# CONGLOMERATE ROCKS "BRECCIA VERDE ANTICA" ARCHAEOLOGY, PETROLOGY, DETERIORATION AND TECHNOLOGY OF QUARRYING AT HAMMAMAT QUARRIES IN THE EASTEREN DESERT.

**D.HESHAM ABBAS KMALLY♦**

**ABSTRACT**

One of the most interesting of the monumental rocks of Egypt is the green conglomerates of the Hammamat valley which was used for bowls, vessels, sarcophagus and other objects, from a very early period. The quarries of wadi Hammamat produced the green ornamental stone known in Roman period as "Breccia verde antica". Generally the ancient conglomerate was used occasionally in Egypt at pharaonic time and late period, but it was quarried chiefly by the Roman for export to Italy. The conglomerate rocks range from coarse to fine conglomerates. They are composed of great assortment of rock fragments such as meta-sediments, meta-volcanic and granites. Some pebbles of the coarse conglomerates are previously deposited conglomerates. Pollution, humidity or moisture, solar radiation, rainfall and groundwater represent important factors for disintegration of green conglomerate rocks. Many types of destruction have been noted such as micro-cracks, fractures, joints, exfoliation, crumbling, discoloration, leaching and staining with iron oxides. The conglomerate rock sometimes changes into fragmented, soft residual and parent matter of the soil. Moreover, individual grains of feldspar and quartz begin to become loosened and the rock shows superficial granular disintegration due to, growth of salts and physiochemical weathering.

♦Restoration Department, High Institute of Tourism, Hotel Management and Restoration, Alexandria, Egypt.

The present work mainly deals with the geology and structural characteristic of conglomerate rocks. It is identify the most important individual changes and the stages of disintegration in the beautiful green conglomerate rocks. In addition, to describe and define the alteration products and deformation of several kinds of pebbles present in the ancient conglomerate rocks. On the otherhand, many problems concerning quarrying still remain to be answered at least those concerning the actual techniques used to split the ancient hard rocks. The present study focused on the criteria, quarrying methods and technologies used by the ancient Egyptians in the Hammamat quarries from Pharaonic time to the Roman period. The main results of the different studies which include petrographic microscope, SEM microphotographs and X-Ray diffraction show that the alteration products of the highly weathered ancient conglomerate rocks are dominated by hematite, magnetite, calcite, chlorite, sericite, kaolinite, nantronite, gypsum and anhydrite.

## INTRODUCTION

The Precambrian meta-conglomerate is the ancient green breccias of ancient Egyptians, the labis hecatontalithos (stone of a hundred stones) of the Romans and the breccias verde d, Egitto or breccias verd antico of the Italian stone cutters. The famous green breccias found in several localities, the best known of which is the wadi Hammamat in the eastern desert on Qena-Quseir road (PL.1, Fig.1). Conglomerate with multicoloured, well rounded pebbles and cobbles in a green sandy groundmass, slightly metamorphosed, quarried ($20^{th,}$ $25^{th}$ and $30^{th}$ dynasties) from the wadi Hammamat. This was a coarser version of the greywacke and sandstone. It contains rounded pebbles and cobbles of a variety of colors and compositions, and is greenish due to the contents of epidote and chlorite[1]. Lucas, 1962 [2] stated that the green breccias consists of fragments of rocks of the most varied description embedded in a matrix, which is variable in colour with green predominating, it is however, not a typical breccias, as while some of the fragments are angular, others are rounded and it is sometimes called a brecciated conglomerate, but since in the past it had always been termed breccia and was the breccias verde antico of the Romans, it is much better to retain the old name.

From the archaeological aspects, there are many facilities surviving from the Roman era that allow us to reconstruct how the quarrymen cutting the conglomerate rocks. Wadi Hammamat site preserved many traces of wedge holes and other tool marks on the quarry faces and several objects such as a Roman bath tub block still laying in the Hammamat quarry (PL.1, Fig.2). The principal and probably the only objects of this conglomerate in the Cairo museum are parts of broken sarcophagus of Nectanebo II (thirtieth dynasty) and in the British museum there is a similar sarcophagus of Nectanebo I (PL.1, Fig.6). Also, the only existing Breccia Verde Antico column in the world was made under the order of Emperor Justininian, it was found in the church of San Vital in Ravenna ( Italy). In addition, Shabaka Stone (British Museum) , a heavy black slab of "Green breccia" from Wadi Hammamat, back to Pharaoh Shabaka (ca.712- 698 BCE), who ruled Egypt in the XXVth Dynasty (ca. 716 - 702 BCE) (PL.1, Fig.7). The durability of wedge holes and other traces of stone cutting on conglomerate rocks in Hammamat quarry and deterioration of other conglomerate objects from different museums mainly depended on: 1) its internal structure and petrographic composition and 2) the environment to which it is exposed. 3) The

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[1] Harrell, J. A. Pharaonic Stone Quarries in the Egyptian Deserts. In *Egypt and Nubia: Gifts of the Desert* (ed R. Friedman). London: British Museum Press, pp. (2002)232-43.

