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Geoarchaeology of Elephantine Rock-cut Tombs, Aswan, Egypt

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Abstract: *Rock – cut tombs of Elephantine Nobles are situated at Aswan town, south of Egypt. They were engraved in the Sandstone, which belonged mainly to the old, middle, and knew kingdoms. These tombs had several deterioration factors: endogenous include heterogeneities in the rock, presence of joints & cracks, and exogenous correspond temperature variation, wind, moisture, biological effect, and natural disasters. Petrographic and analytical studies were carried out on the rock tombs, mortar, plaster, and deterioration products using x-ray diffraction (XRD), polarizing microscope (PLM), and scanning electron microscope (SEM) coupled with energy dispersive X-ray (EDX) unit. Results declared that the rock is a ferruginous argillaceous micaceous sandstone. Experimental laboratory work was done on eleven consolidating materials to evaluate the best ones for conservation of these tombs. This was verified by using SEM examination and determination of physical and mechanical properties of the treated and untreated rock samples before and after exposure to artificial weathering cycles of hot humid and dryness. Data showed the success of three consolidants: nitocote SN 502, wacker 290, wacker BS 1001. A plan for architectural and conservation of elephantine rock-cut tombs was presented.*

Keywords: *Conservation, consolidating materials, Geoarchaeology, Rock-cut tombs, sandstone.*

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I. Introduction

Rock-cut tombs of Elephantine Nobles are located at Aswan town in Egypt, 879 Km south of Cairo the capital. The name Elephantine was derived from the ancient Egyptian name Abu, which means the earth of the Elephant. These tombs are considered ones of the splendid ancient Egyptian tombs, they situated in three levels on the slopes of the hills which form the west bank of Aswan city at the west-north edge of the Elephantine island. They were engraved in the sandstone rocks, belong to the 6^{th} and 8^{th} dynasties, middle kingdom, few to the knew kingdom.

Several deterioration factors act on these rock-cut Elephantine tombs: Endogeneous and Exogeneous, the endogeneous factors concern the nature of the rock itself which has heterogeneities in the mineralogical composition, and that presence of many joints.The exogeneous factors include: temperature variation, wind, moisture (condensation & evaporation), biological effect of (insects, birds & animals), and natural disasters such as earthquakes.This led to a fall, destruction of some tombs; distortion and deterioration in their mural paintings, such as flaking, scaling, exfoliation, and fragmentation, see figs 1-4.

The aim of the present work is to carry out geoarchaelogy of these tombs through analytical and experimental task to achieve a complete plan for their restoration and conservation.

II. Materials and Methods

2.1 Materials

2.1.1 Sandstone samples

Sandstone fragments were collected from the site of the Elephantine tombs.

2.1.2 Mortar, Plaster, and Bees nests samples

Samples of the used mortar and plaster in the tombs were taken from the deteriorated parts. Also samples of bees nests distorted the tombs were gained.

Fig. 1 The joints spreaded in the rock of one of the Elephantine tombs (Khones).

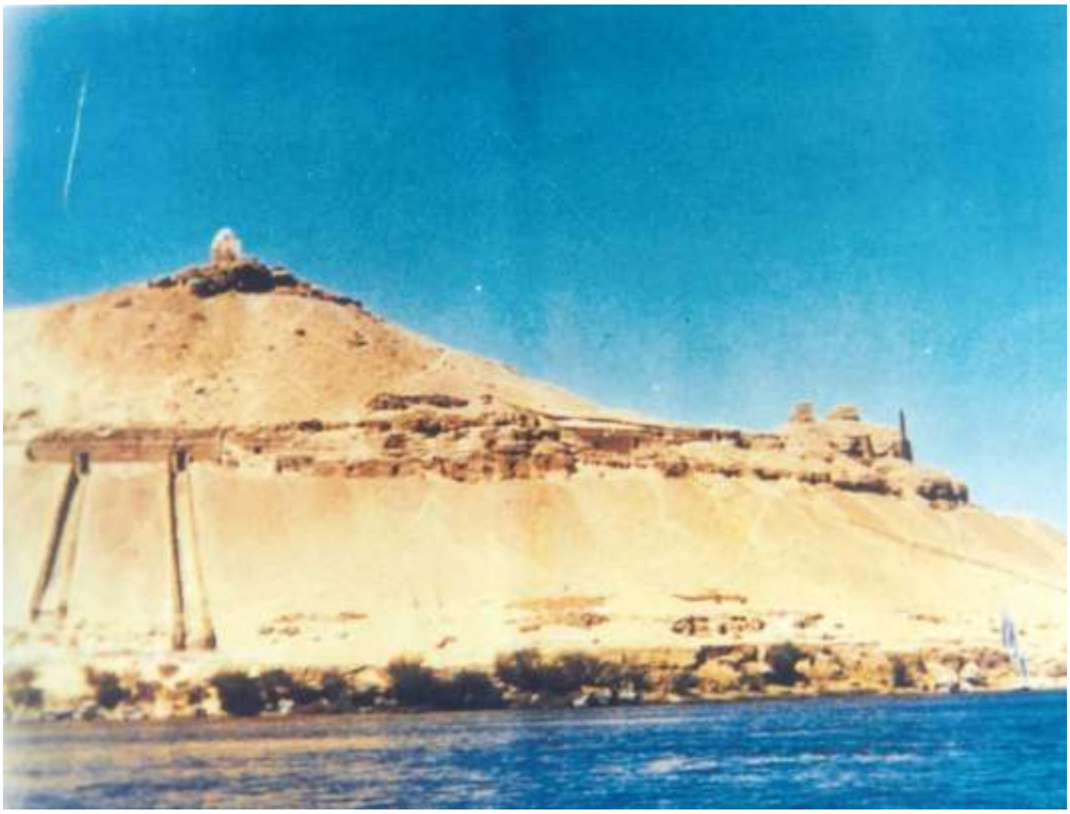

Fig. 2 General view of the Rock-cut Elephantine (Qubbet El- Hawa) tombs in Aswan.

