Deterioration and conservation of monumental stones with polychrome relief decoration in upper Egypt

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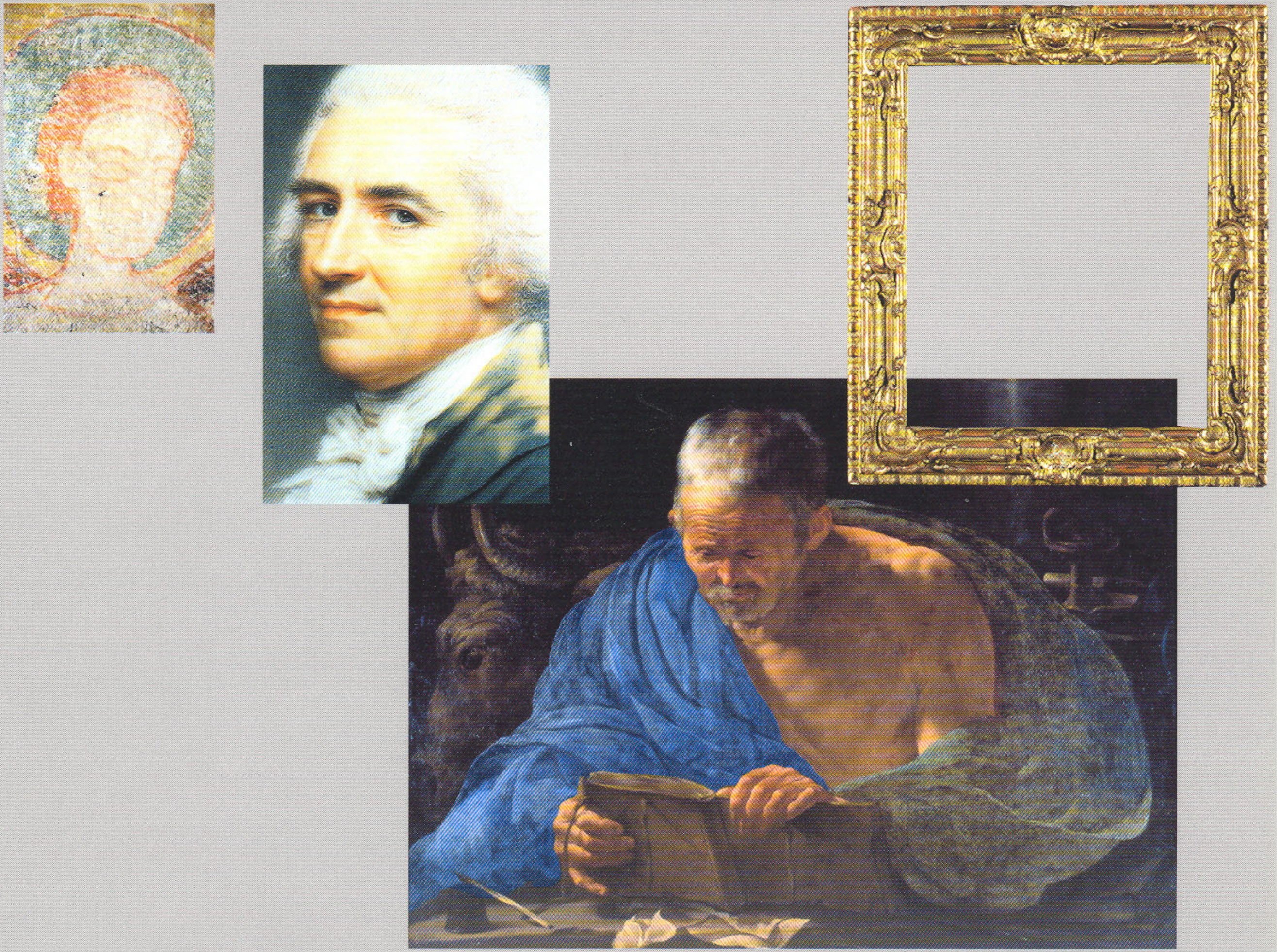

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DETERIORATION AND CONSERVATION OF MONUMENTAL STONES WITH POLYCHROME RELIEF DECORATION IN UPPER EGYPT.

The Archaeological Remains of the Temple of Merenptah

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1 Introduction

Archaeological remains, that are removed from the soil environment and abruptly exposed to the atmosphere may weather and deteriorate very fast. Nearly no traces of polychrome decorations are preserved on the earlier excavated stones exposed at open air lapidaries of the temples in Upper Egypt. The unprotected frail paint layers and the weakened parts of the stones and mortars have rapidly disappeared after their exposure to the weathering. Recent conservation techniques have opened new possibilities to preserve stones and paintings that would have been lost before. Their surfaces are coated or impregnated with protective resins (mainly Paraloid B 72). Nevertheless, these surface treatments have been conceived for the rather humid and polluted environment of Central Europe and even there, they are still arguable. Can such standard treatments be applied offhand on the ancient Egyptian monuments without taking in account the different nature, quality and age of the materials and the disparate environment?

In fact the remains of the ancient Egyptian Monuments are 2000 to up to more than 7000 years old. Many of the famous works of Egyptian art have survived several thousands of years of human destruction and weathering. Very well preserved frail paintings in the temples have been exposed indirectly to the atmosphere during all that time. Entirely weather exposed granite obelisks show still polished surfaces and hieroglyphs with sharp edges and corners; many of the marvellous statues look nearly fresh. The public also admires the brilliant paintings and fragile objects made of wood, papyrus and other very weak materials that have outlasted thousands of years within the tombs. These so well preserved materials are the substrate and the physical essence of the cultural World Heritage in Ancient Egypt. Most of them would not have survived in an environment as it exists in Central Europe.

Is there any better and more realistic prove for a long term durability, than the subsistence over several thousands of years in situ? Of course not. How can we then relate this extraordinary lifetime and state of preservation to the actual interventions for conservation based on trivial normalised laboratory tests and weathering simulations? As we will see later, the qualities of the concerned stones are very diverse, the mortars are extremely friable and the paintings are very weak and not durable at all in terms of the current durability assessments. The fact that they have survived is due to the particular micro climatic conditions rather than to qualities of the material. Hence the special environment is the most determining factor of durability in our context. This also implicates that there is no reason to do any conservation work as long as the materials do not significantly deteriorate. In contrary, there is a considerable risk that a treatment will reduce the long term durability instead of improving it. And finally we also have to keep in mind, that the usual simulations and tests are conceived for a durability assessment in an aggressive climate with high rates of weathering that do not concord with the environmental conditions in Egypt[1].

Of course there is also a significant deterioration occurring on particular places and exposures of ancient Egyptian monuments, such as e.g. in the zone of ground moisture. But even there the deterioration processes are not active everywhere. However, we are also faced with the rapid weathering and deterioration of some of the recently excavated stones and their decorations.

Archaeologists and conservators in Egypt, aware of these problems, asked us for help and advise to preserve the excavated remains of the funeral Temple of Merenptah (1213 – 1203)

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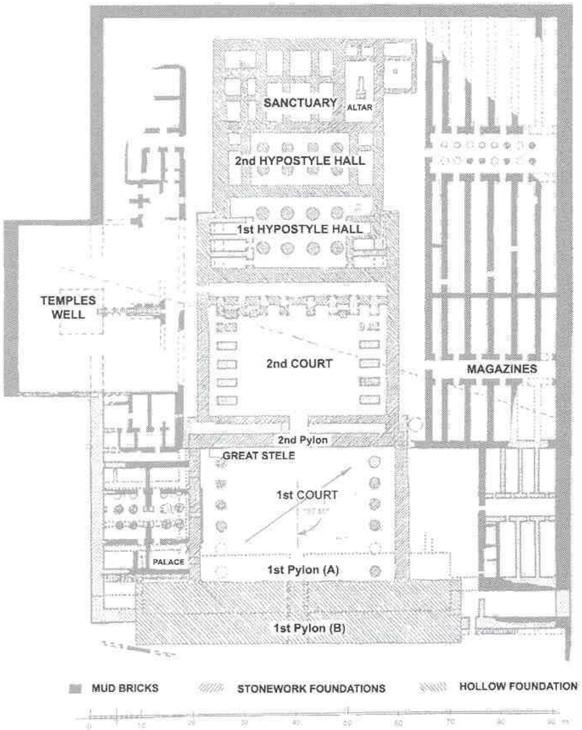
[1] Despite of all investments made in material science, the durability assessment is a still unsolved problem. One of the reasons is the unidimensional thinking in current material science. As long as the durability tests will not be related to distinct microclimatic conditions and weathering situations they will not really be applicable to conservation of monuments. This is evidenced by all the badly qualified but well preserved, several hundreds of years old stones, lime and gypsum mortars and paintings on facades of ancient buildings.



1. Floor plan of the Merenptah funeral temple (from JARITZ et al. 1995).

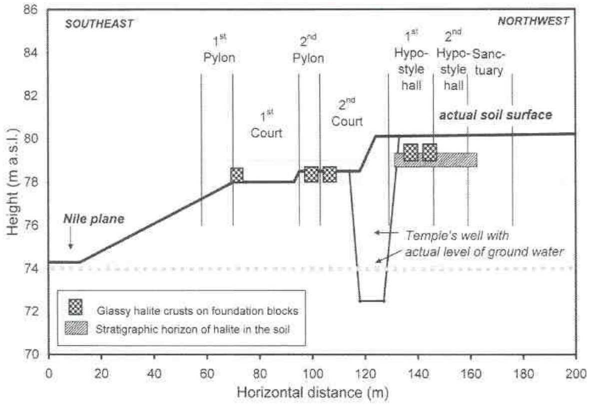
(JARITZ et al. 1995), especially for the very precious monumental stone blocks with preserved polychrome relief decorations found in the foundation. This request gave us the opportunity to study some aspects of the preservation and maintenance of the built heritage in Egypt.[2] The archaeologists planned to preserve and to arrange these remains in order to be exhibited for the public. This intention introduced a further aspect to deliberate in our context as the conservation also depends on the manner how the monumental remains will be stored and presented to the public. Should they be exposed at open air, under a protecting roof or within a closed room? Vice versa, the manner of exhibition should be adapted to the individual susceptibility of the materials to weathering and to the local environment and climate. Preservation now becomes an issue in which archaeology, architecture and natural science are implicated and condition one another. This justifies the Institute of Conservation at the Swiss Federal Institute of Technology to help and advise the Swiss Institute for Architectural and Archaeological Research in Ancient Egypt for the integral preservation of the actual remains, in order to prevent future deterioration as far as possible and to find a suited design for their presentation to the public.

2 Geographical an geological setting

The funeral temple of Merenptah belongs to the ancient Necropolis of Thebes on the West bank of the Nile valley opposite to Luxor in Upper Egypt. The ruin is situated near to the actual village of Qurna, just outside and several meters above the Nile plane at an altitude of 78 m above sea level. The area of the temple (fig. 1 and fig. 2) is 100 m broad and 120 m long with the main axe going from southeast (on the border of the Nile plane) towards northwest. The temple was built on a gently sloped and previously terraced terrain. The floor level (actual surface) at the first Pylon lies 4 – 6 m above the actual Nile plane, and the level of the first and second hypostyle hall and the sanctuary of the temple is 2 m higher.

Behind the temple, the terrain rises along a gently sloped wadi fan, crossed by the main road to the valley of the kings, up to the steeper flank with ancient Egyptian tombs and the actual fellach village, and then further up to the first hills in the foreland of the Thebean massif that stands out by steep cliffs up to the top of Gebel Qurna (462 m a.s.l).

2. Schematized section along the mean axe (southeast to nordwest) of the Merenptah funeral temple (vertical axis 10x inflated), with the levels of ground water and of the zones with salt concentrations).

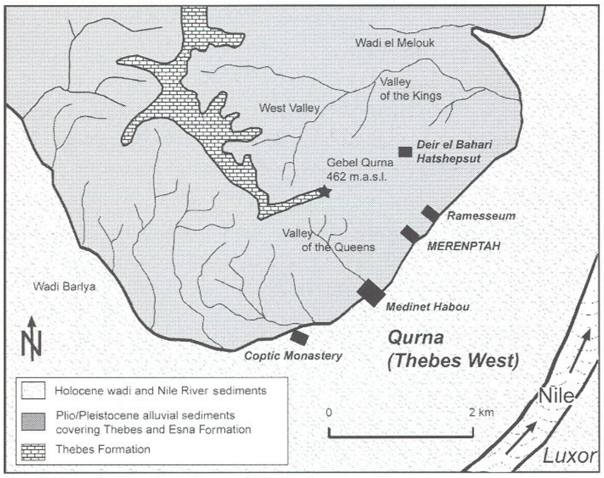


The geologic setting (WÜST 1995 and WÜST 1997) are Tertiary and Quaternary sediments of the Mediterranean sea, intersected by the deep trench of the Nile valley depression (fig. 3 and fig. 4). The main geologic and lithologic units, in their chronological sequence, are presented in fig. 4. They are:

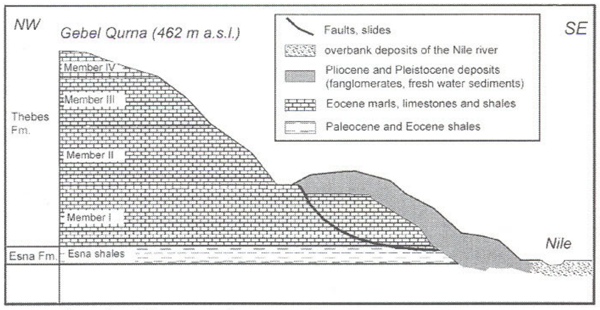
Esna formation (early Tertiary, Paleocene and Eocene) composed of shale and marl appearing at the base the Thebes mountains.