[2] Lucas, A. : Ancient Egyptian materials and industries 4 th edn., rev.J.R. Harris. Edward Arnold - London, (1962).

3 Carrol, D. : Rock weathering. New York, Plenum, (1970).(

type of different pebbles that constitute the rock. The changes produced by weathering in conglomerate rocks are governed by thermodynamic laws and partial or complete migration of both major and minor chemical elements[3].

The Hammamat quarries seem to have been extensively worked in the second to sixth dynasties and during the middle and new kingdoms, inscriptions on the valley walls dating back to these times are common. Most are dedicated to the patron God of the desert, Min or Pan. Thus an expedition sent by Papi I (sixth dynasty) list the names of the chief architect, master builders, artisans, scribes and ship captains. Pharaoh Seti is recorded as having the first well dug to provide water in the wadi Hammamat and Senusert sent mining expedition there. Pharaoh Amenhotep also, sent an expedition to the area, numbered 1000 workers, 100 quarrymen, 1200 solders, 200 donkey and 50 oxen. Also, there is along text of rock carvings in wadi Hammamat which dated back to the third year in the king Rameses IV period.

The ancient methods of working stone after it had been quarried may be deduced partly from the objects tool marks left on objects, particularly statues, sarcophagus or unfinished objects and the illustration of some of the processes that were depicted on tomb walls. Generally, the quarrymen used several simple tools such as hammers, wooden mallets, stone picks, bronze and copper chisels, saws, drill stone and measuring instruments which give us an idea of the manner of work and the techniques used by these ancient builders and quarrymen[4],[5]. This subject has been studied by many others (e.g:Engellbach & Clarke; Edgar; Engellbach; Petrie; Pillet; Platt; Reisner) [6],[7],[8],[9],[01],[11],[21].

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[4] Lehner, M. *The Complete Pyramids.* London: Thames and Hudson, (1997).

[5] Hawass, Z. : The Pyramids of Egypt American university in Cairo press, Cairo, Egypt. (1997), 167 pp.

Engelbach, R. and Clarke, S. : Ancient Egyptian masonry. The building craft. Oxford, [6] London, (1930).

[7] Edjar, : Sculptors studies and unfinished works, Cairo. (1906), 49 - 50. pl. 20.=

## MATERIALS AND METHODS

More than 20 rock samples (included various pebbles and cobbles) were collected, representing fresh and weathered green conglomerates. Samples of weathered conglomerates from wadi Hammamat were studied by X-ray diffraction (XRD) and polarizing microscopy (PL) to find their mineral composition, alteration products and to determine the structural and mechanical features characterized the conglomerate rocks.

Also, several weathered conglomerates were examined by scanning electron microscopy (SEM) to examine the sample's surface (topography), composition and structure features of minerals. Moreover, the field observation was carried out during more than three field trips to study the tools, tool – marks and unfinished objects to determine the quarrying technology which used by the ancient Egyptians in wadi Hammamat quarries. More than 100 photographs were taken for the conglomerate rocks, important tool marks and geological features.

## RESULTS

### Field Observation

Through a complete survey of the wadi Hammamat area which carried out by using visual observation by eye, digital photographs and close visual inspection. The field observation and the primary

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= [8] Engelbach, R. :The Aswan obelisk with some remarks on the Ancient Engeneering. Cairo.Department of Antiquities, (1922).

[9] Petrie, F. : Journ. Royal Anthrop.Inst.,XIII, (1884), 88- 106.

[10] Pillet, M. : L, extraction du granite en Egypte a Tepoque pharaonique, in Bulletin de istitute francais d archeologie oriental, (1936), 71 - 84.

[11] Platt, A.F.R. : The Ancient Egyptian Methods of working hard stones, in proceedings of the society of Biblical Archaeology, (1909), 172 - 185.

