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This paper is one result of a preliminary survey of the tomb of Queen Nefertari, which was unearthed in 1902, west of Luxor, Egypt. The survey is part of a one-year study entitled “Wall Paintings of the Tomb of Nefertari,” jointly undertaken by the Getty Conservation Institute and the Egyptian Antiquities Organization. Prior to the field survey, which was conducted on 8–13 September 1986, a Thematic Mapper image of the site and its environs was computer-enhanced and photologically analyzed. This resulted in establishing patterns of structure and drainage, which follow three major trends: NE-SW, NW-SE, and E-W. Local topography, however, controls the microdrainage patterns of surface water from occasional rainfall.

Observations within the tomb of Nefertari and two shallow tombs on either side indicate that the limestone country rock is highly jointed. The resulting spaces are filled with fibrous crystals of gypsum at right angles to the joint planes. The content of rock salt in these joints appears to increase with depth. This suggests the possible leaching of rock salt from higher horizons to lower ones, where it recrystallizes behind the plaster layer of the wall paintings. The salt crystals appear to force the plaster layer outward, resulting in severe damage. Fear of further deterioration prompted the five-decade closure of the tomb to public visitors.

For a better understanding of the setting of the tomb, it is essential to prepare detailed topographic, structural, and drainage maps; a stratigraphic column; hydrologic and salt crystallization models; and illustrations of the degree of deterioration with time. It is also necessary to gather data on the present environment, including the spectral characteristics of the walls, the sealability of the surface soil, the local microseismicity, and micro-climate changes within the tomb in space and time.

**NEFERTARI**, meaning self-generating beauty, was the favorite wife of Ramses II, who ruled Egypt for sixty-seven years (1292–1225 B.C.). The reign of Ramses II was characterized by unprecedented splendor, great luxury, and the growth of an army that the king used to establish an empire from southern Syria to northern Sudan. Among his famed monuments are the temple at Karnak, the Rameseum, the mortuary temple at Thebes, the temple of Luxor, and the fabled rock temple of Abu Simbel.

The great renaissance in the arts that must have accompanied these achievements is exemplified in the magnificent wall paintings in the tomb of Nefertari. This tomb was carved in the clayey limestone rock on the west bank of the Nile River across from the temple of Luxor. The tomb was unearthed in 1902 by Schiaparelli, but had been plundered in antiquity.

From the time of the tomb’s discovery at the start of this century, it was recognized that the tomb carried the perilous burden of its inherent structural problems (Esmail, 1986). The wall paintings had deteriorated to the extent that large segments, over six meters wide, had fallen off and were destroyed. Because of fear of further deterioration, the tomb was closed to public visitors nearly five decades ago. The only visitors allowed were some heads of state and researchers who studied the possibility of restoring the wall paintings.

Several experiments were conducted concerning the preservation of the tomb, particularly during the past forty years. None, however, proved successful. Thus, the present one-year study was initiated on 8 September 1986 with the aim of understanding the natural setting of the tomb and establishing the best methods of conserving its wall paintings.
The tomb of Nefertari is number 66 in the Valley of the Queens, a small wadi bounded by a high escarpment at the edge of the hills in western Thebes, the ancient name of Luxor. To fully understand the setting of the Valley of the Queens, one is advised to review photographs and images obtained from spacecraft as a prelude to the examination of the larger-in-scale aerial photographs. The best space photographs of the region are those obtained by Gemini XII in 1966, by Landsat satellites starting in 1972, and by the Space Shuttle Large Format Camera (LFC) in 1984.

The hills that surround the Valley of the Queens are part of an extensive plateau that forms the eastern boundary of the Western Desert of Egypt (Figure 1). This boundary also represents the edge of the Nile Valley, which encloses the agricultural strip along the banks of the Nile River.

Based on the study of Gemini XII photographs, Yehia (1973) established that the region is characterized by dendritic and subdendritic to subarellus drainage. He also recognized that drainage lineations are controlled by gravity, structure, and/or lithology.

Images obtained by Landsat were used to delineate geographic features of the region (El-Baz, 1979). Earlier Landsat images were characterized by relatively low ground resolution, about 80 meters. Later images obtained by the Thematic Mapper have 30 meters resolution. An image of the study area was requested from the Earth Observation Satellite (EOSAT) Company. The image, obtained on 22 January 1986 (50069-20746-TMWNO; N26-00 E32-21; Path 175, Row 42), was specially computer enhanced by the Earth Satellite Corporation of Chevy Chase, Maryland; details from this image are discussed below. The higher-resolution photographs (about 20 meters) by the LFC are yet to be studied.

