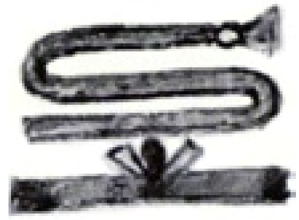
Original Painting Techniques and Materials Used in the Tomb of Nefertari

Stephen Rickerby



Opposite. Chamber G, east wall. Osiris (left) and Atum (right), separated by a magic fan of protection. Symbols of divine power appear in a vertical column behind Atum.

The tomb of Nefertari, favorite wife of Rameses II, is justly famous for the importance and quality of its wall paintings. Other monuments associated with Nefertari certainly demonstrate more explicitly the queen's prominent political role in Nineteenth Dynasty Egypt, such as her temple at Abu Simbel where she is uniquely represented in the same size as the king. The vast building and restoration program that Rameses II initiated also fully conveys the revitalized power his reign brought to Egypt. But it is in Nefertari's tomb paintings, with their unrivaled combination of both artistic superiority and spontaneity, that an aesthetic high point is reached in the Ramesside era.

This outstanding cultural importance and, formerly, the critical state of preservation of the paintings, have long been incentives for various scientific and other investigations aimed primarily at finding solutions for the complex problems of conserving the tomb.[1] These endeavors have also provided information on the original techniques and materials employed in the wall paintings; but, in common with other Theban tombs of the New Kingdom, much knowledge has been derived too simply from empirical observations. In the relative absence of more detailed technical studies and scientific analyses of individual tombs, variations and idiosyncrasies of execution have no doubt been overlooked.[2] Conservation treatment not only allows for the possibility of discovering details of technique that were never intended to be revealed, but it is also the one opportunity to correlate acquired analytical information with firsthand observations. During the process of the joint project of the Getty Conservation Institute (GCI) and the Egyptian Antiquities Organization (EAO) to

FIGURE 1. LOWER STAIRWAY WITH VIEW INTO BURIAL CHAMBER.

conserve the wall paintings of the tomb, this unique chance was offered to establish a fuller understanding of the original techniques used in one of the most important monuments of New Kingdom paintings.

Excavation and Preparation Methods

The esteem accorded to Queen Nefertari, which is reflected most obviously in the quality of the wall paintings, is also implied in the excavated construction of her tomb. The convention of the bent axis that occurs on the stairway connecting the upper and lower chambers (Fig. 1) is a feature Rameses II specifically revived, and sets Nefertari's tomb apart as a site of the highest royal order (Hornung 1990:187; Leblanc, this volume). The favored method of decorating tombs of this standard was to level the excavated rock in preparation for direct carving and painting (Mora et al. 1984:73; Preusser 1991:3). It is well known, however, that the tomb of Nefertari was excavated from fractured limestone interspersed with sodium chloride deposits, and that this poor-quality interior required plastering to create a suitable surface for the high relief work and painted decoration. While disruption from salt activity, most probably present quite early in the tomb's history, had disastrous consequences for the painted plaster, the initial cutting and excavation of the tomb complex must have proceeded without too much difficulty. Harder, more compact rock required the use of bronze chisels and adzes for cutting, and traces of the use of these implements are still visible in a number of other Theban tombs. But fractured rock such as that in Nefertari's tomb must have been easily broken down with simple stone tools, leaving no distinctive excavation marks (Mackay 1921:155; Hornung 1990:40–41).[3] Evidence of some intractability, however, can be found in chamber M where, on the west wall, a large rock extrusion that proved too difficult to remove was simply left, plastered over, and painted, despite the disruption this causes to the regularity of the wall surface.

In some unfinished Theban tombs, preparatory red or black construction lines are visible. These lines were painted or snapped onto the excavated rock and were originally intended to show the masons how the cutting was to proceed.[4] No preparatory evidence of this kind is visible in Nefertari's tomb, either because it does not exist or because it has been simply covered over with plaster and lost to view. However, during conservation work to column II in the burial chamber, the removal of a previous repair on the northwest edge revealed traces of an hieratic inscription possibly indicating the width the stone had to be cut.[5] One other painted inscription on the rock, now visible because the plaster has fallen away, occurs on the ceiling in the northwest corner of the burial chamber and also remains indecipherable.

Plastering Materials and Techniques

It is well known that the ancient Egyptians perfected the use of clay-straw and gypsum-based plasters in rendering wall surfaces for painting (Mackay 1921:160–61; Lucas and Harris 1962:76–77; Mora et al. 1984:73–74; James 1985:13). It is clear, too, that there is considerable variety among Theban tombs in the combination and use of these basic materials. Probably the most common plastering procedure, and certainly the one most frequently described in the literature, was to initially smooth an irregular rock surface with one or more layers of clay mixed with chopped straw, and then apply an upper, finer layer of gypsum-based plaster to receive the painting. Alternatively, and seemingly quite limited in its extent, the upper layer could consist instead of a finer mix of clay-straw plaster made from better quality Nile silt known as *hib,* which originated from the base of the Theban Necropolis hills (Lucas and Harris 1962:76; Mora et al. 1984:73).

Two layers of clay-straw plaster are often present in Nefertari's tomb: a coarse lower layer, and a finer upper layer (Fig. 2). Nile silt usually consists of a mixture of very fine sand and clay with calcium carbonate and gypsum. Analysis of fragments of the leveling plaster from the tomb supports this observation, although it appears crushed limestone was also added as a filler, contributing to the plaster's coarseness (Stulik, Porta, and Palet, this volume). *Hib* silt is composed of a natural mixture of clay and very

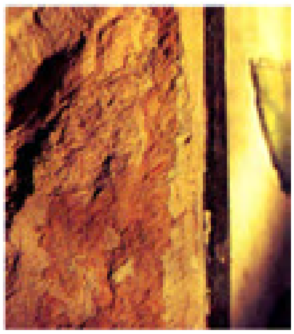


FIGURE 2. STRATIGRAPHY OF CLAY-STRAW PLASTER LAYERS ON THE SOUTH FACE OF COLUMN II. THE LEVELING PLASTER IS COARSER AND DARKER THAN THE UPPER LAYER.

fine limestone, the latter giving the applied plaster a much lighter color. This is noticeable in the upper plaster in the tomb of Nefertari, indicating that *hib* silt was probably employed.

But this combination of plaster layers is not consistent throughout the tomb. In many places only a single layer of the more refined light-colored clay-straw plaster is present, and it varies considerably in thickness. Occasionally, three plaster layers can be seen at points of damage consisting of a base layer of coarse clay-straw, with two upper, light-colored, finer layers, probably *hib* plaster, applied quite thinly. These variations in technique can be partly explained by the divergences and accidental differences that resulted from the division of labor. That a large number of workers were employed in the plastering of the tomb is clear: Two hieratic inscriptions painted within separate niches in the rock-cut bench on the west wall of chamber C refer to the delivery and distribution of plaster in the tomb, and one specifically mentions the division of plaster between gangs of workers on the left and right sides (Leblanc, this volume, Fig. 8; and 1989:pls. CLIV, CLV).

More significantly, however, the variety of plastering techniques also may be explained by matters of expediency in rendering a large rock-cut interior. For example, in the lower chamber K, where the rock is most fractured and irregular, a thicker, lower rendering of clay-straw plaster was essential to level the surface for the application of the finer, upper plaster. Indeed, during conservation, impressions of finger marks were discovered in the lower rendering, showing that the plaster was applied by hand to ensure that it was pushed into every crack and irregularity (Mackay 1921:162). No such measures were required at the entrance to the tomb, where the rock is of better quality and needed only a single layer of fine clay-straw plaster, in places no more than a few millimeters thick. The ceilings, too, all appear to be rendered with a single layer of plaster, even though this was not sufficient to level the most serious rock irregularities at the rear of chamber K, leaving some fissures exposed. Probably this single layer was needed to avoid adding too much weight to the ceilings and to reduce the risks of contraction and collapse of the rendering on drying (Mackay 1921:161). Nevertheless, drying cracks are still evident in the ceiling plaster. These were obviously formed prior to painting, since pigment can be found within the cracks as well as on the plaster's surface.

Preliminary Painting Methods

The many unfinished Theban tombs provide fascinating evidence of how newly prepared wall surfaces were sketched with preliminary underpainting. During the Nineteenth Dynasty the practice of using squared grids as an initial step in laying out the design seems to have been temporarily abandoned at Thebes and replaced by a less formal and systematic approach to preliminary painting (Robins 1986:21). This appears to be the case in Nefertari's tomb where, although much evidence could remain hidden from view, detailed preliminary underpainting seems sporadic and limited in its extent. Usual practice in other tombs involved initially sketching the main elements in red pigment, which were then more definitively outlined in black with corrections and modifications (Mora et al. 1984:74; James 1988:57). In the small chamber Q at the rear of Nefertari's tomb, extensive deterioration has, in places, exposed the lower plaster on which faint traces of red preliminary painting are visible. Although cursorily executed, this sketch was not rectified in black outline prior to further work.

At the bottom of the stairway, on the west wall, removal of a previous repair during conservation treatment revealed an area of red preliminary painting that is corrected in black outline. The underpainting shows the disposition of some hieroglyphs. Interestingly, the final hieroglyphs on the upper plaster still partly survive because they were completed slightly to one side of their red and black preliminary sketches on the lower plaster (Fig. 3). But the use of black as a means of creating a more refined and accurate underpainting seems confined to localized areas in Nefertari's tomb, and is perhaps again only a consequence of the division of labor. However, a more detailed form of preparatory painting may have been reserved for the upper plaster to guide the relief work, and has since disappeared in the carving process.

Relief Carving Techniques

Relief carving mainly takes two forms in Egyptian painting: sunken relief, whereby the carving has an indented effect below the flat surface of the stone support or plaster render on which it is executed; and raised, or high, relief work. An extremely sophisticated form of high relief work characterizes the plaster in Nefertari's tomb, and its virtuosity is unsurpassed (Fig. 4). In particular, facial details such as eyes, lips, and nostrils are finely distinguished, while the graduated layering of relief carving achieves consummate modeled effects. That the relief was carved when the plaster was dry is clear upon close inspection, but possibly the surrounding areas were later dampened and smoothed further in preparation for the application of painting (Paolo Mora, personal communication 1991). This type of high relief work is more usual in stonework, and examples in plaster are limited to only a few other tombs in the Valley of the Queens, all of which are inferior and more deteriorated than the tomb of Nefertari. The quality of carving in Nefertari's tomb, which accords the same attention to relief detail in the smallest hieroglyph as in the largest figure, is certainly unparalleled among other New Kingdom tombs.

Execution of the Paintings

The technique of painting in Nefertari's tomb is certainly tempera; that is, the pigments were ground and mixed with a binding medium, and then applied to dry plaster (Mora et al. 1984:74; James 1985:11–12). Some uncertainty still surrounds the original medium or media used for the application of Egyptian wall paintings, although it is known which natural materials were readily available: egg, fish and other animal glues, and gum (Mora et al. 1984:74; James 1985:11–12). Exact identification had proven elusive or unreliable in the past because analytical methods were not sufficiently sensitive to detect accurately the small traces of original material. More recently, little or no relevant analysis has been carried out on Egyptian wall paintings. In Nefertari's tomb, current analysis by the GCI research team and by Porta and Palet of the University of Barcelona has positively identified a natural gum-based binding medium (Stulik, Porta, and Palet, this volume). The use of this natural gum, commonly known as gum arabic and most probably derived from the acacia tree which is abundant in the Luxor region, is indicated also by the

Figure 3, right. Lower stairway, west wall. Preliminary underpainting in red and black.

Figure 4, below. Osiris, column II, west face. Consummate relief carving characterizes the plaster in Nefertari's tomb.

Figure 5, far right. Chamber K, west wall, with area of unfinished hieroglyphs.

paintings' extreme sensitivity to moisture.[6] While one should not, on the basis of this evidence, overgeneralize on the techniques used in other New Kingdom tombs, and while allowance needs to be made for the possibility of the use of more than one medium, it seems likely that gum binders were preferred for ancient Egyptian wall paintings.

Use of Pigments

The pigments of Egyptian paintings, limited in part by a strict code of permissible symbolic colors, are well known and have been much studied (El-Goresy et al. 1986). The palette of Nefertari's tomb is no exception, and the order of application of the pigments is readily apparent (Stulik, Porta, and Palet, this volume). A thin layer of white forms the background for all the subsequent wall painting. Whether this layer should be considered a plaster or a paint is questionable, though it is mostly applied so thin to be essentially a preparatory wash. Faint guidelines occasionally show through this layer, but otherwise it appears that painting proceeded directly and swiftly once the background was applied. An insight into the methods of painting is gained from some unfinished hieroglyphs on the west wall of chamber K (Fig. 5). These show how the main colors were initially painted over the white layer very lightly and freely, usually

Figure 6, right. Detail of *Djed* pillar showing distinct area of shiny and matte painting, probably the result of selective varnishing.

Figure 7, far right. Detail of *Djed* pillar showing accidentally extruded traces of paint. These appear matte, probably because they were not varnished.

overlapping the edges of the relief work. Each color was then built up with successive layers of paint, the details added, and outlines painted in red or black for emphasis. These outlines also served to mask any carelessly extended or smudged edges of color. If, however, the outlines proved insufficient to completely hide such hasty paint work, retouchings in white were finally added.

Use of Varnishes and Glazes

The unfinished hieroglyphs also reveal how matte the applications of color were in contrast to the shiny appearance of the adjacent completed paintings. This raises the question of whether an original varnish was employed to augment or protect the final colors. It has long been recognized that beeswax and natural resins were used as varnishes on New Kingdom artifacts, though the extent and nature of their application on wall paintings are less clear (Mackay 1920:35–38; Mora et al. 1984:74; James 1985:12). It is thought, for example, that varnished surfaces in the tombs of nobles of the Eighteenth Dynasty, Kenamun, Nebamun, and Nakht, were selectively applied to enhance areas of yellow pigment and simulate the effect of gold; with aging these areas have since become discolored and fissured (Wilkinson and Hill 1983:31-32).

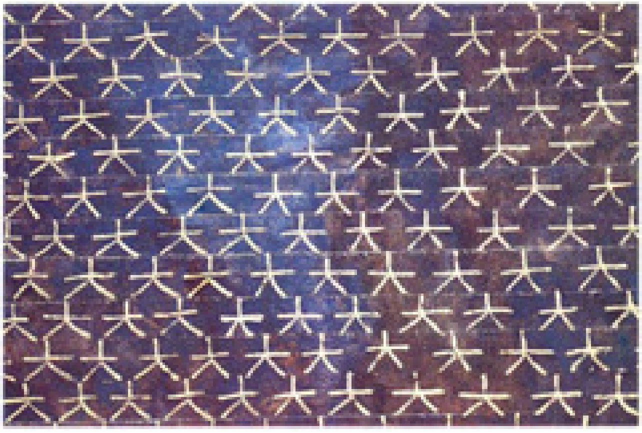
However, optical effects caused by the combinations of paint medium with different pigments may sometimes have been mistaken for the presence of discriminating original varnishes. Pigments capable of being finely ground, such as red and yellow ochres, can take on a more saturated, shiny appearance because a substantial amount of medium rests on the surface of the compact particulate layer. Coarser ground pigments, such as the granular Egyptian blue, do not become fully embedded in binding medium; as a result, diffused reflection of light from the rough pigment surface creates a matte appearance (Preusser, personal communication 1991).

Distinct areas of shiny and matte painting certainly exist in Nefertari's tomb, and in many instances these can be attributed to the varying effects between different pigments and their medium. However, compelling evidence also suggests that other areas of painting, reds and yellows in particular, were sometimes selected to receive the enhancement of a varnish as well. On the *Djed* pillars that decorate one side of the columns in the burial chamber, for example, horizontal bands of red and yellow have a shiny appearance, but are separated by matte red lines applied on top (Fig. 6). Closer examination reveals how paint from the horizontal bands was accidentally extended beyond the defining edges of the relief work (Fig. 7). In comparison, these paint traces are matte and lacking in saturation, presumably because they escaped being varnished (Stulik, Porta, and Palet, this volume).

Working Methods

While much painting was built up in areas of flat, solid pigment, remarkably realistic effects of shading and intermediary tones were also produced by mixing pigments or superimposing thin layers of color; for example, combining

Figure 8. Chamber G, west wall. Naturalistic painting techniques are seen to best effect in the portraits of Nefertari.



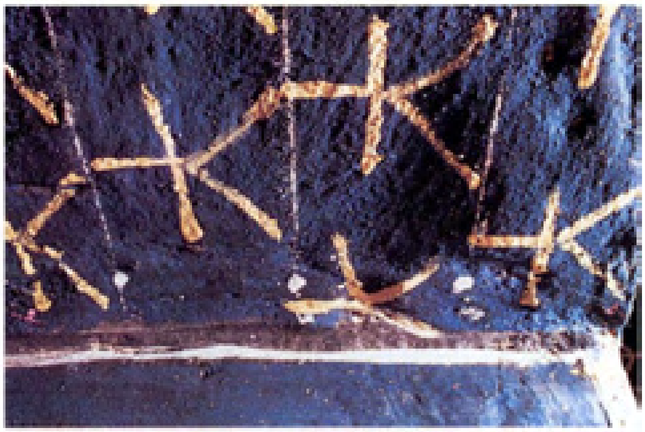


Figure 9, top left. The intense color of the ceiling is achieved by applying Egyptian blue over a layer of black. Typically the appearance is patchy.

Figure 10, top right. Detail of snapped guidelines on the ceiling. Paint splatters and fingerprints are clearly visible from this process.

Figure 11, above left. Chamber K, west wall. Dado niche.

Figure 12, above right. Column II, north face. Accidentally snapped guidelines, paint drips, and uncorrected edges of paint indicate hasty execution.

red and white to create flesh tones, and overlaying these in places with transparent white glazes to achieve the appearance of diaphanous clothing. These naturalistic techniques are a particular feature of Nineteenth Dynasty painting, and nowhere can they be seen to better effect than in the various figures of Nefertari herself (Fig. 8).

Areas painted with Egyptian blue, the synthetic pigment characterized by its large particle size and glassy appearance, were nearly always applied over an underlying layer of black to create a dark blue color. In the few areas where black has been omitted as an underlying layer, Egyptian blue takes on a much more brilliant and lighter color (Tite et al. 1988:297–301). On the ceilings, which are entirely painted in the first manner, there are noticeable regions of patchiness where the black shows through the thin covering of blue, or fails to be covered at all (Fig. 9). It is improbable that these were deliberately intended effects, but were likely the result of rapid painting techniques. These shortcomings did not inhibit the painting of the superimposed yellow stars, which are laid out along parallel guidelines snapped onto the ceiling from taut cords dipped in white

FIGURE 13. STAIRWAY, EAST WALL. DETAIL OF NEFERTARI SHOWING HOW THE PAINTING OF HER WIG DIVERGES FROM THE INITIALLY INTENDED EDGE OF THE RELIEF WORK.

paint (Fig. 10). This process left clearly visible paint splatters, together with smudges and fingerprints where the cords were held and stretched in place.

Much more evidence is present to reinforce the impression that work in the tomb originally progressed rapidly but not always successfully or to the highest degree of finish. The most obvious example of this is the varying quality of paintings resulting from the division of labor. The painting of columns I and II at the entrance to the burial chamber, for example, is far superior to that of columns III and IV at the rear of this chamber. A dado niche in the west wall of chamber K is decidedly inferior in quality to all other painting, executed only in three colors—yellow, red, and black—and not even carved in relief (Fig. 11). Painting in the lower side chambers is of varying quality, and clearly a number of hands were at work simultaneously throughout the tomb.

Upon closer examination, signs of hasty working practice are numerous. Paint drips and splashes occur frequently. Blue paint dripped or splashed against the walls and columns shows that the ceiling was painted last. Preparatory guidelines intended for the ceiling stars were accidentally snapped onto one side of column II (Fig. 12). Most of the final corrections in white to edges of color are hastily done or sometimes entirely forgotten. In the application of background colors, individual relief elements such as hieroglyphs were initially covered over and then occasionally forgotten when the final details were added. Such oversights are accidental in nature, but deliberate alterations to improve the image were also made. Frequently, painted outlines and profiles diverge significantly from the defining edges of the relief work (Fig. 13). These major modifications again point to much more artistic freedom even at this late stage in the painting process than has been generally acknowledged in Egyptian royal art of the New Kingdom period.

Original Restorations

Other modifications were made to compensate for early occurrences of deterioration and damage. In a number of areas, portions of painted plaster must have fallen away soon after completion, either because of contraction on drying or from accidental impact damage. Without repairing most of the revealed holes, these losses were quickly repainted with little effort to achieve a carefully matched restoration. A more ambitious restoration was attempted in chamber Q at the rear of the tomb. The original painted wall plaster here has been severely affected by salt disruption and is now almost entirely lost. This deterioration, however, clearly began during plastering and painting or immediately thereafter. Another layer of plaster overlaps the first painted layer, applied to rectify what must already have been quite advanced deterioration and to provide a new surface for painting. But this new plastering was itself left unfinished and unpainted, presumably because further deterioration again impeded progress. Painting on the ceiling, too, was abandoned after the application of the black undercoat, and another layer of plastering was started on top but likewise was never completed.

Conclusion

That such deterioration problems were encountered so soon, and indeed left unresolved by the original artisans, is most revealing. The study of original techniques and materials thus elucidates far more than those features shared with other Theban tombs of the New Kingdom period. Certainly there are predictably similar aspects of execution, including comparable methods of rock excavation, plaster composition and application, characteristic preparatory painting techniques, and the consistent use of a limited range of known pigments. But significant divergences can also be found in Nefertari's tomb as individual techniques were adapted to particular circumstances. The conservative nature of Egyptian royal painting practice has been too often stressed when clearly few assumptions should be made. In the case of Nefertari's tomb, examination of the nature of the original materials reveals, above all, a remarkably spontaneous approach to painting, as well as insights of great significance in assessing its history of construction and deterioration.

Stephen Rickerby was a member of the Nefertari conservation project from 1988 to 1992. He is an alumnus of the Courtauld Institute of Art, London, and specializes in wall paintings conservation.

Notes

1. For the historical importance of the tomb of Nefertari, its condition before treatment, and a brief survey of previous scientific investigations up to 1983 see Gaballa, "History: Nefertari, For Whom the Sun Shines"; Maher-Taha, "History: The Considerable and Unique Position of Nefertari"; and Kadry and Esmael, "Previous Endeavors"; in Corzo (1987:11–17; 19–23; and 35–38, respectively). The scientific studies carried out in 1986 and presented in Corzo (1987) are themselves summarized in Preusser (1991). For another recent study see Wilson-Yang and Burns (1989).
2. Although individual tomb studies proliferate in the literature of Egyptian archaeology, descriptions of original materials and techniques remain unsupported by scientific analysis. See, for example, Williams (1932) and Brack and Brack (1980).
3. Hornung shows examples of stonecutting in the tomb of Horemheb made with pointed and flat chisels (illustrations on p. 43). For further discussion of cutting tools see Arnold (1991:33; and illustrations on pp. 34–36).
4. Preparatory leveling lines survive on the excavated rock in tombs Nos. 63, 64, 86, 89, 91, 166, 224, and 229 (Mackay 1921:157).
5. See Arnold (1991:16–18) for mention of similar setting marks in ancient Egyptian construction. Alternatively, such inscriptions could refer to deliveries of plaster and division of labor. In tomb 229, vertical red lines define the unfinished edges of the intended columns (Mackay 1921:158).
6. In contrast egg media, for example, become insoluble with age (Mills and White 1987:76).

Bibliography

Arnold, D.
1991 *Building in Egypt: Pharaonic Stone Masonry*. Oxford.
Brack, A., and A. Brack
1980 Das Grab des Haremheb. Theban Nr. 78. *Deutsches Archäologishes Institut*. Mainz am Rhein.

Corzo, M. A., ed.
1987 *Wall Paintings of the Tomb of Nefertari: First Progress Report.* Cairo and Century City, California.

El-Goresy, A., et al.
1986 *Ancient Pigments in Wall Paintings of Egyptian Tombs and Temples—An Archaeometric Project.* Heidelberg.

Hornung, E.
1990 *The Valley of the Kings—Horizon of Eternity.* D. Warburton, trans. New York.

James, H.
1985 *Egyptian Painting.* British Museum Publications 13. London.
1988 Painting Techniques on Stone and Wood. In *Conservation of Ancient Egyptian Materials.* S. C. Watkins and C. E. Brown, eds., 55–59. Preprints of the Bristol Conference 1988. UKIC Archaeology Section. London.

Leblanc, C.
1989 *Ta set neferou—une nécropole de Thèbes-Ouest et son histoire.* Cairo.

Lucas, A., and J. R. Harris
1962 *Ancient Egyptian Materials and Industries.* London.

Mackay, E.
1920 *Ancient Egypt.* London.
1921 The Cutting and Preparation of Tomb-chapels in the Theban Necropolis. *Journal of Egyptian Archaeology* 7:154–168.

Mills, J. S., and R. White
1987 *The Organic Chemistry of Museum Objects.* London.

Mora, P., L. Mora, and P. Philippot
1984 *Conservation of Wall Paintings.* London.

Preusser, F.
1991 Scientific and Technical Examination of the Tomb of Nefertari at Thebes. In *The Conservation of Wall Paintings.* S. Cather, ed. Marina del Rey, California.

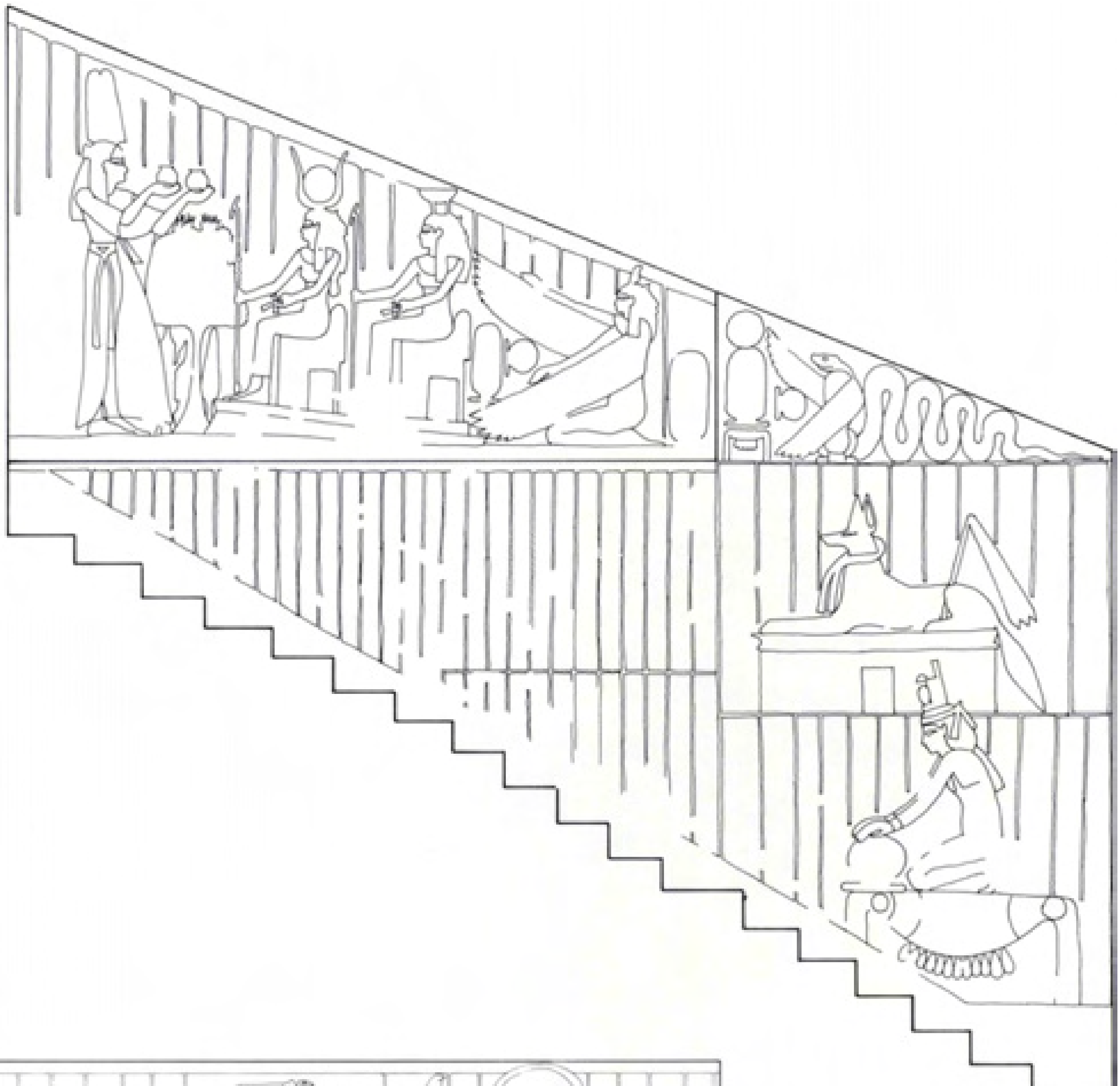
Robins, G.
1986 *Egyptian Painting and Relief.* Aylesbury.

