Durability Characteristics of Some Diorite and Granodiorite Monumental

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Abstract

Many important Ancient Egyptian buildings are composed of granites. Severe decay of granodiorite and diorite monuments has been observed during conservation work. Petrographical characteristics and evaluation of the state of drastic decay that happened to some deteriorated statues from Temples of Karnak and Mut were done. The study also includes the original quarries from which these stones were extracted. From this study, it is found that mechanical and chemical processes of weathering besides saline soil and groundwater are the most effective factors for the deterioration and destruction of some statues. A scheme for chemical treatment of the studied deteriorated samples by different types of resins is also suggested.

Introduction :

Ancient Egyptians used several types of granitic stones for architectural elements, statues and Chapels (Helmi, 1985). The Romans import granite, quartz diorites and granodiorites from quarries near Aswan in Upper Egypt and from quarries in the mountains of the Eastern Desert (Gatetli, 1992). The enormous scale of Roman activity in the Eastern Desert is well indicated by the ruins of scores of quarrying and mining settlements, watering stations, forts and other structures found throughout the region.

Lazzarini (1987) showed that the granites are the most important and widespread stones used in antiquity either for structural or decorative purposes due to their physical properties and ornamentation. Kelmm, 1981 mentioned that the Egyptians were the first to quarry large amounts of granite soon after the beginning of the old kingdom.

The red granite "Sienite" from Aswan (the ancient syene), was in fact initially used for vaults, pillars, obelisks and later on for columns, statues, tubes and vases and also for facing pyramids. The other important granite stones that were used in Egypt are granadiorite and diorite as in Table (1). These were extracted soon after sienite, and not very far from it, they were mainly used for carving statues and architectural elements (Pl. 1-3).

Many diorite and granodiorite monuments have been excavated in Giza, Deir El-Bahri, Mut and Karnak, in Upper Egypt. These works of art are representative of the best Ancient Egyptian stone craftsmanship. These works include statues of Ramses II in the temple of Luxor, a statue of Thutmose III un earthed in the Deir El-Bahri, Several dioritic figures, now in the Boston Museum of fine Art as well as some statues in the National Museum, Cairo. Statues of the Goddss Sekhmet, presently in the Louver and Luxor Museums, also statues of Khufu and Menkure which were discovered in Giza. Plate 2 shows statues of the Goddess Sekhmet at Temple of Mut and part of chapels made of quartz diorite and granodiorite at Temple of Karnak.

Plate 1 (Fig. 1, 4) shows statues of the Goddess Sekhmet excavated from the Temple of Mut and plate 3 (Fig. 2) shows dioritic doorway of Queen Hathpsut's chapel. The chapel is adjacent to and immediately north of the Main sanctuary of the Karnak temples. Also there are other statues of the goddess Sekhmet excavated from the temples of Karnak plate 1 (Fig. 2, 3).

This paper deals with the physicochemical deterioration and durability characteristics of Egyptian diorite and granodiorite monuments on the basis of environmental processes.

Methodology :

Most of the fresh state samples that have been analyzed were collected from ancient Aswan quarries for testing. These stones were analyzed petrographically and their physical and mechanical characteristics were defined to check for any changes in the stones. Then the stones were compared with the deteriorated samples taken from Mut and Karnak temples. The investigated samples were chosen on the basis of the type and amount of deterioration. Mineralogical and petrographical examinations were performed by both polarized microscope and scanning electron microscope (SEM) coupled with an energy disperse X-ray analyzer facility to obtain information on the mineral morphology, chemical composition and new formed phases.

The characteristics of the deterioration of studied samples are made from observations of thin sections under the polarizing optical microscope and scanning electron microscope.

Environmental Management :

Egypt is a sunny country all the year. There is a great difference in temperature between day and night especially in the South (Helemi, 1985). Thus, the stones expand and contract as diurnal temperatures rise and fall and that contraction may be sufficient to set up stresses which exceed the ensile strength of the stones. Also there is a difference in temperature response between the outer and inner portions of a stone with surface layers experiencing more severe temperature regimes than interior surfaces. This might promote exfoliation, disintegration and cracking of the stones. The external layer of the diorite and granodiorite surfaces consists of different minerals having different thermal expansion coefficients that cause the stone exterior to spell off. Winkler (1975) pointed out that tensile stresses of approximately 250 atmospheres can develop upon heating from 10°C to 50°C for stones such as granites, which are significant enought to disrupt the stone. Stones absorb high thermal energy of the sun infra-red radiation which will be stored in this later due to the low thermal conduction of its minerals. This results in disintegration of grain-intergrowth forces and separation of some of these grains and separation of the scales of the surface layer as a result of the detachment and loosening of the bonds that tie the grains of the surface area and those grains of the layer (Helmi, 1985).

The colour of the stones changes and the surface layer was cracked and fell into flakes (Pl. 1, Fig. 2, 3). In addition, fissuring, cracking and porosity and permeability of stones increase (Pl. 3, Fig. 3, 4). On weathering diorite and granodiorite produce and amount of insoluble material and the chemical weathering processes change ferrous iron to ferric ions of the mineral constituents. This alteration produces cracks and weaknesses which cause disintegration of stones and coloration. Granodiorite will disintegrate more rapidly than diorite.

The change in relative humidity also plays a role in stone decomposition. Dark patches are also detected as a result of humidity and the suspended dust particles. The durability analyses show the effect of groundwater which bear different soluble ions giving rise to salinization of the granodiorite and diorite statues (Pl. 1 & Pl. 2). There is a capillary migration of the soluble salts from saline soils in the studied archaeological sites. The ability of salts to cause stone breakdown has been known for many years (Goudie, 1994). The most cited cause of mechanical weathering by salts is that of salt crystal growth from solution in stone pores and cracks, for substantial pressures may be set up (Winkler & Singer, 1972). First sodium sulphate, sodium carbonate, sodium nitrate and magnesium sulphate rapidly decrease in solubility as temperature falls. Second evaporational concentration of solutions and when this occurs, highly salts will produce large volumes of crystals. The third cause of crystallization is common ion effect, whereby the mixing of two different salt solutions with the same major cation can cause salt precipitation. Hydration and dehydration of the crystallized salts also played a role in the stone decomposition as the volume of the salts increases and thus develops pressure against pore walls. The volume increases for sodium sulphate and sodium carbonate. The third possible category of salt weathering process involves the differential thermal expansion of the salts (Cooke & Smalley, 1968). For salts entrapped in stone pores may have greater expansion coefficients than the stone minerals (e.g., when temperatures increase from around 0°C to 60°C, halite expands by 0.5%, here as granite minerals expand by 0.1 and 0.2% Goudie, 1974 suggested that this process is less effective than salt crystallization as hydration.

