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

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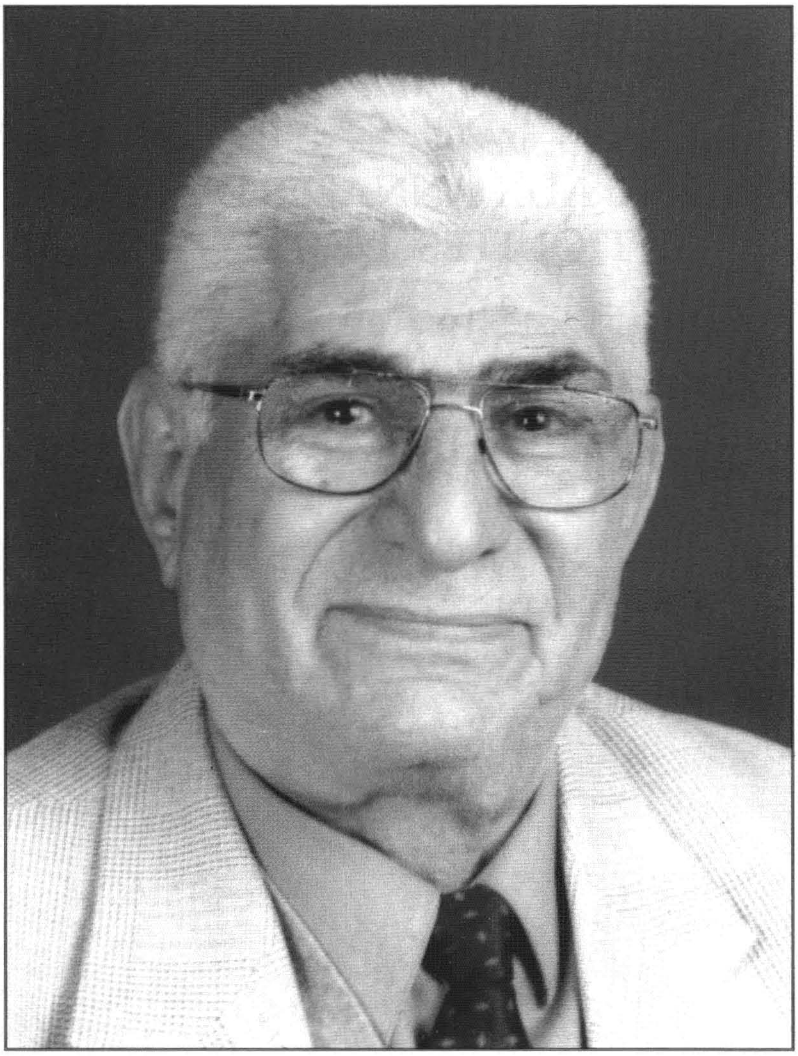
Cover Illustration:
An offering scene from the mastaba of Ptah-hotep, Saqqara.



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IMPRIMERIE DU CONSEIL SUPRÊME DES ANTIQUITÉS

MODERN CONSOLIDANTS: AN APPROACH TO THE CONSOLIDATION OF THE MOTHER ROCK OF THE SPHINX

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I. Abstract

Detailed analyses of the corrosion products and the underlying rocks in the Sphinx showed the presence of amorphous silicic acid in higher concentrations. These results suggest further study of the application of a silicate technology which could lead to the formation of a concrete similar to the highly resistant Roman cement. Monitoring of the environmental conditions could also help towards a better understanding of the state of preservation of the Sphinx.

II. Introduction

Of the different factors affecting natural stone structures, the mechanical and physio-chemical factors are considered the most important since they affect the state of preservation of the Sphinx. Monitoring of climatic conditions at the Sphinx site and that of humidity levels in a test wall built on the left side of the monument facing north as well as on other rocks at the site showed that the wind is mainly from the northwest. Atmospheric humidity is the main source of humidity in the Sphinx's body; daily variations of relative humidity (R.H.) may reach 60% and that of temperature may reach 15°C (Figs 1-4).