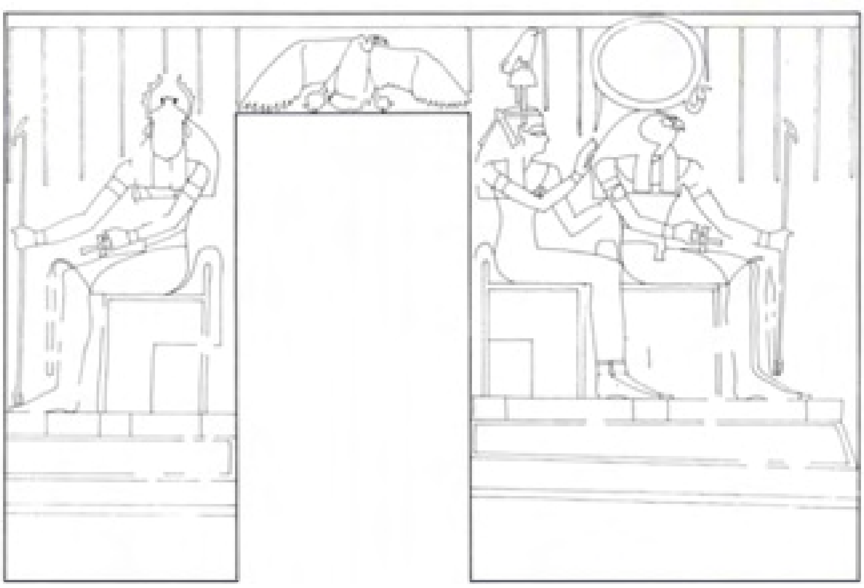
Tite, M. S., B. Bimson, and N. D. Meeks
1988 Technological Characterisation of Egyptian Blue. *Revue d'Archéométrie, Actes du XX Symposium International d'Archéométrie*, 297–301. Paris, 26–29 March 1980. Vol. III. Paris.

Wilkinson, C. K., and M. Hill
1983 *Egyptian Wall Paintings—The Metropolitan Museum of Art's Collection of Facsimiles.* New York.

Williams, G. R.
1932 *The Decoration of the Tomb of Per-Néb–The Technique and the Colour Conventions.* New York.

Wilson-Yang, K. M., and G. Burns
1989 The Stability of the Tomb of Nefertari 1904–1987. *Studies in Conservation* 34:153–170.

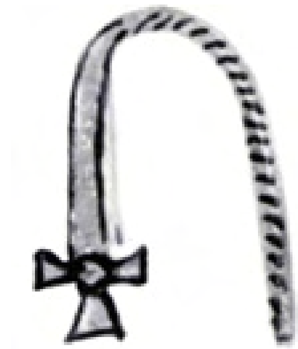




Above, stairway I, west wall.
Left, entrance to chamber G.
Line drawings by Paolo Mora
used to produce the color-
coded condition survey.

Analyses of Pigments, Binding Media, and Varnishes

Dusan Stulik, Eduardo Porta, and Antoni Palet

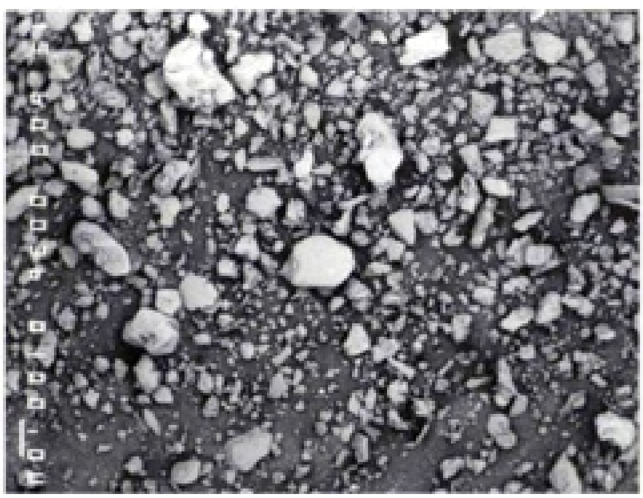


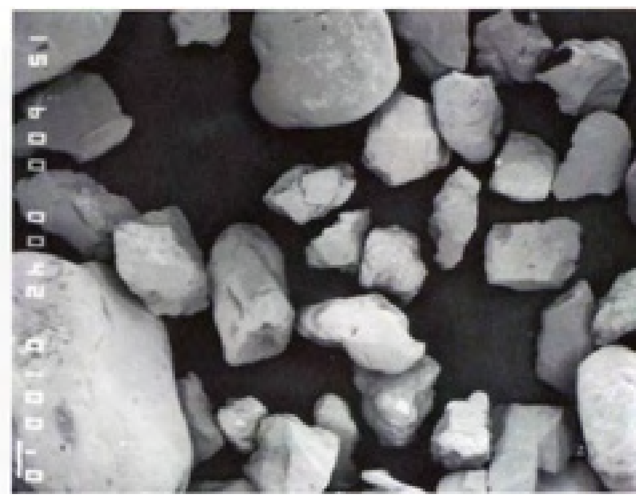
The application of analytical methods and advanced scientific technology to works of art has become standard practice. Minute samples—smaller than a pinhead in many cases—yield information on the chemical composition, physical structure, method of fabrication, age, possible origins, and other factors, depending upon the analytical tool.

When an intervention is planned in the conservation of an artistic or historic work, it is necessary to know as much as possible about the fabric and substance of the object. There are good reasons for this: Examination precedes diagnosis, which in turn defines the nature of the treatment. Specifically, the findings of a scientific examination form part of the body of information about the object, and remain as documentation of the conservation itself. Analytical information frequently can provide insights about the technology and materials of antiquity, in some cases confirming beliefs about the use of local materials, as with the pigments used to execute the paintings in the tomb of Nefertari, in this instance. Analysis will usually establish whether there have been previous restoration attempts through the identification of modern synthetic materials. Furthermore, today's conservator needs to know how historic materials will respond to proposed treatments, solvents, adhesives, and other substances. And while the conservator will certainly carry out reversibility and compatibility tests prior to any full-scale intervention, the results of analytical instrumental science can be of invaluable help in the decisions to be made.

The pigments used in ancient Egyptian wall paintings have been studied extensively over the past few decades. The analyses reported here mainly confirm existing knowl-

Figure 1, right. Backscattered electron micrograph of straw in plaster ceiling.
Figure 2a, below left. Backscattered electron micrograph of crushed rock filler material.
Figure 2b, below right. Backscattered electron micrograph of Nile River sand.





edge of Egyptian painting techniques and materials. New findings since the last progress report include identification of arsenic (though its origin is still unclear), gum arabic from the local acacia tree as binding medium for the paint, tree resin and egg white as varnishes, and two modern synthetic materials used in previous restoration efforts.

In the first campaign, begun in 1986, salt, plaster, and pigment samples from the wall paintings in the tomb of Nefertari were analyzed. These were reported by Preusser (1987:82–93) and Saleh (1987:94–105) in *Wall Paintings of the Tomb of Nefertari: First Progress Report.* These analyses were carried out on fragments that, over time, had fallen from the walls, had been collected in boxes, and were stored in chamber Q; also a few samples were taken by Saleh directly from the ceiling and wall paintings. Following this initial study, the University of Barcelona team of Eduardo Porta and Antoni Palet became involved in the second stage of the work. Porta took a set of samples from the wall paintings. These were analyzed by Porta and Palet and the Getty Conservation Institute team. The results of both the 1986 analytical campaign and the more recent work are summarized here.

Plasters

The low quality and highly fractured nature of the limestone in the Valley of the Queens made the tasks of the ancient artisans of the necropolis especially difficult. Because it was not possible for them to carve directly into the stone or paint directly on the rock, they needed to apply plaster as preparation for the wall paintings. The stratigraphy of the plastering varies considerably throughout the tomb. On the ceilings and on some of the walls only one layer of clay-straw plaster is evident. Typically, however, two layers are present on the walls, though in some places three layers have been observed (Rickerby, this volume). The thicknesses of these

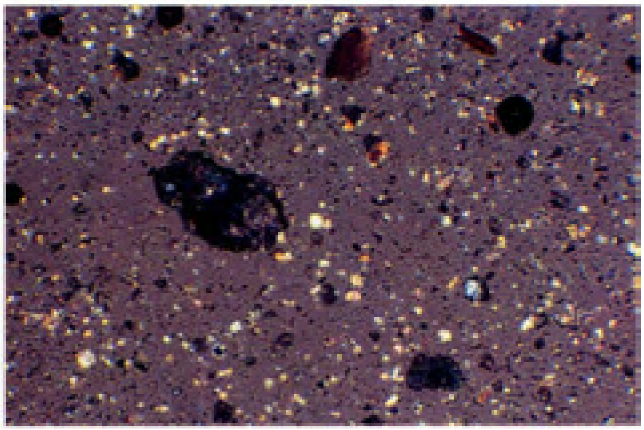
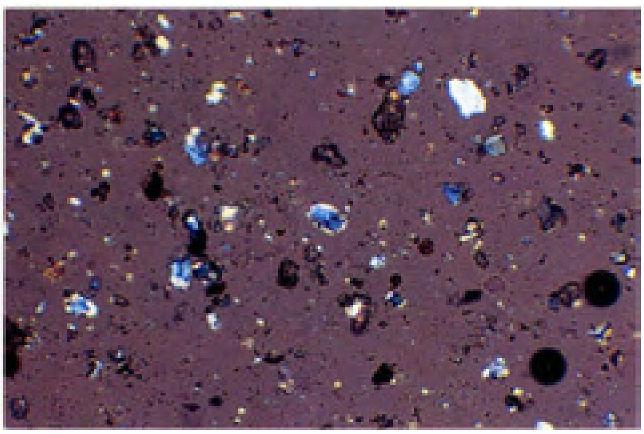


Figure 3, left. Green-blue pigment under cross-polar illumination.
Figure 4, below left. Blue Pigment under cross-polar illumination.



plaster layers are not consistent, and vary from a few millimeters to several centimeters.

Samples available for analysis were all taken from plaster layers immediately adjacent to the rock. These were all composed of gypsum ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$), and Nile silt, with crushed limestone as filler. However, samples from the single layer of ceiling plaster showed, in general, a higher proportion of both gypsum and anhydrite than was found in samples of the leveling wall plaster (~4 wt % of gypsum). Wheat straw was identified microscopically as an additive in the plaster samples (Fig. 1). Microscopic investigation of the filler material showed sharp-edged particles characteristic of crushed rock. In contrast, samples of Nile sand, which could also have been used as a filler, are seen as smooth, round particles when viewed under the microscope. It seems clear, therefore, that the tomb's artisans used the material that was most plentiful and readily available—crushed rock excavated during the original construction of the tomb—for the purpose of making plaster filler (Fig. 2a, b).

On top of the clay-straw plastering the workmen then applied a finer white layer, providing a smooth background for the subsequent painting. This white layer was applied as thinly as a wash, and its composition is discussed in the analysis of pigments below.

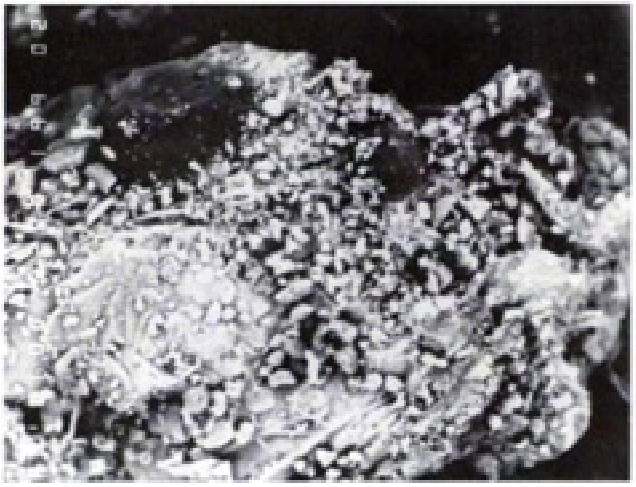
Pigments

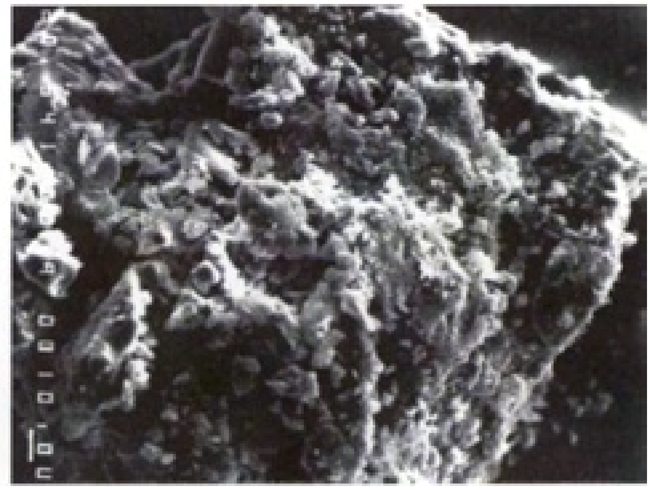
Fifteen samples of painted plaster from the tomb of Nefertari were submitted to the GCI for pigment identification. A similar set of samples was analyzed independently by Porta.

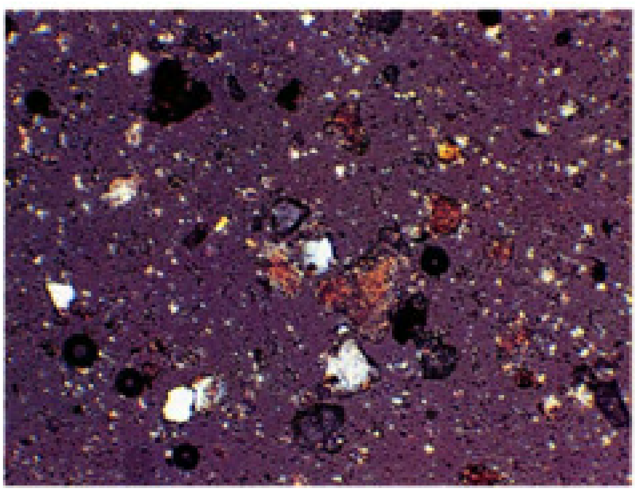
Porta placed samples from the tomb into gelatin capsules. The locations of the sampling sites were marked on Polaroid photographs taken of the wall paintings. Low-power photomicrographs were taken to document the appearance and condition of the samples as they were received. The systems used to analyze the pigments were: polarized light microscopy (PLM), X-ray diffraction (XRD), electron microprobe analysis (EMPA), and X-ray fluorescence analysis (XRF).

Green and Blue

All three blue and green samples appear identical using PLM. (Fig. 3 represents the PLM field of view.) The blue and green components have refractive indices (n's) of <1.66 with low birefringence. These samples do not exhibit pleochroism and possess little color saturation in transmitted light. The XRF spectrum of all these samples, whether they appear blue or green to the eye, show the presence of silicon, calcium, and copper. The green pigment was identified as the synthetic pigment known as Egyptian green, and its composition was confirmed using electron microanalysis







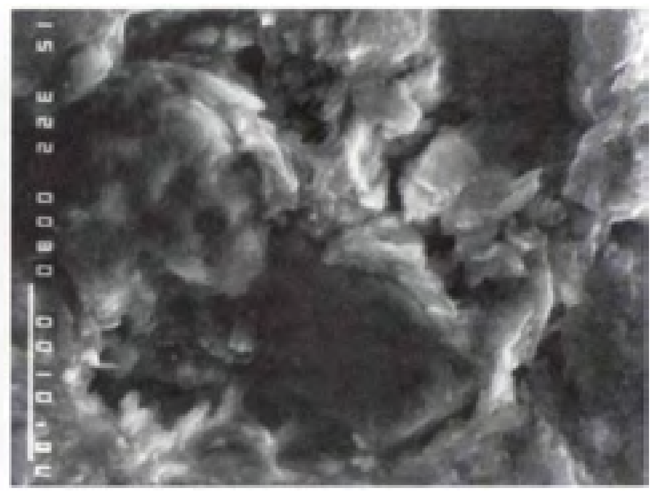


Figure 5a, top left. Electron micrograph of blue pigment grain (blue frit).
Figure 5b, top right. Electron micrograph of green pigment (green frit).
Figure 6, above left. Red pigment (burnt umber) under cross-illumination.
Figure 7, above right. Electron micrograph of quartz particle surrounded by arsenic-rich crystallites (red paint sample).

on separated microcrystals of the pigment. The green samples also contain a large proportion of a component with a birefringence of 0.44, identified as anhydrite. A smaller quantity of feldspar, most likely microcline, was identified on the basis of birefringence (0.007). Small quantities of calcite (birefringence 0.172) and quartz (birefringence 0.048) were also present. The presence of anhydrite and calcite in the green samples was confirmed by dispersion-staining studies.

The blue pigment was identified as the synthetic pigment known as Egyptian blue (cuprorivaite) $CaCuSi_4O_{10}$ (Fig. 4), a pigment used in Egyptian wall decorations from the Fourth Dynasty until the time of Caesar Tiberius (first century C.E.). The anisotropic crystals of Egyptian blue, when viewed by PLM, display blue-violet pleochroism and a pink color under the Chelsea filter. The XRF spectrum shows the presence of calcium, copper, iron, lead, and strontium. These results are consistent with findings reported previously by Saleh using XRD.

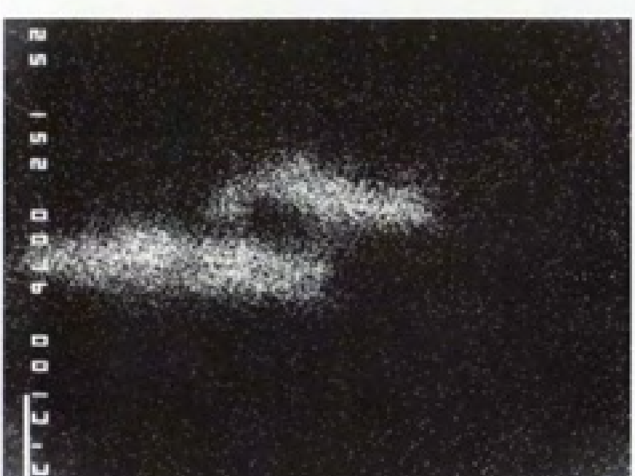
X-ray spectra from the electron microprobe showed the chemical composition of the blue and green pigments to be almost identical: silicon, calcium, copper, iron, sodium, magnesium, and aluminum. The concentration of silicon in the green frit crystals is much higher than the concentration of silicon in the blue pigment. Electron micrographs of green and blue pigment samples (Fig. 5a, b) show detailed frit microstructure with crystallites ranging in size from 1 to 3 µm. Also identified in the samples were calcite, anhydrite, and feldspar particles.

Red

Microchemical analysis by Michalowski (1989) and XRD analysis by Saleh (1987) indicated the presence of iron oxide (Fe_2O_3)-based pigment in the red samples. Saleh also found gypsum. All three samples studied by PLM displayed the presence of isotropic, opaque, red-orange particles typical for burnt umber (Fig. 6). Umbers are Fe_2O_3-based pigments containing variable amounts of manganese. The presence of manganese was verified by XRF analysis using zinc as a secondary target. The quantitative analysis of the 5 µm-thick red pigment layer in the paint cross section shows 16% wt/wt of iron and 0.05% wt/wt of manganese. These analytical results are typical for burnt umber pigments.

XRF spectra of the red pigment taken using molybdenum as a secondary target shows a high concentration of arsenic in the pigment layer. A detailed electron micrograph shows the presence of fine, arsenic-rich crystallites in the pigment mass (Fig. 7). Arsenic was previously reported in the red and yellow pigment samples by Michalowski (1989) based on microchemical studies (qualitative test for As), and by Saleh (1987) based on detailed XRD and XRF studies. The presence of arsenic-containing pigments (realgar and orpiment) was suspected but could not be verified due to substantial interference of a

Figure 8a, below left. Elemental distribution map of the same site of the red paint sample as figure 14. Dot map of arsenic.
Figure 8b, below right. Elemental distribution map of the same site of the red paint sample as figure 14. Dot map of oxygen.
Figure 9a, bottom left. Elemental distribution map from a cross section of a red paint layer. Dot map of arsenic.
Figure 9b, bottom right. Elemental distribution map from a cross section of a red paint layer. Dot map of sulphur.



sodium chloride peak pattern in the XRD diffractograms. Qualitative dot maps produced by an electron microprobe tuned to arsenic and oxygen peaks (Fig. 8a, b) show that the arsenic is bound to oxygen. Dot maps on a cross section of the red pigment sample show a lack of correlation between the distribution of arsenic and sulfur (Fig. 9a, b). The electron micrograph in Figure 9a shows that arsenic-rich crystallites lie parallel to the pigment layer and appear to have precipitated in place. This confirms the PLM results, which excluded the presence of arsenic-based pigments in the red pigment layer. The question of the origin of the arsenolite in the paint remains unresolved. One possibility may be that during a previous restoration attempt, the restorers treated the paintings with an arsenic-based chemical as a means of protecting them from microbiological growth.

Yellow

Previous analysis by Saleh (1987) indicated the presence of hydrated iron oxide, known as limonite, and an arsenic sulfide mineral known as orpiment (As_2S_3); but the presence of arsenic sulfide could not be confirmed with a high level of certainty. PLM analysis conducted at the GCI showed the presence of yellow ochre in the pigment layer (Fig. 10). The detection of iron by XRF supported these findings. Arsenic, which is present in the same sample, is also bound to oxygen, as was found with the red pigments. Microscopic analysis also indicates that calcite, anhydrite, and feldspar particles are present in the yellow paint layer.

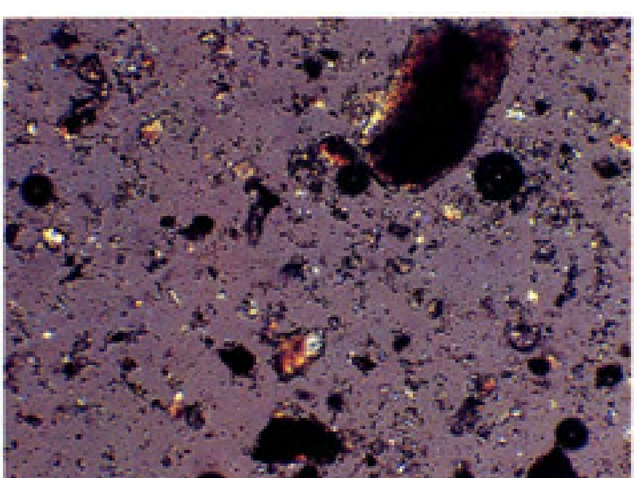


FIGURE 10. YELLOW PIGMENT (YELLOW OCHRE) UNDER CROSS-POLAR ILLUMINATION.

White

Saleh (1987) reported the fine plaster material that appears as the color white in the paintings to be a mixture of calcite and anhydrite together with traces of huntite ($CaCO_3 \cdot 3MgCO_3$). Some traces of iron and strontium were also found by XRF analysis.

White particles in a salt incrustation on other paint samples were identified at the GCI as huntite. The morphology of these particles suggests that this incrustation might have been formed in situ through secondary reactions.

Porta and Palet (1989a) reported that the white samples they analyzed contained huntite with minor amounts of anhydrite, calcite, and quartz.

While all three analysis results found the fine white plaster layer to contain huntite, calcite, and anhydrite, the proportions of the materials varied in the separate samples. These variations can be interpreted in a number of ways. One plausible explanation may be a lack of quality control in the preparation of the paint (or plaster) mixtures by the ancient artisans. The variations in these mixtures may also have been affected by secondary reactions in some areas due to excessive moisture and the presence of sodium chloride.

Black

PLM studies at the GCI revealed the presence of many small, moderately opaque brown particles present in addition to large, black, platy chunks (Fig. 11). These were identified as charcoal particles. Particles of calcite, anhydrite, and feldspar were also present. Porta's analyses confirmed the identification of charcoal.

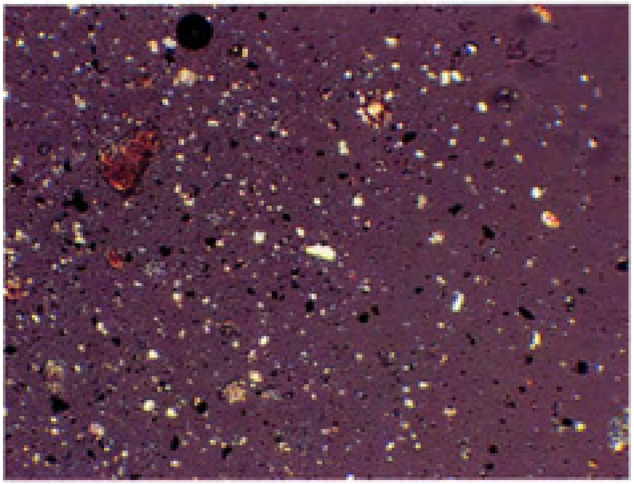
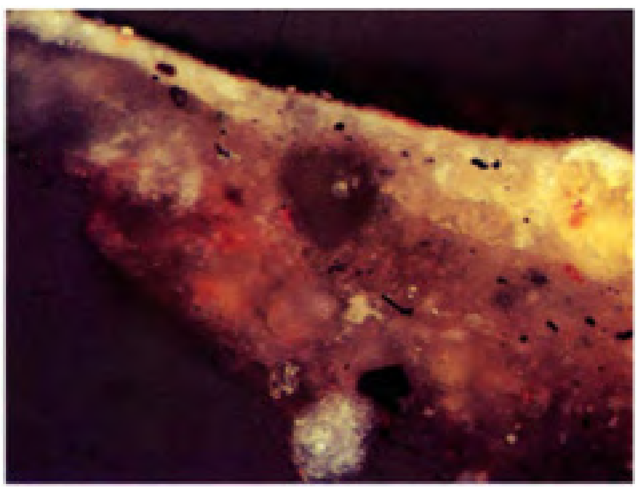
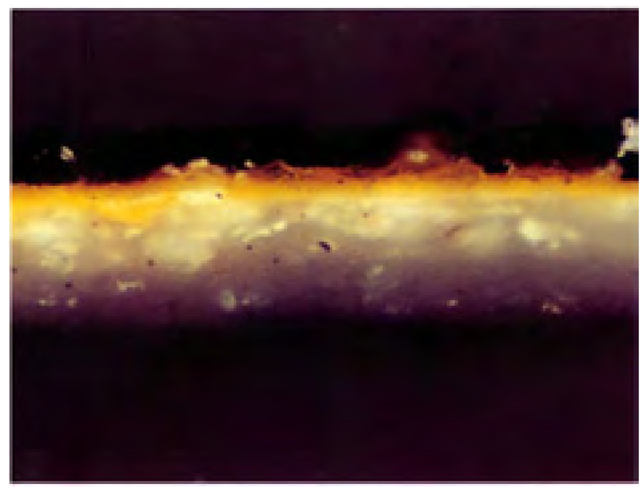


Figure 11, left. Black pigment (charcoal) under cross-polar illumination.
Figure 12, below left. Red paint cross section.
Figure 13, below right. Yellow paint cross section.





Cross-section Analysis

Two of the samples, red and yellow, were substantial enough for study in cross section.

A cross section of the red paint sample analyzed under cross-polar illumination (Fig. 12) reveals a thin (5–10 μm) layer of red pigment residing on the white plaster layer. Some parts of the red paint layer are covered by a thick layer of charcoal. Over both of these colors is a thin, organic top coat or varnish, which covers the majority of the red and black paint layers.

A cross section of the yellow paint sample under cross-polar illumination (Fig. 13) reveals a thick coating covering a bright yellow paint layer, which is composed of finely divided pigment particles over a white plaster layer. The yellow pigment was identified as a yellow ochre (by PLM, XRF, and EMPA analyses). The same cross section photographed under ultraviolet illumination shows strong autofluorescence of the organic coating.

The chemistry of the red and yellow cross sections in relation to their stratigraphy is summarized in Figure 14a, b on the following page.

A summary of the pigments identified in the tomb appears in Table 1.

Binding Media

The GCI research team and the team of Porta and Palet conducted parallel studies of two types of materials: the binding media in paints used by Nefertari tomb artists and organic surface coatings applied to the wall painting by original artists or restorers, perhaps in an attempt to consolidate the paint layer and protect it from damage and deterioration. A series of chemical tests and analytical methods was used to identify both types of materials.

Preliminary tests by Porta and Palet using boiling sul-

Figure 14a, b. Diagram of paint cross sections—observed chemistry and mineralogy.

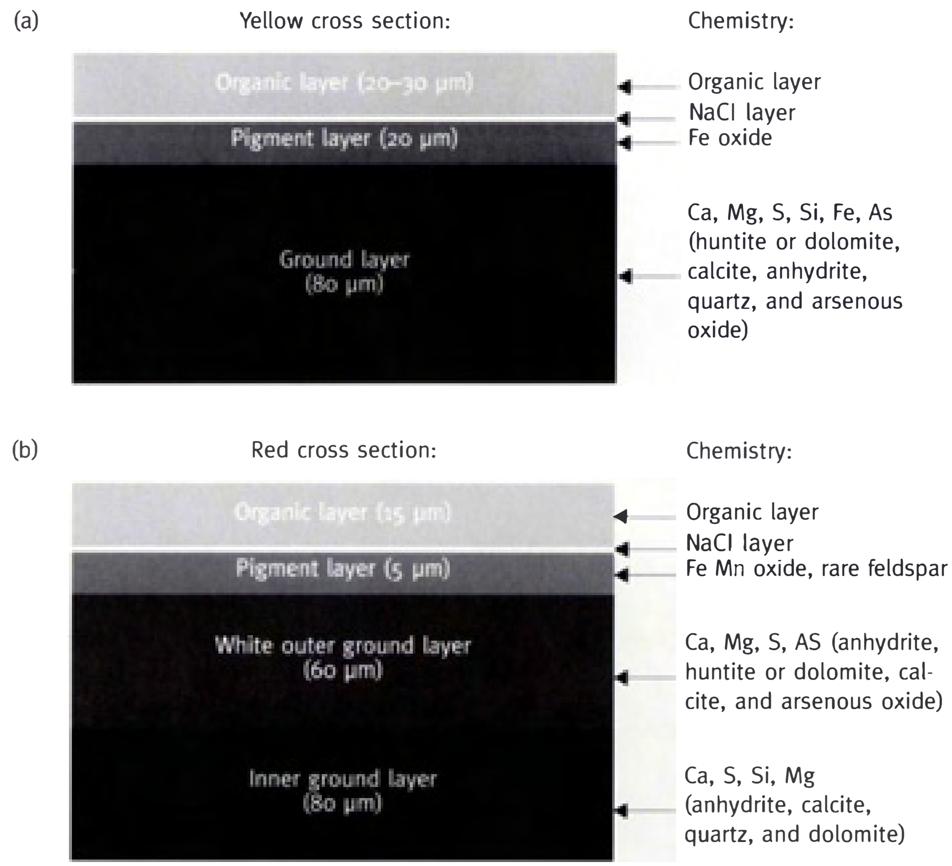


Table 1. A summary of pigments identified in the wall paintings of the tomb of Nefertari (with minor components in italics).