[12] Reisner, G.A. : Mycerinus, the temples of the third pyramid at Giza. Cambridge MA.Harvard unversity press, (1931).

investigation show that great number of tool marks (wedge holes and traces of stone cutting) on the conglomerate surfaces already have partially and sometimes completely disintegration. Accordingly, we decide that there are different deterioration processes, weathering forms and structural disintegration of conglomerates in Hammamat quarry as follows:-

1 -Etching, color bleaching, dissolution of minerals and granular disintegration due to the growth of salt and action of acidic solutions (PL.1, Fig.3), (PL.1, Fig.5).

2 – Scaling, rough surface due to thermal variation, moisture and lithologic heterogeneity of conglomerate rock.

3 – Dissolution of minerals constituent, physiochemical weathering and deep cavities due to the growth of salt crystals and water action at the conglomerate surfaces (PL.1, Fig.4).

4– The mechanical stress accompanying the expansion of clay minerals in pores, cracks, micro-sheeting and fissures in the conglomerates (PL.1, Fig.8).

5 - Physical weathering and deterioration due to minor displacement block dislocation, falling rocks and thermophysical action (PL.1, Fig.10).

**Sample preparation and petrography**

Hand-size rock samples of various conglomerate rocks were collected from several locations throughout wadi Hammamat area. Samples were examined with both hand lens and binocular microscope for initial mineral identification, texture and various type of pebbles were also studied and described. Polished sections were analyzed and photographed under petrographic microscope for mineralogy, decomposition, alteration products, microstructure features. Microscopic examination of twenty thin sections of conglomerate rocks from wadi Hammamat revealed that all investigated samples are not homogeneous in mineral composition. The polymictic conglomerates are composed of pebbles of more than one type (various in composition). The size of pebbles increases progressively southward reaching up to 20 cm long in the conglomerate banks cropping out along Qift-Quseir road.

The conglomerates are fine to coarse, greenish grey in colour and massive. Microscopically, the weakly metamorphosed conglomerates are composed mainly of subangular to rounded clastic grains of quartz, plagioclase and rock fragments (including granites, andesite, metabasalt, greywacke and siltstone) embedded in a silty clayed groundmass composed mainly of chlorite, sericite, muscovite, calcite, recrystallized quartz, epidote and iron oxides. Plagioclase is represented by subangular to subrounded clastic grains, altered and dissected by fractures. It is partially or completely kaolinitized and replacement by calcite crystals. Some plagioclase grains highly weathered, completely altered to epidote, sericite, calcite and tiny muscovite flakes mask its twining (PL.3, Fig.1). Several plagioclase grains exhibit patchy extinction and bent the twin lamellae's which may indicate strain in such grains (PL.2, Fig.5). Some rounded plagioclase clasts appear with zigzag boundaries as a result of largely corroded by the groundmass and chemical alteration (PL.3, Fig.6).

Quartz occurs as subangular to rounded clastic grains and shows wavy extinction. It is appear as either monocrystalline and polycrystalline filling the interstices between the other constitutes. The lager quartz grains are intensely strained, cracked with conchoidal fractures (PL.2, Fig.6) and exhibit undulose extinction (PL.2, Fig.4). Sometimes, the radial growth of recrystallize quartz appears around the rim of calcite grains (PL.2, Fig.2). Also, it is appear as anhedral recrystallize elongate quartz grains as a result of stress and deformation in Hammamat rocks (PL.2, Fig.8).

Muscovite occurs as randomly anhedral flakes and scaly aggregates, that are frequently interlacing the quartz and plagioclase clastic grains. Muscovite grains are intergrown with chlorite (PL.3, Fig.4). Sericite occurs as tiny scales and shard aggregates replacing plagioclase grains. Sometimes the whole feldspar grains

are completely altered into sericite.
Chlorite occurs as irregular patches elongated and shard-like of pale green in colour which frequently interlacing the clastic grains (PL.3, Fig.5). Chlorite is commonly intergrown with muscovite, iron oxides and sericite and coating the clastic constituents. It is commonly enclosed abundant of iron oxide granules and fine grains. Epidote occurs as anhedral to subhedral grains wrapped with chlorite and disseminated in the groundmass (PL.2, Fig.3). Some slices are showing a cluster of epidote and muscovite in rounded form as flowers aggregates in the pilitic groundmass consists of quartz, calcite, chlorite and iron oxides (PL.2, Fig.7).

