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CONSERVATION OF THE EARTHEN ARCHITECTURAL ASSETS AT PEPEY I NECROPOLIS ARCHAEOLOGICAL SITE: HOW TO ADAPT TO CLIMATE CHANGE?

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SUMMARY

During March 2020, Saqqara was subject to an unprecedented spell of heavy rainfall that affected most of the earthen archaeological remains present at the site. As part of the Nile's Earth ANR funded project, a series of missions were carried out at the site in November 2021 aiming at suggesting and possibly starting to implement specific experimental measures that could improve upon the conservation practices already in place at the site for several years.

This paper first describes the Pepy I necropolis and the specificities of the earthen assets present at this archaeological site. It then summarizes the results of the overall condition survey and risk assessment made in 2021, including a critical analysis of some of the previous conservation techniques applied on these structures and, as a result, the justifications for the choices of the first corrective measures which were implemented. It finally covers the first results observed, including after the site had received further heavy rain before the end of 2021, and explains the proposed research activities to be implemented in the future.

INTRODUCTION

During March 2020, the Saqqara world heritage site was subject to an unprecedented spell of heavy rainfall that affected most of the earthen archaeological remains present there. As part of the Nile's Earth project funded by ANR (Agence Nationale de la Recherche), in November 2021 a mission was carried out at the Pepy I necropolis, which is under the custodianship of the Franco-Swiss Archaeological Mission of Saqqara, one of the operational partners of the ANR project. This mission aimed to perform the first overall evaluation of the impacts resulting from the heavy rainfall, and to launch a long-term response to the possibility of similar rainy events in the framework of the global climate change process.

Rather than a detailed condition survey, the methodology was oriented towards making sure that the causes, circumstances, and processes of decay could be identified and understood, in some instances even though the conservation works and protective measures which had been implemented in the past.

This first assessment led to the proposal of some initial corrective measures that could be implemented immediately during the ongoing archaeological campaign, as they were mainly adaptations of existing restoration techniques. Furthermore, in November 2022, a second mission allowed further observations, the implementation of a new set of preventative measures at some of the structures involved, and the launch of an exploratory process to improve the capacity of the mud

bricks used for the restoration of the most exposed parts of the archaeological structures.

This paper provides an overall description of the works implemented, the first results observed, including after the site having received a new heavy rain, by the end of 2021, and what are the proposed research activities to be implemented in the future.

1. BRIEF PRESENTATION OF THE PEPI I NECROPOLIS

Excavations at the necropolis of the royal family of Pepy I have been conducted for several decades by the Franco-Swiss Archaeological Mission of Saqqara¹. The site was first occupied in the reign of Pepy I (\pm 2250 BC) and was then used discontinuously until the end of the Middle Kingdom (~1800) and the Late Period (650-332 BC).

This necropolis benefited from a particularly intense occupation, which was probably the densest and longest of the Old Kingdom². Having been used by several generations, reaching well beyond the reign of Pepy I, it represents a unique case of special interest and thus is highly suitable for the study of the evolution of a royal necropolis. The excavations have also provided archaeological evidence of its uniqueness since it is presently possible to follow the evolution of the necropolis from the reign of Pepy I through until at least the Middle Kingdom³. The royal necropolis of Pepy I (Fig. 1) is organized according to a master plan which uses concentric circles to clearly distinguish the different social strata from the king at the centre, and the rest of society distributed around him, in order of importance. The distribution is simple and the placement of the dead in the necropolis follows the social order of the living.