Blue	Egyptian blue	*calcite* *anhydrite* *feldspar*
Green	Egyptian green	*calcite* *anhydrite* *feldspar*
Red	burnt umber	*arsenolite* (As_2O_3) *calcite* *anhydrite* *feldspar*
Yellow	yellow ochre	*arsenolite* (As_2O_3) *calcite* *anhydrite* *feldspar*
White	huntite calcite anhydrite	
Black	charcoal	

furic acid proved the presence of organic matter in the bulk of the paint samples. Following a series of qualitative chemical tests, the possibility that animal glue was used as a binding medium was excluded. Negative results of Fehling's reducing-sugar tests excluded the presence of simple sugar (honey) within the paint layer. Positive tests for reducing sugars following hot distilled water extraction and diluted sulfuric acid hydrolysis indicated the presence of complex polysaccharides.

These qualitative results were reconfirmed in more detailed analytical studies at the GCI using Fourier transform infrared microspectroscopy (FTIR), pyrolysis-gas chromatography (Py-GC), high-performance liquid chromatography (HPLC), and gas chromatography (GC).

The bulk of several samples available for analysis was extracted with hot water. Dried organic residue from the resulting extract was analyzed by FTIR and Py-GC. Infrared spectra of the water extracts indicated the presence of a natural gum-based binding medium. The presence of a natural gum-based binding medium was also supported by Py-GC studies.

Porta and Palet (1989b) performed TLC, HPLC, and GC studies to identify the type of natural gum used by the ancient artisans at this site. TLC analysis revealed the presence of galactose, arabinose, and glucuronic acid in the sulfuric acid hydrolysate of hot water extract from the bulk of the paint samples. The TLC chromatogram shows that samples from paint layers taken from the tomb of Queen Nefertari resemble the composition of natural gum, which is locally available in the Luxor area today and sold under the name of gum arabic. Other natural gums, such as Senegal gum arabic, which can be obtained from chemical supply houses in Spain, or another gum arabic sold in Cairo do not demonstrate as much similarity to the tomb samples. The main difference is the absence of rhamnose in the samples from the tomb as well as the gum arabic from Luxor (purchased in the market and also collected directly from acacia trees).

Similar results were obtained at the GCI using HPLC and GC analysis. Chromatograms from a reference-standard sample of a monosaccharide mixture (arabinose, glucuronic acid, rhamnose, and galactose) were compared with chromatograms of two kinds of gum arabic obtained in Luxor, samples of Senegal gum arabic and hot water, and sulfuric acid hydrolysate of the bulk of paint from the tomb of Nefertari, which did not have any surface coating. The results again show a good correlation between locally available samples of gum arabic and the binding medium in the wall paintings.

Surface Coatings (Varnishes)

Surface coatings appear to have been applied to several areas of the wall paintings in the tomb of Nefertari. These coatings, or varnishes, are especially apparent on the red and yellow areas of the paintings.

Under microscopic examination, several samples available for study (reds, yellows, and one blue) reveal the presence of an organic coating on top of the paint layer. Microscopic study also shows long organic threads imbedded in the coatings. Infrared analysis of a portion of coating removed from the yellow and red paint samples shows spectra typical for a terpenoid type of natural tree resin.

Analysis of a piece of coating removed from a blue-colored area shows the presence of an acrylic (ethylmethyl-methacrylate copolymer) coating. Infrared microanalysis of the threads imbedded in this coating shows them to be cotton fibers.

In one sample studied by microchemical analysis and ion-exchange chromatography for amino acid analysis, Porta and Palet identified egg white as a surface coating. In another sample taken from a coating that had been selectively applied on a painting in chamber C, they found poly(vinyl acetate).

While in the case of the acrylic coating and the poly(vinyl acetate), it is clear that the surface coating was applied during fairly recent restoration efforts, interpretation of the natural products—tree resin and egg white—is more difficult. These materials have been available throughout history and the question of when each material was applied may never be answered conclusively.

Conclusions

This study confirms that the materials and techniques used in the wall paintings of the tomb of Nefertari are indeed the traditional ones described in the literature. The main cause of the deterioration of the wall paintings is salt crystallization in the rock, plaster, and paint. The pigments are stable against most environmental influences. In view of the long-term preservation of the wall paintings it is important to keep in mind that the binding medium of the paint is water soluble and susceptible to photo-oxidation when exposed to excessive light, especially ultraviolet radiation.

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Appendix

Analytical Techniques and Equipment

All samples were first examined using a Wild M8 stereo microscope, with a magnification range of 6 to 50X, and were documented photographically.

Samples for cross-sectional studies of the painted surface were removed from the bulk samples, mounted in Ward's Bio-Plast, and cured for 24 hours at 50 °C. The resin blocks were wet-sanded on successively finer grits of wet/dry paper using Shell Solv as a lubricant. Final polishing was performed with Buehler 6 μm diamond paste and Shell Solv extender. The polished sections were examined with the aid of a Leitz Orthoplan microscope under polarized light or UV fluorescence illumination.

Samples for pigment analysis were dispersed in a Cargille Melt Mount, refractive index 1.66, prior to examination. A Leitz Orthoplan microscope equipped with strain-free objectives was used for the examination of the mounted pigment samples.

Samples prepared for dispersion staining were dispersed in Cargille 1.648 liquid and examined with the aid of a 10X McCrone dispersion-staining objective fitted with an annular stop.

X-ray diffraction analyses were conducted using a Siemens D 500 X-ray diffractometer using Gandolfi and Debye-Scherrer cameras. The diffractograms were recorded on film, and the film was measured with a densitometer connected to a DEC PDP 11/23 computer, which searched experimental data against JCPDS files using the Hanawalt method.

X-ray fluorescence spectra were recorded using a Kevex 0750A spectrometer consisting of a rhodium tube X-ray source, Kevex energy-dispersive detector, model 7000 spectrometer, and PDP 11/23 computer. The tube was fitted with a molybdenum secondary target and a 2 mm collimator. A 6 mm collimator was installed in the detector. The tube voltage and current settings were 40 kV and 3.3 mA, respectively. Data were acquired for 500 seconds, with a resolution of 20 eV per channel. To improve the detection limit for manganese, a zinc secondary target was used in place of the molybdenum target. Paint samples were mounted on Scotch brand tape prior to analysis.

Electron micrographs, local microanalysis, and concentration maps of selected samples were obtained using a JEOL 733 Superprobe equipped with a Tracor northern energy-dispersive X-ray spectrometer and three wavelength dispersive spectrometers. The image-processing program was used for concentration map recording. Samples for electron micrography were sputter-coated with gold and samples for electron microprobe analysis were vacuum-coated with carbon to eliminate surface charging.

Fourier transform infrared microscopy (FTIR) was performed on a Perkin Elmer 1600 FTIR spectrometer equipped with a Spectra Tech IR-PLAN and on a Digilab 3280 FTIR spectrometer. Some samples (coating layers) were analyzed directly using infrared microspectrometry. Binding media from other samples were separated using hot water and ethanol extraction in an ultrasonic bath. A drop of the extract was then placed on a BaF_2 pellet, dried, and analyzed under the infrared microscope. Each IR spectrum was recorded as a sum of 120 scans collected with resolution of 4 cm^{-1}. Recorded spectra were searched against Sadtler IR Spectra and GCI Standard Spectra Library using a Motorola 3200 computer.

Pyrolysis-gas chromatography (Py-GC) analysis was performed using a combination of the CDS Model 120 pyroprobe with the Hewlett Packard 5890 gas chromatograph. Samples analyzed for binding media were placed inside quartz capillary sample tubes and pyrolyzed using a coil-type pyroprobe. A pyrolysis temperature of 600 °C was used for analysis of standard gum samples and samples from the tomb. Products of pyrolysis were cryofocused at the head of the column before chromatographic analysis. During analysis, the initial oven temperature was -50 °C minimum to a final 250 °C. A Hewlett Packard Ultra, a 2-capillary phenyl-methyl-silicone-coated column (25M, 0.32 mm I.D.), was used with a helium carrier gas at a flow rate of 30 ml per minute and a flame-ionization detector (FID).

TLC analysis was performed on silica-gel G plates with a solvent system of n-butanol, acetic acid, ethyl ether, and water (9:6:3:1) as a developer, and naphto-resorcinol as a detection reagent. Binding media extract for TLC analysis was hydrolyzed for 8 hours using 4% sulfuric acid at 80 °C. The resulting hydrolysate was neutralized with barium carbonate, and the resulting suspension was centrifuged to prepare hydrolysate for TLC plates spotting.

A Hewlett Packard 5890 gas chromatograph equipped with a 25 m SE-54 capillary column and flame-ionization detector was used for analysis of hydrolyzed and derivatized standards and samples. The hydrolysis step was identical to the one described for the TLC analysis. A two-step derivatization procedure was used to prepare volatile derivatives of saccharides. First, the sulfuric acid and hydrolysate was reacted with hydroxylamine hydrochloride in pyridine to obtain corresponding oximes. In the second step the resulting oximes were reacted with hexamethyldisilane and trimethyl-chlorosilane in pyridine to form silainated oxime derivatives.

HPLC analysis was performed on a system composed of Aminex HPC87-C and Aminex HPX87-P columns connected in series, peristaltic pumps, and a Knauer differential refractometer detector. The samples for HPLC analysis were hydrolyzed using trifluoroacetic acid at 100 °C for 4 hours in a hermetically sealed glass tube.

References

Corzo, M. A., ed.

1987 *Wall Paintings of the Tomb of Nefertari: First Progress Report.* Cairo and Century City, California.

Michalowski, S.

1989 Internal report. November 9. The Getty Conservation Institute, Marina del Rey, California.

Mora, P., L. Mora, and E. Porta

1990 Conservation et restauration de la Tombe de Nefertari dans la Vallée des Reines. *ICOM Committee for Conservation. IXth Triennial Meeting.* Dresden: 519–23.

Palet, A., and E. Porta

1990 Análisis químicos de los pigmentos y aglutinantes empleados en las pinturas murales de la tumba de Nefertari. *ICOM. Comité Español. XIIIth Congrés de Conservacio Béns Culturals.* València: Generalitat Valenciana: 452–60.

Porta, E., and A. Palet

1989a Internal Report. November 9. The Getty Conservation Institute, Marina del Rey, California.

1989b Internal Report. December 23. The Getty Conservation Institute, Marina del Rey, California.

Preusser, F.

1987 First Report on Analyses of Samples. In *Wall Paintings of the Tomb of Nefertari: First Progress Report,* M. A. Corzo, ed. Cairo and Century City, California.

Saleh, Saleh Ahmed

1987 Pigments, Plaster and Salts Analyses. In *Wall Paintings of the Tomb of Nefertari: First Progress Report,* M. A. Corzo, ed. Cairo and Century City, California.

North wall of the entrance area, looking down into the burial chamber, ca. 1904. Photo: Courtesy of the Museo Egizio, Turin.

The Nefertari Conservation Program

Paolo Mora and Laura Sbordoni Mora

From the moment of the discovery of the tomb of Nefertari, it was apparent that the wall paintings were in a precarious condition (Fig. 1). One of the principal causes of this can be attributed to the poor quality of the limestone out of which the tomb was originally cut. It was less compact and not as strong as the limestone of other excavated Egyptian tombs in the area and was found to contain substantial amounts of sodium chloride and gypsum (Corzo 1987:92–105, 112–15). From the time of Schiaparelli's discovery and his documentation of the tomb, its fragile condition led restorers, beginning with Schiaparelli's colleague Professor Lucarini, to take conservation measures.

Figure 1. North wall of the burial chamber, showing extensive deterioration, ca. 1920. Photo: Courtesy of The Metropolitan Museum of Art.

Figure 2a. Detail, chamber K, east wall, ca. 1920. Photo: Courtesy of The Metropolitan Museum of Art.

Figure 2b. Detail, chamber K, east wall, October 1989.

Comparisons of the cumulative photographic documentation, from 1904 to the present, reveal widespread deterioration of the tomb paintings and a notable increase in the number of fallen pieces of plaster (Fig. 2a, b). These conditions probably were due more to natural factors than to the deleterious effects of earlier visitors to the tomb or to the inadequacy of previous restoration attempts. Harmful effects include the migration of salts and their consequent recrystallization on the surfaces, and the formation of small pustules corresponding to the borders of reinforced lacunae and in those zones that had been previously consolidated with injections of unsuitable materials. In addition, disordered fragments were found to be overlapping one another under the gauze that had been applied to secure the paint in place.

In some areas, the condition was so precarious that only a slight touch would have been enough to cause fragments to fall, creating further losses.

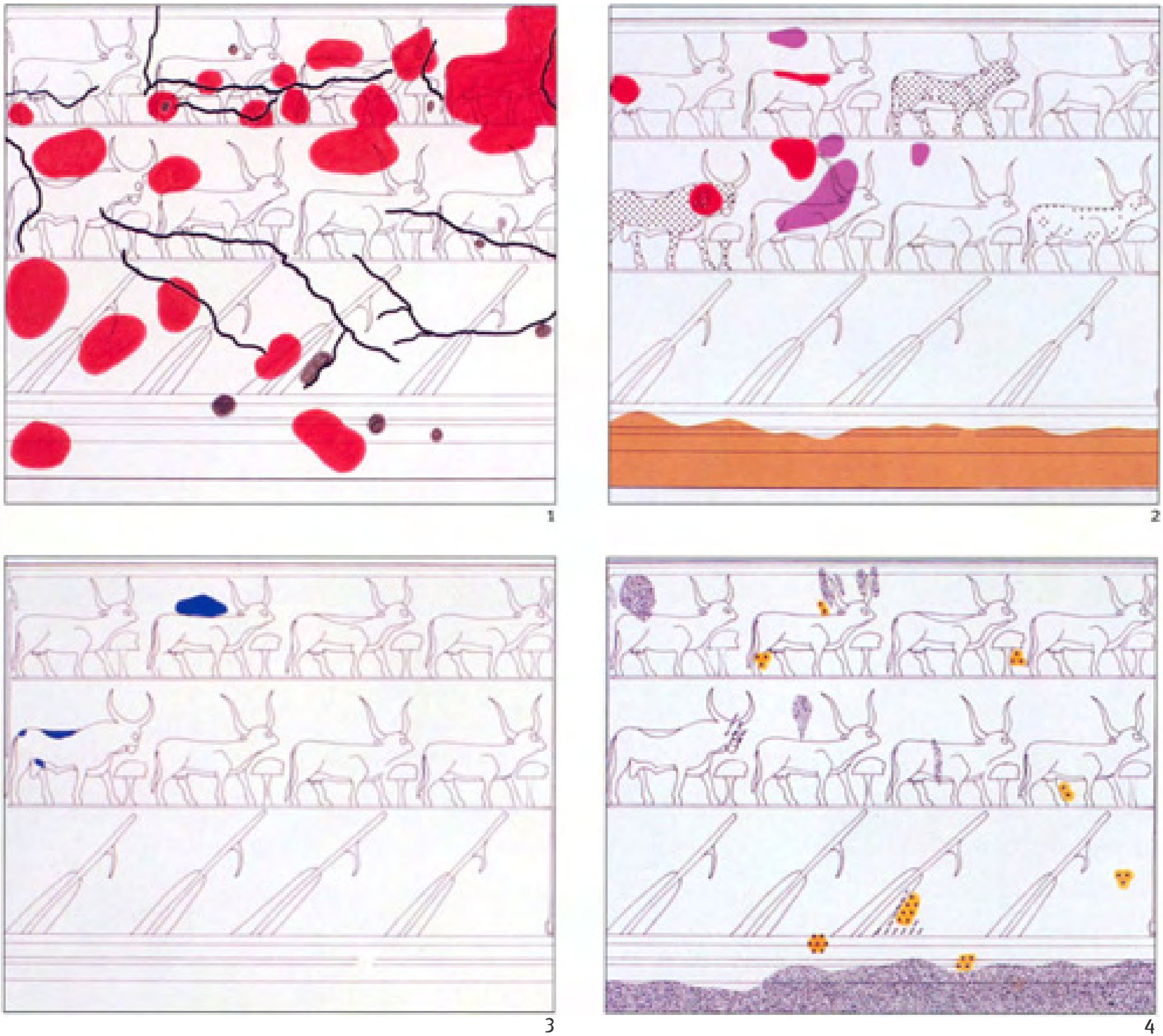
Recognizing the fragility of the tomb, the Egyptian authorities and the Getty Conservation Institute decided that before conservation treatment could begin, an in-depth analysis and recording of its physical state needed to be done. This involved a critical examination of the tomb's surface, which required a thorough knowledge of its constituent materials and execution techniques, as well as the reactions of those materials to a variety of destructive agents and phenomena.

To illustrate the paintings' actual state of conservation, a precise graphic survey was carried out in November and December of 1986.

The assessment of the tomb's condition involved a four-part analysis concentrating on (1) the condition of the support; (2) alterations of the painted layer; (3) typology and localization of foreign substances (primarily salt); and (4) the physical results of previous interventions, some dating back to the tomb's discovery in 1904 and others from later periods (Fig. 3).

In surveying the condition of the support, it was possible to isolate six different types of decay: (1) cracks manifested as fissures or fractures in the rock structure out of which the tomb was cut, and consequently in the stratification of the plaster applied to the rock supporting the painted surface; (2) extrusion of rock chips, that is, geological dislocations of rock onto the surface; (3) separation of the plaster, both within its own stratification and away from the rock support, in which varying degrees of adhesion existed; (4) lack of cohesion of the plaster, or a tendency of the preparatory strata of plaster to crumble and fall apart; (5) losses of the entire plaster stratification visible as deep lacunae; and (6) losses of the surface strata, or the presence of lacunae on the surface.

Alterations of the painted surface were found to con-



Figures 3a—3d. Condition survey of chamber C south wall. Color codes identify and locate the deterioration problems.

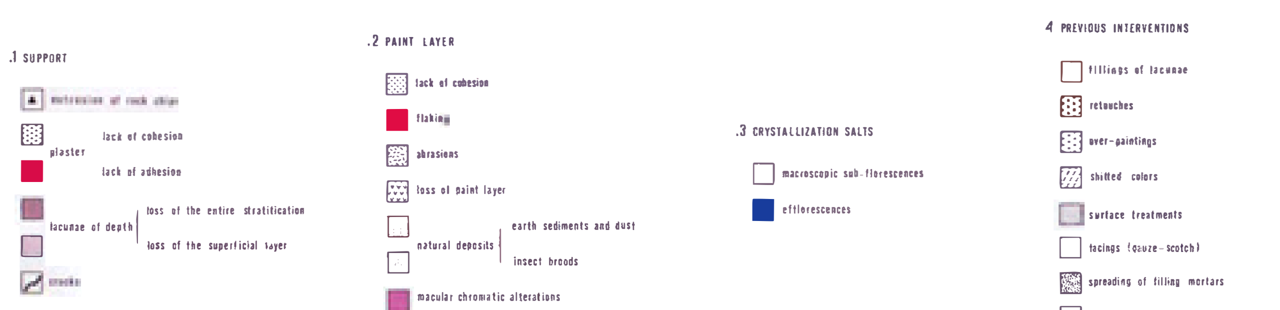





Figure 4, top left. Flaking paint.
Figure 5, top right. Loss of pictorial layer.
Figure 6, above left. Abrasion of painted surface.
Figure 7, above right. Insect nests.

sist of: (1) lack of cohesion of the painted layer, manifested as a tendency toward pigment pulverization; (2) detachment of the pictorial layer with flaking of the paint (Fig. 4); (3) loss of the pictorial layer (Fig. 5); (4) abrasion due to mechanical damage and wear (Fig. 6); (5) macular or spotty chromatic alterations, where paint smears were evident; (6) layers of dirt caused by a variety of factors; and (7) natural deposits on the surface in the forms of earth sediment, dust, and the remains of spider webs and insect nests (Fig. 7).

Of foreign substances, the salts appeared in three forms: (1) macroscopic subflorescence with salt crystallization of especially eruptive and damaging capacity; (2) efflorescence where specific salts crystallized on the painted surface (Fig. 8); and (3) black stains from the crystallization of salts in the pictorial layer.

A visual survey revealed that previous interventions resulted in the following alterations to the paintings: (1) fillings of lacunae either at the surface or subsurface (Fig. 9); (2) splashings of mortar used to fill lacunae onto nearby areas; (3) overlapping of pictorial restorations onto fillings, obscuring the original paint and plaster; (4) retouching of original painting; (5) surface residue of previous applications of conservation materials; (6) shifted colors; (7) facings, either of gauze or adhesive tape,




Figure 8, top left. Salt efflorescence on the painted surface.
Figure 9, top right. Old fillings of lacunae.
Figure 10a, above right. Previously applied gauze facings.
Figure 10b, above left. Old adhesive tapes.

applied with the intention of securing endangered sections of the plaster (Fig. 10a, b); and (8) detached fragments that had been replaced in situ.

To provide the conservation team and later researchers with a clear visual map of these phenomena, a comprehensive photographic documentation of the tomb was undertaken. On each photograph, four transparent acetate sheets were superimposed with symbols indicating the type of decay and the exact location of each type of degradation (Corzo 1987:113–14). Approximately 200 tables with titles, topographic references, and scales were made during the survey, providing a guide for subsequent conservation treatment. These tables were used by the conservation team and also served to document, for future generations, the state of the tomb of Nefertari during the period of its conservation by the Getty Conservation Institute and the Egyptian Antiquities Organization.

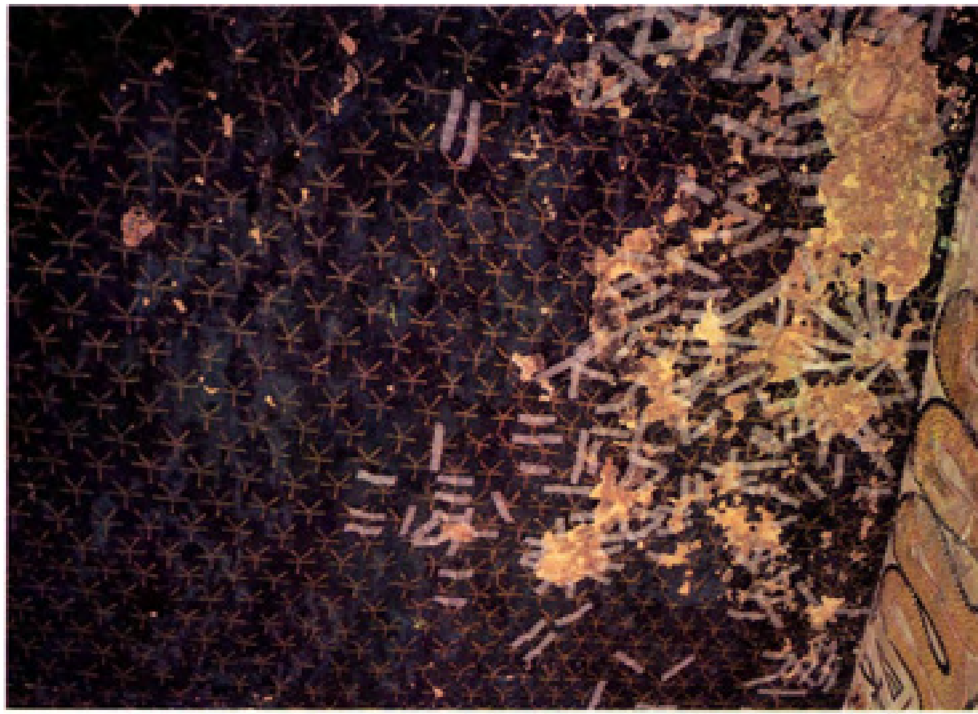


Figure 11, above. Fine-grain paper applied to wall surfaces.
Figure 12, right. Cotton gauze applied to ceiling fragments.

Conservation Methodology

Emergency Treatment

An emergency treatment plan based on tests made during the initial survey of the wall paintings was conceived and executed in the spring of 1987. Its aim was to protect the tomb from further losses while appropriate and definitive methods for a more thorough conservation treatment were being evaluated. This emergency treatment took place over a period of 87 days, from April 5 to June 30, 1987.

The most serious causes of decay were determined to be the fragmentation and separation of plaster layers from the rock wall. The emergency treatment program attempted to stop the structural disintegration of the most fragile areas, preventing the detachment of loose fragments, until a final treatment could be undertaken using fully reversible materials and methods that would not interfere visually with the painted surface.

Strips of fine-grain paper made from Japanese mulberry bark were placed over each of the raised fragments and carefully attached to the wall using an acrylic resin—20% Paraloid B72 in trichloroethane (Table 1, solvent No. 3)—applied at the ends of each strip (Fig. 11). These strips enabled the conservation team to fully control the progress of the emergency treatment and obviate any movement of the wall surface. In addition, compared to large areas of facing, the strips permitted easier reversibility of treatment with less solvent needed for removal. The strips were placed wherever fragments were likely to detach. Where fragments were falling away from the wall's surface, a drop of Primal AC-33 (an acrylic resin emulsion) was placed at the center of the underside of the fragment and it was pushed back into place using a protective sheet of silicon paper and a spatula.

On the ceiling, the method of treatment was slightly different. Because of the roughness and weight of the surface, thicker strips of cotton gauze were used (Fig. 12).

Ultimately, approximately 10,000 paper strips were applied to the ceiling and walls. Once the protective intervention was completed and there was no danger of further deterioration, the tomb paintings were ready for final treatment.

Final Conservation Treatment

After completing their initial evaluation at the end of 1987, the Egyptian Antiquities Organization and the Getty Conservation Institute decided to begin the final conservation treatment. They established a seven-phase time schedule:

Phase	Dates	No. of Days
I	February 1—April 12, 1988	71
II	October 14—December 13, 1988	61
III	October 7—December 17, 1989	72
IV	February 2—April 6, 1990	63
V	October 11—December 15, 1990	66
VI	October 7—December 17, 1991	72
VII	February 3—April 7, 1992	64
	Total	469

The selection of the zones to be treated was based on the type of damage. Priority was given to areas that were in imminent danger of being lost. This approach provided the conservation team with a wide range of problems with very different technical and aesthetic difficulties. The materials and methodologies were selected with the benefit of a long history of proven practice and an extensive body of recent scientific literature on the subject (Afshar, Source Materials, III, this volume).

Primarily, these operations involved cleaning and consolidating the plaster and paint layers in chambers C and K. Stabilization measures included consolidating the plaster by injecting grout or adhesive mortar, detaching and reattaching fragmented portions of plaster, filling of lacunae, reattaching flaking paint, and consolidating powdering pigment. Specific materials and techniques are discussed below.

The treatment sequence consisted of: (1) preliminary cleaning, (2) removing the old gauze facing, (3) consolidating the plaster, (4) reattaching the paint flakes, (5) strengthening the cohesion of the pictorial surface, (6) detaching and reattaching areas of painted plaster, (7) removing and repairing fills, and (8) final cleaning.

Preliminary Cleaning

When conservation began, all the surfaces were covered by a dense layer of dust and some cobwebs and insect nests. Before beginning any kind of operation, it was necessary to remove these deposits.

Choosing an appropriate means of cleaning posed an immediate difficulty because of the extremely fragile state of the pictorial layers, which suffered from lack of cohesion, as well as detachment and flaking. It was determined that mechanical contact, even from the finest brushes or spatulas could damage the paintings. After much consideration, it was decided that the safest alternative would be to clean the walls and ceiling with a low-pressure air gun.

Removal of the Gauze Facing

As in the case of the emergency treatment, conservation treatment began in those zones that were most severely damaged. The first treatment procedure was to remove a dense, heavy, gauze facing that had been applied to the painted surfaces in small squares with a strong resin adhesive (Vinavil) during the nonsystematic conservation attempts of the past. The faced surfaces were brushed with a commercial lacquer thinner (Table 1, solvent No. 1) that was adequate to dissolve the adhesive (Fig. 13). Because of the density and resistance of the synthetic adhesive, however, repeated applications of the solvent were necessary to peel the facing away. The same solvent was also sometimes applied under the facing while it was being removed. The facing was peeled off slowly in a diagonal direction parallel to the plane of the wall to prevent damage to the painted surface.

Another facing made of masking tape that had been applied with wax was also removed in the same manner, in this case using acetone as the solvent applied with cotton wool. The wax-and-tape facing had been used only in small areas and was less prevalent than the gauze facing.

Because removal of the facings often revealed badly disintegrated plaster, interim emergency repairs were frequently necessary. These were made while the facings were being removed using strips of polyamide tissue paper to temporarily secure loose and endangered areas. An acrylic resin in solution (10% Paraloid B72 in lacquer thinner) was used to apply these strips.

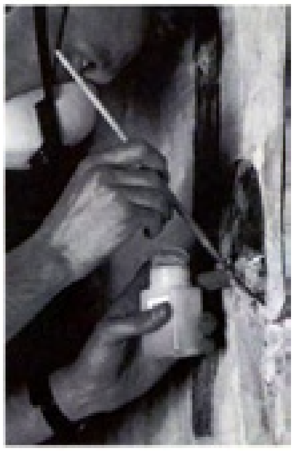


FIGURE 13. REMOVAL OF OLD GAUZE FACINGS.

Removal of the facing also revealed areas where the paint layer had flaked and detached, and these flakes were simultaneously fixed in place with an acrylic emulsion (Primal AC-33) as the facing removal proceeded. Flakes that had collected between the facing layer and the painted plaster were removed and reattached when possible.

Some areas of fragmentation were rigidly held in place by the residual facing adhesive, and care was taken not to dissolve too much adhesive all at once from such areas. More typically, plaster was found crumbled or dislodged behind the gauze. However, many dislodged fragments were retrieved with forceps from the cracks and holes into which they had fallen. These were later repositioned and consolidated in situ.

Consolidation

Reattachment of the plaster to the rock substrate and the plaster's consolidation were vital to the survival of the paintings. Thus, these operations became primary requirements for continued conservation treatment.