The multidisciplinary study entitled “Wall Paintings of the Tomb of Nefertari” is being jointly conducted by the Egyptian Antiquities Organization (EAO) and the Getty Conservation Institute (GCI) and performed by the following team members:

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- Frank Preuss, chemist (GCI)
- Michael Schilling, scientist (GCI)
Study of the Thematic Mapper images of the Luxor area indicates that the Thebes Plateau on the west bank of the Nile is characterized by three major fracture systems (Figure 2a):
A. The East-West fault system that appears to be the oldest because it is truncated in several places by the two other systems.
B. The NW-SE fault system, which is emphasized by numerous primary drainage lines and wide valleys.
C. The NE-SW fault system that is mainly followed by major escarpments, but also parallels secondary drainage lines.

These trends reflect the major fracture pattern of the Western Desert of Egypt as previously deduced from studies of space photographs, particularly from the Apollo-Soyuz mission (El-Etr and others, 1979).

The Nile Valley in this region follows the NE-SW direction (Figure 2b). It is clearly evident that the Nile itself occupies a course in the lowest part of the fertile valley; it is unlikely that its water has much to do with the moisture in the Theban hills at higher altitudes.

Closer examination of the environment of the Valley of the Queens shows that the region is controlled by one major fracture that is parallel to the Nile Valley fault zone. The fracture also shows the distinctive scalloped appearance of other parts of the fault zone as it truncates a protrusion of rock that extends into the Nile Valley (Figure 2c). This particular setting has resulted in the separation of the region of the Valley of the Queens (along with the area of the temple of Hatshepsut) from the regional drainage pattern to the north and west.

This setting is particularly lucky because it will simplify the establishment of a hydrologic model for the region. It may also simplify the potential damming of wadis to minimize the amount of water that reaches the vicinity of the tomb of Nefertari from future occasional rainfall. This would have been much more difficult if the area were fed by the regional drainage pattern.
The rock in which the tomb of Nefertari is located is a clayey limestone, with conoidal fracture. It is very fine-grained and highly fractured by several joint systems. The extensive fracturing and jointing appears to be due mainly to the fact that the region is part of the Nile Valley fault zone. Most fractures developed at the time of the Nile Valley formation; however, more recent fractures and joints are present.

The most pronounced joint system is that which parallels the main escarpment of the Nile Valley. The distances between joints are at times only a few centimeters. All of the resulting spaces appear to be filled mainly with gypsum, whose crystal growths are normal to the joint planes. In most cases the joints themselves are a few millimeters wide, but a few can be measured in centimeters.

The second most pronounced set of joints cuts across the latter joint system, forming a rhomboidal, “baklava-like” pattern. The joints of this set are on the average much thinner and are filled with a powder-like layer of salts, most likely gypsum.

The very high density of fractures indicates a porosity that allows rainwater to seep downward through the joints. This in itself is an important factor in the general setting of the tomb of Nefertari. No one is certain about the cause of deterioration of the wall painting. The possibilities include: (a) rainwater from above; (b) groundwater from below; and (c) humidity from the air inside. If the latter is the main cause, this would speak in favor of closing the tomb to visitors because their presence would significantly increase the humidity inside the tomb. However, from my preliminary observations it appears likely that the largest amount of moisture reaches the tomb as rainwater seeping through the numerous fractures and joints. Nonetheless, the resolution of this very important point must await conclusions drawn from the hydrologic model.

The highly fractured nature of the rock that encloses the tomb of Nefertari suggests that microseismicity can be dangerous in the area. Induced shaking by vehicles and large tourist buses, for example, may dislodge loose pieces of the wall. Further damage may be caused by thixotropy (the property of becoming more fluid when shaken), particularly if water becomes mixed with clays and/or other fine particulate material in the fractures and joints. Therefore, it is here recommended that the present paved road that leads to the tomb (Figure 3) be shortened by at least 200 meters, and a new parking lot established away from the tomb entrance.

For the same reason, disposition of water or any other fluids at or near the surface of the tomb should be prohibited. Any fluids at the surface will eventually make their way to the tomb walls through the fractures and joints in the country rock.

Local structures in the escarpment that trends NE-SW and borders the Valley of the Queens on the north side may play a major role in the structural setting, drainage pattern control, and ultimately the channeling of rainwater to the walls of the tomb. These features, including an open fissure and a tilted block, are clearly illustrated in Figure 4.