In terms of organization, the funerary complex dedicated to the king (pyramid and funerary temple) is delimited by a large 4m wide enclosure (1st circle)⁴. A 5 m wide street runs around the enclosure. This street serves all the funerary complexes of the royal family (royal wives and children) which are estab-

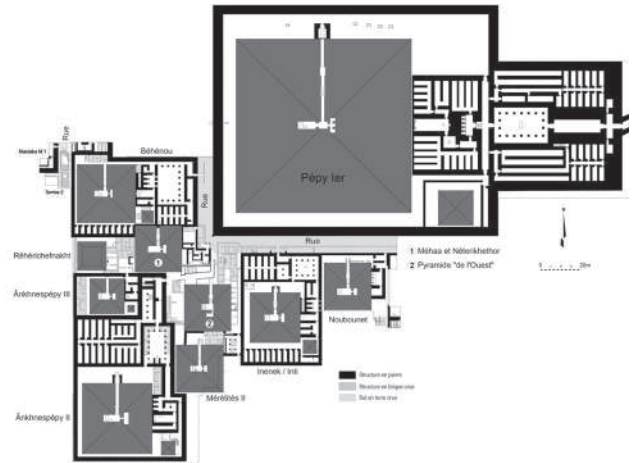


Figure 1: General plan of the Pepy I necropolis.
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lished all around the king, thus forming the 2nd circle. The various funerary complexes of queens which have been excavated to date in the Pepy I necropolis present more or less complex profiles and contours, reflecting the chronological evolution of their establishment, and taking into account previous additions.

Lastly, the necropolis of the elite is established behind the royal family, constituting the third and final circle. The plan of the necropolis, as it appears today, allows us to partly identify the western limit of the second circle: the western enclosures of the complexes of queens *Ankhnespépy II*, *Ankhnespépy III* and *Béhénou* have a perfect rectilinear alignment which is oriented on a north-south axis, demonstrating the planned distinction between the necropolises of the royal family and of the high dignitaries. Moreover, a street similar to that separating the king from the queens runs along the western side of this wall, providing access to all the mastabas in line.

2. EARTHEN STRUCTURES AT THE PEPI I NECROPOLIS

Within the Pepy I necropolis, several types of materials were used for the construction of the monuments: stone, of different qualities and origins (local limestone and from the right bank of the Nile, Aswan granite, Egyptian calcite or alabaster, quartzite, basalt, and so on), wood (cedar, sycamore), and raw earth. The latter has a secondary place in the necropolis, but its use was not negligible; indeed, a quick calculation allows us to estimate earth to have constituted 15% of the surface covered. We can distinguish several types of built structures, from the most massive and complex to the lightest that do not require significant technical knowledge for their construction. To describe them, we have built a typology specific to the site:

a) Mixed constructions (stone/brick)

These stone and brick materials often form the core of struc-

1. The MafS was founded in 1963 by Professor J. Leclant, with the assistance of J.-Ph. Lauer, and was directed until 2007 by Dr. A. Labrousse. It became the Franco-Swiss Archaeological Mission of Saqqara and is now the responsibility of Ph. Collombert, Professor at the University of Geneva. A website dedicated to the work of the mission is available online at: <https://mafssaqqara.wixsite.com/mafS>.

2. The fame of this necropolis was such that the very name of the pyramid of Pepy I, "*Mennefer*", was used to designate the ancient capital of the country, Memphis, nearby, from the end of the Old Kingdom.

3. All the annual reports published in the section "Fouilles et Travaux en Égypte et au Soudan" of the journal *Orientalia* are now available online. Having also benefited for many years from the patronage of the Académie des Inscriptions et Belles-Lettres, the MafS regularly presented the results of its work in its "Comptes-rendus" (LABROUSSE & LECLANT 1998, 2001, 2006; COLLOMBERT 2011). Since 2020, the annual reports have been presented in the *Bulletin archéologique des Écoles françaises à l'étranger*, an online journal (COLLOMBERT *et al.* 2020, 2022, 2023).

4. The entire funerary complex of King Pepy I has been published: LABROUSSE 2019.

tures faced with limestone. To illustrate these cases, we can cite as examples the complex of Queen *Méhaa* and her son Prince *Hornetjerikhet* (Fig. 2) and Tomb No. 2 (excavated in 2022), the main parts of which are made of bricks, with the outer walls covered with limestone “slabs”.