Ground water assists in the weathering of plagioclase and biotite and other minerals. The clay minerals are formed at the site of weathering especially in Temple of Mut Microcracks in the stone become saturated with water while it was buried weakening its structure by enlarging these imperfections. Upon excavation and the evaporation of this absorbed water, these plate-like minerals become more compact. This caused strain and distortion of the stone which eventually contributed to its cracking (Pl. 1, Fig. 3). Environmental impact on the Mut statues leads to cracks in the stones resulted from the crystallization of salts absorbed into the stones. Also, salt-induced dislocation will accelerate weathering during burial and swelling and contraction of subsequent mineral alteration products will contribute to crumbling upon unearthing (Plate, Fig. 4). The relative importance of these mechanisms has been shown to vary according to the precise mineralogy of the stones and the nature of the soil in which the statues are burried.

Results & Discussion :

Petrographical characteristic of quarry samples :

The present investigation reveals that all the studied statues vary in composition from granodiorite to quartz diorite. The petrography of samples from the original quarry and the least decayed statues shows that the majority have the composition of granodiorite. The granodiote statues vary in color, in fresh surface, from greenish gray to dark gray and vary in grain size from medium-grained prophyritic to coarse hypidimorphic stones. They are composed essentially of plagioclase, K-feldspars and quartz with variable amounts of biotite and hornblende. Iron oxides, apatite, zircon and sphene are accessories.

Plagioclase is represented essentially by oligoclase (An 18-32) and constitutes about 35% of the total components by volume. They form small tabular hypidiomorphic to idiomorphic crystals with the characterizing lamellar twinning. Plagioclase shows variable degrees of alteration by kaoline, epidote and calcite (Pl. 4, Fig. 1, 2). K-feldspars are the second mineral constituents of the granodiorite statues. They are represented mainly by microcline with fewer amounts of orthoclase. Some plagioclase crystals are partially enclosed within or replace the K-feldspars. *Microcline* is represented by well-developed euhedral to subhedral grains. They are medium-grained, displaying cross-hatch twinning and commonly turbid by kaoline flakes and occasionally sieved by numerous inclusions of plagioclase and quartz displaying a piokilitic texture (Pl. 4, Fig. 3).

Microcline perthite is also present and usually of the string type. *Orthoclase* is represented by fewer amounts and occurs as short, medium-grained subhedral tabular crystals. *Quartz* occurs interstitially as large xenomorphic grains or as medium grained anhedral crystals. They are water clear, show wavy extinction and discharged by numerous amounts of apatite and zircon inclusions.

Biotite occurs as independent euhedral tabular crystals and flakes scattered throughout the whole samples (Pl. 4, Fig. 5). *Hornblende* occurs as tabular and flakes dispersed between the other components. It is partly transformed into chlorite patches (Pl. 5, Fig. 1).

On the other hand, the quartz diorite statues are medium grained stones of dark gray to green color in the fresh surfaces. Under the microscope they possess a hypidiomorphic granular texture and composed essentially of plagioclase, hornblende, biotite and quartz with minor amounts of chlorite, epidote and zeosite. Magnetite, zircon and apatite are accessories.

Plagioclase (An 30-36) occurs as idiomorphic tabular crystals and lathes. They are generally fresh but sometimes suffered from kaolintized or sericitized and in this stage the alteration products form either thick kaoline mask or dense past with epidote and calcite penetrations (Pl. 5, Fig. 2). They commonly cracked and exhibit strained lamellar and carlsbad twinning. *Hornblende* varies from subidiomorphic prismatic crystals to irregular plates and patches of pale green color or forming large interstitial areas partly between the plagioclase lathes. They are comparatively altered to chlorite especially along the outer peripheries. *Biotite* occurs in small amounts and closely associated with chlorite and iron oxides. They form dark brown resorbed flakes and patches. *Quartz* forms angular and irregular interstitial anhedral grains. These crystals are highly strained and often discharged by dust particles of apatite and zircon inclusions.

Geotechnical Characteristics :

The assessment of physical properties includes dry bulk density, specific gravity, Porosity and void index according to ISRM (1979 a, b). Also the mechanical properties, abrasion, uniaxial compressive strength, tensile strength, shear strength and cohesion. The final results of these properties are summarized in Table (2).

The geotechnical characteristics of the deteriorated granodiorites and diorites according to ISRM (1979a) are as follows : Dry bulk density is 2.53 – 2.57 gm/cm^3. Uniaxial compressive strength is 68 to 40. The total porosity will exceed by 3.60 to 2.90. Generally, stone alteration implies a weakening of physico-mechanical properties, evidenced by an increase in pore volume (void index) and a decrease of strength qualities. Micropetrographic fracture ranges from 3 – 9. Furthermore, the progressive decay of stone geomechanical qualities also carries an external communication that increases the pore of volume and relative surface area.

The weak geotechnical qualities facilitate the disintegration processes of stone. SEM studies show different microcracks which have long, narrow, sharp-ended cracks which were typical at grain boundaries and intragranular. They also found along cleavage directions in stone-forming minerals. It was also found by examining the studied samples that porosity increases by increase in a number of openness of cracks with physical weathering and a decrease of strength qualities. Moreover, cracks were abundant in plagioclase and less common in quartz and potash feldspar. The compressive strength decreases with increasing porosity due to microfracturing of the studied samples. The durability of granodiorite and diorite related to the grain size. In the investigated samples, it was found that the strength increases as the mean grain size decreases. When the grain size increases the length to width ratio of the microcavities also increases and the stress at the crack up tip increases. This, in turn microcracks grow and become penetrative. The alteration of minerals of the studied samples is indicative of the reduction of the mechanical strength, furthermore, in the progressive decay of stone. Microfracturing, including both microcracks and voids may be quantified by counting the number of fractures in a traverse sector ranges from 3 to 9 in thin sections.