Thebes formation (early Tertiary, Eocene) composed of about 350 m of cliff-forming limestones and soft marl intercalations deposited in the shallow sea.

Fanglomerates and stillwater sediments on the slope of the Thebes massif (late Tertiary and Quaternary, Miocene to Pleistocene) composed of complicated intermixtures of stillwater sediments in a very saline milieu of the coastal plane (mainly limestone-marl-intercalations and evaporites), and fanglomerates in the wadis as well as



3. Summarised geological map of the region around Qurna (modified after WÜST 1995).



4. Geological profile accross the region of Qurna (modified after WÜST 1995).

slided rock masses on the slopes of the Thebes massif. This geologic period is characterised by a change from shallow sea to offshore facies, accompanied by a extensive tectonical activity along the Nile fault.

Recent wadi and Nile deposits (Quaternary, Holocene) composed of fanglomerates with gravel and sand bars. The alluvions in the Nile plain are mostly fine grained sediments of sand and silt.

The limestone blocks of the Merenptah temple belong to the Pleistocene stillwater sediments. The stones were quarried in the wadi el Melouk near Qurna northeast of the valley of the kings (upper right hand in fig. 3). The ancient Egyptian quarry is well preserved and still accessible. It also provided the stones for other funeral temples of West Thebes, as e.g. the Hatschepsut temple.

3 Historical highlights

The actual remains with only some stones emerging from the foundations, and their state of conservation are the outcome of a long history whose main «technical« episodes and events are given in table 1.

At least since the stones have been quarried 3300 years ago, they were exposed somehow to weathering and endured an individual (decay) history. The foundation stones with the well persevered polychrome relief decoration remained buried in the foundation from 1210 BC up to 1994 i.e. during about 3200 years. Other stones have been moved several times and were exposed to the weathering for some epoches or all the time, others might first have been unburied and later covered with rubbish. On an old photograph of the temple area from the 19th century (fig. 5) one can see a relatively flat plane of detrital material. After the excavation of Petrie up to 1971, the original floor of the temple was covered by a up to 2 m thick hilly detrital mass, with some blocks lying at the soil surface and others partially buried.

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2 This excavation is undertaken by the Swiss Institute of Architectural and Archaeological Research in Ancient Egypt, Cairo.

Table 1: Important dates and events in the history of the temple of Merenptah

Date	*Event*
Around 1390 BC	*Construction of the funeral temple of Amenophis III* (1390-1352 BC). The stones used were limestone from the neighbourhood, Nubian sandstone from the Region of Assuan, and other stones of unknown origin. The stones have been quarried, transported, built in, carved, equalised with gypsum mortar and painted.
The following 150 years on to the construction of the temple of Merenptah	*Reworking of the relief decoration as a consequence of change in religion.* During the regency of Echnaton (1352-1338 BC) the representations of certain deities and inscriptions have been chiselled out and reworked (iconoclasis). Under Tutanchamun (1336-1322 BC) they where restored, i.e. modelled with gypsum mortar and repainted. Under Sethos I (1290-1279 BC) inscriptions were finally changed. All these interventions can still be read from the decorations. They are important witnesses to be preserved.
Around 1210 – 1207 BC	*Construction of the funeral temple of Merenptah with reused stones from the funeral temple of* Amenophis III and new stones. The reused stones were broken out from the previous masonry and integrated in the new masonry and then redecorated with a new polychrome relief. A part of the stones broken out has been buried into the new foundations. These foundation stones remained in the soil up to 1994, i.e. during 3200 years. For that reason they have survived as well.
After an unknown service life of the temple	*Begin of the destruction of the temple.* Henceforth it was used as quarry to supply building stones, and also to make quicklime since the Ptolomeic period (after 304 BC).
1896	*First archaeological excavation by* W.M.F. Petrie, who has searched for walls over the whole area and made a map of the temple. He created the hilly soil surface with stone blocks encountered in 1971 lying around.
Since 1971	*Archaeological investigation and excavation by the Swiss Institute of Architectural and Archaeological Research in Ancient Egypt.* Since 1992 conservation interventions on the excavated and lying around stones. In 1994, the limestone blocks with polychrome relief decoration have been excavated from the foundation of the 2nd pylon.

4 The materials of the temple

The remains of the temple of Merenptah are composed of the materials summarised in table 2.

4.1 Stones

4.1.1 Qurna limestone

Most of the precious polychrome relief decorations are carved and painted on blocks of Qurna limestone which belongs to the Pleistocene stillwater sediments. It was quarried in a small side valley (Wadi el Melouk) between the Valley of the Kings and the valley of Wadi el Mâchtiar. These quarries also provided the stones for other funeral temples of West Thebes as e.g. the Deir el Bahari Hatschepsut temple.

This bright beige looking limestone is a micrite, originating from mud of precipitated carbonate crystals and microfossils. It is composed of about 65% of calcite (micritic grains, microfossils and shell fragments of 1 to 20 µm in size), 10% of dolomite (rhombohedral grains of 5 – 20 µm), 15% of smectite and 10% of supplementary minerals, such as quartz, feldspar, hydrous ferric oxides and accessory carbonised organic material.[3] The stone is very porous, soft and poorly consolidated. It shows original shrinkage cracks of up to some centimetres width and more than 1 m length in a distance of some centimetres to decimetres from each other. They form the typical polygonal patterns on the bedding plane and cross the stone approximately perpendicular to the bedding. They are partially open, partially filled with sediment mud from the geologic environment, and with mud, mortars from construction activity. The polygonal crack pattern is also visible on some carved and painted surfaces of the blocks (fig. 7).

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[3] Results after own microscopic investigations and X-ray analyses made by the Institute of Geotechnical Engineering of the Swiss Federal Institute in Zurich. Wüst (1995) gives the following petrophysical data for two non spcified marles: densitity 1.9 g/cm^3, porosity about 25%, content of clay minerals 50%.

[4] The sculptor and stones restorer Markus Blödt supposes an origin from the region of Hammamia. SOUROUZIAN (1983) mentions it as 'Calcaire cristallin' without indication about the origin; however KLEMM and KLEMM (1993) do not reference comparable stones.

We may distinguish two petrographic varieties among the stone blocks and in the ancient quarry:

Massive limestone. It is a bright beige stone with a homogeneous and fine grained texture. In the ancient quarry, this variety is scarcely fissured (neither by shrinkage cracks nor tectonically), and it shows a minor tendency to spheroidal weathering compared to the laminated variety.

Laminated limestone with marly intercalations. This variety shows a bedding or lamination of bright limestone layers alternating with darker marly layers in the range of millimetres to centimetres (fig. 6). Irregular intercalations of marly and clayey waved streaks are up to some decimetres thick. Tiny carbonised plant chips are disseminated in the structure. Shrinkage cracks are frequent. This variety is more intensely tectonically fissured than the massive limestone, and it shows a distinct tendency to spheroidal weathering and to flaking at the surface.

5. Old photographic view towards the east from the Temple of Medinet Habu. In the back ground is the Ramesseum. The area of the ruin of the Merenptah temple is situated in the middle directly to the left and behind the white house. (Source: Antikensammlung Erlangen, Institut für Klassische Archäologie, Universität Erlangen, Internet Archive AERIA).

Table 2: The materials of the temple and their use

Material	Use in the temple of Amenophis III	Merenptah
Limestone blocks: *a) with painted relief decoration,* *b) with relief with non painted decoration*	a) and b) in walls of the monumental portal	a) in foundations of the 2nd pylon, b) in diverse walls of the temple
Sandstone blocks: a) fragments of painted statues, b) roughly carved blocks, c) blocks with polychrome relief decoration	a) statues (b and c not yet existent)	a) and b) in foundations and as bases of columns, c) in walls
Compact white limestone: fragments of statues	statues	statues
Diverse crystalline stones: small pieces wihtin the debris	statues	statues
Mud bricks:		in walls of secondary buildings and enclosures
Different mortars: a) repairs and modelling on polychrome relief decorations of the limestone blocks, b) joints, renders and stucco on sandstone and limestone blocks	a) in walls of the monumental portal (in parts removed, repaired and restored repeatedly), b) in statues (?)	a) in foundations of the 2nd pylon, b) in diverse walls
White wash and polychrome paintings: a) on the relief decorations on limestone blocks, b) on fragments of statues of sandstone, c) on renders and stucco	a) on relief decorations of the monumental portal, b) on statues (c as a)	a) and b) in foundations and bases of columns, c) on diverse walls

6. Partial view of a block of Qurna limestone. The bedding is horizontal. On the abutting face, the lamination of bright limestone and darker, slightly undulated marly to clayey layers, as well as darker vertical shrinkage cracks are clearly visible. The rough upper edge of the block has broken off along a clayey layer (bedding plane) and perpendicular shrinkes cracks. Width approx. 80 cm .

7. Detail of a relief on a block of Qurna limestone. The bedding plane lies parallel to the image plane. Shrinkage cracks are visible e.g. on the chest and on the forehead of the figure on the right. Width approx. 1 m.

4.1.2 Compact white limestone

Fragments of statues are made of a bright and dense, marble like limestone, the geographic and geological provenance of which seems to be unknown.[4] On its well preserved, polished (smooth) surfaces, fragments of mollusc shells, fine, undulated strata of clay – they are parallel to the bedding or irregularly arranged and cause a nodular texture –, as well as white veins of coarsely crystalline calcite are visible (fig. 8).

4.1.3 Nubian sandstone

Many blocks from bases of columns and from the foundations are of Nubian sandstone (Cretaceous from the region of Assuan, around 75 million years old). It consists of internally cross bedded 10 to 20 cm thick banks, intercalated by silt and clay and/or gravel bearing layers. The bedding planes show ripple marks which indicate sedimentation by wind or streaming water (fig. 9). The colour is yellowish, greenish or dark grey, with variations to intensive yellow, brown, red and violet colours due to admixing of iron or manganese oxides. It is composed of quartz, feldspar, stone fragments and clay minerals with a mean grain size of 0.3 mm.[5]

4.2 Mortars

Mortars have been used to fill the irregularities on stone surfaces before painting, to make joints, painted surface renders and repairs, and also to model some of the painted relief decorations. They are actually very frail and porous (they can be scratched with the fingers) and have a beige, pale reddish to reddish brown colour. *The binder* (matrix) is actually composed of felted aggregates of 1 to 10 μm long acicular anhydrite ($CaSO_4$) crystals. These aggregates often show an outward crystal form of 50 μm long gypsum crystals ($CaSO_4.2H_2O$): i.e. the anhydrite is pseudomorph after gypsum. This pseudomorphism proves that originally gypsum has crystallised, which then was transformed into anhydrite by dehydration and recrystallisation. *The aggregate* of the mortars consists of a coarse grained fraction of sand and fine gravel (maximal size of 3 – 4 mm) and of a fine fraction of silt and fine sand (grain size of 0.05 to 0.5 mm). Two groups of components may be distinguished among the coarse grained fraction (sand and fine gravel):

(1) Rounded grains of quartz and silicatic minerals (feldspars etc.) that look like grains of crushed Nubian sandstone.

(2) Angular grains of red, brown, dark and sometimes bright colours, of carbonatic, marly, argillaceous, silicic and limonitic stone fragments. They originate probably from crushed local rocks.[6]

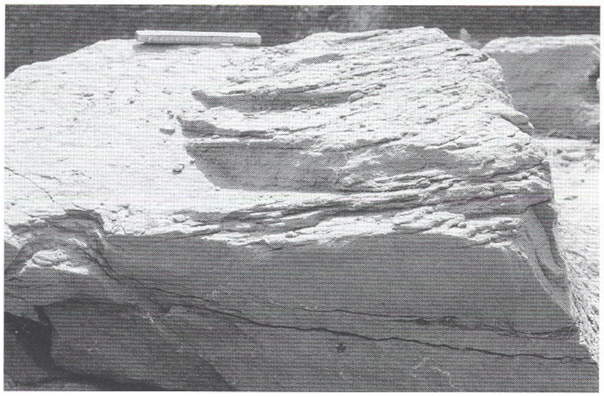
The fine fraction (grain size below 0.05 mm) contains the same components as the coarse fraction and in addition a very fine carbonatic material originating from unconsolidated

[5] ETTL and SCHUH (1991a) indicate the following composition of detritical components: 50% quartz, 20% stone fragments, 6% feldspar, and 1% phyllosilicates, and of the matrix: 15% kaolonite and 8% ore minerals. They state the following physical parameters: open porosity 28% of volume, hygric exapansion 0.18 mm/m.

[6] WÜST (1995) mentions that red marl from fossil soils has been used for old Egyptian painting.

[7] In accordance to the composition of Qurna limestone (see above), as well as to the yellowish, white or reddish powdery limestone from the Thebean massif, the so called Heeba, that is still used to withewash the local cottages (oral indication from Markus Blödt).

8. Compact white limestone, view of a smoothly carved surface. Crumbling begins along irregularly undulated argillaceous films. Width approx. 30 cm.



9. View of a weathered Block of Nubian sandstone. The bedding plane is slightly inclined to the right, the cross bedding in the upper part is rising to the right. The block is disintegrating along the bedding. Width approx. 70 cm.

local limestones.[7] The content of this carbonatic material is mostly of some percents but may sometimes reach up to 30%. The mortars may also contain iron hydroxides and other ore minerals.

Because of the high content in calcium carbonate, the binder of these mortars is considered to be of gypsum and lime when analysed by means of chemical and X-ray diffraction analyses (PREUSSER 1987, SALEH 1987). However, the optical microscope visualises microfossils within the ver fine carbonaceous powder. These fossils would not have survived the burning of quicklime. This shows that the lime powder belongs to the aggregate and not to the binder.