The formation of amorphous silicic acid on the surface of the mother rock in an acid atmosphere suggests further study of the application of a silicate technology that could result in the formation of a concrete similar to Roman cement, which resisted environmental conditions for more than two millennia.

Tests on the surrounding rocks of the Sphinx, in Kom Ombo, Medinet Habu, and in Bab Mahrouk in Fès produced good results for the stabilization of the surface of the limestone.

III. Material and methods

III.1 Natural stones suffer from four types of degradation:

a) Mechanical (wind erosion,.....)
b) Physical (water and salt migration)
c) Biological (effect of microorganisms and insects)
d) Chemical (chemical reactions due to atmospheric pollution)

Of these four types of degradation, the mechanical, physical, and chemical factors are considered the most important as they are responsible for the degradation of the stones.

However, recent analysis of the corrosion products on the surface of the mother rock of the Sphinx showed that an acid atmosphere causes changes in the silicate components of the surface of the rock resulting in the formation of amorphous silicic acid.

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** Institute of Silicates, Vienna.
*** Meteorological Survey of Egypt.

Table I

	1 C stone W. %	1 N flakes w.%	1 S flakes w. %
Ignition loss	42.97	40.98	45.39
SiO_2	2.42	5.45	5.34
Al_2O_3	0.80	0.44	0.17
Fe_2O_3	0.22	0.33	0.40
MgO	4.50	1.28	1.53
CaO	47.21	48.87	48.62
Na_2O	0.94	0.59	0.72
K_2O	0.11	0.17	0.23
CO_2	39.06	39.91	34.89
Total SO_4^{2-}	3.45	1.63	1.99
Water Soluble:			
SO_4^{2-}-	0.24	0.69	0.37
Cl-	0.99	0.69	1.05

1 C: Pieces of stone detached from the center of the chest of the Sphinx, collected in November 1991

1 N: Flakes separated from the chest of the Sphinx (north), collected in November 1991

1 S: Flakes separated from the surface of the chest of the Sphinx (south), collected in November 1991

As this corrosion product could not be eliminated from the stone, it should be stabilized by a silicate chemical bonding.

It is well known that the Romans utilized volcanic ash (puzzolana rich in silicic acid) mixed with lime and sand to obtain the famous Roman concrete, which has resisted environmental conditions over the last two millennia.

Following the same principle, we proceeded by using white cement instead of lime, which in the presence of water and by reacting with the stone corrosion products, will give a silicate bonding.

$2\,(3CaO.\ SiO_2) + 6H_2O \Rightarrow 3\ CaO.\ 2SiO_2.\ 3H_2O + 3Ca(OH)_2$
cement powder ⇒ Hydrated cement + Slaked lime

$3\ Ca\,(OH)_2 + 2\ SiO_2 \Rightarrow 3CaO.\ 2SiO_2.\ 3H_2O$
Slaked lime + Corrosion product ⇒ Hydrated cement
(amorphous silicic acid)

The cement that is produced has a low capillary absorption capacity, a high water vapour diffusion capacity, and a slightly greater elasticity than the treated material as well as an excellent adhesion power to the treated surface due to the silicate bonding (Table II).

These properties are obtained by using an appropriate additive, which has been designed and adapted to the cement leading to the formation of the required silicate bonding.

Table II

Technical Data	Ec. Required value	SANO TEC value	Improving
Tear-off (N/mm)	> 1.5	2.6	73% higher
Tear-off strength frost and damp alternating atmosphere (N/mm)	> 1.0	2.5	150% higher
Bending tensible strength	> 5.5	8.1	47% higher
Compressive strength and resistance	> 22.5	34.6	53% higher
Water vapour diffusion (air layer thickness in meters)	< 490	0.05	80 times better
Codiffusion (air layer thickness in meters)	>50	517	10 times better
Water absorption coefficient	< 0.25	0.16	36% higher

These theoretical results have been tested, particularly on the highly deteriorated mother rock in the vicinity of the Sphinx as well as on the limestone blocks of the Giza Plateau Old Kingdom mastabas in the Western Field (2400 B.C.). These results have also been tested on highly deteriorated sandstone blocks in the temples of Kom Ombo and Medinet Habu in Upper Egypt.