First, areas of detachment not visible to the eye were identified by gently tapping the plaster surface. When a hollow sound resulted, a pocket of air was assumed to exist between the rock and the plaster. Consolidation was usually executed by injections of mortar similar to the original formula used by the ancient Egyptians—three parts washed and sieved local sand to one part gypsum powder—plus three to five drops of Primal AC-33, and a small amount of water as required for fluidity.

The principal mortar formula was modified according to the requirements of the various circumstances in which it was used. For example, in areas such as the ceiling where fragments had to be fixed immediately, double the normal amount of gypsum was added to the mortar.

Prior to injection of the mortar, all vulnerable areas of the mural were faced with polyamide synthetic tissue, applied using a 10 to 20% Paraloid B72 in lacquer thinner solution. In addition to temporarily securing weak plaster, this facing protected the extremely water-sensitive pigments from moisture introduced with applications of mortar. An initial injection of one-to-one Primal AC-33 and water by syringe through existing cracks or lacunae served as a bonding agent and also avoided later water penetration of the plaster. This treatment was immediately followed by an injection of the principal mortar formula. The inclusion of Primal AC-33 in the mortar slowed the drying rate, thereby preventing too-rapid absorption of moisture into the sensitive, painted plaster. Additional mortar was injected over a period of several days to avoid mobilization of salts or the removal of pigment by excessive and sudden water infiltration. If the separated plaster proved sufficiently pliable during consolidation, bulging areas were pressed back using tension presses sprung from a stable scaffold placed in front of the section of the wall in question.

Where larger cracks and lacunae allowed access behind detached plaster layers, a drier preparation of the mortar mixture was used to guard against further moisture damage. The mixture was applied with a spatula. If particularly deep consolidation was required in places where there was significant space between the rock and the plaster, loose stones were inserted behind the detached plaster to bulk out the mortar mix and further reduce the need for water. After the mortar in the consolidated areas had dried, the synthetic polyamide tissue was removed using lacquer thinner as the solvent.

Areas of plaster lacking in adhesion were consolidated with Primal AC-33. For moisture protection, surrounding paint surfaces were first brushed with a weak solution of 3 to 5% Paraloid B72 in lacquer thinner. Subsequently, Primal AC-33 diluted with one part water was applied by syringe or pipette. The protective Paraloid layer was removed with lacquer thinner alone after the consolidation emulsion had dried.

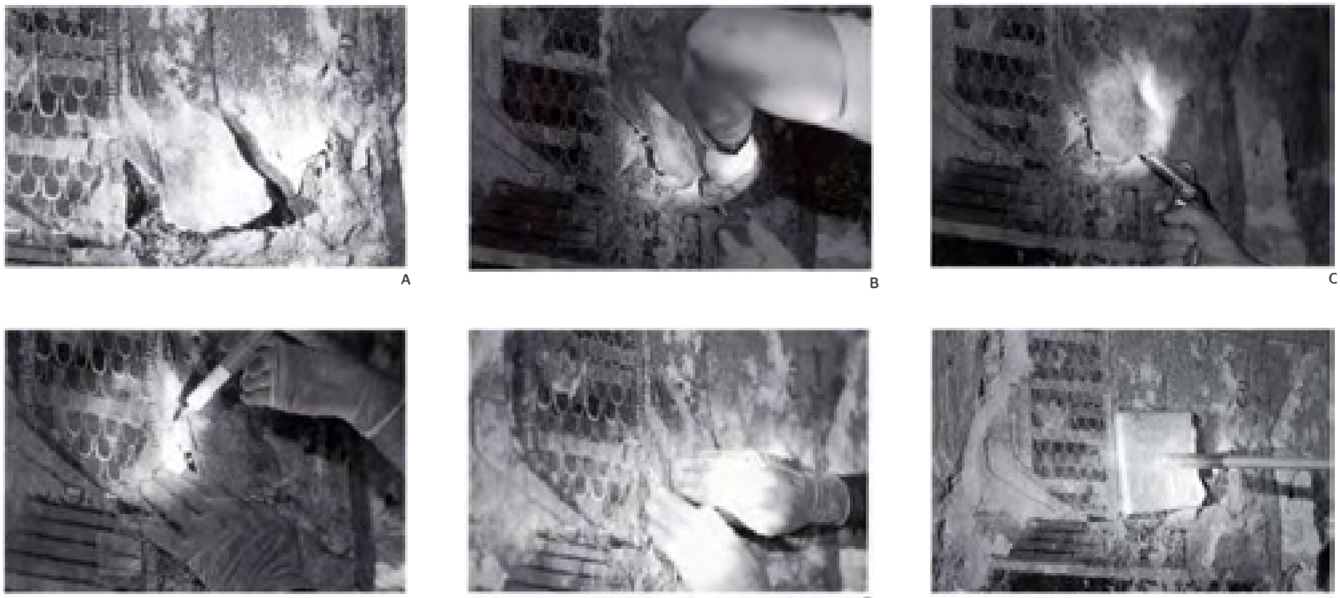
Reattachment of Flakes

Raised or detached paint flakes with some plaster adhering to the back were reattached with infiltrations of acrylic resin in dispersion (30% Primal AC-33 in water). Drops of this solution were applied behind loose flakes with a pipette or syringe, and the flakes were then pressed gently back in place using silicon paper and a steel spatula.

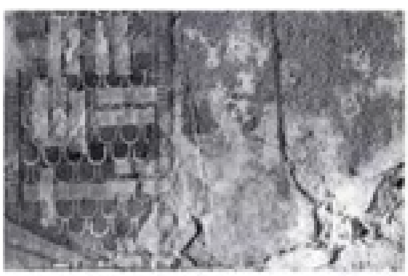
Raised areas of yellow and red pigment in the paint layer only were fixed with an acrylic solution (5 to 7% Paraloid B72 in lacquer thinner) then smoothed with a spatula using an intervening sheet of silicon paper.

Strengthening of the Cohesion of the Pictorial Surface

Over much of the painted surface, the original binding medium for the pigment had disintegrated or weakened, causing the paint to become powdery. This weakening of the cohesion of the pictorial layer was treated with 3 to 5%



A B C D E F



G

H

Figure 14. Osiris's foot, chamber K, north wall, 1987.

A. Detached plaster.

B. Removal of salt crystals with a chisel.

C. Clearing debris with an air gun.

D. Injecting of acrylic resin emulsion.

E. Detached layer pressed back in place.

F. Press used during drying time.

G. Area after consolidation.

H. Area after final conservation and cleaning, 1992.

Paraloid B72 in lacquer thinner. Any overapplied areas were successfully reduced to a homogenous level by brushing with the same solvent.

Detachment and Reattachment

Some areas of painted plaster had separated from the rock substrate in the form of broken and detached or partially detached fragments. These were attached to reestablish their correct alignment according to the two procedures that follow:

1. All detached fragments were faced with synthetic polyamide tissue and 10 to 20% Paraloid B72 in lacquer thinner. For partially detached fragments, the tissue and acrylic resin were applied not only to these areas but also to a larger section of plaster around the unbroken cracked edge, so that a hinge was formed at the crack. In this way, the detached fragments could be lifted up and their reverse surfaces cleared of foreign materials, such as salt crystals and rock grains, by means of small scalpels and microdrills without risking complete detachment of the painted fragment. Completely detached fragments were also faced and cleaned in the manner described above. Making use of existing cracks in the surface, disintegrated clay-straw plaster was raked out to free some of these detached pieces.

Once cleaned, all the fragments were impregnated with a 3% Paraloid B72 in lacquer thinner solution and correctly positioned and reattached using a drier, pliable, and dough-like mortar mixture composed of the same ingredients as the consolidation mortar described previously, but in a one-to-one proportion to accelerate the drying time. This mixture prevented the rock from absorbing water and subsequently releasing salts back into the plaster. In 48 hours, after the mortar was dry, the protective facing was removed from the reattached fragments (Fig. 14a–h).

2. Where large areas of plaster were detached and completely askew, a more complex procedure was necessary to reattach and realign them. The same materials indicated above were used for the protective facing but a heavier weight of polyamide tissue was used and applied in two or three layers with a solution of 30% Paraloid B72 in lacquer thinner. After these protective layers had dried, the whole area was reinforced with a specially designed device composed of one or two layers of polyurethane foam and internal supports of cane. This armature supported the fragment during detachment and reapplication to the wall and provided a partial mold of the original irregularities of the fragment's surface. With special, long metal chisels, the fragments were slowly removed from the wall completely and placed face down on wooden supports covered with a layer of soft polyurethane.

With lightweight hammers and chisels, accumulated dirt, salts, and layers of cement and gypsum from an earlier intervention were mechanically removed from the walls and the reverse sides of the fragments. This operation proved extremely difficult because of the hardness and thickness (in some cases 8 or 9 inches) of the consolidation material used in the earlier restoration. On the reverse side of the cleaned plaster, two processes were instituted to reestablish the original thickness of the fragment: first, the plaster was impregnated with acrylic solution to avoid water penetration; and then a one-to-one mixture of local sand and gypsum with the addition of Primal AC-33 was applied to slow down the setting time. When these operations were complete and the rock had been smoothed, the fragments were then reattached by means of mortar bridges composed of the same mixture. After placement, the fragment was held in place using a tension press until the mortar had completely dried (in approximately 48 hours). In some cases, a more fluid mixture of the mortar compound was injected to further bond the fragment to its mural support. When the drying was complete, the facing was removed using just enough lacquer thinner to loosen and peel it away.

Removal and Repair of Fills

Removal of the old fills and borders of the reinforced sections was particularly difficult because the plastering material used for the fills was pure gypsum, which is much harder than the original plaster, and because the plastering was not limited to the lacunae and to the borders alone but overlapped onto large areas of the original painting (Fig. 15). The removal of this material was made even more arduous and time consuming because the mechanical elimination of the old fills had to be done centimeter by centimeter and needed to be preceded, in some cases, by moistening with a solvent mixture (Table 1, solvent No. 4).

First, the original plaster on the borders of lacunae identified during the conservation treatment survey phase were consolidated with Primal AC-33. To prevent a later deterioration of the painted plaster that might occur as a result of the differences between levels of the painted surfaces and to avoid access by dust, insects, and other animals, it was necessary to fill some lacunae with a mortar similar to that used by the ancient Egyptians. The lacunae were then filled with a more compatible mortar so as not to create differential tensions between the new and the old materials. This consisted of the principal mortar mixture without the addition of Primal AC-33, as follows: three parts local sand to one part gypsum plus water to the consistency required. Because the composition of the mortar included a small quantity of water, the internal edges of the lacunae were preventively impregnated with 3 to 4% Paraloid B72 in lacquer thinner solution, to preclude the migration of salts. For the same reason, the mortar was applied in thin, successive layers allowing time for drying out between one layer and the next. Lower levels were additionally bulked out with small stones inserted for the same reason. The new fills were installed up to the level of the surrounding original plaster, in such a way as to imitate the surface wear of the original mortar, using a

FIGURE 15. OLD FILLS OVERLAPPING ONTO ORIGINAL PAINTING.

specially prepared instrument made from a fine point of wood. In every area with lacunae this procedure produced a perfect homogeneity between the layer of original mortar and the reintegrated areas. Finally, stippling with a pointed instrument made the repairs visually less obtrusive (Fig. 16a–d).

Final Cleaning

The choice of cleaning materials and methods was based on: (1) the nature of the substances to be removed; (2) the resistance of the paint layer depending on the original techniques and materials used by the ancient Egyptian artists and in the present conditions of these materials.

An initial visual inspection of the surfaces was made, supplemented by information that had been gathered on the material history of the wall paintings, including previous restorations, physical conditions of exposure since their creation, and other factors. Subsequently, those foreign substances needing removal were exposed to specific cleaning agents and solvents in order to study their reactions and thereby gauge or suitably modify the cleaning treatment accordingly. At this stage, laboratory analyses of pigments, binding media, and varnishes were made to ensure precise treatment and confirm hypotheses based on visual examination (Stulik, Porta, and Palet, this volume).

The picture layer was covered in an irregular and nonhomogenous manner with a grayish layer especially evident on the white background. This was probably caused by smoke from petrol lamps used during the excavations and inspections earlier in this century. This layer was removed using acetone with compresses (Fig. 17a–d).

Where the surfaces had been touched by the dirty or greasy hands of visitors to the tomb, it was necessary to apply a mixture that could remove the dense layers of dirt without damaging the original pictorial layer. Ethanol with lacquer thinner and water were chosen for this purpose (Table 1, solvent No. 5).

The grayish-orange water stains, produced almost certainly by the injection of aqueous fixatives used during previous restorations, were eliminated with the same solvent using compresses, but with much difficulty.

The dark stains created by the crystallization of internal salts beneath the pictorial surface were easily removed without any mechanical action and with a simple, thirty second application of acetone and water (solvent No. 6; Fig. 18a–b).

A

B

C

Figure 16a. Old filling of lacunae.
Figure 16b. Old filling removed.
Figure 16c. Layer of new mortar filling.
Figure 16d. Surface stippled for texture.

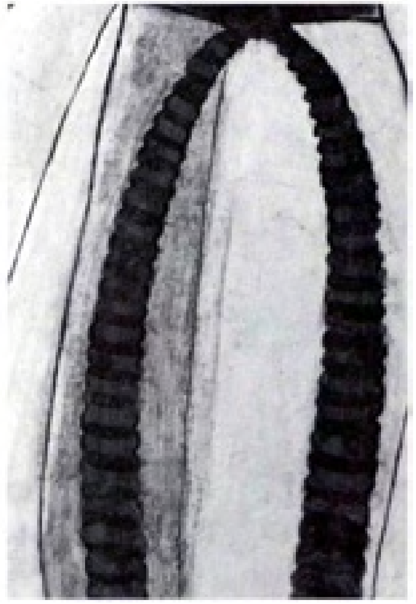
D

A

B

C

D



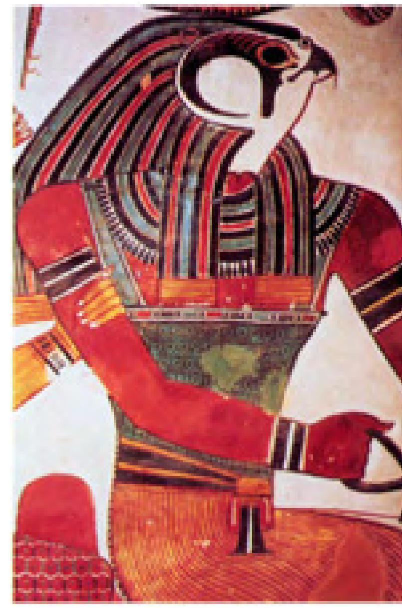


Figure 17, opposite.
A. Detail of portrait of Osiris, before treatment.
B. After conservation and cleaning.
C. Detail of portrait of Nefertari before treatment.
D. After conservation and cleaning.
Figure 18a, above left. Detail of Nefertari's skirt showing dark stains caused by salt activity.
Figure 18b, above center. After cleaning.
Figure 19, above right. Detail of Re-Herakhty, chamber E, east wall, south side.

The numerous and crude repaintings of original painted surfaces found throughout the tomb (Fig. 19) were removed with applications of dimethylformamide in lacquer thinner and water (solvent No. 4) using Japanese paper and subsequent mechanical action, or *a secco* application. One relatively large area of inpainting in the central portion of the east wall of chamber G posed a dilemma. The question was whether to remove the previous restoration which was not too unsightly, or to leave it in place. Photographic evidence showed that the inpainting had been done in the early 1950s. The argument for retaining it was that the area had appeared in this form in all subsequent photographs, which formed part of the tomb's recent history. But the restoration was visually inconsistent with the rest of the tomb and with the project's philosophy of preserving the original without alterations to its surface. The final decision was to retain the inpainted layer but to cover it with unpainted mortar filling that could be removed without damaging the previous inpainting should this be considered desirable in the future (Fig. 20a–d).

The dense layers of old, dark fixatives, identified as polyvinylacetate by Porta and Palet (Stulik, Porta, and Palet, this volume) applied in various zones, were removed with Japanese paper saturated with solvents No. 7a and 7b, as appropriate for a period of two or three minutes.

The reward of this long-term, systematic conservation procedure on the wall paintings of the tomb of Nefertari is not only the satisfaction of seeing these magnificent works having recovered their original state of brilliance, but also knowing that the years of painstaking effort on their behalf are but a drop in time compared to the years that have hopefully been added to their future survival.

A

B

C

D

Figure 20a. Detail of the god Atum, chamber G, east wall, ca. 1904.
Figure 20b. Ca. 1920.
Figure 20c. October 1986.
Figure 20d. April 1992.

FIGURE 21. STEREO VIEW OF CHAMBER E, SOUTH WALL. HARSIESE LEADING NEFERTARI, CA. 1904.

No.	Parts by volume
1	Lacquer thinner (*)
2	Acetone
3	1 trichloroethane : 1 trichloroethylene
4	11 lacquer thinner : 3 dimethylformamide : 1 water
5	3 ethanol : 1 lacquer thinner : 3 water
6	2 acetone : 30 water
7a	Acetone : 7 dimethylformamide : 1 water
7b	7 acetone : 7 dimethylformamide : 3 water

TABLE 1. SOLVENTS USED IN THE CONSERVATION TREATMENT OF THE TOMB OF NEFERTARI 1986–1992.

*All references to lacquer thinner in this article refer to a commercial mixture of solvents used to dilute acrylic and nitrocellulose lacquers. The choice of this solvent was for practical reasons: It is used by automobile body repair shops worldwide and is, therefore, readily available.

Paolo Mora was chief conservator and professor at the Istituto Centrale del Restauro in Rome from 1950. Until his retirement in 1986, he was also coordinator of teaching programs and field work at the Institute's technological section.

Laura Sbordoni Mora was professor of conservation at the Istituto Centrale de Restauro in Rome from 1945 until her retirement in 1988.

Acknowledgments

The authors wish to acknowledge the dedicated contributions of all members of the conservation team who worked with them on this project and who have been listed separately at the beginning of this volume.

References

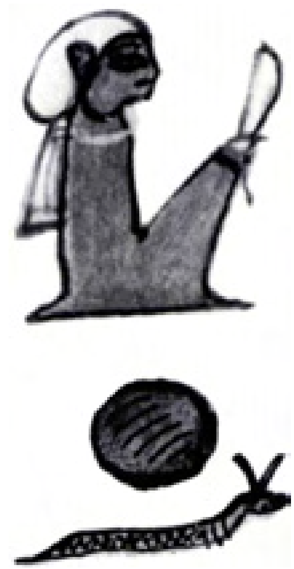
Corzo, M. A., ed.

1987 *Wall Paintings of the Tomb of Nefertari: First Progress Report.* Cairo and Century City, California.

Ceiling of stairway I, looking southwest toward chamber C showing evidence of damage. The lighter area may indicate an early attempt at restoration.

The Color Measurement Program in the Tomb of Nefertari

Michael Schilling



Since the first progress report was published (Corzo 1987), a second field campaign was undertaken to establish, on a quantitative basis, the colors of the wall paintings prior to full-scale treatment. Approximately 1,500 color measurements were made at 160 different locations of the wall paintings in the tomb of Nefertari, on as many colored areas as time permitted during the campaign. An attempt was made to include every color and shade appearing in as many chambers of the tomb as possible.

The color record was subsequently utilized to evaluate the effect of the cleaning procedure on the appearance of the wall paintings. Cleaning resulted in increased saturation of the colors of the paintings, with no measurable change in hue. Reds, blues, and greens took on deeper tones after treatment, whereas yellows became brighter and more vivid, and blacks appeared darker.

Other information was also obtained from the color data. Clustering of data for the blues and the greens was apparent, with the data from chamber K lying within a separate group. Whether this is due to a different manufacture of the synthetic pigments (Egyptian blue and Egyptian green) or to different mixtures of paint cannot be ascertained at this time.

Since the first report, the performance of the Minolta Chroma Meter CR-121 was fully evaluated to aid in the interpretation of the color measurement data from the wall paintings. The degree of precision, accuracy, and stability exhibited by the CR-121 in measurements of reference color tiles indicates that the instrument is ideally suited for field projects in which color changes are to be evaluated.

Ultimately, the color record obtained in the second field campaign provides the basis for future evaluations of any color changes that may occur after treatment due to visitor impact or other environmental influences.

Background

A program of color measurement was initiated in the tomb of Nefertari to provide supplementary documentation for the conservation procedure (Corzo 1987). On careful examination, it became obvious that cleaning and restoration of the wall paintings would enhance the appearance of their colors by the removal of surface dirt and grime. Although many restoration techniques were available to the conservators, they wanted to choose a treatment procedure that would leave the hues of the paintings unaffected, but would enhance the brightness and saturation of the colors.

Thus, it was important to measure and record the colors of the wall paintings prior to treatment, and to use this record to evaluate the proposed treatment method. Several methods exist for this purpose, such as color photography, Munsell color matching, and instrumental measurement, each of which has its advantages and disadvantages. Color photography can rapidly document large areas, but the record is inaccurate and impermanent. Use of the Munsell system (Billmeyer and Saltzman 1981) involves visual comparison to a set of colored reference chips. This procedure is tedious, requires well-controlled lighting conditions, relies heavily on the accuracy of the viewer's color perception, and provides rather broad tolerance limits due to the wide spacing of Munsell chips. Ultimately, the decision was made to use a color measuring device to record the colors of the wall paintings.

The Minolta Chroma Meter CR-121, a portable, battery-operated, tristimulus colorimeter, was chosen for this purpose. A small piece of Goretek applied to the end of the instrument prevented damage to the wall paintings during measurement. The instrument was calibrated against a white ceramic tile prior to use. Measurement data originally expressed in chromaticity coordinates (Yxy) were converted into the CIELAB system ($L^*a^*b^*$) for data evaluation (Billmeyer and Saltzman 1981). The method of Simon and Goodwin (1958), in which uniform chromaticity charts are used to express color changes, was abandoned in favor of the CIELAB system, which is the accepted industrial standard for expressing color difference. The CIELAB system of expressing color measurement data utilizes the principle of opposing colors, as shown in Figure 1a and 1b. Lightness is defined as L^*, and hue is expressed in terms of a^* and b^*. Positive values of a^* refer to red hues, and negative values of a^* to green hues. Similarly, yellows have positive b^* values, and blues have negative b^* values. Chroma, C^*, is defined as:

$$C^* = \{(a^*)^2 + (b^*)^2\}^{(1/2)}$$

Color data can be expressed graphically or in tabular form. Color charts that show graphs of b^* versus a^* or L^* versus a^* are convenient for illustrating groups of color measurement data and for providing visual alternatives to data tables.

Color change or color difference can be easily determined in the CIELAB system (Billmeyer and Saltzman 1981). Changes in chroma are expressed in terms of ΔC^*, and lightness changes in terms of ΔL^*. Color difference, ΔE, as defined by the same authors (1981), is equal to:

$$\Delta E = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{(1/2)}$$

Color charts are excellent tools for displaying color changes for small sets of data. Plots of ΔL^* versus ΔC^* show in which visual direction color changes occur, as displayed in Figure 1b. Additionally, in graphs of b^* versus a^*, Figure 1a, hue differences appear as rotations about the origin.

Instrumental stability was periodically checked against British Ceramic Research Association (BCRA) ceramic color standards (set CCS-II). The data from the color tile standards also serve as a so-called hitching post, or baseline: At a later date, the tomb data can be corrected for instrumental drift by comparison with the reference tile measurement data.

The measurement locations were selected to represent the various states of preservation that were found in the tomb, ranging from well preserved to near total detachment. Measurement locations recorded photographically with Polaroid film were cross-referenced with the floor plan for indexing.

Colored surfaces in the tomb were prepared for measurement by light dusting with a squirrel-hair brush under a gentle stream of air produced by a rubber-bulb syringe. To evaluate the proposed conservation treatment procedure, test areas were measured without this additional treatment.

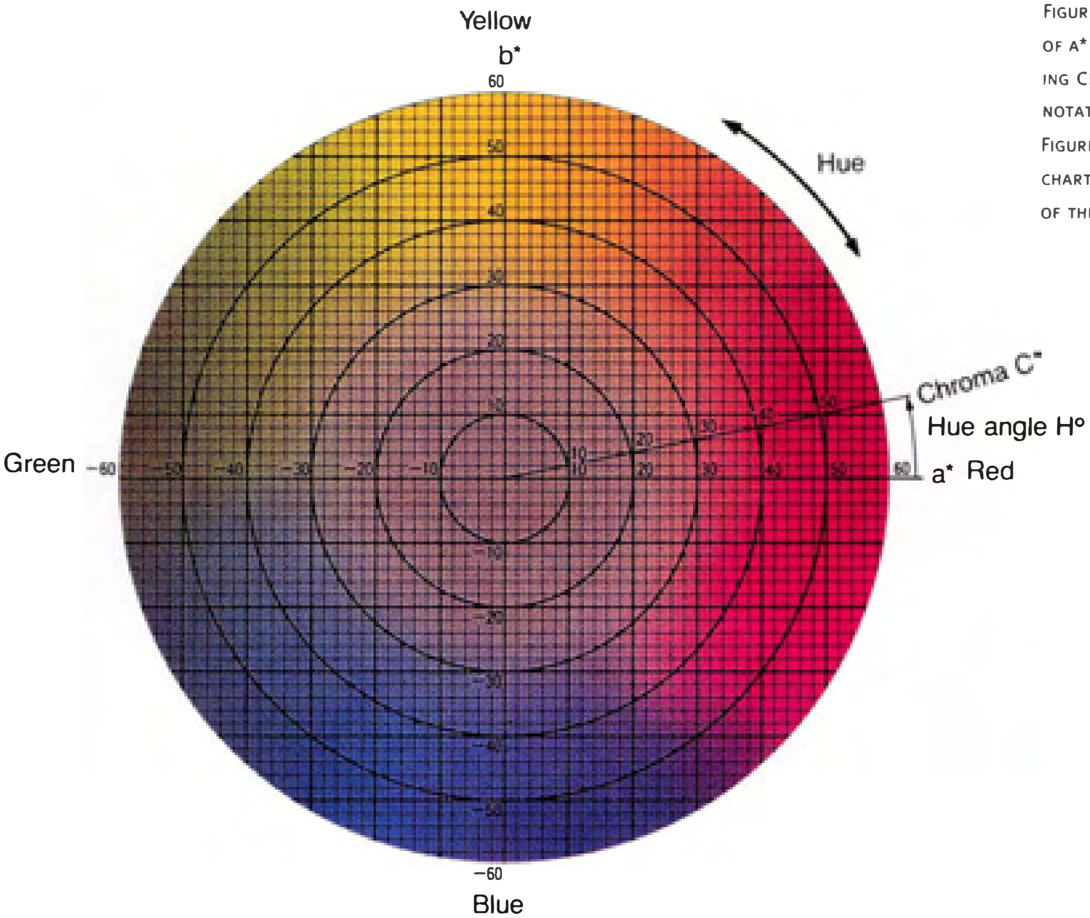


Figure 1a, left. Reproduction of a* b* color chart illustrating CIELAB system of color notation.

Figure 1b, below. Color Tone chart. (Both figures courtesy of the Minolta Corporation.)

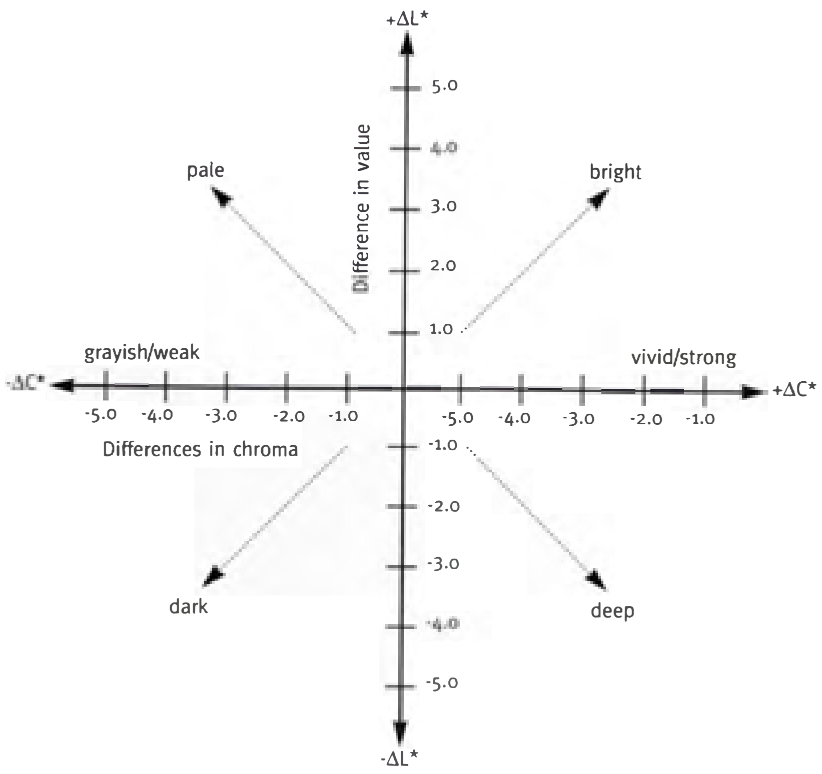
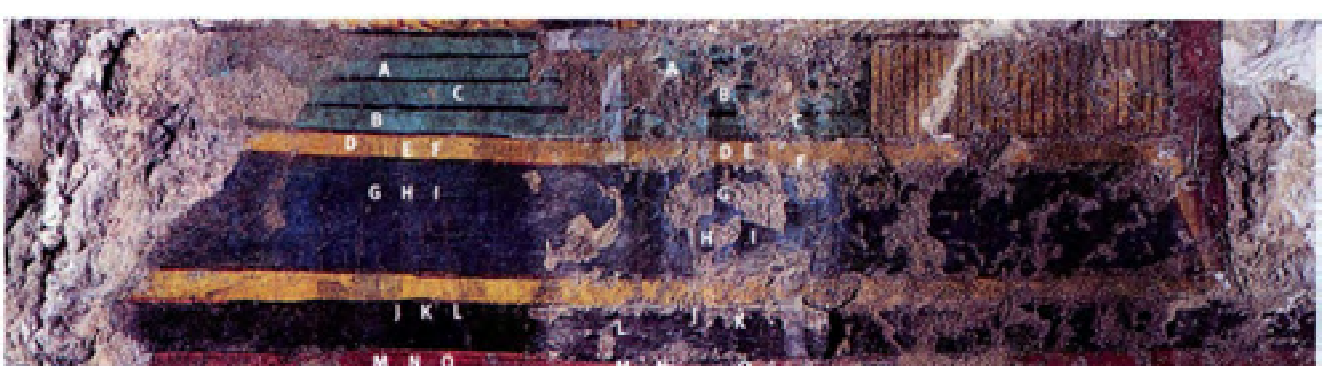


Figure 2a, right. View of chamber K, north wall, east side, after treatment, showing areas where the cleaning procedure was evaluated.
Figure 2b, below. Detail of Figure 2a before final treatment.