Figure 2: Funerary complex of Queen *Méhaa* and her son *Hornetjerikhet* (right), and the anonymous “Pyramide de l'Ouest” (left); use of massive brick walls and mixed constructions.

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b) Brick structures

Structures built entirely of brick are the most common. They are found in the following forms:

- large modules, such as elements of funerary temples (pyramid “of the West” in the Old Kingdom; the *Rêhêrichfnakht* complex in the Middle Kingdom), or tombs built either in the necropolis of officials to the west (between *Béhénou* and *Ouni*) and to the south (south of *Noubounet*) of the complexes of the queens, or within the 2nd circle;
- small buildings whose walls rarely exceed 2 to 3 bricks in thickness; they are poorly preserved, and only remain in the form of a few sometimes disjointed courses that do not stand up well to exposure to the open air after excavation (Fig. 3). They are mostly installed in constrained spaces that were originally either uncovered (e.g., the northern peribolus of the queens, small spaces between the pyramid and the storerooms, against the façades of the complexes of the queens, etc.), or partially covered (porticoes of the pillared courtyards).

c) Materials used in floors and for earthen plaster

Many of the buildings described above contain earthen plaster which is sometimes covered with a layer of gypsum. The floors are also very often covered with a layer of earth mixed with small pebbles and/or cobbles⁵. These were used in the construction of the streets and the setting of the floors of the buildings’ rooms, even when the latter were laid on limestone paving (Fig. 4).

5. These elements, locally called *zalat*, come from the underlying natural terrain in the form of more or less thick terraces covering the limestone.



Figure 3: Queen *Behenou*'s complex: small mudbrick building discovered north of the pyramid. Construction of one to two bricks thick covered in places with a gypsum coating.

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Figure 4: Queen *Behenou*'s complex: small mudbrick building erected in the courtyard north of the pyramid. An earthen floor was laid on a pre-existing pavement.

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3. CONSERVATION EFFORTS REGARDING THE EARTHEN STRUCTURES OVER THE LAST 30 YEARS

For many years, the MafS has had a mission to enhance and protect all the structures uncovered during the various excavations, whether they are made of stone or mud brick. For the latter, we have identified three main and complementary methods, all of which have been implemented on the site (Figs. 5-6):

Method A: partial reconstruction of the walls with identical mud bricks made with local materials; the earth as well as the straw and degreasing agent (limestone chips and pebble fragments) are taken from the silt at the nearby village.

Method B: covering the faces of the structures with earthen plaster made according to traditional methods; a particular aspect (such as traces of smoothing) must make them easily distinguishable from the original elements.

Method C: covering the wall levels in order to protect the tops of the walls with “caps”; first, the structures are completed in order to create a rectilinear top with bricks (method A); when the wall is several rows thick, only the outer courses are rebuilt while those constituting the core are replaced with a filling (fragments of limestone, bricks and earth combined). Finally, the “caps”, made with modern fired bricks bound with lime mortar, are mounted in an overhanging position, and covered by a semi cylindrical shape made from the same mortar mentioned above.



Figure 5: Conservation works on the mudbrick structures (methods A and B).

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Figure 6: The conservation works (method C) did not prove efficient during the 2020 rains.

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Critical observation of the listed methods: advantages and disadvantages.

The use of materials identical to those of the heritage assets (method A) maintains a certain aesthetic cohesion throughout the site. Nevertheless, erosion eventually damages the structures, and many overlaps are caused by drips, especially due to rainfall. In concrete terms, the old and the new coatings mask each other, making it difficult to distinguish between the original and the conservation coatings.

The presence of rendering (method B) protects the faces of the walls which are most exposed to bad weather (rain, and also very erosive sandy winds). However, time and climate bring degradation, which requires regular intervention by the masons on the damaged structures. This, in turn, implies the permanent presence of a team of qualified workers during each season of excavations to ensure both the maintenance of the site and the restoration of new structures which are brought to light.

