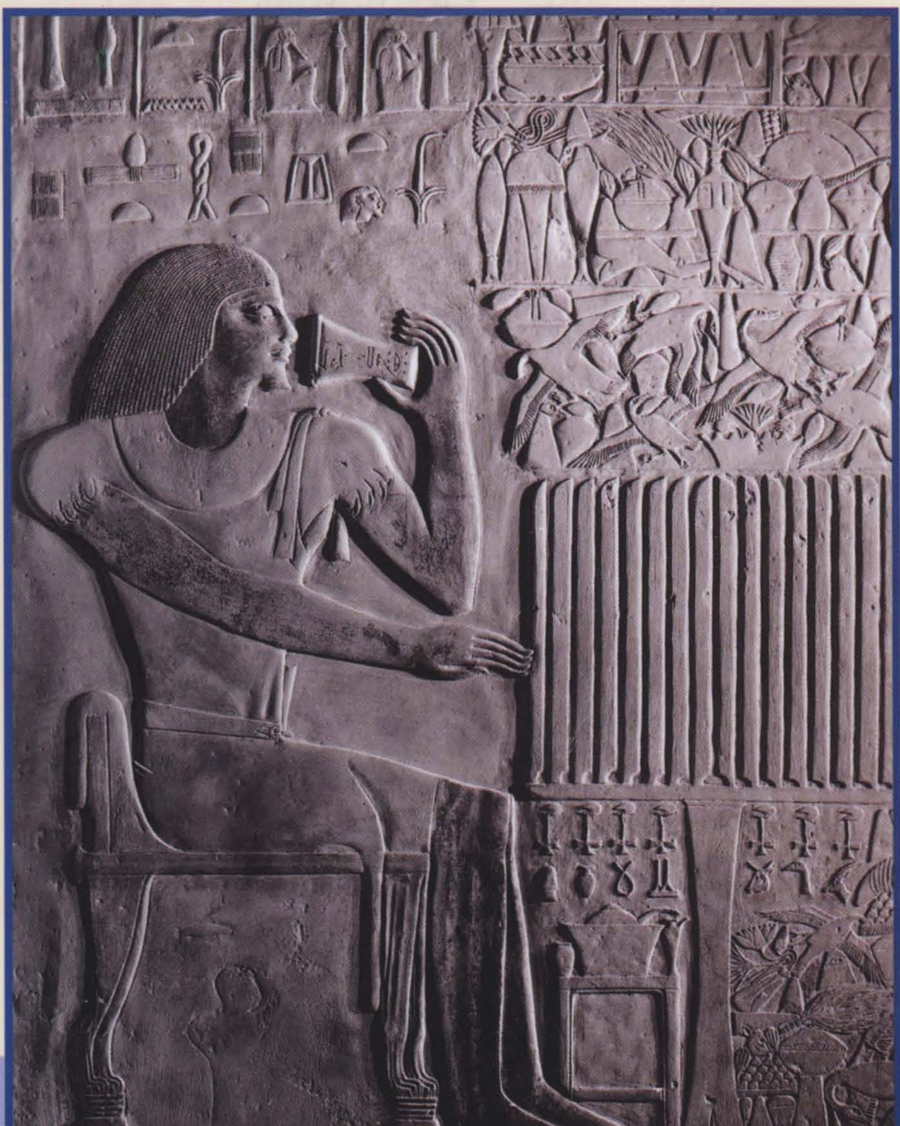
SUPPLÉMENT AUX ANNALES DU SERVICE DES ANTIQUITÉS DE L'ÉGYPTE