Because of inhomogeneity in the colors of the wall paintings, and the difficulty in precisely locating the measuring head at each desired point, three locations within each colored area were selected for measurement, and each location was measured three times. Instrumental reproducibility was calculated from the replicate measurement data.

Effects of the Cleaning Procedure on the Colors of the Wall Paintings

Before the color measurement campaign was begun in September 1987, the proposed cleaning method was tested on a small section of the wall paintings to assess the efficacy of the procedure. Surface contamination was removed from a small section of the back wall in the main burial chamber, chamber K, which contained blue, black, red, green, and yellow paint. This area provided an excellent opportunity to determine the effect of the cleaning method on the color measurement data. Figure 2a and 2b show the area where the treatment was evaluated, and also illustrate the method of recording the color measurement locations.

Color measurements were made at each cleaned area and at a nearby area that remained uncleaned. Unfortunately, it was impossible to make measurements of the original area before cleaning, because the proposed treatment had been undertaken in a previous campaign. However, the present color data serve to illustrate the magnitude and direction of the changes resulting from cleaning.

The b* versus a* color chart of the data, Figure 3, shows that the data for the cleaned areas lie farther from the origin than those for the uncleaned areas, indicating that the treatment increased the CIELAB chroma of the colors.

No measurable hue shift was detected after cleaning. Figure 3 shows that, for each of the five main colors, the data for the cleaned areas lie approximately on the radial line extending from the origin through the data points for

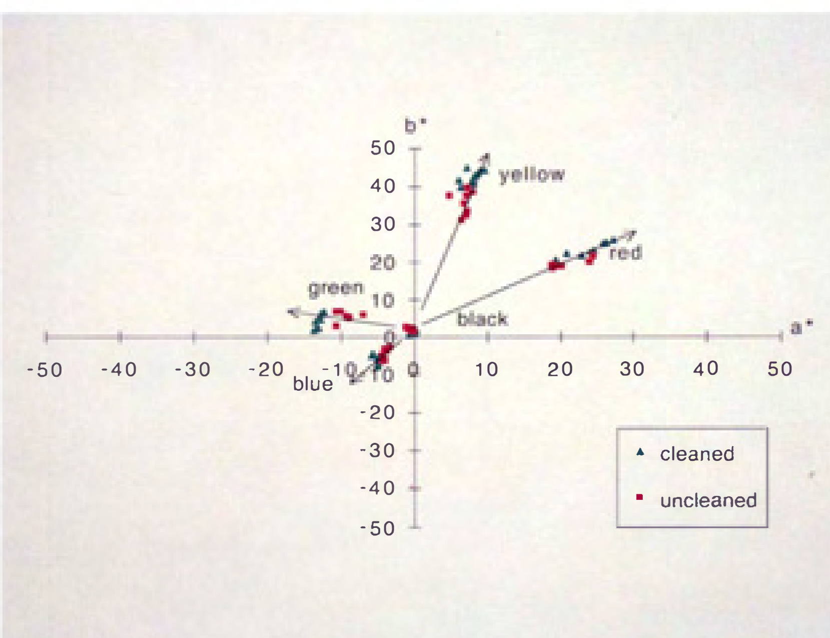


FIGURE 3. COLOR CHART OF B* VERSUS A* FOR UNCLEANED AND CLEANED AREAS IN CHAMBER K, SHOWING EFFECTS OF CLEANING ON COLOR.

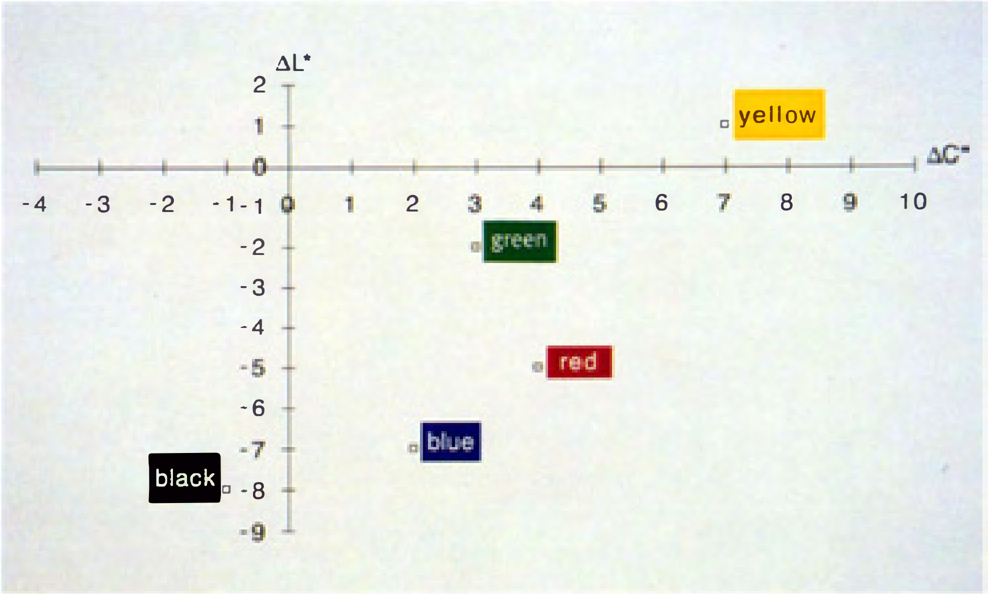


FIGURE 4. COLOR TONE CHART OF DATA IN FIGURE 3, ILLUSTRATING MAGNITUDE AND DIRECTION OF COLOR CHANGES AFTER CLEANING.

TABLE 1. CLEANED AND UNCLEANED AREAS IN THE TOMB OF NEFERTARI; CONVERSION FROM AVERAGE CIELAB TO MUNSELL.

	CIELAB data			Munsell data		
Area Description	L*	a*	b*	H	V	C
Cleaned black	24.3	-0.3	1.6	7.6Y	2.4	0.3
Uncleaned black	32.7	-0.6	2.1	8.9Y	3.2	0.3
Cleaned blue	32.9	-5.0	-6.1	5.0B	3.2	1.7
Uncleaned blue	39.4	-4.1	-4.6	4.8B	3.8	1.4
Cleaned green	48.5	-12.9	4.6	4.9G	4.7	2.5
Uncleaned green	51.4	-9.5	5.8	1.6G	5.0	1.9
Cleaned red	43.4	23.3	23.0	0.6YR	4.2	6.0
Uncleaned red	48.1	20.8	19.4	0.01YR	4.7	5.4
Cleaned yellow	60.5	8.0	42.5	0.4Y	5.9	6.6
Uncleaned yellow	59.3	7.2	36.0	0.2Y	5.8	5.6

the uncleaned areas. If a hue shift had occurred, the radius of data for the cleaned surfaces would not intercept the data points for the uncleaned areas.

Absence of hue shift is also suggested by the Munsell data in Table 1, which show changes in hue number but not overall hue. The green paint exhibits the largest change in hue number, registering a full chip of difference.

All of the above results are easily interpreted in light of the fact that a dirt layer covers the wall paintings. The cleaning process removes the light-colored dirt and returns the colors to a deeper intensity. The color tone chart in Figure 4 shows that reds, blues, and greens become deeper after cleaning (using the terminology indicated in the graph charts in Figure 1a and 1b), whereas yellows become brighter and more vivid, and blacks become darker.

For quantitative evaluation of the magnitude of color changes caused by the cleaning treatment, the data from cleaned and uncleaned areas have been reduced to the bar graph format shown in Figure 5. For blues and blacks the overall color change, ΔE, is dominated by a decrease in lightness, ΔL*. For reds and greens, ΔE is relatively evenly divided between ΔL*, Δa*, and Δb*. For yellows, ΔE is due largely to an increase in b* (positive b* values indicate relative yellowness).

Clustering of Data for Blues and Greens

Figure 6, a three-dimensional graph of the four primary colors (blue, green, red, yellow), shows the relative location of the data in color space and overall clustering into four main groups. Individual b* versus a* graphs for the

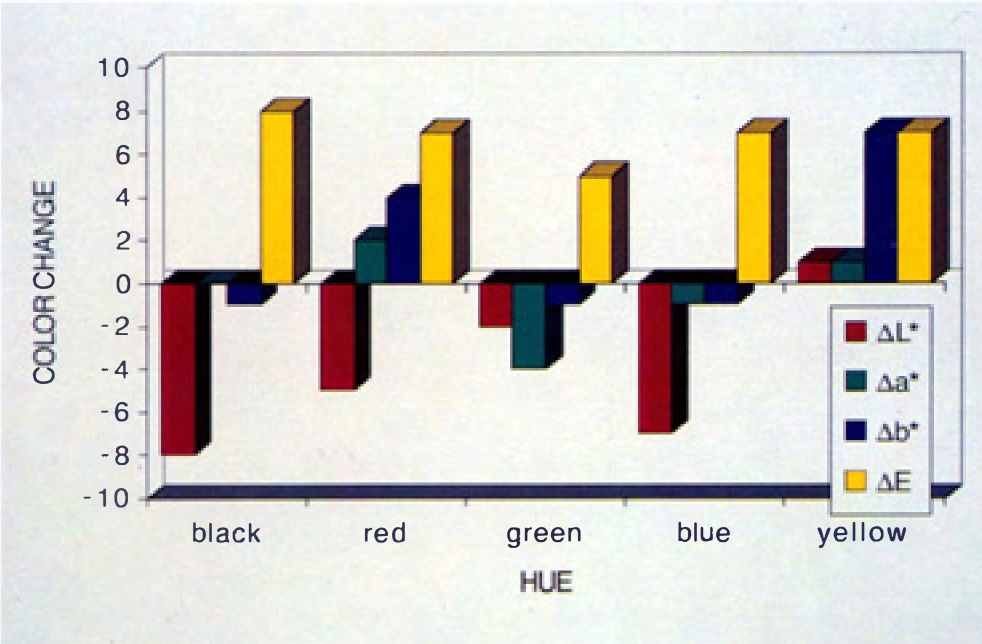


Figure 5. Bar graph of data from Figure 2, showing magnitude of color changes due to cleaning.

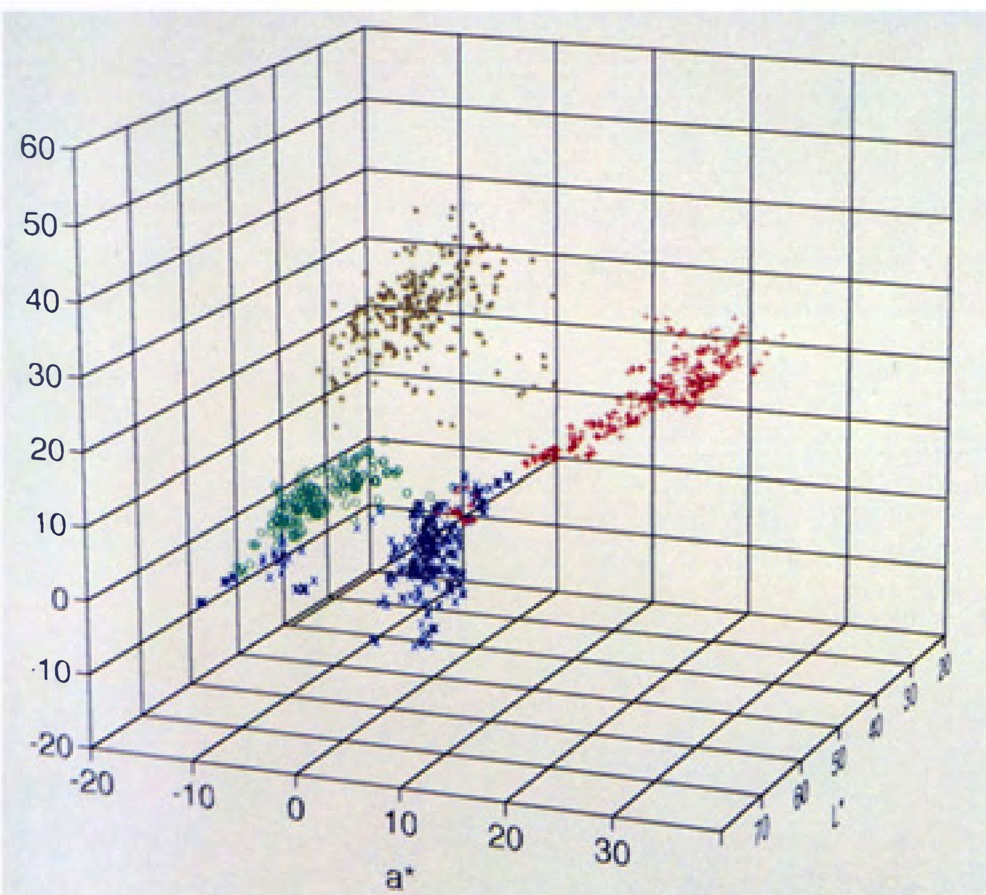


Figure 6. Three-dimensional graph of measurement data for the four primary colors (blue x, green o, red +, yellow •). Note clustering of data into groups based on hue and relative orientation in color space.

four major colors sorted by chamber reveal clustering of the data for blues and greens. In Figure 7, the data for the blue areas in stairway I and chamber K are spread over the entire region of the graph, whereas for the other chambers the data cluster near the top.

For the greens, shown in Figure 8, the data for chamber K are located at the left side of the graph. Because the spread of the data is well outside the reproducibility limits established for the other chambers, as shown in Table 4, the clustering into two distinct groups appears to be an actual effect. Furthermore, the magnitude of this effect exceeds the variability that would result from cleaning alone.

The clustering may be caused by the nature of the pigmentation in the blues and greens, which were identified as the synthetic pigments Egyptian blue and Egyptian green. Batch-to-batch variability of these manufactured pigments may have resulted in two distinct shades of blue and green, which could be detected by the CR-121. This hypothesis requires sampling and analysis for verification. In support of this hypothesis, the mineral pigments yellow ochre, hematite, and burnt umber would be less likely to fall, individually, into two distinct categories. Rather, each would presumably possess a single, broad range of color.

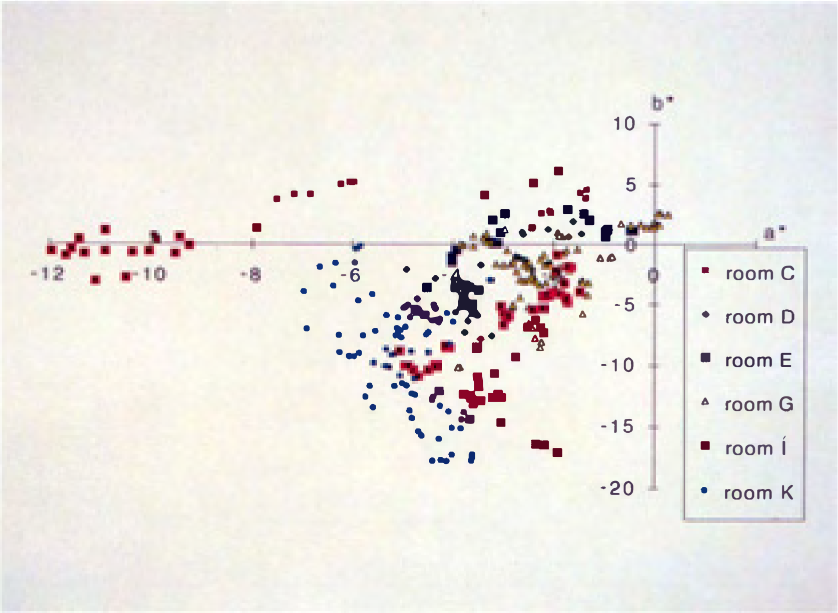
Instrumental Evaluation and Data Evaluation

The performance evaluation of the Minolta Chroma Meter CR-121, serial number 151066, is also of principal interest here. In common with other tristimulus colorimeters, the three filters used to approximate the response of the CIE 1931 standard observer permit the instrumental design to be simplified, but at the expense of accuracy. Thus, instrumental accuracy, stability, and reproducibility were evaluated in order to assess the effects of each on the measurement data.

In measurements of BCRA CCS-II color reference tiles, the CR-121 consistently yielded results accurate to within one Munsell chip of the nominal value for the entire set of tiles, as shown in Table 2. This performance is comparable to that of many human observers, without the corresponding limitations (eyestrain, fatigue). This level of accuracy is perfectly acceptable for most field conservation work.

In a long-term program of color measurement such as the tomb of Nefertari project, in which color changes are to be evaluated over time, stability is an important instrumental parameter. The measuring device must not exhibit erratic behavior, significant drift, or instability—any of which would make accurate assessment of color change impossible.

FIGURE 7. B* VERSUS A* COLOR CHART FOR BLUE AREAS, SHOWING DATA CLUSTERED BY CHAMBER.



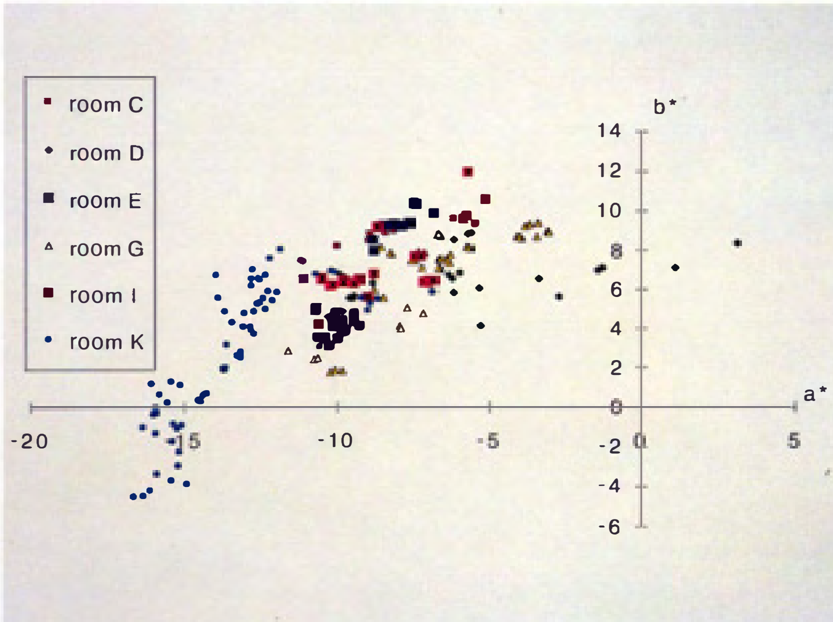


Figure 8. b* versus a* color chart for green areas, showing data clustered by chamber.

Table 2. Munsell and CIELAB data for BCRA color reference tiles; comparison of manufacturer's data to CR-121 measurement data.

	Manufacturer			CR-121			ΔE
BCRA Tile	H	V	C	H	V	C	
Pale gray	2.1G	8.1	0.1	6.8GY	8.0	0.2	1.0
Mid gray	1.7G	5.4	0.1	0.9G	5.3	0.1	1.2
Deep gray	2.4GY	2.5	0.1	5.5GY	2.5	0.2	0.8
Deep pink	0.1R	3.9	6.4	1.8R	3.9	6.3	2.9
Red	8.3R	3.4	12.6	9.1R	3.4	12.4	4.0
Orange	2.8YR	6.4	13.2	3.4YR	6.2	12.9	3.5
Bright yellow	5.7Y	8.3	12.7	6.0Y	8.0	11.7	7.7
Green	3.0G	5.0	6.8	3.9G	4.8	6.1	5.1
Cyan	9.6B	4.8	8.7	0.2PB	4.7	8.6	2.2
Deep blue	8.1PB	0.8	9.4	7.6PB	0.8	7.4	8.3

Note: Munsell conversion performed by a computer program loaned to the GCI by Max Saltzman. Conversion of chromaticity data to CIELAB color difference units was made using the CIE 1976 L*a*b* equation and the CIE 1976 color difference equation.

The stability of the CR-121 was determined by periodic measurement of the CCS-II tiles. Under present storage conditions the tiles are considered stable far beyond the duration of the project. The data in Table 3 are excerpted from the stability measurements that have been collected to date. They exhibit no pronounced long-term drift over the first two years and approximately two units subsequently.

It is possible to improve the accuracy of the instrument, and thus correct for long-term directed drift, by using linear regression analysis. The computer program that performs this correction was developed for Max Saltzman, an independent consultant, by Roy Berns (private communication, April 1990) and his students at the Rochester Institute of Technology. Essentially, the program relies on statistical equations to regress the measured set of tristimulus values onto the manufacturer's data set.

Table 3. Periodic measurement data for BCRA CCS-II tiles; measurement data for evaluating instrumental stability.

BCRA Tile	Date	L*	a*	b*	ΔE	H	V	C
Pale gray	9/86	81.7	-0.8	1.0	ref	6.8GY	8.0	0.2
	12/86	81.6	-0.8	1.0	0.1	6.8GY	8.0	0.2
	9/87	81.4	-0.8	1.0	0.3	6.8GY	8.0	0.2
	3/89	79.8	-0.8	0.5	2.0	1.3GY	7.8	0.1
	3/90	81.6	-0.8	0.5	0.5	1.3GY	8.0	0.1
Mid gray	9/86	55.0	-0.6	0.4	ref	0.9G	5.3	0.1
	12/86	55.1	-0.6	0.4	0.1	0.9G	5.3	0.1
	9/87	55.2	-0.6	0.7	0.4	6.2GY	5.4	0.1
	3/89	53.9	-0.6	0.4	1.0	0.9G	5.2	0.1
	3/90	55.2	-0.6	0.0	0.4	1.2BG	5.4	0.1
Deep gray	9/86	25.3	-0.9	0.8	ref	5.5GY	2.5	0.2
	12/86	25.9	-0.9	1.1	0.6	6.1GY	2.5	0.2
	9/87	25.6	-0.7	1.1	0.5	3.9GY	2.5	0.2
	3/89	25.0	-0.7	0.9	0.4	5.5GY	2.4	0.2
	3/90	25.6	-0.9	1.0	0.4	6.1GY	2.5	0.2
Deep pink	9/86	40.4	28.6	7.7	ref	1.8R	3.9	6.3
	12/86	40.4	28.5	8.0	0.3	2.0R	3.9	6.2
	9/87	40.4	28.6	7.7	0.0	1.8R	3.9	6.3
	3/89	39.7	27.7	8.0	1.2	2.2R	3.9	6.0
	3/90	40.6	28.1	8.2	0.7	2.1R	3.9	6.2
Red	9/86	35.0	50.0	42.4	ref	9.1R	3.4	12.4
	12/86	35.2	50.2	42.6	0.3	9.1R	3.4	12.5
	5/87	35.2	49.8	42.6	0.4	9.1R	3.4	12.4
	9/87	35.4	50.2	42.5	0.5	9.0R	3.4	12.5
	3/89	34.8	48.5	42.4	1.4	9.3R	3.4	12.1
	3/90	35.6	48.9	42.2	1.3	9.2R	3.5	12.2
	5/92	35.7	48.7	41.6	1.7	9.1R	3.5	12.2
Orange	9/86	64.1	36.0	64.3	ref	3.4YR	6.2	12.9
	12/86	64.2	34.9	64.6	1.1	3.7YR	6.2	12.8
	9/87	64.2	35.1	64.8	1.0	3.7YR	6.2	12.8
	3/89	64.0	34.7	65.9	2.0	3.9YR	6.2	12.9
	3/90	64.6	33.4	65.1	2.7	4.1YR	6.3	12.6
Bright yellow	9/86	81.2	-6.8	84.2	ref	6.0Y	8.0	11.7
	12/86	81.5	-7.4	83.6	0.9	6.2Y	8.0	11.6
	9/87	81.3	-7.4	83.5	1.0	6.2Y	8.0	11.6
	3/89	81.3	-7.4	83.5	1.0	6.2Y	8.0	11.6
	3/90	81.6	-7.8	81.7	2.7	6.4Y	8.0	11.3
Green	9/86	50.0	-31.9	12.8	ref	3.9G	4.8	6.1
	12/86	50.2	-32.3	12.7	0.5	4.0G	4.9	6.2
	5/87	50.0	-31.3	12.2	0.8	4.1G	4.8	6.0
	9/87	50.0	-31.8	12.3	0.5	4.1G	4.8	6.1
	3/89	49.0	-30.7	11.5	2.0	4.2G	4.8	5.9
	3/90	49.9	-31.1	10.9	2.0	4.6G	4.8	5.9
	5/92	49.3	-30.8	10.8	2.3	4.6G	4.8	5.9
Cyan	9/86	48.1	-9.5	-33.7	ref	0.2PB	4.7	8.6
	12/86	48.0	-9.0	-33.5	0.5	0.4PB	4.6	8.6
	5/87	48.1	-9.0	-33.6	0.5	0.4PB	4.7	8.6
	9/87	47.9	-8.5	-33.4	1.0	0.5PB	4.6	8.5
	3/89	47.1	-7.7	-33.9	2.1	0.8PB	4.6	8.6
	3/90	47..8	-7.8	-34.3	1.9	0.8PB	4.6	8.7
	5/92	47.2	-7.5	-34.2	2.3	0.9PB	4.6	8.6
Deep blue	9/86	9.0	19.9	-31.6	ref	7.6PB	0.8	7.4
	12/86	8.1	19.9	-31.3	0.9	7.6PB	0.8	7.3
	9/87	9.0	19.4	-31.0	0.7	7.6PB	0.8	7.3
	3/89	8.1	19.6	-30.7	1.2	7.6PB	0.8	7.2
	3/90	8.1	18.4	-29.7	2.5	7.5PB	0.8	6.9

Application of these regression results improves the measurement results relative to the ccs-II tiles, thus correcting for a significant amount of long-term drift.

Uniformity of the colored surfaces to be measured has a direct influence on the reproducibility of the data. Replicate measurements of ideal samples, such as the planar, uniformly colored ccs-II tiles, showed insignificant variations in chromaticity (<0.001 for xy, <0.1 for Y). However, these values overestimate the actual reproducibility of the measurement data from the tomb, because the paint layers in the wall paintings are not uniformly applied, and many of the surfaces are curved.

To provide a realistic assessment of measurement reproducibility within the tomb, the following program was undertaken. Within each colored area, three points were selected for measurement. At each point, triplicate measurements were made and expressed in chromaticity coordinates. After collection the data were sorted into five main colors: blue, green, red, yellow, and neutrals (whites and blacks).

Within each main color, the first measurement at each point was arbitrarily chosen as the reference measurement, and color differences were calculated for the two remaining measurements with respect to this reference point. Color differences were expressed in terms of ΔL^* (variation in lightness), Δa^* and Δb^* (both of which express the hue change), and ΔE (overall color difference).

		ΔL^*	Δa^*	Δb^*	ΔE
Blue	Mean	0.9	0.3	0.7	1.3
	rsd	1.0	0.4	0.8	1.2
Green	Mean	0.8	0.6	0.5	1.3
	rsd	1.3	0.9	0.7	1.6
Red	Mean	0.7	0.6	0.6	1.2
	rsd	0.8	0.7	0.7	1.1
Yellow	Mean	0.8	0.5	1.2	1.6
	rsd	0.9	0.5	1.6	1.7

Table 4. Reproducibility of wall painting measurements; average of triplicate readings at each location.

The mean and standard deviation of ΔL^*, Δa^*, Δb^*, and ΔE were calculated for each of the four primary hues; the results are shown in Table 4. The values reported in this table reflect the entire set of data; none of the readings that exceeded the three sigma limits was disregarded. The variations between measurements at single locations were found to be roughly one unit of difference for L^*, a^*, b^*, and E. These numbers are much smaller than the typical spread of data for readings taken at cleaned and uncleaned areas, as discussed earlier.

In conclusion, it has been demonstrated that the Minolta Chroma Meter CR-121 performs at a level that makes it suitable for measuring the colors of the wall paintings in the tomb of Nefertari and evaluating color changes due to cleaning. The instrument possesses excellent reproducibility and accuracy. In periodic evaluation of stability, no directed drift could be detected after a three-year period; and after five years the directed drift was at a level for which mathematical correction could be made. In addition to these instrumental factors, its portability and ease of use make the CR-121 an ideal tool for conservation.

Michael Schilling is Associate Scientist, Scientific Program, The Getty Conservation Institute.

References

Billmeyer, Fred W., Jr., and Max Saltzman.
1981 *Principles of Color Technology.* 2d ed. New York.

Corzo, M. A., ed.
1987 *Wall Paintings of the Tomb of Nefertari: First Progress Report.* Cairo and Century City, California.

Simon, F. T., and W. J. Goodwin.
1958 Rapid graphical computation of small color differences, Union Carbide. *American Dyestuff Reporter* 47:105.


AGFA PAN 100

Photographic Documentation of the Nefertari Wall Paintings

Mahasti Afshar

Opposite. Proof sheet of glass-plate negatives of the tomb of Nefertari produced by E. Schiaparelli, ca. 1904. Courtesy of the Museo Egizio, Turin.