In combination with methods A and B, method C effectively protects the tops of the walls, and the overflow pushes the runoff beyond the wall. Unfortunately, the Antiquities Service has often reminded us of the lack of aestheticism of this choice, which we have therefore had to replace as best we could for several years. This represents a great deal of work for the Mission, as this method had become systematic in covering all brick walls since the 1990s. Over time, there is a natural tendency for the “caps” to fall off, resulting in infiltrations between the disjointed bricks, causing cracks in the heart of the walls and the plaster to detach. The main consequence is that the walls “open up” following vertical cracks to the base.

4. THE HEAVY RAINS OF MARCH 2020 AND THEIR IMPACT

On May 4, 2018, Egypt Today warned that: “As Egypt’s climate changes, heavy rainfall is becoming more and more common, bringing dangerous flash floods. Flash flooding can make the dry ground become saturated in an instant, allowing torrents of water to rush down mountains like a waterslide, wiping away cities”⁶.

Though official reports on climate change like the recent one published by the World Bank (World Bank Group, 2022) mostly concentrate on the risks linked to coastal flooding due to rising sea levels, it is now recognized that “coastal rainfall... will cause more frequent and intense flash-flood events in Egypt...”

This scenario is what happened in Saqqara in 2020, with heavy rainfall on 12, 13, and 16 March. Though Saqqara may have been affected in a slightly different way due to its location on top of a plateau, 40 m higher than the plain, the data from Cairo airport provides a good idea of the rainfall that occurred. Geoclimat website⁷ reports that: “In Egypt, 64.7 mm fell in 2 days on March 12 and 13 at Cairo airport (including 45.0 mm in 24 hours, a record), i.e., the equivalent of more than twice the average annual rainfall (25 mm/year [24.7 mm according to the 1971-2000 average and 26.0 mm according to the 1961-1990 average]) and 16 times the average monthly rainfall (4 mm) for the Egyptian capital!”

6. <https://www.egypttoday.com/Article/1/49307/On-climate-change-11-Egypt-s-governorates-vulnerable-to-floods>

7. <http://www.geoclimat.org/2020/03/egypte-precipitations-12-13mars2020.html>

In such conditions, it is not surprising that the measures previously taken to protect the earthen structures present at the Pepy I necropolis which had been adequate in the past proved insufficient, leading to numerous instances of damage. Observations made in November 2021 included the following:

At the top of the walls: the flat shapes lead to the formation of gullies, the extent of which varies greatly depending on the shape and surface of the rainwater collection area. The joints between the bricks, especially those positioned as a stretcher, are areas of weakness. Concrete protective caps (method C) that had already been criticized for their poor aesthetics by the Egyptian authorities have also proved insufficient, if not leading to specific types of erosion, just underneath them (Fig. 6).

On the faces of the walls: The western and northern facades appear to be the most affected, but the erosion is quite minimal. The southern and eastern elevations are only affected by gullies from the top. Besides that, deposits are brought by the flows from the tops of the walls.

At the bases of the walls: erosion in the form of “destructive furrows” exists in zones prone to runoff and / or water stagnation. These instances of erosion are very important where damp is retained by sand or powdery earth deposits on the surrounding ground. Wall (and floor) configurations on stone slabs are also very unfavourable (Fig. 7).



Figure 7: The small structure (see Figure 4) built right above stone slabs suffered badly in 2020.

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Finally, sand accumulation can be high, particularly on the western side of the necropolis which is the most exposed to wind. This sand absorbs the rainwater and it remains for a long time. Sixteen months after the heavy rains, damp was still present at the bases of the walls, with an impact as described above when the height of the accumulation is different for the two sides of the wall.

5. DIAGNOSIS AND RECOMMENDATIONS MADE TO ADAPT TO CLIMATE CHANGE CONDITIONS

The diagnosis of the state of conservation of the earthen structures at Pepy I was performed based on observations made on the structures present at the site itself, but also on some other reference structures at sites also located at Saqqara, mainly the *mastaba* of the first dynasty (North of Djoser pyramid) and the tombs of the New Kingdom necropolis (south of the Djoser pyramid).

