SUPPLÉMENT AUX ANNALES DU SERVICE DES ANTIQUITÉS DE L'ÉGYPTE

CAHIER N° 35

THE WORLD OF ANCIENT EGYPT
ESSAYS IN HONOR OF
AHMED ABD EL-QADER EL-SAWI

PREFACE
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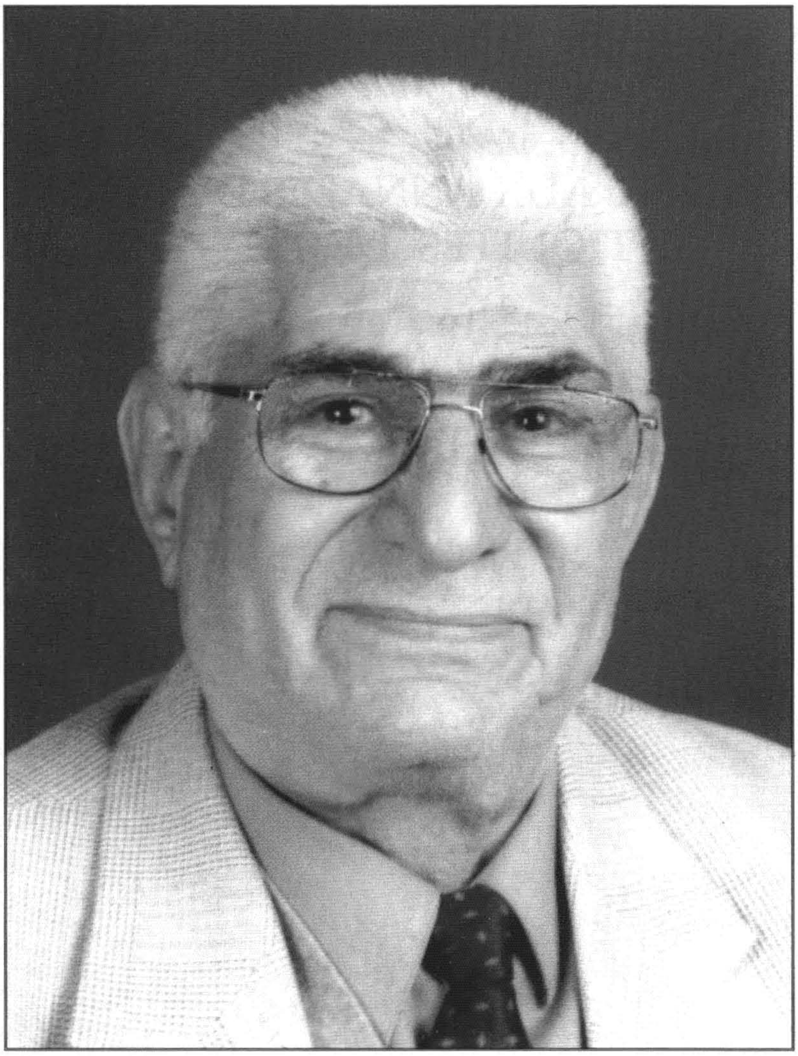
An offering scene from the mastaba of Ptah-hotep, Saqqara.



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IMPRIMERIE DU CONSEIL SUPRÊME DES ANTIQUITÉS

PROPOSED HYPOTHESIS, TESTING AND DOCUMENTATION, AND ACTIONS TO BE TAKEN FOR THE CONSERVATION OF THE SPHINX

John P. GNAEDINGER

Abstract

Since it was first cut from the natural bedrock of the Giza Plateau thousands of years ago, it is apparent that the Sphinx has been undergoing deterioration. However, there have been many and varied causes cited by experts, typically without any effort to document the most probable cause or causes. There has been no effort to arrest the deterioration, except by placing stone facing, particularly around the lower portions of the Sphinx.

It is the hypothesis of this paper that the primary, if not the sole cause of the deterioration of the Sphinx, is the upward movement, due to capillary forces of ground water containing gypsum salts, among others, into the body of Sphinx. Due to evaporation from the face of the Sphinx, this vertical movement is also directed toward the surface of the Sphinx, depositing gypsum crystals on the surface of the lower portions, immediately below the surface at somewhat higher elevations, and well within the body at higher elevations.

On re-wetting these gypsum crystals, due primarily to continuing capillary rise of moisture from below, they expand with considerable force, causing progressive slaking of the limestone where the slaking is immediately below the surface.