The experiments done at Giza since March 15, 1990 and at Kom Ombo and Medinet Habu since January 26, 1992 have produced excellent results concerning the adhesion to the stone as well as the resistance to most severe atmospheric conditions.

Similar experiments have been done at Bab Mahrouk (twelfth century) at Fés on brick and adobe since November 1992. The results obtained are excellent.

III.2 Humidity levels measured periodically on different parts of the Sphinx, partly covered with plastic sheets using a protometer surveymaster, are concordant with those obtained on the test wall and are given in Table III.

Table III
Humidity measurements on the surface of the outer casing stones of the Sphinx

Date		Left front leg (north)		Left back leg (north)		Back of the Sphinx (west)		Middle part of the tail (south)	
Date	Time	Exposed	Covered	Exposed	Covered	Exposed	Covered	Exposed	Covered
18-9-91	8:00-8:30	80-80	60-40	75-80	55-80	60-70	60-15	65-75	5-5
		70-50	45-30	70-40	45-30	90-80	60-55	55-35	35-10
	12: 00-13: 00	70-40	10-10	60-90	60-60	50-40	50-30	80-80	5-5
		75-80	20-20	50-65	20-55	80-60	80-55	30-40	15-15
2-10-91	10:00-10: 20	60-85	40-20	90-85	70-60	50-80	40-25	35-40	20-10
		70-70	40-20	85-85	20-70	85-70	50-30	60-30	30-20
	12:30-12: 40	70-65	30-15	80-75	60-50	60-70	40-15	25-30	10-10
		65-85	40-40	80-60	80-30	60-45	10-25	30-20	10-10
27-11-91	8:00-8:30	90-90	85-85	90-90	80-70	80-40	80-70	60-30	20-10
		90-90	85-85	90-90	75-55	70-40	85-85	40-20	30-20
	12:00-12: 30	90-90	80-80	90-90	85-80	80-80	55-60	65-85	35-25
		90-90	80-80	85-85	80-80	85-85	65-30	85-85	35-30
9-12-91	8: 00- 8: 30	90-90	80-81	90-90	85-80	80-80	55-60	65-85	35-25
		90-90	80-80	85-85	80-80	85-85	65-30	85-85	35-30
	13:00–13: 90	85-85	85-80	80-70	60-60	80-75	70-55	20-70	20-20
		90-85	80-80	80-80	70-35	75-60	70-45	50-80	20-35
9-1-92	8: 00-8: 20	90-90	90-90	90-90	80-35	90-90	85-40	60-60	55-10
		90-90	80-85	85-85	70-30	90-90	70-75	80-90	20-35

IV. Discussion

Monitoring of climatic conditions at the Sphinx site was systematically done through a complete weather station belonging to the Meteorological Survey of Egypt.

Results indicate that the wind prevailing at the site is mainly from the northwest, daily R. H. variations may reach 60% and that of T. may reach 15°C (attached figures).

Monitoring of humidity levels on a test wall built on the left side of the Sphinx and on other parts showed that the source of humidity in the Sphinx is mainly atmospheric.

