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RESTORING AND PRESERVING EGYPT'S SPHINX: THE POLYMERS OPTION

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ABSTRACT

Aggressive environment and urban development in Egypt are posing serious threats to the Great Sphinx. Many attempts have been made in the past to repair, restore and preserve the monument. A brief historical background and a description of the Sphinx and its rock are given. The main problems facing it are analyzed, and the different methods and materials used in the past to preserve it are reviewed. An assessment of the outcome of these efforts is presented.

Polymers are introduced as new effective materials that have great potential for the restoration and preservation of the Sphinx. Methods such as impregnation, plastering, mortars, penetrants sealers, and polymer-based coatings, are discussed, and broad guidelines for their application are reviewed.

Any endeavours to repair, restore, and conserve the Sphinx must first be studied very carefully and approved by the international scientific community and the local Egyptian authorities. Lessons learned from earlier restoration efforts must be considered, and any future preservation attempts must be carried out only after thorough experimentation and thoughtful investigation. The conservation effort must proceed with great thought and absolute certainty that what is done would not adversely affect the Sphinx or its environment, at present and in the future.

KEYWORDS: Sphinx, Egypt, restoration, polymers, sealers, impregnation, coatings, penetrants

INTRODUCTION

The Sphinx and the Great Pyramids of Egypt are among the oldest monuments known to humans—enduring and mysterious edifices that symbolize our links to the remotest known civilization. Mainstream Egyptology says that the Sphinx was carved from bedrock during the reign of Khafre (2520-2494 B.C.) as a self-tribute to the pharaoh [1]. A controversial "old-Sphinx theory" [2, 3] proposed that the Sphinx was far older than the pyramids, and that its severe weathering and erosion were caused not by winds and blowing sand, but by rain.

Almost sixteen kilometres southwest of Cairo, the Sphinx, Figure 1, stands on the Giza Plateau, where it is slowly losing bits and pieces of its unique identity. For over 4,600 years, the great stone structure has survived the ravages of weather, the insidious attack of air pollutants, the assaults of foreign soldiers, and the depredations of tourists. Efforts to save the Sphinx go back over 3,000 years. However, from the pharaohs, Greeks, and Romans, to Napoleon and present-day scientists, the preservation process has puzzled, intrigued, and humiliated restorers.

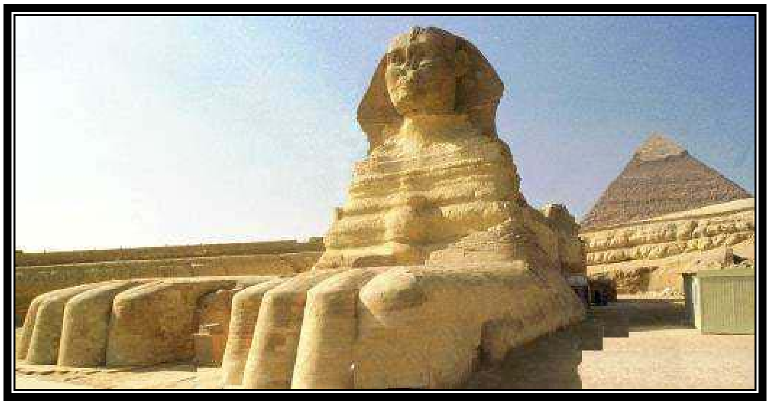

Figure 1 – The Great Sphinx

The well known Egyptologist, Dr. Mark Lehner, once stated [4]: "The history of the Sphinx is a continuous history of restoration." The Sphinx was first restored by Pharaoh Tuthmosis IV around 1400 B.C., almost 1,200 years after it was carved. Various Roman emperors, including Nero and Marcus Aurelius, also touched it up. However, it seems that the Sphinx survived most of its existence buried up to its neck in the sands. Abdul-Latif, the twelfth-century Arabic scholar [5] reported that "Near to one of the Pyramids, is a colossal head emerging from the ground called: Abol-Haul." When Napoleon visited the Giza Plateau in 1798, the Sphinx—except for its head—was still buried in sand. Some experts believe that those drifts of sand protected the Sphinx for much of its existence [6]. The first effort to restore the Sphinx in modern times was done by the French architect Emile Baraize in 1925-26 where he permanently cleared out that sand cover. Since then, the monument has suffered a slow and progressive deterioration of its stone year after year. Some scholars blamed air pollution and ground water seepage for that deterioration [7].