All the original mortars are gypsum mortars with an aggregate made of sand from Nubian sandstone and of local limestones (and dust). The fabric of the mortars became very porous and weak by the secondary transformation of gypsum to anhydrite.

4.3 Paintings

The following pigments have been identified:
Yellow and Red ochre (diverse iron hydroxides and oxides), in yellow and red colours,
Egyptian blue (*cuprorivaite* $CaCuSi_2O_5$) in blue paint layers,
Black of plants in black colours,
Gypsum ($CaSO_4.2H_2O$), *anhydrite* ($CaSO_4$), *calcite* $CaCO_3$), and *dolomite* ($CaMg[CO_3]_2$), as well as *huntite* ($CaMg_3[CO_3]_4$) in white colours, in paint layers, preparations and white washes.

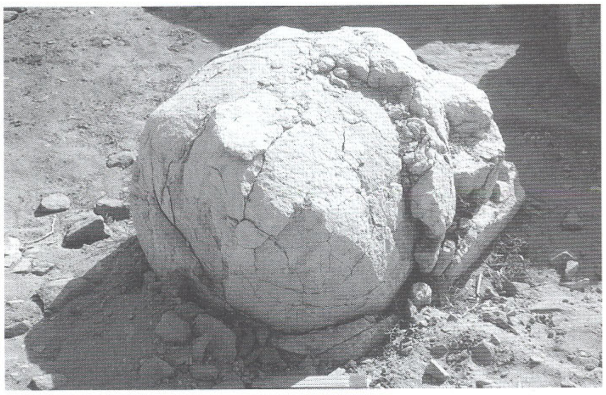
These results accord with the actual knowledge about the pigments used in ancient Egypt (El GORESY et al. 1986, LE FUR 1994), particularly at the period of Amenophis-III and Merenptah.

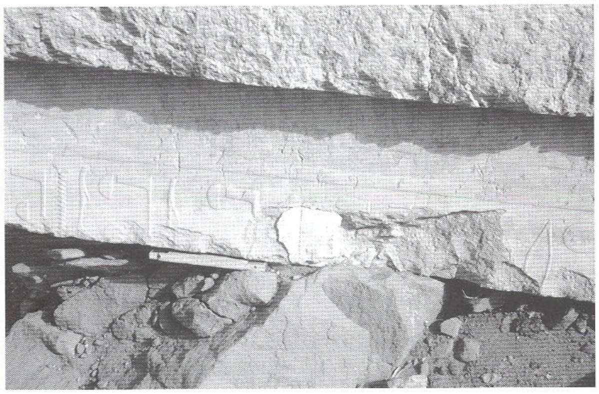
The original binding media are not yet firmly evidenced, of course. The paint technique and the historical sources indicate glues of plants and animals and other organic materials. These materials are decomposed or altered by past restorations, so that we could not univocally determine them by our current analytical methods. The investigation by the restorers show just traces of water soluble organic substances.

5 Situations and forms of deterioration

5.1 Actual situation

Only several hundred blocks of limestone, sandstone and fragments of statues have survived the changing history of man made destruction. Before the recent archaeological excavations, the blocks remained in the soil or on the surface. Many of them have repeatedly been displaced, what complicates the explanation of their damages. For the beginning of the actual excavation we may distinguish the following positions of the blocks:





10. Example of a Qurna limestone block on which spheroidal weathering has developed at an advanced stage. The concentric scales are crumbling due to radial fracturing. This block has lain on the debris surface for a long time (at least many decades). Size of the block about 70 cm.

12. Detail of a Qurna limestone block with brown patina. The outbreak along the bottom edge has partly been repaired by a formerly broken off piece which was found in the surrounding debris. The bright colour of this fragment which was lying in the ground cotrasts with the brownish patination of the weather exposed block. Width approx. 1 m.

Blocks dispersed at the soil surface. They partially stick in the hilly ground composed of a maximal 2 m thick layer of soil and coarse debris atop of the original temple floor. Some of these blocks are deeply weathered, especially where they are affected by salt accumulations.

Blocks entirely covered by debris. Some of them are well preserved, others considerably decayed. Many of the stones lying within this debris still bear some small fragments of paints.

Blocks in the foundations. They are deteriorated particularly on their upper side but well preserved on the lateral and down side faces where they bear carved and painted relief decorations with their repairs. Because of their high quality as well as the delicate carvings and paintings, these stones impose the most challenging task within the conservation and arrangement of the whole actual site. We will now point out this topic.

5.2 Damages on the Qurna Limestone with the polychrome relief decoration

The damages concern the stone as well as the carved, modelled and painted relief decoration. We may distinguish the following artificial (i.e. man made) and natural forms of deterioration:

Outbreaks along edges with a size of several centimetres to decimetres. The fracture surface looks often conchoidal (shell-like). These are mechanical damages caused by punctual overload of the edges during split up, transport, and positioning of the blocks (fig. 6).

Fissures of different kinds. There are fissures along bedding, shrinkage cracks (fig. 6 and 7), fracturing due to tectonic movements and earthquakes, as well as fissures resulting from weathering.

Spheroidal weathering (German 'Wollsackverwitterung'). This term specifies the formation of a concentric system of fissures in a depth of a few centimetres up to more than 10 cm from the block or rock surface. These fissures may have hard and smooth surfaces and look like cracks caused by mechanical overload. This fissure system forms scales that detach and denude a rounded stone core, a so called boulder of weathering (fig. 10). In extreme cases, onion-like multiple scales, combined with radial fissuration splitting the blocks in several parts, form. In the temple area, spheroidal weathering typically occurs along upper side edges of the foundation blocks, and on some stones lying at the soil surface. On the other hand, it is also common in the ancient quarries. Here it develops exclusively on projected and rain exposed parts.[8]

Flaking and spalling at the air soil interface. Several centimetres deep grooves have formed on blocks sticking partly in the terrain, in the zone where the stone surface intersects with the actual soil surface (fig. 11). This zone is 10 to 30 cm broad. It degrades by flaking and spalling and, in extreme cases, the stones split in depth and exfoliate parallel to bedding. In this zone, salts such as halite, gypsum and further hygroscopic compounds are accumulated. It may often look humid. Since the terrain has been ransacked and the affected blocks have prob-

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[8] Within the quarries, spheroidal weathering occurs mainly along upper edges of limestone beds. These are the areas exposed to weather, i.e. to sun irradiation and to the occasional strong rain events. At an advanced stage onion like and nearly spherical stones are fromed.

11. Blocks of decorated Qurna limestone showing a horizontal groove due to intense weathering just above the former air-soil interface. The base of the blocks has already ben uncovered from debris for conservation.

ably been displaced hundred years ago, we may conclude, that this rather intense decay has occurred within only about 100 years.

Spalling and flaking in a superficial zone of marly parts of the blocks. Sometimes this decay remains active even on blocks which are isolated from the soil and stored in protecting rooms.

Coarse spalling associated with shrinkage cracks. Coarse stone fragments of some centimetres detach where the surface is densely fissured by shrinkage cracks. This decay occurs preferably on weather exposed areas. It progresses very slowly, what is evidenced by a brown patina covering the surface of the loose areas (see below).

Brown patina. Weather exposed areas of the stones appear bright to intensely brown (fig. 12). This «patina« consists of a few microns thick coating of a powdery, silty material. The same kind of patina covers the limestone rocks of the surrounding mountains and confers them a characteristic brownish lustre that gets darker with time. Though its evolution is not clearly understood, this process is evidently very slow and therefore occurs only on stable surfaces. Its presence on weather exposed surfaces of blocks on the temple remains indicates that the affected surface areas have been exposed to weather for a long time (up to 100 and more years), and hence that they have resisted to superficial weathering.

Incrustation of gypsum and other salts. Salt incrustations may cover the stone surface and fill the fissures of blocks in the temple area as well as of the rocks in the quarries. They will be discussed later.

This catalogue of deterioration phenomena should not hide the fact that many weather exposed blocks and carved surfaces are very well preserved i.e. poorly weathered.

On the painted surfaces, the following damages have been observed:

Small splitting and detached stone splits of several square millimetres, leaving crater like lacunas in the paint layer. They concentrate in marly zones and where salts are present.

Traces from hits and scratching, that may originate from handling during the first or second use of the stone and during the actual excavation.

The paintings have nearly no binding medium left and have lost most of their cohesion. They disintegrate into flakes and powder where they are exposed to active weathering, e.g. where salts crystallise. As already mentioned, the same is true for the gypsum mortars used to planate the stone surface and for modelling and repair. They are actually very weak and brittle.

5.3 Damages on massive white limestone

Most of the rare fragments of monumental statues made of the massive white limestone are well preserved, with an intact, smoothly carved and polished surface. Yet some of the weathered stones show the following damages:

Eroded clay layers result in fine grooves on the surface (fig. 8).

Superficial spalling results in outbreaks of up to several centimetres along clay layers (fig. 8).

In depth spalling and fissuring in a 10 –20 cm deep zone on the entire height of a block starting abruptly from a fissure.

5.4 Deterioration on the Nubian sandstone

The following deterioration forms occur on column bases of the roughly carved Nubian sandstone.

Fissures oblique to bedding looking like those due to local overload.

Splitting and exfoliation parallel to bedding is very frequent in upper parts of the blocks. The fissures follow the silty and clayey layers between the banks, but also the fine cross bedding layers (fig. 9).

Granular disintegration, flaking and spalling are to some extent generally present but concentrated on silty and clayey zones.

6 Weathering in Upper Egypt

We studied the deterioration of the stones, mortars and paintings with regard to their imminent integral conservation. Our interest focuses as well on the particular historical context and on the regional an local environment of the considered monuments, in order to understand the decay processes and to stop them by proper interventions.

Since the stones have been quarried, build into the walls, carved and decorated, they suffered deterioration by use, demolition, reconstruction, war, fire, erosion by man and animals, earth quacks and by weathering. The actual remains are protected as monuments of course. Nevertheless they are still exposed to human use and erosion and to weathering. While the use and erosion can be avoided and managed, the weathering will still go on and continue to deteriorate the materials. Although we can not entirely avoid weathering, we may minimise its destructive activity by means of an adequate prevention. To do so, we need to understand as much as possible the characteristics of weathering of the ancient monuments in Upper Egypt.

As demonstrated ahead, the actual state of preservation is the result of a long history. Each damaging process has occurred at a certain date on a distinct place, under distinct environmental conditions, with distinct causes and effects and it will continue to occur in future. The possible forthcoming deterioration processes represent a risk of additional loss of cultural substance. We can not assess and prevent these risks without taking in account the historical dimension of weathering. We have to discover when, where, why, how and with which effects past weathering processes occurred and how they evolved. This is, of course, not entirely possible. We encounter problems to recognise even some of the actually active weathering processes, as well as to survey their long and mostly unknown history. We have to base our investigations on observations within the region, the sites, the temples, on old pictures and on what we have heard from the archaeologists, the restorers and from the literature.

6.1 Observations and reflections on weathering in Upper Egypt

Many of the actually preserved remains, having been exposed to the atmosphere since the construction of the temples two to five thousand years ago, have survived in excellent conditions. Others are more or less strongly weathered, especially when they are sensitive and have been exposed to the sun and to the rare but intensive rain falls, or if they are situated in the influence of the ground moisture and of the arid soil moisture regime. The nature and evolution of the weathering damages in these specific situations need our particular attention.

We can also get significant indications on the evolution of weathering and deterioration from the richly illustrated literature of the 19th century. Particularly the very realistic and exact drawings from the beginning, and the photos from the end of the 19th century, show

how e.g. the excavations have changed the weathering situations on the monuments. As an example, we can see on illustrations that dark zones with hygroscopic salts and deteriorations, actually situated several meters above the ground on temple walls, mark the soil surface on the buried walls before the recent excavation. Furthermore, they document that the fissures on the colossal Memnon statues, considered by some contemporary engineers to provoke an imminent collapse, have already been drawn by Charles Berry in 1819 (CLAYTON 1982), and that the Sphinxes at Giseh where buried up to their neck in the sand. Lets remember that the new situation after the excavations exists only for the past 100 to 150 years what represents less than 5% of their life time. If we ignore these circumstances our research on weathering and conservation misses one leg.

6.2 Environmental influences in Upper Egypt

Weathering is the transformation and degradation of materials due to the action of the weather. The regional climate, the microclimate and the ground moisture regime are the crucial environmental impacts in our context. The most important weathering agents are: heat, light, air humidity, meteoric and ground moisture and their interactive variations as well as wind. Man made air pollutants and acid rain are not significant in Upper Egypt as well as frost.

6.3 Some characteristics of the regional climate

The Nile valley is a very long and narrow, only some kilometres broad »oasis« between the Libyan and Red Sea desert. It has a more or less desert climate that is well defined by TRAUNECKER and WUTTMANN (1982). They write: »The subtropical climate in Upper Egypt is characterised by a strong thermal amplitude and a high relative humidity in the morning in winter and a low one in summer. The dew point has never been reached in Karnak. Within the last eleven years, the mean monthly values were very stable and no evolution could be discerned.« The stability of this climate allows a reliable description of the climatic conditions even if continuous long term registrations are lacking.

Table 3: Mean monthly temperatures during day and night in Luxor (°C, from a tourist guide and calculated relative humidity for the day if the night temperature corresponds to the dew point temperature (RH_{Dp})

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Day (°C)	23	26	30	35	40	41	41	41	39	37	31	25
Night (°C)	5	7	10	15	21	21	23	23	21	19	12	7
RH_{Dp} *(%)*	30	30	28	28	33	32	36	36	35	35	30	31

6.3.1 Temperatures

In Upper Egypt, the daily temperatures vary between 5°C and 23°C in January and between 23°C and 41°C in July and August (table 3). The differences between day and night is considerably higher than e.g. in Central Europe. The *mean monthly values* (of more than 45 years) vary between 13.9°C and 32.5°C[9]. The sun irradiation may cause a high surface temperature during the day. On the horizontal surface of a sandstone at Karnak (TRAUNECKER 1972), the temperature has risen from 27°C in the morning up to 54°C in the afternoon and from 36°C to 41°C in a depth of 40 cm within the same stone. Smaller temperature variations are expected on bright stones and higher ones on dark stones. These important daily variations suggest high weathering rates due to thermal expansion and shrinking processes. However, this has not been confirmed by our studies (ZEHNDER et al. 2000).