Fig. 3 Deterioration inside one of the Elephantine tombs.

Fig. 4 Details of the serious joints existed in khones tomb.

2.1.3 Consolidating materials

Eleven consolidating materials were used: Nitocote SN502, Wacker 290, Wacker OH, Waker OH-100, Paraloid B-72, acoseal (water- repellent siloxane base), addicon (acrylic resin), kemtekt (potassium methyl silicone), Wacker BS-1001, Wacker SMR 1311, and Befix 1W (acid mineralic natural silicates). They were supplied by Aldrich chemical company.

1.1. Methods

1.1.1. X-ray diffraction analysis (XRD)

The mineralogical composition of sandstone, mortar, plaster, and bees nests was visualized by x-ray diffraction analysis using a Philips x-ray diffractmeter unit PW 1710. The operating conditions are: Cu K_α radiation $\lambda = 1.5418$ A˚ with Ni filter, 40 kv, 35 mA, receiving slit 0.2, Scanning spead 0.02˚/sec.

2.2.2 Polarizing microscope (PLM)

The petrographic study of sandstone samples was performed using Niconeclepce LV100 POL polarizing microscope.

2.2.3 Artificial weathering cycles

The sandstone samples were subjected to 30 cycles of artificial weathering. Each cycle cosists of exposure to hot humid conditions (4 hrs), then to complete dryness (4 hrs), and 16 hrs. at room temperature. This is a simulation to natural weathering to evaluate the durability and stability of consolidating materials.

2.2.4 Scanning electron microscope (SEM) coupled with EDX unit

Quant 250 SEM was used to determine the morphology of sandstone and its elemental chemical composition. Also to certify the durability and stability of the used consolidants before and after exposure to artificial weathering cycles.

2.2.5 Physical and mechanical properties

Porosity, water absorption, bulk density, and compressive strength of the untreated and treated sandstone samples were determined before and after exposure to artificial weathering cycles.

III. Results And Discussion

3.1 X-ray diffraction analysis (XRD)

XRD Pattern of sandstone shows that it consists mainly of quartz SiO_2 (JCPDS 5-0490),and kaolinite Al (Si_2 O_5) (OH)2 (14-164) after carrying out separation of the clay portion, treating with ethylene glycol, then heated at 550^{o}C, as shown in Figs 5,6.

Results showed that; the mortar used consists essentially of gypsum $CaSO_4$. $2H_2O$ (6-0046), anhydrite $CaSO_4$ (6-0226), and traces of quartz. The plaster composed of quartz, gypsum, and kaolinite, in another samples of mainly quartz, minor amounts of calcite, anhydrite and traces of gypsum, and kaolinite. Bees nests consist mainly of quartz, tridymite SiO_2 (14- 260), and a small amount of illite (9-334) Figs 7-10.

3.2 Polarizing microscope (PLM)

Thin section of sandstone showed that it is ferruginous argillaceous micaceous sandstone, moderately sorted consists of fine to medium quartz grains have angular to subangular grains, has a lot of heterogeneities in iron-oxide minerals see Figs 11-14

3.3 Physical and mechanical properties.

Physical properties of sandstone are: porosity: 20.1%, water absorption: 12.5, Bulk density: 1.64 gm/cm^2, compressive strength: 19.2. Data showed that the treated sandstone with nitocote SN 502 gave the best results, there was no effect on the appearance, and become hydrophobic. In case of paraloid B-72 and addicon, they were failed due to darkening in colour. So they were excluded in the next experiments. The nine another consolidants showed good enough results. Fig 15 shows the increase rates in compressive strength of sandstone after consolidation. Whereas figs. 16,17 show the decrease rates in porosity and water absorption respectively.

3.4 Scanning Electron Microscope (SEM) coupled with EDX unit

EDX results by SEM declared the elements constituting sandstone which proved the presence of quartz (a), kaolinite (B), hematite (c), and muscovite (D) Fig. 18.

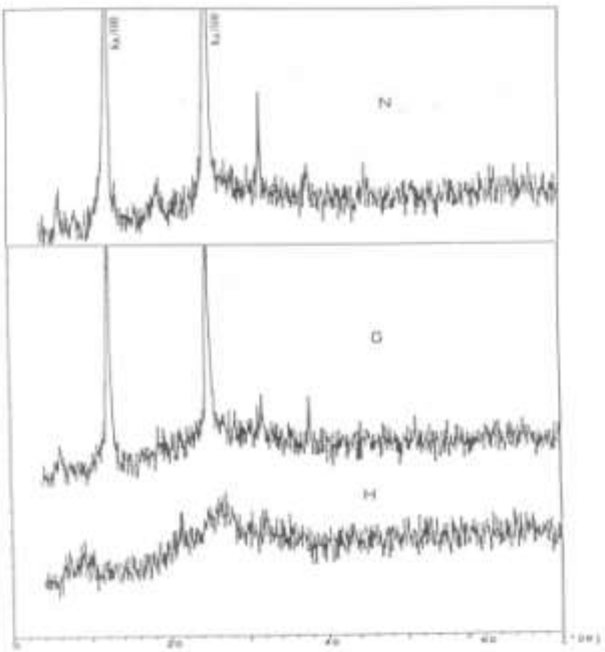

Fig. 5 X-ray diffraction pattern of clay minerals after separation from sandstone, for normal specimen (N), glycolated (G), and heated (H).