CAHIER N° 35

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

PREFACE
ZAHI HAWASS

EDITED BY
KHALED DAOUD
SAWSAN ABD EL-FATAH



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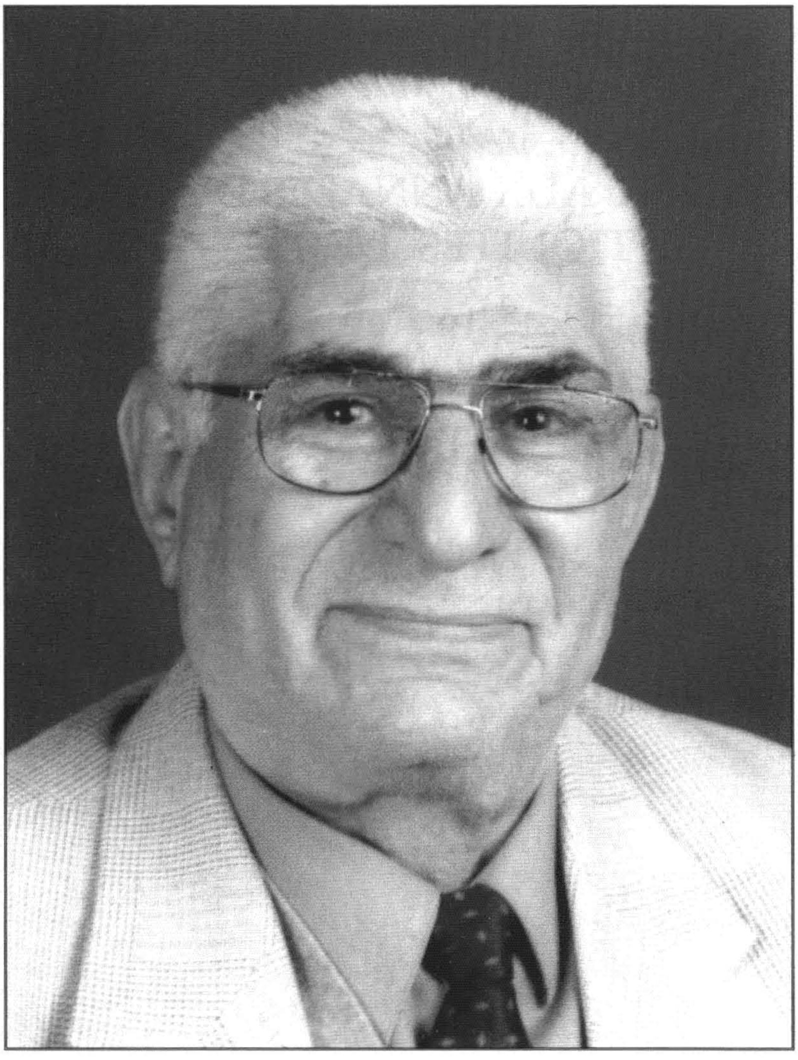
Cover Illustration:
An offering scene from the mastaba of Ptah-hotep, Saqqara.



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IMPRIMERIE DU CONSEIL SUPRÊME DES ANTIQUITÉS

MORTARS AND STONES FOR THE RESTORATION OF MASONRY WORKS IN THE SPHINX

*S. M. NAKHLA and M. ABD EL KADER**

I. Abstract

Twenty ancient mortar samples have been collected from different parts of the Sphinx's body, which could represent the evolution of mortar composition applied to the Sphinx throughout its history.

The samples were analyzed by XRD (X-ray diffraction). The results show that mortar composition varies from gypsum, gypsum/ lime and cement together with other components.

Different mortar mixtures have been studied, and the one consisting of lime-sand L_1S_3 < 500 mM, having compressive strength 8.5k.g cm-2 and specific gravity 1.68 gm cm-3, has been found to conform to ICCROM recommendations and appropriate for restorations in the Sphinx.

Ten limestone samples from different quarries near Cairo were tested for physical properties with the one near the 15th of May town southeast of Cairo found compatible with the Sphinx mother rock and appropriate for masonry works.

II. Introduction

The study of ancient mortars is of great importance from a historical and technological point of view. Moreover, the selection of a given mortar for restoration is of vital importance as mortar properties play an important role in the functioning of a given structure and its outer skin, hence on its state of preservation.

Throughout its history, the Sphinx at Giza was subjected to several restorations intended to preserve the monument. The most important interventions are those of the New Kingdom (Thutmose IV), Roman Period, and Baraize's restoration in 1926. Since that time, several interventions have taken place using different materials varying from gypsum, lime/gypsum, hydraulic lime, and cement mortars.