An understanding of the physical history of an object, monument, or site is essential when planning a conservation program. Engravings, paintings, and photographs are used by art historians to reconstruct the history of a subject and to understand the surface or structural alterations it has undergone over time. Using a comparative methodology much like that used by historians, conservators also gain valuable insights from historic photographs. More reliable than engravings or paintings, photographs contain information that is recorded with greater objectivity and detail. They also provide a source for understanding the rate of deterioration and the effects of previous restoration work. Photographs are often dated, or else contain information that enables a date to be assigned to them. Therefore, they can be used to create a chronology where enough photographic documentation is available. Photography is also used by the conservator as a basic tool for documenting actual conservation problems and treatments. Such documents serve future investigators and fulfill an important ethical mandate in conservation.

Fortunately, a large variety of historic photographs of the tomb of Nefertari exist today, albeit of varying quality, scope, and intent. They range from photographs produced by Egyptologists for recording and studying the tomb, to commercial postcards produced for the early tourists, to images made sporadically or reproduced more methodically in publications dealing with ancient Egyptian art. The photographic records produced by the Getty Conservation Institute between 1986 and 1992 that document the condition of wall surfaces before, during, and after conservation treatment are now part of this historical collection.

The following is a chronological survey of the photographic records of the tomb of Nefertari, beginning with the earliest historic photographs. Publications in which these photographs are reproduced have been listed in Section I of "Source Materials for the Study of the Nefertari Wall Paintings," at the end of this volume with the plates duly cited at the end of each bibliographic reference.

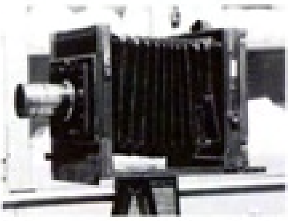
The earliest record of black-and-white photographs of the tomb of Nefertari is a collection of some 132 glass-plate negatives, taken under Ernesto Schiaparelli's directorship after his discovery of the tomb in 1904. With the exception of negative E621 which is 20 x 30 inches, details of interior walls are all in a 13 x 18-inch format, while exterior and general views of the site, totaling about twenty images, are 18 x 24 and 20 x 30 inches (Fig. 1). The original plates are housed in the photo archives of the Museo Egizio in Turin and are classified as: *Scavi Schiaparelli—Valle delle Regine e tomba di Nefertari—album 2 e 3.* They were taken by a member of Schiaparelli's mission,[1] Don Michele Pizzio (Figs. 2, 3),[2] in collaboration with the Egyptologist Francesco Ballerini (Fig. 4; Schiaparelli 1923). Don Pizzio was also responsible for making the architectural plans, as well as the model of Nefertari's tomb which is housed in the Museo

FIGURE 1, ABOVE. ERNESTO SCHIAPARELLI (FAR RIGHT) AT THE ENTRANCE TO THE TOMB OF NEFERTARI, VALLEY OF THE QUEENS, EGYPT. PHOTO: COURTESY OF THE MUSEO EGIZIO, TURIN.

FIGURE 2, TOP RIGHT. DON MICHELE PIZZIO, THE ITALIAN MISSION PHOTOGRAPHER. PHOTO: COURTESY OF THE MUSEO EGIZIO, TURIN.

FIGURE 3, MIDDLE RIGHT. DON PIZZIO PRODUCED ABOUT 132 GLASS-PLATE NEGATIVES WITH THIS CAMERA FROM 1904 TO 1905. PHOTO: JOHN ROSS.

FIGURE 4, BOTTOM RIGHT. FRANCESCO BALLERINI HELPED IN THE GRAPHIC AND PHOTOGRAPHIC DOCUMENTATION OF THE TOMB OF NEFERTARI. PHOTO: COURTESY OF THE MUSEO EGIZIO, TURIN.



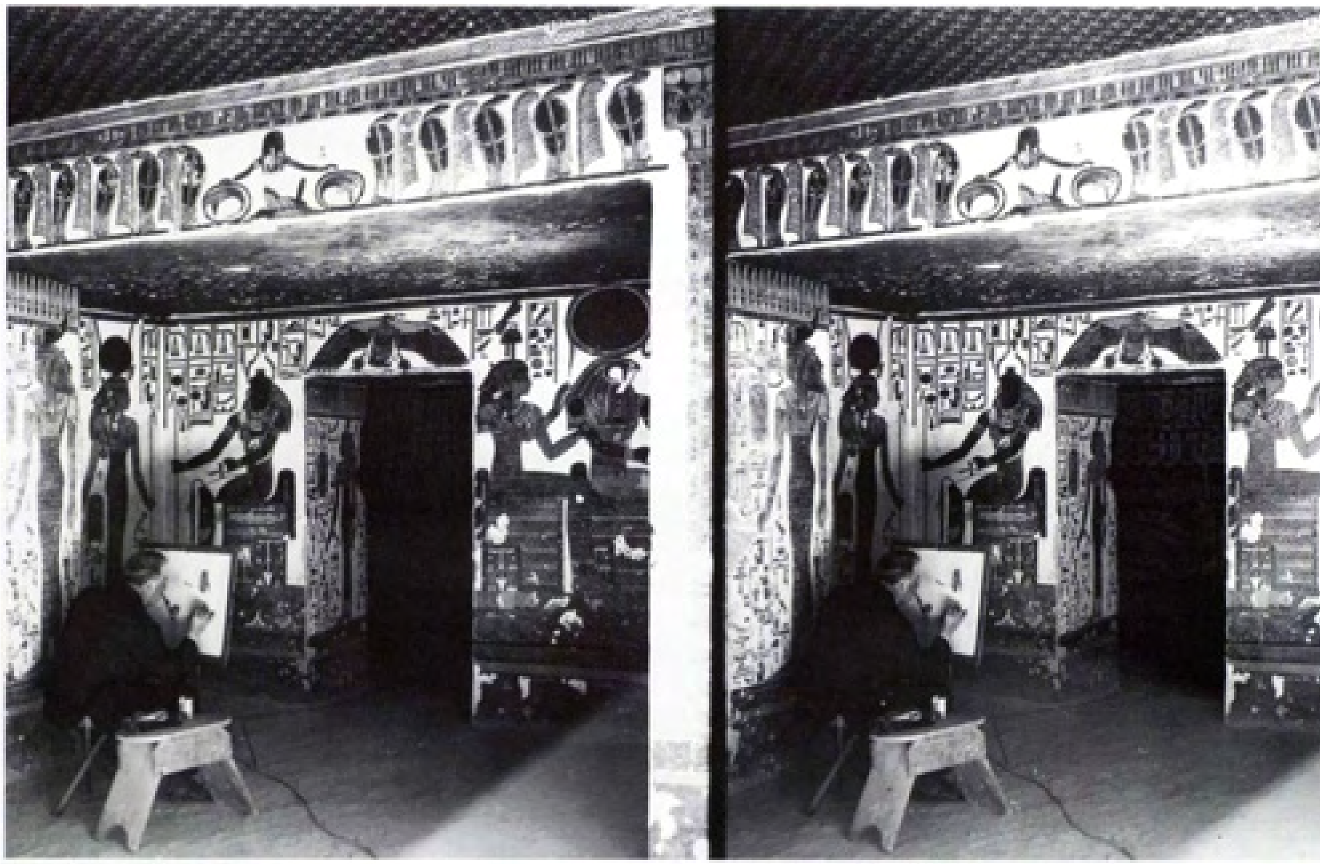


Figure 5. Stereo view of the east wall of recess chamber E. Baglione and Ballerini's drawings were later used to produce a 1:15 scale model of Nefertari's tomb. Photo: Courtesy of the Museo Egizio, Turin.

Egizio in Turin. The model is a color replica, in 1:15 scale, of original drawings by Ballerini and Eduardo Baglione, restorer at the Turin museum (Fig. 5). Born in 1870 in Casanova di Carmagnola, near Turin, Don Pizzio was ordained as a priest in 1894. From the early 1900s to 1930, he served as a parish priest to Italian immigrants in Brazil and was brought into contact with Schiaparelli through their mutual interest in charitable work. He collaborated with Schiaparelli on his last expedition at el-Gebelén as well, and later worked with Barnocelli in copying *a tappeto* the rock inscriptions at Monte Bego. He died a chaplain in Borgosalsario near Carmagnola in 1951.

While it was previously assumed that the Schiaparelli photographs spanned the period of 1904 to 1920—the length of the Italian archaeological mission's work in Egypt—they in fact date from 1904 to 1905, from Schiaparelli's discovery of Nefertari's tomb to the end of his activities at the site. It is known that, as director of the mission, Schiaparelli excavated the Valley of the Queens from 1903 to 1905, and moved his campaign to the Theban workers' village in Deir el-Medineh in 1905. He then went on to energetically explore other sites, ending with his last expedition at el-Gebelén in 1920.

Next, in chronological order, are two photographs by the Rev. Campbell, minister of Dundee parish, taken probably during 1906–1907 and reproduced in his *Two Theban Queens: Nefert-Ari and Ty-Ti,* in 1909. One is of Harsiese leading Nefertari (chamber E in the GCI tomb plan; Ia in Thausing and Goedicke 1971[3] [Thausing]), and the other is of the seven sacred cows scene (G south [GCI]; II [Thausing]), which seems to have always enjoyed a special appeal for photographers. Sir John Benjamin Stone, M.P., a prolific British photographer, also produced two views of the tomb during his travels in Egypt in 1907.[4]

Subsequent to these are sets of photographs produced by A. Gaddis and G. Seif, The Oriental Institute of The University of Chicago, Robert Mond, and Harry Burton of the Metropolitan Museum's Egyptian Expedition—all of which date from the second decade of the twentieth century. Gaddis and Seif's collection is hard to date with precision, but we do know that twenty-five images were purchased by The Oriental Institute in 1921. Copy prints are on file in the archives at the university in Chicago, with catalogue numbers 381–402 (three are not numbered). Nearly one thousand Gaddis and Seif large-format glass-plate negatives were purchased by the Epigraphic Survey of The Oriental Institute in 1987. They are stored at Chicago House in Luxor, which is presently in the process of cleaning, printing, and computerizing its photo archives, including its Nefertari collection.[5] A second set of Gaddis and Seif photographs is owned by the National Geographic Society Archives with a purchase date of 1930. Gaddis and Seif's old photography studio in Luxor continues to function today as a bookstore *cum* tourist shop, with an extensive holding of old photographs and postcards, including hand-colored images of Nefertari's tomb. Four of Gaddis and Seif's photographs were published in 1929 in Milan by Fratelli Treves among the 205 plates reproduced in Giulio Farina's *La Pittura egiziana*. These include: (a) a view of the upper chamber looking east (C, E [GCI]; I, Ia [Thausing]), (b) a column in the burial chamber (column II, east face [GCI]; #101 [Thausing]), (c) Nefertari making an offering to Hathor in the stairway, east side (I [GCI]; No. 53 [Thausing]), and (d) the seven sacred cows scene in the south side of the upper level auxiliary chamber (G [GCI]; No. 40 [Thausing]).

Robert Mond's photographs of the same chamber (G [GCI]; II [Thausing]) date from 1914 to 1916 (Fig. 6a, b). These black-and-white plates are of particular interest for their mosaic reconstruction of each wall painting to scale and are housed at Oxford University's Griffith Institute in the Ashmolean Museum. Mond started excavating in Egypt in 1902 and finished with 4,000 negatives of about fifteen tombs, including some color photographs where it was possible to use reflectors to throw sunlight into tomb chambers. Mond originally gave custody of his collection of photographs to the Archaeological Institute of Liverpool University and offered his camera—which E. Sanger Shepherd had made to his specifications—to The Metropolitan Museum of New York for its Egyptian expedition. Mond constructed a special, portable electric-lighting installation and used a small "motor-dynamo" to photograph the tomb exteriors. He constructed other devices for his photographic work as well, including a cast-iron carriage for the camera that ran on rails and allowed the apparatus to be raised or lowered as desired. The camera lamp had a set of incandescent attachments and used a lens of very deep focus to ensure sharp images. Mond avoided using color-sensitive plates in order to decrease the length of exposure time, and made two separate shots of each subject to avoid loss in case of breakage. Details of his material and methodology were published after an illustrated lecture that he delivered at the meeting of the Royal Photographic Society in 1932 (Mond 1933).

The Metropolitan Museum of Art's Egyptian Expedition resulted in a collection of more than sixty photographs of exceptional quality taken by another Englishman, Harry Burton, from 1920 to 1923 (Fig. 7). Burton was an experienced fieldworker who had a penchant both for objectivity and aesthetic worth. He was also a proven improviser and is known to have hung blackout curtains in empty tombs which he used as darkrooms! His original 18 x 24-inch glass-plate negatives are stored at the museum's Egyptian Department archives in New York. The exterior photographs are marked M524, M525, and T278. Interior views are marked as follows: 1920/21: T855–874; 1921/22: M4147; and T1038–1078 (Burton 1923).

The last important collection is an extensive set of black-and-white images by Ghazouli (1958) and Fathy Ibrahim (1965), photographers of the Egyptian Antiquities Organization (EAO). This historical collection is housed at the EAO Documentation Center in Zamalek, Cairo, and is the largest and most meticulously documented collection of its kind.

The earliest color photograph that has come to light is a Kodachrome print by B. Anthony Stewart which appears in the April 1940 issue of the *National Geographic Magazine,* Vol. LXXVII, No. 4 (Price 1940: Pl. IV). It is a view of the entrance to an upper level passageway (D east wall [GCI]; Ia [Thausing]). Also in color are three photographs taken in 1953 by Claudio Emmer. One is of the well-known portrait of Nefertari playing the *senet* game (C [GCI]; I [Thausing]). The other two show the queen offering a gift of fine linen to the god of craftsmen, Ptah, and in the act of worship, respectively—both in the upper level chamber that contains the famous sacred cows scene (G [GCI]; II [Thausing]). Emmer's photographs were published in Geneva in the French and English editions of *La Peinture égyptienne/Egyptian Painting* by Arpag Mekhitarian, secretary general of the Fondation Egyptologique Elisabeth at Brussels (Mekhitarian 1954). This book is part of a series

Figure 6a, above. Robert Mond's mosaic photographs of the east wall of chamber G, ca. 1914–1916.
Figure 6b, left. Mond's reconstituted photograph of the same wall. Photos: Courtesy of the Griffith Institute, Oxford University.

Figure 7. Detail of the south wall of chamber C. Burton's photographs are exceptionally clear records of the condition of the wall paintings in the early 1920s. Photo: Courtesy of The Metropolitan Museum of Art, New York.

titled *The Great Centuries of Painting,* planned and directed by Albert Skira. Of approximately the same date are three color photographs by Hassia, a photographer from Cairo. These were reproduced in André Lhote's previously mentioned *Les Chefs-d'oeuvre de la peinture égyptienne,* published by Hachette in the Arts du Monde series in 1954 (Lhote 1954). The photographs are of Nefertari being led by Isis—identified by Lhote as the goddess Hathor—(D north side [GCI]; Ia, No. 30 [Thausing]); Isis and Re-Herakhty in the south side of the east wall of the same chamber—again, with the identities of Isis and Hathor confounded; and lastly, the sacred cows scene. During the same period David S. Boyer took a photograph of the stairway connecting the upper level to the burial chamber. It was printed in an article by J. Caffery titled "Fresh Treasures from Egypt's Ancient Sands" in the November, 1955, issue of the *National Geographic Magazine* CVIII, No. 5.

Next in time is a major collection of some 155 color plates by E. Ritter dating from the late 1950s to 1960s that appear in Thausing and Goedicke's *Nofretari: A Documentation of her Tomb and its Decoration.* Published in Graz, Austria, in 1971, this is the single most complete documentation of the wall paintings in consistent scale to date. It is an invaluable book for anyone interested in this subject, but is unfortunately out of print and not as readily accessible as one would wish. The quality of the reproductions is inconsistent and somewhat inferior to the project as a whole. This shortcoming is offset, however, by the methodical display of frontal views of the walls and individual panels, each accompanied by a tomb plan on which the camera location and visual point are specified. Complemented by architectural views of the tomb interiors, these data collectively provide a coherent impression of the tomb structure, the interrelationship between connecting chambers, and the surface paintings. Undecorated areas of the walls are not documented. A tomb plan indicating the camera location and angle for location photographs precedes the plates which are organized in three groups: (1) architectural views (Plates 1–15), (2) the documentation in a 1:15 scale (Plates 16–130), and (3) details of the paintings (Plates 131–155).

In 1976 Kodak-Pathé reproduced full-scale photographic replicas of the wall paintings in Ramsès le Grand, an exhibition at the Galeries Nationales du Grand Palais in Paris. Ten views of the upper chambers, plus the stairway leading to the burial chamber, and an architectural view of the latter are reproduced in the exhibition catalogue in a chapter titled "La Reconstitution photographique de la tombe de Nofretari" (Kodak France 1976). Descriptive texts on the paintings and the dimensions of each chamber and stairway, and a plan and cross section of the tomb to scale accompany the illustrations. The replicas were also displayed at the Museo Arqueológico Nacional in Madrid in 1978 (Basch 1978). They toured Munich, Berlin, and Hildesheim on the occasion of the exhibit Nofret Die Schöne—Die Frau im Alten Ägypten during 1984 to 1985, and appeared in a pamphlet by Dietrich Wildung titled *Das Grab der Nefertari* that was published in 1984 in Munich by the Haus der Kunst. The replicas also formed part of The Great Pharaoh Ramses II and His Time exhibit at Montreal's Palais de la Civilisation in 1985, and toured Bruxelles (Musées Royaux d'Art et d'Histoire), Barcelona (Caja de Pensiones), and Geneva (Musée d'Art et d'Histoire) in the following year.[6]

Denis Moriarty's *Nefertari: For Whom the Sun Shines,* a 1987 production in the British Broadcasting Corporation's *Chronicle* series, is the visual source that introduces the most recent era of the tomb's history. This one-hour color

Figure 8. Aldana documented the Nefertari conservation project in more than 7,000 photographs from 1986 to 1992.

film documents the condition of the wall paintings in 1987, and contains related archaeological, historical, and scientific information. Its main focus is the Getty Conservation Institute/Egyptian Antiquities Organization Nefertari conservation project. A short version of the video running about eleven minutes was produced on the occasion of the exhibition In the Tomb of Nefertari: Conservation of the Wall Paintings, that opened at the J. Paul Getty Museum on November 12, 1992. The exhibition was a collaborative venture between the Getty Conservation Institute and the J. Paul Getty Museum. Nefertari photographs used for didactic purposes and in the exhibit catalogue were the work of the Mexican photographer Guillermo Aldana, who was also responsible for the full-scale photographic reproduction of chamber G displayed at the exhibit (*In the Tomb of Nefertari* 1992; Fig. 8).

As an integral part of the Getty Conservation Institute's conservation project, Aldana has produced the most extensive and systematic collection of photographic documents of the Nefertari wall paintings to date. The documentation covers the conservation problems—including past restorations—as well as the methods and techniques used by the GCI conservation team throughout the six years. Taken together with the earlier historic photographs, these sources provide invaluable data regarding the kind and quality of damage sustained by the wall paintings over the eighty years that separate the tomb's discovery and the recent conservation of its wall paintings.

Numbering over 7,000 images taken from September 1986 to April 1992, the photographs document the condition of the wall paintings before, during, and after their conservation treatment. For purposes of comparison, the collection includes 4 x 5-inch transparencies in both color and black-and-white, taken from the same angles and covering the same wall space as Schiaparelli's original photographs. The conservation program itself, from emergency consolidation through final treatment and cleaning has been documented in 35 mm transparencies, with some areas recorded in a 4 x 5 format as well.

The slides are organized chronologically according to year and campaign dates. The slides within each section are identified and labeled in a numbered sequence of treatment events. Each slide has two labels. Top labels are marked "Tomb of Nefertari" with captions below giving the general category to which the slide belongs; e.g., "Before Treatment; salts." The bottom labels indicate the exact location of each shot and give more specific information, such as, "old repairs; losses; repainting," etc. The different chambers and passageways in the tombs are identified on the slides by an alphabetical system (A–Q). The upper chambers include areas A–G; the stairway, H–J; and the lower chambers, K–Q. Different walls are indicated by compass direction.

The collection is housed in a series of three-ring binders. Information sheets have been inserted at the front of each binder and before each section. The front sheets list the different sections of slides contained in that file. The internal sheets give more detailed information on the subject area grouped in that section.

These records were recently complemented by a video documentary produced by the Mexican television center, Televisa, S.A., in cooperation with the Getty Conservation Institute. The video program is directed by Héctor Tajonar, based on a script by Jeffrey Levin titled *Search for Eternal Life.* Filmed in late October 1992, this documentary includes information on the history, iconography, conservation problems, and treatment methods of the Nefertari wall paintings. This wealth of information has been documented in spectacular images deserving of this exquisite cultural monument. It goes without saying that a moving camera offers a sense of architectural space and depth beyond what may be achieved in still photography.

The future of visual documentation may well lie in the area of electronic imaging. Until such time as high technology becomes widely available and feasible, however, it seems clear that a well-planned combination of still pho-

Chamber K, south wall, east side. Above, Schiaparelli mission, ca. 1904. opposite, EAO-GCI project, ca. 1989. Photographs are a rich source of information on the rate and types of deterioration.

tography together with film or video productions is the best means for documenting the precious and fragile records of the human cultural heritage.

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Notes

1. In addition to Pizzio and Ballerini, the members of Schiaparelli's mission included Evaristo Breccia, Roberto Paribeni, Giovanni Marro, Pietro Baroncelli, Fabrizio Lucarini, Count Alessandro Casati, the Marquis Antonio di Soragna, Duke Tommaso Gallarati Scotti, Father Zaccaria Berti, Giacomo Biondi, Giulio Farina, Pietro Molli, Count Aldobrandino Malvezzi, and Virginio Rosa.
2. See Curto 1973:75.
3. Thausing and Goedicke (1971) use a different alphabetical and numerical order for tomb chambers and columns than the one adopted by the GCI and published in the *Wall Paintings of the Tomb of Nefertari* Corzo 1987). Both are cited here, as "GCI" and "Thausing," respectively.
4. One is a view of the *senet* game scene and the entrance door (C south); and the other, Isis leading Nefertari (E south). See *The Sir Benjanmin Stone Collection of Photographs c. 1860–1910* [microform]. London: World Microfilms Publications, 1988. Box 360: Print No. 27. Neg. No. 25631; and Print No. 28. Neg. No. 25639, respectively.
5. The Oriental Institute also has copies of three tempera facsimiles from Nina M. Davies' *Ancient Egyptian Paintings* (1936), Plates XCI–XCIII. More recent additions include fourteen images taken in 1986–1987 by Seif Taudros Ibrahim, the Epigraphic Survey photographer. These are housed in Chicago with catalogue numbers Chic.Or.Inst.photo. 2859–65, 3378–88, 3462.
6. For exhibition catalogues see *Nofret—Die Schöne: Die*

Frau im Alten Ägypten, and *La Femme dans l'Égypte des Pharaons,* which do not refer to Nefertari, however, for lack of directly related objects.

References

Basch, M.A., et al.

1978 *La Tumba de Nefertari.* Photographic Reconstruction: Kodak, S.A. Museu Arqueológico Nacional. Ministerio de Cultura, Dirección General del Patrimonio Artístico, Archivos y Museos. Monografías Arqueológicas, No. 4. Madrid.

Corzo, M. A., ed.

1987 *Wall Paintings of the Tomb of Nefertari: First Progress Report.* Cairo and Century City, California.

Curto, S.

1954 "Une Egittologo comaso: Francesco Ballerini." *Rivista Archeologica dell'Antica Provincia e Diocesi di Como* 135. Como.

Lhote, A.

1954 *Les Chefs-d'oeuvre de la peinture égyptienne.* Paris.

Mekhitarian, A.

1954 *La Peinture égyptienne.* Geneva.

______ . *Egyptian Painting.* S. Gilbert, tr. New York.

Mond, R.

1933 "A Method of Photographing Mural Decorations." *The Photographic Journal* 73. New Series, LVII: 12–14.

Price, W.

1940 "By Felluca Down the Nile." *National Geographic Magazine* LXXVII, No. 4 (April):467-68.

Schiaparelli, E.

1923 *Relazione sui Lavori della Missione Archeologica Italiana in Egitto (1903–20).* 2 vols. Vol. 1. *Esplorazione della "Valle delle Regine" nella Necropoli di Tebe.* Turin.

Thausing, G., and H. Goedicke

1971 *Nofretari: A Documentation of Her Tomb and Its Decoration.* Graz, Austria.

Environmental Monitoring at the Tomb of Nefertari

Shin Maekawa

The causes of deterioration of the wall paintings in the tomb of Nefertari have been the subject of many investigations (Plenderleith et al. 1970, Wojtuniak-Struzynska et al. 1973, Burns et al. 1988, Wilson-Yang and Burns 1989). The report published by UNESCO (Plenderleith et al. 1970) concluded that three deterioration processes may be affecting the paintings: seepage of rainwater, formation of sodium chloride crystals, and dehydration of the plaster.

The crystallization of salt, present in the bedrock limestone, can be confirmed on many surfaces of the limestone and on the paintings. However, the source of the water that activates the movement of salt has not been identified. Some investigators have speculated possible sources to be rainwater moving through fissures in the bedrock, occasional flooding through the tomb's entrance, water used in the initial preparation of the mud plaster and paint, and environmental moisture generated by visitors to the tomb.

Although several investigators have surveyed the microenvironmental condition of the tomb, none have produced complete year-round data for both the tomb and the surrounding Valley of the Queens (Burns et al. 1988). The UNESCO mission (Plenderleith et al. 1970) found the moisture content of the air outside the tomb to be less than that inside. Researchers observed a natural ventilation pattern: Cooler outside air entered the tomb at floor level, and warm air exited along the top of the entrance staircase. The report, based on measurements taken during January 1970, indicates that drying of the wall paintings and dehydration of the plaster took place during the cold season.

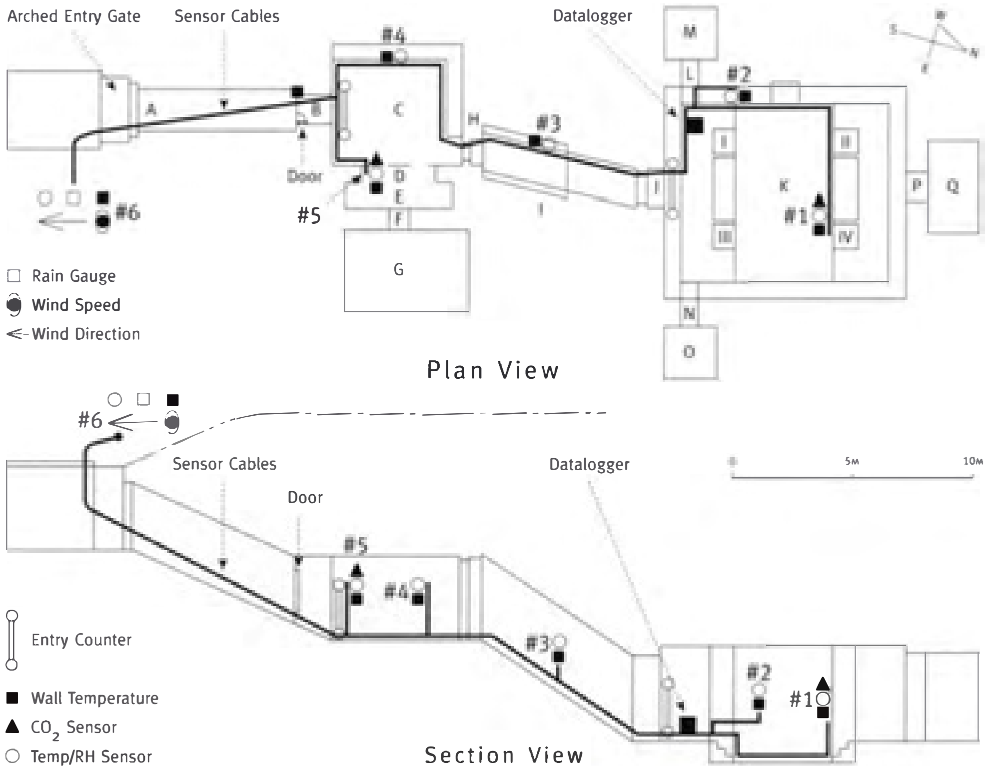


Figure 1. Microenvironmental monitoring system in the tomb of Nefertari.

The ICCROM report (Mora et al. 1981), which studied the impact of increased tourist numbers in the Theban tombs, concluded that the climatic impact of visitors was well below levels considered to be dangerous. The report also recommended continuous monitoring and data collection of the tomb's microenvironment and the outside environment. Small yet popular tombs such as those of Tutankhamun and Sennedjem are constantly visited by an ever-increasing number of tourists. As a result, baseline relative humidity (RH) levels in these tombs have risen significantly, and microenvironments are being created that may be endangering the wall paintings in these tombs. The author's findings based on hand-held sensor readings indicate that deep or large tombs provide a less-than-safe microenvironment for visitors (low oxygen content and high carbon dioxide concentration), since these tombs handle a large volume of people with no monitoring of those parameters.

Due to the increasing numbers of tourists in the area since the early 1980s and renewed interest in the tomb of Nefertari brought about by recent publicity on the completion of the wall-painting conservation work, pressure on the Egyptian Antiquities Organization (EAO) to open the tomb to visitors has been high. However, operational procedures or criteria to ensure a minimum impact on the microenvironment of the tomb (such as the number of visitors, their length of stay, and their touring pattern) have not yet been established.

The objectives of this study are to document the microclimate and investigate the impact of visitors on the microenvironment of the tomb of Nefertari by measuring changes in air temperature, relative humidity (RH), and level of carbon dioxide in the tomb. The purpose of this and future environmental monitoring is to develop recommendations for the operational procedures and conditions necessary to maintain the microenvironment in the tomb and the state of preservation of the wall paintings.

Orientation and Geometry of the Tomb

A microenvironmental monitoring station was set up in the tomb of Nefertari, which is considered to be small in size compared to other tombs in the area. The tomb is oriented north to south and carved approximately 13 m deep into the limestone bedrock.