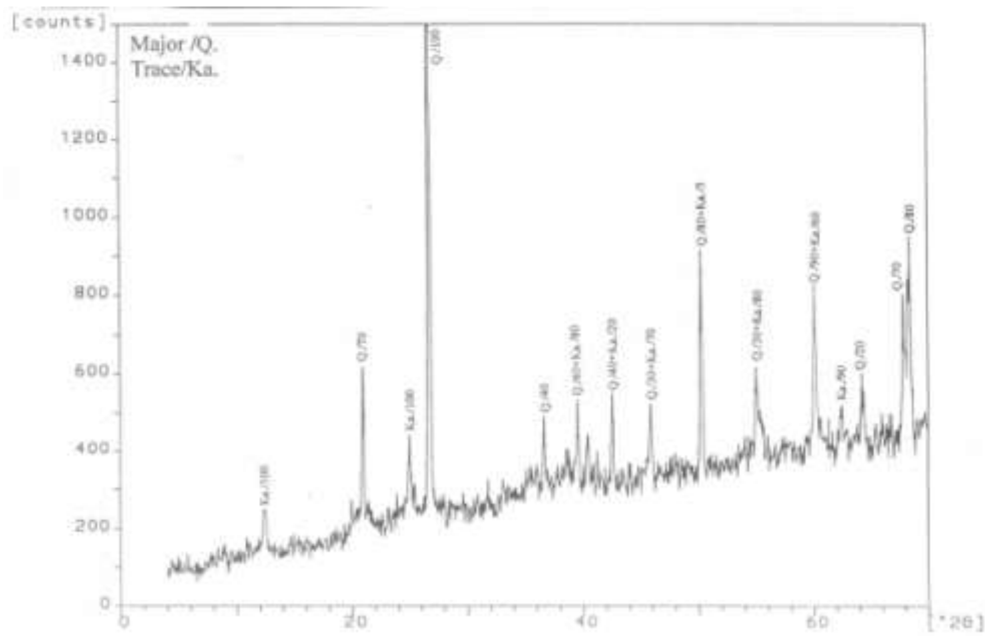

Fig. 6 X-ray diffraction pattern of the sandstone whereas Elephantine tombs were engraved.

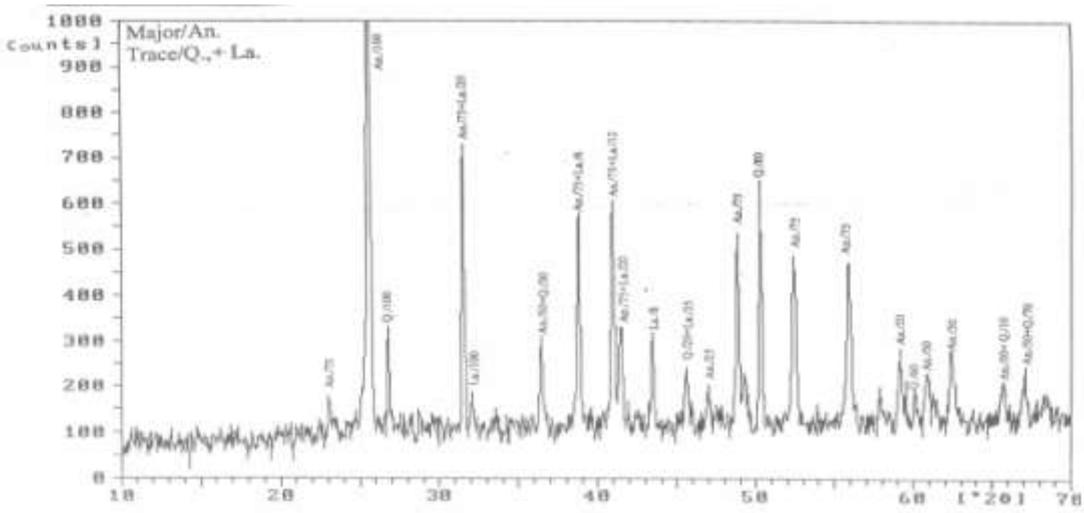

Fig. 7 X-ray diffraction pattern of mortar used in Sarnbut II tomb (Elephantine tombs).