The increase of porosity is due chiefly to the great density of pores in micropores and microfissures disseminated all around the stone, predominantly in feldspar grains and nearly observed by optical and scanning electron microscope (Pl. 6, Fig. 1-3).

Durability Characteristics of Monumental Samples :

Physical weathering of quartz diorite and granodiorite statues and chapels are also detected. The outer surfaces of these monuments are very densely fissured. Under the microscope, both inter- and intra-granular fractures especially parallel to the planes of weakness of micas and feldspars are detected (Pl. 4, Fig. 6; Pl. 5, Fig. 2-4). In this stage of deterioration, granodiorite is completely transformed into paste and patches of Quartz, chlorite and calcite assemblage with obliteration of the characterized igneous textures (Pl. 5, Fig. 2); network systems of fractures are also performed. These fractures increase the chemical weathering as the surface area of reaction increases.

Exfoliation, crustification, planar disjunction and tensional, radical cracks (like mud-cracks) are also detected, (Pl. 3, Fig. 3) and these appear as a result of thermal cycles of strong thermal oscillations. Due to these processes, fragments from the outer parts of these statues fell down due to the absence of cohesion.

As it is shown from the petrographical investigation that feldspars and mica represent important constituents of the studied statues. These two minerals have a serious contribution to the decay of the statues. Detailed study of these minerals shows that they are easily weatherable minerals. Natural weathering, caused by microclimatic, has transformed the feldspars plates into turbid aggregates of kaolin, calcite and epidote. The degree of alteration varies from partly altered to completely altered. In the more advanced stages, the morphology of the feldspars is completely destroyed and transformed into patches of calcite and kaoline. Water adsorption by kaoline has effect the physical degradation (clay mineral swelling). This swelling creates stress inside the stone and the formation of microcracks subparallel to the external surface. The kaolinised process is mainly achieved by meteoric water at low temperature. Sheppared (1977) and Bird & Chivas (1988) used hydrogen and oxygen isotope data to conclude that kaolinite is a result of low-temperature weathering. Biotite and hornblende are also affected by natural weathering and partly transformed into fine chlorite flakes with shaded iron oxides along their cleavage. A volume change in biotite during weathering leads to an increase in permeability and disruption of the stones (Isherwood & Street, 1976; Bustin & Matthews, 1984). For examples, Banfield & Eggleton, 1984 described 30% volume change as biotite alters to vermiculite.

The inherent weakness planes of the constituents minerals also affect the deterioration of the statues. Petrographical studies and scanning electron microscopy demonstrate that both the twin planes of the feldspars and (0001) cleavage planes of biotite are affected by the natural weathering and cause expansion in the surface of these weakness planes (Pl. 6, Fig. 4-6). This also assists in the alteration processes of these minerals as the surface area of reaction increases. Respectively, cavities and vugs are also formed parallel to the twin cleavage due to this mechanism and these pores are filled with salts. The efflorescence of salts in these holes also play a role in the decay of these stones (Pl. 6, Fig. 7). Thus, both the expansion of the weakens planes and the pressure of crystallization of salts originate internal tensions in the stone. The presence of mica grains and plagioclase crystals parallel to the outer surfaces of the stone is related to the open macroporosity and the fall of lamellar fragments of the stone (Pl. 6, Fig. 8), perhaps favored by the weathering. These are also pits detected in the outer surface of the investigated statues and this may be due to the leaching of the biotite grains. Biotite expands and decays in the outer surface much more than in the inner parts of the studied statues. SEM studies also show that clay minerals can also expand and defect as biotite and plagioclase.

Some calcite crystals are also observed filling the interpores of the granodiorites or forms white patches. The calcite rhombs filled the spaces either partially or completely. The calcite is soft and unstable mineral to the weathering processes and thus may leave an important effect on the durability of the stones.

Staining also played a role in the deterioration of the granodiorite statues. A blood red to black pigmentation as a thin surgical layer or crust is detected in the studied statues. Detailed examination by SEM also shows the pigmentation of the crevices and interspaces between the grain boundaries of the mineral constituents.

Pigments penetrated also into cracks and cleavage planes in the individual mineral grains or coating the grains as thin film. This pigmentation may be due to the degradation of the iron – bearing minerals (e.g., magnetite, hornblende and biotite) by groundwater.

Pittings are also present on the studied monuments. They are also observed in both the vertical and horizontal surfaces. The diameters and depths of these pits vary from macroscopic to microscopic scales (Pl. 6, Fig. 9). Some microflora is present inside these pits (Pl. 7, Fig. 1). There is a positive correlation between both the diameter and the depth of these pits. Several authors believed that pitting is more commonly associated with the activity of microorganisms (Caneva et al., 1992). Besides the biodeterioration mechanism, a direct decay mechanism of mechanical and chemical nature for these pits are not neglected, especially for easily weatherable mafic minerals (biotite and hornblende) where a myriad of submicroscopic pits was formed.

Pores especially in the outer surfaces of the statues are very frequent in some samples and less in others. These pores (0.03 to 0.2 mm in diameter) are either occur as individuals or connected. The connected pores act as channels for the soluble salts and the movements of these soluble salts play a great role in the deterioration of the statues. The result is powdering and flaking the surface of these statues, in addition to carving the relief. It is shown that the distribution of porous system control the different patterns of deterioration.