The phenomenon is more evident on the north face than the south because the greater solar energy on the south face creates the crystallization well within the body of the Sphinx, thus avoiding the surface flaking, or at least slowing it down.

The primary effect of 'protecting' the body of the Sphinx with limestone blocks, even with lime mortar (not gypsum mortar!), is to increase the remoisturization of gypsum crystals that have been forming within the Sphinx for thousands of years, which actually increases the rate and the depth of deterioration. In other words, the limestone blocks being placed with such care, even now, are clearly counterproductive.

A permanent arresting of the deterioration can best, or perhaps only, be obtained by preventing capillary rise of moisture within the Sphinx, since gypsum crystals are already distributed throughout the body of the Sphinx. This fact could be rather easily verified by testing samples from small cores in the body, taken at locations well away from the head, at least initially.

The rise of moisture can be prevented by the use of a desiccation system beneath the Sphinx. Using lateral porous pipes at perhaps two meter spacings, beneath the external ground surface, and using chemical or mechanical dehumidification of the air in these porous wall pipes, will create a meniscus which is concave downward within the entire mass of the Sphinx. The system would first perhaps be tested for its effectiveness beneath one of the front paws of the Sphinx. It would have further benefit at such

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locations in rendering the beautiful masonry work, now being installed, as being essentially permanent.

Monitoring of the capillary tension within the Sphinx would be very important. Chemical desiccation could be rendered ineffective if replacement or redrying were not regularly and reliably implemented.

The same, or better, effect could be obtained by cutting a horizontal slit plate beneath the Sphinx, with a wire cutting technique and inserting a stainless steel plate that would underlie the full plan of the Sphinx, albeit installed in perhaps one meter wide strips. This idea was proposed by a prominent Egyptian geologist, acting independently of the author.

Other methods of creating an impermeable layer beneath the Sphinx can be devised, such as by mining in increments and backfilling with a strong but impervious mass.

An anchor to prevent the head from falling and / or reconstruction of a beard, primarily for stability purposes, should be implemented as soon as possible. Microseismic detectors should be used at 'the earliest possible 'opportunity to see if 'microseismics' are even now being generated, as are characteristic of progress rock failure.

It is recommended that peer reviewers be assembled to review and approve all plans, testing, monitoring, and implementation.

Introduction

The author's knowledge of the Sphinx, other than as a tourist for an hour in 1979, originated in a private discussion and a viewing of a series of slides and photographs presented by Zahi Hawass.

Between that first exposure to the problems of deterioration of the Sphinx and a more detailed inspection of the monument and its environs on January 13, 1992, the author has had many discussions and read substantial materials on the problems of the Sphinx and possible solutions to these problems. This visit was with Bruce Mainwairing and was followed by several hours of discussions with Zahi Hawass. The January visit also included discussions with Mansour Bouraik, an Inspector of Antiquities at Giza, under Zahi Hawass.

There is no claim by this author that available writings, from academia and elsewhere, have been studied. In fact, if the thoughts expressed in this paper have been presented at an earlier date by others, this would be considered a positive reinforcement of these views.

Before actions can be taken to implement ideas expressed herein, for an antiquity as important as the Sphinx, it is believed that a program to document the assumptions made in this approach to the problem, through tests and measurements, should be undertaken as soon as possible.

It is further suggested that a review board should be established consisting of chemists, geologist, material scientists and engineers, and restorers of antiquities, so that every action would be thoroughly planned and reviewed. The panel assembled for the conference held on Febuary 29, 1992, on the Sphinx would be an ideal group for this review.

However, there appears to be a sense of urgency in this matter. There is a serious question as to the amount of risk involving the head of Sphinx that it might collapse, and an even more serious concern is about the current damage being done to the Sphinx by the present covering of its lower portion with limestone blocks and lime mortar.

Observations and History of Deterioration

There are many early papers discussing the Sphinx, containing data and observations of the past, which will not be repeated here. The central elements of the Sphinx and its environs demonstrate that it was carved thousands of years ago from the limestone which comprises the Giza Plateau, near the pyramids.

There are very interesting elements of the Sphinx, not the least of which are those dealing with the purpose of construction in the first instance; the religious significance of the Sphinx; its methods of construction; or, even the economic value of the Sphinx as a tourist attraction of great importance to Egypt; and, for that matter, to the millions of tourists who marvel at it and at the obvious genius of Egyptians who created it.

What is important, but, unfortunately, has been studied in the preparation of this paper, is the record of past efforts to restore the Sphinx. However, it also appears to be a reality that these efforts have all failed!