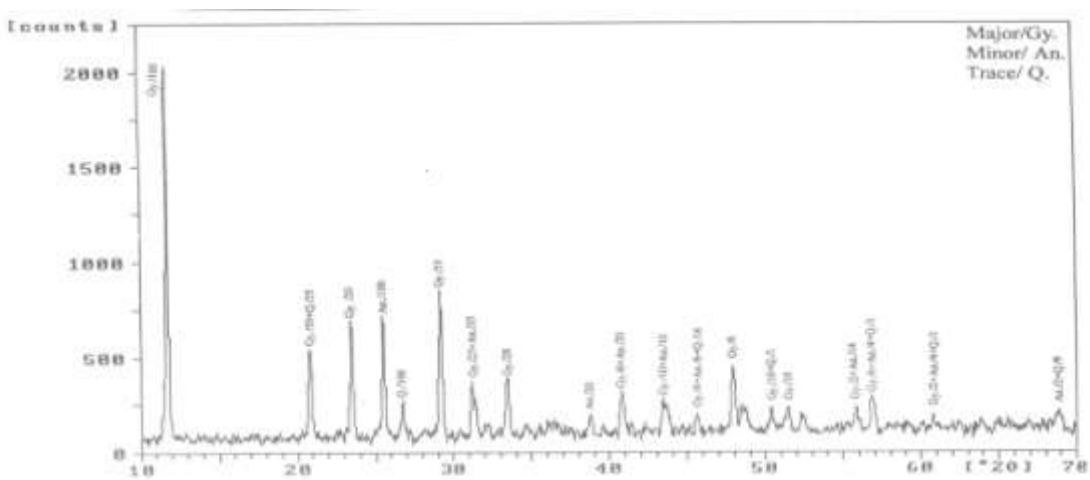

Fig. 8 X-ray diffraction pattern of plaster sample from Meko&Sabny tombs.

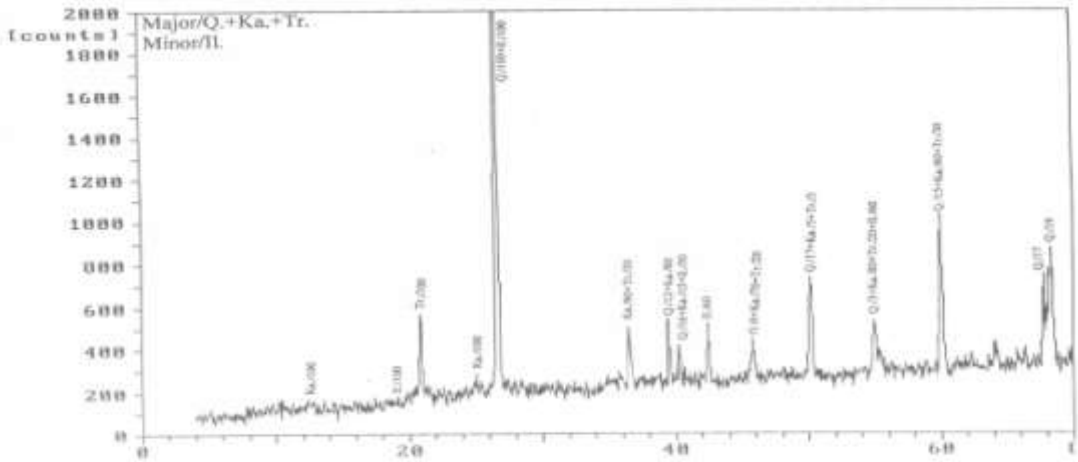

Fig. 9 X-ray diffraction pattern of plaster sample from Kakem tomb.

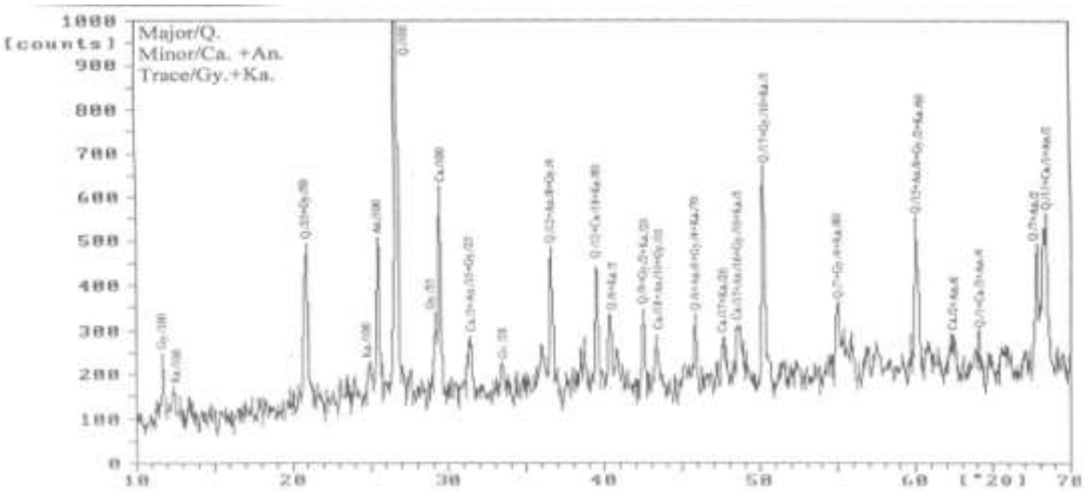

Fig. 10 X-ray diffraction pattern of wild bees nests in tomb No. 34B (Elephantine tombs).