In recent years, Portland cement and gypsum were used excessively in the restoration of masonry works in the Sphinx regardless of the environmental conditions prevailing at the site and the rise of subsurface water level. As a result of the inadequate properties of these materials and the heavy crystallization of soluble salts, separation of the veneer wall of the left rear leg took place in 1981.*

In the 1982 to 1987 restorations, cement in a semi-liquid form was used in great quantities as a filler between limestone blocks and the mother rock (body of the Sphinx). As a result of its large thermal expansion coefficient (which may even be twice as large as that of lime mortars and most types of bricks and stones) and its low porosity as well as the formation of soluble salts while setting and the subsequent volume increase, the displacement of limestone blocks and flaking of the surface took place.

* Supreme Council of Antiquities (SCA), Cairo, Egypt.

In this work, twenty ancient mortar samples were studied by XRD in order to understand the evolution of mortar technology during the different periods.

Following the ICCROM recommendations (1981) which state that the ideal conservation mortar should have values of mechanical strength and modulus in the same range as those of good lime-sand mortar and its pore-size distribution should be comparable with that of lime-sand mortar, a primary program has been elaborated in order to choose appropriate lime mortar.

Ten limestone samples from different quarries were tested with the one near the 15th of May town southeast of Cairo selected, being compatible with the mother rock of the Sphinx.

III. Study of ancient mortars

Ancient mortars are an important source of information; the analysis of these mortars may give an indication of the composition of mortar mixtures used during the different periods as well as their state of preservation.

Twenty mortar samples were collected from different places on the Sphinx's body following the photogrametry prepared by Mark Lehner in 1979 as well as other samples recovered during restorations.

Sample location is presented in figures 1 and 2. Samples are analysed by XRD both in the Department of Chemistry, Faculty of Girls, Ain Shams University and in the Center of Research and Conservation of Antiquities, E.A.O. Results are presented in tables 1 ,2, and 3 following the relative composition of mortar samples and in figures 3 and 4.

IV. Preparation of an appropriate mortar for restoration

A general requirement for materials used in restoration is that they should not cause an acceleration of the deterioration rate of the adjoining ancient material in addition to performing satisfactorily in their mechanical action.

Although gypsum was the main component of mortars in ancient Egypt, its physical side effects makes it inappropriate for restoration, especially in humid-dry cycles. The failure of restorations in the last couple of years where cement has been extensively used is typical in situations where a strong modern material is used in a comparatively weak context. Portland cement is too strong with a high compressive strength. It has a large thermal expansion coefficient, low porosity mainly consisting of small pores hindering water movement, and it forms soluble salts while setting and increasing with time.

However, the use of hydraulic lime/cement mortars in the 1926 restoration showed no signs of failure both in exposed areas as in the *nemes* headdress as well as in places far from the surface, such as the inside of the right rear leg.

For the restoration of masonry works in the Sphinx, both gypsum and cement mortar have been rejected. Emphasis has been placed on lime mortars, though some tests were conducted on lime mortars containing certain proportions of crushed fired brick or white cement for surface consolidation. Samples were prepared at ordinary room temperature and relative humidity conditions. Both lime and sieved sand were washed thoroughly to eliminate soluble salts.

Moulds were prepared in the National Institute of Building Materials, Cairo and kept there for curing for one month as indicated in table 4. Compressive strength and density values for twelve samples are given in table 4. Sample no. 1 L1.S3. < 500 mM has been selected by the Sphinx committee for restoration.

V. Selection of suitable limestone for masonry works

Several samples collected from different quarries and from previous restorations were tested in the laboratories of the National Institute of Building Materials, Cairo.

The sample collected from the quarry of the 15th of May town has been chosen by the Sphinx committee (Table 5, no. 9).

VI. Discussion

1. Ancient mortars can be classified into four main categories:

a. Gypsum mortars where gypsum is the main component

Nine samples were found consisting mainly of gypsum, while calcite is only present in small proportions.

Such mortar compositions can be attributed to the Old Kingdom; the same composition is known from a mortar sample collected from the Chephren pyramid.

b. Gypsum/lime or gypsum/calcite mortars where calcite is present in relatively higher concentrations in seven samples. Dolomite has been found in four of them. This type of mortar represents a change in mortar composition, apparently not belonging to the Old Kingdom as the previous ones. It may be attributed to New Kingdom restorations or to Roman times?

c. Lime mortars consisting mainly of calcite with varying proportions of gypsum, probably Roman?

d. Mortars used for the consolidation of the *nemes* headdress were known to consist of lime and cement mixture (Garas, person. comm.). Another similar mortar sample was collected from the abdomen zone on the left side.

