biofilm microbiological growth including algae, bacteria, and lichens

Photo: G10, East wall, exterior



Biofilm microbiological growth including algae, bacteria, and lichens

Photo: G10, North wall, exterior



Lichens on sandstone

Photo: G10, West doorframe, interior



Macrobiology (includes all plants and mosses)

Photo: G10, North wall, interior

Glossary



Soil deposit due to termite colonization inside crack

Photo: G10, SW corner, interior



Soil deposit due to termite colonization on sandstone

Photo: G10, East, doorframe, lintel



Salt crust on brick

Photo: G5, North wall, interior



Salt crust on sandstone

Photo: G10, East, lintel

Structural damage



Unstable area in danger of collapse



Gap



Crack

Photo: G10, NE wall/corner, interior

Photo: G5, North East, interior

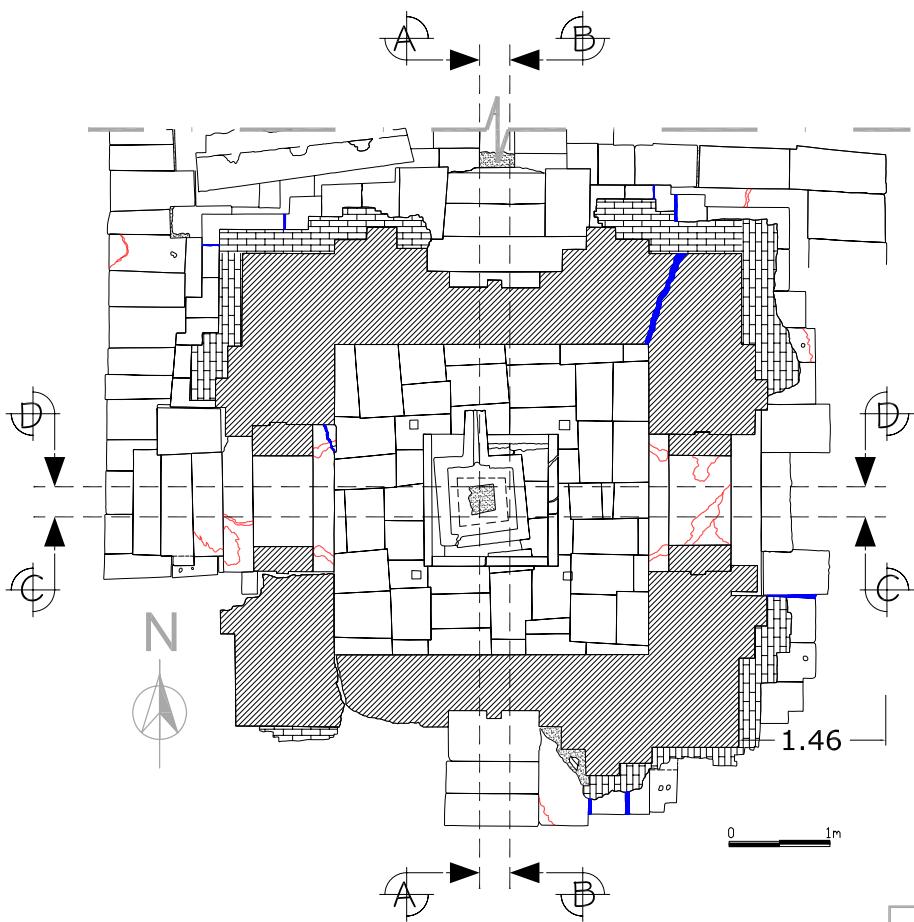
Photo: G10, East wall, exterior

Condition Survey of Brick Shrines G5,G10, and G34

List of Drawing

Sheet No	Title	Scale
01	Plan of G5 - Existing Condition	1/50
02	Exterior Elevation of G5 - Structural Condition	1/50
03	Interior Elevation of G5 - Structural Condition	1/50
04	Exterior Elevation of G5 - Materials	1/50
05	Interior Elevation of G5 - Materials	1/50
06	Exterior Elevation of G5 - Deposits	1/50
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08	Exterior Elevation of G5 - Decay	1/50
09	Interior Elevation of G5 - Decay	1/50
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17	Exterior Elevation of G10 - Decay	1/50
18	Interior Elevation of G10 - Decay	1/50
19	Plan of G34 - Existing Condition	1/50
20	North and East Elevation of G34 - Existing Condition	1/50
21	South and West Elevation of G34 - Existing Condition	1/50
22	Section BB and DD of G34 - Existing Condition	1/50
23	Section AA and CC of G34 - Existing Condition	1/50
24	Photos Sample Foundation of Brick Shrines	
25	Photos of G5, G10, and G34	

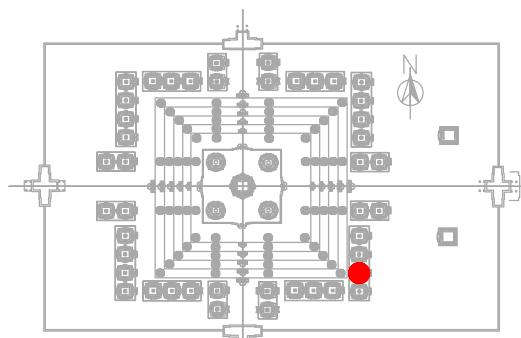
Plan of G5 - Existing Condition



Plan Brick Shrine G5



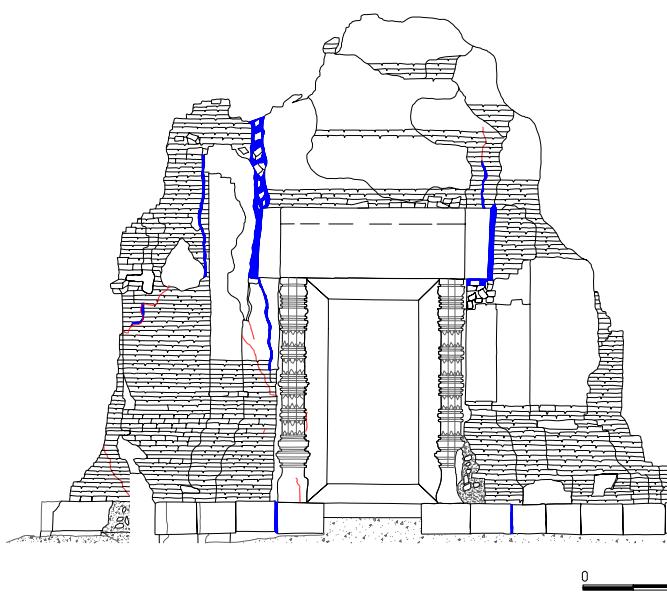
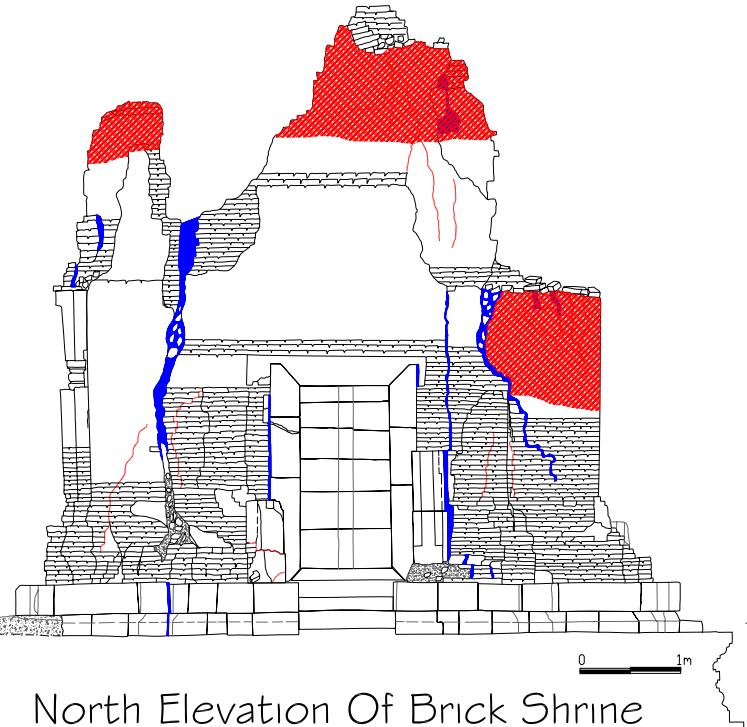
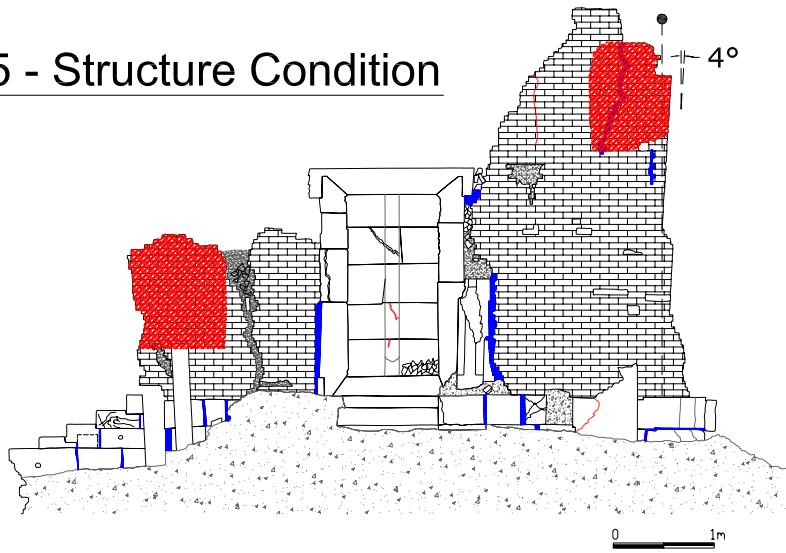
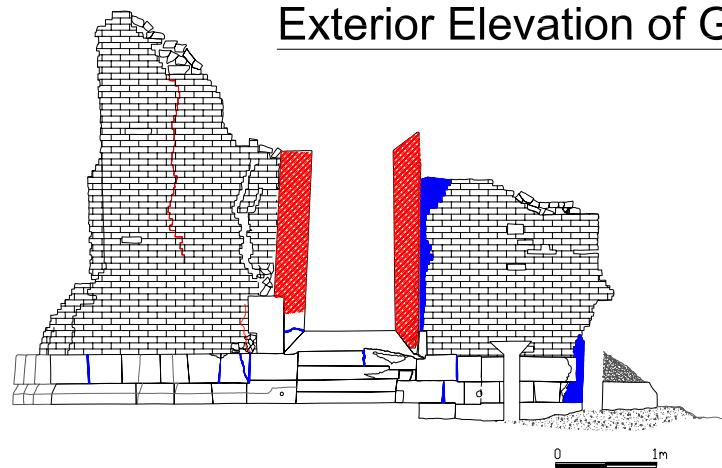
Photo Of G5



Location

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Plan of G5 - Existing Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 01

Exterior Elevation of G5 - Structure Condition

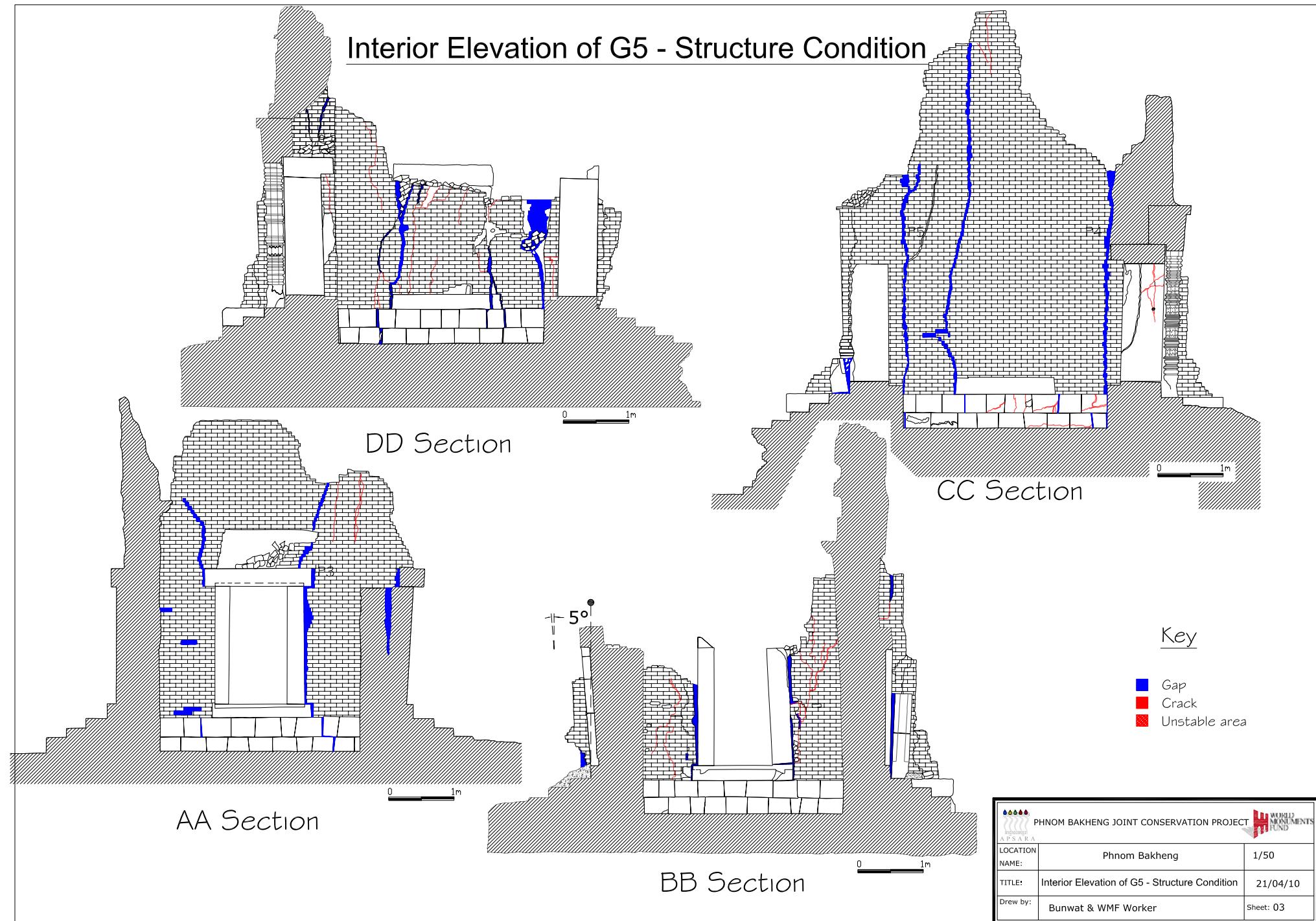


Key

- Gap
- Crack
- Unstable area

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
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TITLE:	Exterior Elevation of G5 - Structure Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 02

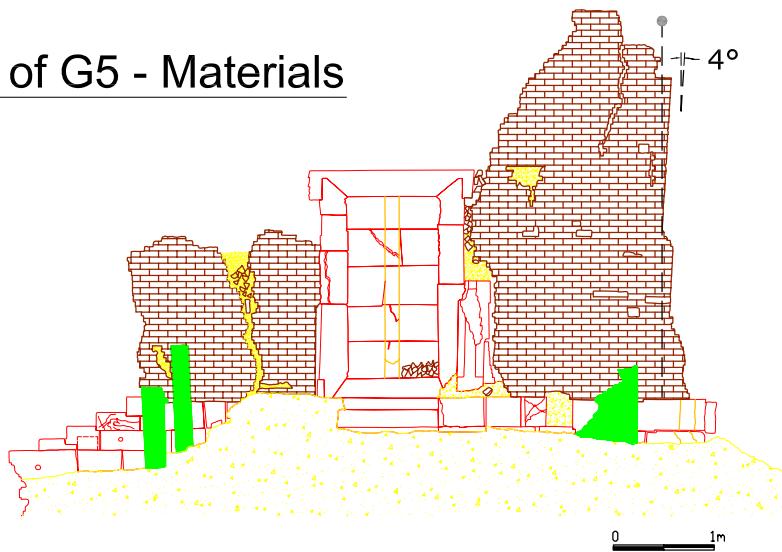
Interior Elevation of G5 - Structure Condition



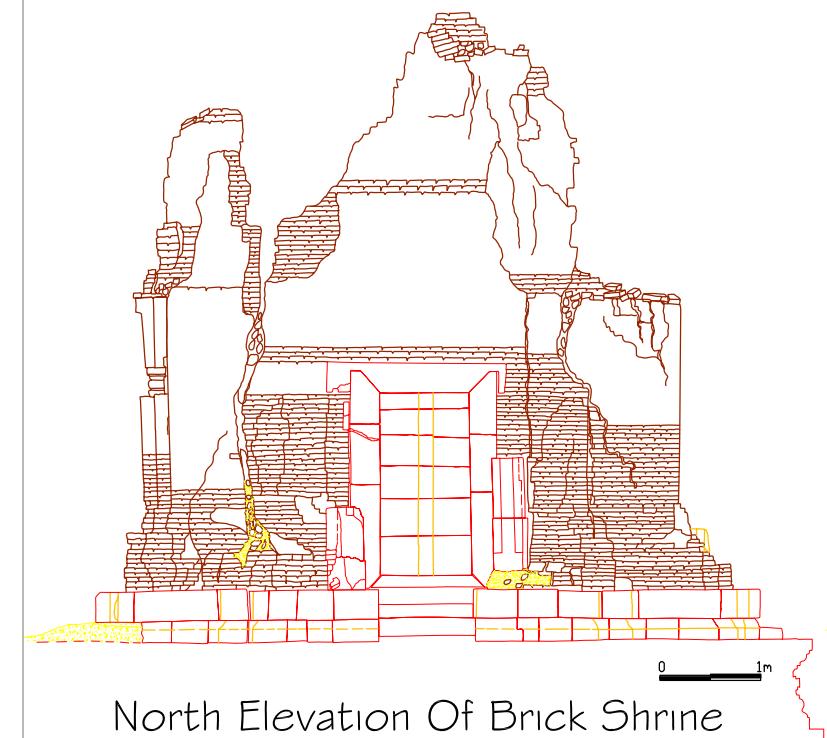
Exterior Elevation of G5 - Materials



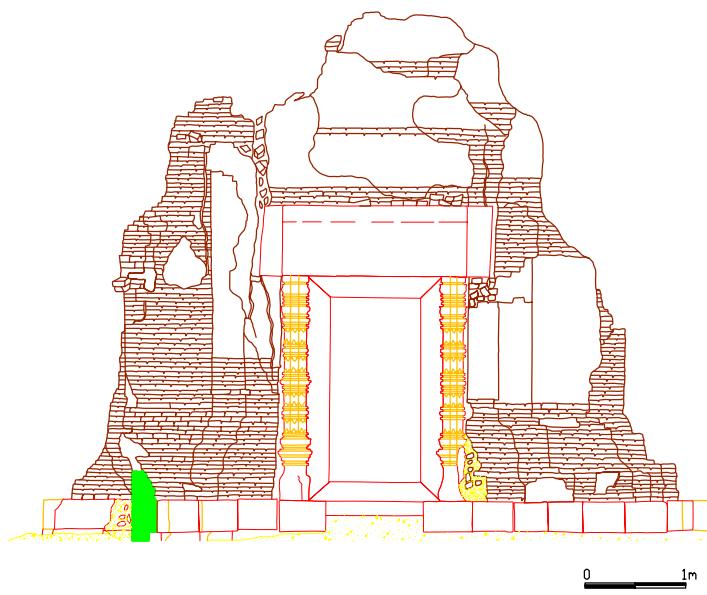
West Elevation Of Brick Shrine



South Elevation Of Brick Shrine



North Elevation Of Brick Shrine



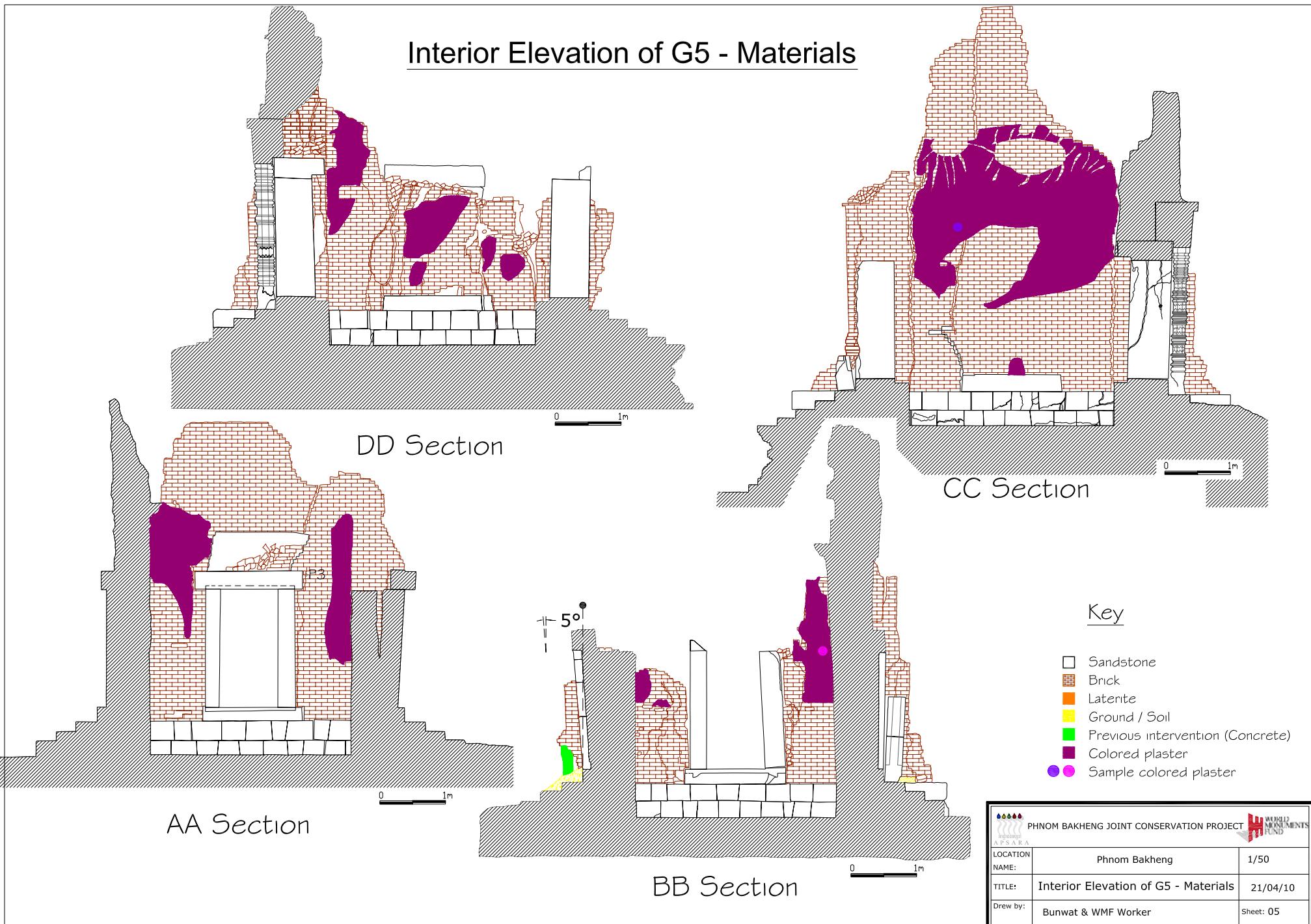
East Elevation Of Brick Shrine

Key

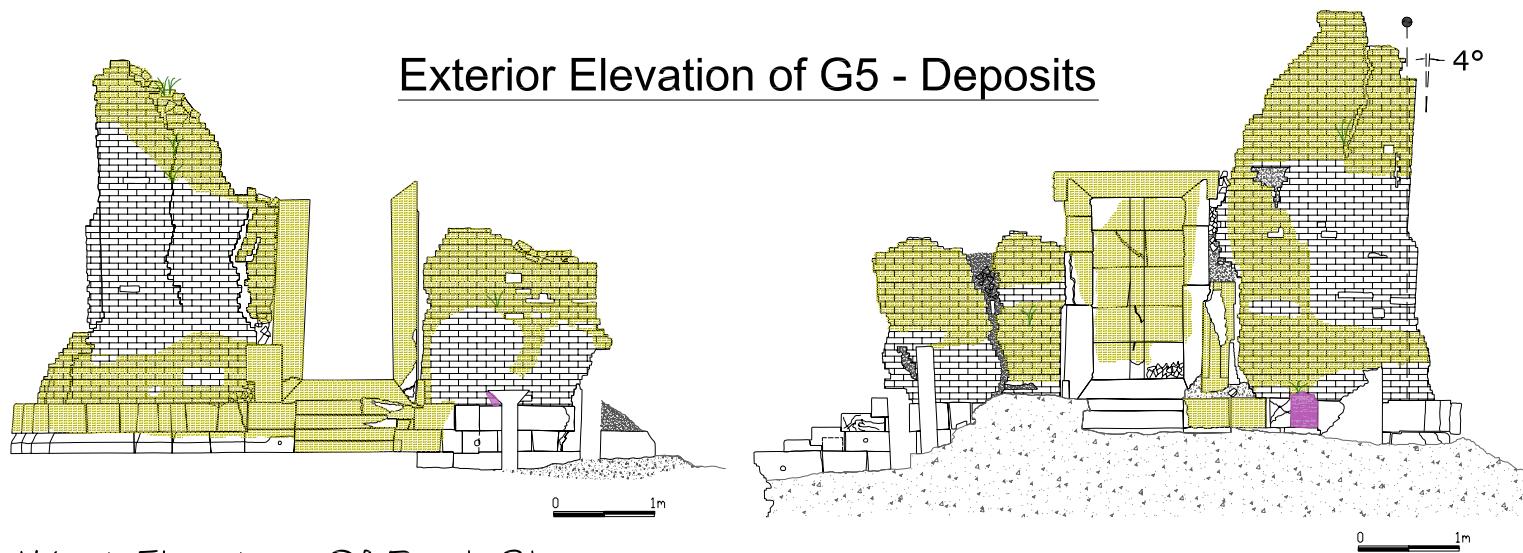
- Sandstone
- Brick
- Laterite
- Ground / Soil
- Previous intervention (Concrete)
- Colored plaster
- Mortar Sample Location

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
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TITLE:	Exterior Elevation of G5 - Materials	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 04