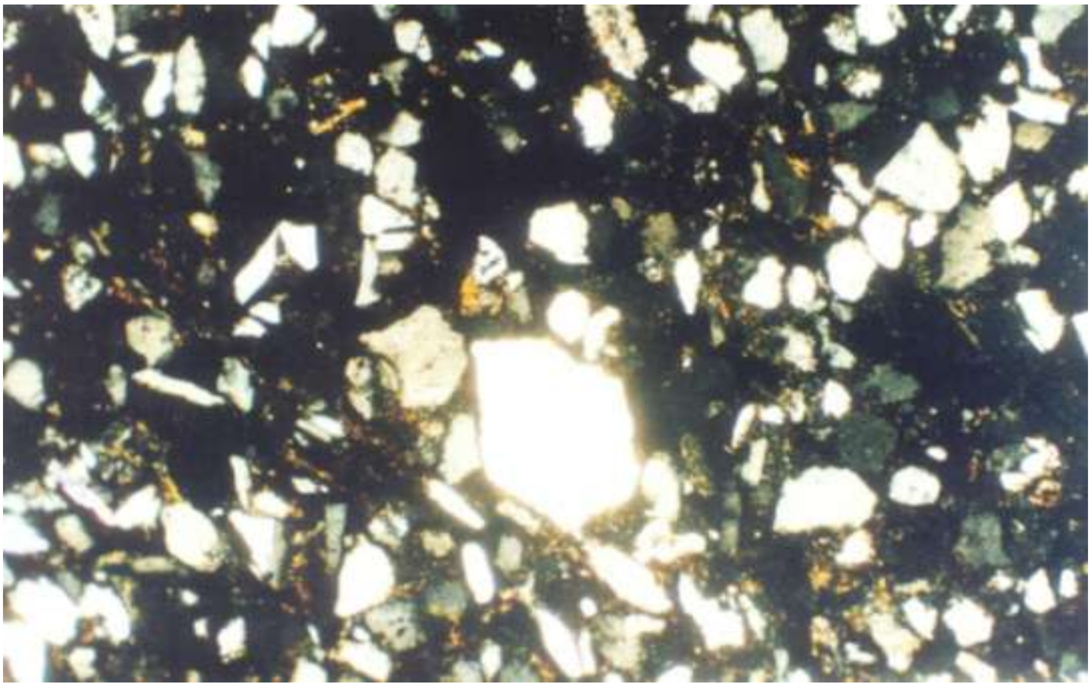

Fig. 11 Thin section of sandstone under CN (10X)

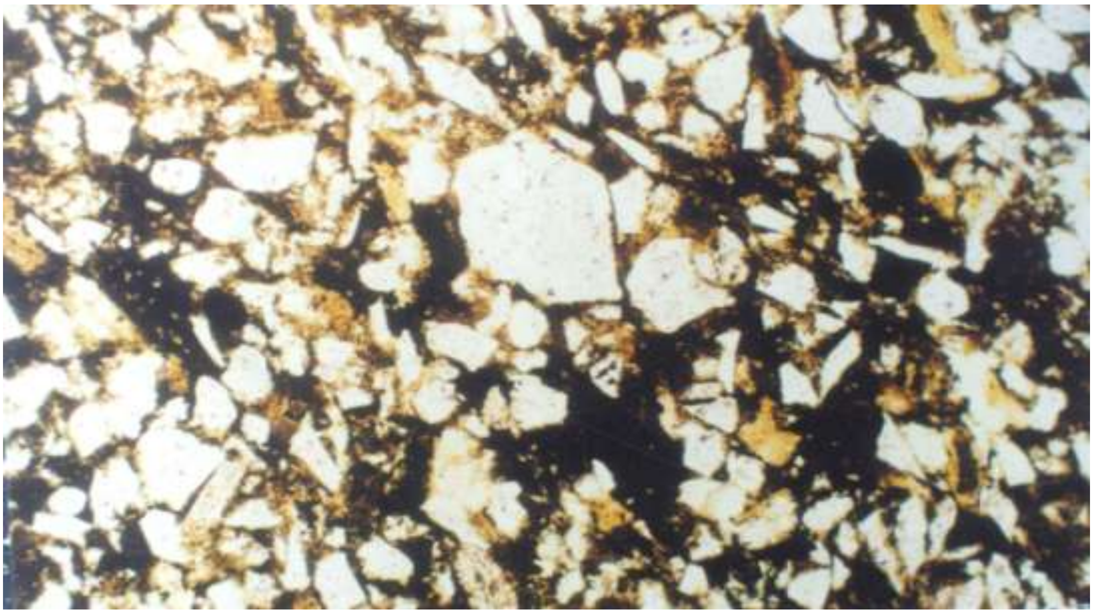

Fig. 12 Thin section of sandstone of Sarnbut II tomb, shows fine to medium quartz grains angular to sub angular in a matrix of iron oxides (P.L)(10X)..