2. Gypsum and cement have been rejected for use in restoration:

Several lime mortars with various additives were tested, and the one consisting of L1S3 < 500 mM was selected.

3. Limestone of high compressive strength and law:

Abrasive specification has been chosen being compatible with the mother rock of the Sphinx.

Table 1

Sample No	Sample Description	$CaSO_4$ $2H_2O$	$CaSO_4$	$CaCO_3$	NaCl	SiO_2	NaAl Si3O8	Ca5Si3o11 3H2O	Mg2Si2O5 (OH)5	Impurities
1	Ancient mortar from the elbow of the north front paw, fourth row from the ground	55		8	10	4	15			2
2	Ancient mortar from the surface of the north back paw, 160cm from the ground	74		13		12				1
3	Ancient mortar collected between the ground and the first row, north back paw	77		10		7			4	2
4	Ancient mortar collected between the body and back support, left side and fifth row from the ground	85		4		7		2		2
5	Ancient mortar collected from the abdomen in front of the fourth row of the south back paw	64	3	5		27				1
6	Ancient mortar recovered during restoration above the south back paw	80				19				1
7	Ancient mortar collected from the back support, first row, right side of the Sphinx	78		5		8			8	1
8	Ancient mortar collected from the front support, right side of the Sphinx	59		8	28			4		1
9	Ancient mortar collected from the corner abdomen, front support, right side of the Sphinx	75		5		19				1

Values are given as relative percentages following the standard curves for major components.

Table 2

Sample No.	Sample Description	$CaSO_4$ $2H_2O$	$CaSO_4$	$CaCO_3$	CaMg $(CO_3)_2$	SiO_2	NaCl	B $Al(OH)_3$	$Ca_3Si_3O_{11}$ $3H_2O$	OCFO Fe_2O_3	$CaCu_4O_3$	Impurities
10	Ancient mortar near the elbow of the north front paw, eleventh row from ground	40		29		12	13		4			2
11	Ancient mortar from the end of the north front paw, abdomen, fifth row from the ground	44		25	11	1		14				5
12	Ancient mortar from the left side, from the abdomen near the elbow, sixth row from the ground, east to the front support	48		27	6	3		13				3
13	Ancient mortar from the left side northwest corner, fourth row from the ground	30		30	5	8	25					1
14	Ancient mortar collected from the northwest corner of the back support, left side of the Sphinx	59		35		2						4
15	Ancient mortar collected at the end of the abdomen, right side of the Sphinx between a pharaonic block and another old restoration block	47	2	25		9		2		9	4	2
16	Ancient mortar collected from the abdomen, near the elbow, left side of the Sphinx	12		23		46	8	9				2

Values are given as relative percentages following the standard curves for major components.

Table 3

Sample No.	Sample Description	$CaSo_4$ $2H_2O$	$CaCO_3$	NaCl	SiO_2	Al_2O_3	B $Al(OH)_3$	Impurities
17	Mortar collected from the left side of the Sphinx, middle of the abdomen, seventh row from the ground	6	89	3				2
18	Sample collected from the surface of a striated block on the abdomen, near south back paw	21	70	3			5	1
19	Mortar collected from the *nemes* headdress, back of the head (1926 restoration)	8	33		58			1
20	Mortar collected from the abdomen, left side of the Sphinx, fifth row from the ground	12	23		46	9		2

Values are given as relative percentages following the standard curves for major components.