DESCRIPTION OF THE SPHINX

Shaped as a lion's body and topped with the head of a man, the Sphinx's awesome frame measures 72.6 m (242 ft) long, 19.8 m (66 ft) high, and 5.4 m (18 ft) average width. Its face is 6 m (20 ft) wide, 6.6 m (22 ft) high and its eyes are over 1.2 m (4 ft) high [8]. It reclines with its head upright and its front legs extended and parallel, while its back legs are folded underneath its body and its gaze contemplates the rising sun in the East. On its head, it wears the characteristic royal and divine headdress. The uraeus, the sacred cobra, adorns its forehead. It is believed that the Sphinx used to have a false beard, most of which has been lost. Part of the nose and the uraeus are also missing. However, the colossus remains mostly intact after thousands of years.

The Sphinx, located at the southeastern slope of the Giza Plateau, was hewn from limestone rock, some of it strong and some weak. While the head is made of relatively durable rock, the body and shoulders are not. The rock is among the world's oldest—from the Middle Eocene limestone of the upper Mokattam Formation. Gauri [9] divided this part of the Mokattam Formation into three geological layers or members, namely, the Rosetau Member (I), Setepet Member (II) and Akhet Member (III).

The 100-ton head is composed of harder stone, and experts have long worried that it might topple from the statue's decaying neck. The Sphinx's midsection is particularly fragile, a sandwich of soft and hard limestone that has eroded at different rates, giving the body a wavy profile. The weathered silhouette of the sphinx exhibits alternating projected and recessed layers. Besides the influence of porosity, this differential damage [10] was attributed to pressures generated by the crystallization of salts in the stone. In research at the University of Louisville, Kentucky [11], the weathering characteristics of the limestones of the sphinx were evaluated in the context of their pore system. This pore system was found to vary from one stratum to another.

PROBLEMS FACING THE SPHINX

It is believed that much of the recent deterioration of the Sphinx is due to environmental effects as well as human-induced conditions and processes that affect the mother rock. These can be summarized as follows:

1. Rising groundwater table and upward percolation of water into its body.
2. Salt and gypsum crystallization inside the mother rock of the monument.
3. Vibrations and quake emanating from nearby quarries and vehicular traffic.
4. Leaking of waste water systems of nearby slums where over 200,000 people reside.
5. Construction of the Sound and Light show and its facilities.
6. Environmental factors, such as rain and fluctuations in humidity and temperature.
7. Pollution due to industrialization and construction of nearby factories.
8. Poor restoration and conservation methods.

The past 70 years of excavation and development seem to have worked more damage on the Sphinx than the 4,600 years that came before. Protected for most of its years of existence by the desert sands that covered it, the Great Sphinx was revealed in all its glory only in the mid-1920s. Since then [12], "The Sphinx has deteriorated more (in the last 50 years) than in all the previous centuries of its existence combined," said Sayed Tawfik, Chairman of the Egyptian Antiquities Organization, Cairo.

Figure 2 – Deterioration of the Great Sphinx

The Sphinx lies on the Giza Plateau at the eastern margin of the Western Desert of Egypt, close to the edge of the fertile bank of the River Nile. Naturally, processes that are active in both the desert to the West and the agricultural land to the East affect the Sphinx's environment. Meanwhile, the characteristics of the rock from which the Sphinx was carved dictate how the monument is influenced by its environment. One of those characteristics [13] is that the rock is jointed by an intersecting set of fractures. A major fracture goes through the main body of the Sphinx, while other smaller ones criss-cross it in an "X" pattern. These fractures are clearly visible along the walls of the Giza Plateau, particularly at the walls around the Sphinx.