Calcite occurs as irregular patches and shreds dispersed in the groundmass or filling the fractures dissecting the conglomerate rocks. Some calcite crystals display rhombohedral characteristic cleavage (PL.2, Fig.1). It is commonly replacing the plagioclase grains. Iron oxides are represented by subhedral grains and irregular granules, commonly dispersed in the groundmass.
Lithic fragments of pebble size are subangular to subrounded with different color. They are composed of granite, andesite, quartz diorite, metabasalt and rewarked greywacke and siltstone (PL.3, Fig.2).

**Petrographic of pebbles**

Petrographic description of the examined pebbles from the Hammamat conglomerates will treated under the following headings: - I -Volcanic pebbles include: metabasalts and porphyritic andesites II – Granitic pebbles include: graphic granites and tonalite

III – Rewarked Hammamat clasts including: Siltstone

**I -Volcanic pebbles include :**

**a - Metabasalte**

These rocks are fine grained, grayish green in colour and massive. Microscopically, they are composed of plagioclase, subordinate calcite, sericite, chlorite and iron oxides. Commonly the basaltic rock fragments (pebbles) are surrounded by coarse quartz grains embedded in fine grained groundmass in conglomerate rocks (PL.3, Fig.7). Intergranular texture is characteristic. .

Plagioclase occurs as subhedral to anhedral laths, commonly disposed in triangular habit in the groundmass (PL.3, Fig.8), which depicting to these rocks their intergranular texture. Plagioclase crystals are intensely kaolinitized and saussuritized which mask its twin planes. Calcite occurs as irregular small patches scattered in the groundmass and sometimes filling the interstices between the plagioclase laths. Chlorite occurs as irregular patches that are commonly filling the spaces between the plagioclase laths.

Iron oxide occurs as irregular granules, fine dust which disseminated throughout the rocks and frequently occupied the interstices between plagioclase laths.

**b- Porphyritic andesite**

These rocks are fine grained, grayish brown in colour and massive. Microscopically, they are composed of plagioclase phenocrysts embedded in a phaneric fine grained groundmass consists of plagioclase, chlorite, calcite, iron oxides and minor quartz. Porphyritic glomeroporphyritic and amygdaloidal textures are characteristic. The amygdales are frequently filled by chlorite and calcite and display irregular outline.

Plagioclase is represented by two generation. The first phase occurs as subhedral phenocrysts , locally corroded by the groundmass. Generally, plagioclase is twinned accoding to albite laws and occassionlly altered into sericite, calcite and epidote which mask its twin planes. Quartz occurs as anhedral crystals, water clear and frequently concentrated in the groundmass.

Calcite occurs as irregular patches and displays rhombohedral cleavage. Calcite is commonly replaced plagioclase crystals and occupying the cavities in the rocks.

Chlorite occurs as irregular small patches of pale green in color and commonly scattered in the groundmass and filling the cavities. Epidote occurs as subhedral grains scattered in the groundmass and frequently associated with plagioclase crystals.
Iron oxide occurs as irregular granules, disseminated in the groundmass.

**II – Granitic pebbles includes:**

**a – Graphic granites**

These rocks are medium to coarse grained, grayish pink in color and massive. Microscopically, they are composed of alkali feldspar, quartz and plagioclase. Epidote, calcite and chlorite are secondary minerals, whereas iron oxides are accessories. Hypidiomorphic, granular, graphic, granophyric and myrmekitic textures are common.
Alkali feldspars are represented by orthoclase perthite which form subhedral to anhedral crystals, intensely kaolinitized and saussuritized. It is enclosing completely and partially plagioclase crystals or encloses irregular granules of iron oxides.
Plagioclase forms subhedral tabular crystals, intensely kaolinitized and saussuritized. It is twinned according to albite law and myrmekitically intergrown with quartz blebs along the margin.
Quartz occurs as subhedral to anhedral crystals, frequently filling the interstices between the other constitutes and occasionally exhibit wavy extinction. Quartz crystals commonly intergrown in alkali feldspars which displaying graphic and granophyric textures.
Chlorite forms irregular patches and scaly aggregates of pale green in color and commonly enclosing iron oxide granules.
Epidote occurs as subhedral crystals dispersed throughout the rocks and frequently associated with plagioclase crystals.
Calcite occurs as irregular patches replacing the feldspars and filling the fractures.
Iron oxide occurs as irregular granules and octahedron shape. It is enclosed by chlorite and feldspars.

**b – Tonalites**

These rocks are medium to coarse grained, grayish in colour and massive. Microscopically, they are composed of plagioclase, quartz, chlorite, calcite, minor epidote and iron oxides. Hypidiomorphic texture is a characteristic.