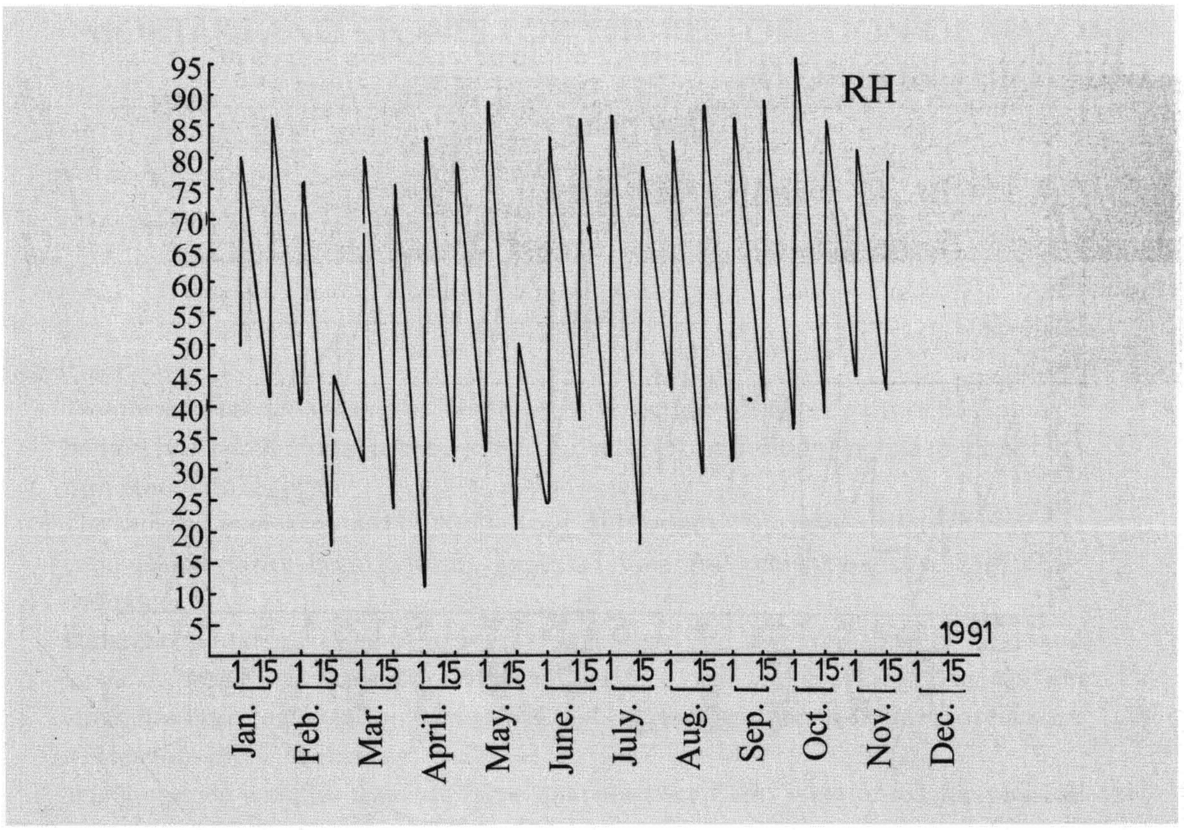