Microfracturing, including both microcracks and voids facilitating the disintegration processes of the studied samples. In some cases, it is difficult to differentiate between the primary microfractures (which develop during cooling of the pluton, by subsequent tectonism, or through unloading) and the latter fractures which formed after excavation of the stones. Fracturing of the studied samples is detected on all scales from megascopic to submicroscopic and stones with more fracturing will have better access and throughflow of weathering groundwater than those with less fracturing. As a result, highly fractured statues are most susceptible to weathering. Microfractures are widely accepted as being very important for weathering of granites (Whalley et al., 1982; Pye, 1985; Hill, 1994). Within minerals grains they increase the ratio of surface area to volume, providing greater access to weathering solutions. Dessolution cavities are also detected in the studied samples. These cavities are either empty or partly to completely filled by salts (Pl. 5, Fig. 5, 6). The efflorescence salts have the ability to absorb the humidity and that have serious effect. The removal of stabilization of these soluble salts with time affected also the stability of the studied statues.

Salt Efflorescence and EDX :

Salt formation and weathering have dangerous role in the degradation of the studied statues. The infiltration of soluble salts into buried statues stones from the saline soils in Temple of Karnak and Mut leads to the crystallization of the salts therein. The development of possible structural weaknesses would be critical in the extended existence of dioritic monuments (Pl. 3, Fig. 1-4). The chemical deposition of complex salts in the form of crust is common. They are made up of gypsum, calcite and common salt. These crusts are characterized by their high porosity, high proportion of micropores and surface area and sometimes exhibit a numerous amount of microorganism.

Gypsum occurs as aciculate crystals growing perpendicular to the stone surface, as fibrous, plates (Pl. 7, Fig. 4-6), desert rose (Pl. 7, Fig. 3) or as irregular aggregates. Gypsum crystals are not restricted to the surface layers but are also distributed in the cavities and penetrate towards inside. Cubes of common salts (sodium chloride) are also observed (Fig. 2, Pl. 7). It is worth to mentioning that the high clay content produced through the weathering of feldspars accompanied by relatively large amounts of highly soluble salts, determined as sulfate, nitrate and chloride in addition to the enrichment of flaky minerals are considered as serious factors affected the studied statues.

Preliminary bulk chemical analyses of these crusts shown that they are predominantly composed of sulfate (gypsum) with various amounts of carbonate, chlorides and nitrates. The salt crystallization involves swelling, produces flaking and spilling and thus may cause inward erosion from the external surface. The origin of these soluble salts is accepted as being external to the stone materials.

Taking into account that calcium ions are not very abundant in granodiorite and diorite stones, it may be expected that the mineralized groundwater act as a source for the calcium ions requires for the deposition of both calcite and gypsum.

EDX analyses of studied samples are shown in (Table 3). Many consequences could be inferred from this table. In general, it is observed a silica loss with the alteration process. There are increases in the more soluble ions mainly Ca, S and Mg with a decrease of the less leached oxide (Si and Fe). Analyze of salts by EDX shows them to be elementally complex (Table 3 & Figure 1). Various types of components can be shown but gypsum represented by significant quantities. EDX analyses of diorite and granodiorite surface (Table 3) show them to be dominated by sulphur and calcium from gypsum and high chlorine content might from halite. Other elements are conformable with the presence of silicate minerals. High iron concentration (e.g., samples DC1, DC2, GG1) may be from ferromagnesian minerals or external flyash source. High calcium content may be due to the presence of calcite (sample No. IC4, for example).

Some statues were burried in contact with saline mud for long time and this mechanism response for the degradation of the several studied statues. Penetration of saline ground water into the statues through capillary and moisture also played a severe role in the degradation of the stones and the results are decomposition and destruction of the outer parts of the statues. Also moisture played an important role as it acts as carrier of soluble components mainly salts.

Treatment of the Deteriorated Samples :

The main concerns in this study are the possibility of characterizing a given resin by its appearance under the scanning electron microscope (SEM), visualization of the attachment of the resin to the deteriorated stones, degree of penetration and the possibility of linking this type of data to the aging and performance of a given resin. Two types of treatment have been applied to the deteriorate diorite and granodiorite samples in the present investigation. The first treatment was a Polarid B72 that acts as a consolidant as well as a protector. The product was applied diluted at 15% in Touline. The second treatment was a Polarid B72 diluted at 20% in Touline. Mechanical brushing at high-pressure water jet has been applied to clean the samples. After drying, the different chips of the deteriorated diorite and granodiorite samples were immersed, cleaned and left to dry. The degree of penetration was assessed by low magnification scanning electron microscope. In order to obtain the most suitable concentration to give the best consolidation, capillary absorption tests were carried out. According to the test data, an optimum consolidation condition took place with a resin percentage varying between 10% and 15%. SEM observation in the 5% treatment of the deteriorated samples was not promising. The addition of B72 in the amounts that were studied (Approx. 5%) does not seem to change the appearance of the impergent significantly when viewed by SEM. Plate 7 (Fig. 7-9) shows the appearance of polished and etched surfaces of granodiorite treated with Polarid B72 diluted at 10 – 20% in Touline. It is found that the covering of the deteriorated stones by the resin is not uniform especially those treated by diluted 20%. SEM (Pl. 7, Fig. 7) shows thin film of resin partially covering the large crystals and cavities of the stone treated by 20% diluted. SEM (Pl. 7, Fig. 8, 9) is view of stone was treated by 10% diluted. The resin form a fairly uniform and heavy coating on the stone particles indicating good penetration by the resin (may be due to the effect of viscosity). So treatment of the deteriorated granodiorite and diorite stones by such method is recommended.

Conclusion :

The physicochemical deterioration and durability characteristics of Egyptian diorite and granodiorite monument on the basis of environmental processes are studied. The studied samples were taken from Temple of Karnak and Temple of Mut. Some Fresh samples were also collected from ancient Aswan quarries for testing and comparing. Petrography, physical and mechanical characteristics of these stones were defined to check for any changes in them. The present investigation reveals that all the studied statues vary in composition from granodiorite to quartz diorite. The geotechnical characteristics of the deteriorated granodiorites and diorites according to ISRM are as follows : Dry bulk density is 2.53 – 2.57 gm/cm^3. Uniaxial compressive strength is 68 to 40. The total porosity will exceed by 3.60 to 2.90. The weak geotechnical qualities facilitate the disintegration processes of stone.