Table 4

Some mechanical and physical properties for certain mortar samples

	Mortars Components	Compressive strength kg/Cm2	Specific Gravity
1	L1 S3 < 500 mM (V)	8.50	1.68
2	L1 S3 500-1000 mM (V)	5.00	1.78
3	L1 S3 1000 – 2000 mM (V)	5.70	1.83
4	L3 S8 < 500 mM C13 (V)	4.10	1.70
5	LI S3 < 500 mM B1/4 (W)	2.63	1.40
6	L1 S3 < 500 mM B1/2 (W)	2.72	1.48
7	LI S3 < 500 mM B3/4 (W)	3.27	1.48
8	L1 S3 < 500 mM B1 (W)	2.44	1.42
9	L1 S2 < 500 mM C1/4 (W)	5.31	1.68
10	L1 S3 < 500 mM C1/2 (V)	4.13	1.66
11	L1 S3 < 500 mM C3/4 (V)	8.10	1.69
12	L1 S3 < 500 mM C3/4 (V)	22.70	1.76

L : Lime putty
S : Local dune sand
Cl: Clay
B: Brick powder
C : White cement

V: Volume
W: Weight

Table 5

Characteristics of limestone samples

Sample No.	Site	Compressive strength kg/ Cm^2	Abrasive Test Loss in mm	Specific Gravity	H_2O Absorption %
1	Near Mokattam, SE Cairo	96.00	5.31	1.97	10.69
2	Near the Citadel, Mokattam	86.00	3.95	1.94	11.72
3	Near Mokattam	77.00	3.62	1.91	13.78
4	Restoration of 1940 -1950 (North back paw)	287.00	5.424	2.23	9.91
5	Restoration of 1960	175.00	4.67	2.09	8.38
6	From the walls of the east boat pit of the Cheops pyramid	163.00	3.76	1.97	10.48
7	EJ -Masan quarry	138.00	3.0	2.05	6.95
8	Rock south of the Sphinx	258.00	4.00	2.28	9.08
9	15th of May quarry	382.00	3.51	2.10	4.55
10	15th of May quarry	154.00	8.19	2.05	4.13
11	15th of May quarry	57.00	4.56	2.02	10.17

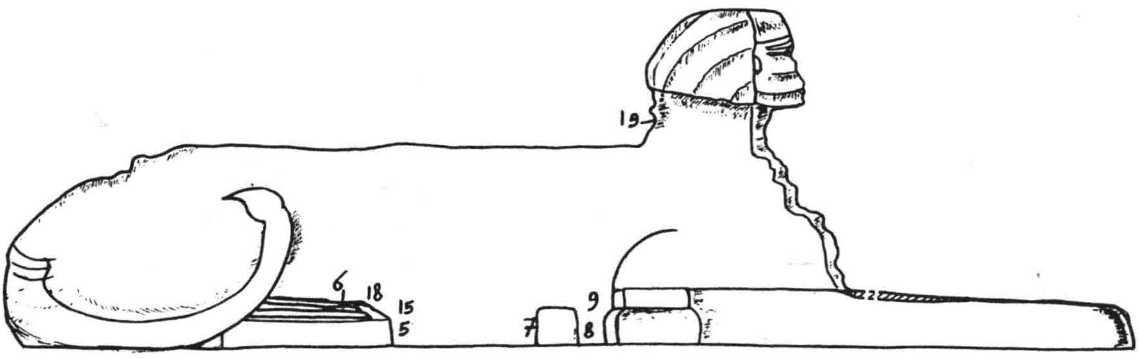

Fig. 1. Sphinx-Giza, South Elevation.

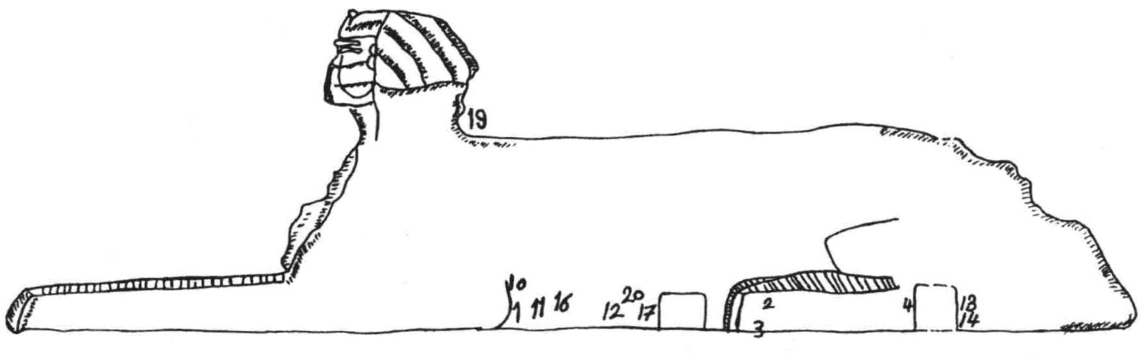

Fig. 2. Sphinx-Giza, North Elevation.