The open fissure is a few meters wide, and from it emanate minute drainage lines that lead to the level of the tomb entrances below. One of these lines runs parallel to the edge of the major rockfall, which forms a delta-like pattern that covers part of the scarp (Figure 3). This fissure and associated features should be studied in detail to establish their effects on the porosity of the rocks in the region and on surface and subsurface drainage.

The tilted block bounds the region of the tombs on the south side (Figure 4). The considerable degree of tilt indicates a major event that must have affected the microeconomics of the region. Thus, this block should also be studied in detail to establish its effects on the region.

Figure 3. Aerial photograph of part of the Valley of the Queens (after Weeks, 1981).

Figure 4. Photograph of the southwest edge of the escarpment that bounds the Valley of the Queens, showing part of the highly fractured limestone rock of the Nile Valley fault zone.
In order to establish the particular setting of the tomb of Nefertari, two tombs—one on either side—were visited for comparison. It was immediately noticed that both tombs are at higher levels than that of Nefertari and that their wall paintings and plaster layer are not as badly affected by the same processes that have caused deterioration in Nefertari's tomb.

The shallower tomb is on the right side of Nefertari's. It is assigned number 68 and belongs to Queen Merit-Amon, who is believed to have been the daughter of Ramses II. Upon entering this tomb one is struck by the ordered nature of the joint systems in the clayey limestone rock. The rhomboidal fracture pattern is particularly pronounced in the ceilings of the entrance hall and the two chambers on either side. The tomb has been inhabited in recent times, and parts of its walls and most of its ceilings are covered by a thick layer of soot from cooking fires. The joints in this tomb are usually thin (a few millimeters wide) and contain gypsum. Tasting of the gypsum filling indicates the lack of NaCl. This is true even when the joints are only hair thin.

The tomb to the left of Nefertari's is deeper than number 68 by a few meters and is similar in its fracture pattern. However, its limestone appears to be more clayey, and its concoidal fracture is not as obvious as in the shallower tomb. The ceilings in this tomb are comparatively high, which hampers observation of their texture. They appear to be even higher than the ceilings in the tomb of Nefertari.

The joints in the deeper tomb appear to be more closely spaced and contain just as much gypsum as in the shallower tomb. A most interesting observation, established by tasting, is the presence of minute amounts of rock salt mixed in with the gypsum that fills the joints.

Comparison of the Three Tombs

Cursory comparison of the three tombs suggests a distinct stratigraphic layering in this section of the limestone in the Valley of the Queens. It appears that in the uppermost horizon the limestone is denser and its joints are spaced more widely. The deeper the horizon, the irregular and, in most cases, more closely spaced the jointing pattern becomes.

The most significant change with depth appears to be the increase in NaCl content in the gypsum filling the joints and fissures in the rock. Preliminary examination of the plaster in these tombs indicated that its deterioration increases with depth: it is least affected in the shallowest tomb and most deteriorated in the deepest burial chamber of the Nefertari tomb (Figure 5). This condition strongly suggests correlation between the presence of rock salt and the deterioration of the plaster along the walls of Nefertari's tomb.

It is perhaps significant to note that there are several degrees of deterioration in the tomb of Nefertari. Upon entering the tomb, one immediately notices the vast network of minute fractures in the ceiling, which is painted blue, a color that is believed to be "synthetic" (Jaksch and others, 1983). This fracturing is unlike any elsewhere in the tomb and is not duplicated in the ceiling of the lower burial chamber.

The second—and unique—deterioration is that which accompanies the dark green color in the wall paintings (Figure 6a). This is most noticeable in the figure of the goddess Hat-hur painted in the stairway that leads from the upper chamber to the lower one. This particular deterioration appears to affect a paper-thin layer and may be related to the paint or its binding medium. Therefore, it may be one case in which moisture in the air may be playing a role in deterioration.

Figure 5. Floor plan (top) and cross-section (bottom) of the tomb of Nefertari; 10 meters deep.
The third and most damaging type of deterioration is related to the crystallization of rock salt. This takes several forms. The most common is where salt crystallized along the line that separates the plaster layer from the rock. In most cases this induces buckling of the plaster layer with its paint layer until it cracks and falls off (Figure 6b). In some cases this causes a segment of plaster, usually a few centimeters in diameter, to separate from the wall and protrude on a pedestal of rock salt crystals.