6.3.2 Air humidity

The air is very dry during the day and rather humid during the night because of the high thermal daily variations. In the lowest line of table 3, relative humidity values that would corre-

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[9] Source, internet: www/worldclimate.com

spond to the dew point during the night (100% of relative humidity) are given. That means that the monthly values of relative humidity during the day are lower than 28-36%.[10] On the other hand, the maximal daily humidity amplitudes may be in the order of 50 to 70%. That indicates that the daily variations are the most important and most frequent microclimatic variations.

There are no strong condensation events persisting during several days, as they occur frequently in a humid climate in Central Europe.[11] Of course we have also to take in consideration the occasionally high relative humidity during the rare thunderstorms.

6.3.3 Precipitation

The mean annual precipitation (over 51 years) does not exceed 1.5 mm per year[12], 0.8 mm of which is occurring in October. There are two kinds of precipitation:
(1) *Short and week rain falls*. Every year showers of several minutes up to at most a quarter of an hour may occur. The rain exposed parts of buildings become just slightly wet and sometimes slight rain wash traces are formed on the walls.
(2) *Thundershowers*. They occur now and then and may produce catastrophic mud flows and flooding. Such a thundershower happened in October 1994 and carried away entire houses. Similar events have certainly caused water and humidity impacts on the tombs. Visible traces of their secondary effects are e.g. the dark patches of fungal growth on the walls paintings in the burial chamber of Tutanchamun that predate its discovery in 1922 (FAHD 1994) and the formation of thick salt crusts behind the render in the tomb of Nefertari (SALEH 1987).

With respect to a lifetime of 3000 years and to the actual regional climate, the temples suffered several thousands of weak rain falls and possibly several hundreds of thundershowers.

6.3.4 Ground and soil moisture

The most intense deterioration on stones of the temples occurred within the range of ground and soil moisture action. We may distinguish two kinds of moistening:

1. Moisture from the groundwater

The Nile determines the hydrological regime in Upper Egypt. Since 1969, it has been drastically changed by the barrage of the Assuan lake.

In the *ancient regime* (before the Assuan dam) the Nile flooded the plain each summer during about 3 months from July to October. At Karnak, the level of the Nile (table 4) varied between the altitude of 76.5 m during flooding and 69 m during spring while the ground water table fluctuated between the altitude of 74.5 and 70 m with a delay of one to two months. The maximal amplitude of the levels was of nearly 8 m for the Nile and 5 m for the ground water. The level of the Nile was higher than the ground water in late summer and autumn and lower during winter and spring. Therefore, the water flew from the Nile to the ground water during flooding in the summer and from the ground to the Nile during winter and spring. Sometimes the Nile flooded the floors of the temples of Karnak situated at an altitude of 74 m. Many old illustrations show that the main damages on the temples at Karnak and Luxor were concentrated on that level; the stones were deeply back-weathered and the walls loosened. Today these damages are repaired.

In the *new regime* since 1969, the dam of Assuan retains the excess water, and the Nile remains in his bed at a level varying between 69.5 and 71 m a.s.l. This level lies 1 to 2 m below the ground water table, that actually fluctuates between 72.5 and 71.5 m. The ground water is actually supplied by the irrigation channels, and it flows permanently to the Nile river (TRAUNECKER 1972). The actual floor of the temple at the altitude of 74 m is now permanently at least 1.5 m above the ground water level.

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[10] This is a reasonable assumption as the daily evaporation in the aridic climate is very low.

[11] Such strong condensation occurs when a front of relatively warm and humid air follows a cold weather period. Then the materials cooled down may remain significantly cooler than the new surrounding humid air during several days, and thus allow prolonged condensation on their cool surface. On non porous materials the surface gets wet, on porous materials the humidity is absorbed into the pore space.

[12] Source, internet: www/worldclimate.com.

[13] The values for the levels are estimated from the curves and the those of the amplitudes are cited from TRAUNECKER 1972

Table 4: Hydrological conditions in the temple of Karnak (values in meters a.s.l., after TRAUNECKER 1972 and TRAUNECKER et al.1982)[13]

	1900	*1971*
Nile – high level	76.5 m	71 m
Nile – low level	69 m	69.5 m
Nile – maximal amplitude	*7.85 m*	*2.5 m*
Ground water – high level	74.5 m	72.5 m
Ground water – low level	70 m	71.5 m
Ground water – maximal amplitude	*4.85*	*1 m*

The actual cultivated plain is 3 m above the soil of the temple; we may therefore assume that the soil of the Nile plane has risen about 3 m since the antiquity because of the mud deposition.

2. The zone of aridic soil moisture at the soil-air interface.

This moisture regime is independent form the ground water. After BATES and JACKSON (1980) it is »A soil moisture regime characteristic of arid climates. There is little or no leaching, and soluble salts may accumulate....« We call the corresponding situation *zone of aridic soil moisture.* On the monuments it can be recognised as a dark and humid zone with salt accumulations at the air-soil interface. On the ancient temple walls, this zone appears frequently as a 0.5 to 2 m high, dark and often spotted band at levels up to several meters above the actual floor. These levels mark the soil surface before the recent excavations.. Some times a new zone has formed on the actual soil level and both zones, the ancient above and the new one on the actual floor might be visible on some places. TRAUNECKER (1972) has already mentioned that hygroscopic calcium and magnesium salts (probably with nitrate and chloride) are concentrated in this zone. These hygroscopic salts equilibrate with the air humidity. These hygroscopic zones absorb humidity and get dark and humid during the night and in the morning, when the relative humidity is high, and they evaporate and become brighter in the afternoon, when the relative humidity is low.

On the temples, at least a part of the hygroscopic salt accumulations are due to settlement. Where the temples have been inhabited during centuries, nitrates and chlorides have been formed and accumulated from the refutes. Because of the continuous dryness, far above the influence of ground water, these salts have never been leached out. For instance on colums at the Luxor temple, the paintings have disappeared in these zones, while they are still visible on the areas below, that remained within the soil until the excavations. In these zones the stones deteriorate by periodic salt crystallisation.

6.3.5 Sand storms

Strong winds and storms that raise up and transport sand are rather frequent. They may depose dust and erode especially weakened and loosened areas such as the painted surfaces exposed to the winds.

6.4 Environmental particularities on the temple area of Merenptah

The temple is situated on the West bank at 4 to 6 m above the cultivated Nile plain on the border of the desert. Thus (normal) west winds bring more dust compared to Karnak, and the situation on the inclined hang exposes the remains to more risks of occasional mudflows and flooding after heavy showers. The local microclimate and the local conditions of ground and soil moisture will control essentially the local weathering.

6.4.1 Micro climate

Systematic data on the microclimate from the temple site are not available. During the campaign in 1999 the restorers have registered microclimatic data during several days (table 5).

Table 5: Measured values of temperature and relative humidity in the area of the Merenptah temple[14]

	Temperature *(°C)*				Relative Humidity *(% RH)*			
	Open air		*Shelter room*		*Open air*		*Shelter room*	
Date	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*
1.3.99	13	40 1)	20	22	18	66	28	34
2.3.99	14	28	21	24	20	65	20	38
3.3.99	14	26	21	23	16	60	18	32
4.3.99	14	26	21	23	16	57	16	34
5.3.99	13	28	21	23	25	55	26	34
Mean	*14*	*30*	*21*	*23*	*19*	*61*	*22*	*34*
Mean amplitude	*16°C*		*2°C*		*42% RH*		*12% RH*	

1) Compared to the other values the extreme value of 40°C is doubtful (sun exposition?).

Though these records are not representative to explain the microclimate as a whole, they give us precious and reliable indications about the possibilities of condensation and salt crystallisation, provided that they are discussed in the context with the observations in situ and with the results from other objects and with respect of the very constant climate in Upper Egypt.

During the campaigns from 1992 to 1998 in February we observed dew on the grass and on the tables in the morning. That means that dew events occur at least on exposed places at the end of the night in wintertime. Table 5 shows the following characteristics during five days at the beginning of march 1999:

At open air the daily temperature varied between 13°C and about 30°C, with corresponding relative humidity values of 66% down to 16%, indicating mean amplitudes of 16°C and 42% respectively.

Within the shelter rooms the amplitudes of the daily variations are strongly reduced to about 2°C and 12% RH, respectively, which corresponds to a reduction of 8:1 for the temperature and 4:1 for relative humidity.

These results allow the following conclusions. The highest probability of condensation is given in winter when the air temperature becomes very low at the end of the night. Condensation can occur when the surface temperature of a material is lower than the dew point temperature of the air and thus colder than the air. In our context there are two possibilities to get surfaces colder than the air: the cooling of the surfaces by heath radiation emission during the night and the impact of warm and humid air to cool surfaces. In both cases, the heat capacity of the material also controls the surface temperature.

In the first case, cooling results from the difference between emitted and immitted heat radiation. Horizontal surfaces emit but do not get heat radiation during the night and thus they cool down and may become cooler than the air. This may allow condensation on that surfaces. The vertical surfaces emit but also get heat irradiation from the neighbouring objects, what limits the cooling. In addition, the stones have a high mass and a high heat capacity both of which impede the cooling during one night. Therefore condensation will occur first on grass, then on the table with a low heat capacity, but probably not on stone blocks at open air. Within the shelter rooms condensation can be excluded because of the strongly reduced amplitudes of the temperature and air humidity variations.

The second possibility of condensation (i.e. the supply of warm humid air on cold surfaces), as it happens in humid climates can be excluded. Here we don't have these variable and humid weather situations persisting during several days as they happen e.g. in the Atlantic climate of central Europe

Thus we may resume that condensation may be possible sometimes on favoured surfaces, but it is improbable on big stone blocks, and it can completely be excluded in open or closed sheltered rooms.

Salts, on the other hand, may partially dissolve and crystallise under the actual daily variations of the relative humidity. Yet this process is limited due to the inertia of the materials. In many observed cases, the crystallisation of salts on walls due to drying air needs days to weeks to have effect what is long compared to one night in or case (ARNOLD et al. 1991).

6.4.2 Ground water and arid soil moisture

In the old *ground water regime*(before the Assuan dam) the flooding water of the Nile reached a maximum level at the altitude of 76 m; that is still 2 m below the soil level in the first and lowest court. Today it is continuously at a level of 73.5 m, i.e. at least 4 m below the soil of the first court (see fig. 2). Considering that the level of the Nile plane has raised about 3 metres since the antiquity, it is probable that the ground water level was significantly lower as well and did never really influence the weathering of the stones of the temple. This is also supported by the facts that the salt crusts on the stone diminish from top to the bottom and that the polychrome relief decorations situated at the lower surface of the blocks have well survived.

The aridic soil moisture on the other hand, is certainly active at least where salt bearing mortars and stones are at the soil-air interface, what is the common situation of these remains.

6.5 Relevant weathering processes

The weathering agents produce reversible and irreversible transformations. The ageing and weathering forms are the visible effects of irreversible alterations. The stones of the Merenptah temple are affected by the following weathering processes:

Thermal expansion and contraction are the reaction of the materials on temperature variations. The generated tensions may lead to fissures. Their effective contribution to (spheroidal) weathering in our context is not yet clear but seems rather negligible (see chapt. 8).

Hygric and hydric[15] *expansion and contraction* are the effect of humidity variations within the material. They are particularly effective on the Qurna limestone where it contains swelling clay minerals, and they produce fissures and spalls.

Salt crystallisation processes exert pressure on the walls of pores and cavities by crystal growth. It can burst the fabric of the materials and cause fissures and disintegration. This process is the most important damaging factor in our context.

Dissolution and other chemical reactions (hydration, dehydration, ion exchange, oxidation etc.) are produced by chemically aggressive water with dissolved gases and salts, and can corrode the stones, mortars and paintings. Although chemical corrosion of limestones and degradation of the paint media have been important factors in the past and to some extent still active at present we consider them today as negligible for the risk assessment.

Erosion by water and mud flows may become important when the rare thunder showers occur. Floods can wear away buildings and may fill tombs with mud. We still don't know exactly what happened in the past. However, these actions are a crucial factor within the strategy of conservation of the site.

Erosion by wind with sand probably affect only the very weak surfaces and already loosened surface particles. The alveolar weathering attributed to wind erosion in the past is in fact caused by soluble salts.

Deposition of dust caused by wind with sand should not be neglected since it may cause serious problems in conservation if it is to be removed.

Growing plants and metabolism of micro organisms may burst and corrode materials. We con-

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[14] Data from the report by Oskar Emmenegger and sons (Zizers, Switzerland), »Fotodokumentation und Bericht über die Notsicherungs- und Konservierungsarbeiten am Totentempel Merenptah in Qurna, Luxor vom Februar und März 1999«.

[15] We use the terms as follows: hydric expansion refers to the absorption of liquid water, hygric expansion to absorption of water vapour from humid air.

sider these processes as irrelevant because of the very dry micro climatic conditions.

Movements by earthquakes disintegrate the wall structures and physical (material) compounds. Actually they are supposed to be only a minor risk for the present temple ruin.

Erosion and destruction by man and animals are always present. The people used stones to produce caustic lime. Together with the pets they contaminated the local environment with nitrate and chloride as products of metabolism. In the neighbouring temple ruins one can see children, goats and dogs climbing the ruins and thereby also causing damages.