To that end, rather than a detailed condition survey, the methodology was oriented towards building an overall understanding of the behavior of the earthen structures present at the site during the spells of heavy rain, through identifying signs of decay, and ensuring that the causes, circumstances, and processes of decay were identified (JOFFROY, MORISET 1996) so that, where possible, corrective measures could be proposed. A multi-scale and multi-level approach was adopted, starting from the site itself and further zooming in to examine individual structures and their fabric at the top, elevation, and plinth levels. In that respect, the first important asset studied was the topography of the site. Located 40 m above the plain, the site is almost totally free of any vegetation, which indicates that no damp rises from the water table, and as such, there is no presence of salts.

Thus, the main threat to be considered here is water originating from rainfall, a subject on which numerous studies have been done since the 1990s (HOUBEN *et al.*, 1990; BENDAKIR, 1999).

On the walls themselves, the phenomena observed starts at the surface of the wall which has the initial potential to absorb the first drops of water. When the surface is saturated, there is a continuity of absorption inside the structure (possibly including through micro cracks), but this is also when the water accumulating at the surface starts to flow. That process always starts at the top of the wall as it is more exposed, though if the rain is accompanied by wind, then the exposed elevations can be prone to a similar phenomenon. The main issue, then, is that the water accumulating on the top surface of the wall finds a way to flow down to the vertical surfaces. How this happens depends on the regularity of the top surface, but it is clear that even if the top of the wall is flat, it is never flat enough to ensure that the flow of water is equally distributed. That issue leads to the creation of concentrated flows which, if the rainfall lasts long enough, results in the erosion of the vertical faces of the walls in the form of gullies. An important point here is that the thicker the wall, the more water is collected, and thus the deeper is the gully formation (Fig. 8).

When heavy rainfall occurs, water flows down the walls towards ground level, where it joins rainwater which has



Figure 8: Gullies formed on a recently partially reconstructed entry pylon of one of the tombs of the New Kingdom necropolis at Saqqara.

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fallen directly on the ground and has not been absorbed. Additionally, there is the potential presence of runoffs from the nearby environment. Almost always at archeological sites, the presence of debris pits all around tends to create “funnel effects”, that often result in “swimming pool effects”. In such circumstances, wall bases become humid and lose their bearing capacity, resulting in the leaning out of the structures and further collapse, thin walls being more quickly affected than thick ones. At the Pepy I necropolis, two factors aggravate this process. The first of these is that some of the courtyard floors are paved with stones, with little capacity to absorb water, though it should be noted that around the main pyramid, the original pattern of the stone paved floor is that it had been levelled to ensure drainage towards exits and drainage pits. The second aggravating factor is the presence of sand deposits (brought by wind) that keep the humidity high, and thus also keep the walls wet.

Additional threats with minor or isolated impacts come from the presence of animals at the site, mainly dogs, who dig cavities in which to rest at the bases of some walls (the north side as it is fresh), and a few birds trying to establish their nests in the structures.

6. NEW RESTORATION TECHNIQUES IMPLEMENTED OR BEING TESTED

Considering both the existing evaluation of the former achievements and this detailed diagnosis, it was agreed that reflection should focus on improving solutions A & B described in part 3 of this article, and testing revised or complementary ones that would reinforce the prevention of damage at the site (JOFFROY, 2012).

Capping

For the better protection of the walls and their plaster from rain damage, it was agreed to test rounded shape capping. This capping has three main advantages when compared to a flat surface. First, it represents a huge mass at the top of the wall,

with good capacity to absorb substantial amounts of rainwater. Second, a rounded shape favors the partition of water flowing down towards the wall faces, thus greatly limiting the possibility of flow concentration, and therefore, the formation of deep gullies. Third is that by providing a mass of earth at the top of the wall, the phenomenon that occurs during limited rains - of the transfer of matter from the top of the wall towards the vertical surfaces - is favored, repeating on these occasions the process of formation of a thin protective plaster-like layer.