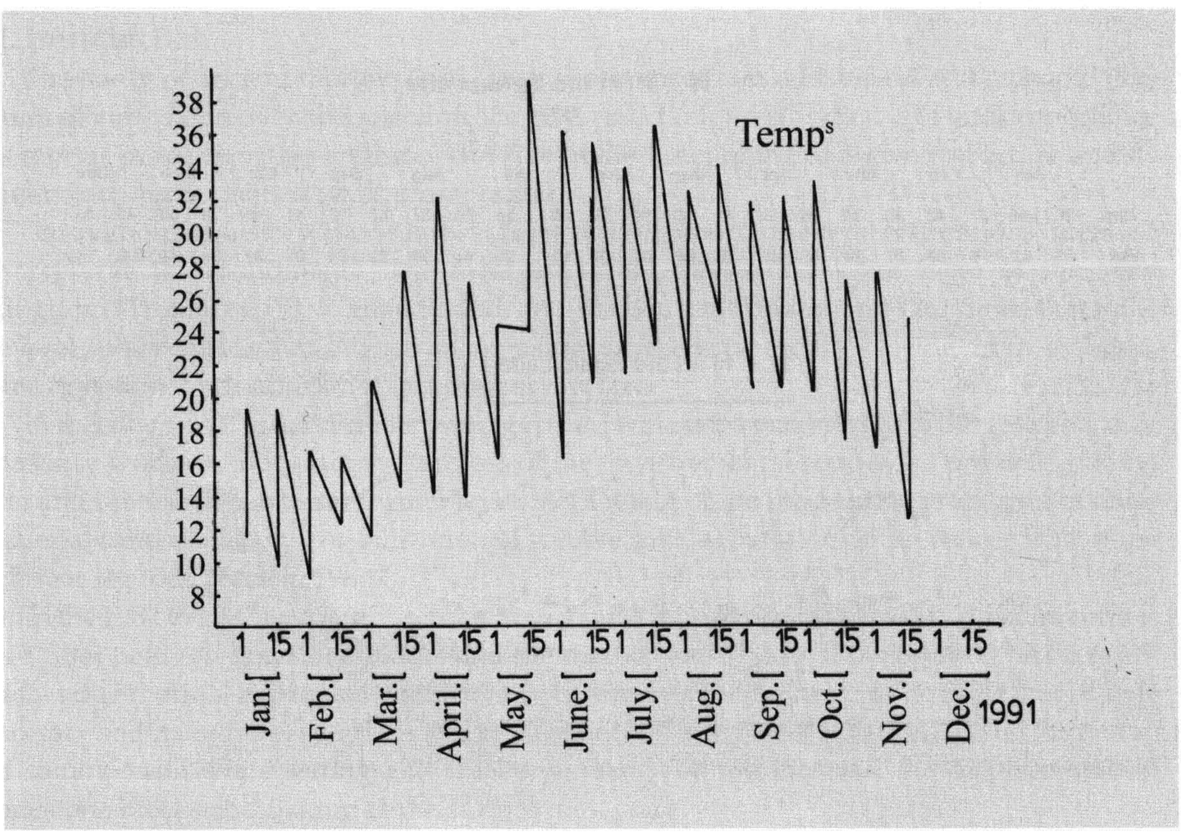