Interior Elevation of G5 - Materials

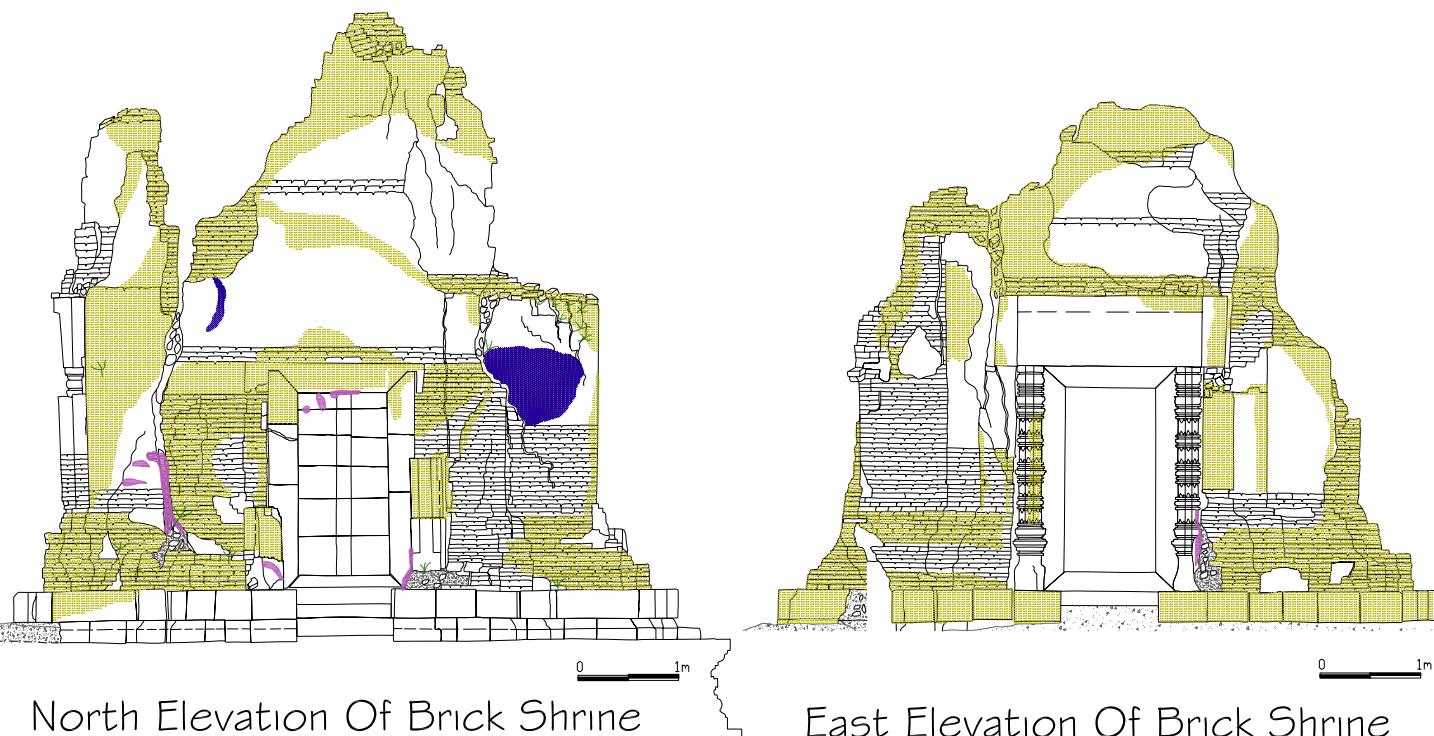


Exterior Elevation of G5 - Deposits



West Elevation Of Brick Shrine

South Elevation Of Brick Shrine



North Elevation Of Brick Shrine

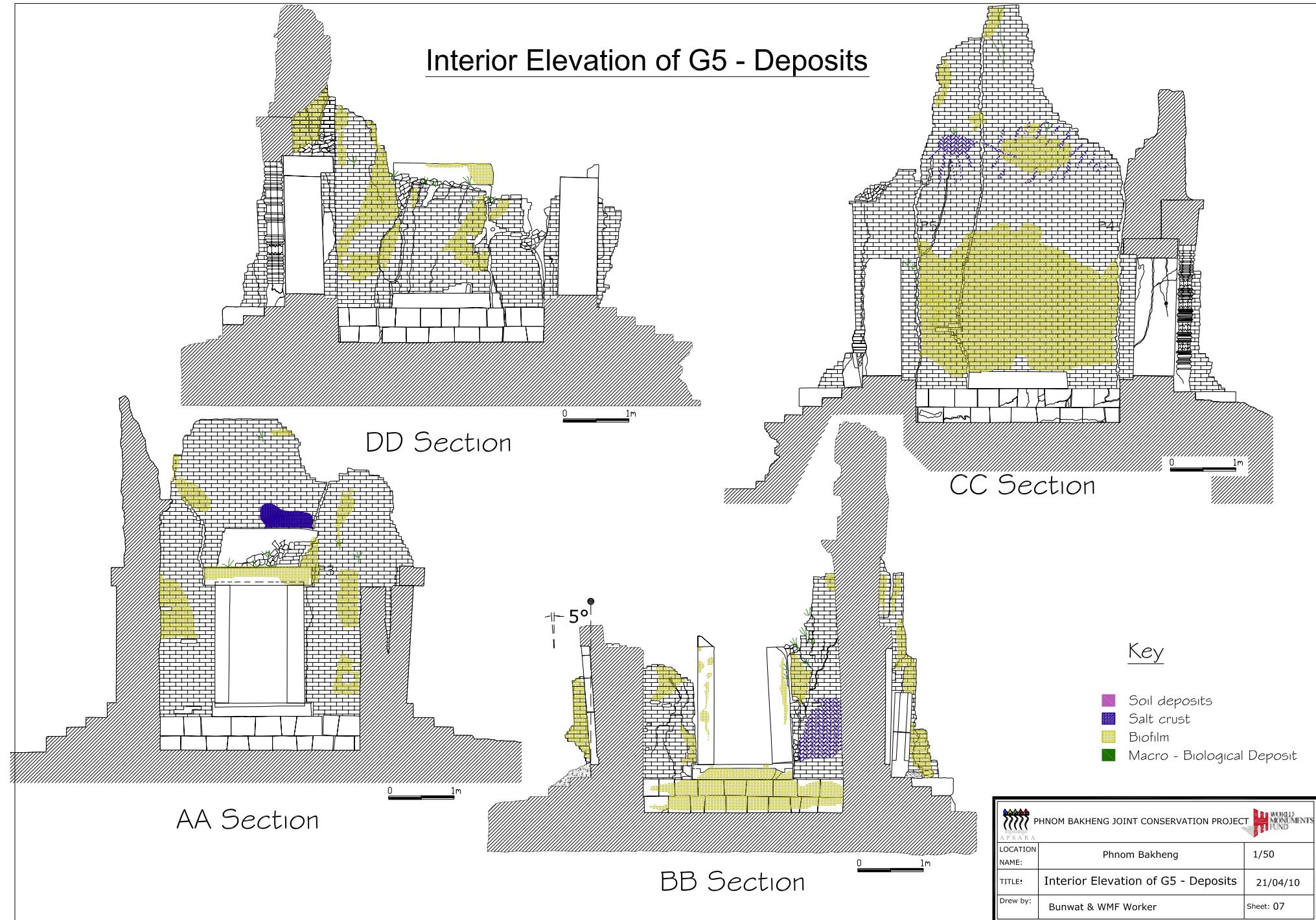
East Elevation Of Brick Shrine

Key

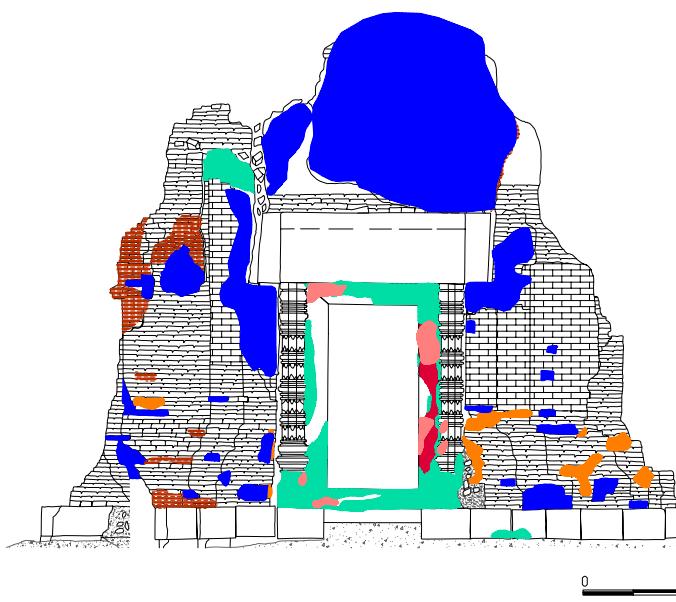
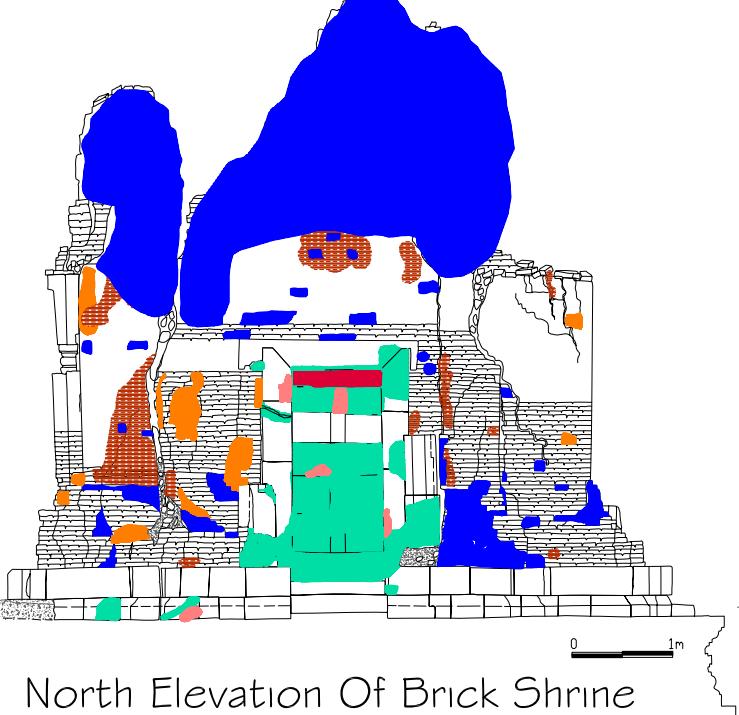
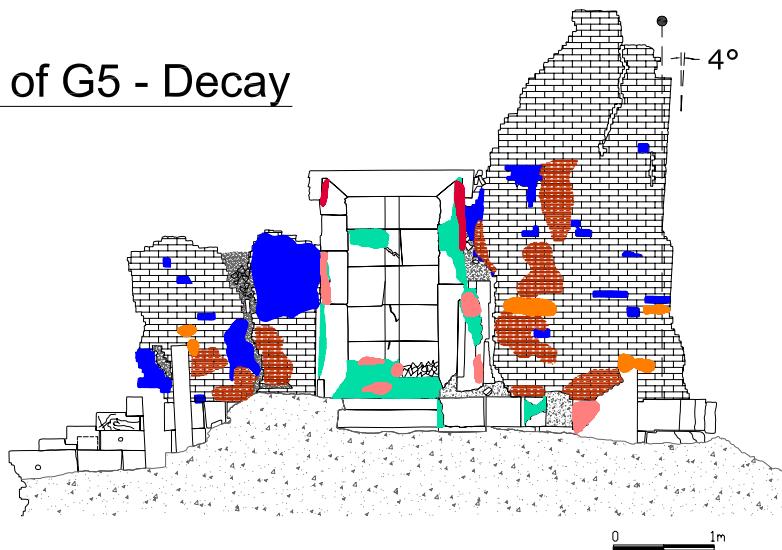
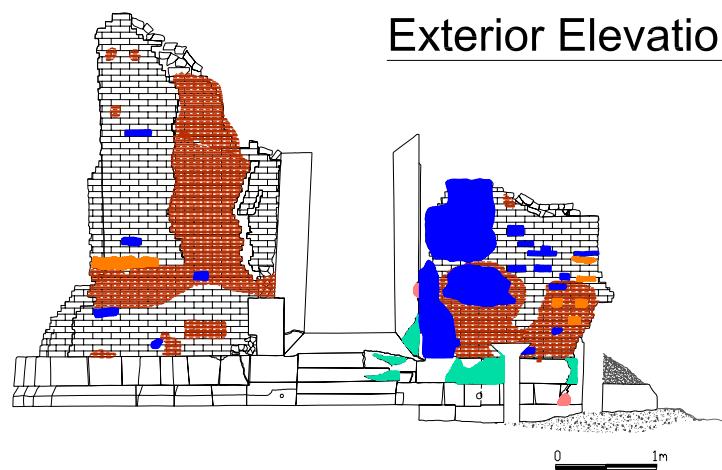
- Soil deposits
- Salt crust
- Biofilm
- Macro - Biological Deposit

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Exterior Elevation of G5 - Deposits	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 06

Interior Elevation of G5 - Deposits



Exterior Elevation of G5 - Decay



Key

Brick

- Brick deterioration
- Loss of material
- Loss of material due to insect colonization

Sandstone

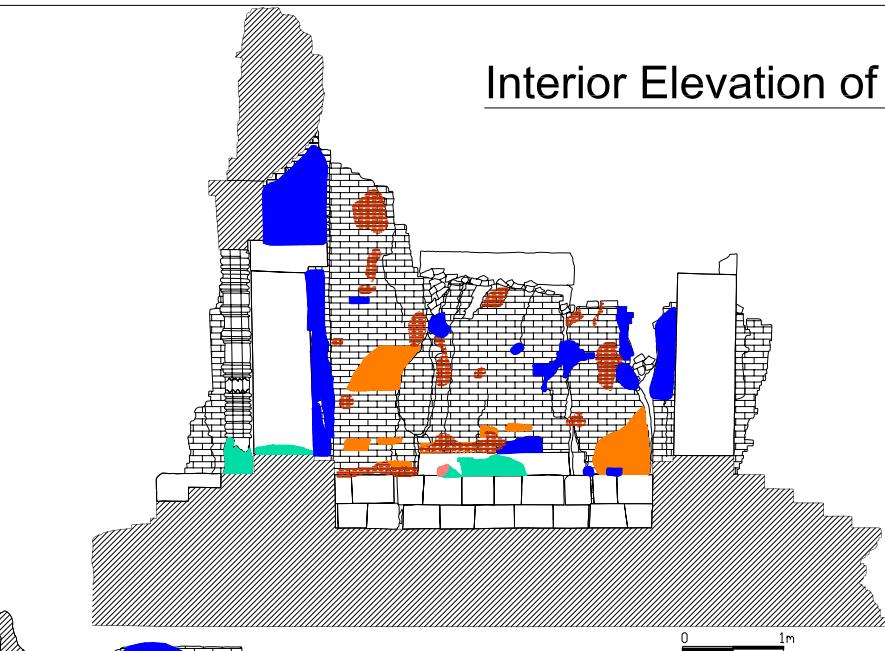
- Sandstone deterioration
- Exfoliation
- Scale
- Loss of material

Laterite

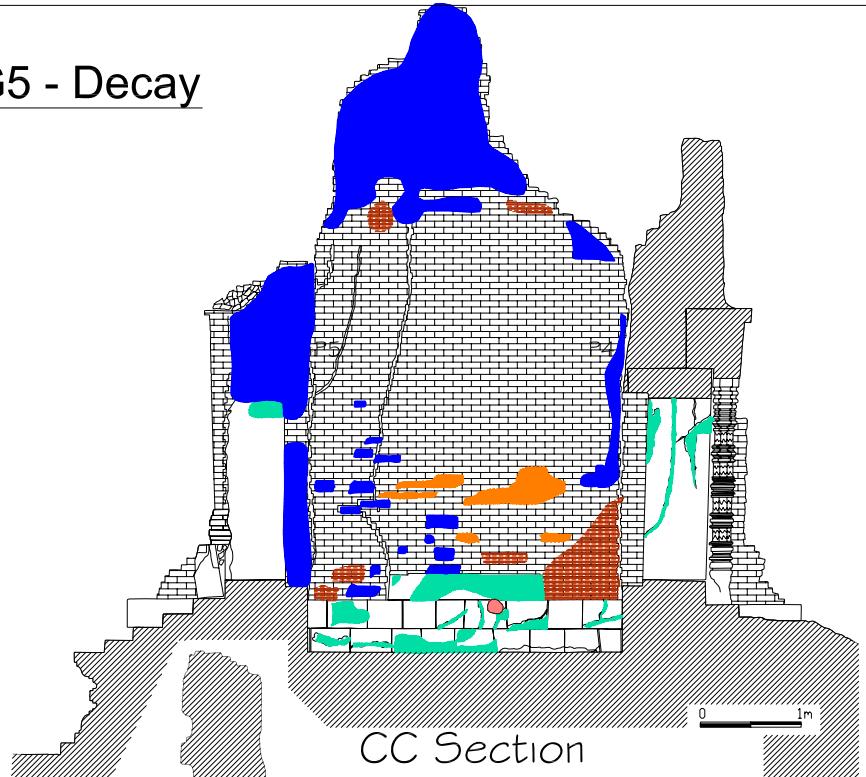
- Laterite deterioration

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Exterior Elevation of G5 - Decay	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 08

Interior Elevation of G5 - Decay



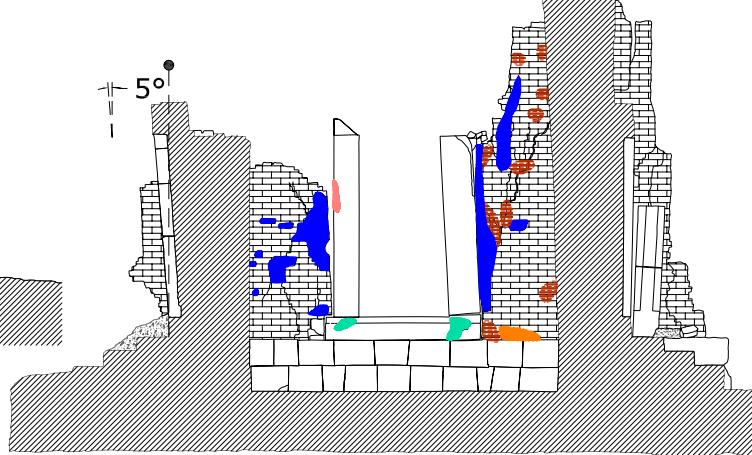
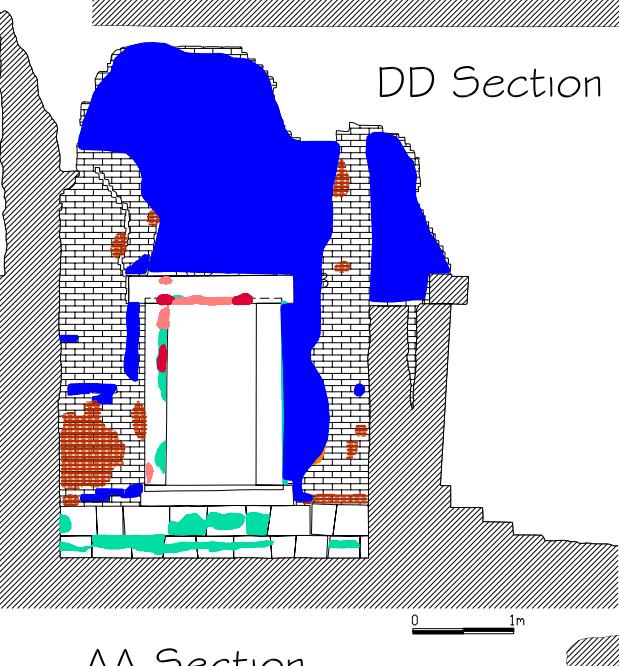
AA Section



CC Section

Key

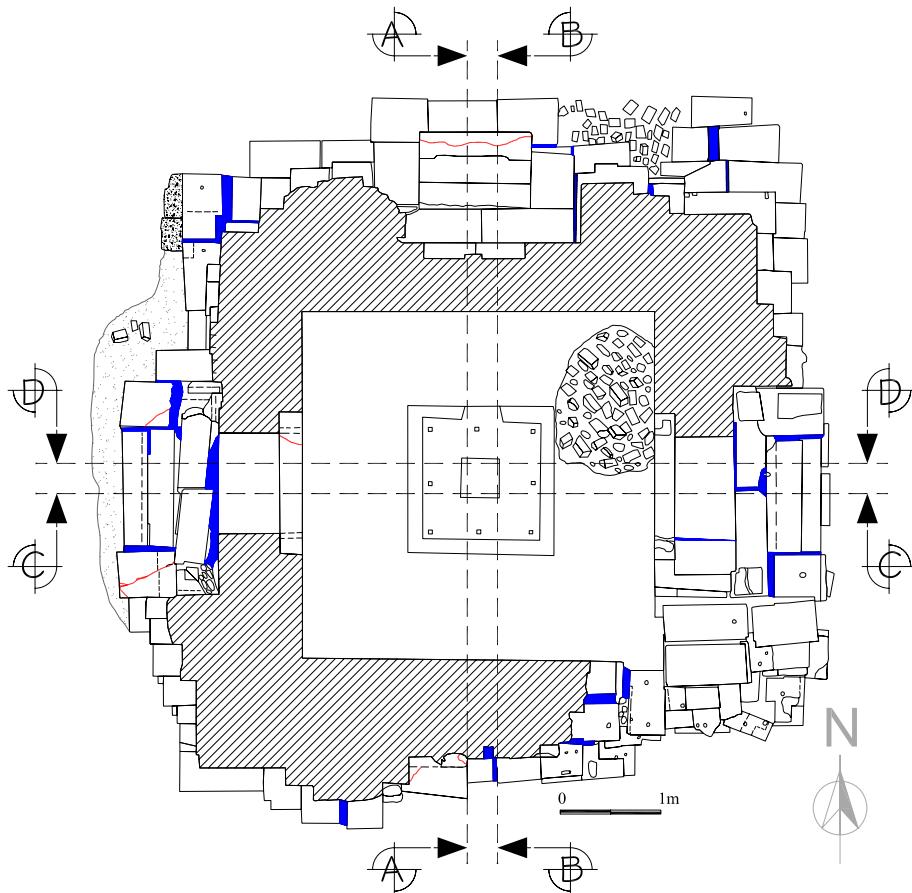
- | | |
|------------------|---|
| Brick | |
| ■ | Brick deterioration |
| ■ | Loss of material |
| ■ | Loss of material due to insect colonization |
| Sandstone | |
| ■ | Sandstone deterioration |
| ■ | Exfoliation |
| ■ | Scale |
| ■ | Loss of material |
| Laterite | |
| ■ | Laterite deterioration |



BB Section

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Interior Elevation of G5 - Decay	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 09

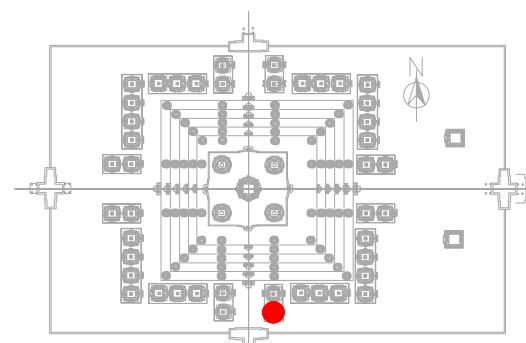
Plan of G10 - Existing Condition



Plan Brick Shrine G10



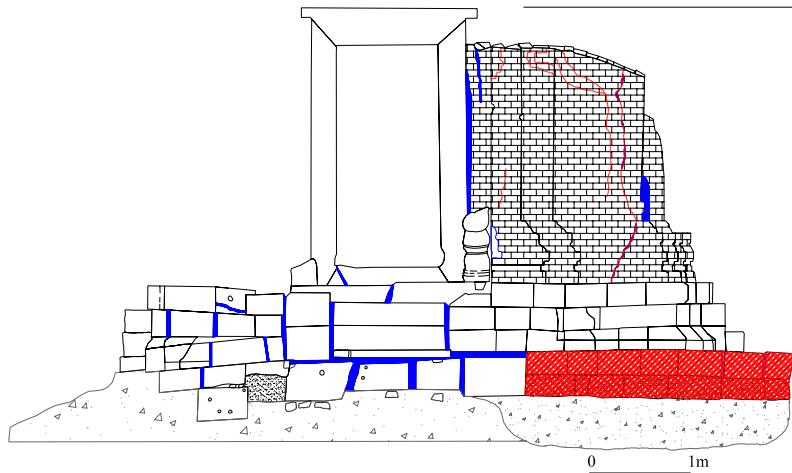
Photo Of G10



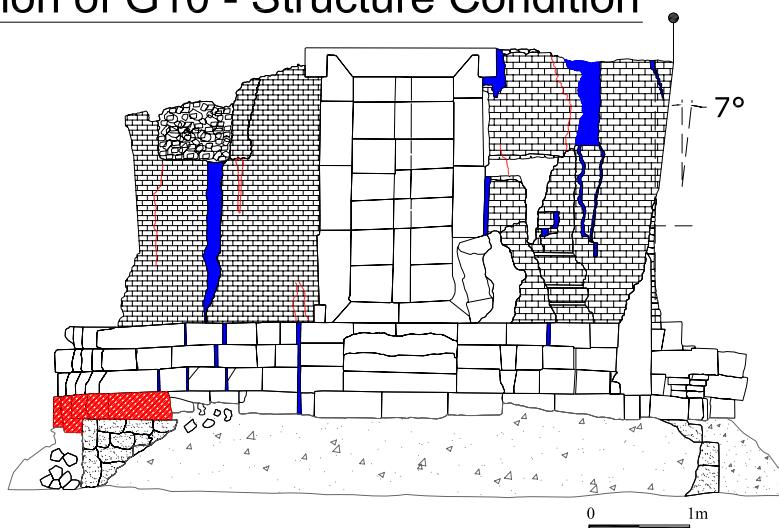
Location

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Plan of G10 - Existing Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 10

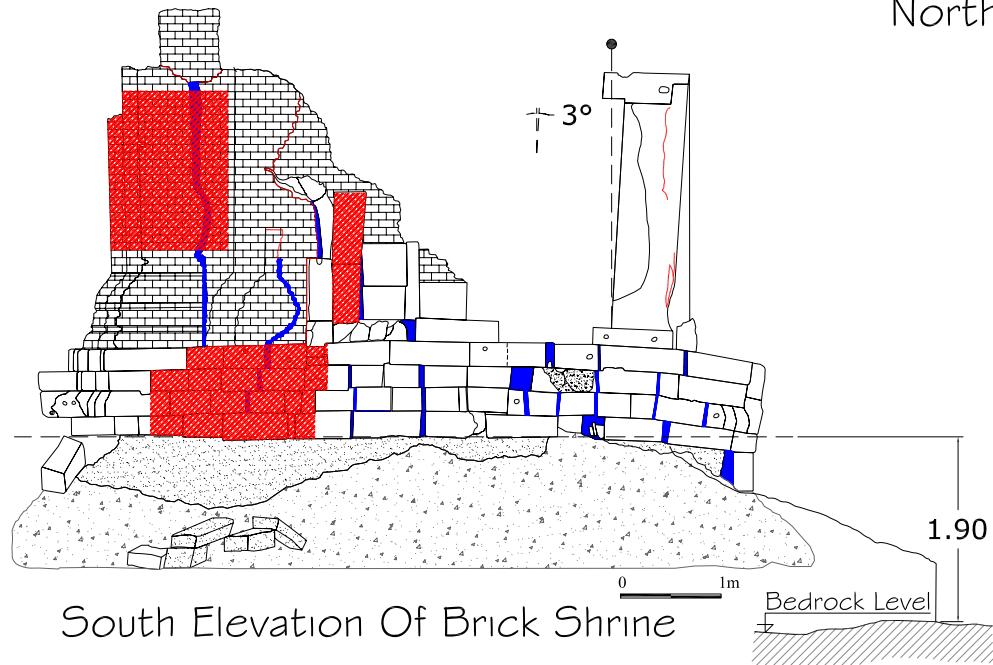
Exterior Elevation of G10 - Structure Condition



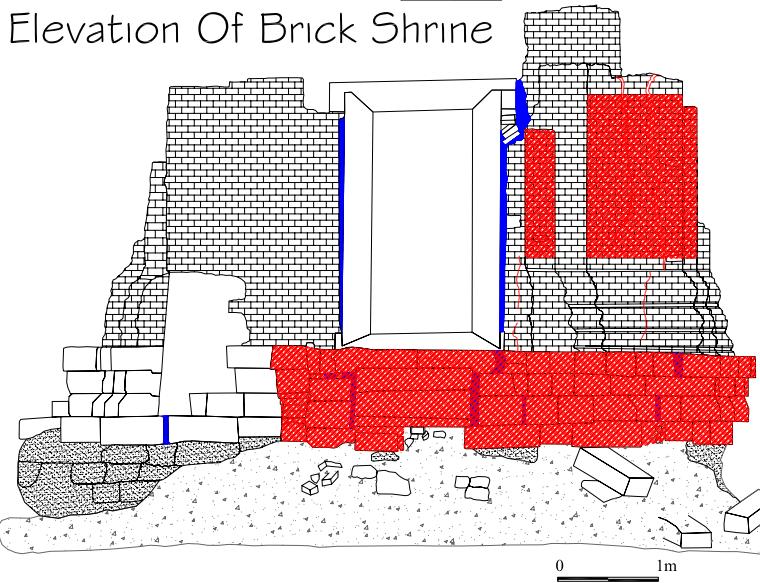
East Elevation Of Brick Shrine



North Elevation Of Brick Shrine



South Elevation Of Brick Shrine



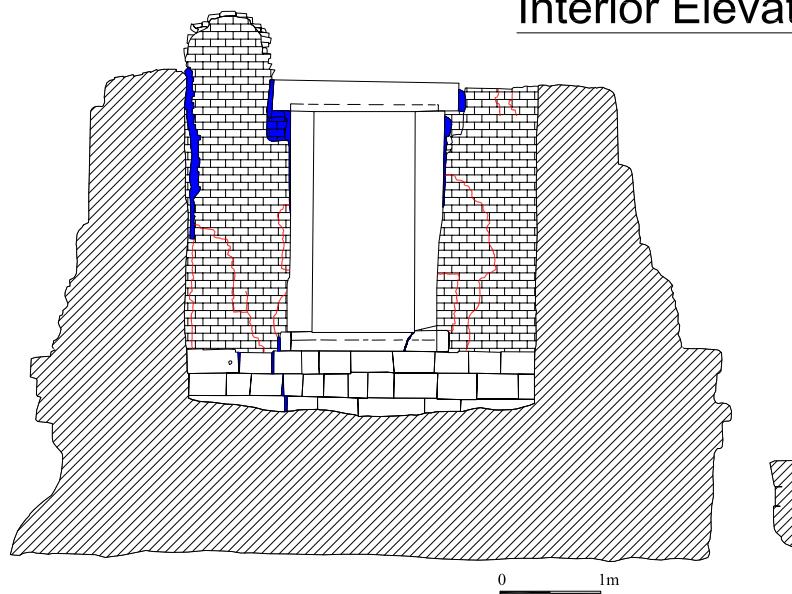
West Elevation Of Brick Shrine

Key

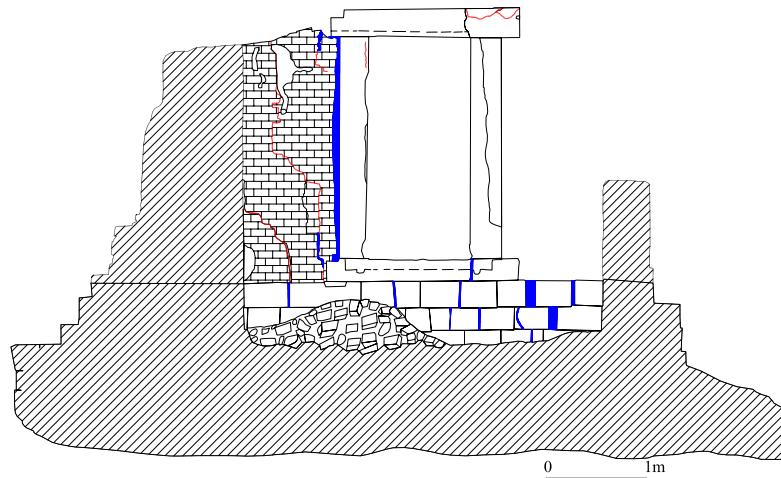
- Gap
- Crack
- Unstable area

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Exterior Elevation of G10 - Structure Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 11

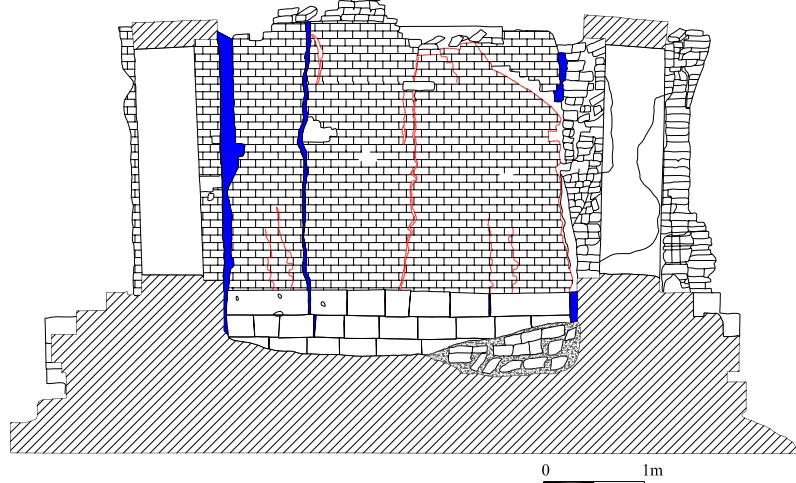
Interior Elevation of G10 - Structure Condition



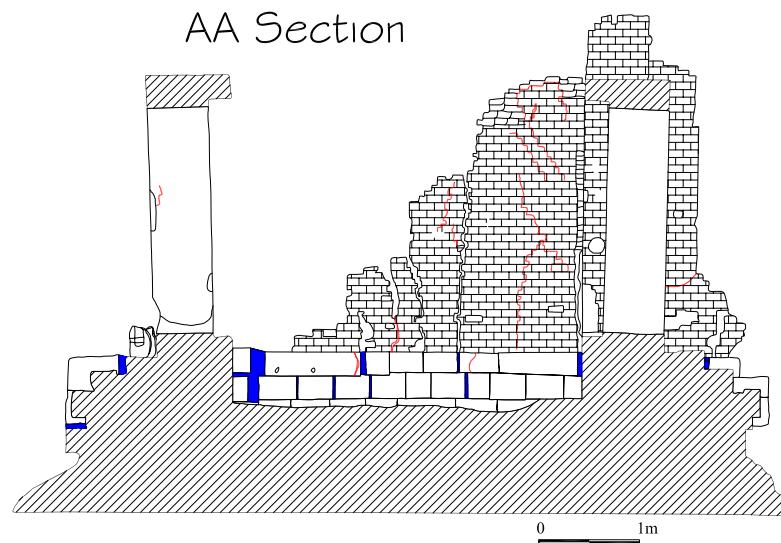
BB Section



AA Section



CC Section



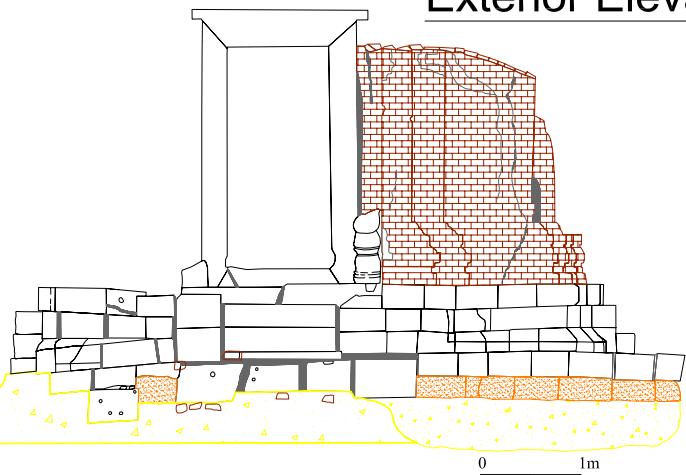
DD Section

Key

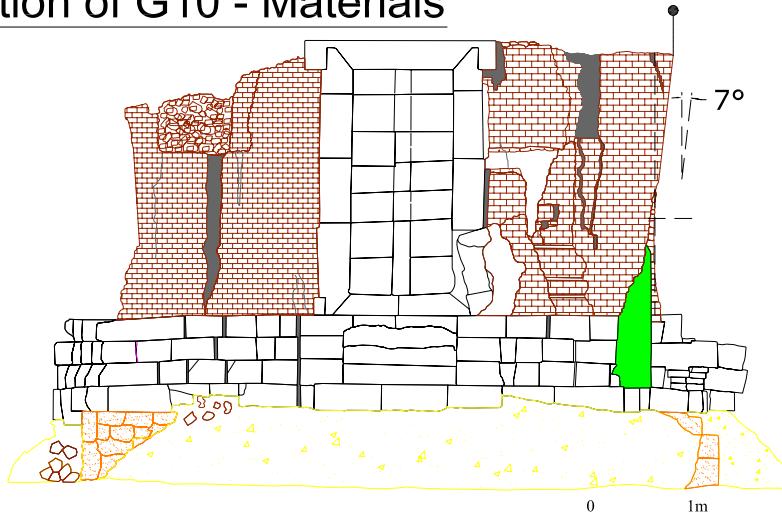
- Gap
- Crack
- Unstable area

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Interior Elevation of G10 - Structure Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 12

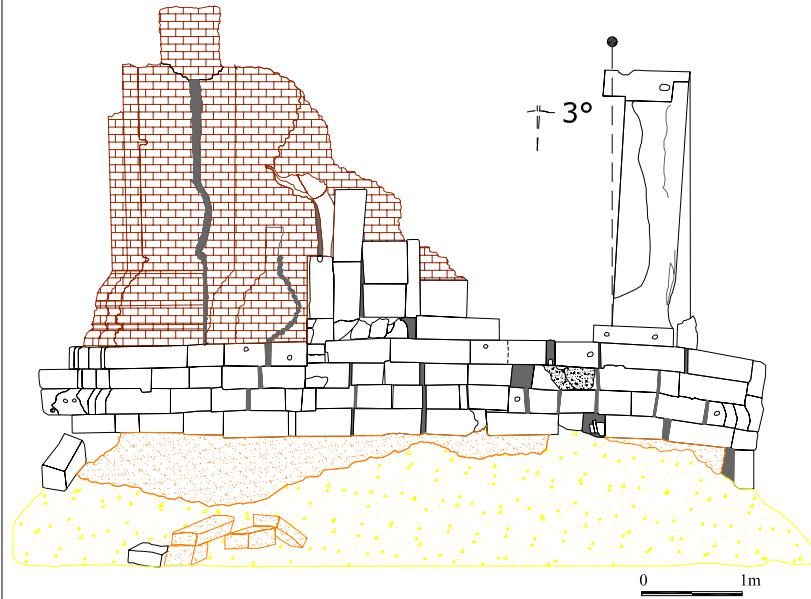
Exterior Elevation of G10 - Materials



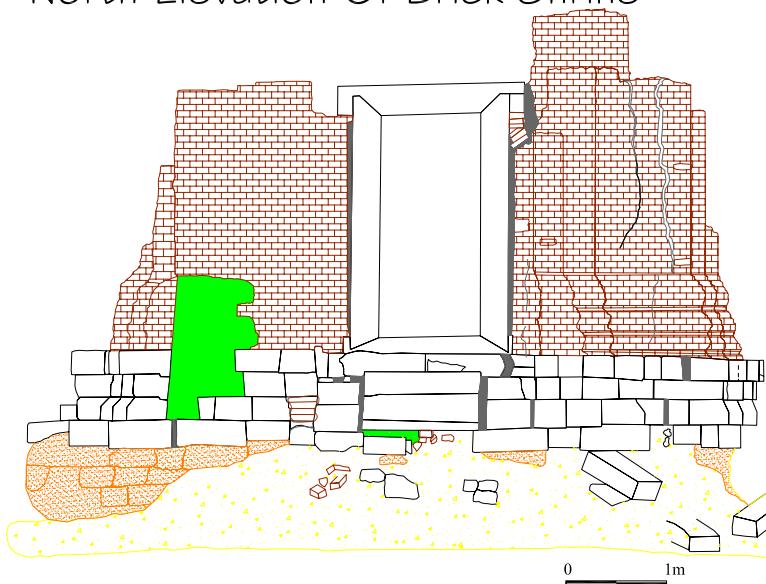
East Elevation Of Brick Shrine



North Elevation Of Brick Shrine



South Elevation Of Brick Shrine



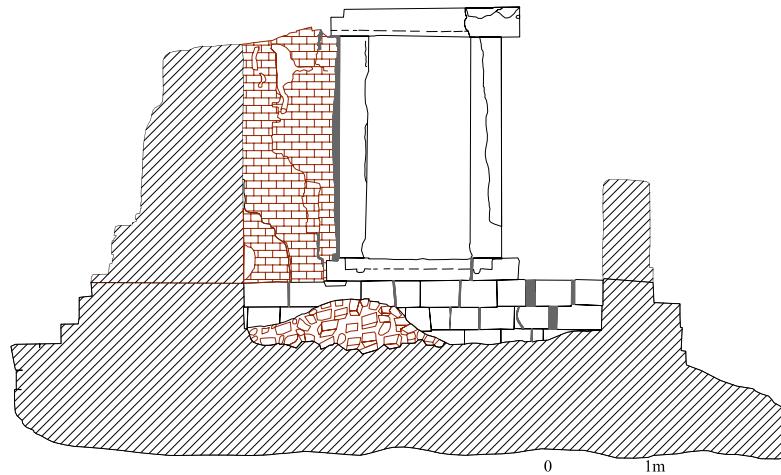
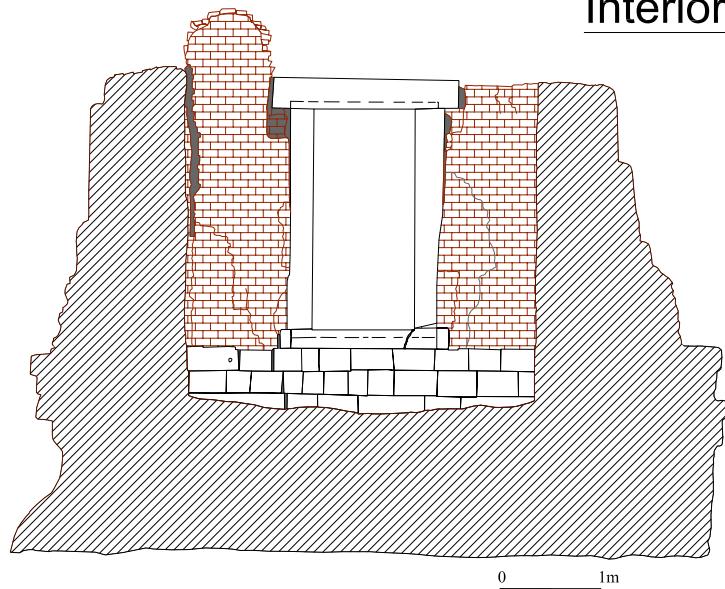
West Elevation Of Brick Shrine