To keep the changes reasonable in aesthetic terms, the first experimental capping that was realized at the site was limited in height, and to make the process quick and easy, the shape was designed to be obtained simply by laying bricks on the edge and by modelling plastic mortar. The finish is obtained with two coats of plaster, the final one being flush with the plaster layer of the wall faces (Fig. 9).



Figure 9: Rounded shape forming the protective capping prepared with bricks and two coats of plaster finish.

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Protection of wall basis

To avoid the possibility of water stagnating by the sides of the bases of the mud brick walls, a scenario that would endanger their stability, the test zone (Méhaa complex) was studied to identify its potential “natural” slopes. The idea was to install a drainage system that drives the water towards potential superficial drainage canals or existing ancient drainage pits. Zones where water could stagnate far from the wall bases were also identified. The response here was to first clean the debris and then undertake a ground (or floors) levelling with slopes of approximately 5cm/m towards either the center of the rooms or areas which could serve as superficial drainage canals. Where a stone wall basis was present, the cleaning was done in a way which would ensure that this original protective measure would be recovered on at least 10 cm high (Fig. 10). That was possible at places where the ground (floor) is made of compacted earth (or debris). But, there are also numerous places at the site where this system will not be possible due to the presence of flat stone floors, which is why an additional experiment has been launched.



Figure 10: Levelling of the ground around the structures for proper drainage and the recovery of the stone wall basement.

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Alternative wall basis for stone floors

An unfortunate but clear pattern at the Pepy I necropolis is that when heavy rains occur, the capacity of mud structures built on stone flooring systems around the main buildings (pyramids or mastaba) to cope with the water is very limited. Several structures that had withstood several years without problems were seriously affected during the 2020 heavy rains, to the point that it is now difficult to restore them except by rebuilding them as they were documented when brought to light. This limited reconstruction is ethically possible, but there is also the opportunity to propose a reconstruction using more resistant materials, at least for the first one or two rows of bricks, which are most at risk. The way to do that is known as stabilization (DOAT *et al.*, 1979), though how to undertake it to create and use mud bricks with compatible aspects / colors requires experimentation. To that end, a first series of sam-

ples were prepared using the locally available soil with the following additives: cement, white cement, lime, and gypsum (Fig. 11). These samples will be tested next season, primarily through a cycle of capillarity tests to check the capability of the bricks to withstand a temporary humid state.

CONCLUSION AND THE WAY FORWARD

Pepy I necropolis has been excavated for more than 50 years. Through time, the need to conserve the unearthed structures arose, and works were implemented with a specific focus on earthen structures that were more affected by the rains than the stone structures. Through that process, a variety of solutions were suggested and implemented with results that appeared satisfactory, though one of them, thought to be more durable, was criticized as too intrusive. Interestingly, this latter solution did not work well during the heavy rains that occurred in 2020. In response to what appears to be the result of climate change (such heavy rains have tended to become more frequent in recent years in northern Egypt), solutions need to be found which are both visually satisfying, and meet maintenance requirements.

The sample restoration works implemented to date have already received substantial amounts of rainfall. Their behavior has been quite good; however, as the rains were not at the level observed in 2020, it is too early to assess the advantages and the limits of these solutions. Additional experiments are planned, but more work will need to be implemented in the future to draw conclusions and possibly extend applications. To that end, there is a definite need to find a proper balance between technical efficiency and the desired aspects of the remains brought to light. This will require strong collaboration between the archaeologists and the conservators involved, in



Figure 11: Samples of bricks prepared using a variety of stabilizers and dosages.

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order to also meet the requirements of authenticity and proper documentation and identification of both original and new fabrics used for the protective layers.

The collaboration at Pepy I acknowledges the need to identify temporary solutions that are inexpensive and quick to install to ensure the protection of recently exposed vestiges between two successive seasons, allowing for their proper study before a longer-term, in-depth conservation plan can be implemented.

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