Perhaps in view of the specific approaches recommended in this paper, if there is an interest among those in higher education involved with the Sphinx, a study of past efforts in the context of the present approach might provide additional insight into explaining past failures.

The Problem

It is self-evident that the Sphinx was carved from limestone, which is slightly sloping in its bedding, with alternating zones of very hard layers and intermediate soft layers. The stratification is clearly visible in photographs and described in the work of Mark Lehner and others.

It is also known that the limestone contains substantial amounts of gypsum and other salts, the extent of which can easily be determined by laboratory tests (which should be run promptly), particularly in the areas that are failing at the present time.

In 1986 information was presented showing the water level in a pit inside the Sphinx itself was at a depth of approximately 3 meters. Since human activity in the vicinity of the Sphinx has been reduced in recent years, it is understood that the present water level is now at a depth of 7 meters.

However, this minor lowering in the level is of no significance when viewed in the context of capillary forces that can carry moisture and dissolved salts to heights of many hundreds of feet.

Tests might readily be performed to determine these capillary forces, initially perhaps testing the stratification on the sides of the excavation surrounding the Sphinx, to minimize any unnecessary sampling of the body of the Sphinx itself.

Determination of the gypsum, sodium chloride, and other salts in limestone should also be performed both solid and dissolved.

The body of knowledge concerning the behavior of gypsum as it dries out, and then is re-wetted, is substantial.

As moisture rises in the Sphinx due to capillary forces and approaches the surface of the Sphinx, it evaporates as it interacts with the hot dry air, typical of the Giza Plateau area. Anhydrous gypsum is formed.

On the south side, which has maximum energy from the sun, the moisture and air interface must be further inside the mass of the Sphinx than it is on the north side, which is not heated as much by the sun's energy. As a result, rehydration of the anhydrous gypsum formation on the south side of the Sphinx, which has exhibited less deterioration than the north side, is much less than on the north side. This could easily be measured by sampling and testing.

If these anhydrous materials are formed on the outside of the surface of the Sphinx, they become visible as a powdery substance, which would not damage the Sphinx. If the deposits form barely inside the surface of the Sphinx, then as the solids rehydrated, they create expansive forces as the gypsum expands. This causes surface deterioration in a progressive manner, which is worse on the north side.

When the anhydrous gypsum is formed, and then rehydrated well within the mass of the Sphinx, the natural strength of the limestone prevents damage from occurring, though obviously the problems are more severe in the weaker limestone layers than they are in the harder limestone.

Ancient Egyptians must certainly have known that limestone had these problems, since they built many of their temples from granite quarried in Aswan, presumably floated down the Nile with logs, in order to provide a more permanent structure where used. Albeit one that costs many times as much, in labor, to build.

The Present Program of Limestone Blocks and Lime Mortar

During the January 13, 1992 visit to the Sphinx, Bruce Mainwairing and the author observed that much of the concrete block, that had been previously placed using a certain mortar, had been pushed away from the main body of the Sphinx, as evidenced by the cracking pattern. In a few cases, it was necessary to prevent the block from falling by using four timber struts placed against the loose blocks (Fig. 1).

Recognizing this failure, a decision was made to replace the concrete block and mortar with limestone blocks and lime mortar (Fig. 2), on the presumption that it was the original mortar that was causing the problems rather than recognizing that the problem was originating with the rehydration of anhydrous gypsum within the mass of the Sphinx.

It is the author's opinion that the net effect of the concrete block or limestone block, in either case, is to minimize evaporation, and therefore maximize the rehydation of many thousands of years of accumulation of anhydrous gypsum that has formed within the mass of the Sphinx since it was built.

It could thus be predicted that, with the present plating of limestone blocks, while it may take a century or two to deteriorate, the ultimate result will be the total destruction of the Sphinx by progressive deterioration due to rehydration of gypsum, and perhaps other salts.

However, the process is greatly accelerated by the limestone covering of the Sphinx. In the short term, of course, even though it changes the texture of the Sphinx from its original nature, the Sphinx as a monument can appear to have a much more stable and attractive appearance than it would if the limestone were not being placed, but the benefit is clearly temporary.

If gypsum mortar had been used rather than cement for the original concrete block covering, then this could perhaps have contributed to the problem, but not much. The mortar, if it contained gypsum, would have been wet when it was placed, and therefore would already have been hydrated.

What Can Be Done?

Inasmuch as the body of Sphinx is saturated with moisture containing dissolved gypsum, it would be almost impossible to leach these materials out because of low permeability of the limestone.