During the past few decades, the Sphinx has visibly suffered from increased denudation of its outermost surface layer. In particular, the strongest winds strike the Sphinx at its weak chest that is carved from the weakest of the three rock strata forming the monument. Further, blocks have fallen from its solid-rock body, and from the retaining wall that surrounded its base. The main agent of decay in the limestone rock from which the Sphinx was carved is the salt and gypsum crystallization at or near the outermost surface of the Sphinx. This salt is mobilized by upward groundwater percolation as well as precipitation of moisture from the air. Salt crystals force a thin layer of rock outward, and the resulting flakes are easily separated from the rock surface by gravity, or if touched by people, by wind vortices, or by seismic shaking of the Giza Plateau. The situation is even aggravated by extreme climatic conditions and excessive air pollution from industrialization and urban growth near the Sphinx.

Since the early 1950s, the population of Cairo has grown from about 2.5 million people to over 16 million, plus a few million visitors a day. The parallel growth of industry (particularly steel and cement) at Giza and Helwan exacerbates the problem of air pollution. Industrial plants emit vast amounts of sulfur dioxide into the air. When mixed with moisture, the sulfur dioxide forms acids that crumble the outermost layers of the Sphinx.

The moisture in the air is mostly generated by evapotranspiration of vegetation east of the Sphinx. The sources of near-surface groundwater in the immediate vicinity of the Sphinx are those irrigated fields, the service area of the Sound-and-Light show that is performed for visitors in the evening, and a huge slum called Nazlet Es-Semman that was illegally built there. After over thirty years of urban growth [13], this 200,000 “town” finally installed a sewer system in 1992. Until then, however, all the wastewater soaked into the ground, raising levels of near-surface water in the well at the tail end of the Sphinx to 0.5 meters below the surface.

As reports of advancing decay poured from sites all along the Nile, some scientists suggested that the Aswan High Dam completed in 1970 brought the water table in the Nile Valley closer to the surface, allowing water to penetrate limestone monuments and activate the salt crystals that ravage them. Others disagreed and proposed that the easily available water has encouraged runaway growth, and farmers started to irrigate their fields more intensively using fertilizers that leech into exposed monuments.

Repeated ground quakes promote movement along fractures within the Sphinx and may induce rock failure. The ground is remarkably shaken from dynamite blasts in rock quarries nearby, and from the tourist buses as they get very close to the Sphinx, particularly when they park there with their engines left running for hours to keep the vehicles air-conditioned. Furthermore, exhaust from the multitude of engines burning diesel fuel produces considerable emissions of smoke that pollutes the environment and harms the Sphinx.

Even restoration efforts themselves pose high risks and may cause damage to the monument. Over the last few decades, the Sphinx has suffered from well-intended but hasty, careless, and misguided attempts at preservation. As will be mentioned below, an effort by conservationists from 1981 to 1987 to shore up the Sphinx only hastened its deterioration. Scientists shot the monument's weak chest with chemicals, creating a coating that unfortunately soon flaked off and took a layer of mother rock with it. The restoration also used about 1,700 large limestone blocks and cement mortar around the base. However, the blocks not only distorted the monument's profile, but also cracked. Moreover, water used to mix the cement mortar seeped into the Sphinx's limestone innards, activating salts that formed damaging crystals.

HISTORY OF RESTORATION EFFORTS TO PRESERVE THE SPHINX

The first major restoration of the Sphinx was done by the Ancient Egyptian Pharaoh Tuthmosis IV of the Old Kingdom around 1400 B.C.—almost 1,200 years after the monument was carved out of that limestone knoll on the Giza Plateau . More repairs were undertaken in later Pharaonic times, and again in the Greco-Roman period. All of these attempts are still visible today in the intricate mosaic of stone and bricks around the base of the statue that Dr. Mark Lehner has carefully documented [14]. However, as the Pharaonic Kingdoms declined, the already ancient figure was neglected, and sand built up around it, preserving it from deterioration. Only its head is believed to have always poked above the dunes.