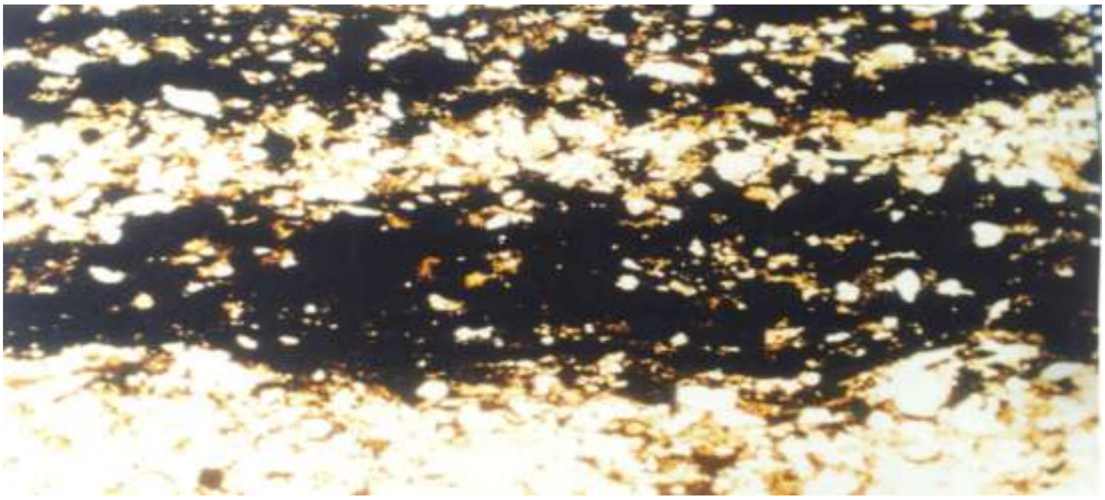

Fig. 13 Thin section of sandstone shows the presence of iron-oxide minerals interbedded with quartz and clay minerals

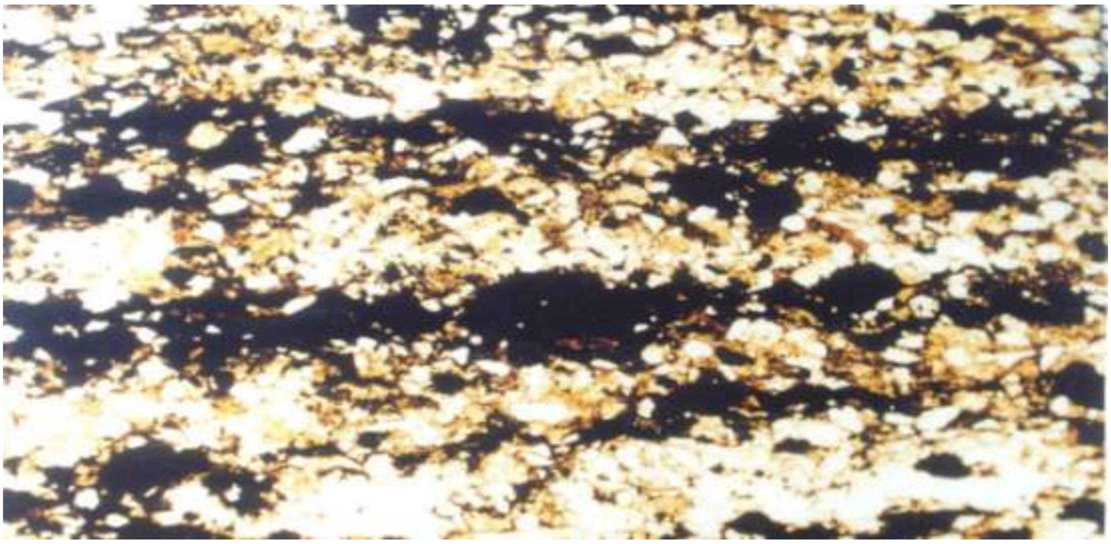

Fig. 14 Thin section of sandstone declares iron oxide minerals between quartz grains P.L (4X)

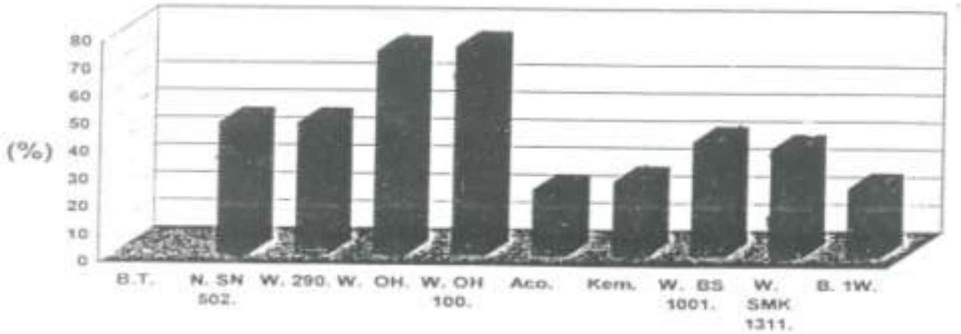

Fig. 15 The increase rates in compressive strength of sandstone after consolidation.

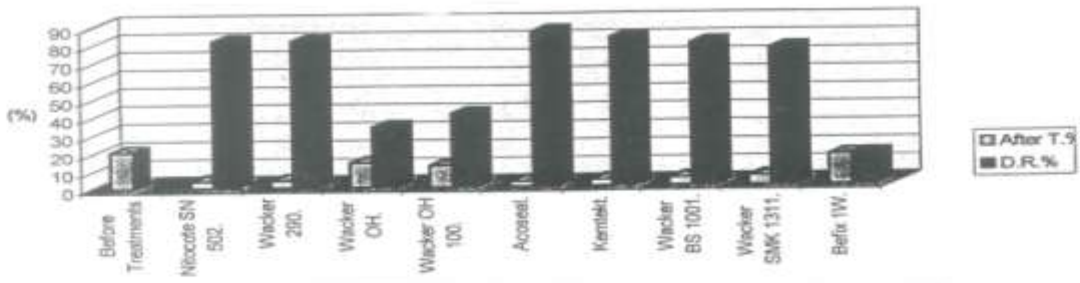

Fig. 16 The decrease rates in porosity of the untreated and treated sandstone with consolidants