Figure 1 shows plan and section views of the tomb. The tomb consists of two major chambers: the upper chamber, C, and the burial chamber, K. There is a 3.3 m

Upper chambers	B	C	D	E	F	G	H	I
Volume	2.7	82.4	7.6	14.6	1.7	50.2	3.0	16.8
Lower chambers	J	K	L	M	N	O	P	Q
Volume	4.7	257.6	1.0	10.7	1.0	8.8	1.8	10.4

Volume of upper chambers (B + C + D + E + F + G + H) = 162 m^3
Volume of connecting staircase (I) = 17 m^3
Volume of lower chambers (J + K + L + M + N + O + P +Q) = 296 m^3
Total volume of tomb = 475 m^3

Table 1. Sectional volumes of the tomb of Nefertari. Unit of volume is in cubic meters. (See figure 1 for identification of sections.)

drop between the floors of the two chambers, which are connected by a staircase (I) approximately 7 m long. The staircase links the north wall of the upper chamber to the south wall of the burial chamber. The upper chamber is approximately 5.2 m square with a 3.1 m high ceiling. The rectangular burial chamber (10.5 x 8.4 m) has three split-level floors that are 2.7 m, 3.4 m, and 2.7 m from the ceiling. A painted steel entry door (1 m x 1.7 m) is attached to a large steel bulkhead on the south wall of the upper chamber. A step staircase, A, approximately 4.5 m long, leads to the arched entry gate of the tomb at ground level. Two rectangular rooms, D and E (1.2 x 4 m and 3.1 x 5.2 m), are connected to the east wall of the chamber in series through two passageways (3.1 x 0.8 m and 1.1 x 0.8 m). Three small chambers, M, Q, and O (4.0 x 2.3 x 1.5 m, 2.4 x 2.3 x 1.9 m, and 2.3 x 2.2 x 1.8 m), are individually connected to the west, north, and east walls, respectively, of the burial chamber. Table 1 indicates the approximate volume of each section of the tomb.

The Environmental Monitoring System

An autonomous monitoring station was installed in August 1991 to measure and record values of environmental parameters inside and outside the tomb. The data are stored in the station for three to four months and are periodically uploaded to a personal computer for analysis. Figure 2 gives a schematic overview of the system, which consists of a datalogger (programmable microprocessor-controlled measurement and control unit), self-powered storage module, multiplexer, relay driver, photovoltaic cell, rechargeable gelcell battery, and environmental sensors.

The large photovoltaic cell (30 watts rating) charges a rechargeable gelcell battery, which powers the entire system, including the datalogger and sensors. The datalogger controls the multiplexer and relay driver, which powers sensors and transducers on and off depending on the time of the day. Analog signals generated by the sensors and transducers are converted to digital values by the datalogger and are stored in self-powered, solid-state storage modules.

An air-temperature and relative-humidity sensor, sealed from solar radiation, is mounted approximately 1.5 m from the ground on a tripod, on which the solar panel was also mounted. The tripod is installed outside the entrance of the tomb as shown in Figure 1. A ground-surface temperature sensor and rain gauge are positioned adjacent to the tripod. Wind direction and wind speed sensors were installed on the tripod in May 1992, nine months after the initial installation. The datalogger and rechargeable battery of the station are placed inside the tomb for security and simplicity of design.

Two sets of sensors for air temperature, RH, and wall-surface temperature were positioned in the funeral and burial chambers (Fig. 1, #1, #2, #4, #5), and one set was installed in the staircase connecting the two chambers (Fig. 1, #3). One CO_2 sensor was also placed in each chamber (Fig. 1, #1, #5). These five sets of sensors were installed in the tomb for documenting the local as well as average changes near wall paintings. One additional set was positioned outside the tomb for documenting the outdoor conditions (Fig. 1, #6). The air-temperature, RH, and CO_2 sensors were mounted on lightweight tripods and positioned close (between 2 and 3 cm) to the wall surfaces where surface temperatures were measured. The surface-temperature sensors were mounted with Paraloid B-72 adhesive directly on the walls where the original painted surface had been lost.

The first set (#1) of the sensors was installed near the south side of column IV at approximately 1 m from the

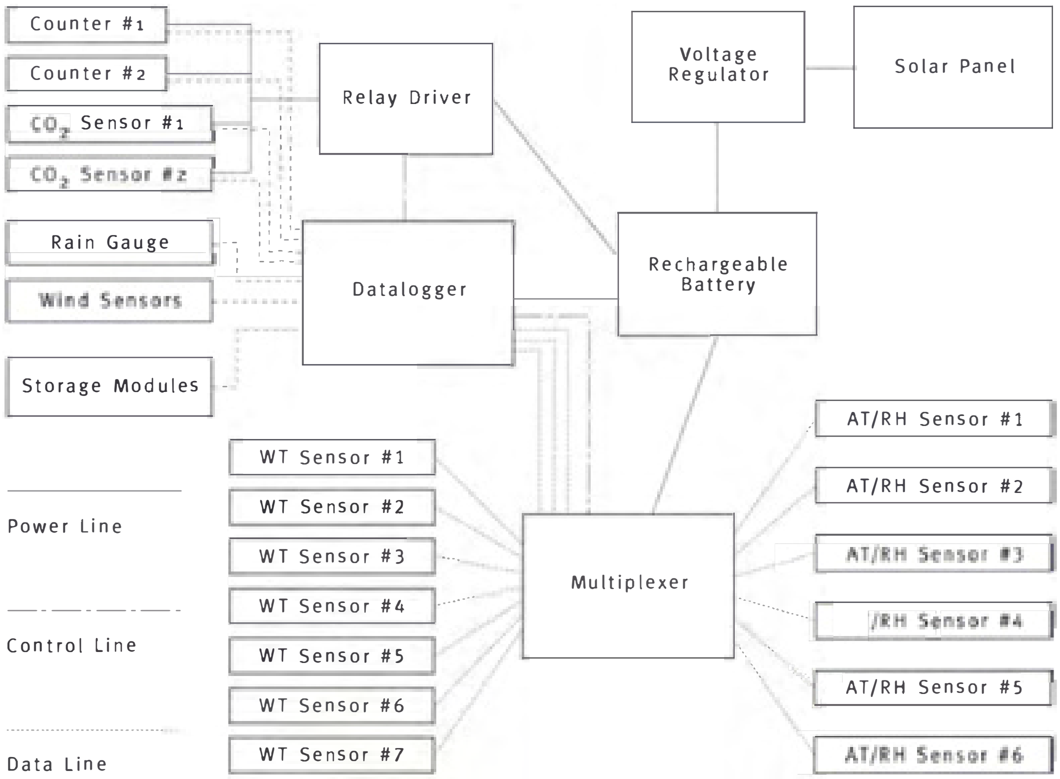


FIGURE 2. SCHEMATIC OF THE ENVIRONMENTAL MONITORING SYSTEM.

floor, and the second set (#2) was positioned near the south end of the west wall at 2 m from the floor in the burial chamber (K). The third set (#3) was positioned near the center of the west wall approximately 1 m from the floor in the stairway (I) between the upper and burial chambers. Set #4 was located on the limestone shelf near the west wall at approximately 1.5 m from the floor, and set #5 near the south wall (in subchamber D) 1 m from the floor in the funeral chamber (C).

An additional wall-surface temperature sensor was mounted on the outside face of the steel door at the entrance of the tomb (subchamber B), which constitutes a physical barrier between the tomb's microenvironment and the outside environment. The full complement of these sensors were positioned to measure the temperature and RH gradient from the entrance to the deepest end of the tomb as well as to estimate the moisture content in the surfaces of the paintings.

In addition, a CO_2 sensor was located approximately 1 m from the floor at the #5 position in the upper chamber and No. 1 position in the burial chamber to document the increased levels of carbon dioxide generated by visitors in each of the chambers and the subsequent decreased levels following their departure, allowing evaluation of the air-exchange rates of the tomb. Photoelectric sensors, which counted entries and exits of visitors, were positioned at the bottom of the stairways in the two major chambers (C and K) to keep track of the number of visitors who entered into the chambers and their residence time.

Due to the high power consumption of the CO_2 and photoelectric sensors, they were activated only during the operational hours of the site, between 7 A.M. and 4 P.M. With this reduced operating time, the system had enough battery power to sustain the operation of these sensors for three and a half days, even without sunshine.

Monitoring the Microenvironment

The microclimate monitoring conducted in the tomb by Esmael (1987) using portable temperature and RH recorders indicated that the microenvironment in the tomb was stable, despite frequent entries of small groups and occasional entries of large groups of visitors. However, preliminary measurements using hand-held sensors showed immediate increases of RH and CO_2 as visitors entered the tomb. These effects seemed to be greater in summer. Therefore, it was necessary to select a measurement interval short enough to capture the effects of the visitors' activities inside the tomb.

Although the tomb of Nefertari is presently closed to visitors, three other tombs in the Valley of the Queens are not; at these sites, groups of thirty to forty visitors are taken on guided tours with an average duration of 15 minutes each. The tours are conducted between 7 A.M. and 4 P.M. daily, often with no intervals between tours. Therefore, the sampling rate for such monitoring must be carried out at least once every 7.5 minutes during visiting hours to capture the effects of entry and exit activity.

At present, the tomb of Nefertari is officially open only to distinguished national guests, and to international scholars on recommendation of the director of the Getty Conservation Institute (GCI) and with the permission of the chairman of the EAO. Although it is difficult to estimate how long these visitors spend in each chamber, a reasonable estimate is that each tour lasts at least 30 minutes—a minimum of 15 minutes each in each of the upper and lower chambers—long enough for the guests to receive detailed explanations and comments from guiding curators and Egyptologists. Three measurements (taken soon after the entry of visitors and again just before and after their exit from the chamber) can be collected in each chamber while it is occupied; 5 minutes is used as a sampling period. (A 7.5-minute sampling time may generate only one set of data in the chamber.) The smaller the sampling interval, the more detailed the recorded information can be. However, the limitation of the station's memory will ultimately determine the maximum sampling rate possible during periods of visitor activity.

On the other hand, a lower sampling rate is sufficient for nonvisiting hours, between 4 P.M. and 7 A.M., since changes of microenvironmental parameters are very gradual at night. Climatic data are normally collected once an hour, but more detailed climatic information may be evaluated by recording higher sampling rates. A 15-minute sampling rate, for example, would provide high enough resolution on changes of wind conditions and sudden increases and drops of temperature without overspending the available memory of the station.

Although the system is capable of being programmed for the several sampling or recording intervals discussed above, a 5-minute interval was selected for recording air temperature, relative humidity, CO_2 concentration, wind direction, and wind speed around the clock. This interval was chosen for logistical reasons: Members of the GCI staff were scheduled to travel to the site at least once every three to four months, the maximum amount of time over which the two storage modules can continuously collect data at 5-minute intervals. Each time staff members arrived, they replaced the storage modules connected to the station for data recovery.

The temperatures of the tomb's wall surfaces are stable throughout the year at approximately 29 °C. Heat generated by visitors or cooler air from the outside affects the wall temperature very little, since the walls are buffered by the enormous rock mass at a constant temperature. Therefore, the sampling rate of once an hour is satisfactory.

Data Collection

One full year of monitoring has been successfully completed since the installation of the station on August 5, 1991. The first set of data was collected November 12, 1991, but only the data generated between August 5 and October 10, 1991, were recovered. The data generated between October 10 and November 12 were lost due to a logistical error of a replacement component. Therefore, monthly summaries for October and November 1991 were based on 10 and 18 days of data for those respective months. The second data recovery was performed on January 5, 1992; the third data collection was performed on May 11, 1992. The latest (fourth) data collection from the station was conducted on August 4, 1992.

The wall-painting conservators worked in the tomb between November 12 and December 16, 1991. The conservation work resumed on February 1 and continued until April 24, 1992. On April 2, the sensors located in the tomb were removed from the original positions for photodocumentation. These sensors were recalibrated and returned to their original locations on May 11. Therefore, data generated in the tomb during that period are incomplete at these specific locations.

Results of Environmental Monitoring

Several important microenvironmental conditions of the tomb were recorded during the first year. A total of four controlled experiments with visitor groups were conducted; the results of three of these are analyzed in this report. Conditions during the conservation work were documented at two separate time intervals during the winter season. Many unscheduled small and large group tours and some irregular entries into the tomb were also detected and recorded.

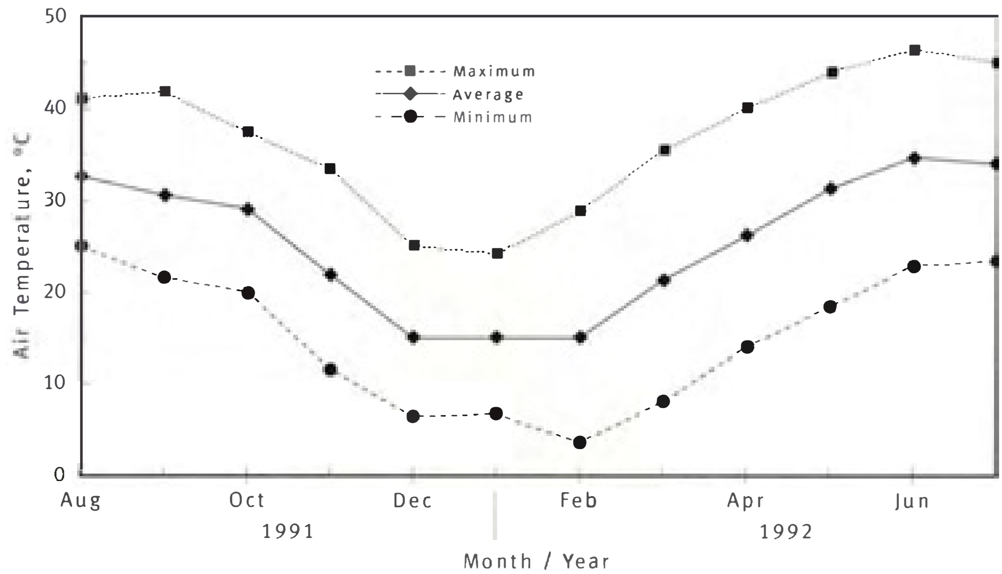
Microclimate of the Valley of the Queens

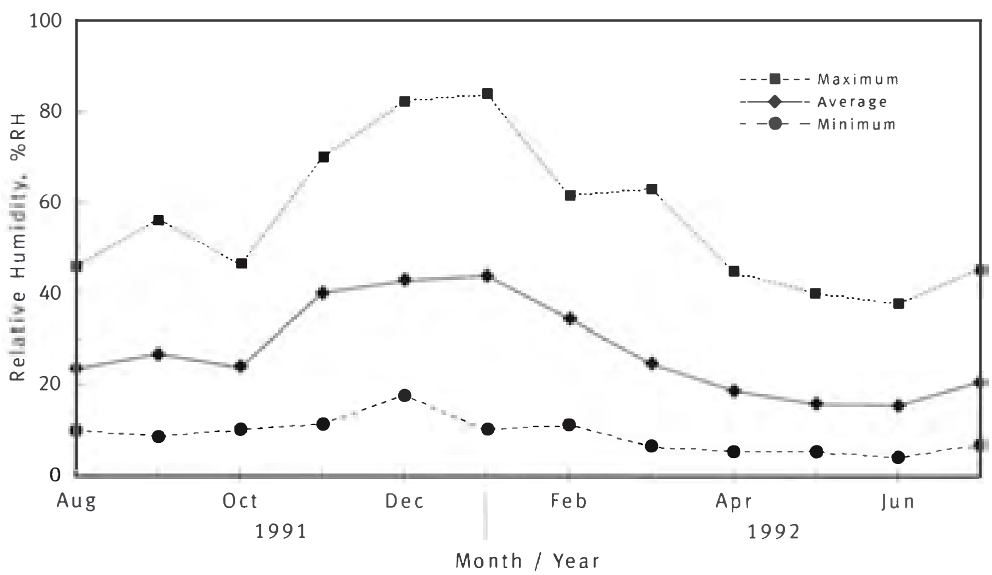
Heating due to solar radiation and cooling by radiation heat loss dominate the climate of typical desert regions, such as Egypt's Valley of the Queens. The climate consists of dry summers and mild winters with cold nights and dry, hot days throughout the year.

Figure 3 shows the annual summary of air temperatures measured by the monitoring station just outside the entrance of the tomb between August 1991 and July 1992. Considering the narrow range of climatic variability in the

Figure 3, right. Monthly average of air temperature outside the tomb.

Figure 4, below. Monthly average of relative humidity outside the tomb.





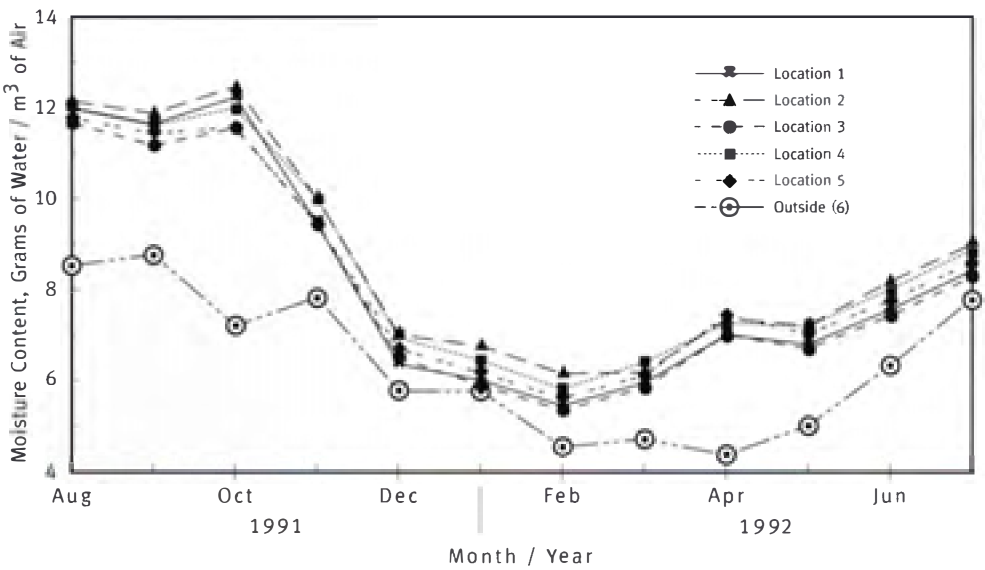


Figure 5. Monthly average of moisture content of air inside and outside the tomb.

Valley of the Queens, a year can be divided into two seasons: winter and summer. November through March may be considered winter, with the average air temperature remaining in the low 20s or high 10s °C. During the so-called winter months of 1991–1992, 6 and 33 °C were the minimum and maximum temperatures. The longer summer season, which starts in April and continues through October, has an average air temperature ranging between 29 and 35 °C. During the summer months of 1991 and 1992, the maximum air temperature ranged between 35 and 45 °C, and the minimum temperatures fell between 20 and 24 °C in early morning. The extremes of air temperature year-round were 46 °C in June and 6 °C in December.

Figure 4 shows the annual summary of relative humidity measured outside the tomb. In the summer months, it averaged approximately 18 to 22% RH; its daily swing ranged between 10 and 35% RH. The daily maximum seldom reached 50% RH, but the minimum often dropped below 10% RH on sunny afternoons. During winter, the average relative humidity was higher than in summer and ranged between 30 and 45% RH. It reached as high as 85% RH in early mornings and dropped to 5% RH in the afternoons on hot, dry days. The daily swings of relative humidity were larger in winter than in summer.

The average relative humidity ranged from 18% RH in June to 45% RH in December. Although the relative humidity was higher in the winter months than in summer, the moisture content in the air was 30 to 40% less in winter, as shown in Figure 5.

Wind measurements were conducted for three months from early May to July 1992. During this period, the wind speed averaged 1.8 m/sec from the south-southwest direction. The maximum recorded average wind speed over 5 minutes was 8.16 m/sec from the south-southwest direction in July 1992.

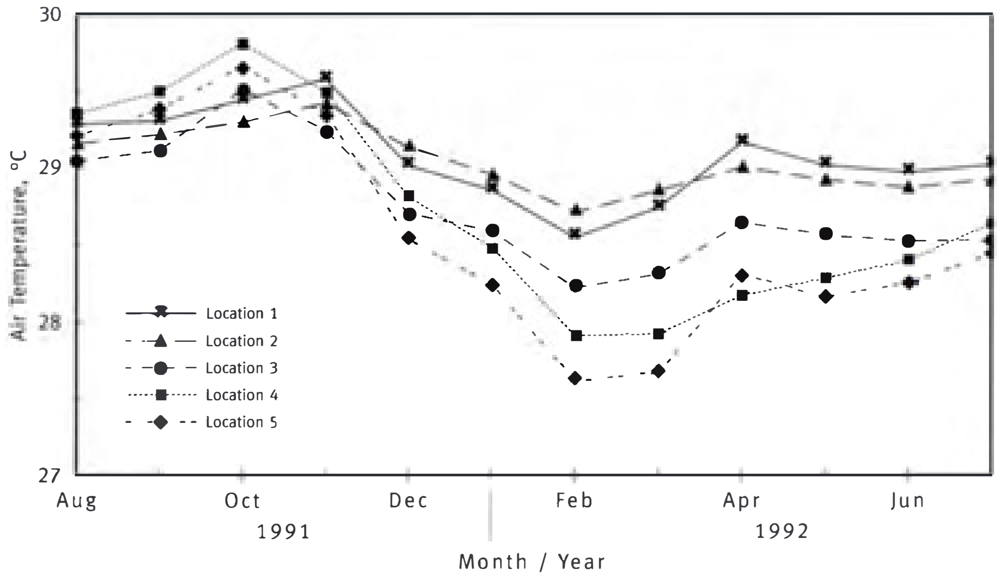
Microclimate of the Tomb

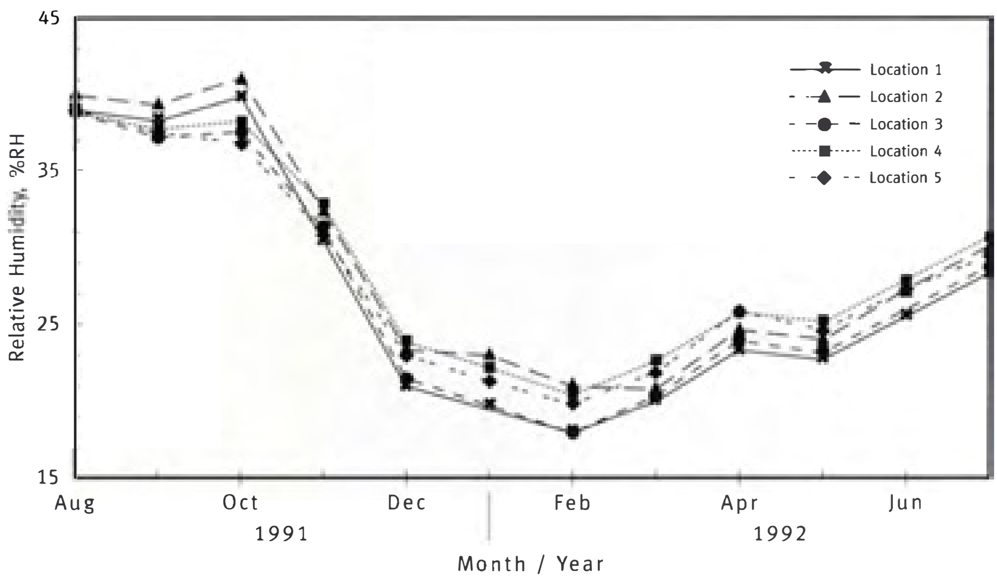
The monitoring station recorded the environmental parameters in the tomb for one year. The data indicated strong influences of visitors, conservators, and controlled experiments conducted in the tomb. Specifically, the readings were strongly affected by the presence of humans and the forced ventilation used during the work conducted by wall-painting conservators during the winter months. Even after the completion of the conservation work, streams of visitors affected the microclimate. In order to estimate the stable values not affected by the above factors, the effects of these changes would have to be extracted from the data collected. Since this is not feasible, focusing on the general trend of recorded parameters is the best way to use these data for gaining an understanding of the nature of the tomb's microenvironment.

The sensors in the tomb chambers were removed from their original locations for the entire month of April and the first ten days of May 1992 for photodocumentation conducted immediately following the completion of conservation work on the wall paintings. Therefore, the

FIGURE 6, RIGHT. MONTHLY AVERAGE OF AIR TEMPERATURE IN THE TOMB.

FIGURE 7, BELOW. MONTHLY AVERAGE OF RELATIVE HUMIDITY IN THE TOMB.





data collected in April and early May are not consistent with the rest of the data.

Figure 6 shows the summary of average air temperatures in the tomb recorded between August 1991 and July 1992. The air temperatures remained at approximately 29.0 ± 0.5 °C and 28.9 ± 1.0 °C all year round in the burial and upper chambers, respectively. The larger annual variation recorded in the upper chamber was driven by the exchange of air with the outside. Therefore, the temperature drop in winter was larger than the increase in summer. The air temperature in the burial chamber was higher than that of the upper chamber between November 1991 and July 1992; the largest temperature difference, 0.2 °C, was recorded in March.

The summary of monthly RH averages of in the tomb is shown in Figure 7. The highest monthly average, 41% RH, was recorded in October in the burial chamber, and the lowest, 18% RH, was recorded in February, also in the burial chamber. The annual average was 28% RH, and the swing was symmetrical, six months above the average and another six months below the average. Sensors indicated less than 2% variation in RH between the upper and lower chambers throughout the year.

In summer the moisture content of the outside air increased, resulting in an increase of the relative humidity in the tomb (Fig. 5). Although the moisture content of the inside air paralleled that of the outside air for both seasons, the measures inside were always somewhat higher. This

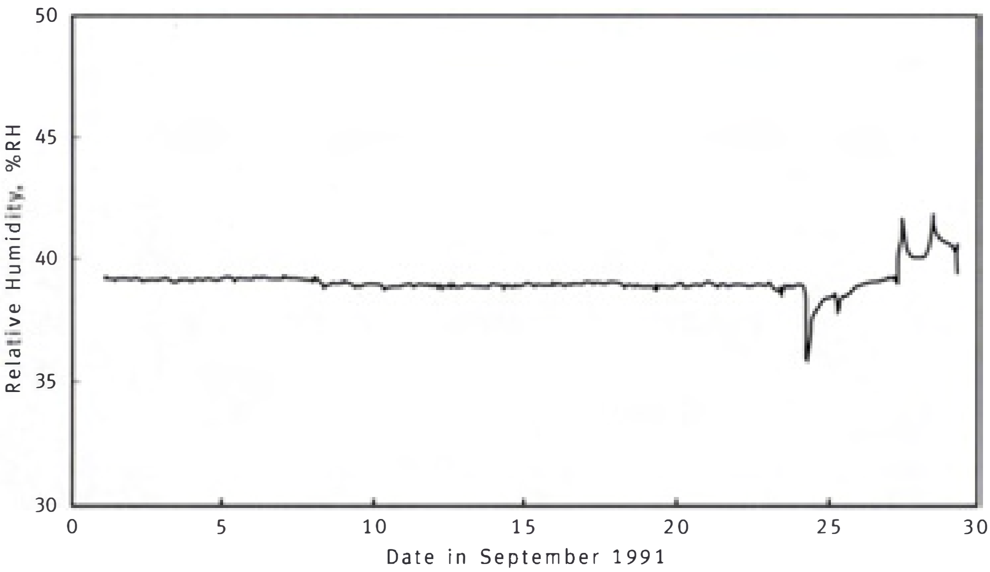
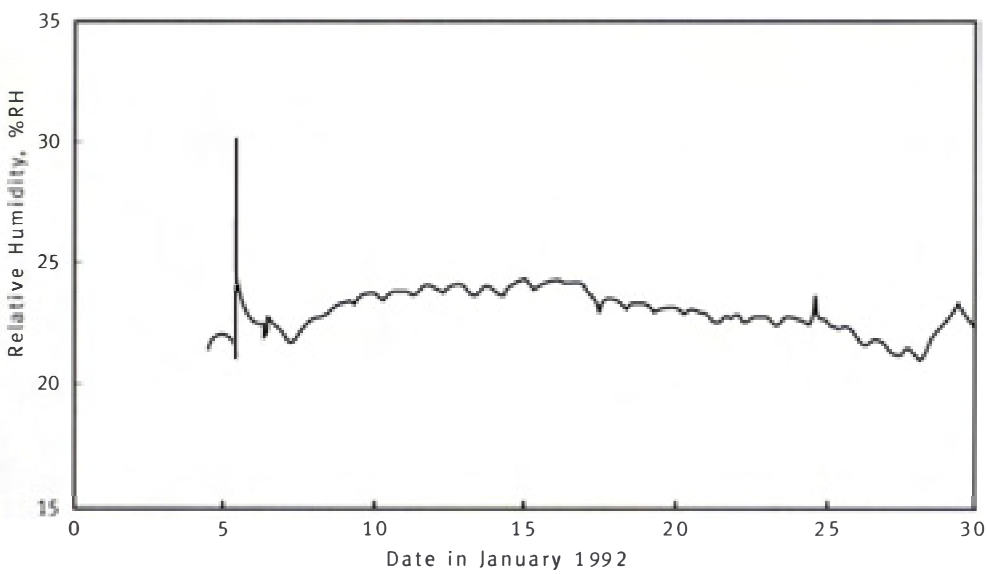


Figure 8, left. Relative humidity in the burial chamber in September 1991.
Figure 9, below. Relative humidity in the burial chamber in January 1992.



may be due to the hygroscopic characteristics (faster absorption and slower desorption) of the bedrock limestone, mud plaster, paint, salts, and flooring canvas in the tomb, or the moisture contained in the bedrock limestone. It would be extremely interesting to know the relative humidity and its fluctuation in a sealed tomb (the buried condition of the tomb without air exchange), since the moisture content of the outside air dominates the inside of the tomb once it is opened and the air starts to exchange. Such information would reveal whether the tomb's wall paintings are constantly being desiccated by dry outside air.