Key

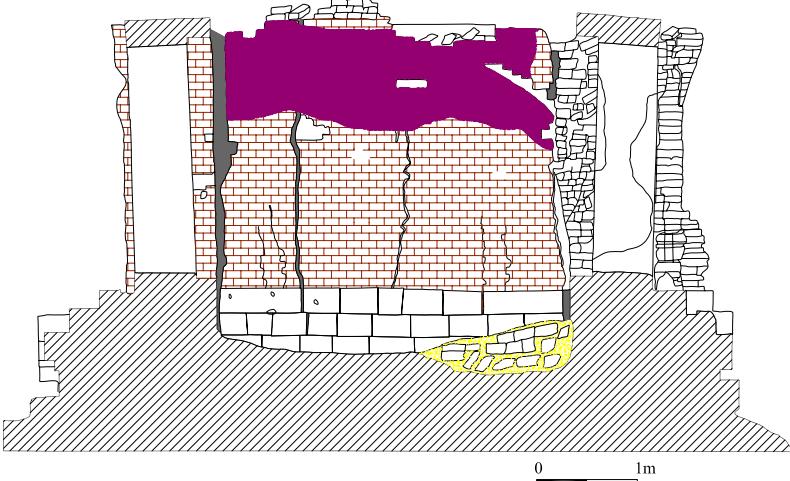
- Sandstone
- Brick
- Latente
- Ground / Soil
- Previous intervention (Concrete)
- Colored plaster

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Exterior Elevation of G10 - Materials	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 13

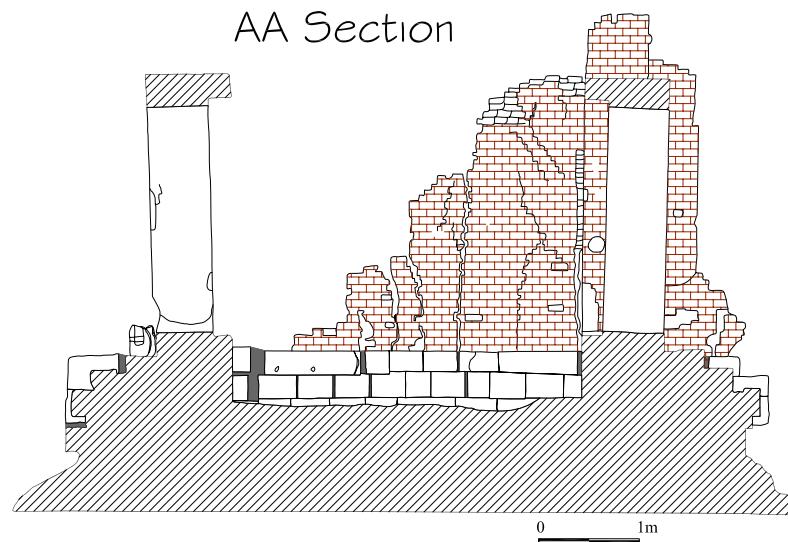
Interior Elevation of G10 - Materials



BB Section



CC Section



DD Section

Key

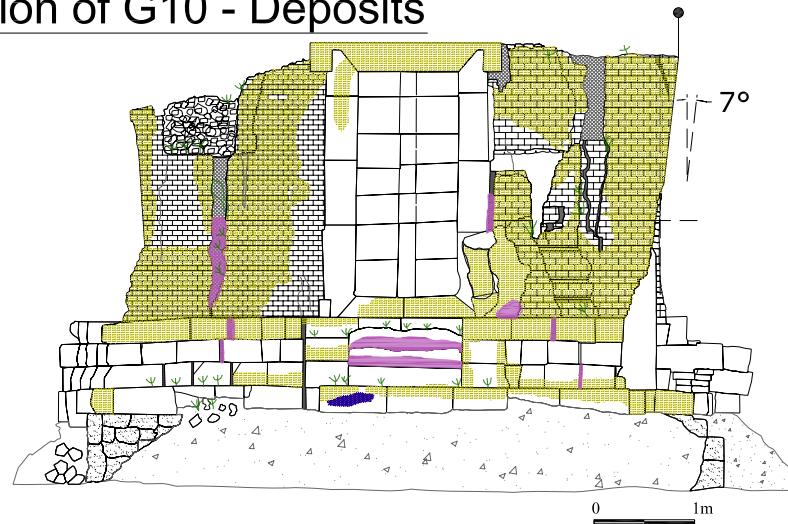
- Sandstone
- Brick
- Latente
- Ground / Soil
- Previous intervention (Concrete)
- Colored plaster

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Interior Elevation of G10 - Materials	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 14

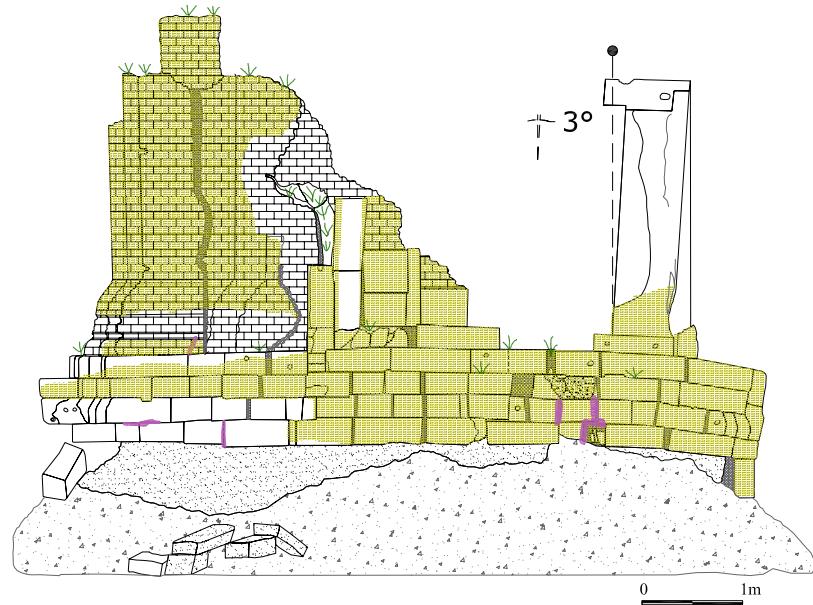
Exterior Elevation of G10 - Deposits



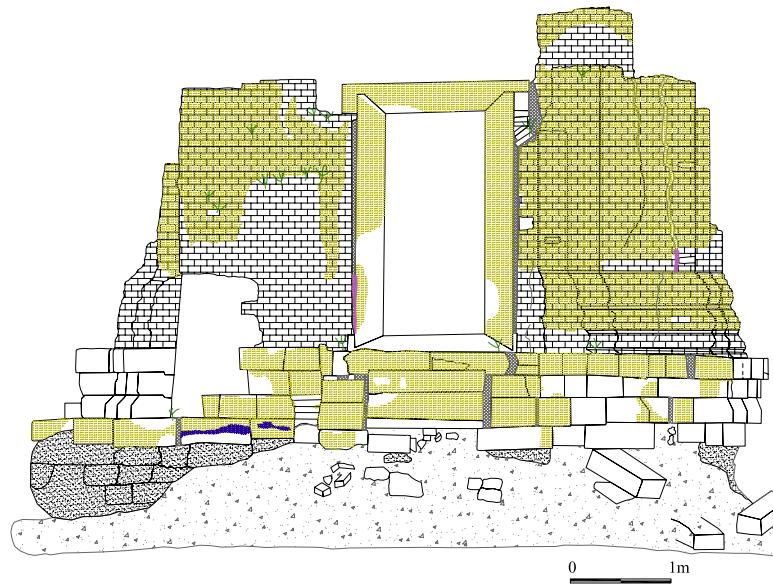
East Elevation Of Brick Shrine



North Elevation Of Brick Shrine



South Elevation Of Brick Shrine



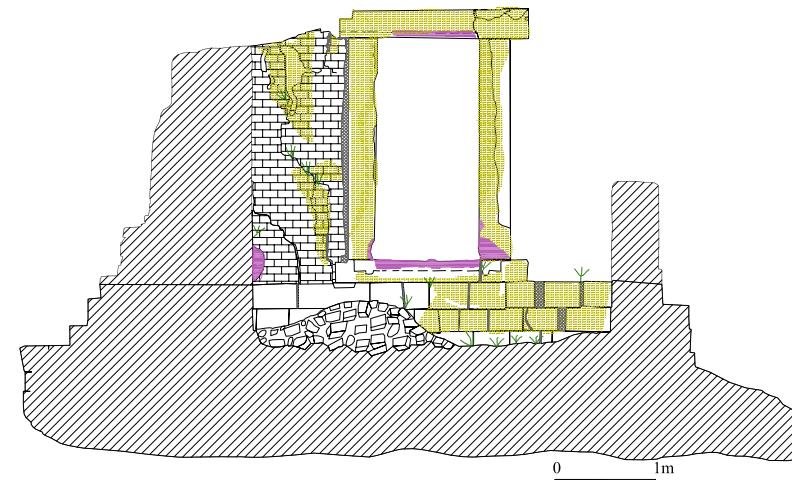
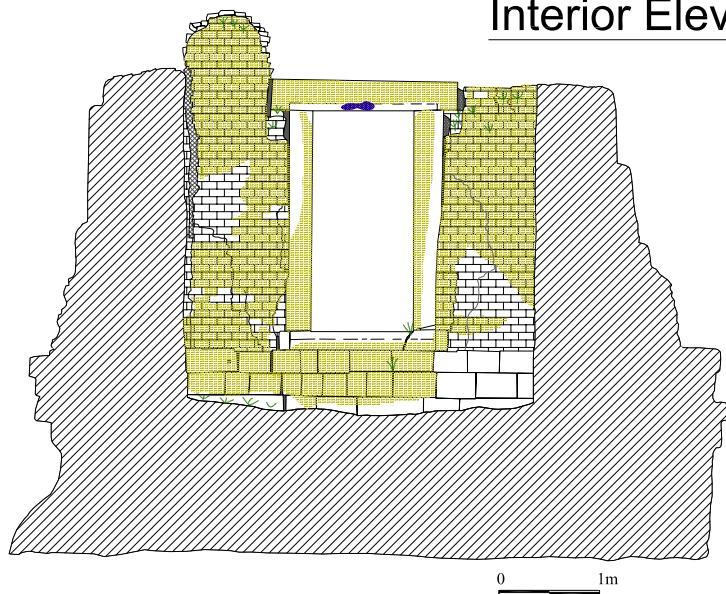
West Elevation Of Brick Shrine

Key

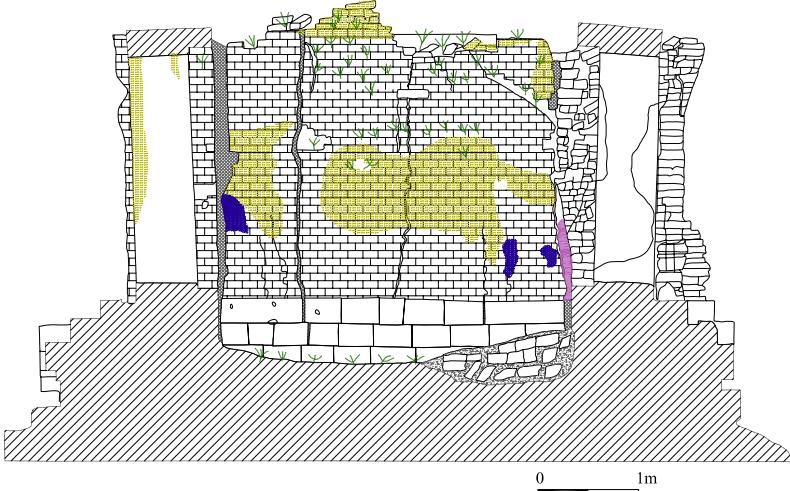
- Soil deposits
- Salt crust
- Biofilm
- Macro - Biological Deposit

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Exterior Elevation of G10 - Deposits	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 15

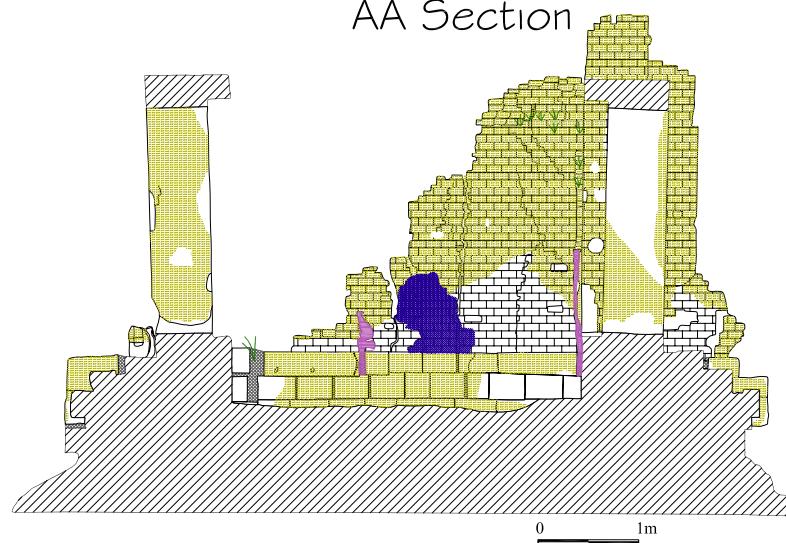
Interior Elevation of G10 - Deposits



BB Section



CC Section



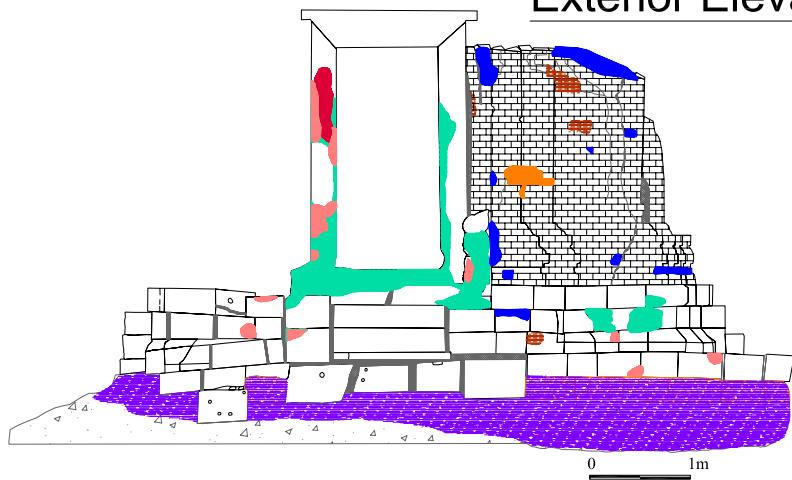
DD Section

Key

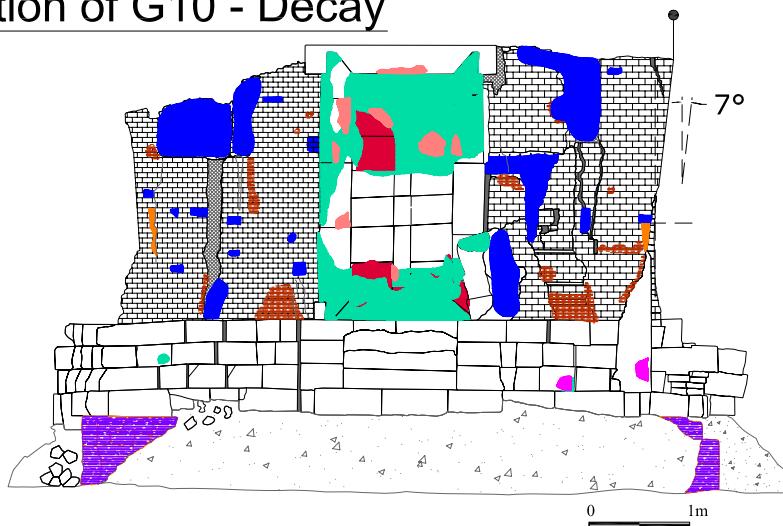
- Soil deposits
- Salt crust
- Biofilm
- Macro - Biological Deposit

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Interior Elevation of G10 - Deposits	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 16

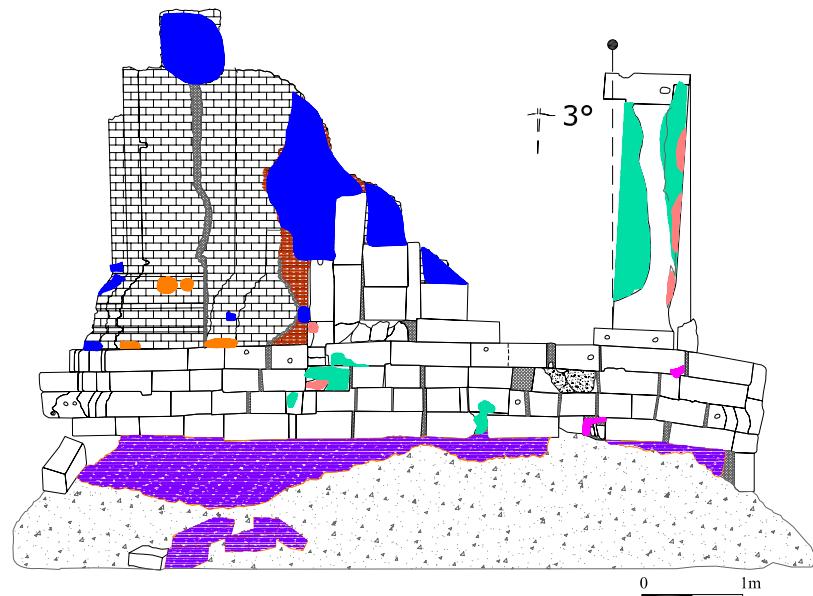
Exterior Elevation of G10 - Decay



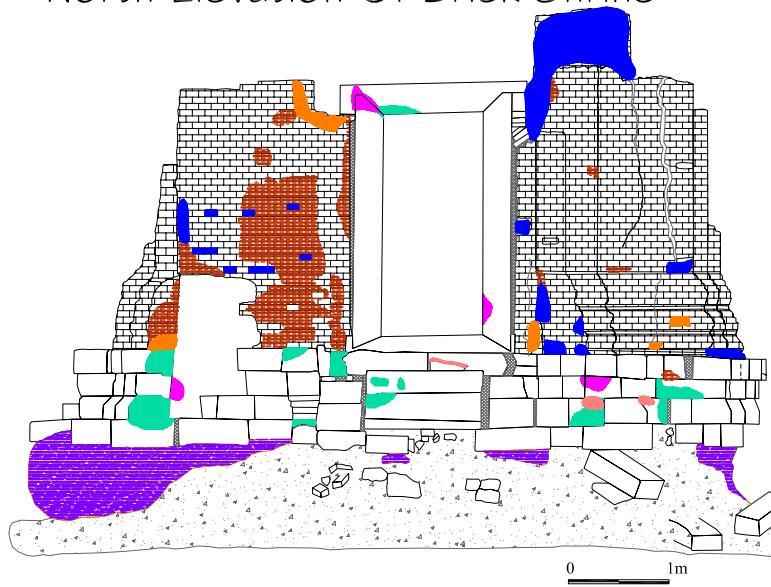
East Elevation Of Brick Shrine



North Elevation Of Brick Shrine



South Elevation Of Brick Shrine



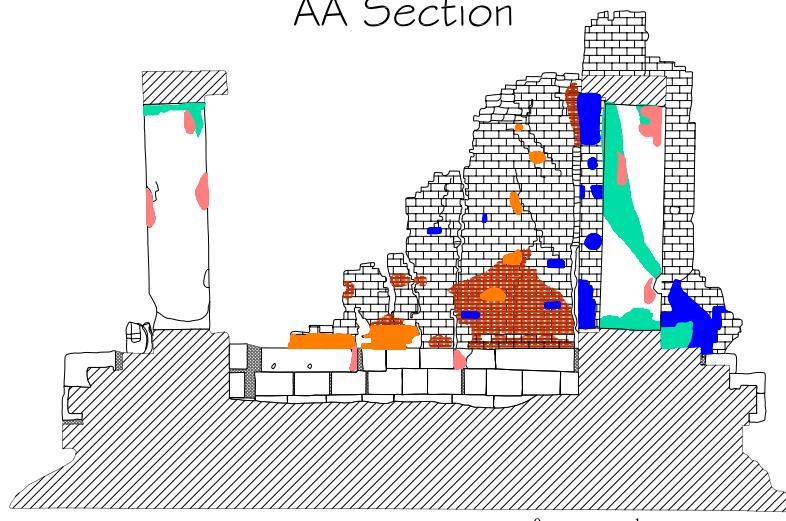
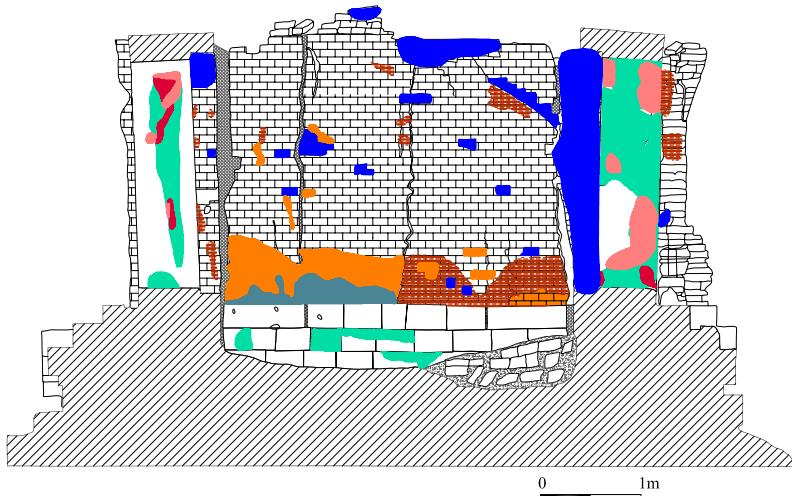
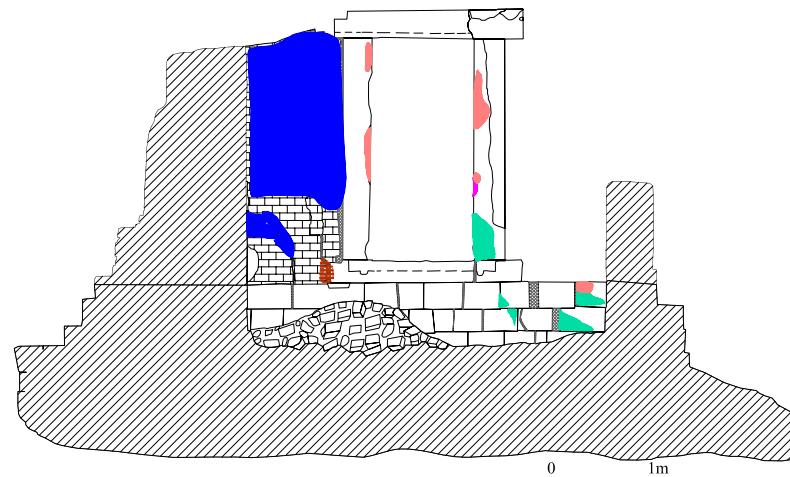
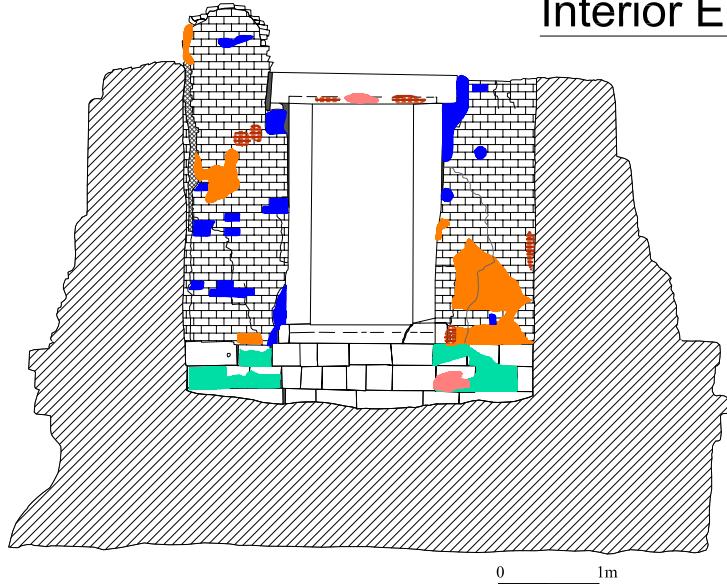
West Elevation Of Brick Shrine

Key

- | | |
|------------------|---|
| Brick | |
| ■ | Brick deterioration |
| ■ | Loss of material |
| ■ | Loss of material due to insect colonization |
| Sandstone | |
| ■ | Sandstone deterioration |
| ■ | Exfoliation |
| ■ | Scale |
| ■ | Loss of material |
| Laterite | |
| ■ | Laterite deterioration |

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Exterior Elevation of G10 - Decay	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 17

Interior Elevation of G10 - Decay

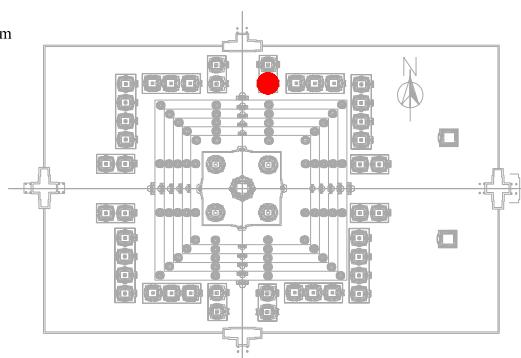
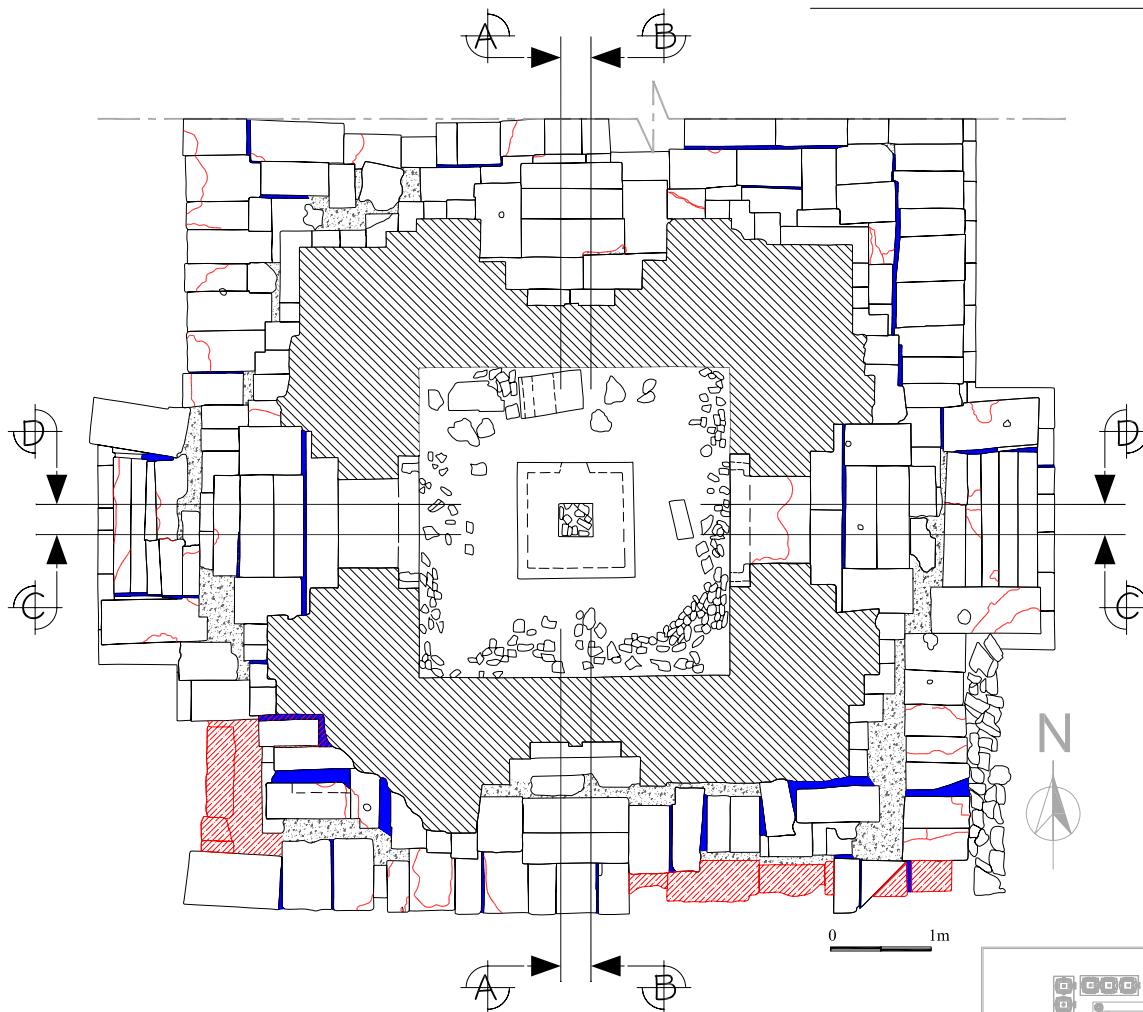


Key

- | | |
|------------------|--|
| Brick | <ul style="list-style-type: none"> ■ Brick deterioration ■ Loss of material ■ Loss of material due to insect colonization |
| Sandstone | <ul style="list-style-type: none"> ■ Sandstone deterioration ■ Exfoliation ■ Scale ■ Loss of material |
| Laterite | <ul style="list-style-type: none"> ■ Laterite deterioration |