Therefore, the most probable means of avoiding further deterioration would be to prevent ground water from rising, by capillarity, into the body of Sphinx in the future.

This could perhaps best be accomplished by creating capillary menisci that are concave downward, across a horizontal plane beneath the Sphinx, thus not only preventing further moisture rising, but bringing the exiting moisture down to a lower level.

The optimum process would have to be studied and demonstrated in adjoining formations beyond the limits of the Sphinx, which would be a relatively simple matter to accomplish. It is anticipated that the first step in the process would be to prevent free movement by ground water from around the perimeter of the Sphinx into the limestone formation immediately beneath the Sphinx by a series of chemically grouted holes, using sodium silicate-formamide-ethylacetate grout with necessary catalysts.

Observation holes inside the grout could readily be monitored to establish the effectiveness of this grout curtain.

The purpose of the grouting is to cut off free movement of water. It would affect capillary movement, which would continue through the grout curtain itself, where it existed, as well as the limestone.

Vertical movement of capillary moisture throughout the body of the Sphinx can best be prevented by creating a horizontal space, approximately 1/8 inch thick at the bed of the Sphinx, into which would immediately be inserted an aluminum plate or stainless steel plate, as suggested by a prominent Egyptian geologist. This work can be demonstrated under the front paws of the Sphinx to determine the amount of reduction in moisture content of the monument, which would take immediately after installation.

It has been suggested that use of wise or rope saws, with abrasives, was the mechanism used by the ancient Egyptians to cut limestone, and even granite, thousands of years ago. Certainly, new technology would improve the process compared to what was done a thousand years ago - we hope.

The second, but preferred, alternative would be to reverse the capillary menisci, the capillaries of the limestone, by installing lateral holes beneath the Sphinx, at perhaps 2 meters on center. Desiccants or dehumidification would lower the humidity as close to zero as possible. At the same time, this would bring moisture downward instead of letting it rise by capillary forces.

The chemical desiccants, of course, would have to be re-dried at intervals of perhaps every week or every month. Maintenance of the dehumidification equipment would be necessary, if it were used.

A much preferred and less expensive method of desiccation would be to install the lateral holes at 2 meter spacings, perhaps one meter below the ground surface, and to continuously pass heated air through these holes. Electrically heated coils, using low cost Aswan power, would appear to be the optimum source of energy, though ambient air might be effective, certainly in the summer.

Instrumentation to constantly monitor the moisture within the Sphinx would be extremely important.

If additional lateral holes are necessary, they can easily be drilled at one meter spacing or even 2 to 3 meters spacings.

It is strongly urged that the above hot air process be implemented as soon possible under the north front paw of the Sphinx, and later, under the main body of the Sphinx.

The Sphinx Head

There appears to be differences of opinion as to where the head of the Sphinx is on the verge of falling forward, due to deterioration of weaker limestone in the neck, or whether it is stable, at least for the foreseeable future (Figs 3-4).

It has been well-known, for at least thirty years, that rock masses, during periods of stress, emit 'noises' called acoustic emissions, which become more frequent as failure approaches.

The detection of such acoustic emissions can be complex when the purpose is the detection of impending failure in mines and tunnels, requiring elaborate and expensive installation of sensors throughout the rock mass surrounding and above the mine.

However, epoxy-mounting of simple, inexpensive geophones at several locations on the head and neck of the Sphinx would provide useful data concerning the state of stress in the neck in a matter of weeks after a decision is made to proceed. A simple, signal amplifier and sequential recorder, all equipment costing less than $ 10,000, are all that is necessary, plus geophones, ladders, and a tube of epoxy.

Periodic measurements should be made at, perhaps, weekly intervals to see if any increase in the rate or magnitude of emissions is taking place. Such an increase would suggest that the future is actually occurring.

Lest the authorities be accused of 'fiddling while Rome burns', a plan should be implemented for actions to be taken immediately. The obvious action would appear to be the installation of several rock anchors, placed in holes carefully drilled from the top of the head, slightly sloping toward the head of the Sphinx, and well into the body. Stainless steel anchors, threaded at the top, would be anchored in the holes using Roc-Loc, and tension added and locked in with appropriate components at the top. Strain gages and sonic data should be taken to verify that the designed measures are achieved and maintained forever.

Data obtained on the dimensions of the Sphinx would be ideal for the design of this anchorage / reinforcement.

Perhaps a later program could reconstruct the beard that originally is said to have existed on the neck, using it to further stabilize the head of the Sphinx.