Frost damages and man made pollution can be excluded and still neglected, respectively.

Who wants to do an effective prevention needs to know which deterioration processes are actually effective and will probably be active in the future. We actually suspect three weathering processes to be the most relevant in our context: salt bursting, hydric (and hygric) expansion and thermal expansion. Salt bursting is a general problem and concerns all the materials, while the thermal and hydric/hygric expansion and shrinking affect particularly the Qurna limestone. The transformation of gypsum into anhydrite is a further very important process of weathering, even if it has mainly occurred in the past. Therefore we focus on these major issues in next two chapters.

7 Salt weathering

7.1 Introduction

Local salt concentrations represent a substantial and imminent risk for the most precious and sensitive polychrome relief decorations. As such they need a special attention of the conservators and scientists. The salts are locally concentrated in natural outcrops, in the soil, in building stones, in mortars and paintings of the ancient temples. They already have produced important deterioration.

Damages due to the action of salts are well known in Upper Egypt at least since the 19th century. A radical desalination method was tried by Grand Pacha in the 19th Century (TRAUNECKER and WUTTMANN 1982). He has flooded the temple of Karnak with Nile water in 1888, what probably caused one column to tip over thereby to push 10 other columns to fall in 1889. The salts have e.g. been observed and investigated on the Nubian sandstone on the basal zone of the temple of Karnak (TRAUNECKER 1972, TRAUNECKER and WUTTMANN 1982). There, the main salt ions are considered to originate from ground water and thus from the Nile. The actual salt regime of the Nile plane is different of course from the former one. Before the Assuan dam the Nile flooded the plain, and salts where not only supplied but also leached by the Nile water. At the present the water flows from the irrigation channels to the cultured land where the evaporation accumulates salts in the system.

In the hygroscopic dark zones above the actual soil near to the Nile at Karnak, mainly halite (NaCl), some sodium sulphate (Na_2SO_4) and gypsum ($CaSO_4.2H_2O$) as well as some magnesium salts were found The same salts (gypsum and halite) are found within the tomb of Nefertari (SALEH 1987) in the Valley of the Queens and in other tombs. Gypsum, anhydrite ($CaSO_4$) and halite also fill fissures in the surrounding limestone rocks. Gypsum and halite accumulations are in fact not just a local phenomenon but very widespread in Egypt. Within this context, some of the salt accumulations in the site of Merenptah are very peculiar.

7.1.1 The salts present in the Merenptah temple ruin

The identified salts in the site are given in table 6. They occur as follows:

A stratigraphic horizon of a *halite crust* is situated at the level of the original temple floor and on top the foundation blocks of the second pylon. Both layers were covered up to 2 m with debris before the excavation.

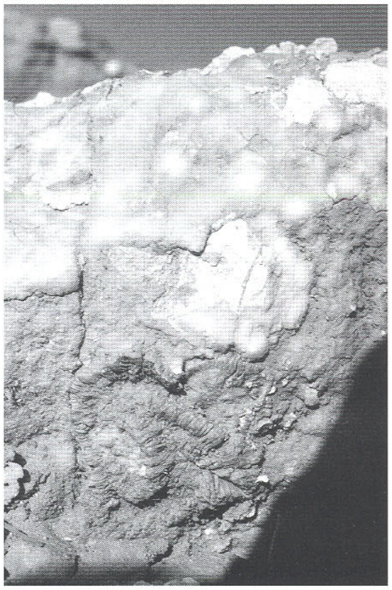
Gypsum crusts occur on the lateral faces of the foundation blocks of the second pylon, and *anhydrite* is found in old probably geological fissures.

Acumulations of *halite*, *gypsum* and *anhydrite* are present on some blocks situated at a level

Table 6: Salt species identified in the site of the Merenptah Temple

Ion group	*Salt species*	*Formula*
Chloride	Halite	NaCl
Nitrate	Nitronatrite	$NaNO_3$
Sulphate	Mirabilite Epsomite Anhydrite Gipsum	$Na_2SO_4.10H_2O$ $MgSO_4.7H_2O$ $CaSO_4$ $CaSO_4.2H_2O$
Carbonate	Calcite Dolomite Huntite	$CaCO_3$ $MgCa(CO_3)_2$ $Mg_3Ca(CO_3)_4$

14. Fragment of a fibrous halite crust which was found in debris. This crust was almost 10 cm thick. Horizontally oriented stone flakes which have been pushed off by the growing crust are incorporated between the upright standing crystal fibres. Width approx. 20 cm.



13. Glassy halite crust on the upper side of a limestone block (above) passing downward in fibrous halite crust. The glassy crust appears grey and glossy. In the lower part, fibrous and bended aggregates of whiskers are visible. Width approx. 8 cm.

above he original temple floor on the soil surface created by the past excavation (19th Century).

Veins of *gypsum* and *anhydrite*are found within the natural soil. The binder of the original *gypsum* mortar is actually of *anhydrite.*

Calcite, *dolomite* and *huntite* are components of the stones, mortars and paintings. They are stable in the present environment and have not been transformed.

7.1.2 Halite crusts on limestone blocks

As different crystal habits and fabrics of salt crusts give indications on the conditions of their formation (ZEHNDER and ARNOLD 1989), it makes sense to distinguish between glassy and fibrous halite crusts.

Glassy halite crusts are several millimetres to centimetres thick, colourless, translucent or grey (fig. 13). Their surface is either smooth and shiny or rough and showing the characteristic dissolution form (microkarst) that develops when water dissolves soluble materials at their surface. Under the microscope compact aggregates made of big (>100 microns) cubic or irregular and parallel fibrous crystals are visible. Some of the crusts are full of sand grains giving them the aspect of grinding paper. These crystal habits and aggregate forms are known to crystallise within a solution at low supersaturation, i.e. in a wet milieu (ZEHNDER and ARNOLD 1989).

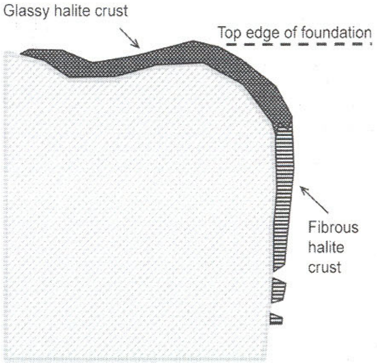
Fibrous halite crusts are composed of parallel fibres perpendicular to the substrate. They are several millimetres to centimetres thick (fig. 13 and 14). The microscope reveals a parallel intergrowth of whisker bunches. Such crusts are known to form when crystals grow out from a wet porous substrate which is imbibed with solution. Much solution is needed to form them.

The glassy halite crust lies systematically on the top surface of the foundation blocks, and it passes into a fibrous crust on their lateral surfaces. The fibrous crusts are thick on top and successively thin out downwards (fig. 15). Fibrous crusts occur also within joints and fissures of these blocks. This distribution corresponds to a typical succession within experiments when an initially completely wet porous substrate dries out (ZEHNDER and ARNOLD 1989). In particular the morphological properties of the glassy crusts clearly indicate that they could not be formed from solutions diffusing out of the porous substrate. If this would be as the case, a fibrous crust would have formed.

In addition, as such glassy crusts are nowhere found in the neighbouring natural environment, neither on the rocks nor in the soil, we can explain them only by an artificial deposition. We suppose that they have crystallised either from a salt mash or within a salt layer which became wet after its deposition and formed subsequently by repeated recrystallisation.

The formation of the fibrous crusts then is a secondary process. Sodium chloride from the glassy crust has been dissolved. The brine penetrated downward through the joints and fis-

15. Schematical section through the upper edge of a foundation block with the typical setting of a glassy halite crust on top, passing into a fibrous halite crust at the lateral face.



sures impregnating the pore space. The fibrous crust crystallised by evaporation from these brines on the stone surfaces and in the fissures.

The same sequence has also been observed on blocks in the debris as glassy crusts covering parts of lateral surfaces in a range of several decimetres at the soil-air interface. They transform into fibrous crusts upward and downward. Since the situation of these blocks before the excavation of 1896 is unknown these glassy halite crusts can not yet definitely be correlated to the previous ones.

7.1.3 Gypsum crusts on limestone blocks

Gypsum crusts are very common on the lateral faces of the foundation blocks. They occur on the lower, the halite crusts on the upper part of these surfaces. In the transition zone both salts occur side by side, but we have not seen mixed aggregates. They may totally cover stone surface areas or form separate hunches. They are several millimetres thick, rather hard, and show cauliflower like, tubercular forms and often blisters. They are thicker on the upper parts of the lateral stone surfaces and thin out downward. Under the microscope they show aggregates of parallel fibres and whisker bundles perpendicular to the substrate. These aggregates enclose fine particles of the limestone.

The genesis of these gypsum crusts is not yet so evident. Considering merely the fact that less soluble gypsum accumulates below and very soluble halite above, one could apologise for precipitation out of a solution moving up from the soil. As explained ahead, the distribution as well as the crystal habits and the fabric of the halite crusts clearly indicate an other genesis: i.e. precipitation out of solutions moving downwards. Therefore the gypsum crusts have probably an individual and different genesis. The calcium sulphate may originate from the gypsum mortars formerly present at the places where the actual gypsum crusts occur. Strong wetting from upside (e.g. after thunder storms) could have dissolved calcium sulphate of the mortar and then the solution penetrated into the porous stone. During drying gypsum crystallised out of the pore solution and formed the fibrous crusts. Apart from this most probable genesis, there is enough gypsum in the natural soil and in the debris to form these crusts.

7.1.4 Anhydrite crusts in fissures of the limestone blocks

White and dense veins within the Qurna limestone are of anhydrite. Under the microscope they show a fibrous to prismatic fabric of large crystals that are pseudomorph after gypsum. The anhydrite looks opaque, made of very fine particles, what is characteristic for a dehydrated salt. This fabric and structure shows clearly that originally gypsum has formed which dehydrated later to anhydrite. Both processes are supposed to have happened in geologic times.

7.1.5 Hygroscopisc salt accumulations on the limestone blocks

Humid looking dark spots occur sometimes also on the painted surfaces of foundation blocks. The analyses show that mixtures of sodium, magnesium, calcium and chloride ions as well as some traces of nitrates are present. These hygroscopic accumulations are at least partially of biogenic and man made origin: chloride and nitrate may come from refutes.

7.1.6 Gypsum and anhydrite crusts in the soil

Fibrous crusts of gypsum occur frequently within the natural soil. They form horizontal, a few millimetres to 1 cm thick, often lenticular layers made of parallel and perpendicular standing fibres. In an irregular distribution there are also some white bulbs or grains of anhydrite. This shows that the natural soil is at least locally strongly enriched by calcium sulphate.

7.2 Genesis and evolution of the salt accumulations (synthesis)

Accumulation of gypsum, anhydrite and halite in the rocks, soils and buildings is a regional phenomenon in Upper Egypt. On the Monuments the salts are particularly active in the zone situated within the influence of ground water and of arid soil moisture. Significant parts of the built archaeological remains are concerned. The ground water regime has controlled the salt regime of the temples in the Nile plane since thousands of years. It has drastically changed by the Assuan dam. In the zone of arid soil moisture, the natural salt concentrations have been increased by nitrate and chloride from settlement. These zones have been transferred during their long history by burying, settlement and excavations. The remains of temple of Merenptah were allways situated at least 2 m above the Nile ground water table i.e. out of the direct influence of the actual ground water regime that is supposed to supply the salt concentrations on the temple of Karnak and Luxor. The important salt accumulations, have a diverse origin and long the history that can be summarised as follows.

Solutions of sodium, calcium, chloride and sulphate have impregnated the rocks during sedimentation and diagenesis in a strongly saline milieu. As the stones got into the influence of weathering, the salts mobilised and recrystallised, forming the numerous veins of gypsum, anhydrite and halite.

The stones, mortars and paints used to build and decorate the temple of Amenophis III have been exposed to weathering during a period of about 150 years. A further artificial introduction of new and partial mobilisation of existing salts are possible.

Sodium chloride has been introduced artificially at the floor level during the construction of the temple of Merenptah where it actually forms a stratigraphic layer and the glassy crusts on the top side of the foundation blocks. The crystal habits, the aggregate forms, the distribution, and the fact that such salt crusts do not occur in the local environment make it reasonable to admit that sodium chloride has been introduced artificially on the foundations of the temple[16]. On the other hand, the mortars have supplied important amounts of gypsum to the walls of the temple. It is possible and probable that the halite and gypsum crusts on the lateral faces of foundation blocks have begun to form already during or short time after its construction.

During the next nearly 3000 years the temple has been destroyed successively, and the remains have been exposed to weathering or covered by sand and debris. Dozens to hundreds of thunder showers may have wetted the ruin, dissolving a part of the halite crusts on the foundation stones. Halite then recrystallised on the lateral faces and within the fissures of the limestone, causing the actually visible deterioration. But none of the thunder showers could completely dissolve the glassy crusts on the top of the foundation blocks. Gypsum and anhydrite as well have partially been mobilised and redistributed on and within the blocks. And finally most *of the gypsum in mortars has transformed into anhydrite*.

By the excavation of Petrie and since 1896 a new hilly surface with blocks emerging from the debris was left. Along this new soil surface, a new zone with local salts accumulations and deterioration has developed.

7.3 Dehydration of gypsum

The increase of volume when anhydrite transforms into gypsum is apprehended in mining and tunnelling since decades. In our context the inverse transformation of gypsum into anhydrite causes problems. Gypsum as the original binder of our mortars has nearly completely been transformed into anhydrite, what caused the loss of cohesion of these mortars. The pseudomorphism of anhydrite after gypsum proves this transformation that must have occurred at temperatures below 40°C. Up to now, we could not find any publication that satisfactory explains this low thermal reaction. It is also rather strange that the gypsum of the mortars dehydrated to anhydrite while the gypsum crusts in the same environment did not. Since this transformation of gypsum into anhydrite is relevant for the conservation of old and the use of new gypsum mortars on the ancient Egyptian monuments, we will now look at this transformation within the literature and in some simple experiments.