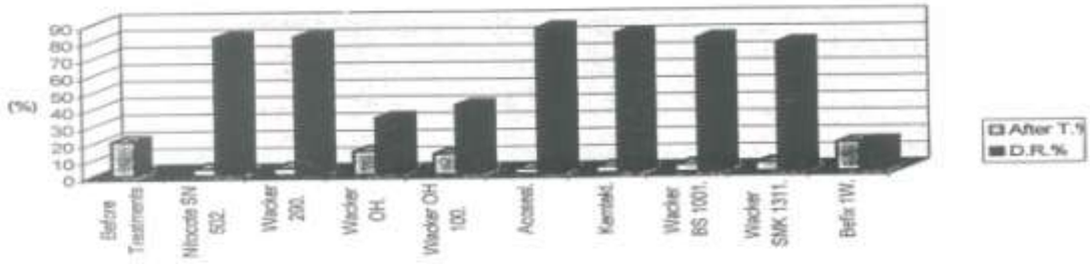

Fig. 17 The decrease rates in water absorption of the untreated and treated sandstone with consolidants

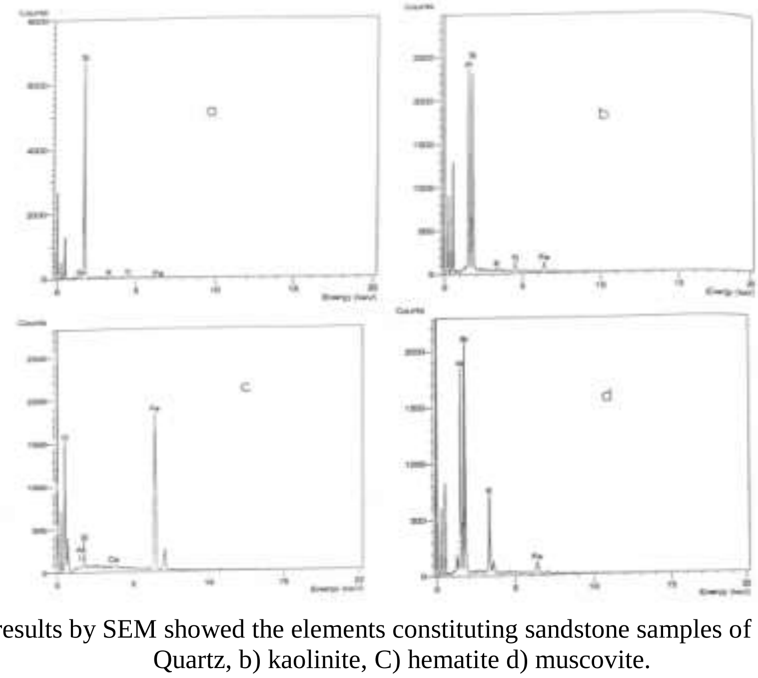

Fig. 18 EDX results by SEM showed the elements constituting sandstone samples of Sarnebut I tomb a) Quartz, b) kaolinite, C) hematite d) muscovite.

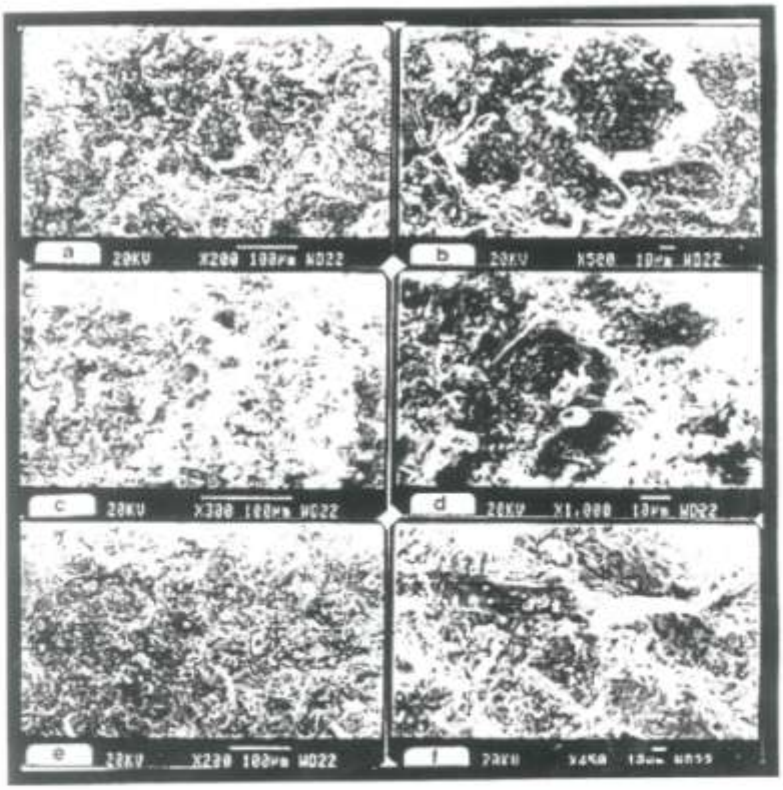

Fig. 19 SEM micrographs of treated sandstone after artificial weathering. a& b: Nitocote SN 502 showed stability of the polymer, c& d: Wacker 290 showed the relatively shrinkage of the polymer, e & f: Wacker OH showed the migration of silica to the surface.