When French explorers partially dug the Sphinx out of the sand in the early 19th century, they inadvertently started the clock ticking again, and throughout the 20th century archaeologists have been struggling to preserve the monument's rapidly eroding body. In 1926, the French engineer Emil Baraize led the first major restoration effort in the modern times. That endeavour pushed the dunes completely back from the Sphinx, exposing its body to the elements—which was soon to add to its decline. Mr. Baraize [15] reclad the lower body in stones and filled in gashes in the headdress with cement. He also built supports under the neck and the wings of the headdress. Unfortunately, the cement plastered around the base of the structure formed salt crystals that began to eat into the limestone. Interestingly, however, Egyptologists say that the repair work on the head and the neck, though considered unattractive by many, did not cause salt erosion and has held up well.

The efforts to preserve the Sphinx continued to the present day, not always with positive results. In recent years, Egyptian archaeologists have tried numerous remedies. Glues, such as polyvinyl acetate and barium hydroxide, have been painted on the surface and injected into the stone. However, none of the treatments has stopped the deterioration for long. In fact, some have made it worse. From 1981 to 1987, the lower third of the statue—its paws, rump, and tail—were encased in new limestone blocks that, in fact, distorted the monument. Furthermore, the blocks were joined with cement mortar instead of a more neutral lime-based one, which exacerbated the salt problem. During the same period, a chemical injected into the body to harden the rock, soon flaked off, taking some of the invaluable mother rock with it. Awareness of how badly the Sphinx has deteriorated came with a shock in February 1988 when a large chunk from the middle layer, weighing some 700 pounds, tumbled off the Sphinx's right shoulder.

Fixing the botched job took almost 10 years (1989-1998) and cost some $2.5 million. That restoration approach made better use of the expertise of Egyptian specialists and skilled conservationists from around the world. It followed a combination of ancient and modern techniques in an attempt to halt the damage that pollution, time, and previous improper restorations have caused to the Sphinx's body. In a painstaking process, the conservation team carefully mapped the statue, giving a number to every block covering the vulnerable lower area.

Photographs of the Sphinx dating back to 1841, and an intricate map showing each stone and curve of the monument's former shape were studied. Subsequently, workers hand-cut 12,478 limestone blocks from a quarry in Helwan, a few miles up the Nile. The stone was chosen to match the original as closely as possible and was cut to the exact size of the original ones—to the same dimensions Greco-Roman restorers cut centuries before. Workers then removed the blocks that were stuck on with cement or concrete in the early 1980s, and replaced them with the new ones that were built with a natural mortar of lime and sand that would not damage the bedrock [16]. The 10-year restoration effort was unveiled on May 25, 1998 in a special ceremony. Although that latest restoration appears to be the best that could be done at present to preserve one of the world's most ancient treasures, it is inevitable that the Sphinx will continue to need constant attention.

In 1990, during that major restoration project, the Getty Institute mounted a mini-climate station on the Sphinx's great haunches, which collected data on temperature changes, wind speed and direction, humidity, and aerial pollution. The data collected show that environmental effects are more serious than previously believed. Further, a UNESCO-financed sonar examination has determined that the Sphinx's neck is sound and able to safely carry the head [12].

In 1992, during that same restoration project, a multidisciplinary, international conference on saving the Sphinx was held in Cairo and several techniques were proposed [13], such as:

- Cover the site with a clear inflated dome to seal it from the surrounding environment.
- Insert an insulating layer under the structure to seal the Sphinx from the subsurface water below.
- Spray sealants on its outermost surface to protect it from moisture.
- Pump chemicals into the 4,600-year-old limestone monument to harden its surface.
- Consolidate the outer layer of rock to protect it from wind erosion.
- Secure the head of the Sphinx to the body by a metal rod.
- Cover the shoulder and neck of the Sphinx with a layer of limestone rock to save them from further wind erosion.
- Place slabs of stone around the Sphinx to protect it against the elements.
- Re-erect the beard of the Sphinx to support the head and protect the neck from further wind erosion.

THE POLYMERS OPTION

The progress achieved in the production of polymeric materials is unsurpassed, with new materials and methods being developed at an amazingly accelerated rate. These new materials may carry with them a solution to some of the problems facing the Sphinx.