A further type of salt crystallization is what appears as pustules on the outer surface of the paint layer. This is particularly visible in the side chamber to the right of the burial chamber. This type may also be related to the humidity inside the tomb. Therefore, examination of the microclimate inside the tomb chambers would be significant in establishing such relationships.
The observations discussed above were made during a few days of site inspection and must not be considered conclusive. However, these observations point to several courses of study that may shed more light on the geographic and geologic setting of the tomb of Nefertari. A full understanding of this setting is essential to the planning of any consolidation and treatment, temporary as well as permanent, of the wall paintings of the tomb. Therefore, it is recommended that the following steps be accomplished as soon as possible and the results distributed to all members of the study team.

Detailed Topographic Mapping

The available topographic maps from the Egyptian Survey Organization (1926) and the “Berkeley Map of the Theban Necropolis” are inadequate for the ongoing project because of requirements for accuracy and coverage.

A detailed topographic map is essential to the understanding of the site, its peculiarities, and its environment. Such a map constitutes a significant component of the hydrologic model. It is, therefore, recommended that a map of the region be made with the following specifications:

A. The map area should include all tombs north of the paved road and cover the high ground to the continental divide, which separates two main drainage systems.
B. The map should be compiled at 1:1,000 scale, to be reduced later to other convenient scales.
C. The contour interval should be one meter.
D. Accurate profiles of all significant wadis should be made using laser instruments.
E. Efforts should be made to establish points with absolute (rather than relative) control, perhaps using GPS coordinates.

Such an endeavor is likely to be both time-consuming and rather costly. Therefore, it is recommended that this activity be a separate project and funding for it be sought from other sources. It is quite likely that this can be accomplished by enlisting the expertise of the renowned cartographer, Dr. H. Bradford Washburn, Jr., former director of the Boston Museum of Science and presently a member of the Advisory Council of the Boston University Center for Remote Sensing. The work can be conducted by a volunteer surveying crew under his supervision, to be sponsored by Earthwatch of Watertown, Massachusetts.

Structural Mapping

Mapping of surface structures, particularly major faults, is also essential to the hydrologic model of the region. This can be conducted by the study of aerial photographs in stereopairs and by later checking in the field. Such a map can be produced at the Boston University Center for Remote Sensing using aerial photographs, which have been requested from the Egyptian Antiquities Organization Documentation Center.

It is important that the structural geology map be compiled at the same scale as the topographic map to allow correlations between the two maps. Fracture systems that delineate faults and joints should be distinguished from lineaments which may be due to other than tectonic characteristics.

A geological sketch map should accompany the structural map. This combination would be useful in relating local geology to structural patterns and stratigraphy.

Drainage Network Mapping

It is evident from Figure 2 that the major drainage pattern west of the Nile in the western Thebes Plateau follows the trends of major faults. This pattern is particularly emphasized by NW-SE trending fractures, although several wadis trend E-W and some are oriented in a NE-SW direction.

As noted earlier, the enclosure of the Valley of the Queens trends NE-SW, as it is bounded by a faultline along this direction. However, the slope in the area of the tomb of Nefertari is towards the southeast, and several drainage lines can be observed running along this direction. This is by no means universal in the region, and a detailed drainage map is required. This map should be made utilizing stereo aerial photographs of an area from the continental divide to at least the level of the road leading to the Nefertari tomb.

In the course of preparation of the drainage map, it is recommended that:
A. The map should be drawn at the same scale as the topographic map to allow their correlation.
B. Care should be taken in measuring the length and width of drainage channels in case they affect the hydrologic model.
C. The potential damming of some of the channels to lessen the amount of water reaching the immediate vicinity of the tomb of Nefertari should be taken into consideration, perhaps by marking potential bottlenecks in dry valleys as possible dam sites.
Establishing Local Stratigraphy

Perhaps the most important contribution to understanding the natural setting of the tomb of Nefertari will come from the establishment of a detailed stratigraphic column. The sequence of rock layers, the pattern of intervening cracks, and the composition of the salts that fill these cracks are all significant components. Therefore, the following examinations should be conducted:

A. Detailed study of the limestone rock sequence in the tomb of Nefertari coupled with close examination of the two tombs on either side and others in the vicinity.

B. Study of the chemistry and mineralogy as well as the porosity and permeability of the rock sequence, with careful marking of sample locations. Special emphasis should be placed on the clay component in the limestone rock.

C. Measurements of strike, dip, and geometric patterns of the fractures and joints in the rock.

D. Study of the chemistry and mineralogy as well as the crystallization patterns of the salts that fill the fractures and joints in the country rock.