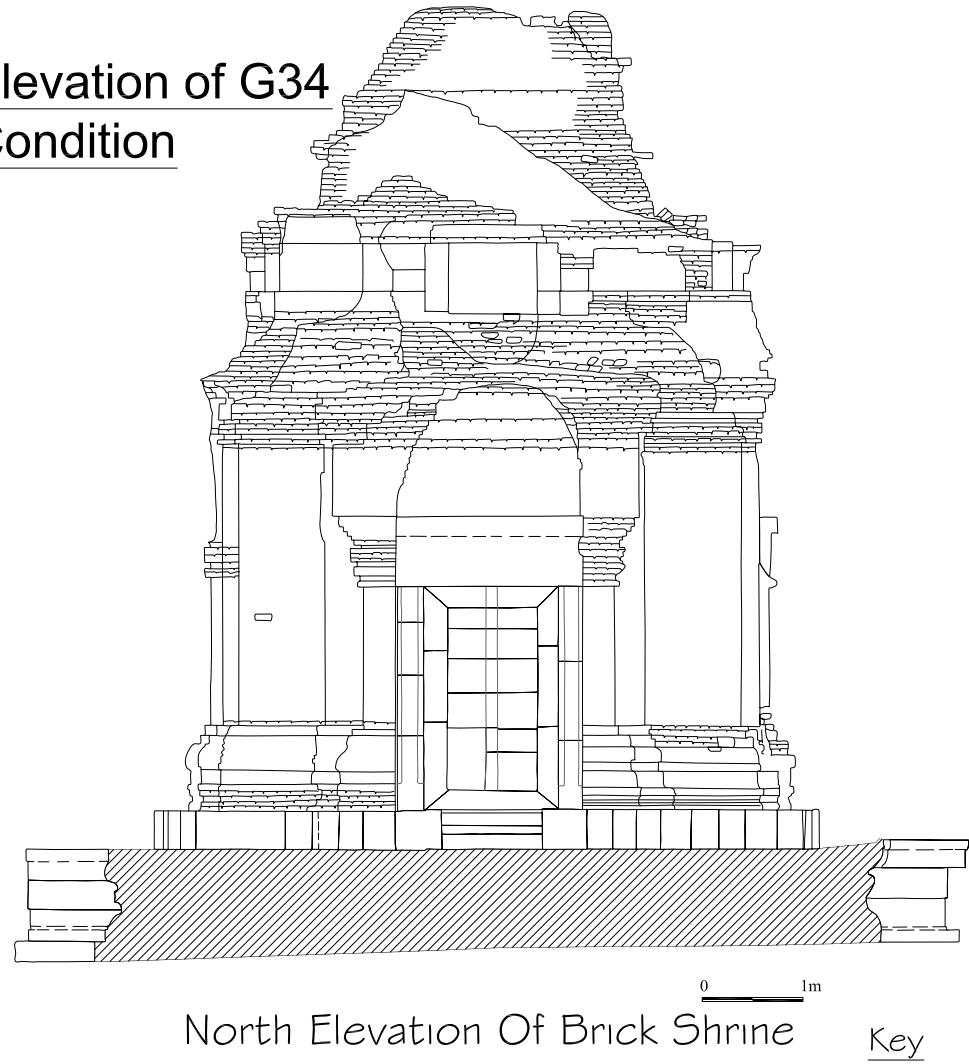
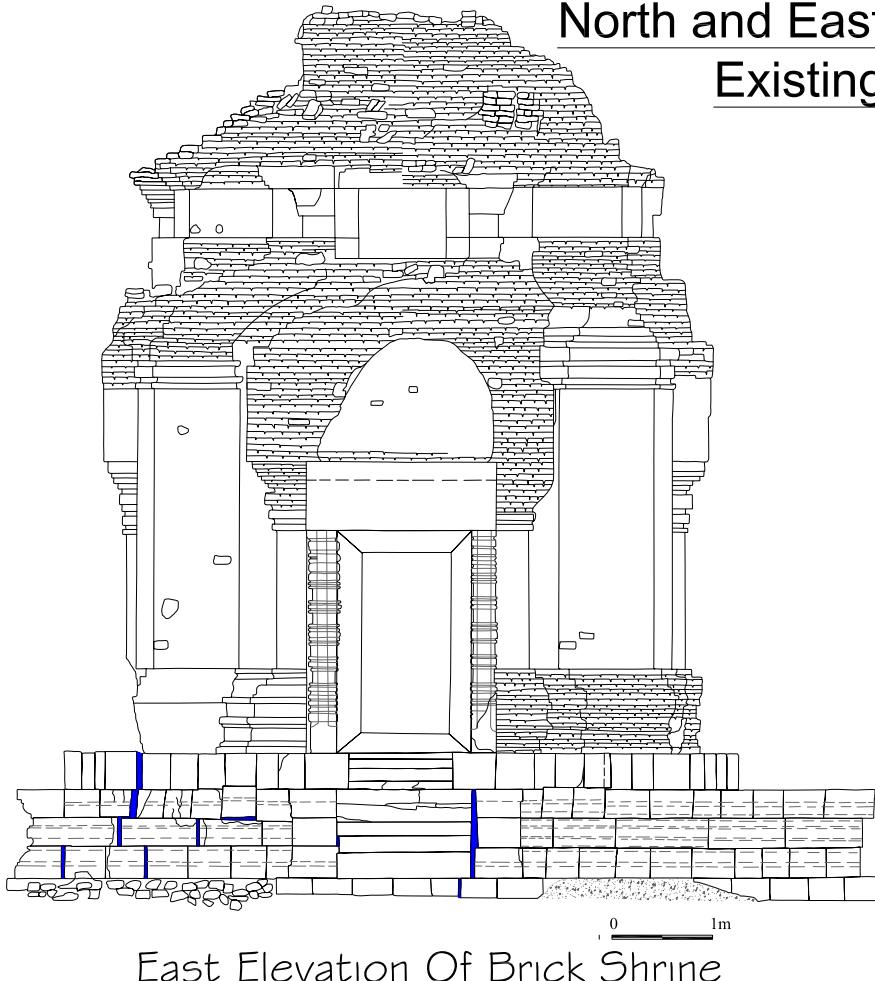
PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Interior Elevation of G10 - Decay	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 18

Plan of G34 - Existing Condition



PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	scale
TITLE:	Plan of G34 - Existing Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 19

North and East Elevation of G34 Existing Condition

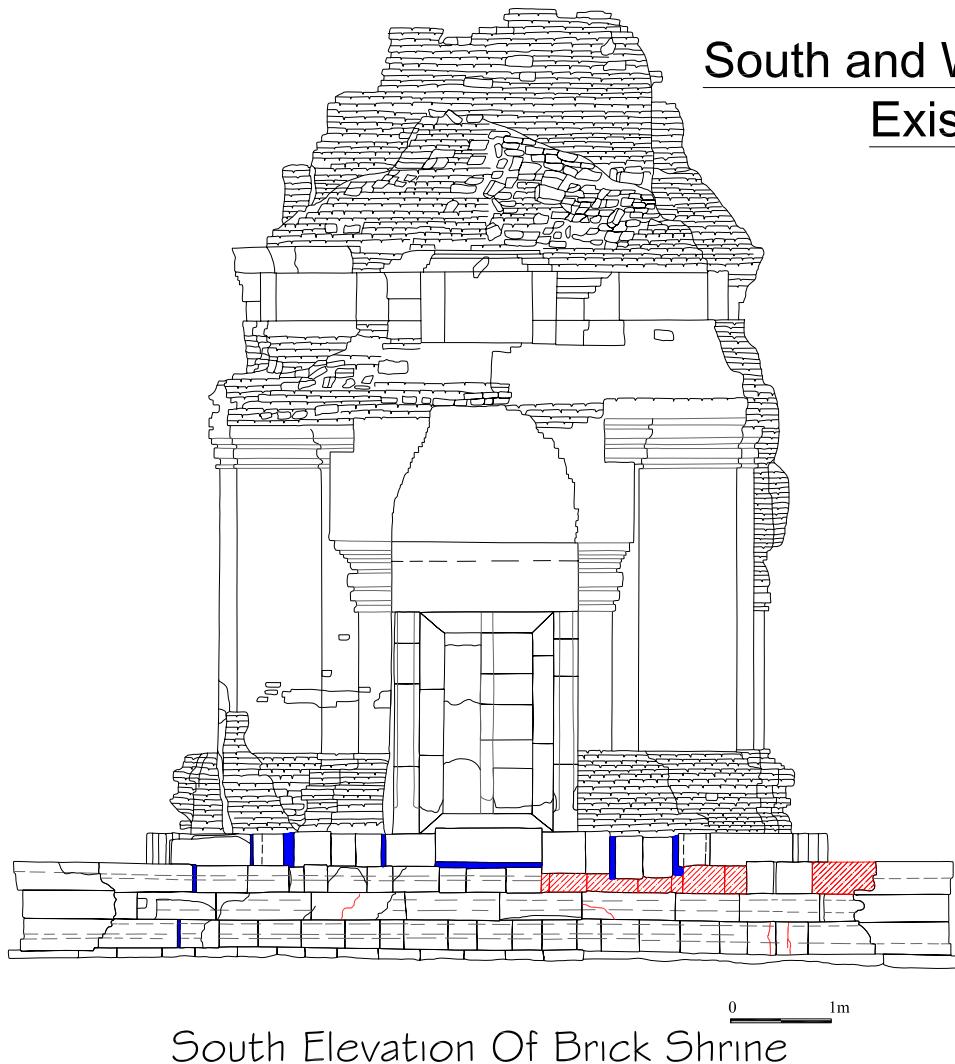


Key

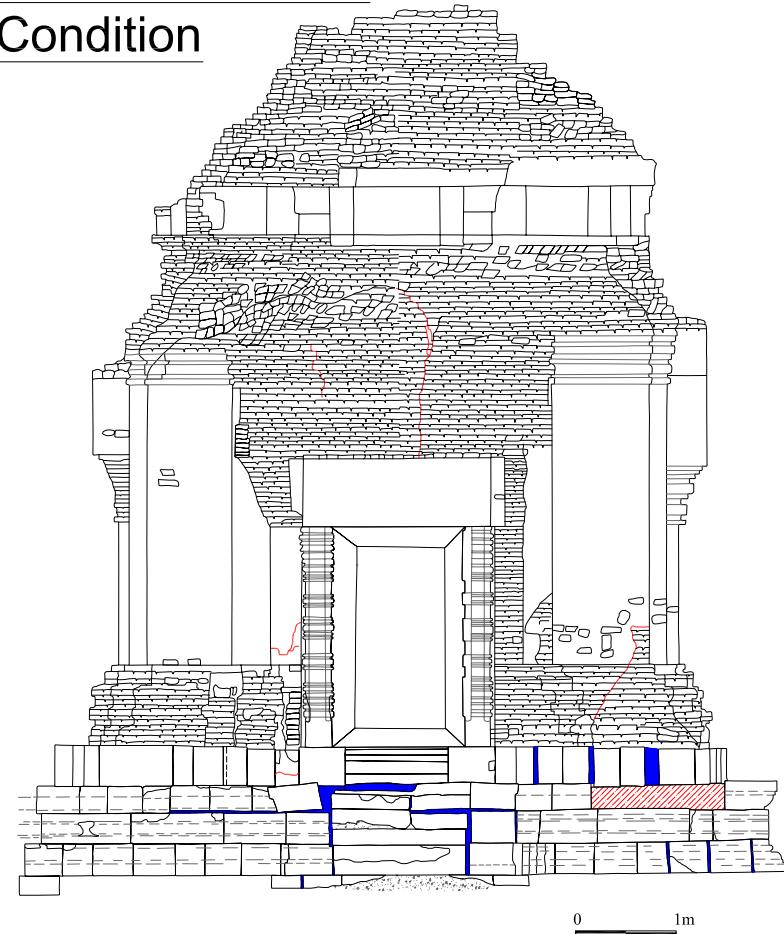
- Gap
- Crack
- Loss stone

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	scale
TITLE:	North and East Elevation of G34 - Existing Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 20

South and West Elevation of G34 Existing Condition



South Elevation Of Brick Shrine



West Elevation Of Brick Shrine

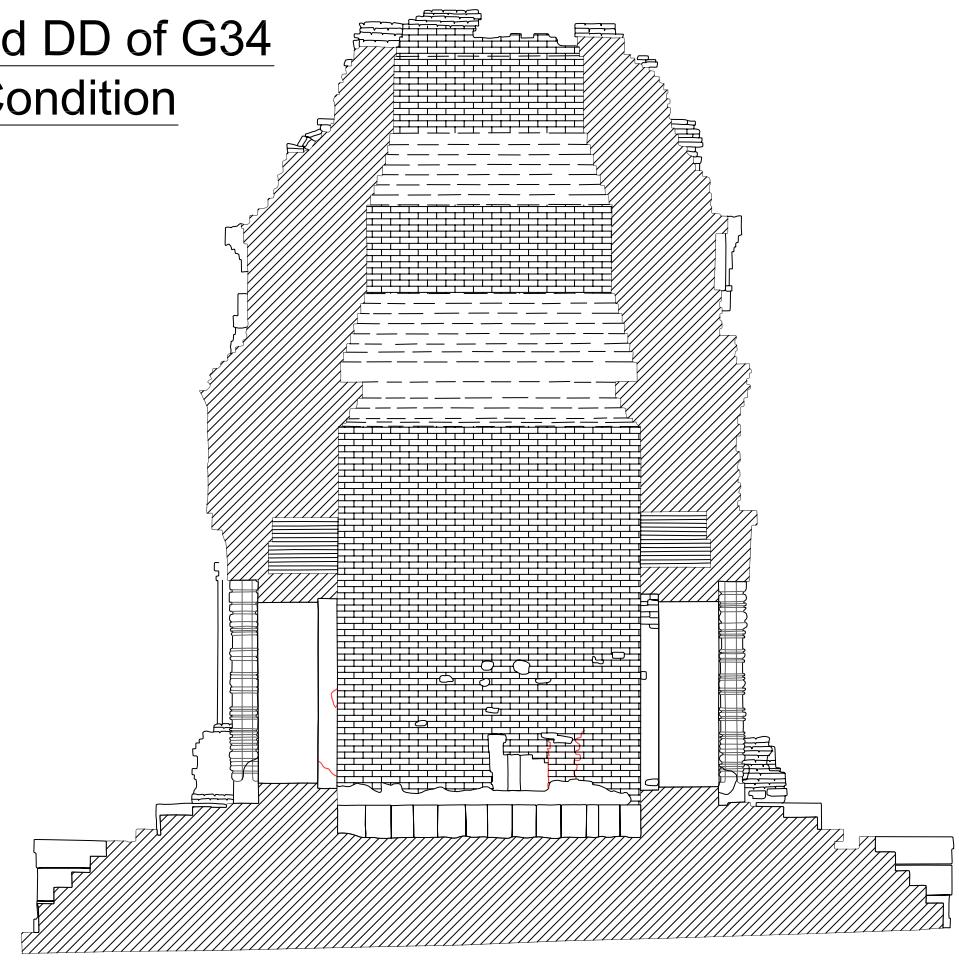
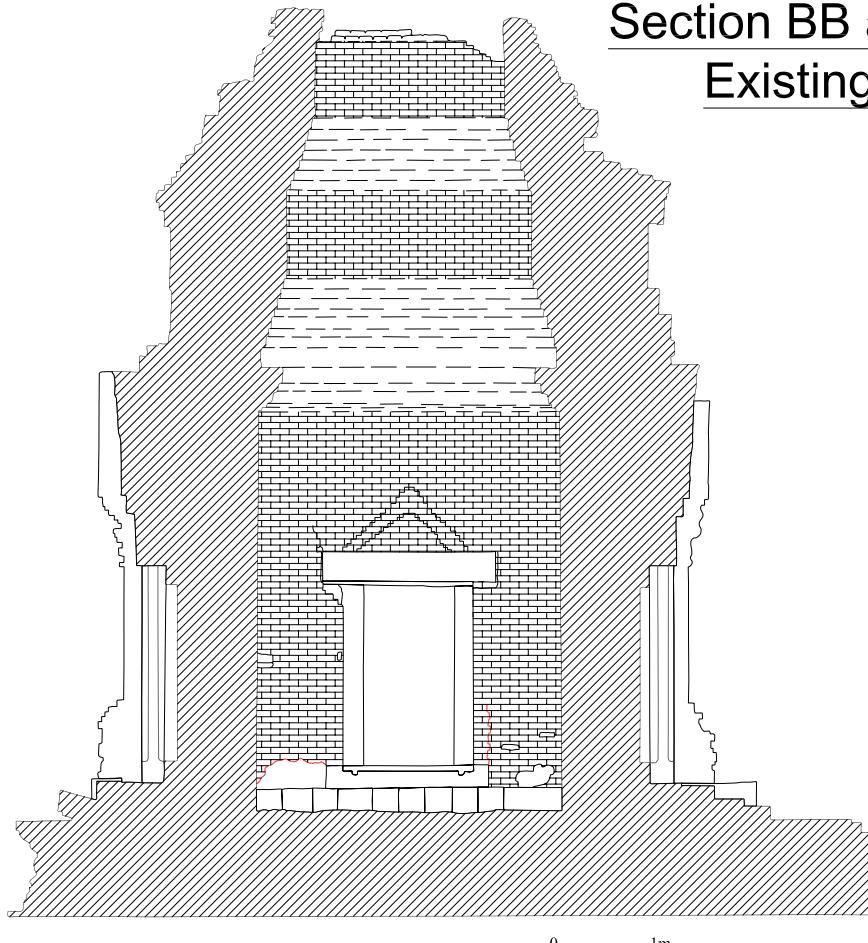
Key

- Gap
- Crack
- Loss stone

 APSARA National Authority	PHNOM BAKHENG JOINT CONSERVATION PROJECT		
	LOCATION NAME:	Phnom Bakheng	
	TITLE:	South and West Elevation of G34 - Existing Condition	21/04/10

Drew by:	Bunwat & WMF Worker	Sheet: 21
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Section BB and DD of G34
Existing Condition

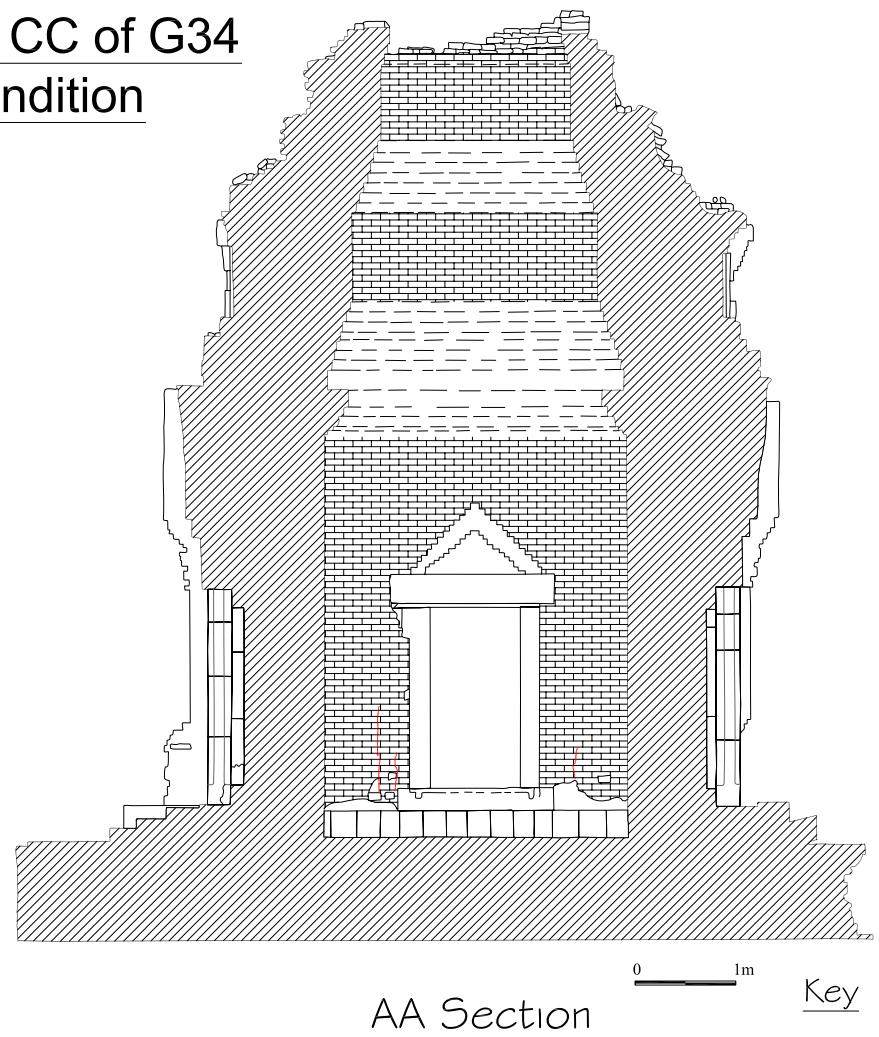
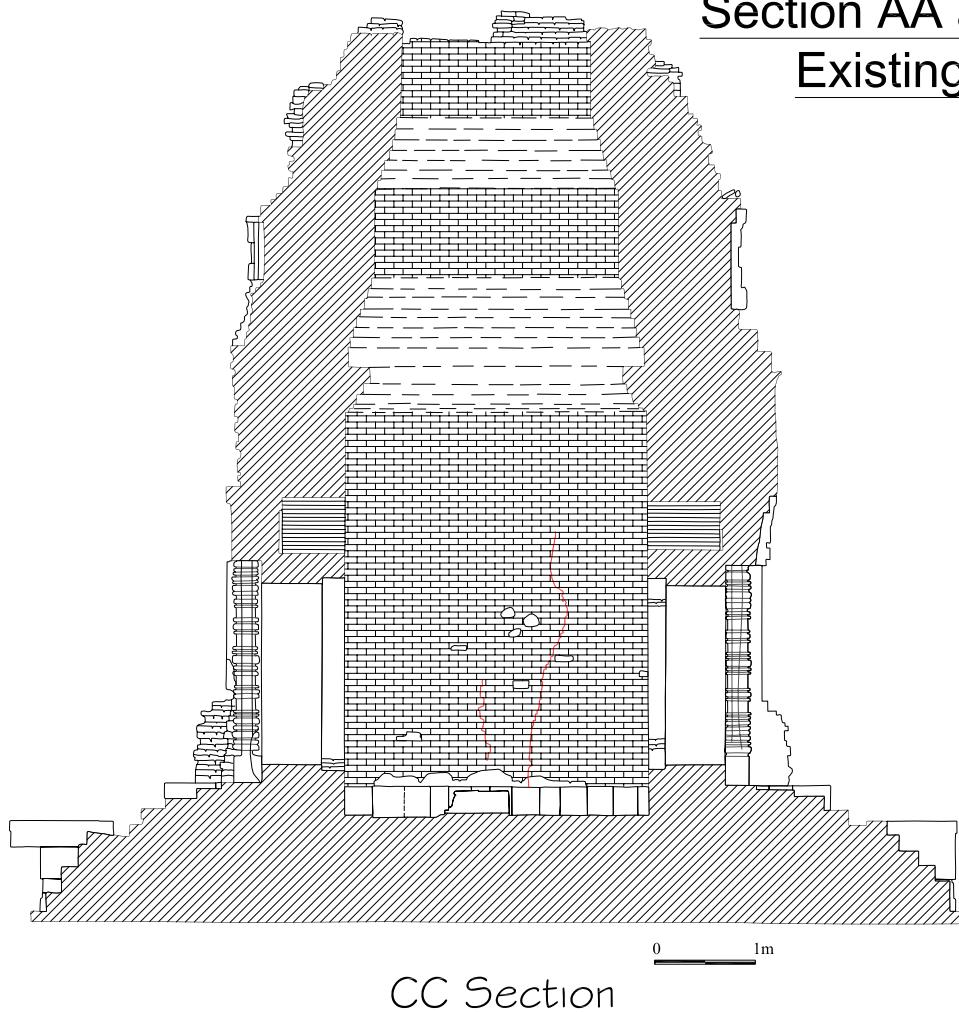


Key

- Gap
- Crack
- Loss stone

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	scale
TITLE:	Section BB and DD of G34 - Existing Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 22

Section AA and CC of G34
Existing Condition

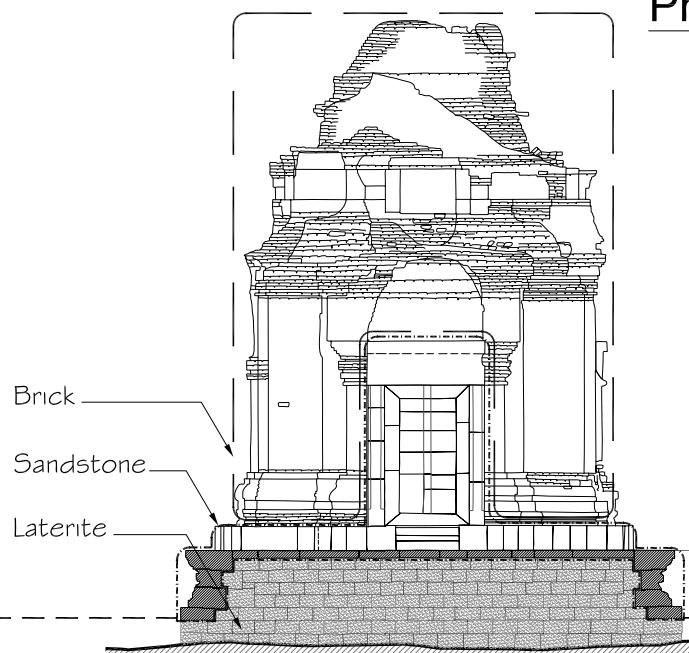


Key

- Gap
- Crack
- Loss stone

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	scale
TITLE:	Section AA and CC of G34 - Existing Condition	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 23

Photos Sample Foundation of Brick Shrines



Sample A



Sample B



Sample A



Sample B

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	scale
TITLE:	Photos Sample Foundation of Brick Shrines	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 24



Southeast Elevation Brick Shrine G10



Southwest Elevation Brick Shrine G10



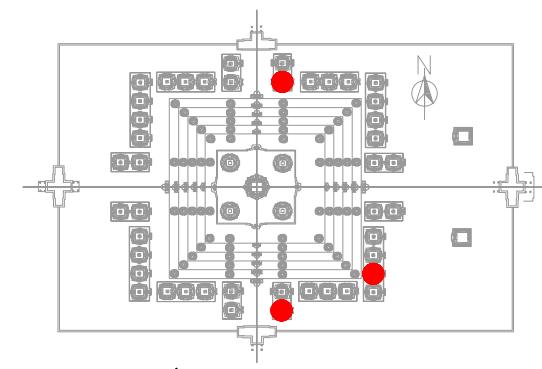
Northeast Elevation Brick Shrine G34



Southwest Elevation Brick Shrine G5



East Elevation Brick Shrine G5



Location

PHNOM BAKHENG JOINT CONSERVATION PROJECT		
LOCATION NAME:	Phnom Bakheng	1/50
TITLE:	Photos of G10, G5, and G34	21/04/10
Drew by:	Bunwat & WMF Worker	Sheet: 25



Phnom Bakheng: Preliminary Materials Testing Report

Angkor, Cambodia

prepared for:

Phnom Bakheng Brick Shrine Workshop

prepared by:

Integrated Conservation Resources

41 East 11th Street

New York, New York, 10003

May 2010

INTEGRATED CONSERVATION RESOURCES, INC.

41 East 11th Street, #310 New York, NY 10003 t 212.947-4499 f 212.947-7766 icr-icc.com

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APPENDIX A: X-RAY DIFFRACTION AND PETROGRAPHIC EXAMINATION OF BRICK

APPENDIX B: FOURIER TRANSFORM INFRARED SPECTROSCOPY OF MORTAR AND STUCCO

APPENDIX C: X-RAY DIFFRACTION SPECTRA OF MORTAR

APPENDIX D: X-RAY DIFFRACTION SPECTRA OF STUCCO

1 INTRODUCTION

Integrated Conservation Resources, Inc. (ICR) conducted and coordinated several analyses on brick, mortar, and stucco samples from Brick Shrine G4 at Phnom Bakheng, Angkor, Cambodia. These samples were taken for the purposes of providing limited relevant data for the workshop.

Additional testing may be required. This report presents the methodologies and findings of the analyses as outlined in the table below.

Brick	Mortar	Stucco
Reflected Light Microscopy	Reflected Light Microscopy	Reflected Light Microscopy
Absorption by Immersion	Fourier Transform Infrared Spectroscopy	Fourier Transform Infrared Spectroscopy
X-Ray Diffraction	X-Ray Diffraction	X-Ray Diffraction
Petrography	Microchemistry	Microchemistry
Compressive Strength	<i>Gas Chromatography-Mass Spectrometry</i> (pending)	

2 BRICK

The brick is buff-colored, low-fired and approximately 10" by 6" by 2 ¼" (25.4 cm by 15.2 cm by 5.7 cm) in size. Samples of the brick were analyzed by reflected light microscopy, water absorption by immersion (and indirect porosity), x-ray diffraction, petrography, and compressive strength testing for limited characterization. The findings are presented below.



Figure 1

View of brick in plan.

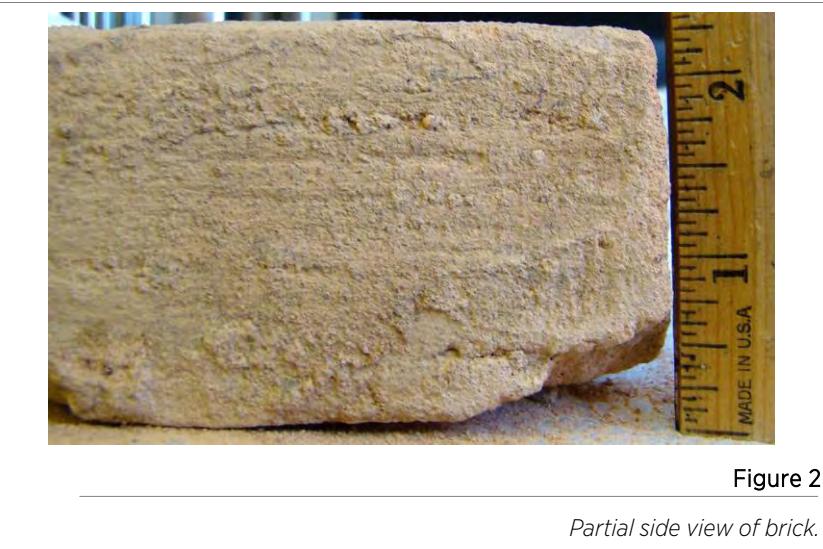


Figure 2

Partial side view of brick.

2.1 REFLECTED LIGHT MICROSCOPY

2.1.1 METHODOLOGY

Freshly broken fragments of the bricks were viewed under a variable magnification, stereo-binocular microscope with a fiber optic light source (3200 Kelvin, with daylight blue filters). The samples were viewed for general characterization (color, texture, pore structure, granular components) of the material. The sample was also matched to a color standard of the Munsell Soil Color Chart. The Munsell System of Color Notation identifies color in terms of three attributes: hue, value, and chroma; color standards are opaque pigmented films on cast-coated paper, mounted on charts for each hue.

2.1.2 FINDINGS

The brick is typically two-tone in overall color, matching Munsell 7.5 YR 7/3 (pink) and 5YR 7/4 (pink). Its aggregate consists of sub-angular and angular grains that are clear, rose, peach, and brown in color. There are iron red inclusions also found throughout the brick. The buff-colored matrix surrounds every aggregate grain and the brick is porous.

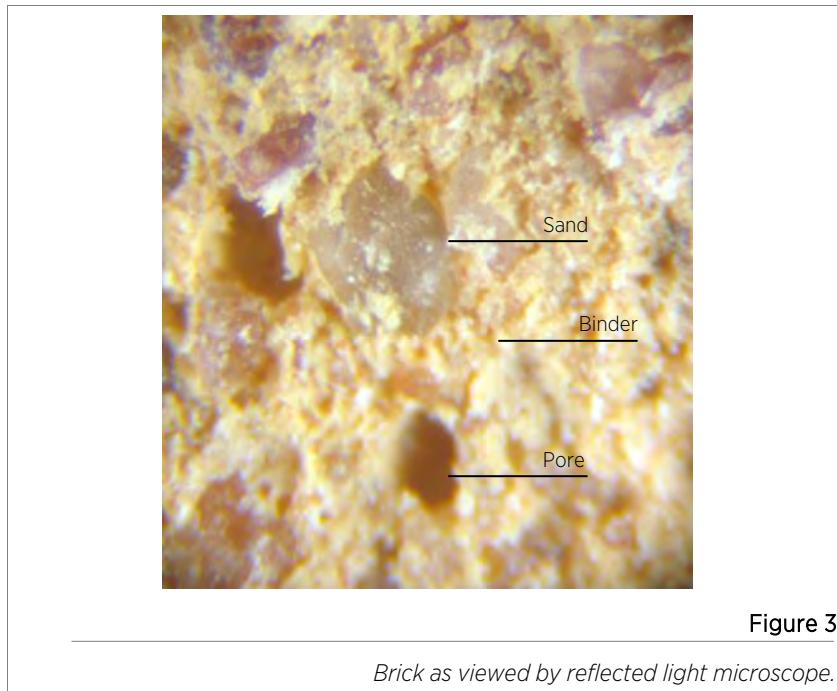


Figure 3

Brick as viewed by reflected light microscope.

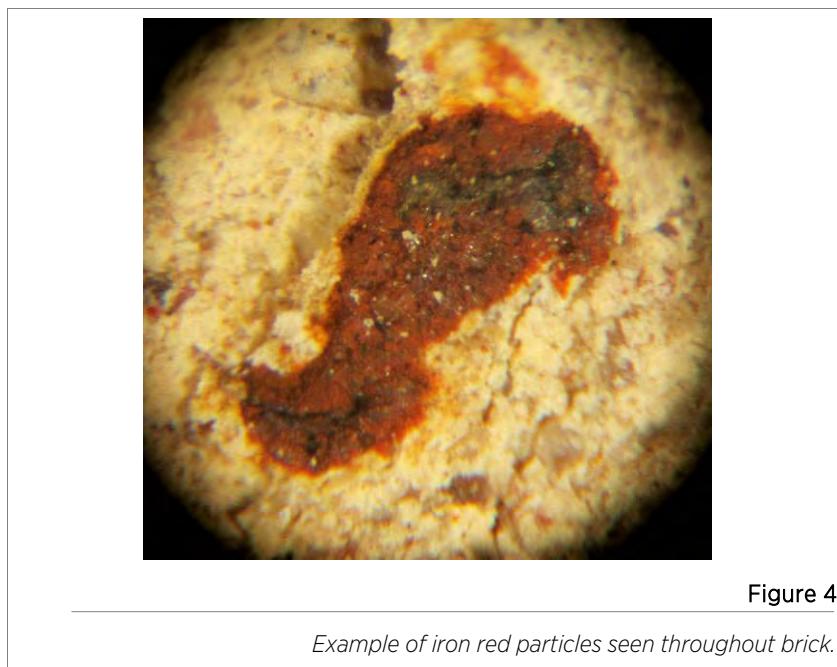


Figure 4

Example of iron red particles seen throughout brick.