It is found that mechanical and chemical processes of weathering and groundwater are the most effective factors for deterioration and destruction of some statues. The inherent weakness planes of the constituent minerals also affect the deterioration of the statues. Petrographical studies and scanning electron microscopy demonstrate that both the twin planes of the feldspars and (0001) cleavage planes of biotite are affected by the natural weathering and cause expansion in the surface of these weakness planes. Salt crystallization and weathering have a dangerous role in the degradation of the studied statues. In order to obtain the most suitable consolidation, for the deteriorated samples, treated with Polarid B72 diluted at 10% in Touline was recommend.

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Table (1) : The important granite stones that were used in Egypt for architectural elements and statuary.

Type of Stone	Locality	Period	Macroscopic Description	
			Colour	Grain size
Granodiorite	East of Aswan (Gabel Nagug) Nubian Desert	Egyptian Kingdom	Dark gray to black	Coarse to fine grained
	Mons Claudinaus	Roman	Gray	Medium grained
	Wadi Qattar	Roman	Dark to light gray	Fine to medium grained
	Bir Umm Fawakhir	Roman	Gray	Coarse to medium grained
Diorite	East of Aswan	Roman	Dark gray	Medium to fine grained
	Wadi Umm Shegilat	Roman	Light gray	Very coarse to coarse grained
	Wadi Barud	Roman	Light gray	Medium to coarse grained
	Wadi Fatiri El Bayda	Roman	Dark to light gray	Medium grained
	Wadi Umm Balad	Roman	White to dark green	Fine to medium grained

Table (2) : List of the most important measured physical and mechanical properties of the studied diorite and granodiorite.

Type of stone	Density gm/cm^3	Specific gravity	Total Porosity	Connected Porosity	Void index	Abrasion	Compressive Strength	Tensile Strength	Shear Strength	Cohesion
Diorite	2.62	2.71	2.25	1.37	0.48	1.44	70.2	6.9	13.3	12.00
Granodiorite	2.85	2.82	3.10	2.52	0.88	1.38	71.2	7.4	11.2	12.00

Table (3) : Element percentages from Energy Dispersive X-Ray analyses of granodiorite and diorite samples.

	Granodiorites												Diorites										
No	FF2	FF3	GG1	GG2	WW1	WW2	WW3	RR1	CD4	DC1	DC2	DC3	DD1	DD2	DD3	FF1	IC1	IC2	IC3	IC4	CD1	CD3	RR2
Na	0.04		1.31		2.25	1.40		0.44	0.25	0.90	4.71		6.28	4.02	9.09	2.47	1.04	0.90		0.08	6.97		
Mg	3.30	10.8	0.63	0.19	3.95	3.51	2.96	0.10	1.34	0.99	0.41	0.51		0.22		0.86	0.55	2.49	0.49	0.36	0.38	1.95	
Al	0.49	5.28	10.6	6.71	2.59	2.52	2.71	12.3	3.33	0.34	0.81	1.14	7.19	2.37	6.95	8.06	0.87			0.49	8.73	2.71	16.9
Si	31.9	6.95	26.3	33.3	30.1	31.5	31.9	30.5	34.7	31.1	29.8	25.9	26.0	35.3	23.9	14.6	5.96	27.5	2.19	6.76	31.0	37.6	27.7
S	5.74	18.2	1.32	0.13	1.82	1.72	2.37	0.23	1.01	0.41	0.22	0.82	3.36	1.64	0.84	15.6	18.2	4.75	21.8	9.56	0.07	0.22	0.10
Cl	2.03	4.25	2.19	0.12	5.14	5.01	5.80	3.05	3.50	3.46	11.0	1.47	0.66	3.24	11.0	6.91	1.20	0.32	0.21	1.66	1.01	1.14	0.96
K	0.49	0.36	1.11	0.10	0.75	0.88	1.05	1.02	1.28	0.50	0.37	0.34	1.41	1.41	0.83	0.20	1.20	0.40	0.39	5.95	0.33	0.66	0.43
Ca	3.67	2.14	1.90	0.72	3.71	3.58	4.50	1.39	3.69	2.16	1.13	2.63	5.33	2.28	5.28	2.31	24.3	17.3	26.9	30.4	1.74	1.97	0.72
Fe	2.16	2.70	8.05	9.05	3.76	3.31	2.87	2.86	2.96	15.4	9.82	23.8	2.83	1.37	1.26	0.75	1.13	0.02	0.07	5.44	2.15	4.20	4.28
O	50.1	49.2	46.6	48.7	45.9	46.6	45.9	48.2	47.9	44.8	41.7	43.4	46.9	48.1	40.8	48.2	45.7	47.1	47.1	38.6	47.6	49.6	48.9