E. Study of the shale layer beneath the limestone (exposed farther to the northeast of the tomb of Nefertari and elsewhere). Within the fractured shale horizon emphasis should be placed on the potential supply of groundwater by capillary action to the level of the tomb of Nefertari.

Hydrologic Modeling

The previously mentioned items pertaining to the topography, structure, drainage, and stratigraphy are all prerequisite to the establishment of a hydrologic model of the region. This model should be based on both the geologic and tectonic setting of the tomb of Nefertari as well as on the extremely arid environment in which it is located. Models of humid or temperate regions would not apply here. An innovative approach must be found to deal mathematically with the question of what happens to rainwater in the region and how much it affects the wall paintings.

Digital Image Analysis

The UNESCO Report of 1970 states that “we are in agreement that almost no change is detectable. Even in places where the plaster is dangerously detached from the rock wall, no important losses could be found on comparing the original with the pictures taken in 1904” (Esmail, 1986). If this is true, and if to this day there has been no change, then all of the deterioration of the wall paintings occurred prior to this century. This would lend support to the theory that the deterioration is due mainly to a major flooding of the tomb rather than to incipient rain; it is definitely not due to humidity in the air.

This conclusion cannot be established without careful comparison of all available photographs of the tomb. Digital image-enhancement techniques allow making such comparisons. The available photographs are digitized, registered, and ratioed to obtain an accurate presentation of differences, if any. This comparison should be attempted using all available photographs of the tomb. A set of the photographic collection at the Documentation Center of the Egyptian Antiquities Organization will shortly be made available for this purpose. These photos should be studied along with any other photographs of the tomb.

A map of the change over time should be made to show the differences, making it easier to locate centers of deterioration. This information may further indicate the potential causes of the deterioration.

Nondestructive Remote Sensing

Deterioration of the wall paintings of the tomb of Nefertari is rather obvious to any observer. However, there are degrees of deterioration, and some may not be visible to the human eye. For this reason it is recommended that a series of measurements be made using nondestructive remote sensing methods and techniques including:

A. Thermal infrared imaging to delineate air pockets behind parts of the plaster layer.

B. Ultraviolet imaging to detect differences in paint and variations in the surface layer. This is also required to delineate areas that have been “restored” in the past.

C. Multispectral imaging to detect variations in moisture and reflectance properties of the wall plaster, or paint.

D. Spectral reflectance measurements of various textures and colors on the wall to establish a baseline for calibration of instruments as well as for future comparisons in support of the color change measurements.

E. X-ray or neutron measurements to establish the composition of various salts at or near the surface.

Salt Crystallization Modeling

Results of the hydrologic model, image analysis, and remote sensing can be integrated to establish a salt crystallization model. Naturally, the model would be based on the physical characteristics of the country rock and its joints as well as the results of detailed chemical analyses of the salts from various parts of the tomb. This model would also benefit from detailed studies of the habit, or crystal form, of the various types of salt occurrences. These can be obtained from scanning electron microscope (SEM) photographs of the salts.

Testing of Soil Sealers

It is not proven, but it is quite likely that rainwater has had an effect on the deterioration of the wall paintings of the tomb of Nefertari. Therefore, one of the objectives of this study is to investigate ways of minimizing the amount of rainwater that reaches the immediate vicinity of the tomb. One way to do this is to channel the water to other routes as discussed above (Item 3, dealing with “Drainage Network Mapping”).
Another potentially useful way of minimizing the effects of rainwater is to seal the soil above and around the tomb. This is nondestructive as well as inexpensive. Several polymers are now available on the market that have proven useful in sealing various types of soils and desert sands. A test is recommended for the most suitable chemical for this purpose, in case it is required to protect the surface above the tomb from rainwater.

Monitoring of Microseismicity

The question of whether or not the tomb of Nefertari should be opened to public visitors (tourists) will undoubtedly be posed at the end of the one-year study. For this reason it is essential to monitor contemporary changes to the environment. Most significant among these are parameters of microclimate, including temperature, humidity (air and rock), and partial pressure of the atmosphere inside the tomb. These parameters will be monitored during the study period.

It is also recommended that the local microseismicity be measured to evaluate: (a) the natural rhythms of the region; (b) the shaking induced by tourist traffic; and (c) the effects of human movements inside the tomb. All these factors will help to intelligently answer the question of the admission of public visitors. They will also contribute to better understanding of the natural as well as the manmade forces that affect the tomb. Such knowledge will help establish the parameters of a successful restoration and preservation for all of humanity of the magnificent 3,250-year-old wall paintings of the tomb of Nefertari.

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