2.2 ABSORPTION AND POROSITY

2.2.1 METHODOLOGY

In order to test the absorption rate of water by immersion, a modification of ASTM C67: Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile was used. The brick specimens were irregular in shape due to the size and fragility of the brick and ranged in size from 1"

x 2" x 2" (2.5cm x 5cm x 5cm) to 2" x 3" x 2" (5cm x 7.5cm x 5cm). A total of seven specimens were tested and each specimen had both top and bottom bedding faces intact.

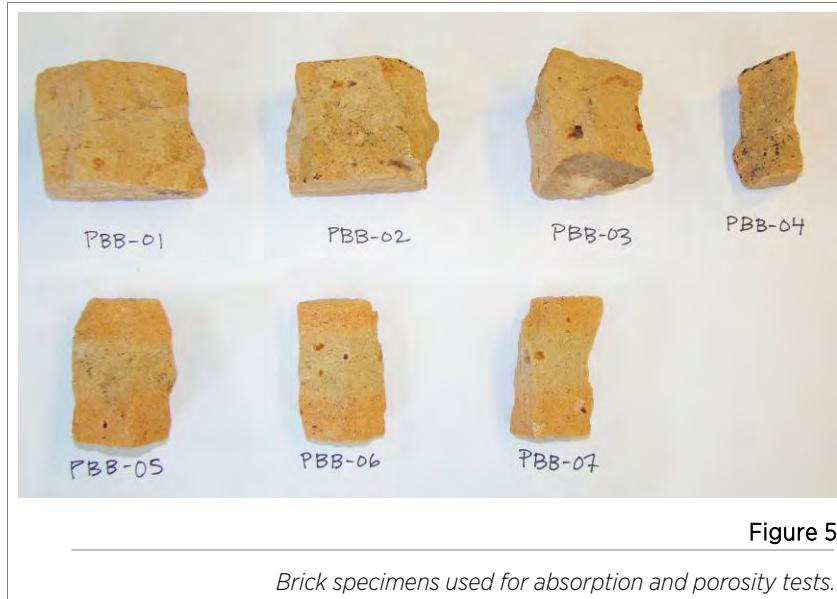


Figure 5

Brick specimens used for absorption and porosity tests.

The specimens were dried in an oven at 230° F (110°C) for several days until two successive weighings at intervals of 2 hours showed an increment of loss not greater than 0.2% of the previously determined specimen weight. The specimens were then cooled in the laboratory (72-75°F/22-24°C and 35% RH) until the brick surface temperature was within 5°F (2.8°C) of the room temperature. The specimens were weighed after cooling and submerged in de-ionized water for 24 hours. The test assemblies into which the specimens were placed contained glass beads so the greatest possible amount of surface area of the brick made contact with water.

After the 24-hour immersion, the specimens were removed from the water, excess water was blotted from the surface of each, and then the specimens were weighed.

Immediately after the 24-hour immersion test was complete, the wet specimens were placed in beakers in boiling water for 5 hours. They were allowed to cool to room temperature and weighed again.

Following the 5-hour boil, select wet specimens were placed in a graduated beaker with a known volume of water and the displaced water volume was measured. Due to equipment limitations, only three specimens were measured for volume.

2.2.2 FINDINGS

Only slight variation in the percentage of water that the seven specimens were able to absorb within a 24-hour period was observed. The 5-hour boil (after the 24-hour water immersion) pushes additional water into pores within the specimens so that they reach nearly maximum absorption. The average percent absorption after boiling was 12.51%.

Comparing the two absorption values, the saturation coefficient for the specimens can be calculated. The saturation coefficient is typically used as an indicator of the durability of the brick. The saturation coefficient for all seven specimens showed very little variation, with an average of 0.68. The tested specimens fall within the parameters for Grade SW (for severe weathering) brick. Following ASTM C216: Standard Specification for Facing Brick, this grading applies to brick that has a maximum absorption of 20.00% or less and a maximum saturation coefficient of 0.80 or less for each individual test brick.

Sample No.	Dry Weight (g)	After 24 hours (g)	After 5 hour boil (g)	24-hour Cold Water Absorption (%)	5-hour Boiling Water Absorption (%)	Saturation Coefficient
PBB- 01	157.039	170.330	176.568	8.46	12.44	0.68
PBB- 02	141.798	153.394	159.338	8.18	12.37	0.66
PBB- 03	105.253	113.472	118.004	7.81	12.11	0.64
PBB- 04	30.965	33.392	34.731	7.84	12.16	0.64
PBB- 05	84.044	91.627	94.733	9.02	12.72	0.71
PBB- 06	47.187	51.247	53.195	8.60	12.73	0.68
PBB- 07	46.208	50.486	52.219	9.26	13.01	0.71
Average				8.45	12.51	0.68

Once the specimens have cooled to room temperature, weighing them while they are still nearly saturated provides the mass of water filling the pores within the specimens. Dividing this mass by the density of water at room temperature (approximately 0.997 g/cm³) provides an estimate of the pore volume within each specimen. The apparent volume of the specimens can be determined by measuring water displacement. Using this volume value, porosity for the three select specimens was calculated. The average percent porosity for these specimens was 24.99%.

Sample No.	Dry Weight (g)	After 5 hour boil (g)	Water Volume (cm ³)	Apparent Specimen Volume (cm ³)	% Porosity
PBB- 04	30.965	34.731	3.755	15	25.03
PBB- 06	47.187	53.195	5.990	24	24.96
PBB- 07	46.208	52.219	5.993	24	24.97
Average				24.99	

The values recorded for water absorption and porosity are similar to those reported for low-fired common brick of the 18th and 19th centuries. The saturation coefficient numbers suggest good resistance to salt crystallization phenomena.

2.3 X-RAY DIFFRACTION

2.3.1 METHODOLOGY

X-ray diffraction (XRD) is an analysis tool that provides identification of crystalline materials. Since wavelengths of x-rays are of the same order as the distances between atoms in crystalline

materials, the latter can act as diffraction gratings. X-rays are directed at the sample while a detector picks up the diffracted x-rays. A diffraction pattern results that is characteristic of each crystalline substance in the sample. This pattern is then compared to reference standards.

2.3.2 FINDINGS

X-ray diffraction analysis indicates quartz is the dominant component of the brick. No other phases were in high enough concentration for a positive identification, but ferripyrophyllite and possible illite clay both have peaks that match some of the very small peaks in the spectra. No hematite or other iron oxides were detected in the pattern despite being present as seen through microscopy and petrography. No evidence of salts (gypsum, halite) were found. The complete report can be found in Appendix A, submitted by James B. Murowchick, Ph.D. with the University of Missouri - Kansas City.

2.4 PETROGRAPHY

2.4.1 METHODOLOGY

Samples were submitted to a petrographer for optical mineralogy investigation. Samples were prepared by vacuum impregnation with clear epoxy, followed by slicing a thin section approximately 30 microns thick. These thin sections were then polished and mounted on a slide for observation under incident light and a polarizing microscope in transmitted light at magnifications from 40x to 400x. A synopsis is provided below; for the complete report refer to Appendix A submitted by James B. Murowchick, Ph.D. with the University of Missouri – Kansas City.

2.4.2 FINDINGS

Petrographic examination revealed that the brick contains abundant silt to sand-sized quartz grains in a fine-grained ferrigenous matrix. The quartz grains range in size from 0.1 to 2 mm. A few grains of chert were found in addition to the quartz. Pores were rounded and 0.4 to 0.7 mm across and are evenly spread throughout the brick. A dark red spot of fine-grained hematite was seen in the thin section and no evidence of salts were found in the matrix or pores.

2.5 COMPRESSIVE STRENGTH

2.5.1 METHODOLOGY

In order to test the compressive strength of the brick, a modification of ASTM C67: Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile was used. Due to some cracking and fragility in the bricks, a consistent and exact sample size for testing was not possible. Sample dimensions are provided in the table below, with area and strength. The instrument used for testing was an Instron 5567 Mechanical Analyzer with a strain rate of 0.01 mm/sec all in a compression mode. Testing was conducted by the Metropolitan Museum of Art.

2.5.2 FINDINGS

The following table presents the results from compressive strength testing.

Brick Sample	Sample Size inches (cm)	Area in ² (cm ²)	Compressive Strength psi (MPa)
1	4.5 x 4 x 2 ¼ (11.43 x 10.16 x 5.72)	13.66 (88.11)	552 (3.81)
2	4.5 x 4 x 2 ¼ (11.43 x 10.16 x 5.72)	13.09 (84.43)	711 (4.90)
3	4 x 3.5 x 2 ¼ (10.16 x 8.89 x 5.72)	10.32 (66.56)	798 (5.50)
4	4 x 3 x 2 ¼ (10.16 x 7.62 x 5.72)	8.18 (52.76)	909 (6.27)
5	5.5 x 4.5 x 2 ¼ (13.97 x 11.43 x 5.72)	18.78 (121.13)	683 (4.71)
Average			731 (5.04)

While the compressive strengths are low compared to modern brick, they are sufficient. For each meter in height there is a compressive strength needed at the base of 0.0226 MPa/m. If it is assumed that there is an uneven distribution of the load, a conservative safety factor of 10 can be applied, which increases the compressive strength needed to 0.226 MPa/m. Given that a typical maximum height of the brick shrine walls is about 10 meters, the required minimum compressive strength, with the safety factor, is 2.262 MPa/m (328 psi). This is well below the crushing strength values recorded in the tests.

3 MORTAR

The mortar extant on the two bricks submitted for testing is irregular in thickness, though generally 1/16" (0.16 cm). Its appearance is similar to the brick in color and texture. The mortar was analyzed by reflected light microscopy, Fourier transform infrared spectroscopy, x-ray diffraction, and microchemistry testing.



Figure 6

Mortar samples from between the bricks.

3.1 REFLECTED LIGHT MICROSCOPY

3.1.1 METHODOLOGY

Freshly broken fragments of the extracted mortar samples from the interior of the joint were viewed under a variable magnification, stereo-binocular microscope with a fiber optic light source (3200 Kelvin, with daylight blue filters). The samples were viewed for general characterization (color, texture, granular components) of the material. The sample was also matched to a color standard of the Munsell Soil Color Chart. The Munsell System of Color Notation identifies color in terms of three attributes: hue, value, and chroma; color standards are opaque pigmented films on cast-coated paper, mounted on charts for each hue.

3.1.2 FINDINGS

The mortar is typically buff in color, matching Munsell 7.5 YR 7/3 (pink). Its aggregate consists of sub-rounded, sub-angular and angular grains that are clear, rose, peach, and brown in color. The buff-colored matrix covers every aggregate grain evenly.

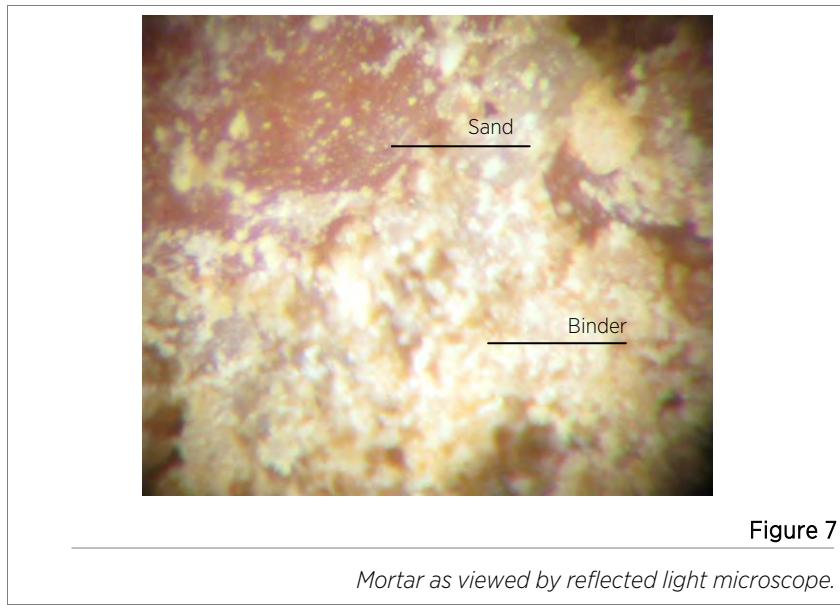


Figure 7

Mortar as viewed by reflected light microscope.

3.2 FOURIER TRANSFORM INFRARED SPECTROSCOPY

3.2.1 METHODOLOGY

FTIR spectroscopy is a tool to characterize organic and inorganic molecules. An infrared beam is directed at the sample and the sample's response is monitored. The energy is transmitted through, reflected off, or absorbed by constituent compounds at a rate that is characteristic of each compound. The frequencies are recorded, measured, and translated into a spectrum that represents particular molecular transmissions, reflections or absorptions, which are unique to each compound. The analysis thus creates a molecular fingerprint of the sample which is then compared to that of a known standard.

The sample was sent to an independent laboratory, Orion Analytical LLC, for analysis (see report and spectra in Appendix B). Analysis was directed at identifying organic compounds, which might suggest some technique or material used in construction. The sample submitted was from the interior of the joint - not from the joint surface (the bricks submitted to ICR's laboratory were not adhered to one another and did not reveal a pointing joint surface at the face of the brick).

3.2.2 FINDINGS

The resulting spectra for the mortar indicated the presence of silica, including quartz. There was no indication of the presence of hydrocarbons. However, a detectable amount of material is necessary in order for the instrument to read the molecular fingerprint. Additionally, the principal materials detected can interfere with the readings of less detectable compounds such as the organics. Further testing is currently being pursued by gas chromatography-mass spectrometry (GCMS). GCMS has a lower threshold for detecting compounds within a material.

The findings suggest no typical binder, such as lime (there was no detection of calcite), was used for pointing or bedding the bricks. However, it is possible that the binder has eroded and washed

away. It is also possible that no mortar was used, but that the bricks were rubbed together during construction resulting in the present appearance of a joint material. This is corroborated by the remarkable similarity of the mortar to the brick by gross visual assessment and reflected light microscopy. Further testing is required.

3.3 X-RAY DIFFRACTION

3.3.1 METHODOLOGY

X-ray diffraction (XRD) is an analysis tool that provides identification of crystalline materials. Since wavelengths of x-rays are of the same order as the distances between atoms in crystalline materials, the latter can act as diffraction gratings. X-rays are directed at the sample while a detector picks up the diffracted x-rays. A diffraction pattern results that is characteristic of each crystalline substance in the sample. This pattern is then compared to reference standards.

3.3.2 FINDINGS

The spectra that resulted from the x-ray diffraction analysis matched that of quartz. The spectra can be seen in Appendix C of this report.

3.4 MICROCHEMISTRY

3.4.1 METHODOLOGY

Samples were tested for water solubility, carbonates, calcium and sulfates using ion specific quantitative test strips and micro-chemical spot testing.

Semi-Quantitative Strip Tests

Calcium and sulfate ions were tested with semi-quantitative strips. A set amount of each sample was powdered, mixed with a set amount of de-ionized water, and stirred for one minute. The test strips were dipped into the sample solution. The concentration of the specific ion causes the reaction zones on the test strip to change color. The test strips were compared to the color chart in the product literature and any color change, indicating the presence of the specific ion, and corresponding concentration was noted.

Micro-Chemical Spot Testing

Testing for solubility in water and the presence of carbonates was completed using chemical spot tests.

A sample was tested for solubility in water by using de-ionized water, which was added to the samples. It was then monitored over a two minute period to determine if all or a portion of the sample was dissolved by water.

The sample was also tested for the presence of the carbonate ion using several drops of 3M hydrochloric acid, which was added to the sample. It was monitored for the evolution of bubbles, a positive indication of the carbonate ion.

3.4.2 FINDINGS

The ion analysis for the mortar resulted in no indication of solubility in water and no presence of carbonates. Semi-quantitative strip tests showed no calcium or sulfate ions present in the mortar.

4 STUCCO

The stucco was taken from the north interior wall of Brick Shrine G5. It is irregular in thickness with a pitted, rough surface that is deep maroon in color. The stucco was analyzed by reflected light microscopy, Fourier transform infrared spectroscopy, x-ray diffraction, and microchemistry testing.

4.1 REFLECTED LIGHT MICROSCOPY

4.1.1 METHODOLOGY

Freshly broken fragments of the submitted stucco samples were viewed under a variable magnification, stereo-binocular microscope with a fiber optic light source (3200 Kelvin, with daylight blue filters). The samples were viewed for general characterization (color, texture, granular components) of the material. The sample was also matched to a color standard of the Munsell Soil Color Chart. The Munsell System of Color Notation identifies color in terms of three attributes: hue, value, and chroma; color standards are opaque pigmented films on cast-coated paper, mounted on charts for each hue. Select samples were mounted in clear resin and polished for better viewing in cross-section.

4.1.2 FINDINGS

The overall surface color of the stucco matches Munsell 5YR 4/4 “reddish brown”. In general, the stucco samples in cross-section exhibited three distinct layers. The typical stratigraphy of the stucco samples submitted for testing includes a cream-colored layer (layer 1); this was followed by a red-orange layer (layer 2), and finally a very thin whitish, semi-opaque layer (layer 3). The cream and red-orange layers feature visible aggregate. The red-orange layer provides the reddish color that is clearly visible in plan, the color coming from both the aggregate within the layer and from the matrix of the layer itself. The whitish layer 3 may be a coating or deposit. Preliminary solubility tests showed that it did not appear to be soluble in either water or hydrochloric acid. There was one sample that contained a bright green layer (layer 4 in Figure 8) over the semi-opaque layer. Advanced analysis did not identify anything that might suggest the components of this layer.

It is known that laterite, which contains iron oxides, is found in the soil in the surrounding area, and may possibly have been added to the stucco as a pigment, thus contributing to the color of the red-orange layer (layer 2).

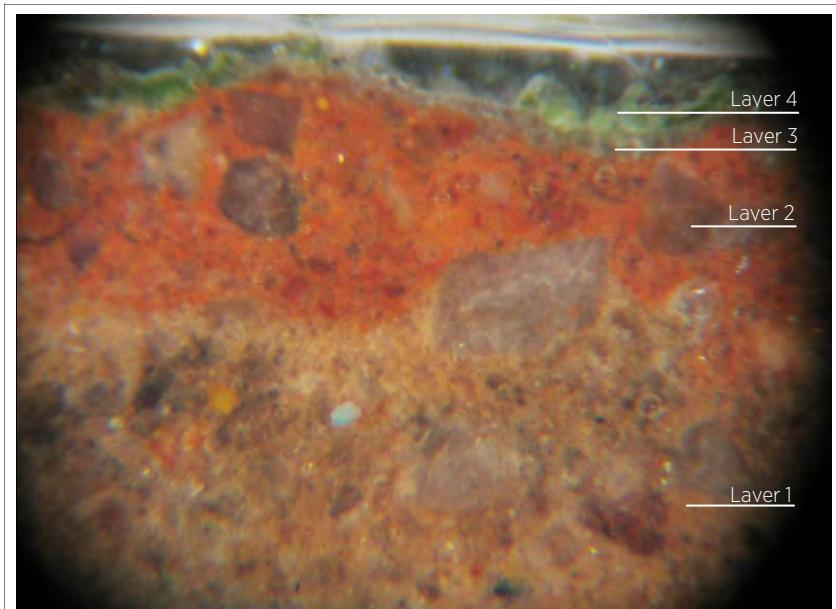


Figure 8

Cross-section of stucco under reflected light microscope.



Figure 9

Exposed surface of stucco, note semi-opaque layer 3 over red-orange layer 2.

4.2 FOURIER TRANSFORM INFRARED SPECTROSCOPY

4.2.1 METHODOLOGY

FTIR spectroscopy is a tool to characterize organic and inorganic molecules. An infrared beam is directed at the sample and the sample's response is monitored. The energy is transmitted through, reflected off, or absorbed by constituent compounds at a rate that is characteristic of each

compound. The frequencies are recorded, measured, and translated into a spectrum that represents particular molecular transmissions, reflections or absorptions, which are unique to each compound. The analysis thus creates a molecular fingerprint of the sample, which is then compared to that of a known standard.

The sample was sent to an independent laboratory, Orion Analytical LLC, for analysis (see complete report in Appendix B). Analysis was directed at identifying organic compounds, which might suggest the use of a coating remaining from previous treatment interventions.

4.2.2 FINDINGS

The resulting spectra for the stucco indicated the presence of clay and silica, including quartz. There was no indication of the presence of hydrocarbons. However, a detectable amount of material is necessary in order for the instrument to read the molecular fingerprint. Additionally, the principal materials detected can interfere with the readings of less detectable compounds such as the organics.

4.3 X-RAY DIFFRACTION

4.3.1 METHODOLOGY

X-ray diffraction (XRD) is an analysis tool that provides identification of crystalline materials. Since wavelengths of x-rays are of the same order as the distances between atoms in crystalline materials, the latter can act as diffraction gratings. X-rays are directed at the sample while a detector picks up the diffracted x-rays. A diffraction pattern results that is characteristic of each crystalline substance in the sample. This pattern is then compared to reference standards.

4.3.2 FINDINGS

The spectra that resulted from the x-ray diffraction analysis matched that of quartz. The spectra can be seen in Appendix D of this report.

4.4 MICROCHEMISTRY

4.4.1 METHODOLOGY

Samples were tested for water solubility, carbonates, calcium, sulfates and iron using ion specific quantitative test strips and micro-chemical spot testing.

Semi-Quantitative Strip Tests

Calcium and sulfate ions were tested with semi-quantitative strips. A set amount of each sample was powdered, mixed with a set amount of de-ionized water, and stirred for one minute. The test strips were dipped into the sample solution. The concentration of the specific ion causes the reaction zones on the test strip to change color. The test strips were compared to the color chart in

the product literature and any color change, indicating the presence of the specific ion, and corresponding concentration was noted.

Micro-Chemical Spot Testing

Testing for solubility in water and the presence of carbonates and iron was completed using chemical spot tests.

A sample was tested for solubility in water by using de-ionized water, which was added to the sample. It was then monitored over a two minute period to determine if all or a portion of the sample was dissolved by water.

Testing for the presence of the carbonate ion used several drops of 3M hydrochloric acid, which were added to the samples. Samples were monitored for the evolution of bubbles, a positive indication of the carbonate ion.

A sample was also tested for iron (III) ions by micro-chemical spot test. Iron (III) ions will dissolve in hydrochloric acid and after drying on an oven will react with potassium ferrocyanide to form ferric ferrocyanide, a bright blue complex (Prussian blue).

4.4.2 FINDINGS

The ion analysis for the stucco resulted in no indication of solubility in water and no presence of carbonates. There was a positive result for the iron (III) ion spot test. Semi-quantitative strip tests showed 0-10 mg/L of calcium and no sulfate ions present in the stucco.

APPENDIX A: X-RAY DIFFRACTION AND PETROGRAPHIC EXAMINATION OF BRICK

Petrographic examination of Cambodian fired brick sample

A sample of red fired brick was provided for petrographic examination. The sample is brick red, has a dull luster, and is moderately lightweight, fairly soft, and porous.

X ray diffraction analysis of the sample (Figure 1) indicates quartz is the dominant component of the brick. No other phases were present in a high enough concentration to permit positive identification, but ferripyrophyllite ($\text{Fe}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$) and possibly illite clay both have peaks that match some of the very small peaks in the pattern. Surprisingly, no peaks for hematite (Fe_2O_3) or other red iron oxides/oxyhydroxides were detected in the pattern. No evidence of salts (gypsum, halite) was found by X ray diffraction.

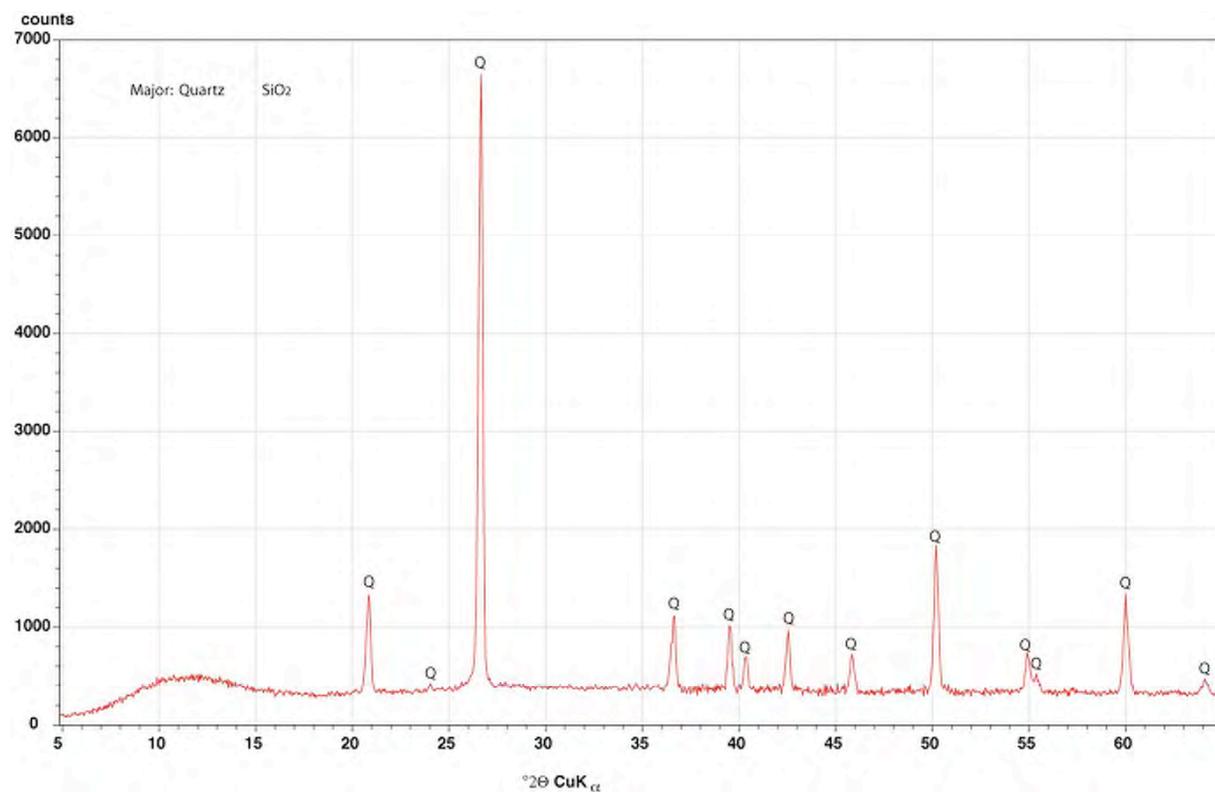


Fig. 1: X ray diffractogram of fired brick. Quartz is the dominant phase present, though the very small peaks near 10° may be due to clay minerals. The broad hump from 7-15° is produced by the mounting plate, not the sample.

Petrographic examination revealed that the brick contains abundant silt to sand-sized quartz grains held in a very fine-grained, ferrigenous matrix (Figures 2 to 6). The quartz grains range in size from 0.1 to 2 mm. Nearly all the grains are monocrystalline quartz grains, though a few grains of chert were found. Rounded pores 0.4-0.7 mm across are evenly spread throughout the brick. A dark red spot (2.5 x. 3 mm) of very fine-grained hematite was exposed in the thin section (Figures 2 and 7). No evidence of salts was found, either in the matrix or in the pores.

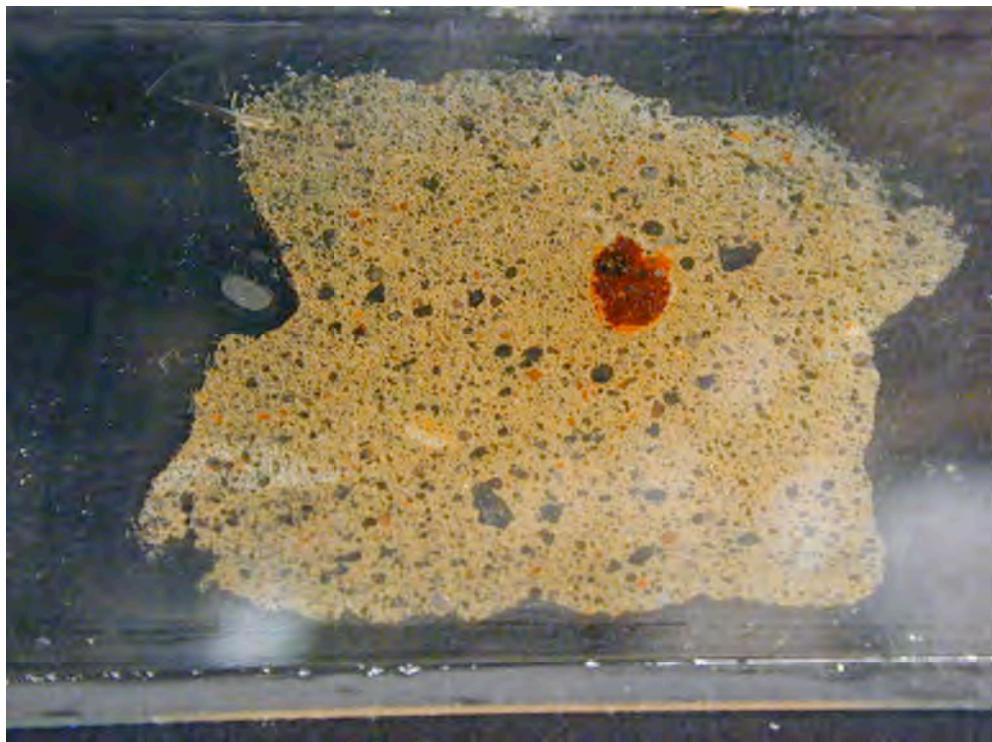


Fig. 2: Thin section of fired brick. The large red hematitic clot is about 2.5mm x 3 mm, with numerous small red-orange pigmented spots throughout the sample in an otherwise tan matrix. Quartz grains and pores are dark gray. The sample is 28 mm wide. Incident light.

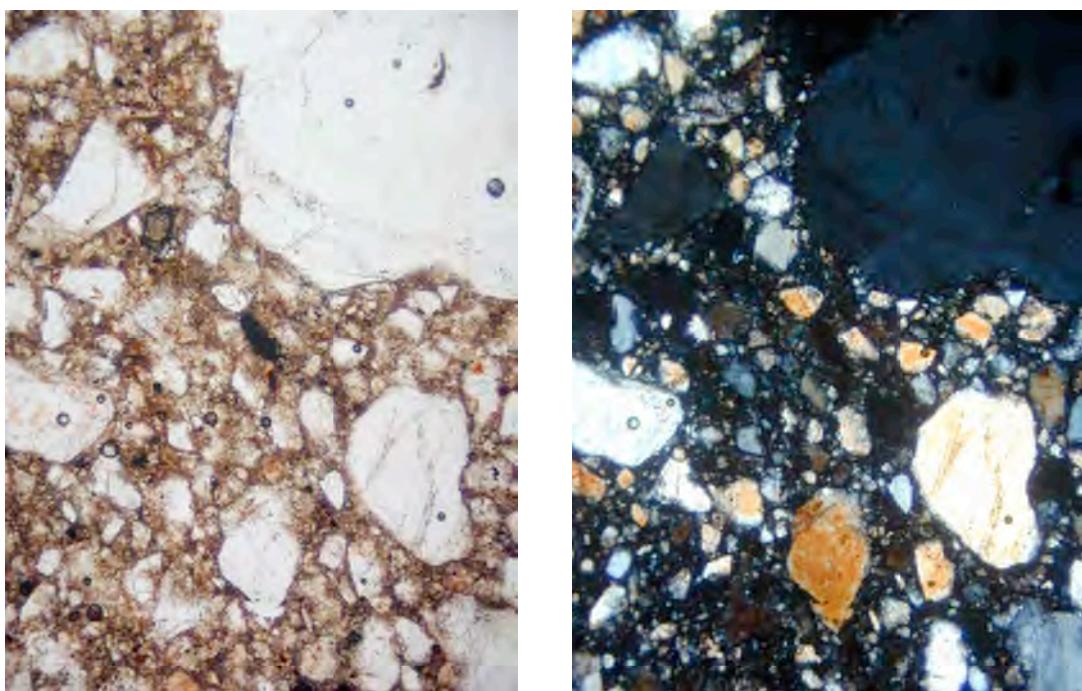


Fig. 3: Thin section, fired brick. Angular to subangular grains of quartz in ferrigenous matrix. Left, plane polarized transmitted light, right, crossed polarizers. Field of view=1.6 x 1.2mm.