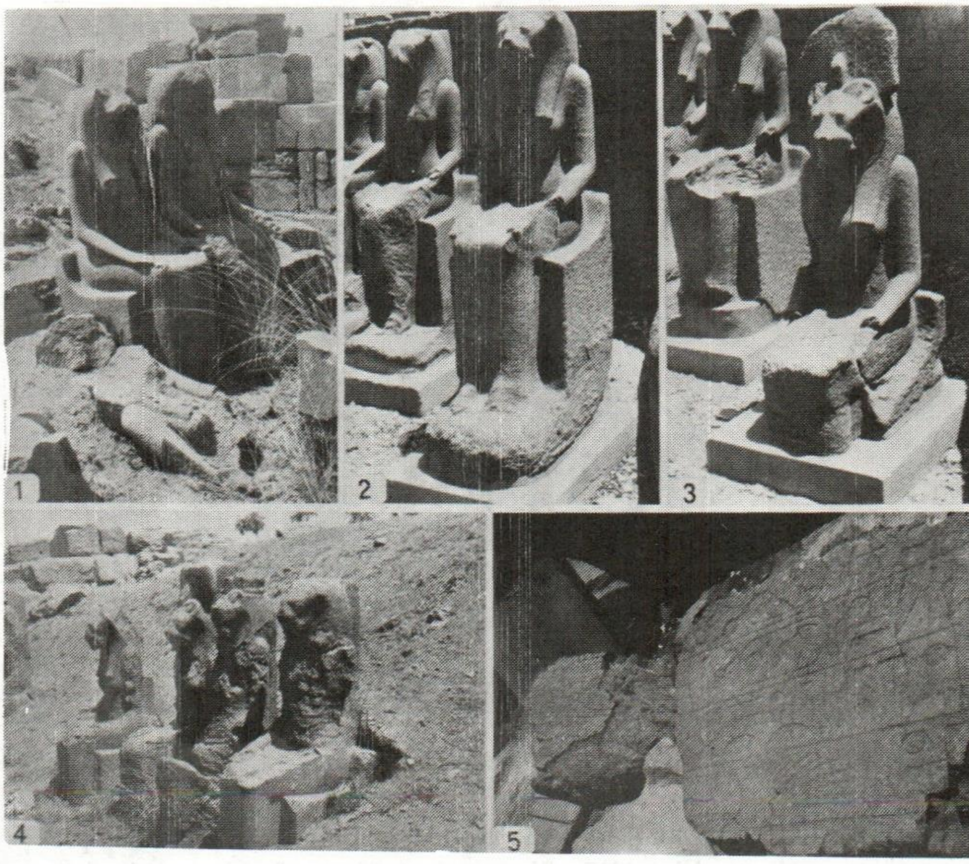

Plate 1 : **Fig. (1, 4) :** Statues of Sekhmet Goddess at Mut Temple show the deterioration phenomena, **Fig. (2, 3) :** Statues of Sekhmet Goddess at Temple of Karnak shows the change in the colour of stones and kaolinization processes, **Fig. (5) :** Inscribed deteriorated diorite stone (may be a part of chapel) at Temple of karnak.

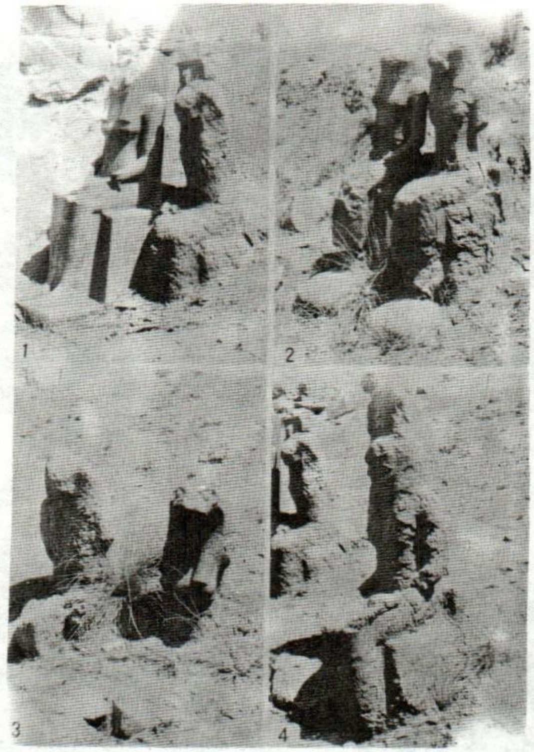

Plate 2 : Different statues of the Goddess Sekhmet at Mut Temple show. **Fig. (1) :** Shows the effect of salt weathering resulting in the transformation of statues to disintegrated stones. **Fig. (2) :** Shows cracks and damage on the surface of statues due to the erosian resulting from salt weathering. **Fig. (3) :** Shows the effect of saline soil in temple of Mut that led to the deterioration of there statues. **Fig. (4) :** Shows the remains of some completely deteriorated statues as a result of the high salinity of the soil of Mut temple. **Fig. (5) :** Show the change in color of statues due to physical weathering that lead to mineral transformation inside the stones of the statues.

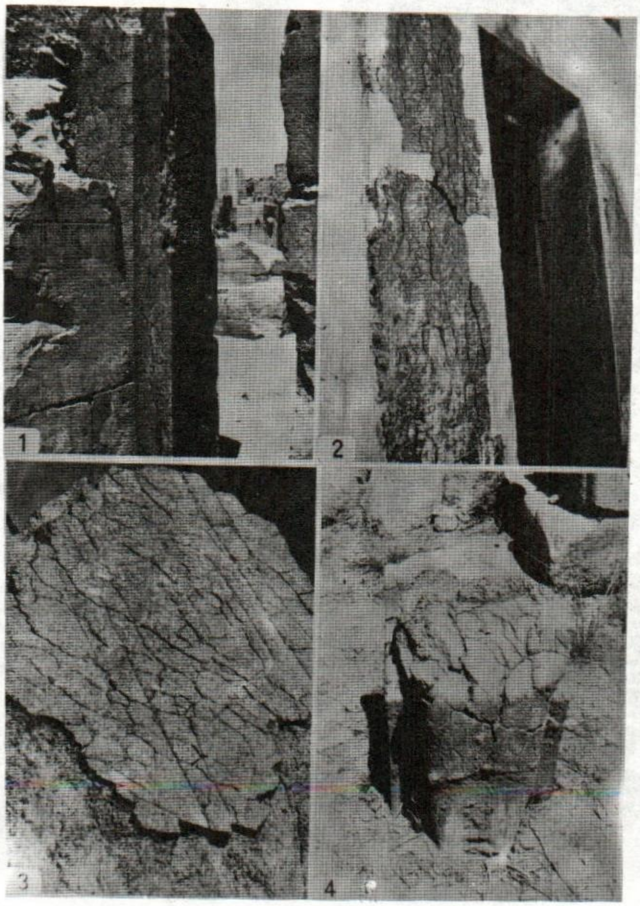

Plate 3 : Fig. (1) : Shows cracks and fissures in the Pillar of chapels at Temple of Karnak. **Fig. (2) :** Partly dioritic doorway of Queen Hathpsut's chapel at Temple of Karnak. **Fig. (3) :** Shows cracked inscribed diorite stone at Temple of Karnak. **Fig. (4) :** A remaining part of partly cracked granodiorite statue at Mut Temple.