Reports on another project in Egypt [17] show the potential of these new materials, which brings hope to other monuments, including the Sphinx. Araldite adhesives have played a crucial role in the restoration of the Egyptian Temple of Luxor. The restored stonework is a group of almost 3000-year-old sandstone-columns. Their crowns and footing blocks form part of the Temple's

Court of Arnenophis II - an important example of XVIII Dynasty Work. Soil settlement had caused the columns to lean dangerously. Initial consolidation of the 13m columns was achieved by injecting them with Araldite. The columns' twelve sections were removed one-by-one so that the fallen pieces could be bonded back. Weak sections were reinforced with stainless steel bars bonded inside the stone.

MATERIALS AND METHODS - IMPREGNATION

Impregnation under vacuum/pressure is one of the most effective methods to achieve good penetration and effective sealing. Originally, the polymer impregnated concrete (PIC) process was developed as a method to produce concrete of superior strength and durability. The same technique can be extended to impregnate sandstone and monuments. In the case of the Sphinx [18], small size sandstone blocks can be individually impregnated and then used as a wall casing for the Sphinx, or parts thereof, to protect it from the aggressive environment. The blocks can be shaped so that they interlock with each other without mortar, while having provisions for the monument's "breathing." Impregnation is a technically feasible (though not always economical) way to convert a poor quality, porous mass into a high quality, durable one.

Currently, there are not many known manufacturers of polymer-impregnation-treatment [19]. Between 1985 and 2000 polymer-impregnation-treatment was carried out on natural stone only three times [20], in which it succeeded twice and failed once. In both of the cases that succeeded, the natural stone was sandstone, while in the case that failed the stone was clay-stone. This confirms that natural stones having large porosity may be more suitable for polymer-impregnation-treatment than those with low porosity. The polymer-impregnation-treatment of sandstone improved its compressive strength almost 5 times, from 8 MPa to 40 MPa. It is highly recommended that impregnation of a specimen would always be performed before applying the process to the monument. The maximum size of sandstone monuments that can practically be impregnated is 1m x 1m x 1m [20]. It has been 10 years and 5 years since the polymer-impregnation-treatment was performed on the two sandstone monuments mentioned above and, so far, no problems have been reported.

MATERIALS AND METHODS - MORTARS AND PLASTERING

One solution to some of the Sphinx's problem could be in plastering certain parts of it, or its outer stone casings, with polymer-based mortar. Countless surface repair mortars are now commercially available for repairing deteriorated surfaces of concrete and stone that are damaged by erosion and severe climatic conditions. Unfortunately, the essential data provided by manufacturers are very limited and, even if available; they are usually restricted to lab values.

Surface repair mortars must be carefully evaluated for each particular field application on the Sphinx as regards their types, mix designs, performance, and effect on the mother rock. Performance includes properties such as bond strength, permeability, coefficient of thermal expansion, thermal compatibility with substrate stone, and erosion resistance. Experimental work done in Canada [21] on surface repair mortars for concrete surfaces showed that epoxy mortars have significantly higher bond strength and erosion resistance among some 35 other surface repair mortars that were tested. However, although the bond strength and erosion resistance of epoxy mortars are high, the performance of these surface repair mortars was poor in most of the other essential physical tests. They still require more study for modification and optimization of their properties in order to be used effectively with the restoration/preservation of the Sphinx.

MATERIALS AND METHODS - SEALERS, COATINGS AND PENETRANTS

Sealing the Sphinx may sound as a simple and relatively inexpensive means to protect it from aggressive agents and harmful exposure conditions. However, extreme care must be exercised in light of the obvious archaeological value of the monument, and the risk of any irreversible damages that could happen while trying to preserve it. Generally, sealers can be used to repair, maintain, and preserve monuments made of natural stone through "sealing" the stone surface to prevent the transmission of water through it, thus slowing or even stopping the gradual deterioration of these monuments.

The term "sealant" or "sealer" as used here refers basically to a liquid polymer that is applied to the surface of a natural stone to form a barrier layer. However, this does not necessarily exclude other forms or functions of sealers such as membranes, coatings, penetrants, joint fillers, or caulks that can simultaneously be applied to different localized areas on the Sphinx's surface as need be. There are two major types of barriers: one is an impermeable barrier that excludes all materials, including liquids and gases. The other is a semi-permeable or perm- selective barrier that selectively excludes some types of substances, yet permits the passage of other substances—such as the "breathable" sealants which exclude liquid water yet pass water vapour [22].