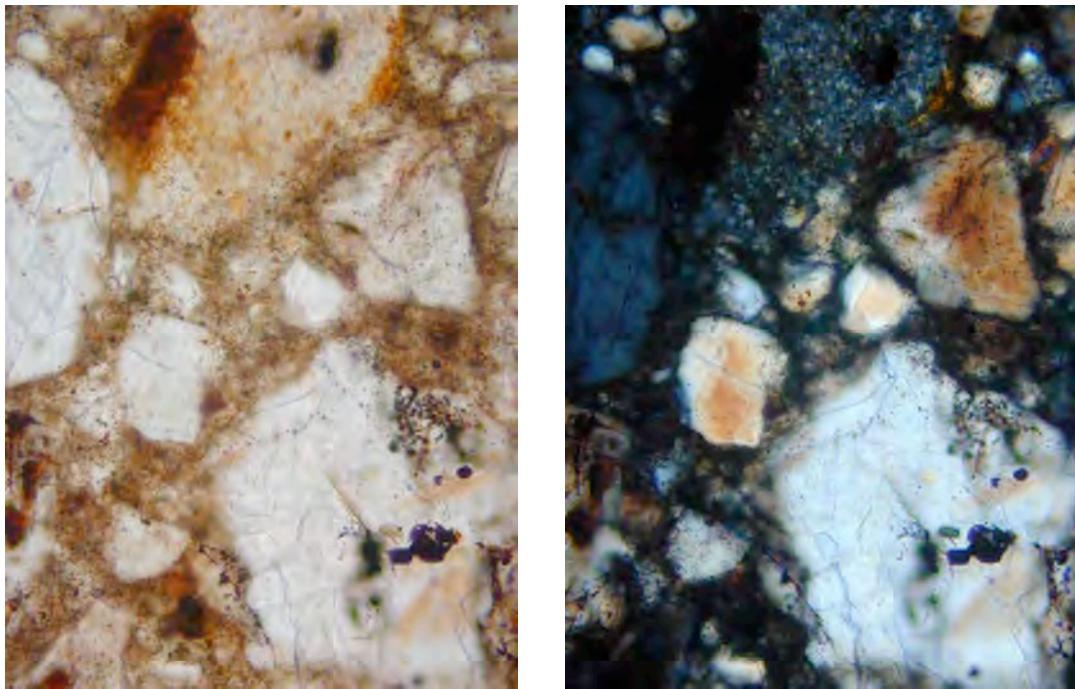


Fig. 4 Thin section, fired brick. Monocrystalline quartz grains, some containing hematite. Large grain at top is a chert grain. Tiny pigment grains are visible in the matrix. Left, plane polarized transmitted light, right, crossed polarizers. Field of view = 0.42 x 0.32mm.

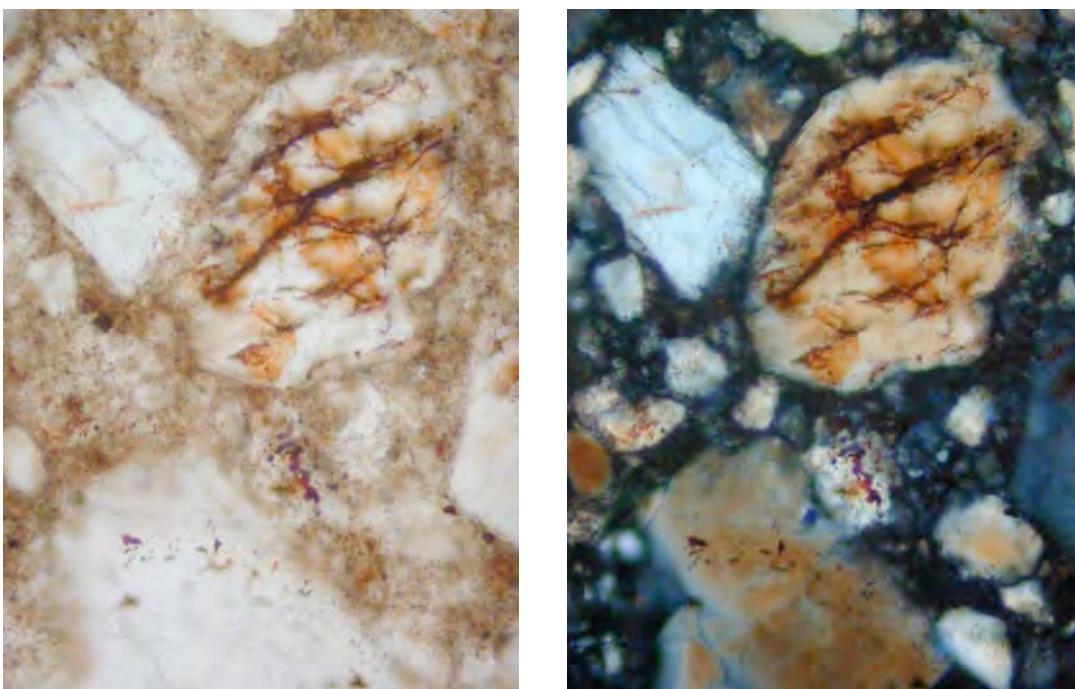


Fig. 5. Thin section, fired brick. Angular to subangular quartz grains with varying amounts of hematitic pigmentation. Left, plane polarized transmitted light, right, crossed polarizers. Field of view = 0.42 x 0.32mm.

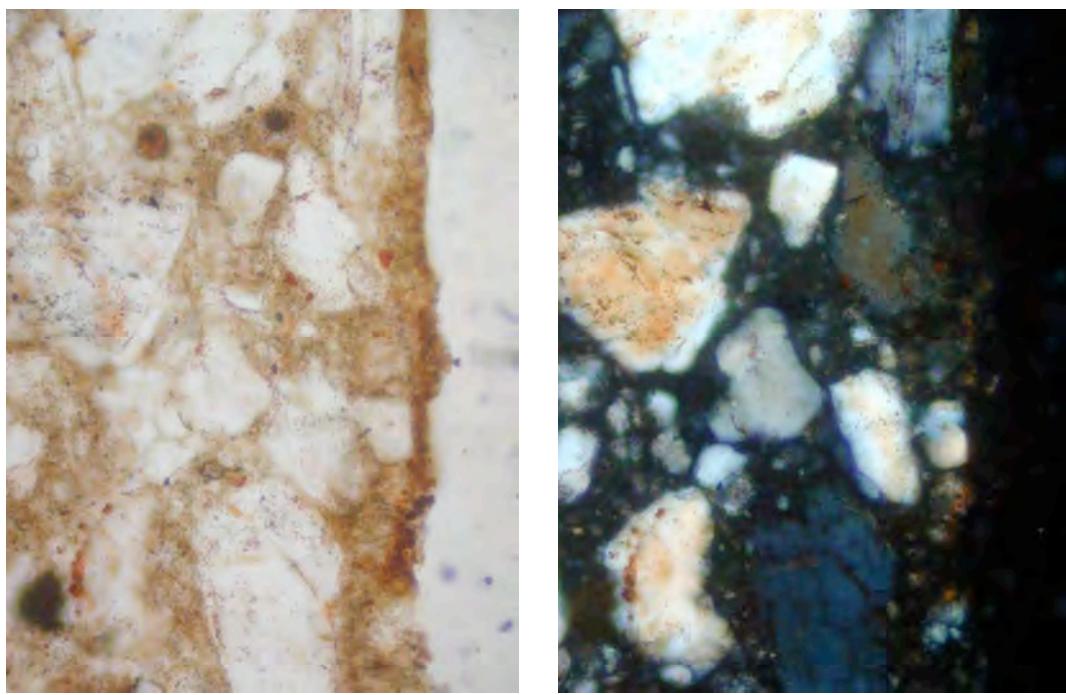


Fig. 6. Thin section, fired brick. Weathered surface of brick at right side of image. . Left, plane polarized transmitted light, right, crossed polarizers. Field of view = 0.42 x 0.32mm.

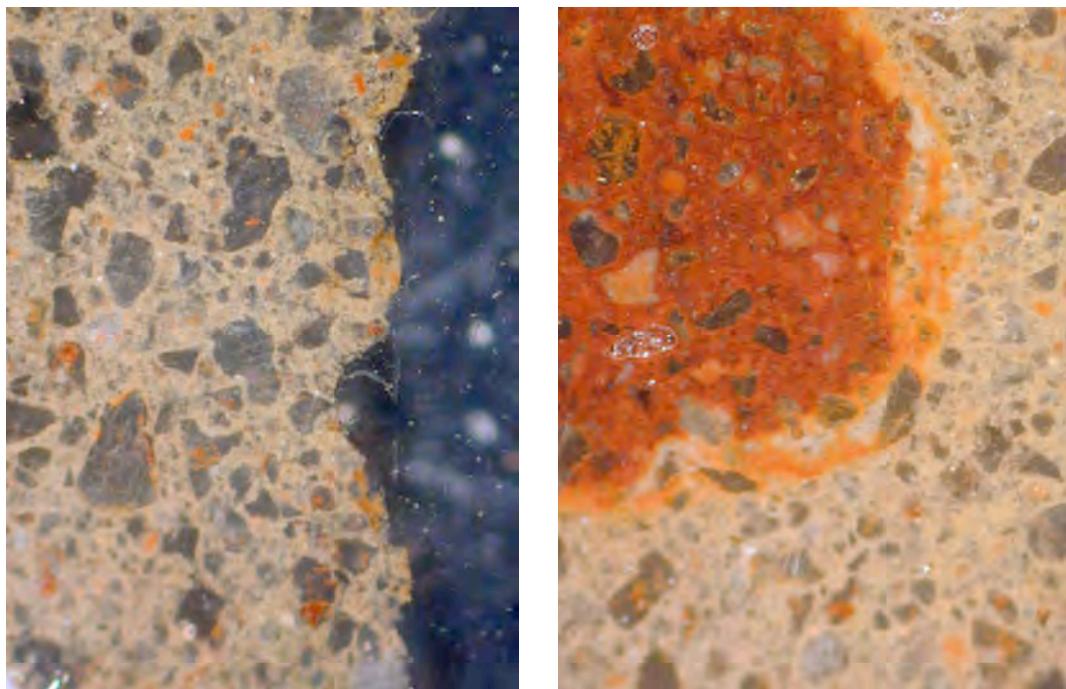


Fig. 7. Thin section, fired brick. Incident light view of brick. (Left) weathered surface is to the right. Quartz grains are gray, matrix is tan, and scattered small clots of hematitic pigment are orange. Field of view = 0.42 x 0.32mm. (Right) Incident light view of hematitic pigment clot (see Fig. 2). Field of view = 3.17 x 2.38mm.

Submitted by

James B. Murowchick, Ph.D.
Consulting Mineralogist
Lenexa, KS

April 1, 2010

APPENDIX B: FOURIER TRANSFORM INFRARED SPECTROSCOPY OF MORTAR AND STUCCO

March 31, 2010

Ms. Amanda Trienens
ICR
41 East 11th Street, #310
New York, NY 10003

Via: Email as a PDF attachment to atrienens@icr-icc.com
Re: Orion Project No. 1606

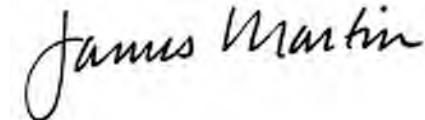
Dear Amanda,

Thank you for asking Orion to assist your study of pigmented stucco from a brick façade and mortar from brick joints.

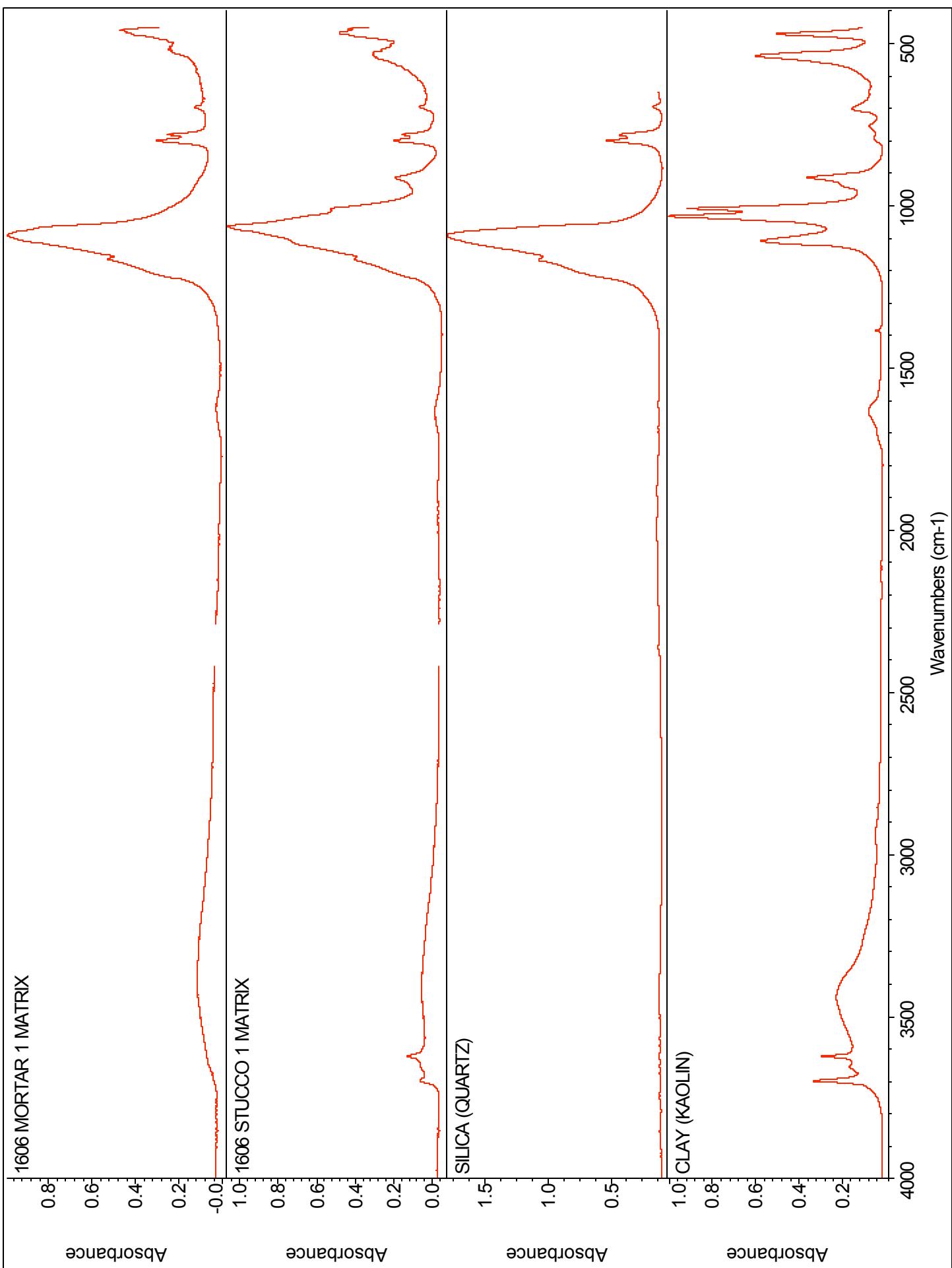
As per your request, Orion collected FTIR spectra (attached) of the matrix of each sample. The spectra did not reveal carbon-hydrogen stretching vibrations to indicate the presence of a detectable amount of organic material, or organic materials present in amounts that are detectable in the presence of the principal detectable components of each sample. The stucco spectrum showed features consistent with clay and silica, including quartz. The mortar spectrum showed features consistent with silica, including quartz.

It has been a pleasure to assist you. Please do not hesitate to contact Orion if you have questions about this report or would like further analyses of the samples.

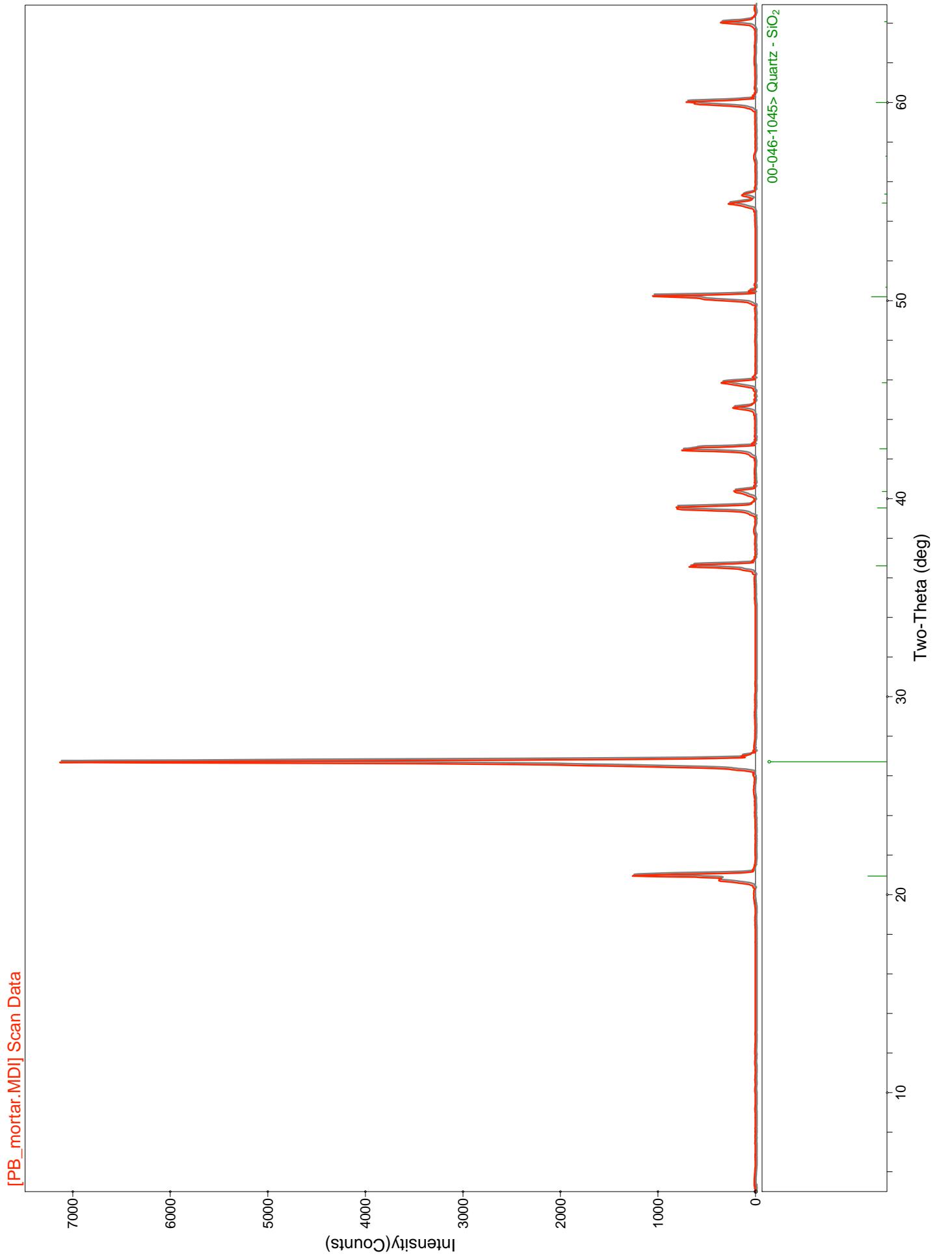
Very truly yours,

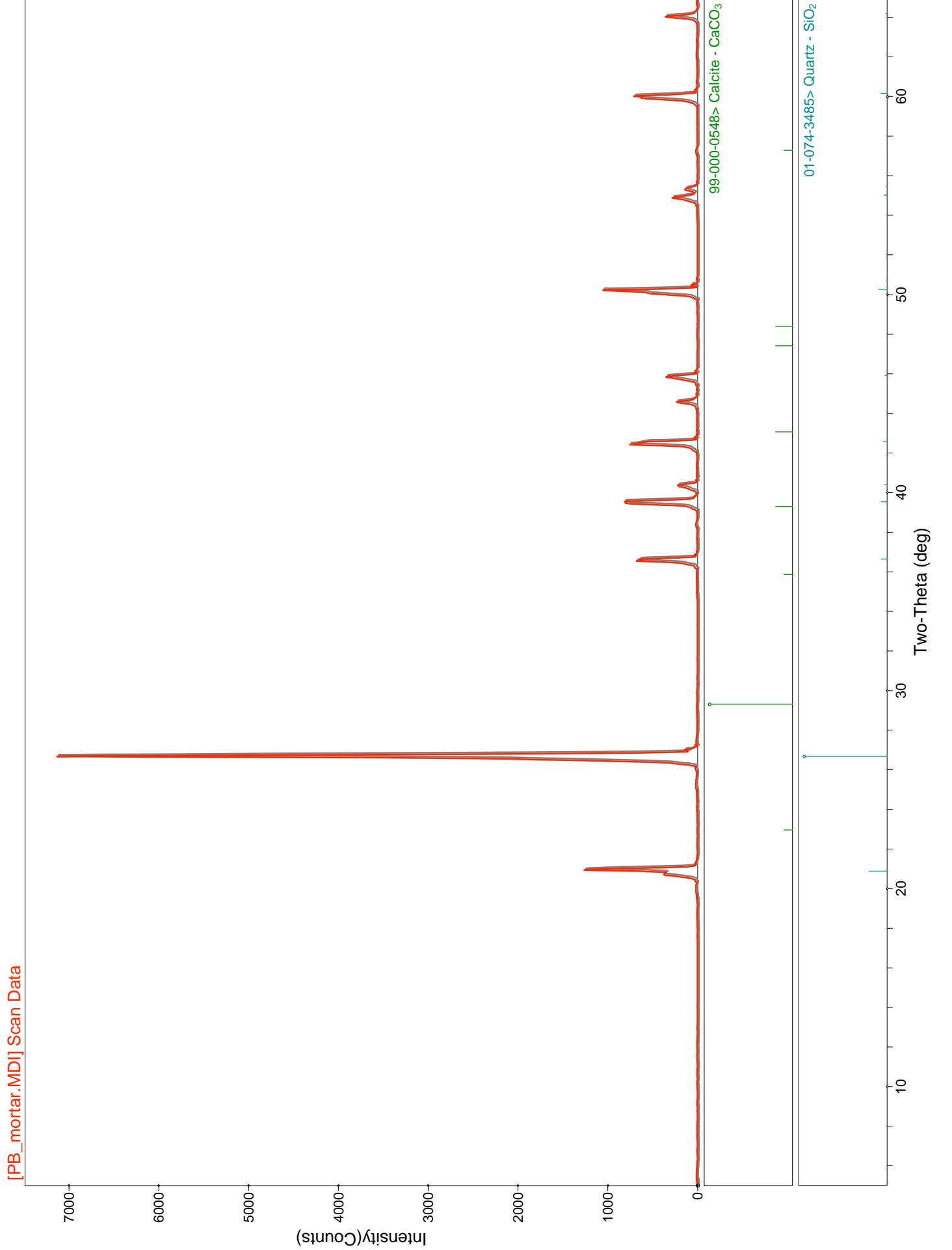


Orion Analytical, LLC
By James Martin, Principal

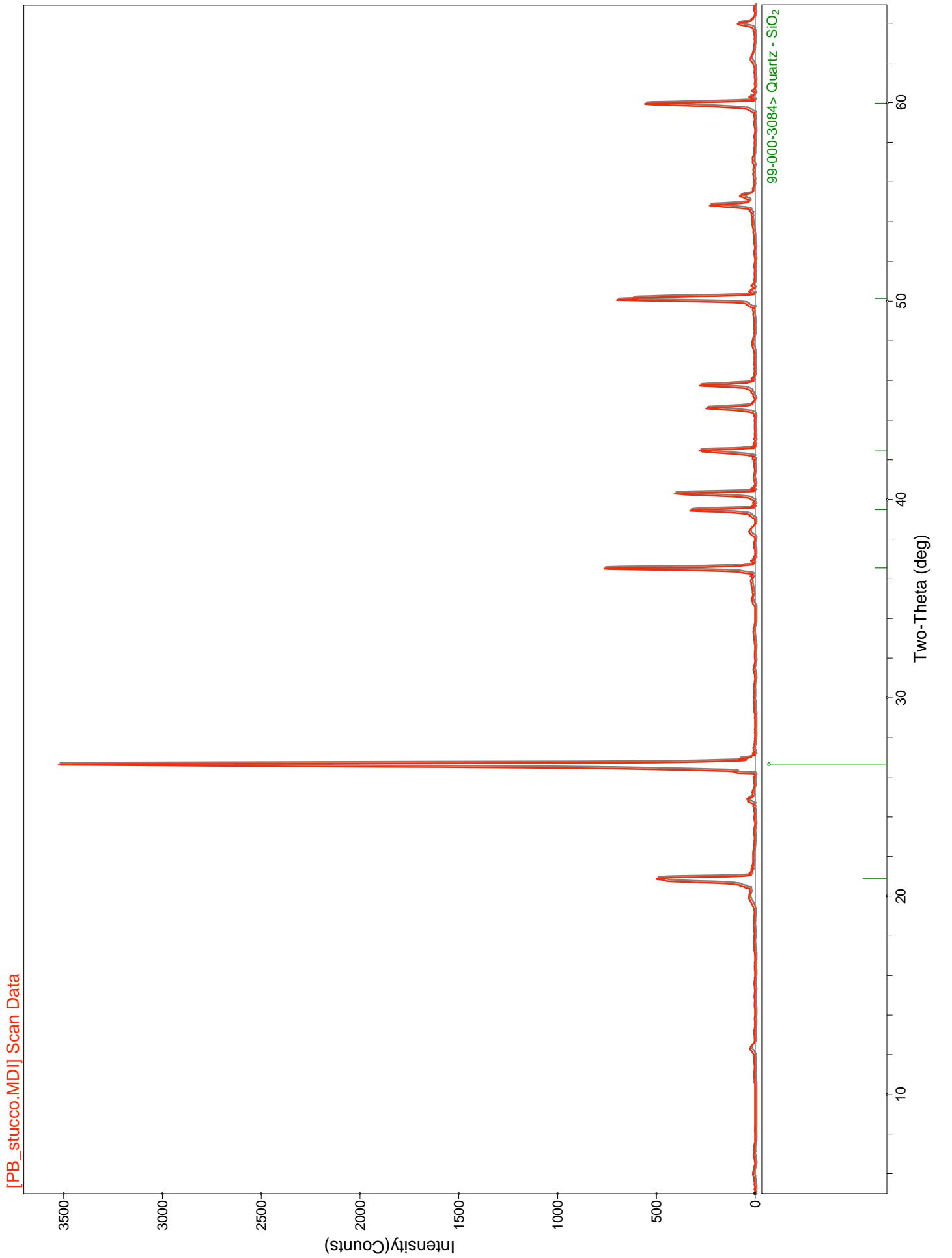


APPENDIX C: X-RAY DIFFRACTION SPECTRA OF MORTAR





APPENDIX D: X-RAY DIFFRACTION SPECTRA OF STUCCO



Results on the analyses of three samples from Phnom Bakheng

Inorganic (XRD): Giacomo Chiari

Organic materials (GC/MS): Joy Mazurek

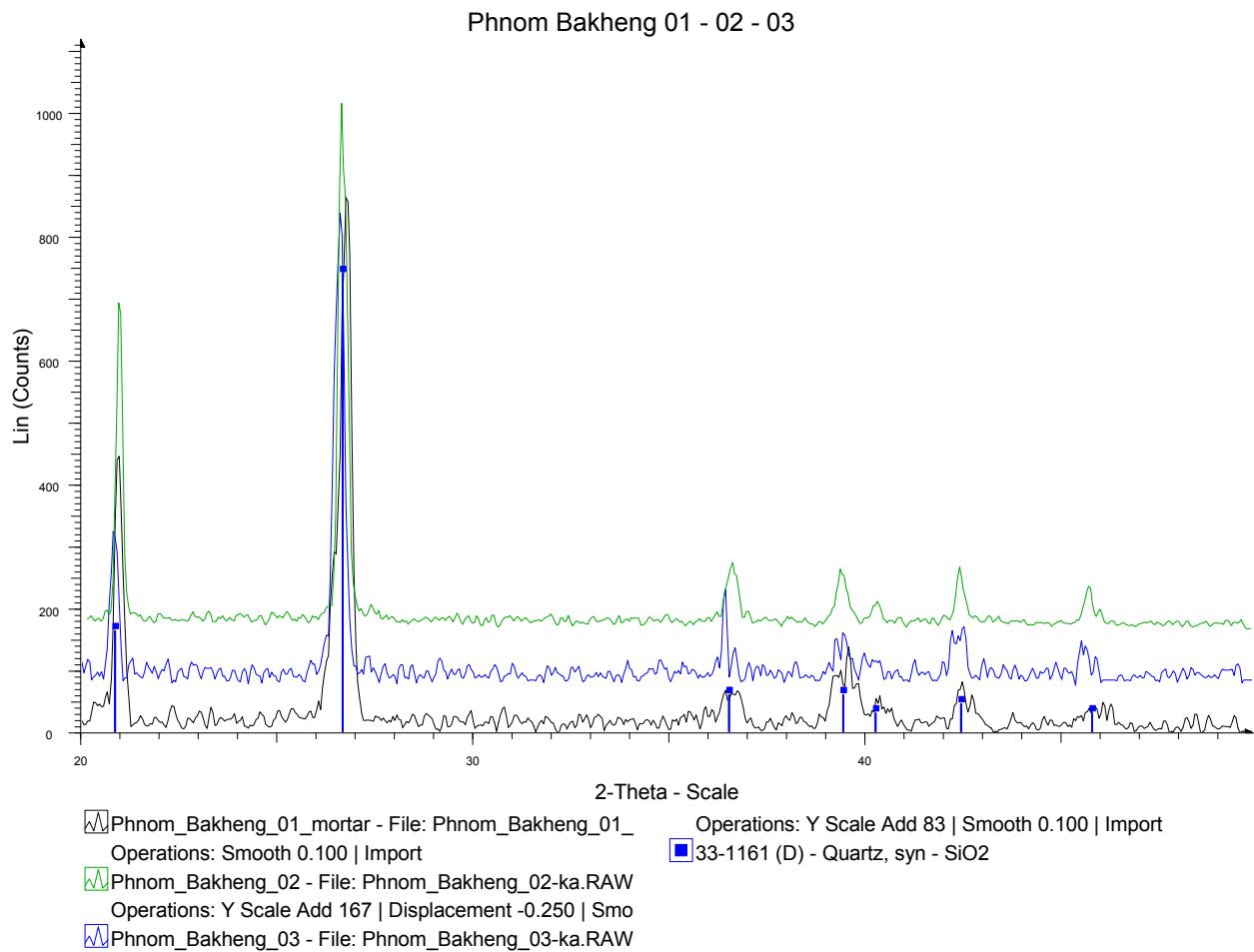
May 15, 2010

A handwritten signature in blue ink that reads "Giacomo Chiari". The signature is fluid and cursive, with "Giacomo" on the top line and "Chiari" on the bottom line.

The Getty Conservation Institute

All three samples are composed of pure **Quartz**.

The plot below shows the X-Ray diffraction analysis of all three samples identified as “mortar”. One can easily see that the three patterns are identical and that only Quartz is present, identified by the blue lines with a square.



Beside the X-ray diffraction other investigations were carried out, namely infrared spectroscopy (FTIR) and Gas chromatography mass spectrometry (GC/MS).

The results are shown below.



THE GETTY

CONSERVATION

INSTITUTE

SCIENTIFIC LABORATORY: BINDING MEDIA ANALYSIS

May 11, 2010

Sample Description: Phnom Bakheng Mortar Samples

Analysis by: Joy Mazurek, Assistant Scientist

Introduction and Discussion

Three red plaster samples from Phnom Bakheng, Cambodia were analyzed for organic components. They were tested by gas chromatography with mass spectrometry (GC-MS)² and it was found that they do not contain waxes, fats, natural resins, or drying oils. However, the samples do contain very low amounts of carbohydrates or sugars (0.02% by weight) and the data is shown in table 1.

Table 1. Carbohydrate analysis of red mortar samples from Phnom Bakheng. Reported in milligrams/Liter or parts per million.

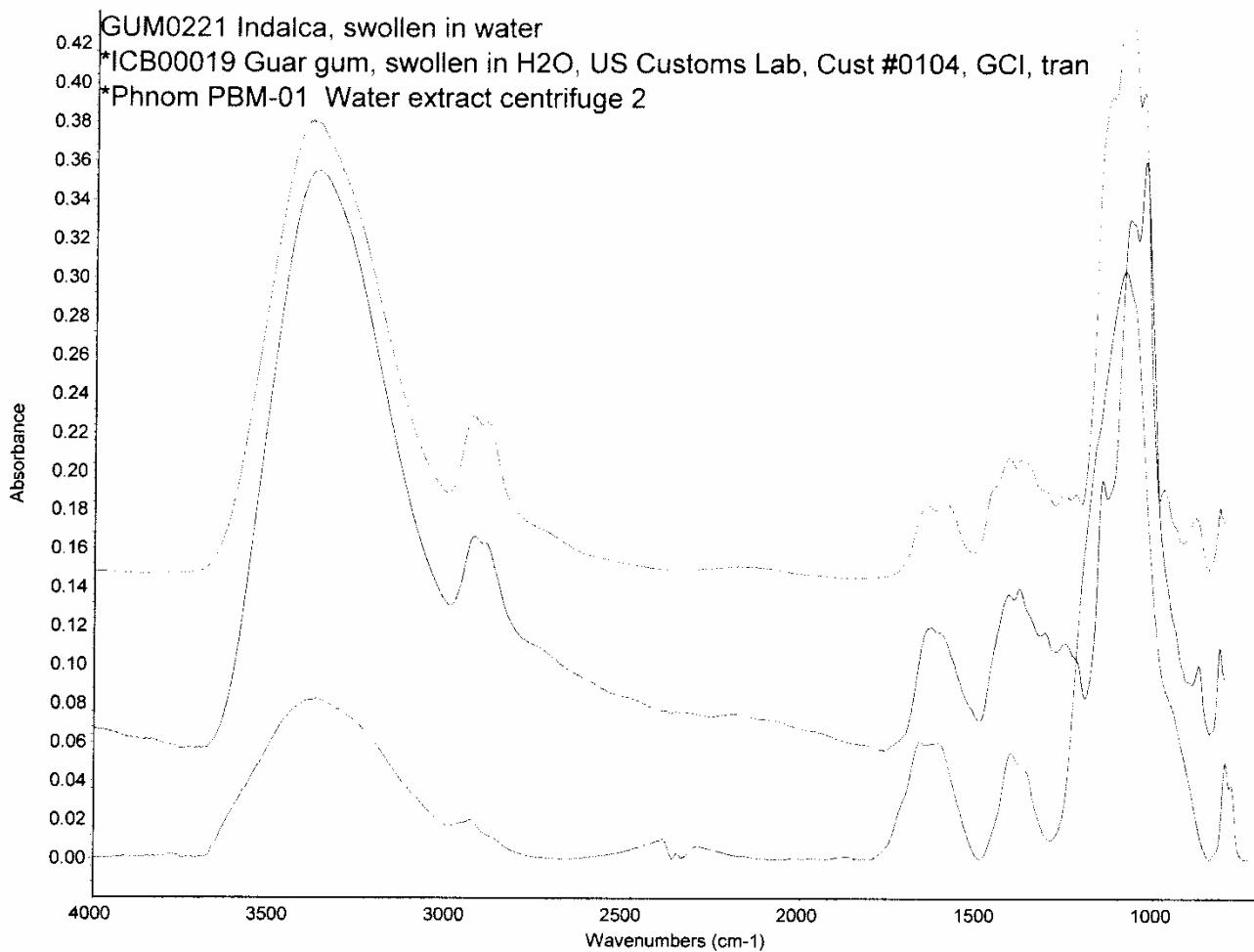
Sugar	PBM01	PBM02	PBM03
Rhamnose	10	3	4
Fucose	5	2	2
Ribose	1	0	1
Arabinose	10	7	6
Xylose	10	6	7
Mannose	15	8	9
Fructose	2	1	1
Glucose	32	16	18
Galactose	19	13	11
Total% sugars	0.02	0.02	0.02

The samples were also analyzed by FTIR in order to better understand the possible inorganic and organic components. The samples were put into vials, water was added, and it was heated to 60 °C for one hour. The solution was decanted and allowed to dry on glass slides. This extracted material was then analyzed by FTIR. The extracted material was found to contain quartz silica (1000 cm⁻¹) and 2 peaks around 1400-1500 cm⁻¹ that most closely resembles a polysaccharide (Spectra 1).