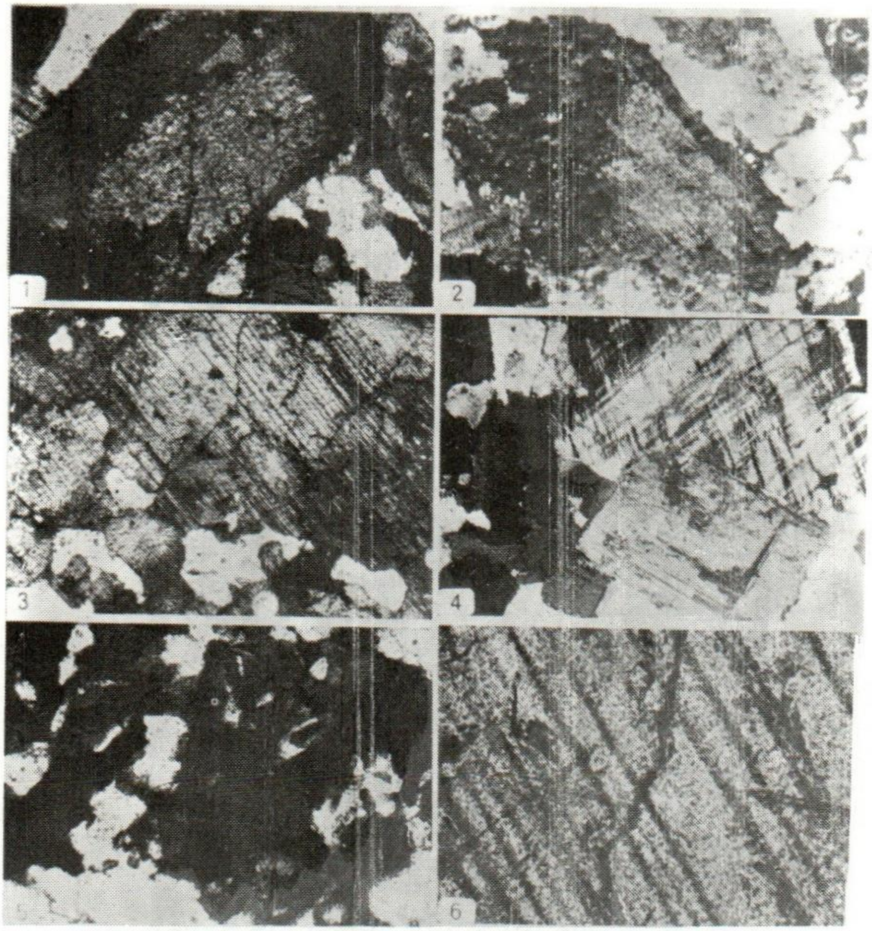

Plate 4 : Photomicrographs using polarizing light (X = 40) showing: **Fig. (1) :** Partially altered plagioclase plate in granodiorite. **Fig. (2) :** Completely altered plagioclase plate in granodiorite. **Fig. (3) :** Inclusion of quartz within the altered feldspar crystal. **Fig. (4) :** Plagioclase crystal partially enclosed within microcline. **Fig. (5) :** Biotite partly altered to chlorite. **Fig. (6) :** Highly altered plagioclase dissected by inter-granular cracks.

Plate 5 : Photomicrographs using polarizing light (X = 40) showing: **Fig. (1) :** Chlorite patches after hornblende. **Fig. (2) :** Highly altered quartz diorite. **Fig. (3-4) :** Intergranular Practures. **Fig. (5) :** Irregular microfractures dissected the stones. **Fig. (6) :** Dissolution cavity filled with salts.

Plate 6 : SEM micrographs showing : **Fig. (1) :** The nature of deterioration inside the granodiorite samples, **Fig. (2) :** The expansive mechanism due to the pressure exerted by the prismatic crystals, **Fig. (3) :** Interpartical porosity, **Fig. (4) :** Sub microfractures dissected plagioclase plate parallel to the twin planes, **Fig. (5, 6) :** Plate pore in biotite, **Fig. (7) :** Efflorescence of crystalline salts in holes inside the biotite, **Fig. (8) :** Fall of lamellar fragments, **Fig. (9) :** Micropits in plagioclase crystals.

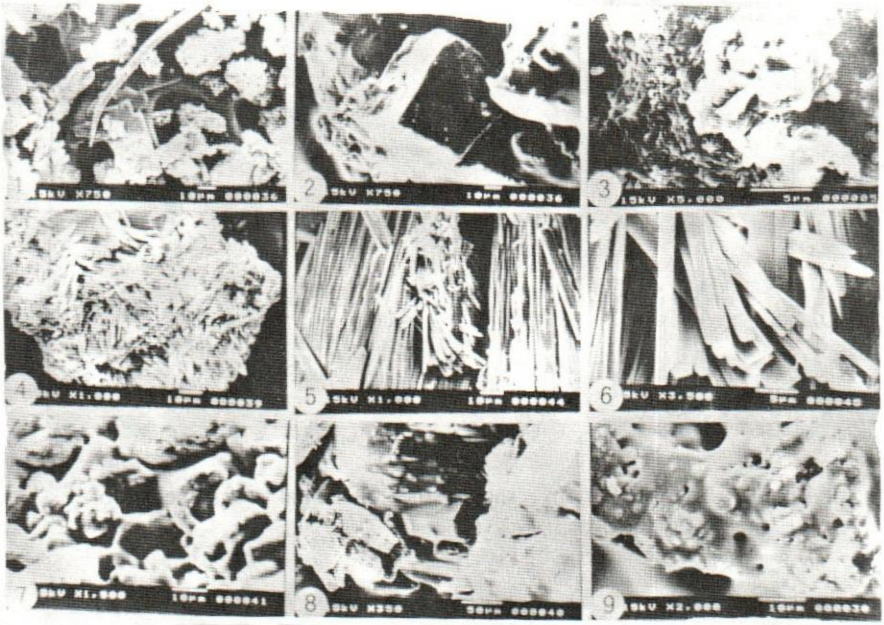

Plate 7 : SEM micrographs showing : **Fig. (1) :** Microflora inside the pits, **Fig. (2) :** Cubes of common salt (halite), **Fig. (3) :** Desert rose habit of gypsum crystals, **Fig. (4-6) :** Concretion of crystalline gypsum plates and aciculate fibrous, **Fig. (7) :** deteriorated sample treated with 20% B72 in Touline showing thin film of resin partially covering the large crystals and cavities of the stone, **Fig. (8-9) :** deteriorated sample treatede with 10% B72 in Touline showing the resin covering the mineral grains and forms a fairly uniform and heavy coating on the stone particles.