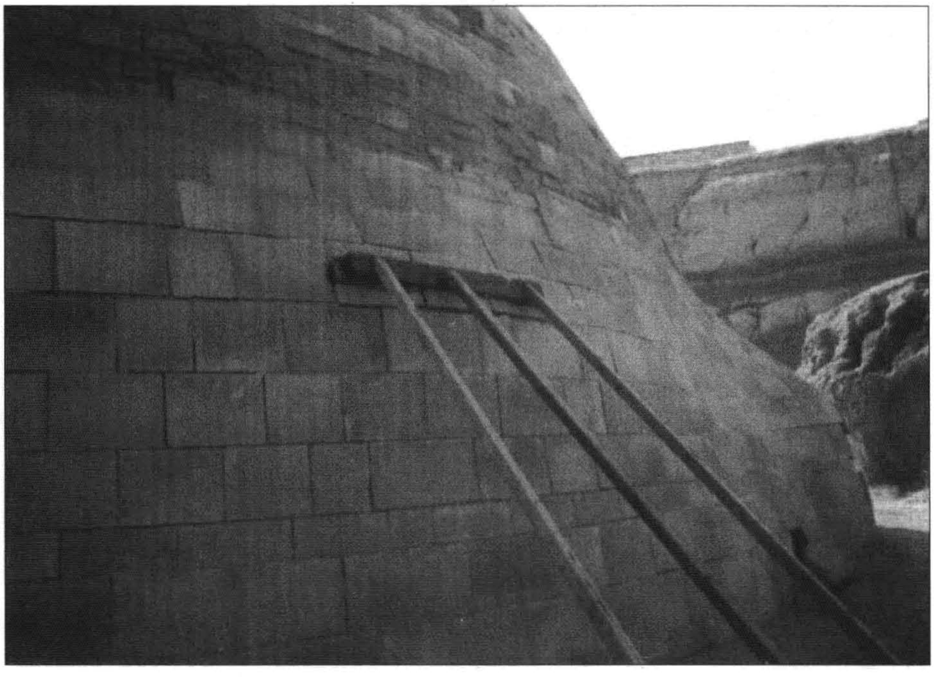

Fig. 1. Timber struts placed against the loose blocks.

Fig. 2. Limestone blocks covering the Sphinx.

Fig. 3. View showing the weaker limestone in the neck.

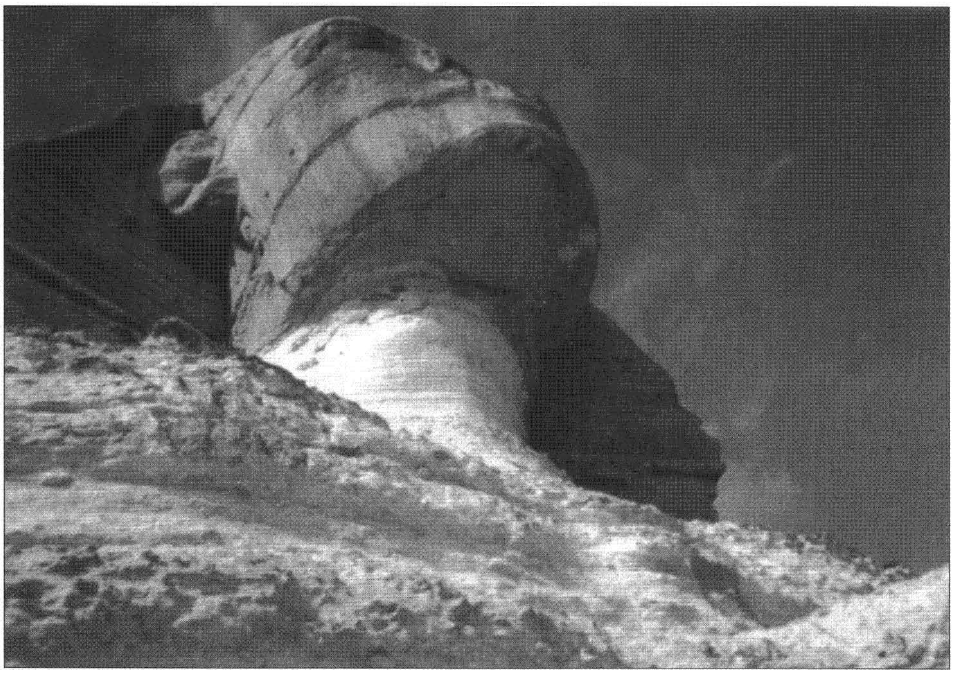

Fig. 4. Closer view of the weaker limestone in the neck.

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