[16] Relief decorations in the Edfu temple show that the foundations of the temples have been cleaned with natron after placing the foundation stones (GOLVIN and GOYON 1987).

7.3.1 The dehydration of gypsum in the literature

Actually five phases (table 7, LEHMANN and HOLLAND 1966) are known within the system $CaSO_4 - H_2O$, that are: gypsum, bassanite, anhydrite III, II and I. Among these five phases bassanite and anhydrite III are metastable. Bassanite and anhydrite III have two different forms α and β. There is an agreement, that the α-hemihydrate can only form at a high water vapour pressure, while only β-hemihydrate is formed at normal pressures. High temperature anhydrite (anhydrite I) exists only at temperatures above 1180°C. Gypsum and natural anhydrite (anhydrite II) are the only stable calcium sulphate phases in the system $CaSO_4 - H_2O$.

Within water both phases are in equilibrium with the saturated solution at temperatures of 38 – 50°C or 58°C respectively according to the authors and the used experimental methods (HARDIE 1967). The equilibrium reaction between gypsum and anhydrite II, is strongly inhibited. This is the reason why the metastable phases, hemihydrate (e.g. stucco, plaster of Paris) and anhydrite III, form by heating. Because there is no equilibrium between the singular phases (e.g. between anhydrite III and anhydrite II) or, if there is an equilibrium, it is only very slowly reached, the thermodynamic data alone indicate only the possibility, but not the real formation of the individual phases. Contradictory explanations are given for the kinetics of the reaction of dehydration of calcium sulphate hydrates (KURPIERS 1970). Dehydration is obtained much easier under very dry conditions i.e. absence of liquid water, than in presence of liquid water.

Table 7: Mineral phases and their stability ranges in the system $CaSO_4 - H_2O$

Designation	Formula	Other designations (mineral and trivial names)	Thermodynamic stability range
Calcium sulphate dihydrate	$CaSO_4 \cdot 2H_2O$	Gypsum	<40°C resp. 58°C
Calcium sulphae hemihydrate	$CaSO_4 \cdot H_2O$	Bassanite, Hemihydrate	Metastable
Anhydrite III	$CaSO_4$	Soluble anhydrite	Metastable
Anhydrite II	$CaSO_4$	Natural anhydrite, non soluble anhydrite, to dead burned gypsum	40°C resp. 58°C – 1180°C
Anhydrite I	$CaSO_4$	High temperature anhydrite	>1180°C

On the air (i.e. under dry conditions) the equilibrium gypsum hemihydrate and hemihydrate – anhydrite depend only from the water vapour pressure (MCADIE 1964; KURPIERS 1970; RIEKE 1974; MOHAMMED 1978). Two dehydration processes are given in the literature:

1) Under normal vapour pressure (i.e. 1 atm) gypsum transforms into hemihydrate at 107°C and then into anhydrite III at 150 – 207°C. The calculated and experimental values correspond for the dehydration from gypsum to hemihydrate, while they differ very much for the dehydration of hemihydrate into soluble anhydrite.

2) At very low water vapour pressure, gypsum transforms directly into soluble anhydrite. The partial vapour pressure must be very low, thus the produced water vapour must leave the system rapidly during the dehydration reaction. This is the case at a water vapour pressure of 10^{-5} Torr and at temperatures above 80°C or at a water vapour pressure of 45 Torr and at temperatures above 110°C. After cooling the soluble anhydrite transforms slowly into hemihydrate when it stays

The quantity of anhydrite III or hemihydrate formed depends also on the *grain size* of a gypsum stone or mortar. A high water vapour pressure may by maintained within the large grain and impede the dehydration even if the environmental vapour pressure is very low.

Other influencing factors are the porosity and the purity (LEHMANN, MATHIAK and KURPIERS 1969). If foreign ions e.g. chloride are present in the system, the temperatures of the reaction may be reduced significantly, what is relevant when thinking in geological terms e.g. oceanic depositions. Within a brine saturated in sodium chloride, gypsum can transform into anhydrite already at temperatures above 18°C (HARDIE 1967).

7.3.2 Formation of anhydrite and dehydration of gypsum in nature

Anhydrite, supposed to have precipitate directly from a brine, was found for the first time in a recent salt deposit (evaporite) of the Sabkha sediments in the *Persian Golf (Trucial Coast). There the rain precipitation is very low and, the air temperatures as well as the evaporation rates during the day are very high and the mean temperature of the ground water is of 34 – 35°C in a depth 30 – 120 cm. Anhydrite, partially combined with halite and gypsum occurs together with carbonates. The authors suppose that most of gypsum and anhydrite directly precipitated from the brine and that a smaller part was formed by a reaction between the brines and the sediments. Gypsum and anhydrite may replace one each other (CURTIS et al. 1963; KINSMAN 1965).*

At *Clayton Playa* (Nevada, USA) a sample of a silty clay sediment saturated in NaCl was brought from a depth of 7.6 m to the surface, where it dried on the air without contact to the groundwater. First some small and after 11 months up 0.6 – 7.6 cm large crystals of gypsum formed, many of them where covered by a more or less adherent white coating composed of *bassanite* and *anhydrite.* This coating was best developed on the surfaces exposed to the atmosphere without contact to the soil. Bassanite and anhydrite grew successively from gypsum with topotaxial intergrowth. A mean annual precipitation of 127 mm and a mean annual temperature of 15.6°C reaching 35°C on warm summer days are characateristic in this arid local climate (MOIOLA and GLOVER 1965).

The salt crust on the floor of *Death Valley* (California, USA), which ranges from a few centimetres to one meter thick, has formed on silt and clay (saltpan). The alteration of salt and clay silt continues to a depth ot at least 300 m. The superficial salt deposits are divided into two zones and facies both containing partially some *bassanite* and *anhydrite*:

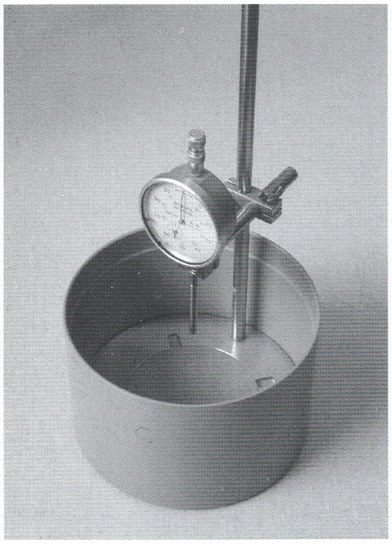
The carbonate zone, a silty sand with carbonate minerals, is covered by 0.5 – 2.5 cm thick, blistery salt crust, locally containing gypsum, that is partially dehydrated to *bassanite.* The crystallisation and dehydration follows the seasonal rise of ground water. The salt crust contains up to 80% of salts (thenardite, calcite, magnesium sulphate, sylvite and halite).

The sulphate zone, a massive 0.5 to 1.5 m thick gypsum deposit, lies on a humid to wet, calcitic, sandy silt and is covered by a superficial, 0.5 – 15 cm thick layer of *anhydrite* or *bassanite* (caprock). Two hypothesis are given for the formation of anhydrite and bassanite: (1) gypsum precipitates first and then dehydrates to bassanite and anhydrite on the surface due to the very high temperatures of the soil surface of 50°C and with peaks of 85°C in summer; (2) anhydrite precipitates originally and then hydrates to gypsum, while the surface doesn't react due to the high temperatures (HUNT et al. 1966).

In the semiarid gypsum karst area east of *Foum Tatahouine* (South Tunisia) gypsum is transformed into bassanite on south inclined hillside of the Wadi Mestaoua. The bassanite forms a some cm thick layer of fibrous and long prismatic crystals. In the SEM they show the primary parallel texture of the gypsum crystals that are disturbed but preserved as relicts by the dehydration. The authors mean that the transformation occurred at temperatures between 70°C and 80°C and very low air humidity (SMYKATZ-KLOSS et al. 1985).

7.3.3 Laboratory tests on dehydration of gypsum

Since no reliable explanations are obtained neither from observation nor from literature we have tried to dehydrate gypsum at low temperatures with the following results:



16. Dilatometer with dial gauge used in the on-site laboratory.

- a mixture of NaCl and $CaSO_4 \cdot 2H_2O$ (1 : 1) has been mixed with different quantities of water in petri dishes to form a series of weakly humid salt mass on to a saturated brine. After some hours of exposure to 70°C some gypsum and halite crystallised. Anhydrite was not observed.
- *on dry air* some gypsum transformed successively into bassanite after one month. Anhydrite did not occur even after 4 years. In a further experiment a dry air dehydration of natural fibrous crusts of gypsum was induced on a hot plate. At 100°C only some hemihydrate (bassanite), but no anhydrite has formed.
- In further experiments small cubes of gypsum, of hemihydrate and of natural coarse grained gypsum (Marienglas) in a saturated solution of NaCl were heated at 70°: They showed some transformation of gypsum into bassanite after 2.5 month. A further dehydration to anhydrite did not occur.

7.3.4 Conclusions on the gypsum–anhydrite transformation

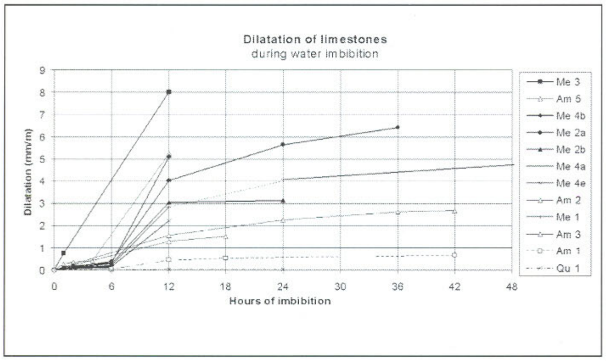
Within the literature a possible transformation of gypsum into anhydrite in a strong saline milieu and at temperatures comparable to those of Qurna, was reported only in one case (MOIOLA and GLOVER 1965). The partial water vapour pressure is the most important factor within the dehydration reaction under dry conditions as they occur in upper Egypt. In nature and in the laboratory high temperatures combined with low relative humidity dehydrated some gypsum into hemihydrate, but no anhydrite has formed. Thus it is still an open question how anhydrite has formed by dehydration of gypsum in the mortars of the Merenptaht-Temple and in the fibrous crusts.

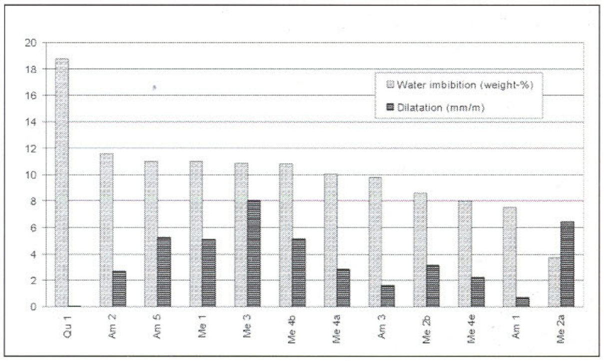
8 Hydric swelling and fissuration of Qurna limestone

Weathering situations are related to weathering forms, and both give us the key to understand the basic weathering processes. The most conspicuous weathering forms on Qurna limestone are: *spheroidal weathering* on rain exposed situations in the temple and in the ancient quarry, and *spalling and flaking* in the zone of the soil-air interface. Humidity (with or without salts) is supposed to be the main weathering agent in both situations. The stone quality is an additional factor in this interplay. So we observe strongly disintegrated and well preserved stones side by side in open air lapidaries e.g. at the Ramesseum and at Deir el Bahari. A closer inspection clearly indicates that under the same exposure conditions the massive variety of the Qurna limestone has better resisted to weathering than the laminated and marly one. This fact suggests that decay may be greatly influenced by hydric swelling and shrinking of the stone which is a consequence of wetting and drying cycles following the rare thunderstorms.

Based on these observations we have tested the influence of wetting and simulated relating decay processes on samples on-site by means of the simple field laboratory set shown in fig. 16. The imbibition and swelling behaviour related to the specific stone properties has been observed and measured. The results (ZEHNDER et al. 2000) show that a dilatation of 4 – 8 mm/m occurred within 12 hours on 4 of 12 samples of weathered as well as of fresh laminated marly Qurna limestone (fig. 17). This very intensive swelling caused fissuration and cracking in two cases. On the other hand, a sample of massive Qurna limestone swelled only by 0.5 mm/m. Although all of the samples contain sodium chlorine, no correlation could be established between the swelling intensity and salt content. Dilatation does neither correlate with the amount of overall water imbibition (fig. 18). The swelling can be attributed to the presence of up to about of 15% of smectite as a swelling clay mineral. However, it is confusing to note that the massive limestone varieties which have been verified to contain as well and as much smectite nonetheless do not swell. That indicates the microscopic structure, in particular the 'accessibility' of the swelling clay minerals to water, seems to be crucial rather than their quantity.

The correlation between swelling behaviour and clay minerals of Egyptian marly limestones has been reported earlier by (BRADLEY et al. (1988), RODRIGUEZ-NAVARRO et al.





(1997 and 1998). These authors also argue that soluble salts may significantly enhance the expansion as a result of ion exchange reactions. Nevertheless, important questions remain, as e.g. the swelling capacitiy in relation to the microscopic structure, the interaction with salts etc.