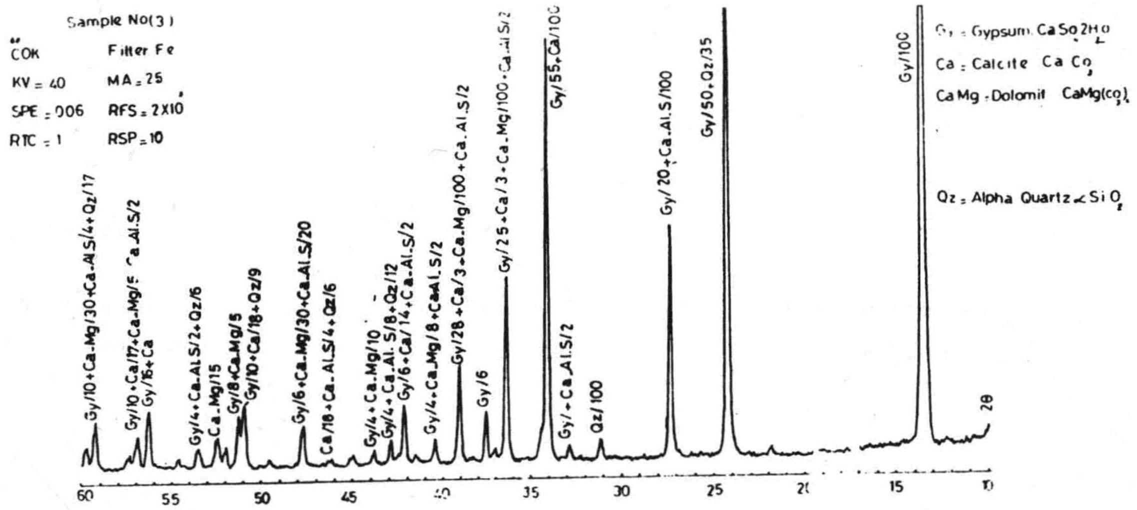
Sample No(3)
COK
Filter Fe
KV = 40
MA = 25
SPE = 006
RFS = 2X10
RTC = 1
RSP = 10
Ca = Calcite Ca Co3
CaMg - Dolomit CaMg(co3)2
Qz = Alpha Quartz α Si O2

Fig. 3

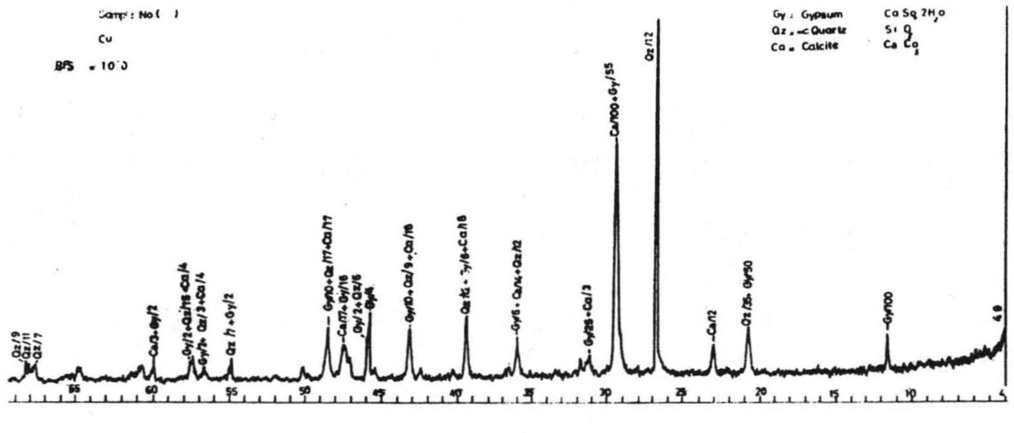
Gy = Gypsum Ca SO4 2H2O
Qz = α Quartz Si O2
Ca = Calcite Ca CO3

Fig. 4

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