Sealants have been used for a wide variety of purposes which include: waterproofing, moisture proofing, water repellent, protection from freezing and thawing effects as well as from chemical attack by aggressive liquids, barrier to atmospheric gases, surface sealant, to improve durability and aesthetic or architectural appearance, and/or as a cleaning aid or anti-graffiti product. They can also be used in the restoration/preservation of the Sphinx. Before venturing that, however, it should be noted that not all applications were successful. In some situations [22], sealants trapped moisture inside the stone pores and proved to be detrimental to the monument.

Other questions that need to be answered include, but are not limited to, whether sealing is indeed the best option; what is expected of a sealant's performance; which products in the market are most likely to provide the needed protection; whether they really perform as the supplier claims they do, and for how long; are they easy to apply; are they hazardous; do they require maintenance, and how often; and most importantly whether they could have any adverse side effects on the mother rock, such as changes in appearance, colour, or structural integrity.

A physical system would comprise a polymer that is dissolved in a solvent to reduce its viscosity. As the solvent evaporates, the polymer dries out and forms a solid film. A reactive system in solution would comprise the active ingredient or a monomer dissolved in a solvent, which reacts with another component to form a polymer. The solvent is only used to reduce the viscosity and is not involved in the formation of the polymer. It evaporates after the polymer is formed.

In other systems, the active ingredient can be dissolved in a reactive solvent that not only reduces the viscosity, but also joins in the chemical reaction and becomes a part of the final polymer. A solvent-free reactive system can be used when the reactive components intrinsically have the required low viscosity. In that case, the components would react directly with each other to form the polymers. Reactive resin systems, or liquid plastics, react when a specific hardener system is added and polymers are formed.

Epoxy resin systems harden by polyaddition of the hardener with active hydrogen atoms and resins with epoxy groups. The resin and hardener must be dosed in stoichiometric amounts. The hardening reaction is temperature dependent. In methacrylic resin systems, the polymerization is brought about by radicals derived from peroxide and an aromatic amine. This class of resin is distinguished from all the other reaction resins by the fact that monomeric methylmethacrylate is already polymerizable with a viscosity of 1 mPa.s. If required, however, the viscosity can be set at any desired level by means of dissolving polymethacrylates [23].

The unsaturated polyester resins are considered the most economical standard resins. However, these resins should be carefully examined since they are not alkali resistant and are not sufficiently ultraviolet (UV) and weatherproof. Polyurethane resins harden through poly-addition. The hardening is strongly catalyzed by moisture. Using aliphatic isocyanates in conjunction with aliphatic polyalcohols, light- and weatherproof polyurethane systems are produced. The resistance to UV has to be improved by adding UV-inhibitors.

Silicic acid ester reacts with water and forms silicium dioxide that works as a bonding agent to disintegrating sandstones. Silanes are silicon compounds that contain ester groups, which form silanols during hydrolysis. This alkyl-silanol is stable and reacts immediately with another molecule, but also with OH-groups of quartz in the natural stone, thus linking or cross-linking the silanol with a silicon atom in the stone. Through the intermediate stage of siloxanes, polysiloxanes (silicon resin) are then formed, showing an excellent water-repellent finish, protecting the stone from penetration by water and the pollutants dissolved therein. Deep penetration into the material [24] is made possible through using monomeric silanes with a molecular length of approximately 10 A.

Polymethyl Methacrylate (PMMA) solutions are non-yellowing, with excellent UV- resistance. These polymers are dissolved in appropriate solutions, and become effective after evaporation of the solvent by forming films of varying strengths. As these PMMA films are permeable to water vapour but resistant to air-borne pollutants, they are used with great success as a protective paint for paintings, frescoes, marble and gold-platings, and for preserving stonework [25].