The tests also evidenced that thermal expansion is negligible. A sample actually did shrink by 0.6 mm/m when heated in an oven from 20 to 60°C. We may infer from this that the effect of shrinking-by-drying is overcompensating the effect of swelling-by-heating during a realistic natural temperature increase by solar irradiation. Thus the dimensional changes of these limestones are chiefly controlled by moisture and not by thermal variations.

We can conclude that the massive Qurna limestone is rather resistant, while the laminated variety is very sensitive to hydric dilatation. The most essential petrophysical property is the swelling capacity by water imbibition that is mainly due to the presence of swelling smectite. A further action is attributed to the concentrations of soluble salts at particular places. They interact with the hydric expansion and enhance their disruptive effects. Temperature variations cause comparatively negligible dimensional changes.

The sensitivity to water reflects in the observed weathering forms and situations. Spheroidal weathering develops on rain exposed areas, and intense spalling and flaking develops in the zone affected by ground moisture and salt accumulations. The primordial influence of occasional heavy rains throws new light on weathering under 'arid' climatic conditions. *It is stupendous to admit that one singular wetting event may cause the break down of the mineral fabric of some most sensitive varieties of Qurna limestone.*

17. Dilatation of Qurna limestones by water imbibition. The thick lines represent samples of laminated Qurna limestone from the temple ruin (Me 2, 3, 4), thin lines samples of laminated Qurna limestone from the ancient quarry (Am 2, 3, 5). The dashed line represents a massive Qurna limestone from the ancient quarry (Am 1), the stippled line a sample of massive limestone from the Thebes formation (Qu 1). The greatly swelling samples Me3 and Am5 became fissurated and cracked during imbibition. The generally slow dilatation in the first 6 hours corresponds to the gradual wetting of the samples by capillary suction from the bottom.

18. Water imbibition and dilatation of Qurna limestones. The final values after 12–96 hours of imbibition (consistent with fig. 17) are shown.

9 Risk assessment

Conservation intends to prevent future deterioration of monuments. Deterioration is due to physical hazards i.e.man made destruction, weathering, and other incidents (earth quacks, fires etc.). The future deterioration, i.e. material damages and loss of cultural value, may actually be considered as hidden or open risks. These risks arise from the physical hazards, from the vulnerability (resistance to weathering and use), and from the nature and importance (value) of possible future losses. Consequently, a risk assessment includes the estimation of the value (that can be lost or diminished), the sensitivity (vulnerability) of the objects, their physical state of preservation, the study of the past and present deterioration processes (nature, location, process, conditions of occurring, evolution and the effects), and of a prognosis of the probable future deterioration incidents. In our case, it is based on a phenomenological study of the site and its regional context, on the analyses made during the campaigns and on literature.

9.1 Value, sensitivity and state of preservation

The temple is actually a ruin composed of stones dispersed on the soil. The individual blocks and their surfaces have different cultural values. The front face with polychrome relief decorations weight much more than the roughly worked backside of the same block, and decorated stones are more valuable than non worked stones. In consequence, we estimate the expected damages and risks to be higher on the decorated faces, and we are ready to invest more attention and resources for their study and conservation. The limited resources request a selection anyway.

The sensitivity of the individual materials to deterioration varies as well. Fragments of granite and syenite are stable unless in extreme situations where salts and ground moisture are involved. The marbles and the Nubian sandstones are less resistant. Some of the Qurna limestones are most sensitive stones to weathering because of their poor original sedimentary compaction and consolidation, their high reactivity of swelling clay minerals, and their salt accumulations of sodium chloride and gypsum. On these stones, a singular wetting event may cause heavy damages. The mortars and paintings are very sensitive to weathering. The mortars have lost their cohesion as gypsum (the original binder) has transformed into anhydrite, and the paint layers have lost their original organic binding medium. In conclusion, the argillaceous and salty Qurna limestones with gypsum mortars and polychrome relief decorations are the most precious and at the same time the most sensitive artefacts. These objects have only survived due to the excellent environmental conditions.

9.2 Summary of the past deterioration processes and damaging history

The actual state is a result of a long history of physical deterioration. The ancient Egyptian constructors quarried and cut the stones and integrated the blocks into the walls of the temple of Amenophis III, where the artisans equalised the surface with gypsum mortar, and carved and painted the relief decorations with pigments bound by natural resins. The decorations then suffered the first relevant damages when the effigies of deities and inscriptions were removed (iconoclasis) under Echnaton, Tutanchamun and Sethos I and subsequently restored with gypsum mortar and new painting. Later the blocks were broken out of the wall fabric, and some of them were buried in the foundations of the funeral temple of Merenptah where they remained during 3200 years up to their actual excavation in 1994.

A main intrinsic cause of weathering is the probably artificial deposit of halite at the level of the temple floor. This salt has incrusted the top sides and subsequently the lateral sides of the foundation blocks where they caused most of the damages on the polychrome relief decorations. The salt has also filled some of the fissures previously formed by spheroidal weathering and other physical impacts.

However, if we relate the degree of deterioration to the sensitivity of the stones, the gypsum mortars and the paintings, we realize that the deterioration is very weak, what is exclusively due to the excellent environmental conditions in the foundation. Yet we have to emphasise that the clay minerals and the salts make the concerned stone very sensitive to humidity variations.

The remaining stones of temple, that were not buried in the foundations have randomly escaped to a reuse and the production of caustic lime. The first excavations in the 1890^{ies} have exposed them (again) to weathering in contact with the soil, or vice versa covered them by a thin layer of debris. These stones have lost most of the colours and got the brownish patina on the weather exposed parts. Most of these stones are well preserved, while some are deteriorated and exfoliating, superficially spalling, throughout fissuring and spheroidally weathering.

9.3 The risk pattern (prognosis)

The history reveals that the main hazard in the past came from human intervention. It has produced much more deterioration than weathering and use. The excavation itself is such a human hazard for the affected monument. Therefore a serious risk assessment should be a precondition for any excavation work. Its goal would be to minimise the excavation damages and to define the best preventive conservation after the excavation. The normal moment to begin the study of conservation is of course the planning of the excavation. Already then the archaeologist and the conservator would benefit from a pertinent information about the materials, the techniques of construction and art and about the environmental conditions before, during and after the excavation. Thus, the main risk pattern is composed of three hazard groups: the excavation, the weathering and the use.

9.3.1 Excavation damages

In our context where the entire blocks are unburied, the mechanical damages and deterioration due to the abrupt change from the soil to the open air environment are the main problems.

Mechanical damages are low if intact stones can be excavated and moved under normal precautions. But the already weathered and fissured stones, the mortars and the polychrome decorations can not be uncovered and moved without damages, even if the highest precautions are taken. This hazard has to be recognised and taken in account for the *prevention during excavation*.

The abrupt change of the environmental conditions occurs immediately when the very sensitive buried artefacts are removed from the stable and favourable soil environment and exposed to the external microclimate. This becomes very crucial, if the stones are affected by salt concentrations and contain fragile and loosened surface zones, mortars and paintings. Without any prevention, these blocks would lose the polychrome decorations already during the ongoing excavation and in a short period of time after.

9.3.2 Weathering

The actual *risk pattern by weathering* in the upper Nile valley differs in many respects from that of Lower Egypt and Central Europe.

Frost, air pollution and periodic rain precipitation are not relevant. But the persisting sun irradiation and the rare but very strong thunder showers with flooding locally produce considerable damages. The daily variations of the air humidity and temperature are relevant where the stones are affected by hygroscopic salts. Most of the buildings and artefacts are exposed to weathering since two to seven thousand years, what allows direct conclusions on the weathering evolution and its risk assessment:

1. *Not sensitive stones* (e.g. granites, syenites, dense limestones and sandstones) are durable even if they are completely exposed to weathering, with the exception of extreme situations, as e.g. persistent contact with rising damp and salts. The dense and homogeneous variety of the Qurna limestone also belongs to the resistant stones. These stones are not, or only poorly at risk even in contact with the soil. Of course this does not apply to the paintings on these stones.
2. *Sensitive materials* such as the argillaceous variety of the Qurna limestone, the mortars and paints are still stable if they are protected from rain and sun, spared from flooding and the influence of ground and arid soil moisture. The same stones, mortars and paints are not stable where they are exposed to these agents. A unique thunder shower may be catastrophic for the paintings, and the variations of the relative humidity remains a durable risk for them. Therefore it can be expected that they will continue to deteriorate by repeated salt crystallization and by swelling and shrinking of clay minerals even in sheltered situations.

9.3.3 Damages by use (tourists, inhabitants and pets)

Risk arises when man and pets (dogs, goats) walk on the walls and stones, and when non cautioned visitors touch sensitive painted surfaces. A particular attention has also to be called to damages due to non suited »cleaning and refreshing« of dusted parts of the paints.

10 Conservation

The physical conservation of the archaeological remains is based on a risk assessment of course. In the actual case it goes side by side with the arrangement of the site for the public. The preservation work begins with the planning of the excavation and finally merges in a sustained monitoring and care after the conservation work. The conservation involves the prevention of excavation damages, as well as protections from the defined environmental hazards by weathering and from the use and abuse. The most sensitive and precious parts of the stones and the polychrome relief decorations needed an additional consolidation and treatment to make them able to survive under the chosen environmental conditions.

10.1 Prevention of excavation damages

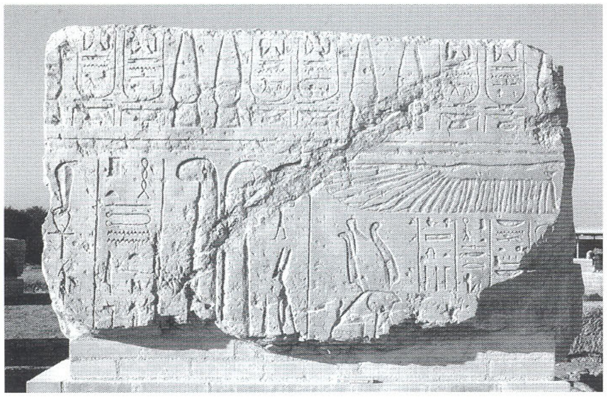
Although precaution and care are actually a standard of professional archaeological uncovering, it is not yet granted that a restorer takes care of the objects already during the excavation. Fortunately that was the case in the actual site. For the arrangement and the environmental protection, many stones had to be displaced. This was done very carefully in order to avoid transport damages. Before their shifting, many blocks have been consolidated by the restorer: fissures and coarse spalls have been glued with epoxi resin and nailed. If necessary the blocks have additionally been consolidated at the new position. The more sensitive and precious stones have been covered by mud bricks during the intervals between the excavation campaigns. A restorer of wall paintings has investigated the carving and paint techniques of the polychrome relief ornaments and consolidated lose parts of the stone and paint layers. The intervals between the campaigns have been used to make tests with different products and methods of consolidation, what is very seldom.

10.2 Environmental protection

According to the assessed risks and adapted to the individual value and sensitivity to weathering, the stones were protected from the hazards of weathering by placing them on natural and built protected places. Durable stones without paintings may be left at open air without protection, less resistant ones are just removed from soil contact and put on pedestals, the very susceptible stones are placed in protecting open and closed shelters. Parts of stones and the decoration that are already damaged and affected by salts were consolidated and fixed according to the provided place and condition of store and exhibition.

10.2.1 Pedestals for the blocks at open air

At open air, the blocks of Qurna limestone are placed on pedestals made of cement bricks (fig. 19). So they are protected from ground moisture and flooding. The pedestal also permits to regroup the blocks approximately in their original positions what improves their legibility. The upper surfaces of the blocks and the flat hollows on them are covered with mortars to ensure the occasional rain water to run away.



19. A block of Qurna limestone showing a diagonal groove due to intense weathering along the air-soil interface before the actual excavation. This block has been set on a pedestal of bricks for protection from rising damp. Width of the block about 1.5 m.

10.2.2 Covered lapidary

The lapidary is a simple construction of three walls made of mud bricks and a roof of sheet metal and translucent resin plates. The space is aired, the blocks stay on a base made of bricks. That way the objects are protected from sun irradiation, rain and thunder showers and flooding, but not from the diurnal variations of air temperature and humidity and from the wind. The micro climate corresponds nearly to that of the sheltered areas in the temples. The diary variations of temperature and relative humidity are like in shadows at open air. The more sensitive and finely carved stones with some preserved polychrome decoration and numerous fragments of limestone and sandstone will stay here.

10.2.3 Shelters of the second pylon

These shelters are built instead of the former foundations of the two towers of the second pylon. The shelters are built around the very precious and susceptible blocks with the polychrome relief decorations. They are made of simple brick walls erected on top of the blocks with a roof of sheet metal. Gras mats pinned down with stones are placed on the roof for isolation. The blocks form the basal zone of the walls; they stay punctually on a concrete basement. Some of the blocks with the polychrome relief decoration inside the room merge out of the wall on their back side where they are exposed to the outside climate. These parts are protected with a lime render. The shelters protect the polychrome relief decorations from sun, rain, wind and flooding. Grilled openings permit aeration. Because the deposition of fine sand and dust created a new problem, the grates of aeration have been covered by translucent synthetic plates and the carved and painted surfaces have been covered provisionally with clothes. As a secondary effect they are now soiled by the excrements of Geckos.

The micro climate in the shelters is very different from that at open air and within the lapidaries. Amplitudes of the outside daily temperature variations are reduced by a factor of 8:1 and those of the relative humidity by a factor of 4:1 (table 5, page 10). The remaining amplitudes are of some centigrades and of 10 – 15% of relative humidity. Thus, it is evident that there is no condensation in these rooms even when this is the case at open air. Nevertheless, the hygroscopic salts crystallising by variations of the air humidity are a further problem. Though the daily variations are too short and too weak to cause crystallisation cycles, it has been evidenced that the seasonal variations with a somehow higher relative humidity in winter and lower in summer still cause some salts to crystallise and dissolve periodically. These most precious and sensitive blocks are carefully treated for conservation by a wall painting restorer. In the future, they imperatively need to get a sustained care as well as the shelters have to be maintained regularly.