Figures 8 and 9 show the relative humidity recorded in the burial chamber during the months of September 1991 and January 1992, respectively. The relative humidity was very stable with less than 1% RH fluctuation in summer. Three small dips around September 10 were the result of natural ventilation when the tomb's door was left open for visitors. Large peaks at the end of the month were also caused by visitors. The relative humidity in the tomb varied significantly in winter months, as shown in Figure 9. The diurnal fluctuation, which was not identifiable in summer months, ranged from 1.0 to 2.5% RH, and the monthly fluctuation was approximately 4% RH in the burial chamber. These indicate changes of natural ventilation rates between day and night. Evidently the tomb's microenvironment is quite sensitive to changes of outside climate in winter.

Table 2. Summary of controlled experiments.

Experiment	1	2	3
Date conducted	August 7, 1991	January 5, 1992	May 11, 1992
Time started	11:57 a.m.	10:39 a.m.	11 a.m.
Duration of stay	30 min.	60 min.	30 min.
Number of adults	37	21	24
RH increase at #1	8.3% RH	4.2% RH	5.5% RH
RH increase at #2	8.5% RH	7.9% RH	6.6% RH
RH increase at #3	6.9% RH	4.9% RH	5.8% RH
RH increase at #4	2.4% RH	5.0% RH	3.8% RH
RH increase at #5	2.6% RH	5.2% RH	3.4% RH
AT increase at #1	0.5 °C	1.1 °C	0.5 °C
AT increase at #2	0.9 °C	0.7 °C	0.4 °C
AT increase at #3	0.4 °C	0.7 °C	0.3 °C
AT increase at #4	0.2 °C	0.4 °C	0.2 °C
AT increase at #5	-0.2 °C	-0.1 °C	0.1 °C
CO_2 increase at #1	429 ppm	788 ppm	809 ppm
CO_2 increase at #2	404 ppm	673 ppm	525 ppm
Outside Air Temp.	35.1 °C	12.2 °C	28.3 °C
Outside RH	21.2% RH	41.3% RH	14.6% RH
Wind direction	NA	NA	East-SE
Wind speed	NA	NA	2.3 m/s

Four peaks are present in Figure 9, all created by entries of visitors into the tomb. The largest peak, on January 5, was the result of a controlled experiment in which twenty-one adults remained in the burial chamber for 60 minutes (Table 2). The peaks in Figure 9 are sharp, almost like needles, compared to the peaks observed in the graph for September (Fig. 8). This difference indicates the faster recovery of the tomb in winter months, a recovery which is driven by natural ventilation.

Effects of Conservation Work

A team of wall-painting conservators worked in the tomb during the winter months during the last two phases of the conservation project. The monitoring station recorded their activities between November 12 and December 16, 1991. They returned to the tomb on February 1, 1992, and continued to work for nearly three months until April 24, when the last phase of the wall-painting conservation was completed.

The conservation work was conducted with a group of five to seven conservators, plus one or two helpers working daily between 7 A.M. and 12 noon. The entry door of the tomb was fully open, and a large (approximately 50 cm diameter impeller), axial, flow-type ventilation fan remained on during working hours in the tomb. The intake of the ventilator was placed in the middle of the burial chamber using a long, corrugated plastic duct of approximately 50 cm diameter; its exhaust was located outside the entry arch. The conservators moved freely within the lighted tomb during the operation.

Figure 10 shows the relative humidity recorded during the conservation work in December 1991. The daily presence of people is clearly indicated in the sawtoothed pattern of peak-and-decay cycles. Upward peaks indicate underventing, and downward peaks indicate overventing. Approximately 3 to 5% RH positive and negative peaks were commonly observed. The sawtoothed pattern of fluctuations stopped with the departure of the conservators on December 16, and a stable environment was maintained until the end of the month.

Figure 11 shows the relative humidity of the burial chamber in March 1992. The largest peak of relative humidity, 8% RH, was recorded in late March. Several reverse peaks of relative humidity, which probably were induced by overventing of the tomb on very dry days, were also recorded in March. The minimum relative humidity of 16% RH, recorded in the burial chamber May 4, was the result of overventing.

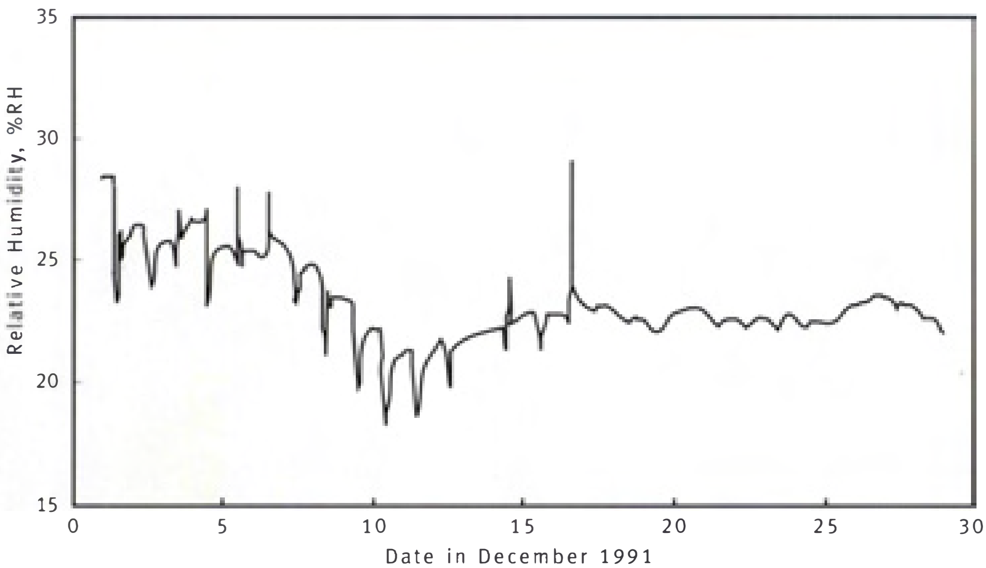
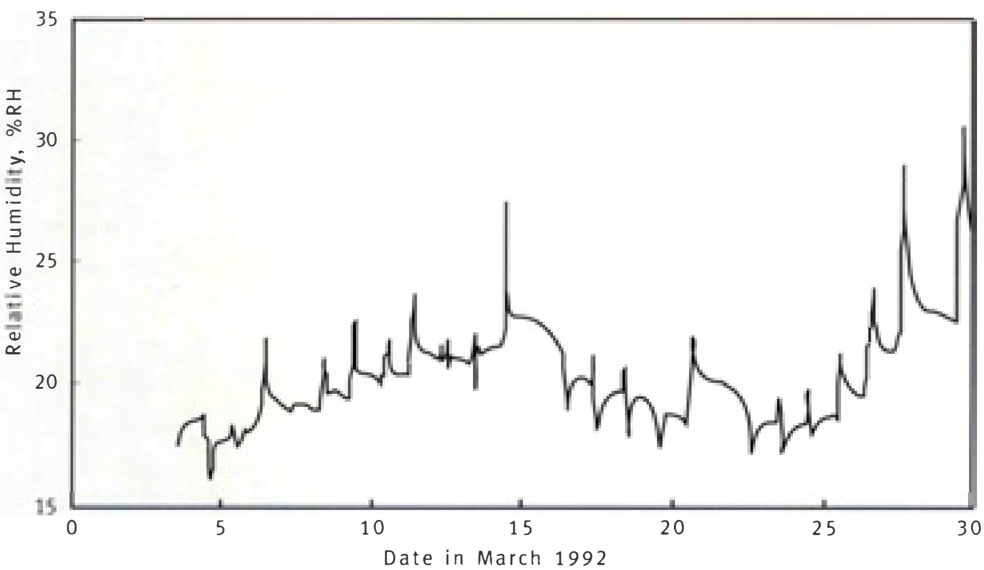


FIGURE 10, LEFT. RELATIVE HUMIDITY IN THE BURIAL CHAMBER DURING CONSERVATION WORK IN DECEMBER 1991.

FIGURE 11, BELOW. RELATIVE HUMIDITY IN THE BURIAL CHAMBER DURING CONSERVATION WORK IN MARCH 1992.



Controlled Experiments in the Tomb

Since the installation of the monitoring system in August 1991, four controlled experiments have been conducted for evaluating changes of the environmental parameters in the tomb caused by a typical group tour and the tomb's ability to recover its natural microenvironment following the group's exit. The experiments were conducted in August 1991 and in January, May, and August 1992 to identify the effects of seasonal variation. (Esmael [1987] also reports some changes of the microenvironment in the tomb affected by the seasonal variations outside.)

In each of the first three experiments, twenty-one to thirty-seven local site-guards and EAO inspectors entered the tomb as a group, stayed either 30 or 60 minutes, and exited the tomb at once. Each group remained in the burial chamber throughout the experiments in order to model the worst possible case for the microenvironment of the tomb. It took approximately 2 minutes for each group to enter and 2 minutes for each to leave. During their stay they walked around the chamber as tourists typically do. The entry door was opened 60 to 120 minutes prior to the experiments and remained fully open throughout the experiments. It was subsequently closed and locked 30 to 60 minutes after the exit of each group.

Changes of environmental parameters were recorded at 5-minute intervals during and after each experimental visit. Analyses were made on rates of increases and

Table 3. Rate of CO_2 production for the three experiments conducted in the tomb.

Experiment	CO_2 production rate (ppm/hr/adult)
1	23
2	36
3	59

Table 4. Rate of RH increases for the three experiments.

Experiment	CO_2 production rate (% RH/hr/adult)
1	0.34
2	0.27
3	0.43

decreases of the parameters. Unfortunately, however, EAO staff or visitors inadvertently entered the tomb the next day following each of the experiments, which made the analyses of the decay data difficult to interpret. Table 2 summarizes the changes of the parameters during the experiments.

Rate of changes

The median CO_2 production rate is 0.019 m^3 per hr for each adult, according to the design value model for indoor air quality established by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) in 1985. If the total volume of the tomb, 475 m^3, is used to calculate the immediate dispersion of CO_2, the estimated rate of increase of the concentration will be 40 ppm per hr for each adult. Table 3 summarizes the results of CO_2 increases measured during the three controlled experiments conducted in the tomb. The values of 23, 36, and 59 ppm per adult are in good agreement with ASHRAE's value. If a group of thirty visitors enters the tomb after another during the site's nine operational hours without a recovery period for the microenvironment, the CO_2 concentration in the tomb will reach 1.1% by the end of the day. Although healthy individuals can tolerate 0.5% CO_2 without undesirable symptoms, a level of 0.25% provides a safety factor against increased activity and reduced ventilation (ASHRAE 1985).

The expected increases in relative humidity caused by visitors in an enclosed space can be estimated by knowing the latent heat released by an adult and the volume of the enclosure. ASHRAE uses 95 W as the value, which corresponds to the evaporation of 141 g/hr of water in a 30 °C environment. Other published values range

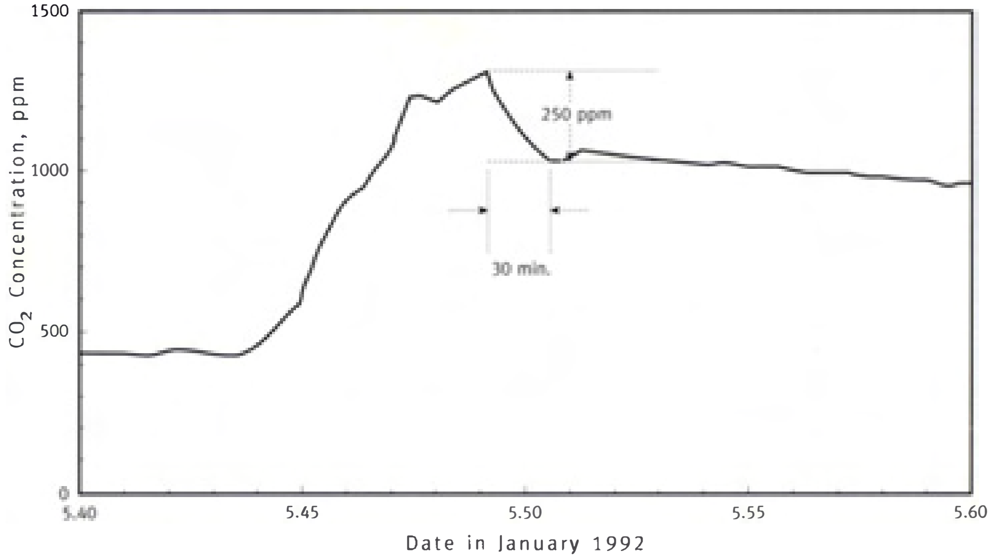


Figure 12. Natural ventilation in winter with entry door open; changes of CO_2 in the burial chamber.

Experiment	Air exchange (m^3/hr)	Month
1	24	August
2	338	January
3	114	May

Table 5. Air-exchange rate during the experiments.

Experiment	Air-exchange rate (hrs) (m^3/hr)	Average outdoor temperature (°c)
1	53 (8.86)	32.9
2	7 (67.8)	14.9
3	17.5 (27.1)	21.3

Table 6. Air-exchange rate and average temperature for the three experiments.

between 100 and 400 g/hr depending on the activity level of the adults and their degree of acclimatization. Since these experiments were conducted with local Egyptians who are well acclimatized to the region, the value of 100 g/hr for each adult may be used, which yields an expected rate of approximately 0.8% RH/hr for each adult in the tomb. Some portion of the relative humidity increase will be absorbed by visitors' clothing as well as by the materials of the tomb during the period of moisture emission, however, so the experimental value should be somewhat discounted from the actual value expected.

Data for the rate of relative humidity increases, shown in Table 4, were derived from Table 2.

The values range from 0.27 to 0.43% RH/hr, which compares well with the calculated value 0.8% RH/hr. Larger air-exchange rates during the winter may be the cause of the lowest relative humidity increase.

If the average of the values in Table 4, 0.33% RH/hr for each adult, is used to estimate a case of the full visitor load on the tomb (group after group of thirty visitors entering the tomb for nine hours a day), the relative humidity in the tomb will reach 100% RH before the end of the day. (An estimated 11 kg of water will be released in the tomb.) However, the hygroscopicity (moisture-absorbing capacity) of the tomb takes over as the higher relative humidity environment is created, and the amount of moisture in the air will not reach the saturation value unless the materials in the tomb have already been saturated with the water. The rate of absorption of moisture during its emission is very difficult to estimate, since the rate is a function of both the relative humidity of air and materials and the relative humidity potential between the materials and the environment.

Rate of decay

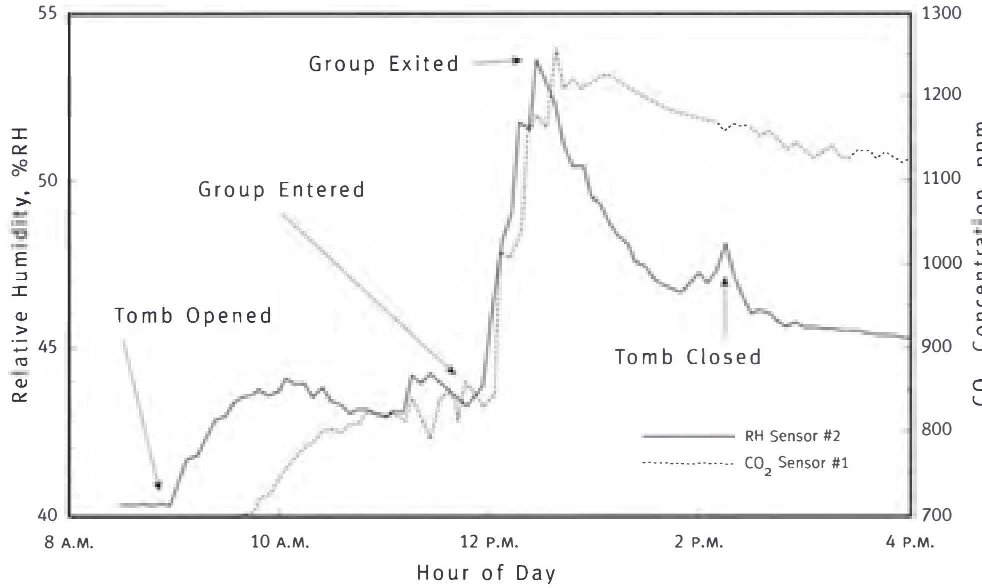
Immediately following the exit of visitors from the tomb, abrupt drops in CO_2 were recorded in the controlled experiments while the entryway door was left open. The drops were 80 ppm in 85 minutes, 250 ppm in 20 minutes, and 100 ppm in 20 minutes for experiments 1, 2, and 3, respectively. Table 5 summarizes the corresponding air-exchange rates in the burial chamber.

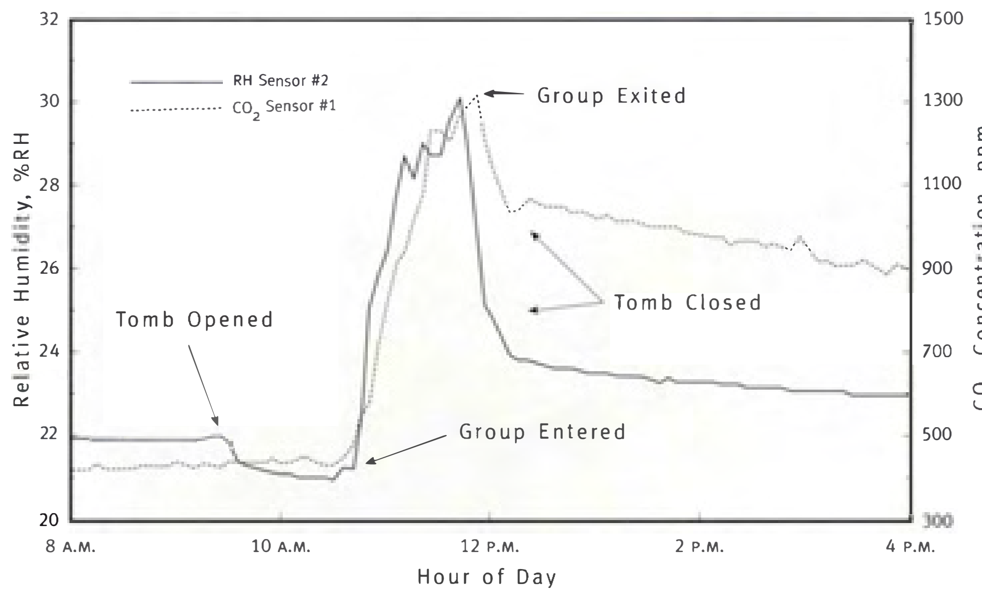
The air-exchange rate of 338 m^3/hr in experiment 2 (Fig. 12) is approximately 10 cm/sec at the lower half of the open entryway. Larger drops were recorded in winter compared to those in summer. As the visitors exited the tomb, the spaces that they had occupied were replaced by the inflow of outside air. If the outside air was cooler than the air inside the tomb, which is the case in winter, the airflow appeared to generate a large convective flow in the tomb and started an immediate flushing of the tomb with dryer outside air. In summer, however, warmer outside air remained near the top of the tomb, creating a stable atmosphere inside.

Long-term (two to three days) decay rates of CO_2 measured in the burial chamber following the experiments were used to evaluate the tomb's air-exchange rates. The air-exchange rate can be affected by temperature differences between the inside and outside environments, closure condition of the entry door, and outside wind conditions. Table 5 shows the seasonal variation in air-exchange rates with the tomb's entry door closed. Neither the entry door nor the bulkhead into which it fits is airtight. The steel door, which swings inward, is loosely mounted with hinges to the larger steel bulkhead, which is loosely fitted to the inside of the arch-shaped entryway

FIGURE 13, RIGHT. CONTROLLED EXPERIMENT ON AUGUST 7, 1991. COMPARISON OF CHANGES OF RH AND CO_2.

FIGURE 14, BELOW. CONTROLLED EXPERIMENT ON JANUARY 5, 1992. COMPARISON OF CHANGES OF RH AND CO_2.





passage. The bulkhead is drilled with twenty airholes, each 6 cm in diameter, half of which are left open for ventilation. The entry door, when open, allows a large quantity of air to pass through, especially in winter. The temperature fluctuation of the steel door and bulkhead may also affect the tomb's microenvironment.

Table 6 summarizes the rates for these experiments. As indicated in Table 6, the air-exchange rate was strongly dependent on the outdoor temperature (difference between the tomb and the outside). The cooler the outside air, the higher the ventilation rate. In winter, the heavier, cooler outside air easily penetrated the underground tomb and destabilized the microenvironment. In summer, however, the warmer outside air created a stable atmosphere in the tomb by placing a lid of light, warmer air on it, just like an inversion layer.

Decay rates of the relative humidity in the burial chamber after the experiments were also evaluated. The initial decays of the relative humidity were much faster than those of CO_2, as shown in Figures 13 and 14 for

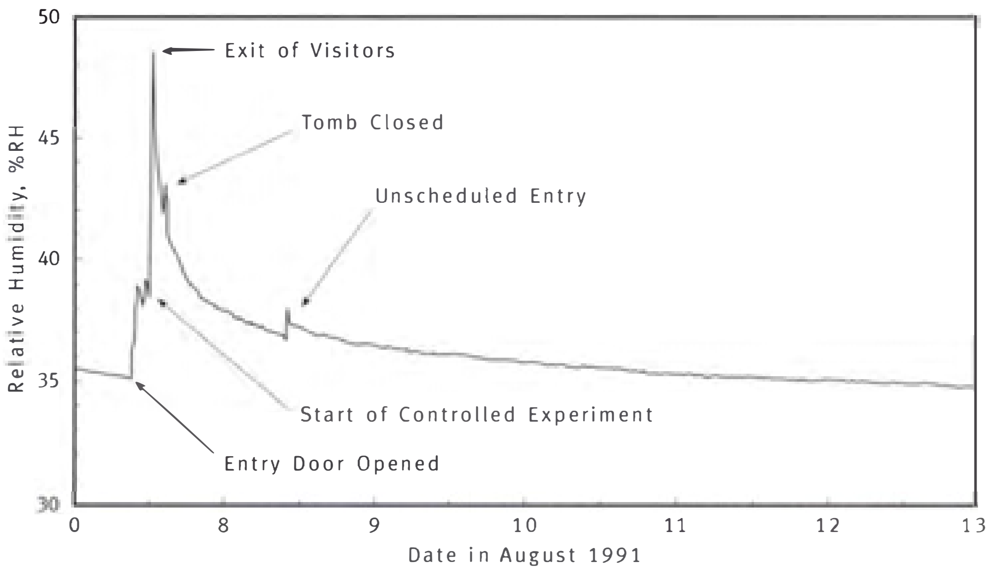
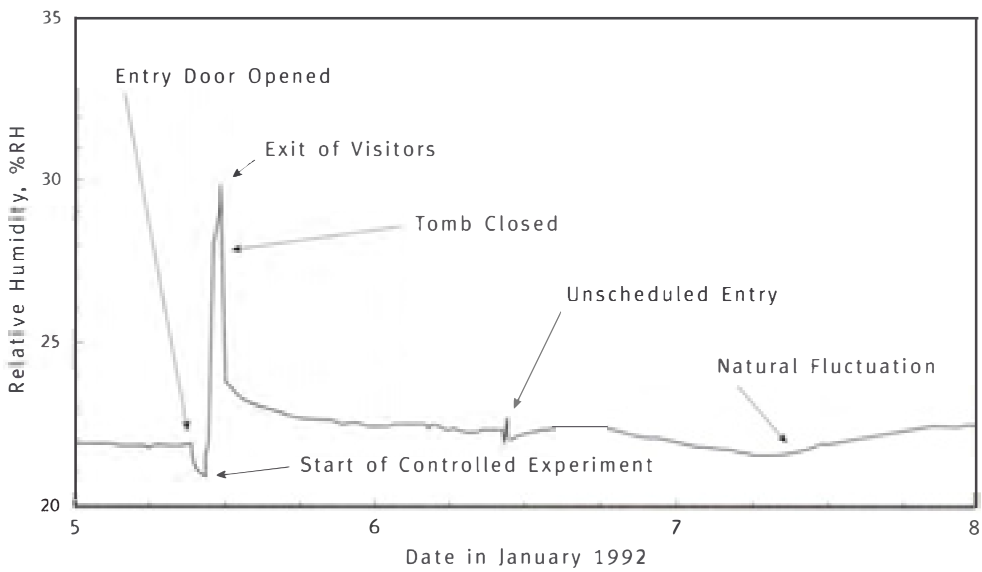


FIGURE 15, LEFT. RELATIVE HUMIDITY DECAY IN THE BURIAL CHAMBER IN SUMMER.
FIGURE 16, BELOW. RELATIVE HUMIDITY DECAY IN THE BURIAL CHAMBER IN WINTER.



experiments 1 and 2, respectively. The higher the relative humidity potential generated, the faster the moisture absorption (absorption speed). However, the relative humidity decay rates approached the decay rates of CO_2 in four to five days during summer and within one to two days in winter, when they reached rates slightly less than those of the CO_2. Figures 15 and 16 show the decay of relative humidity for several days after emissions.

The moisture left in the tomb by visitors was quickly absorbed by the hygroscopic materials of the tomb, which consist of the wall paintings, mud plaster, bedrock limestone, salts, dust, and cotton canvas flooring. The moisture remaining in the air was then transported to the outside of the tomb by natural ventilation. The hygroscopic materials started to release the moisture as the relative humidity in the chambers decreased. These materials continued to give up excess moisture until they reached equilibrium with the microenvironment of the tomb.

During August, 47% of the moisture generated in the burial chamber remained in the tomb three days after a group visit; it took twelve days before the effect was reduced to 5%. In January, however, the moisture decreased to 30% in only one day and went down to 5% in less than two and a half days.

Conclusions and Future Work

The temperature in the tomb of Nefertari remained stable at approximately 29 °C year-round, but the relative humidity ranged between 18% RH in February and 41% RH in October. The moisture content of the air in the tomb tracked that of the outside air, but always remained higher. Although the microenvironment of the tomb was stable in the summer months, it responded quickly to changes of the outdoor environment in the winter months. This was due to a large ventilation rate, which is thermally driven in winter.

Conservation work in the tomb produced a saw-toothed pattern of peak-and-decay cycles in relative humidity. Use of the ventilation fan during the work occasionally resulted in extremely low relative humidity inside the tomb. The alternating use and nonuse of the ventilator resulted in a gradual rise or fall of the baseline RH level, since the overnight recovery capability of the relative humidity of the tomb was limited even in winter.

Emission rates of CO_2 (39 ppm/hr per adult) and moisture (0.33% RH/hr per adult) were measured through three controlled experiments conducted in situ in the tomb in August 1991, January 1992, and May 1992. A high rate of natural ventilation was observed with the entry door both open and closed during winter, but natural ventilation declined by one-eighth of that amount in summer. The rate of moisture absorption by the tomb immediately following the presence of visitors was significant in summer but not as significant in winter, when the rate of natural ventilation was high. The natural ventilation diluted the moisture in the air and then desorbed the moisture from the tomb. Therefore, long-term decay rates of relative humidity inside the tomb were very similar to those of the air-exchange rates, indicating natural ventilation is the tomb's moisture-removing mechanism.

These data suggest that, for the safety of visitors as well as stability of the paintings, visitation of the tomb during summer months should be strictly limited when the baseline RH is high and natural ventilation is at a minimum. Limited numbers of visitors may be allowed in winter if the microenvironment is carefully monitored.

Information on the variable microenvironment of the tomb of Nefertari was gained through one year of continuous monitoring. However, the data presented provide only partial understanding of the microclimate and the dynamics of the microenvironment to any disturbance. In order to fill the gap which was identified during the preparation of this report, the following study will be conducted during the next year of monitoring:

- The year-round condition of the undisturbed or least disturbed tomb will be monitored. A good set of data has been obtained for the summer months, but not for the winter season, because of the presence of conservators during the first four months of 1992.
- Controlled experiments, similar to those described above, will be conducted throughout the year to further evaluate rates of natural ventilation in various seasons.
- An attempt will be made to develop a simple mathematical model which will be developed to simulate effects on the microenvironment of the tomb by various visiting patterns, including the number of visitors, duration of individual tours, recovery periods between tours, and periods of operation. The model will be calibrated or verified by conducting controlled experiments.
- Monitoring of the microclimate of the sealed condition of the tomb will be attempted. It will be necessary to obtain this information since the moisture content of the outdoor air is always lower than inside, and the exchange of air dominates relative humidity in the tomb. Plans are underway to completely seal one of the small chambers connected to the burial chamber of the tomb and monitor the relative humidity and temperature of the sealed chamber. The results should indicate whether the wall paintings are constantly being desiccated by dry, outside air.

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References

ASHRAE Handbook, 1985 Fundamentals.

1985 American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. Atlanta, Georgia.

Burns, G., K.M. Wilson-Yang, and J.E. Smeaton

1988 Archaeological Sites as Physicochemical Systems: The Tomb of Nefertari, Egypt. In *Archaeological Chemistry IV. Advances in Chemistry,* Series No. 220:289–310. Washington, D.C.

Esmael, F. A.

1987 Microclimatic Conditions. In *Wall Paintings of the Tomb of Nefertari: First Progress Report.* M. A. Corzo, ed. Cairo and Century City, California.

Mora, P., G. Torraca, P. Schwartzbaum, and E. Smith

1981 Luxor West Bank Visitor Management Study: Possible Impact of Increased Tourist Numbers on the Tombs and the West Bank at Luxor. *ICCROM Mission Report.* Rome.

Plenderleith, H. H., P. Mora, G. Torraca, and G. de Guichen

1970 Conservation Problems in Egypt. UNESCO Consultant Contract No. 33.591. Rome.

Wilson-Yang, K. M., and G. Burns

1989 The Stability of the Tomb of Nefertari 1904–1987. *Studies in Conservation* 34:153–170.

Wojtuniak-Struzynska, J., Z. Brockwicz, and W. Domaslowski

1973 The Problem of the Conservation of the Mural Paintings in the Tomb of Queen Nefertari, Western Thebes, Egypt. In *The Tomb of Queen Nefertari: Problems of Conserving Wall Paintings.* Conservator's Information Center Monograph. Warsaw: ICCROM.

Chamber E, showing the state of the tomb paintings in the early 1920s when they were photographed by H. Burton. Photo: Courtesy of The Metropolitan Museum of Art.