CONCLUSIONS

The progress achieved in the production of polymeric materials is unsurpassed, with new materials and methods being developed at an amazingly accelerated rate. Such new materials have great potential and may carry with them an effective solution to some of the problems facing the Sphinx. This can help in its ongoing restoration and preservation efforts. Before applying any materials or methods to the monument or any part thereof, it is imperative that a sample, which resembles the mother rock, be tested first under simulated natural conditions.

REFERENCES

1. Hajar, R., "The Sphinx: Part 3," World and I, v14 i2, p228, February 1999.
2. West, J. A., "Serpent in the Sky," 1979.
3. Schoch, R., "Old-Sphinx Theory," Boston University, 1990.
4. Hawass, Z., and Lehner, M., "The Great Sphinx of Giza: Who built it, and Why?" Archaeological Institute of America, V47, #5, pp. 30-41, September/October 1994.

5. Gale Group, a Thomson Corporation Company, “Perils of the Sphinx,” Academic Universe, http://web.lexis-nexis.com/universe/, 2000.
6. Wiens J., “Tomb Discovery Adds to Burden of Ancient Sites,” The Daily Telegraph, Telegraph Group Limited, 1995.
7. Maugh, T., “Scrambling To Save The Sphinx,” Los Angeles Times, The Times Mirror Company, June 4, 1990.
8. News World Communications, 1999.
9. Gauri, K.L., “Geological Study of the Sphinx,” American Research Center in Egypt, Newsletter, 127, p. 19-27, 1984.
10. Gauri, K.L., and Holdren, G. C., “Deterioration of the Stone of the Sphinx,” American Research Center in Egypt, Newsletter, 114, p. 35-47, 1981.
11. Chowdhury, A., Adinara, Y., Punuru, A., and Gauri, K., “Weathering of Limestone Beds at the Great Sphinx,” Environ Geol Water Sci, Vol. 15, No. 3, Springer-Verlag New York, Inc., pp. 217-223, 1990.
12. Phillips, J., “A Riddle for the Conservationists,” The Jerusalem Report, p. 34, March 1992.
13. El-Baz, F., “Saving the Sphinx,” Geotimes, v38 n5, p. 12, May 1993.
14. Lehner, M., “Computer Rebuilds the Ancient Sphinx,” National Geographic, pp. 32, 1991.
15. Hedges, C., “Sphinx Poses Riddle about its Own Fate,” The New York Times, Science Desk, The Environment Page, March 10, 1992.
16. Academic Universe, http://web.lexis-nexis.com/universe/, 1998.
17. Miller Freeman Publications, “Pyramids are Built on Glue,” What's new in Design, pp. 57, January 1997.
18. Wahby, W.S., “Saving the Sphinx,” A research project, Eastern Illinois University, School of Technology, work in progress, 2000.
19. Ohama, Y., “Recent Progress in Concrete-Polymer Composites,” Review Article, Elsevier Scince Ltd., 1997.
20. Tsuruta, K., “Polymer Impregnation,” e-mail to the author, September 11, 2000.
21. Mirza, J., “Evaluation of Surface Repair Mortars for Erosion-Damaged Concrete,” Proceedings of the VII International Congress on Polymers in Concrete (ICPIC), Moscow, September 22-25, pp. 739-756, 1992.
22. DePuy, G.W., and Arney, D.O., “Concrete Sealers For Hydraulic Applications,” Proceedings of the VII Int. Congress on Polymers in Concrete (ICPIC), pp. 69-85, Moscow, September 22-25, 1992.
23. Koblischek, P. J., “Protection of Surfaces of Natural Stone and Concrete Through Polymers,” Proceedings of the International Conference on Surface Engineering: Current Trends and Future Prospects, Elsevier Applied Science, England, Editor: Meguid, S.A., University of Toronto, Toronto, Ontario, Canada, pp. 62-71, June 25-27, 1990.
24. Koblischek, P. J., “Polymers in the Renovation of Buildings Constructed of Natural Stone,” Proceedings of the VII International Congress on Polymers in Concrete (ICPIC), pp. 298-305, Moscow, September 22-25, 1992.
25. Furlan, V., and Pancella, R., “Properies d’un gres tendre traite avec des silicates d'ethyle et un polymers acrylique, Proceedings of the International Symposium, Bologna, pp. 27-30, October 1981.