10.2.4 Storage rooms

About hundred meters west of the temple, not decorated tombs are used as closed storage rooms for fragments that will not be exposed to the public. The measured micro climate is very stable in these rooms.

10.2.5 Burial within the debris

Many fragments are again buried within the debris where they are expected to survive as they did during many centuries.

10.2.6 Protection from flooding

A wall of mud bricks around the whole area of the temple will protect the site from flooding during thunder showers, and also from unauthorised visitors (people and animals). The wall has resisted to a thunder shower in October 1994 with some repairable damages.

10.3 Protection from abuse

The protection of the archaeological site against abuse has already begun by the arrangement of the site. It is of course very important that the stones with the polychrome relief decorations are protected from touching and any physical contact.

10.4 Sustained monitoring and care

Now that the very precious and sensitive stones with polychrome relief decorations are removed from the soil, protected from environmental impacts and exhibited to the visitors, they require a sustained monitoring and care by professionals. The stones and the constructions have to be controlled and, if necessary, repaired after each thunder shower or other environmental event e, g. sand storm or earth quacks. Only under these conditions the polychrome decoration will survive authentically for a long time. Being aware that sustained care is a duty of the actual cultural society, the prescriptions for its implementation have to be formulated very clearly and without compromises – even if the chance of their complete realisation may be low.

11 Documentation and consolidation of the deteriorated polychrome relief decorations

After their environmental protection, the damaged parts of polychrome relief decorations needed to be consolidated to allow them to persist under the new conditions (i.e. in the shelter and exhibited to advised visitors). Let's remember that the blocks were buried during around 3200 years up to 1994, when they have been uncovered, displaced and positioned with upright figures in the shelters. Their state of preservation has been documented by a professional photographer just after the uncovering. The most urgent consolidation work began already then. The extremely fine carving, the original flattening and later remodelling with gypsum mortar, and the different paintings and over paintings required first a differentiated study of the carving, modelling and paint techniques as usual in restoration of mural paintings. This study, supported by laboratory analyses has been done during the recovering and consolidation.

11.1 Documentation

The initial detailed documentation of the materials, of the damages and of the measures for consolidation was carried out by the restorer and a conservation scientist since February 1997. It focuses on the most important information about the particular blocks and serves as a base for sustained care. The following items are noted:

The materials, their nature, composition etc. The relief decorations, the mortars and the paint layers stay in the foreground.

The original and the actual setting (position) of the blocks, characteristics of the former and the actual environment, which are essential to understand the weathering pattern.

The state of preservation and the deterioration mainly in the area of the painted surfaces but also with respect to the blocks as a whole. Mechanical (hurt) damages and weathering damages, visible salt accumulations (complemented by chemical analyses if needed) and their actual activity (either observed or presumed) are documented. The damages due to salts are described more extensively because they are still active and crucial for the preservation.

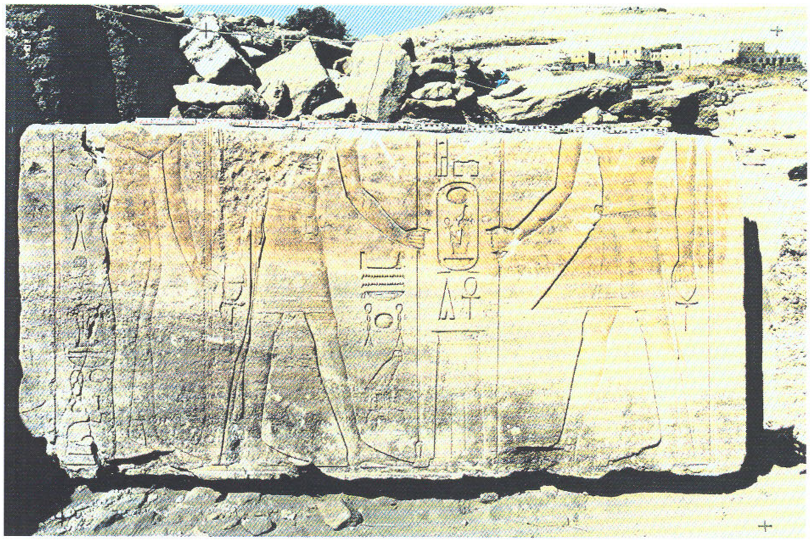
Past, present and foreseen measures are summed up (referring to the reports of the restorer). If necessary, open questions and special remarks for the care are added.

The text refers to the existing photo documents and reports. The linked graphic documentation is executed on the basis of the overall view of the painted surface immediately after excavation (fig. 20 – 21, page 33). The photograph which reveals the morphologic details, and the map which categorises and schematises the damages complement one another.

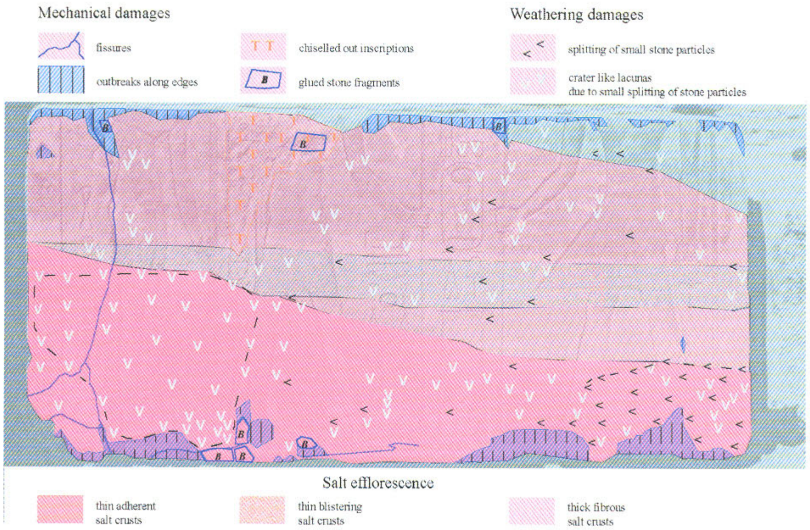
11.2 Consolidation

The details of the important and differentiated consolidation work will be reported by the restorers. As already mentionned, an initial consolidation was essential to fix the losened parts of stones. *It was originally intended to preserve the actual substance just as it was, and to consolidate only the loosen areas at imminent risk without any additional cleaning and uncovering.* Yet it turned out that in many cases fixing was not possible without removing the dirt and the salt crusts. An adequate compromise had to be found very carefully since no precedent cases and models for this approach existed.

During the campaigns of 1997 to 1999, urgent consolidations have been done parallel to the mentioned study and documentation. Simultaneous in situ test series for consolidation allowed to observe the effectiveness of different products between the campaigns. Organosilicates – Motema (M 30 and M 29), Klucel, Paraloid B 72, Epoxy resin – and Arabic gum have been tested.



20. View of the block no. 323 during the recovery in 1994 (photo Bertrand de Peyer).



21. Graphic documentation of the damages

It became necessary to fill and fix cracks in the stone, to consolidate spalling stone surfaces, powdering paint layers, lose and detached gypsum mortars etc. That required the use of different fixing products. Based on the preliminary tests, the surfaces were cleaned mechanically as far as necessary, and salt crusts were weakened first by means of poultices and then removed mecanically. In particular situations, ammonium carbonate solutions were utilised to remove gypsum crusts. Large fissures were glued with epoxy resin, small fissures were fixed an filled with a lime slurry (seldom with addition of white cement). Loosened parts of the stone and the mortars and paintings were consolidated with Motema. Minute stone spalls were glued with UHU glue. Finally, unsightly spots created by repairs have been retouched by means of water colours.

All this consolidation and »cosmetic« work has been done with prudence and after intensive reflections on the object and on the local damage activity in the actual context. The methods were guided by the principle of the minimal necessary intervention, and all the interventions have been documented.

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Zusammenfassung

Die präventive Konservierung der Überreste des Totentempels des Merenptah in der Nekropole von Theben (Oberägypten) wird vorgestellt. Die Untersuchung beginnt mit einer kritischen Wertung der gängigen Methoden und Mittel zur Konservierung in Oberägypten.

Dann wird versucht, eine umfassendere Sicht der Dinge einzuführen, welche die Frage nach dem ausgezeichneten Erhaltungszustand und der Dauerhaftigkeit vieler sehr empfindlicher Werke ebenso einbezieht, wie die Umwandlung und Schädigung durch den Menschen und die Verwitterung im Lauf einer langen Geschichte. Das sich daraus ergebende Konservierungskonzept berücksichtigt die Erkenntnisse aus der Untersuchung der Schädigung ebenso wie die Vorstellungen der Archäologen und Denkmalpfleger, wie die archäologische Stätte der Öffentlichkeit zugänglich zu machen sei, was sich gegenseitig bedingt.

Die geographische und geologische Lage, die historischen Höhepunkte des Tempels, die Art und Eigenschaften der Steine (Kalksteine, Sandsteine und Granite), der Mörtel und der Malmittel (Pigmentarten und Bindemittel) werden beschrieben und zum Teil analysiert. Vor den Ausgrabungen weilten die Steinblöcke im Boden oder an der Oberfläche. Die Fundamentblöcke sind an der Oberseite geschädigt, seitlich und unten, wo sich der farbige Reliefschmuck befindet, aber gut erhalten. Der Erhaltungszustand der verschiedenen Steine des Tempels ist sehr unterschiedlich, je nach ihrer Art und Wetterexposition. Die Schädigungsvorg änge an den Steinen, Mörteln und Farben werden in Hinblick auf die bevorstehende integrale Erhaltung untersucht.

Die Verwitterung in Oberägypten geschieht unter speziellen Umweltbedingungen. Es herrscht ein subtropisches Klima mit recht hohen Temperaturschwankungen, mit niedriger relativer Luftfeuchte, mit seltenen aber heftigen Starkregen, mit dem durch den Nil bedingten Grundfeuchteregime und der ariden Bodenfeuchte.

Der Tempel des Merenptah liegt an der Westseite des Niltales und über dem Einfluss des Nil-Grundwassers. Die Materialien sind besonders betroffen von den seltenen Starkregen und von der Grund- und Bodenfeuchte. Es gibt keine Hinweise auf Kondensation an den Steinblöcken. Wir vermuteten, dass die drei wichtigsten Schadenvorgänge die Salzsprengung, die Feuchtedehnung und die Wärmedehnung sind. Die Kristallisation von Natriumchlorid und die Umwandlung von Gips zu Anhydrit sind die wichtigsten bisherigen Schadenvorgänge. Die Umwandlung von Gips in Anhydrit ist ein vergangener Schadenvorgang. An den Denkmälern sind die Salze besonders aktiv im Bereich der Grundfeuchte und der ariden Bodenfeuchte. Die Entwässerung von Gips und seine Umwandlung zu Anhydrit hat die Bindung der Gipsmörtel aufgelockert. Die Frage, warum Gips bei so niedrigen Temperaturen zu Anhydrit entwässert, wird anhand der Literatur und von Laborversuchen diskutiert. Der Wasserdampf-Partialdruck ist der wichtigste Faktor. Eine zutreffende Antwort konnte jedoch noch nicht gefunden werden.

Feldversuche über die Feuchte- und Wärmedehnung zeigen, dass bestimmte Varietäten des Qurna Kalksteins durch Feuchte stark quellen und sogar eine Durchnässung genügen kann, um das Gefüge der empfindlichsten Varietäten völlig zu zerstören, während die Wärmedehnung sich als unwirksam erwies.

Die vorgeschlagene Konservierung beruht auf einer Risikoanalyse. Die Risiken sind mögliche künftige Verluste an materieller und kultureller Substanz. Sie ergeben sich insgesamt aus der materiellen Gefährdung durch Verwitterung und Abnutzung einerseits, und aus der Art und Verletzlichkeit der Objekte und dem Wert, den man ihnen beimisst andererseits. In unserem Zusammenhang sind die aus dem versalzten, mergeligen (tonhaltige) Qurna Kalkstein, sowie aus Gispsmörtel und Farbfassungen bestehenden polychromen Reliefdekorationen, die wertvollsten und zugleich empfindlichsten Kunstwerke. Die Art und Geschichte der Schadenvorgänge ergibt ein Risikobild, in welchem Grabungs-, Verwitterungs- und Nutzungsschäden (Touristen, Bewohner und Haustiere) zusammenwirken.

Die vorgeschlagenen Konservierungsmassnahmen beinhalten:
die Vermeidung von Grabungsschäden,
den Witterungsschutz mit:
Isolierung der Blöcke im Freien, und in Lapidarien unter Schutzdächern gegen die Bodenfeuchte durch Podeste,
Bau von Schutzdächern über Lapidarien für mittel empfindliche Steine
Einrichtung geschlossener Schutzräume in den beiden Fundamenten des zweiten Pylons für die Blöcke mit der polychromen Reliefdekoration,
Einlagerung sehr empfindlicher Steine in geschlossenen Magazinen,
Vergraben der kleineren Fragmente in den Schutt,
Bau von Lehmmauern gegen Überschwemmung durch Starkregen,
Schutzeinrichtungen vor Missbrauch und nachhaltige Pflege.

Das letzte Kapitel beschreibt die Methoden der Schadendokumentation und der Festigung des geschwächten und geschädigten, sehr wertvollen, polychromen Reliefschmucks in den geschlossenen Schutzräumen. Die Eingriffe erfolgen unter dem Prinzip vom minimal notwendigen Eingriff im Hinblick auf die künftige Umweltexposition in den Schutzräumen. Alle Eingriffe wurden dokumentiert.

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