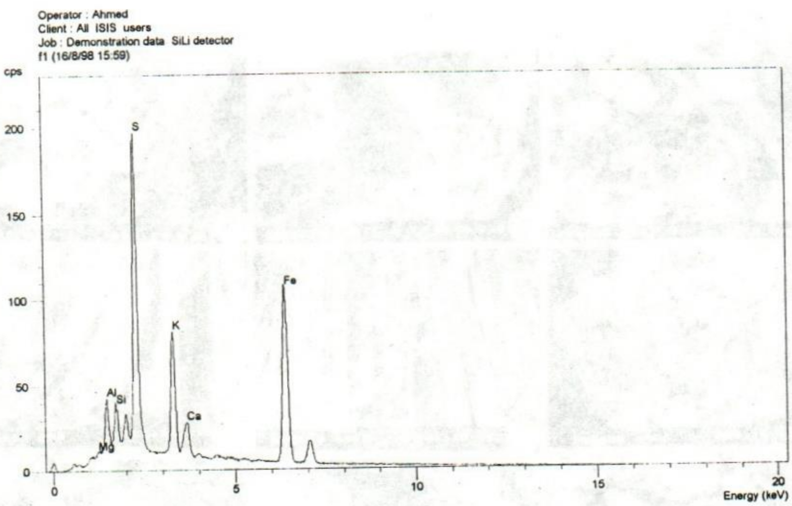

Fig. (1) : EDAX pattern shows the elemental constituents of granodiorite.

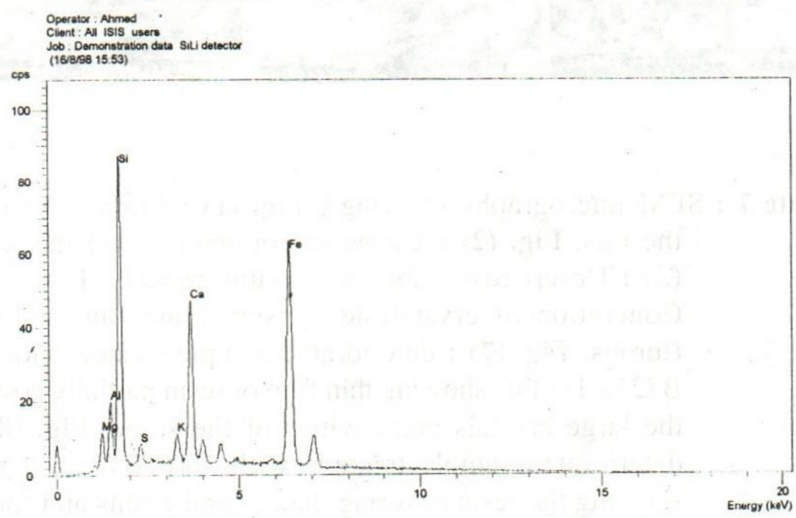

Fig. (2) : EDAX shows high calcium and high iron concentration.

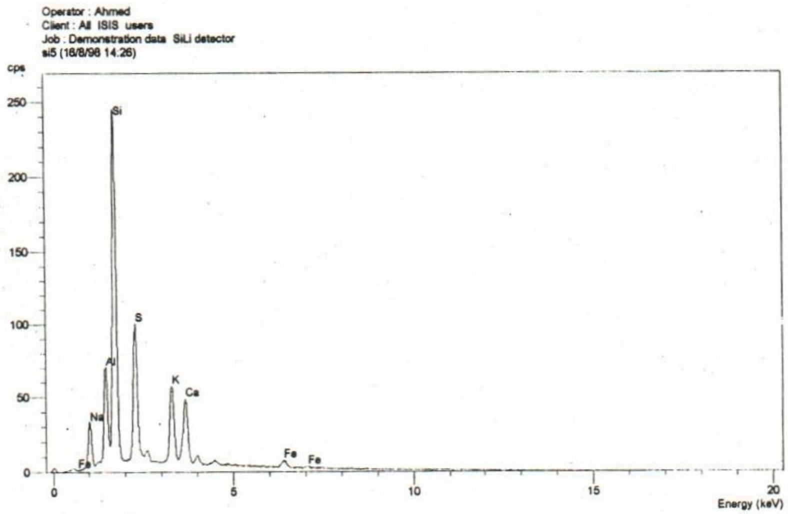

Fig. (3) : EDAX pattern shows sulphur and calcium from gypsum.

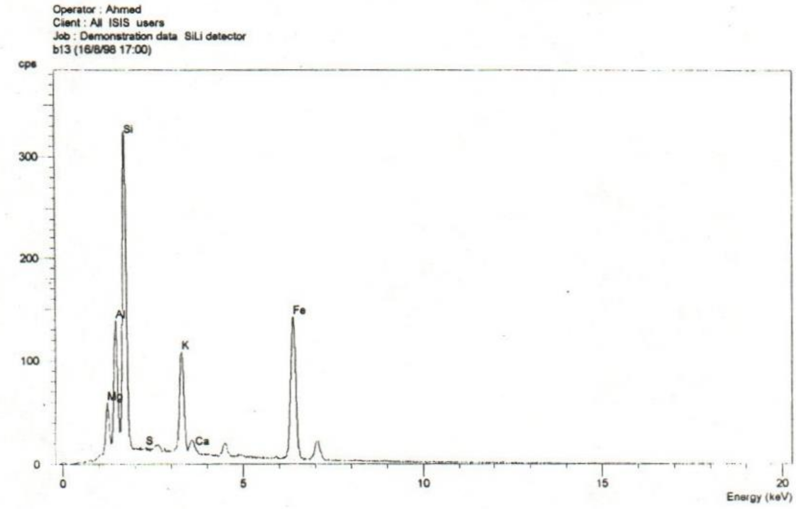

Fig. (4) : EDAX shows high iron concentration from external flyash source.