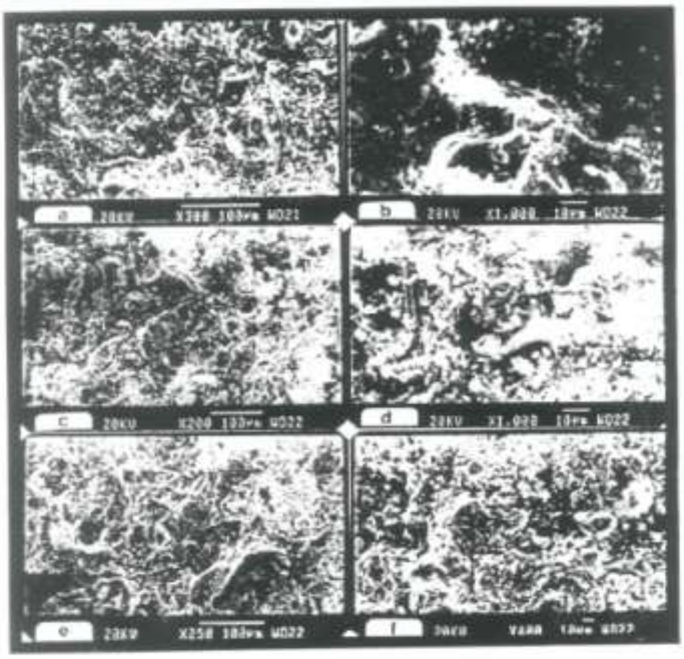

Fig. 20 SEM micrographs of treated sandstone after artificial weathering. a & b: Wacker BS 1001 showed partial shrinkage of the polymer, c& d: Acoseal showed partial leaching of the polymer, e& f: Kemtekt declares the disappearanee of the polymer around the grains.

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SEM micrographs showed that the treated sandstone samples with most of the used consolidants had a deep penetration of the polymer and coating of the grains without closing the pores. In case of acoseal, Kemtekt and wacker SMK-1311 consolidants they have weak bonding and separation of stone grains.

After exposure to artificial weathering (hot humid & dry cycles), the micrographs showed the success and stability of the following consolidants; nitocote SN 502, wacker 290, wacker BS 1001 whereas there was a failure of Befix and relative leaching, shrinkage, and weakness in bonds at the rest of the applied consolidants, Figs 19,20.

From the present study, it was declared that the rock-cut tombs of Elephantine Nobles at Aswan in Egypt (1-3) suffered seriously from the presence of joints (4, 5) as a geological structure in the hills rocks. It gives a special case for geoarchaeology of these tombs and their deterioration. X-ray diffraction and thin section analysis showed that the rock of the tombs constitutes of argillaceous ferruginous-micaceous Nubian sandstone (6) which has a lot of heterogeneities in clay, iron oxides, and mica minerals. Fortunately,the types of the existed clay minerals are kaolinite and illite, so the percentage of their expansion and shrinkage will be low due to the absorption and loss of humidity respectively. The presence of hematite (iron oxide) and muscovite in sandstone play another role in deterioration. These minerals will be more rapidly weathered than quartz grains in the sandstone. The study showed that sandstone is a moderately sorted consisted of fine to medium quartz grains, have angular to subangular ones which will be more susceptible to be deteriorated. The effect of physical weathering including temperature variation and wind is great. The latter, acts seriously specially at the places of vertical joints led to falling of some sandstone blocks from the upper parts of the tombs and erosion (7-10).

The transformation of gypsum into anhydrite in the mortar and plaster layers of the mural paintings in the tombs is another deterioration factor which cause a shrinkage in the volume of crystal structure cell by 30% giving rise to cracks and flacking (11). The biodeterioration of the Elephantine tombs comprises the bees nests & remains of birds and bats (12, 13), which cause distortion of surfaces. Hence it is very urgent to carry out treatment with consolidants, restoration, and conservation work of these tombs to prevent more deterioration in the future (14 – 21). Scanning electron microscope examination of the treated sandstone with consolidants clarified the success and durability of nitocote SN 502, wacker 290, and wacker BS 1001 after exposure to artificial weathering cycles. They penetrate the stone structure, increase the mechanical properties of the sandstone, decreasing its water absorption. & porosity, forming strong bonds between quartz grains and homogeneous smooth layer on the surface. The pores were not be closed completely but permitting air movement inside the stone.

The architectural and fine restoration proposed plan of Elephantine tombs will include: 1st: Field study of joints and cracks, their dip and sites, determination of their strikes, widths, their types, amounts and activities. 2nd: classification of tombs depending on their danger and types of problems. 3rd: joints and cracks must be injected by suitable mortars mixed with consolidants using stone blocks in case of the presence of large ones. The proposed mortar is 3.5 sand; 1 white cement: 1 consolidant. The upper weak parts of the tombs containing vertical and serious joints must be treated with consolidants to prevent more destruction and fall of stone blocks. 4th: restoration and conservation of the tombs. 5th: preventive conservation of these important tombs is urgent to save them from any deterioration in the future.

IV. Conclusions

In the present study, geoarchaeology of ancient Egyptian Elephentine rock-cut tombs was carried out to save them from serious deterioration. Eleven consolidating materials were evaluated to select the best ones for application. Data declared that the addition of silicon-based consolidants to sandstone improved its physiochemical and mechanical properties. Three consolidants; nitocote SN502, wacker 290, and wacker BS 1001 gave the best results. It is recommended to be used for conservation and protection of these tombs. They will stabilize the existed joints and cracks, consolidate the fragile ferruginous argillaceous micaceous sandstone without effect either on color, or closure completely of pores as proved by SEM micrographs.

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