Conclusions:

Carbohydrates are ubiquitous in nature and contamination by micro-organisms and plants complicate the identification of plant gums in outdoor environments. In order to obtain more conclusive results, additional samples need to be tested from the surrounding site, for example areas where the brick does not contain mortar and organic material was not likely to be added. When analyzing for sugars and polysaccharides it is necessary to establish background or environmental levels of sugars.

Spectra 1. FTIR spectra showing a good match to polysaccharides (gums).



¹ Fourier-transform infrared microspectroscopy (FTIR) is a technique that has a number of advantages over GC-MS. FTIR can be used directly on a paint sample without requiring aggressive chemical pre-treatment. Because samples may be recovered for subsequent analysis by other methods, it is termed a non-destructive technique. Furthermore, it can also identify pigments and other non-volatile species (such as acrylic media) that cannot be detected by GC-MS. However, it can only detect components present in concentrations above five to ten weight percent, although many substances are well below that level in commercial paints.

A representative sample particle was placed on a Diamond window, and analyzed by transmitted infrared beam with an aperture of approximately 100 x 100 microns, using a 15X objective. Each spectrum was the sum of 200 scans at a resolution of 4 cm⁻¹. Based on the initial analysis results of bulk material, extraction was made by placing a microdroplet of solvent on the sample, and analysis was performed on the resultant extracted dry solvent ring. Infrared spectra of the samples contain bands that correspond to the paint components. To identify materials in a paint sample, the infrared spectrum may be matched to spectra for reference materials using a computer algorithm. Of course, other components may be present in the samples at concentrations below the 5% detection limit. For more details see M. R. Derrick, Practical Guide to Infrared Microspectroscopy, edited by Howard J. Humecki, (New York: Marcel Dekker, 1995).

² Gas chromatography with mass spectrometry (GC-MS) is a technique that can be used to identify organic binding media, such as proteins, oils, waxes, resins and plant gums, in addition to many types of paint additives. The samples must be treated with reactive chemicals prior to analysis, and each type of medium may require a specific pre-treatment procedure. Procedures were developed at the Getty Conservation Institute for the identification of the common organic binding media. Moreover, for plant gums, proteins and oils it is possible to measure the amount of medium present in the sample.

EFEO INTERVENTIONS AT PHNOM BAKHENG

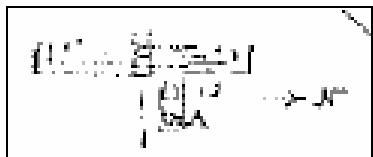
Work at Phnom Bakheng conducted between 1923 and 1929 excerpted from the excavation journals and translated from the original French

JUNE 1923

A team of 20 laborers continues the removal of the mounds of dirt from the upper terraces to the north of the stairway E of the pyramid. We are also clearing the two brick shrines at the base of these mounds of dirt.

JULY 1923

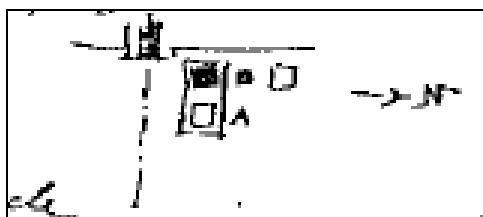
A team of 22 laborers continues to clear the two brick shrines and removal of the mounds of dirt to the north of the stairway. As the stones are being removed from the slab that is shared by the two shrines, in order to re-seam the joints and reinforce the slab, I noticed that the infrastructure is composed of a mixture of dirt and disintegrated laterite which is not sufficiently strong for the slab that rests on it (A and B).



Sketch July 11, 1923, Journal de Fouilles 04, page 36

Position of the brick shrines mentioned in report 1923-1929, "... to the north of the stairway (East)," therefore it has to be G43 and "A" should be G44.

The clearing of the inside of the first shrine (coming from the east) has revealed in the center of the slab (at 0.9 m below the level of the door frames) a square stone with square holes drilled into it for the usual 17 lingas. In the center hole, a faience decorated bowl was found, full of charred bone fragments, and a grayish small round covered pottery bowl. Next to that was a large, pedestal broken into several pieces, and a somewhat shapeless religious statuette, standing, with 4 arms. We are now beginning to clear the second shrine to the west.

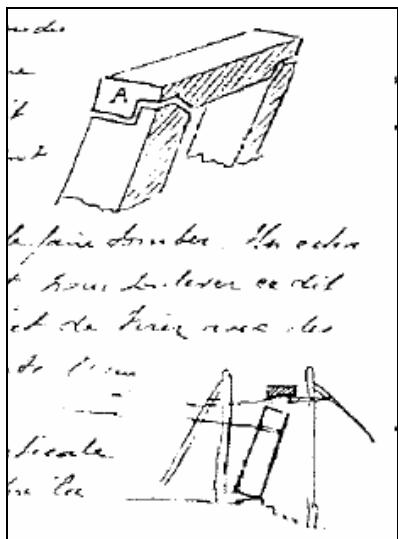


Sketch July 25, 1923, Journal de Fouilles 04, page 43

First shrine "A" should be G44, second shrine "B" should be G43.

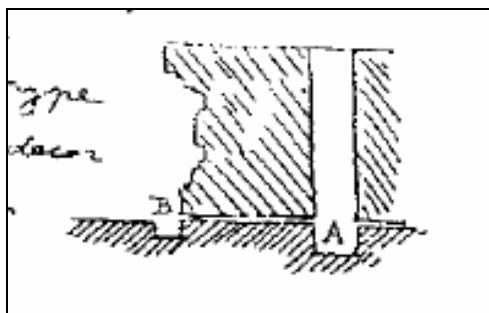
AUGUST 1923

A team of 22 laborers continues clearing the two brick shrines and the base of the pyramid has been completed. The frame of the door of the east façade of the first shrine [G44] has been rebuilt. This was difficult due to the fact that the lintel was barely holding on the north side, and it had to be supported by scaffolding while ropes were used to fix the door posts.



Sketch August 8, 1923, Journal de Fouilles 04, page 49

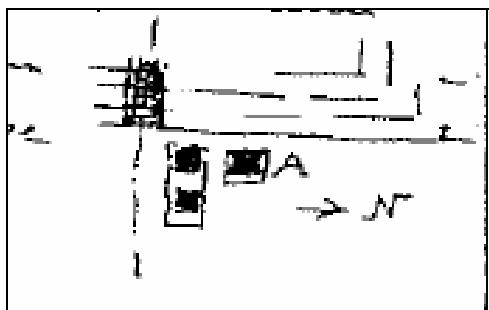
Inside the second shrine we found a somewhat well-maintained slab of sandstone, in the middle of which stood a pedestal with a center hole extending into the slab [should be G43]. A gutter (B) completely surrounds the slab pedestal, with square holes in all four corners.



Sketch August 13, 1923, Journal de Fouilles 04, page 52

SEPTEMBER 1923

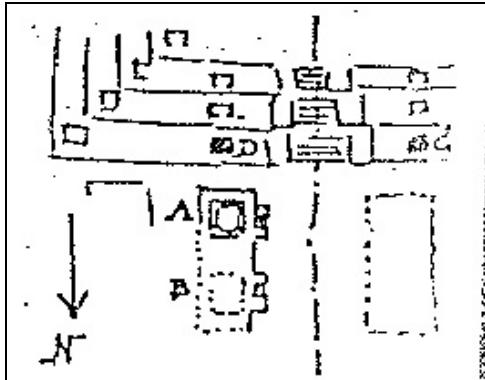
20 laborers began clearing the interior of the 3rd brick shrine A, to the north of the east face of the pyramid and the interior of shrine B on the same side. The latter is completely demolished and planed down to the level of the first layer of the foundation, covered by a thick layer of dirt.



Sketch August 14, 1923, Journal de Fouilles 04, page 53
 "A" should be G42.

DECEMBER 1924

A team of 25 laborers continues to clear the shrines, or what remains of them, on the eastern side of the north base of the pyramid. As with the east façade, on each side of the central stairway there were two brick towers on a shared foundation, but here only one tower remains, the other having been completely demolished, no doubt intentionally, but there remains not the slightest vestiges of the foundation of the wall, and the masonry has been planed down to the level of the sub-flooring.



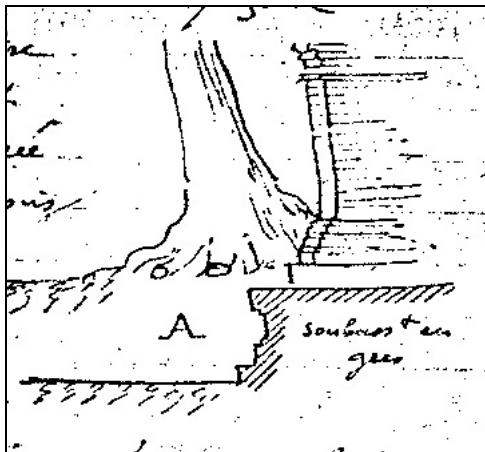
Sketch December 11, 1924, *Journal de Fouilles*, 05, page 74

"A" should be G34 and "B" should be G35.

The three facades of the southwest and north of the brick shrine that are still standing have been cleared; there remains only the east façade where a very large tree is blocking the entrance. The foundations of chapels A and B on the first level of the pyramid have been sealed with cement, as many stones had fallen and left gaps beneath these chapels.

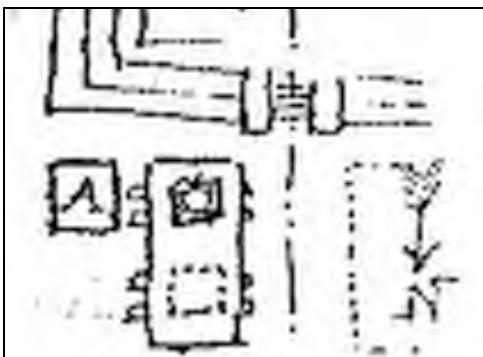
JANUARY 1925

A team of 22 laborers has finished clearing the brick shrines to the east of the north stairway at the base of the pyramid. The large tree that blocked the eastern entrance to this shrine has been split into pieces and taken down. As a result, the view from the central sanctuary to the top of the pyramid can encompass the entire city of Angkor Thom, with the tip of Bayon emerging from the forest.



Sketch January 8, 1925, *Journal de Fouilles* 05, page 92

Tree blocking the east facade.



Sketch January 25, 1925, *Journal de Fouilles* 05, page 98

We are removing the rock that was supporting the foundation of a matching shrine on the east side, but this shrine is completely demolished and there remains nothing but a heap of dirt and bricks. The stones themselves that made up the covering of the sub-flooring have disappeared. We found a pedestal that appears to still be "in situ" and that marks the center of the missing ... this can be seen in photo 523, which can be compared to photos 509-510 and 513 showing the same view.



Photo CA 523, 14132, East façade of G34



Photo CA 509, 14127, pyramid: base N, rapport 12/24

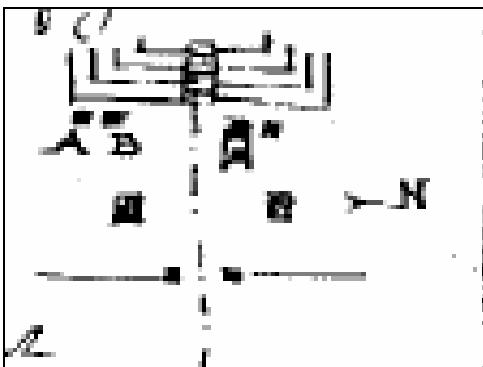


Photo CA 510, 14128, pyramid: base N, rapport 12/24

Similar to the work on the north stairway last month, the damaged risers of the stairway on the south side have been replaced, and the dirt and roots were removed that had dislodged the stones and threatened the stability of the lion that is located there.

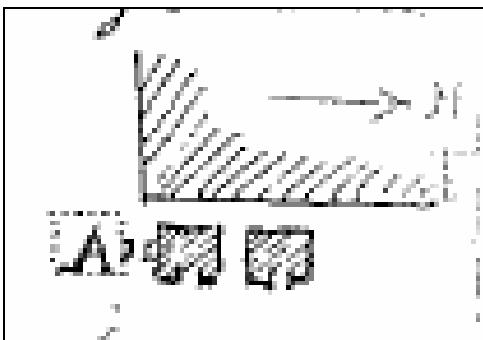
AUGUST 1927

A team of about 20 laborers began working to clear the brick towers at the base of the east façade of the pyramid near the south corner. The upper level of all of the structures has collapsed, and the facades have all been more or less modified by the addition of lightweight wooden construction by the Annamese monks that lived for a long time in this location.



*Sketch August 15, 1927, Journal de Fouilles 06A, page 127
“A” should be G5, “B” should be G4.*

We demolished the remnants of the add-on constructions that were already half rotten (it has been ten years since the monks decamped). Even the foundations of the brick shrines had been covered in an artificial partition held up by half-walls made of stones from nearby ancient Khmer buildings. The site of a completely demolished brick shrine is visible after removal of rubble and debris. Only the threshold of a doorway and a small sandstone stairway remain.

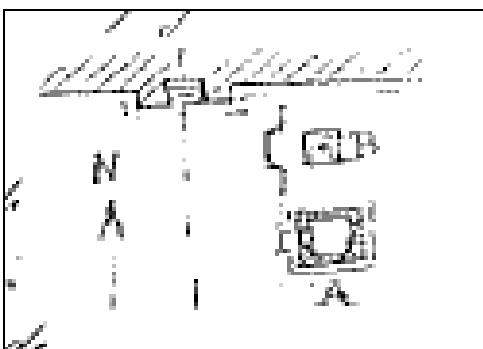


*Sketch August 26, 1927, Journal de Fouilles 06A, page 132
“A” is probably the completely demolished brick shrine.*

MAY 1929

The team of concrete workers, with less work to do on reinforcements this month, were brought to Bakheng to complete the clearing of the base of the pyramid. This team of 28 laborers continued the removal and disposing of the dirt and brick debris that surrounded the first level of the pyramid, which appeared to have been systematically demolished. Removal is being done by way of the eastern section of the south stairway. Near the base of this stairway we found pieces of laterite wall that seem to be rather difficult to explain.

We found in A (sketch 3), on a block of laterite that must have formed the foundation of the demolished shrine, a pedestal that appears to be in its original place. Since its neighbor, shrine B, still has part of its walls standing, the removal of debris was halted. No masonry was found here that would have supported the walls of the south and west façade. The removal of debris revealed the interior of a sandstone pedestal similar to one previously found. Near this one, we found a square sandstone slab drilled with 17 plain holes. Its size indicates that it must have been encased in the central hole of the pedestal, which would seem to confirm Parmentier's theory that the holes in these stones were not meant to hold lingas, but parcels of precious metals.



Sketch May 28, 1929, Journal de Fouilles 07, page 170

Photos 1537 and 1538b (combined to form a single view) and photo 1538 show two perspectives of this work. I sent to the warehouse the statue found in August 1928 near the foundation of shrine B. This statue is 1.5 m high, with all of the characteristics of style 1 – photos 1539 and 1540.



Photo 1538, 13958, rapport 05/29, G10 avant degagement (before clearing)

JUNE 1929

The team of 26 concrete workers did not have much reinforcement work this month, and so were able to continue clearing the south base of the pyramid to the east of the central stairway. The laterite foundation where two brick shrines stood, one of which was no doubt intentionally demolished, was cleared of the pile of debris that covered it. This foundation does not appear to have a very precisely drawn shape. All of its sandstone layer covering it is gone, also clearly intentional since there is not a single stone remaining. The removal of this wall has resulted in the walls of the east, south and west façade of the intact shrine (the one to the south) resting partly over a void. Further, the laterite has mostly collapsed and the rubble that I initially left in order to support the foundations of these walls doesn't appear sturdy enough. I had it carefully removed and replaced with stone blocks.

Photo 1555 shows the southeast corner of this shrine during clearing, and 1556 shows its northwest corner. A hole in the foundation at this corner threatened to cause the wall to collapse, and had to be filled with cement. The pedestal mentioned in my earlier report is still in place. The interior of the shrine's cella has been cleared of rubble. It should be noted that the slab of the cella is .9 m below the level of the east and west door frames.



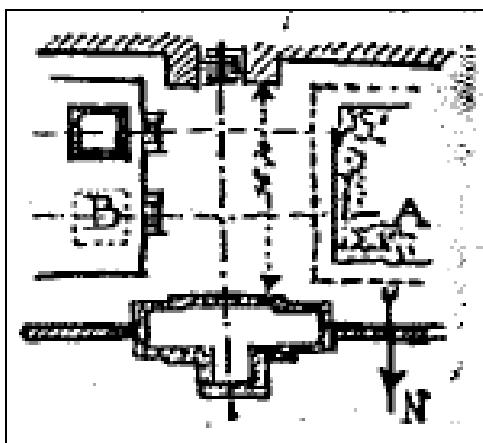
Photo 1555, 14140, G10, 06/29

The snanadroni slab was found in the rubble and replaced on the pedestal - photo 1557, taken from the east doorway. A few barely legible cursive characters were found on the center mullion of the misplaced sandstone door of the north face.

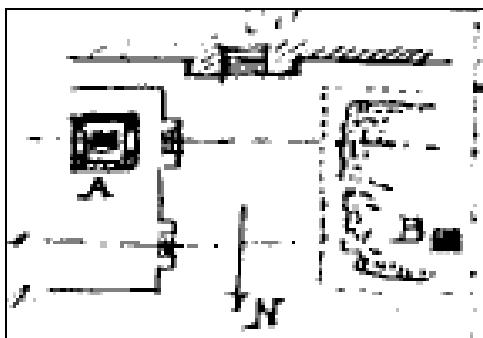
As for the completely demolished shrine to the north [G11], I noted that during the removal of debris, there were portions of the walls where bricks remained attached to each other in spite of there being no trace of mortar. This could have resulted simply from wear on the surface that are in contact.

This job of clearing the base of Bakheng is taking so long that I had another team of 25 laborers (who have just finished clearing Prasat Suor Prat) begin the same work on the north side.

On this side also, there remain intact only some of the brick shrines that surrounded the pyramid. Clearing began to the west of central stairway. One or more of the brick shrines in A and B (sketch 3) have completely disappeared and only the laterite sub-foundation remains. At the site of shrine B we found a pedestal like those found on the south face, which is all the remains intact of this shrine. The snanadroni was found a little further away.



Sketch June 22, 1929, *Journal de Fouilles* 07, page 185



Sketch June 27, 1929, *Journal de Fouilles* 07, page 187

The native people have requested that we cover a buddha statue that was found in an shrine whose entire vault is missing, to the south of the east stairway of the pyramid. I ordered that done, out of respect for the religious principles of the native people, who would not want to leave it exposed, but on the condition that this roof or shelter remain out of sight from the outside.

I should add that a frame and roof had been covering this shrine, but that I had had it removed at the same time as the baroque additions of the Annamese monks.

Before the buddha returned to the shade of its restored roof, I took photo no. 1560, not because the buddha is especially well made, but because it's a rather unique type.

JULY 1929

The team of 28 concrete workers continued to clear the base of the pyramid to the east of the south stairway. We got as far as the laterite foundation supporting the shrines to the east of the one already cleared. Photo 1615, which can be compared to photo 1538, taken almost in the same spot, shows the progress of the work.

AUGUST 1929

The team of 28 concrete workers continued to clear whatever remains of the shrines that existed to the south of the pyramid. There is almost nothing to be found under this debris and fallen stones except the stone of the laterite foundation, but there are pedestals more or less "in situ" on the south side, as on the north face, indicating where shrines used to be located.

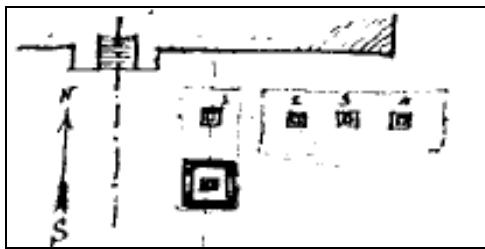
Photo 1654 shows the work site, with the previously cleared shrine in the foreground, and pencil marks indicating the stones brought in for reinforcement.



Photo 1654, 13961, G10, 08/29

SEPTEMBER 1929

A team of 26 laborers continued clearing the south side of the pyramid. This work uncovered a fourth pedestal near the southeast corner, indicating the location of another demolished brick shrine (sketch 1) on the communal laterite foundation.

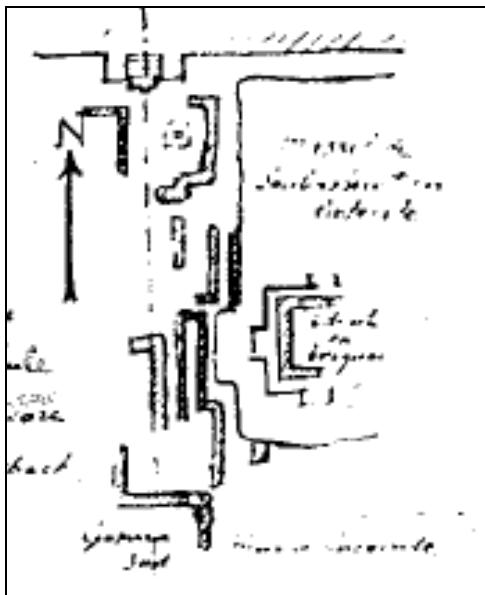


Sketch September 9, 1929, Journal de Fouilles 07, page 231

OCTOBER 1929

South Face - the team of 28 concrete workers continued to clear the base of the pyramid. In front of the south stairway, we continued to uncover traces of laterite walls and remnants of sandstone slabs whose

presence is not easily explained, as they don't appear to be related to the brick shrines or even the stairway that they strangely abut.



Sketch October 1, 1929, Journal de Fouilles 07, page 243

In any case, it's been shown that these slabs and walls were much later than the monument itself, since they are partly composed of re-used stone originating in the towers decorating the levels of the pyramid, or the sandstone walls lining the tiers.

Photo 1748 shows the view from the south. we have begun to clear the brick shrine to the west of the south stairway. This shrine, whose façade walls are still standing, is filled with dirt up to the top level of the pedestal which is still in place in the middle of the cella. This corresponds roughly to the level of the threshold of the door. We know that the slab in all of these shrines is significantly below that. [G10]



Sketch October 18, 1929, Journal de Fouilles 07, page 255

Near the southeast corner of the pyramid, we found another pedestal under the rubble of bricks and dirt, marking the location of a demolished chapel on the extension of the diagonal. Its location is simultaneously on the east-west axis of the shrines along the south face of the pyramid, and the north-south axis of those along the east façade.

A stone lintel and two simply lined sandstone columns lay near the foundation that remains "in situ" as well as a slab of the threshold and two steps of the north façade of the chapel.

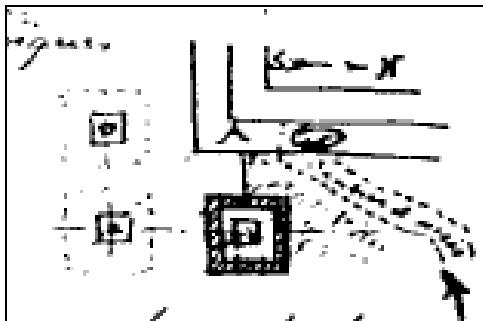
NOVEMBER 1929

South Face - a team of 26 laborers continued to clear the brick shrines on the south face of the base of the pyramid: the entire section between the north-south axis and the southeast corner is finished. Now only the infrastructure of the sub-foundation and pedestals remaining "in situ" can give away the presence of these chapels.

In the southeast corner of the first tier of the pyramid, after removal of the rubble, the bedrock of the hill was completely revealed, as the sandstone cladding of wall has completely collapsed. Photo 1792.



Photo CA 1792, 13969, pyramid SE angle, 12/29



Sketch November 21, 1929, Journal de Fouilles 07, page 271

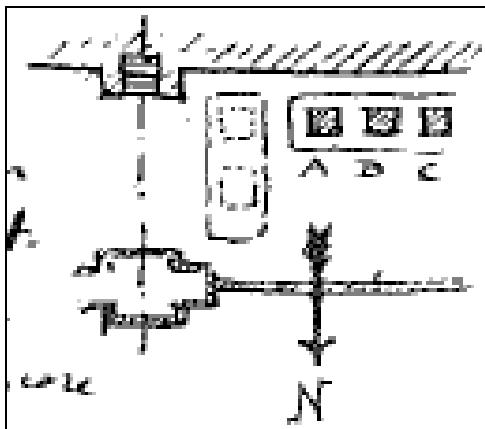
We began to clear the shrines on the west side of the south face [G13-16] – photo 1794. In the debris, entirely composed of dirt and bricks from the intact tower to the west of the south stairway, we found a bronze plaque carved in the shape of a lotus flower, 95mm in diameter. It would appear that the rich Khmer style has given way to simple observation of nature. The receptacle, stamens and corolla of the flower appear sufficiently accurate, but with almost no relief.

Then this team went back to clearing the brick shrines at the base of the pyramid to the west of the north stairway. The foundations of these shrines are buried in the brick rubble of the upper sections that have completely collapsed. The second tower (nothing remains of the first) has just one façade wall still intact.

Part of the decoration of the entrance is still intact, but we had to put back the column that was resting on the debris.

While clearing this shrine it was noted, just as on the south side, that entire sections of the walls had fallen, without any of them being separated from each other.

We had to take down carefully, section by section, a tree that had grown in the rubble of the collapsed shrine, so as not to cause any damage.



Sketch December 18, 1929, *Journal de Fouilles* 07, page 284
“A” is G31, “B” is G30 and “C” is G29.

DECEMBER 1929

South Face - a team of 25 laborers continue to clear the base of the pyramid on the south face to the west of the central stairway. The brick shrines are without their crowns or much of their superstructure, and where walls are still standing they are riddled with holes that are difficult to explain, although it is most likely due to trees and other vegetation. [G12-16]

Photo 1822 shows the walls beginning to collapse, and 1823 and 1824 show wall fragments. [These photos do not exist.]

While clearing the second shrine, near the south façade we found an oval shaped intaglio crystal rock, 27mm by 27mm.

A plaster mold will be sent soon for analysis of the character gesticulating and dancing on a leafy branch depicted on the flat side of the intaglio. I don't know who this figure can be, which is neither Khmer nor Chinese.

North Face – a team of 22 laborers have nearly finished clearing shrine A (sketch 2) except for the section west of the north wall, where a dangerously leaning tree had to be removed. I had this part of the shrine reinforced, and using a jack have succeeded in lifting up this section of the wall and wedging the holes and cracks in the foundation with bricks found in the rubble, as a temporary measure until it can be properly sealed with cement. [Probably G31 (shrine A, sketch November 1929).]

While clearing the interior of the *cella* of this shrine A, we found three stone antefixes decorated with a standing figure holding a club. On the slab could be seen light traces of sandstone indicating the original location of the pedestal that was laying on its side. In the center of the slab there is a hole the same size as the one in the base of the pedestal to hold offerings (previously referred to as stone *lingas*). We were able to restore the fragments of the molded sandstone veneer of the enclosure wall that were found in the debris.

We have begun clearing the shrines further to the west (B and C on sketch 2) that are blocked off by the debris from the upper levels, making this work difficult. The two photos no. 1825 and 1825b, which can be connected, show the current view of the work site as seen from the northwest. Photo no. 1832, taken at the request of the head of the Archaeology Department, shows the west lion, the best preserved, found at the base of the north stairway.

Compilation of photographs from EFEO archives and similar photos showing conditions existing in April 2006.

EFEO Photos in black and white

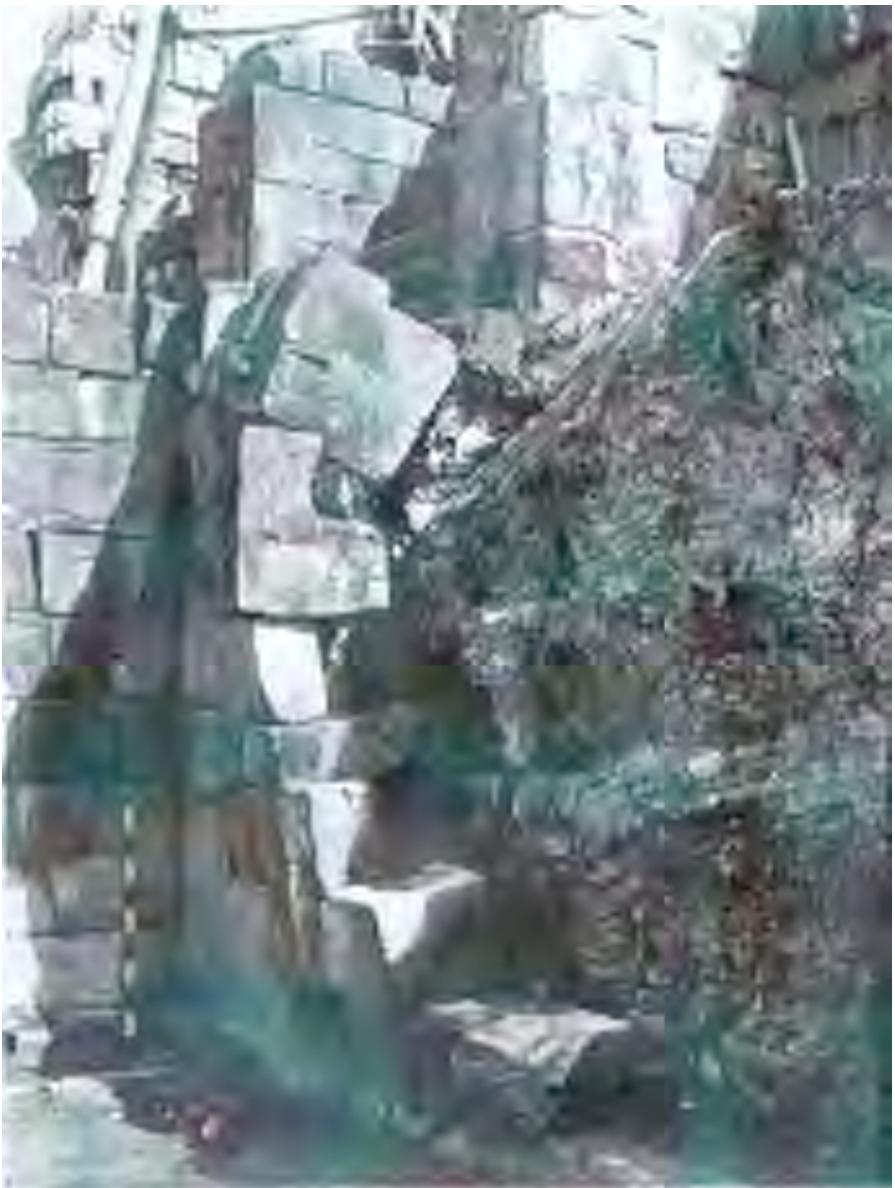
Existing conditions in color photographs, taken April 18-24, 2006 by Michael Schuller.

Additional photographs to be taken May 2006.



View from above, southwest.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions ""



South Stair, 2nd level. Note : image is reversed. This is the west side of the stair.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



West elevation north of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



West elevation north of stairs. Stone shrine dismantled, stones laid on level below with most stone in order of placement for each course.



Note bedrock section also removed, lichen growth and stains on end of stair wall similar to older photo.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



West elevation north of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



West elevation north of stairs. Tree blocking exact reproduction of photograph.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



South elevation, east of stairs. Tree blocking exact reproduction of photograph.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



South elevation, 1st level, to east of stairs. Trees in the way for exact photo reproduction.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



East elevation, to north of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



South elevation, east of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



South elevation, east of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



South, just west of large remaining shrine, to west of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Northeast corner, top platform, photo taken from west. (Location re-verified May 2006).

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



North side, east of stairs. East elevation of brick shrine.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



North elevation east of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



West elevation main temple tower.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Northwest corner, main temple tower.