RH
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
1991
Jan.
Feb.
Mar.
April.
May.
June.
July.
Aug.
Sep.
Oct.
Nov.
Dec.

Fig. 1


Temp^s
38
36
34
32
30
28
26
24
22
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18
16
14
12
10
8
Jan.
Feb.
Mar.
April.
May.
June.
July.
Aug.
Sep.
Oct.
Nov.
Dec.
1991

Fig. 2

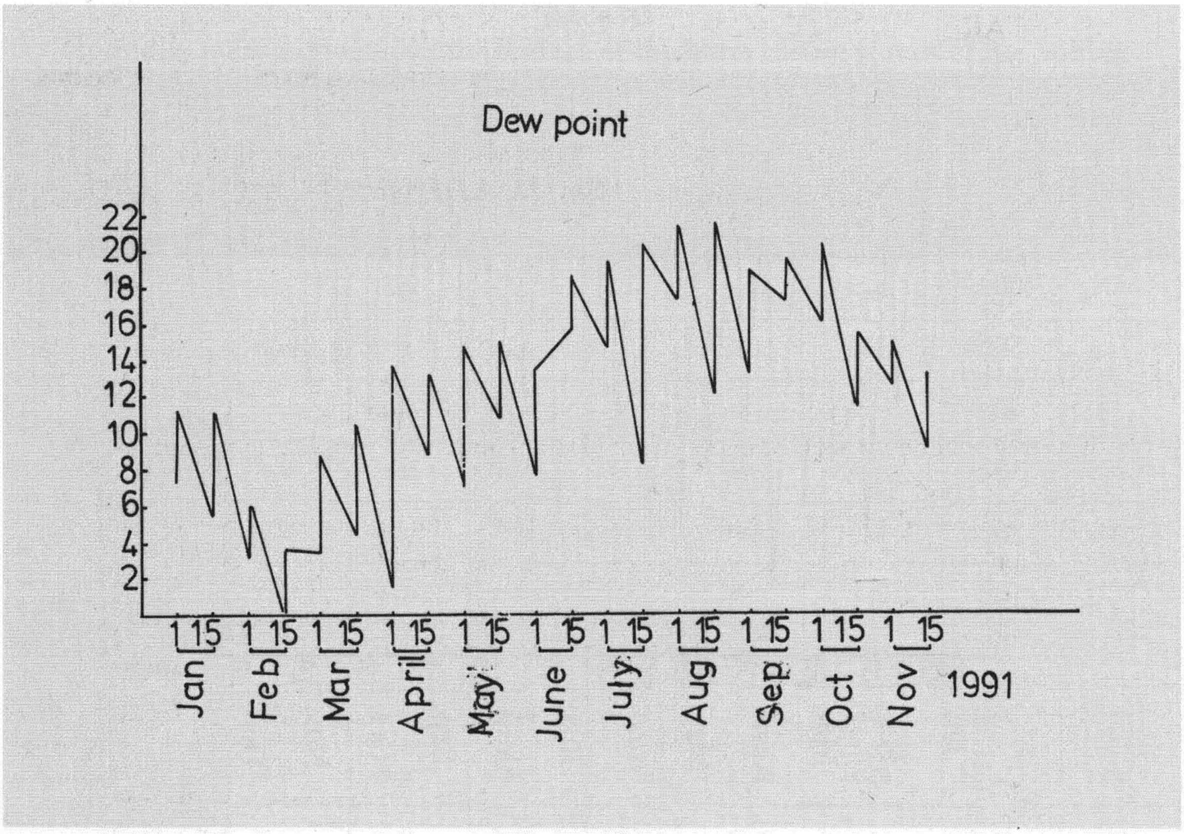

Fig. 3

R . H in the Sphinx site

1993

	Jan.		Feb.		Mar.		Apr.		May		Jun		Jul.		Aug.		Sep.		Oct.		Nov.		Dec
Min.	28	44	37	42	40	30	45	9	31	10	36	20	30	34	36	37	42	37	41	45	36	35	49	36
Max.	83	87	78	87	87	74	87	35	76	65	81	82	93	81	84	96	90	88	96	94	84	79	90	91

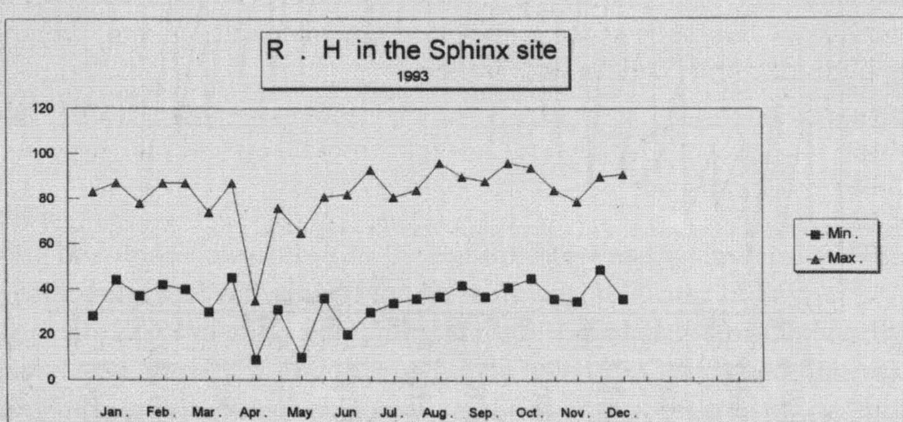

Fig. 4

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