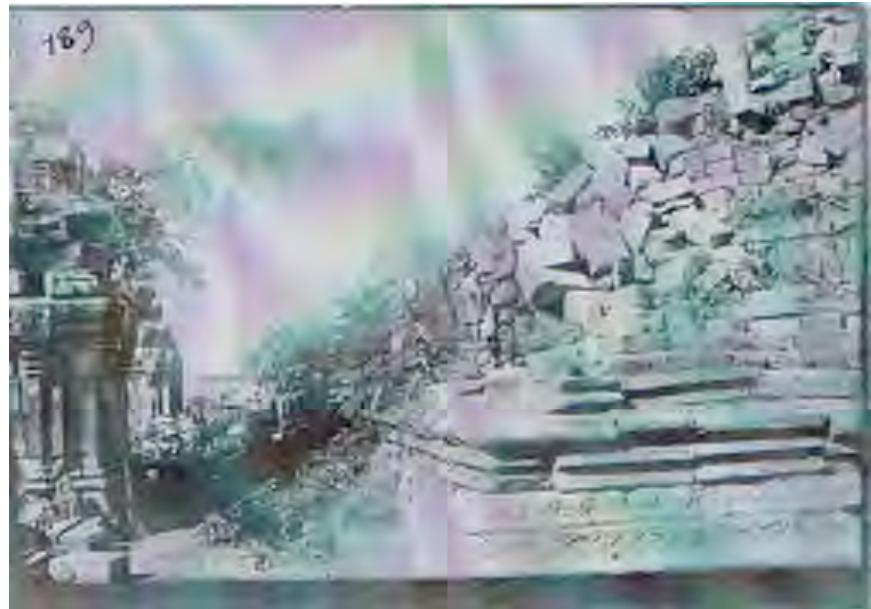


Southwest corner, main temple tower.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



This does not exist at Phnom Bakheng.



Top platform

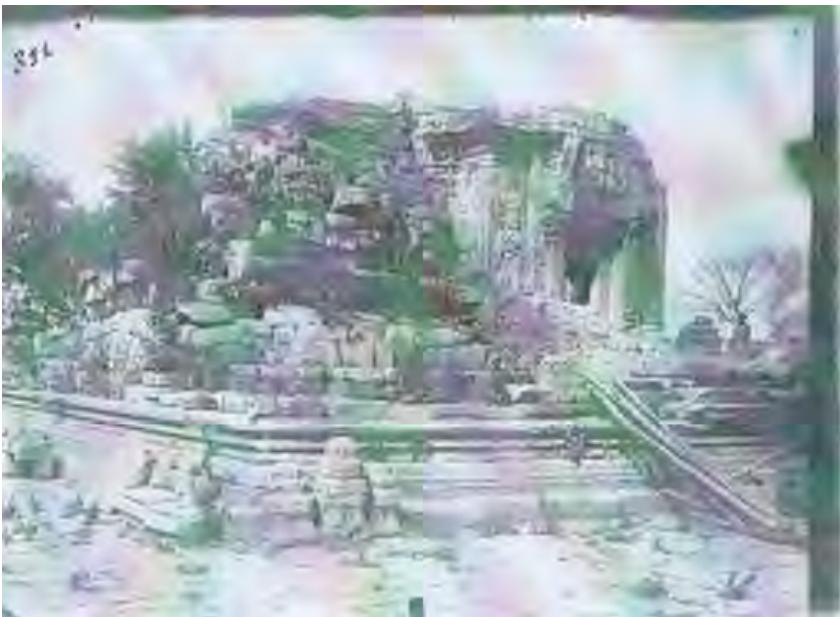
PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Top platform from northwest.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Top platform from southeast? Not sure.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Top platform

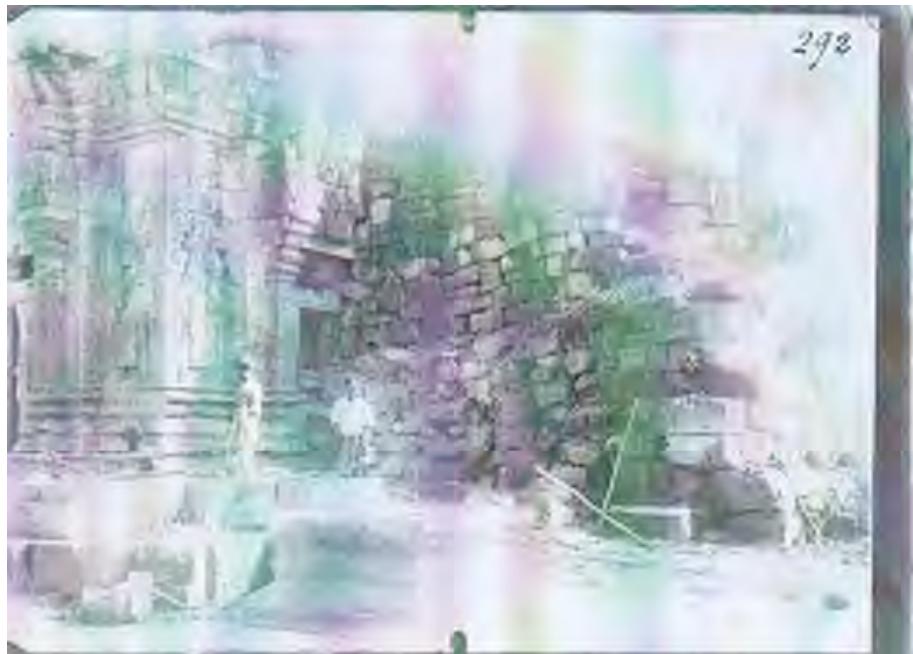


Top platform



Top platform

PHNOM BAKHENG Photos EFEO compared to April 2006 Condition



Top platform.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



All are top platform.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



4th or 5th platform ? Note – looks like laterite infill at stair wall



East, west, or south ?



?



East or west ? At brick shrine

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Could be the east elevation



Top platform, at west? Not sure.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Northwest or northeast corner.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Not clear where this is, but it may be one of the rebuilt shrines at the top platform or the shrine on the west that was dismantled (1st platform).



West ? Or north ?



Large remaining shrine on north, just east of stairs.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Large remaining shrine on north, just east of stairs. Photo taken from 1st platform.



East ? Note stairs at middle of image.



North or south ? May also be west.



Southeast corner. 4th or 5th platform.

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Southwest or northwest ?

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



North



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



East



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



North stairs



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



West from north, photo take from 1st platform.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



East

Re-position photo to be slightly more to the right to capture brick shrine.
See angle of stair walls.



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



East near southeast corner



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions



Northwest corner



PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions

228



East, west, or south ?

PHNOM BAKHENG Photos EFEO compared to April 2006 Conditions

Historic Images G10

1929



2009



សិក្សាសាលាស្ថីពីការពង្រីននិងការអភិវឌ្ឍសំណង់បែមធ្វើអំពីតួដ្ឋ



ca.1911



2010

ថ្ងៃទី១ ដល់ ថ្ងៃទី៤ ខែមិថុនា ឆ្នាំ២០១០

១. សេចក្តីផ្តើម

ក្រុមមូលនិធិប្រាសាទពិភពលោក ដែលគេហោកាត់ជាភាសាអង់គ្លេសថា WMF (World Monuments Fund) គឺជាអង់ការមួយក្នុងចំណោមអង់ការអន្តរជាតិដៃទៀតជាប្រចើន ដែលបានត្រឡប់មកបំពេញបេសកកម្មរបស់ខ្លួននៅអង់គ្លេសពីឆ្នាំ១៩៨៩។ តាំងពីពេលនោះមក អង់ការ WMF បានបំពេញបំពេញបេសកកម្ម និងធ្វើការងារផ្តើសជុលប្រាសាទជាប្រចើន ត្រូវនៅរដ្ឋមន្ត្រីប្រជាធិបតេយ្យ នៃប្រាសាទព្រះខែន ប្រាសាទកាលេម នៅទីក្រុងក្របខណ្ឌនៃការងារផ្តើសជុលប្រាសាទរយៈពេលជាងម៉ែនត្រូវក្នុងមកនេះ ក្រុម WMF បានចូលរួមបណ្តុះបណ្តាលបុគ្គលិកខ្លួនចាប់នាទី ១៥០នាក់ ត្រូវវិស័យផ្សេងៗជាប្រចើនដូចជា វិស័យបុរាណវិទ្យា ស្ថាបត្រកម្ម វិស័យកម្ម និងការគ្រប់គ្រងប្រាសាទជាផើម។ បច្ចុប្បន្ននេះ ក្នុងចំណោមបុគ្គលិកក្រុម WMF ចំនួនជិតមួយរយនាក់នៅក្នុងជាមុជ មានបុគ្គលិកបន្ទេសតែពីនោករៀងប៉ុណ្ណោះ។ ដើម្បីសម្រេចបានលទ្ធផលទាំងនេះ ក្រុម WMF បានធ្វើការសហការយ៉ាងជិតស្ថិតុជាមួយអាជ្ញាធរអប្បយោរ និងសាកលវិទ្យាល័យនានាដើម្បីនឹងគ្រឿងកម្មវិធីនៃវិស័យជូនបានរៀបរាប់ខាងមឱ្យ។

នៅឆ្នាំ ២០០៥ ក្រុម WMF បានទទួលហិរញ្ញវត្ថុការងារសាមេរិក ក្នុងទីក្រុងប្រាក់ចំណុះនហាសិប
ប្រាំមុនដូចរាយការងារ ដើម្បីធ្វើការតាមដាន វិភាគ ស្រាវជ្រាវ និងរៀបចំផែនការអភិវឌ្ឍប្រាសាទភ្នំពាល់ខោ។
ពេលនោះ វិធានការបន្ទាន់មួយចំណុះនគ្គបានចាត់ឡើងដើម្បីក្រុមការខួចខាតកាន់តែងតាំងនូវការបង្កើត។

ផ្នែកលើទូដលនៃការសិក្សា នៅឆ្នាំ២០០៥ ក្រសួងការបរទេសអាមេរិកបានផ្តល់ហិរញ្ញប្បទានលើកទីពីរដឹងទ្រូវតាមដល់ WMF នូវទីក្រុងការប្រចាំឆ្នាំ លានដុល្លារអាមេរិក ដើម្បីអនុវត្តគម្រោងអភិវឌ្ឍក្នុងរយៈពេលវិះ។ ក្នុងចំណោមការងារជូសជុលជំនាំទាំងអស់ មានការងារជូសជុលដែលបានកែតែនៃត្រីប្រាសាទ រួមទាំងក្នុងម ដែលនៅខាងលើតាមប្រឈមប្រាសាទ ការងាររៀបចំប្រព័ន្ធការពារមិនឲ្យទីក្រុង និងប្រព័ន្ធបង្កើរទីក្រុងប្រព័ន្ធដែលនៅតាមជាន់នីមួយា នៅផ្លូវការងារដើម្បីនិងខាងក្រោម។ ការងារទាំងអស់នេះត្រូវបានរៀបចំឡើងដោយ WMF ប្រើពេលអស់រយៈពេលថ្មី។ ទៅ:ជាយ៉ាងនេះ តី តី នៅខាងបញ្ញាដាច្រើនទ្រូវតាមដល់គេមិនអាចមើលរំលងបានទៀត។ ដូច្នេះ ដោយសហការជាមួយអាជ្ញាធរអប្បយក និងមានជំនួយពីមូលនិធិ Wilson Matching Fund ក្នុង WMF បានចាប់ផ្តើមឡើងការយកចិត្តទុកដាក់លើក្នុងមន្ត្រីទាំង៥៥នៅជិរញ្ញប្រាសាទ។ ជំហានទីមួយ តី ផ្តើការតាមជាន់លើលីនីជុំចេនាសម្រាប់នៃក្នុងមួយ។ តាមរយៈការធ្វើបែបនេះ គោរចរកយើងមូលហេតុនៃការ

ខ្សែខាត ភាពធ្លន់ជូរបស់ការ និងកំណត់អាជីវកម្មដៃលក្ខ្យរដោះស្រាយ។

បន្ទាប់ពីក្រុមអ្នកជំនាញ អាជ ហក អាយ សី សី របស់អង្គភាពយេណាស្តូចានចុះទៅពិនិត្យប្រាសាច័ត្តបានខ្លួន កាលពីខែធីចុនា ឆ្នាំ២០០៨ និង ផ្លូវការបើកពិភាក្សាការងារអ្នកជំនាញ អាជ ហក ដាម្មីយក្រុម WMF ព្រមទាំងយោងទៅតាមអនុសាសន៍ដែលផ្តល់ជូនក្នុងសម្រាប់ប្រជុំបច្ចេកទេស អាយ សី សី លើកទី១៨ ក្រុម WMF ក៏បានឯកភាពចាត់វិធានការ ការពារបណ្តុះអាសន្ន ត្បូប៉ែមពីរធ្វើពីក្នុងដែលស្ថិតនៅក្នុងសភាគទ្រួមជាងគេ។ WMF បានទ្រូវឈ្មោះត្បូប៉ែមទាំងពីរនោះថា G5 និង G10។

២. អត្ថន៍យសដោបន់កិច្ចពិភាក្សាបស់អង្គភាព

សិក្សាសាលាមួយស្តីពីការអភិវឌ្ឍន៍និងការព្រឹងតួប៉ែមធ្វើពីតួដ្ឋ ក៏ត្រូវបានរៀបចំឡើងពីថ្ងៃទី១ ដល់ថ្ងៃទី៤ ខែមិថុនាទ្វាចំឆ្នាំ២០១០ ដោយមានការចូលរួមពី សមាជិកក្រោមអ្នកជំនាញ អាណ ហុក នាយ សុ សុ នស់អង្គការ យុណៈ អ្នកជំនាញក្នុងស្រុកនិងអន្តរជាតិដែលមានជំនាញនិងបទពិសោធន៍ជាងការផ្តល់ជុលប្រាសាទកដ្ឋនៃអង្គរ ក្រោមទាំងអ្នកជំនាញអន្តរជាតិដែលមានជំនាញជាងការអភិវឌ្ឍន៍និងការព្រឹងប្រាសាទតួដ្ឋដែលមិនធ្លាប់ធ្វើការនៅអង្គរពីមុនមក។

នៅក្នុងពេលសិក្សាសាលានេះ ឯកឧត្តម នឹង បួនីត់ បានពិត៌លីវា នាគ្រោះអំពីប្រវត្តិនៃការប្រើប្រាស់តំណែនក្នុងការធ្វើសំណង់បេតិកភណ្ឌក្នុងព្រះរាជាណាចក្រកម្ពុជា។ សំណង់ដំបូងបំផុតដែលគេប្រើតំណែនក្នុងអំឡុងសព្ទរក្សីទី៥ក្នុងសម្រាប់បញ្ហាថាន សម្រាប់បញ្ហាផ្លូវការនៅអង្គរធំបានរួមចិត្តរបី បុសំបូរៈព្រមទាំងម៉ោង នៅសម្រាប់បញ្ហាដែលជួយដំនានដើម្បីប្រាស់តំណែនក្នុងសំណង់ ក្នុងចន្ទោះពីសព្ទរក្សីទី៥ ទៅសព្ទរក្សីទី៩ ហើយនៅពេលដំនួនសព្ទដោយចិត្តកកវិញចាប់ពីចុងសព្ទរក្សីទី៩ រហូតមកដល់ពាក់កណ្តាលសព្ទរក្សីទី១០។ បន្ទាប់មក គេយើងាយនានការប្រើប្រាស់តំណែនជានីមួនឡើត ដូចជានៅប្រាសាទិប្រុបជាមីន ហើយកំពាត់ទៅវិញនៅក្នុងអំឡុងសព្ទរក្សីទី១២រួចមានមុខបន្ទាន់រហូតមកចាប់ពីចុងសព្ទរក្សីទី១៣។

ធ្វើក្រុមចាត់ដូរត្រូវបានគេនិយមប្រើប្រាស់ជាសម្បារ៖ សំណង់ បុន្ថែមទៅនៅតែមិនទាន់ដឹងច្បាស់ពីរហ័លដែលចាត់ ឡាដែនដើមិនលិតតិដូរនៅឡើយ ហើយគេកិច្ចិនដែលរកយើងឡួយដូចបុរាណដើរ។ ការអភិរក្សានិងការជួសិល សំណង់តិដូរមានការលំបាកជាងការអភិរក្សានិងការជួសិលសំណង់ធ្វើពីចិត្តកំហែកនៃការ រៀបចំធ្វើសិក្សាសាលានេះពីតាមានសារ៖ សំខាន់បំផុត។

ពម្រិរការបន្ទាន់ក្នុងការគ្រប់គ្រងចំណួនទេសចរម្បាតនលូ វិមនីងកិច្ចខិតខំប្រើដែលប្រង់រួមត្រូវក្នុងការអប់រំក្នុះទេសចរម្បាយលំអំពីបញ្ញាថាដំអស់នេះ។

លោក សាយមុន វីរ៉ាត បានលើកឡើងអំពីបញ្ហាទូទៅដើម្បីតមានឡើងចំពោះសំណង់តិចនៅអង្គរ រួមមានបញ្ហាសម្រារ៖ បញ្ហាបច្ចេកទេស (ត្រី: តំណាង ចម្លាក់) បញ្ហាអាកាសធាតុ (ការផ្តាស់ប្តូរកំដៅ សំណើម ទីកភ្លីង) បញ្ហារួចធាតិជុំ: ពីលើ និងបញ្ហាបណ្តាលមកពីការជួសជុលពីមុន។

ដែលបានទៅមើលដល់កន្លែងជាប់ចុះ បានផ្តល់ពីពីមានចា ពេលអោលដែលល្អបំផុតសម្រាប់ជាប់យកចុះដែល
មានគុណភាពតីមុនដូរស្ថាបន្ទាយ (ចន្ទាន់ខេមិតា និងខេមសា) ធ្វើយកទៅក្នុង គេសំគាល់យើងឱ្យចា នៅប្រទេស
រៀបចំការងារ គេមានទម្ងន់ជាប់យកចុះបន្ទាយប៉ុណ្ណោះដូរស្ថាបន្ទាយបានកន្លែងធម្មតទៅ។ បន្ទាយប៉ុណ្ណោះជាប់យកចេញមក ចុះបាយ
ក្រែមត្រូវបានគេយកទៅហាលទ្វួស្សិតសិនមុននឹងគេយកវាទៅប្រើ។ ក្រោមដីបុនបានស្រាវជ្រាវយើងឱ្យចា ចុះ
បាយក្រែមបច្ចុប្បន្នមានគុណភាពមិនសូវល្អជាបាយក្រែមដែលខ្លួននាន់ដើម្បីប្រើប្រាស់។

ចំពោះតួប៊ម G10 អង្គសាលាថានចោទសំណុរចា តើគេគូរបង្កើងតួប៊មធ្វើពីតិដ្ឋសិន មុននឹងពាយីតិដ្ឋសិន បុយ្យាងណា? ហើយតើគេមានជម្រើសផ្តើមខ្លះ? ចំពោះតួប៊មនេះ គេយើងធ្វើករដ្ឋិតិដ្ឋមានសភាពឡាច្រោមខ្សោះ ជាងត្រី: មានបញ្ហាប្រសិទ្ធិដែលធ្វើឲ្យតួប៊មប្រេ: ចំកណ្តាល ពីលីចុះមកក្រោម បណ្តាលឲ្យដឹកជញ្ជាក់ជាបំណែក។ ការសិក្សាដោយឲ្យកម្មួយឡើងតានបង្ហាញពីការសិក្សារិចនីលវនេតួប៊មជូនឲ្យប្រាសាទដោយសារទីក្រោង។ ការការពារដើម្បីបញ្ចូសកំឡើមានការរិចនីលបន្ទូឡើងតិដាមានទិន្នន័យសំមួយ។ នៅពេលដែលគេបង្កើងធ្វើករដ្ឋិតិដ្ឋសិន វាការបង្ហាញរួចរាល់ការបំបាត់ពាល់ដោយឡើងឡើងតិដាមានលក្ខណៈ ពហុជនាថ្មី ហើយខណៈដែលត្រីស្តីនៃការធ្វើសិលលនៅនឹងកន្លែងចំងារតាមរបៀបនៃការបំបាត់ពាល់ គិតចំណុច គេកំគូរគេតិតិដលវិធីរួមឱ្យបង្កើងវិញ្ញានករណីនឹងខ្លះដើម្បីយកឈានទៅសម្រេចគោលដៅ។

សិក្សាសាលាតានពីភាគ្យអំពីវិធីពីរក្សងការពន្លឹងត្រី: ទីមួយ គេអាចជាក់បង្កាលទៅប៉ូតាយក្រោមដែលជាត្រី: នោះបណ្តាឃោះអាសន្នសិន រួចដើរការយដើម្បីជាក់ត្រនល់ពីក្រាម។ ពេលដែលប៉ូតាយក្រោមមានលំនីងហើយ គេអាចដកបង្កាលចេញពាន់។ វិធីទីពីរ គឺគេអាចជាក់បង្កាលទៅប៉ូតាយក្រោម និងការយដើម្បីជាក់សុប្បញ្ញត្រី: ត្រួតពិនិត្យក្នុងស្ថាបន្ទូរទៅលើវិញ រួចកល់ដោយជុំប៉ូតាយក្រោមចិញ្ចុះ។ បើនេះគេបានសំគាល់យើងចា ការជាក់ត្រនល់ទល់ពីក្រាមប្រហែលជាការលំបាកប្រសិនបើចន្ទាន់សម្រាប់បញ្ហាលទ្ធនល់នោះក្នុងពេក។

ខ្លះដែលត្រូវធ្វើ ដើម្បីរកឲ្យយើងនូវជំណាញ៖ត្រាយដែលសម្រប។

ការស្រាវជ្រាវរបស់ក្រុម WMF កាលពីឆ្នាំ២០០៥បានបង្ហាញថា ត្រីវគ្គចំណេះមានស្ថានភាពនឹងលូ បុន្ទែនគេបានសន្លិដានថា ទីកដែលបានបង្ហាញមានច្បាប់ជីវិញ្ញុប៉ុមានបញ្ហា វាដាការសំខាន់ដែលគេត្រូវយល់ពី ធម៌បែបបោះពាល់នៃលំហូរទីកដ្ឋានទៅលើលីនីអីនៃតួប៉ុម G5 និង G10។ ក្រុម WMF បានទាញចំណាប់អារម្មណី ថា គម្រោងដូសជូលធ្វើកក្នុងក្រសាងចុំបានខិះជ្រាបទីក នឹងនាំចូរទីកដែលបានផ្តល់ទៅក្រោមមុន្តុប៉ុមកាន់ពេល មានបរិមាណច្រើន។ ការរៀបចំប្រព័ន្ធគ្រប់គ្រងទីកជាស្រែដែលបានបង្ហាញថា ការស្វែងយល់អំពីចិត្តចំណេះមានភាពនឹងលូ បុន្ទែនគេបានសន្លិដានថា ទីកដែលបានបង្ហាញមានច្បាប់ជីវិញ្ញុប៉ុមានបញ្ហា វាដាការសំខាន់ដែលគេត្រូវយល់ពី ធម៌បែបបោះពាល់នៃលំហូរទីកដ្ឋានទៅលើលីនីអីនៃតួប៉ុម G5 និង G10។ ក្រុម WMF បានទាញចំណាប់អារម្មណី ថា គម្រោងដូសជូលធ្វើកក្នុងក្រសាងចុំបានខិះជ្រាបទីក នឹងនាំចូរទីកដែលបានផ្តល់ទៅក្រោមមុន្តុប៉ុមកាន់ពេល មានបរិមាណច្រើន។ ការរៀបចំប្រព័ន្ធគ្រប់គ្រងទីកជាស្រែដែលបានបង្ហាញថា ការស្វែងយល់អំពីចិត្តចំណេះមានភាពនឹងលូ បុន្ទែនគេបាន

ចំពោះគួរបាយ G10 ត្រូវពិនិត្យ វាពិនិត្យចាប្ត់សំណងសំណងមានវគ្គមានអំបីល ហើយការសិក្សាអំពីអំបីលនេះ អាចធ្វើឡើងបានដោយប្រើប្រាស់ការសិក្សាសាលាថានផ្តល់អនុសាសន៍ទូសិក្សាមួយបានសូជាម្រោយ អំពីអំបីលនេះលើកដូចនេះ។ វិនិច្ឆ័យនៃការសិក្សាដែលប្រើប្រាស់បេក្ខភាព សិក្សាបេក្ខភាព ខាងក្រោមមិនប្រើប្រាលេឡើតទេ តែ ក្រោនទៀតដូចជាសមូលរបាយទីកន្លែង និងរបៀបស្វែកការណ៍ឡើង ដូចជាប្រើប្រាស់បេក្ខភាព សិក្សាបេក្ខភាព ខាងក្រោម និងក្រោនទៀតដូចជាសមូលរបាយទីកន្លែង និងរបៀបស្វែកការណ៍ឡើង។

៣. សេចក្តីសន្និដ្ឋាន

អងសិកាសាលាបានសរបសេចក្តី និងធ្វើការសន្និជានជូនខាងក្រោម៖

ស្ថានភាពនៃត្រីជាងក្រាម និងដំណើរទីកហ្មរនៅខាងក្រោមតួប៊មគឺជាបញ្ហាសំខាន់ពាក់ព័ន្ធនឹងស្ថានភាពទ្រខ្សោមនៃតួប៊មខាងលើ។

ចិត្តយក្រោម៖ ការស្វែងយល់អំពីចិត្តបាយក្រោមគឺជាដឹកនាំដែលសម្រាប់ការងារអភិវឌ្ឍន៍។

- គេគូរកម្រិះលាងកសារដែលនិយាយអំពីការស្រាវជ្រាវថ្មីប៉ុណ្ណោះ។
 - យកចូលរួមទៅពីសោដង (ចូលរួម ចូលចូល ចូលស្ថិត។)
 - ស្លៀងយល់អំពីយន្តការនៃការខ្ចោះខ្ចោះរបស់វា ជាបិសសប្បីដែលនៅជ្រើនខាងក្រោម។
 - ស្លៀងយល់អំពីលក្ខណៈ: ចូលចូល និងចូលរួម។
 - កំណត់ថាគីឡូដីដែលគេយកមកប្រើ គេត្រូវទុកចុរាប់នៅសភាពីជីដែលប្រើប្រាស់ដូចចូលរួម។
 - គេភាពប្រើប្រាស់សំណើន៍ប្រើប្រាស់ដូចចូលចូល ចូលស្ថិត។
 - គេគូរកសារមិទ្ធកំពោរចាស់ទន្លេដែល។

ការគ្រប់គ្រងទឹក៖

- វាគារចំណាំក្នុងពីនិត្យ តានជានមួយ ដើម្បីក្រោមពាណិជ្ជកម្ម ទៅកន្លែងណាយ

ជាតិកំងតុជ្រះ

- ពង្រីកចាប់ផ្តើមលំនីង គេអាចចងការណ៍ប្រព័ន្ធដែលប្រពិបត្តិការរកល់ត្រីវិភាគ។
 - គេត្រូវប្រើសៀសដៃកេហលីហើចស៊ត្ថាប់តុជាងក្រារទៅដាក់ចាប់ផ្តើមខាងក្រោម។
 - គេត្រូវទេប់កន្លែងដែលមានស្មាយប្រប់ច្បាប់ មននឹងដែលបានឈ្មោះថាកំពង់កំពង់។

- ការធ្វើសង្គមបិទកនៃនៅប្រែ: គួរបៀវសារធាតុដែលការពារកំច្យក្នុងជាតិដូចតាន។
- បន្ទាប់ពីកល់ត្រី: ខាងក្រោមហើយ គេអាចបៀវខ្សោចនៅផ្ទាល់ពារណ៍ខាងលើ ដើម្បីកែត្រូវ ដ្ឋានតួប៉ះមដែលមិនទាន់ត្រង់។
- ផ្ទើកខាងលើនៃជាព្យាមទាំងបីនាទានបាត់បង់ បាក់បែកឆ្លាក់ចុះមកក្រោម។ គេគួរកត់ត្រាតដែលខ្ពុចខាត ហើយនៅពេលធ្វើសង្គមបិទឡើងវិញ គេត្រូវបង្កើតឲ្យមានផ្លូវទីកហូរ។

កដ្ឋានឱងកដ្ឋានសំ៖

- សភាពប្រាបទីកនៃកដ្ឋានសំ៖នឱងកដ្ឋានឱងកដ្ឋានសំ៖។
- គេគួរស្វែងយល់ឲ្យបានច្បាស់អំពីកដ្ឋានសំ៖ ដើម្បីជួលិតកដ្ឋានឱងកដ្ឋានសំ៖។
- ផ្តល់ព័ត៌មានឲ្យអ្នកជួលិតកដ្ឋានឱងកដ្ឋានសំ៖ ដើម្បីជួលិតកដ្ឋានឱងកដ្ឋានសំ៖។

ជំនះ:

- គេត្រូវស្វែងយល់ចាត់ដីដែលគេយកមកបិទនៅថ្ងៃនៅក្នុងខែមិថុនា ហើយ ស្រាវជ្រាវឡើលបាត់ដីដែលជួលិតមកពីដើមឈើក្នុងស្រុក រាជបៀវបានប្រើបានប្រើបាន។
- គេត្រូវសិក្សាអំពីការប្រើដីរឈើជាប្រាសការពារទីក។

ផ្ទើខាងក្រោម:

- ការធ្វើសង្គមផ្ទើកដ្ឋានក្រោមការស្រើយទៅលើស្ថានភាពអំប឵ល និងទីកដែលហូរពីលើ គេអាចប្រើកំហែរបាយអប្បប្រើបាយដែលបានប្រើបាយដោយស្រួល។

កណ្តុះំនះ:

- ការប្រើចូលសម្រាប់សំបុកកណ្តុះំនះដោយការប្រើបាយក្រោមបាត់បង់លីនីងជួងដែរ។
- ការសិក្សាអំពីដើមឈើដែលនៅជួងវិញពីជាប្រើបាយសំខាន់ ព្រមទាំងការប្រើបាយការពារទីក។

ការទល់ពីក្រោម:

- ការទល់ក្រោមការប្រើបាយក្រោមបាត់បង់ ដើម្បីយកចូលបាយក្រោមបាត់បង់ដែលពីរុកដួយ ចេញ និងជិនសដ្ឋាមបាយក្រោមបាត់បង់។
- គេអាចប្រើបាយក្រោមបាត់បង់ត្រីពីក្រោមទៅទល់និងចូលបាត់បង់ ដើម្បីឲ្យទម្រង់តួប៉ះមទាំងមូលសង្គត់ទៅលើចូលបាត់បង់។

ការធ្វើសង្គមសាកល្បង៖

- គេគួរពីការធ្វើសង្គមសាកល្បងដើម្បីបង្ហាញអំពីបច្ចេកទេស វាតាការសាកល្បងឯង និងជាការបណ្តុះបណ្តាលបុគ្គលិកជួង។

ជំហានបន្ទុះ

- ពិនិត្យមេលការខួចខាតរចនាសម្ព័ន្ធនិងសម្បារ៖នៃសំណង់ ហើយចាត់ភាគទិន្នន័យដូល។
- កំណត់ប្រភេទនៃការវិភាគ ធ្វើពិសោធន៍ន និងការតាមដាន ដើម្បីរកទួយឱ្យយន្តការនៃការខួចខាត។
 - + មិនអាចសរស្រារវិនិច្ឆ័យបញ្ហាផលពិសោធន៍នពីមុន ហើយក្រោមក្រោមនឹងប្រាសាទដៃរឿង។
 - + ប្រើបច្ចេកទេសពិសោធន៍នដែល WMF ត្រូវបានប្រើបន្ថែមនៅក្នុងផ្សេងៗ។
 - + គួរក្រោមក្រោមនឹងប្រាសាទដៃរឿង។
- ពិភាក្សាអំពីជម្រើសនៃវិធីដែលគេត្រូវប្រើដើម្បីដឹងសិល្បៈ។
- រៀបចំគម្រោងជួសជុលសាកល្បងតួចម្លាយ ដើម្បីកំណត់ជម្រើសវិធីជួសជុលចុងក្រាយ។

តាំងពីសិក្សាសាលាឌែមិចុនា ឆ្នាំ២០១០ នេះបានផ្តល់របាយការណ៍ជួចបានរៀបក់ខាងលើចម្លក គេបានធ្វើការសរស្រារវិនិច្ឆ័យ យកសម្បារ៖ទៅពិសោធន៍ន និងធ្វើការតាមដាន ស្រាវជ្រាវនៃនិងប្រាសាទជ្ញាល់។ នៅខែកញ្ញា ឆ្នាំ២០១១ WMF បានរៀបចំគម្រោងជួសជុលសាកល្បង តួប៊ែម G10 ក្រោមការដឹងនាំរបស់លោកសាស្ត្រាចាយ ចចចុ ក្រុលី អ្នកជំនាញ អាណ ហុក អាយ សុ សុ របស់អង្គការយុណៈស្តី។

ចំណាំ៖

1. របាយការណ៍លំអិត និងលទ្ធផលនៃការធ្វើពិសោធន៍នផ្សេងៗដែលមានរៀបក់នៅក្នុងរបាយការណ៍សង្គមជាការណ៍ខ្លួន៖ មានសរស់នៅក្នុងរបាយការណ៍សិក្សាសាលានេះជាការអង់គ្លេស។
2. របាយការណ៍សង្គមខ្លួន៖ ត្រូវបានរៀបចំឡើងទៅតាមរបាយការណ៍លំអិតជាការអង់គ្លេស ដែលមានបង្កោះនៅក្នុងវិបសាយរបស់ WMF។
3. របាយការណ៍សុំអំពីលទ្ធផលនៃការជួសជុលសាកល្បងតួប៊ែម G10 មានសរស់ជាការអង់គ្លេសជាតិដោយទូរក្រ។