Plagioclase occurs as anhedral to subhedral tabular crystals, slightly kaolinitized and saussuritized which mask its twin planes. It is commonly twinned according albite and Carlsbad albite laws. Quartz occurs as subhedral to anhedral crystals, water clear and sometimes displays wavy extinction. Generally, quartz is filling the interstices between the plagioclase.
Calcite occurs as irregular patches commonly replacing the plagioclase crystals.

Chlorite occurs as irregular patches of pale green in colour and faintly pleochroic.

Iron oxide occurs as irregular granules and occasionally as cubic shaped of black color, scattered throughout the groundmass.

Epidote occurs as subhedral crystals, commonly associated with the altered plagioclase crystals.

**III – Reworked Hammamat clasts including:**

**a – Siltstone**

These rocks are fine grained, pale green in colour and massive.

Microscopically, they are composed of subangular to subrouned clastic grains of quartz and plagioclase of silt size set in a matrix of quartz dust, sericite, muscovite and iron oxides (PL.3, Fig.3).

Quartz occurs as turbid colour, fine grained, subangular to subrounded grains, monocrystaline and showing wavy extinction. Plagioclase occurs as subrounded grains, slightly kaolinitized and sericitized.

Muscovite occurs as thin flakes and anastomosing scales between the clastic grains. *Iron oxides* occur as fine grained dust disseminated throughout the rocks, occasionally as cubic shaped of black color, scattered throughout the groundmass.

**Scanning Electron Microscope (SEM)**

Several conglomerate samples were examined by scanning electron microscopy (SEM), carried out at the Scientific Mobark City. SEM micrographs on the external deteriorated surfaces of conglomerate rocks from Hammamat quarries are showing many etch pits, microsheet fractures, black spots, dissolving and removal of minerals due to weathering processes. Also, SEM micrographs are showing numerous deep cavities and dissolving cement and removal of rock fragment (pebbles) as a result of physiochemical action (PL.4, Fig.8). The large or small cracks and incipient joints present lines of weakness, commonly along individual mineral crystals and pebbles in conglomerates microsheet fractures and exfoliation may occur (PL.4, Fig.7).

One of the most important weathering process at the Hammamat quarry is the sulfate salt efflorescence's ( gypsum and anhydrite) develop typically in the form of prismatic growth and flower aggregates on the conglomerate surfaces (PL.4, Fig.6).

Moreover, SEM micrographs of weathered conglomerates revealed the formation of Halite and calcite minerals. Halite crystals were usually occuring in cubic form(PL.5, Fig.6), sometimes encapsulated by kaolinite plates, while calcite crystals commonly occur as rhombic shape with Rhombohedral characteristic cleavage and growth spiral on the calcite boundaries. (PL.4, Fig.2).Commonly,the dissolution of calcite and epidote grains were observed as a result of chemical alteration(PL.4, Fig.5).

Other important weathering process on the conglomerate surfaces at the Hammamat quarry is black spots. SEM micrographs showing the black spots and black flakes scatter on the conglomerate surfaces. Several black spots occur as deep groove cover with thin black flake due to salts (introduced from polluted air) and transformation of minerals (PL.5, Fig.1). The black flake dissected and encapsulated by salts and kaolinite aggregates. SEM photomicrographs also, showing salt efflorescence, s under the tope surface of the black crust, appear more porous, deep micro- grooves and micro-sheet fractures parallel to the weathered surface in conglomerate rock (PL.5, Fig.2).

On the otherside, Kaolinite aggregates also, identified by SEM micrographs, develop into hexagonal crystals and fine grained particles in the altered feldspar grains as a result of feldspar alteration by hydrolysis process (PL.5, Fig.5). Micro-porosity presents between large overlapping clay platelets, quartz and calcite grains (PL.4, Fig.4). In addition, SEM micrographs are showing the weathered feldspar surfaces with spherical particles and circular fibrous forms of amorphous aluminum hydroxide. These are produced by the earliest stages of feldspar weathering (PL.5, Fig.4). Moreover, numerous etch pits in the feldspar grain, commonly rounded and enlarged. The differential etching of the feldspar grain is also observed (PL.4, Fig.1).

**Analysis**

Three samples from weathered conglomerate rocks were examined by X-ray powder diffraction analysis. This analysis reveals that, the weathered conglomerates are essentially composed of quartz, orthoclase, calcite, forsterite, silhydrite, brucite, magnetite and anhydrite. Hematite, calcite, apatite, kaolinite, nantronite and magnetite represent the alteration products of feldspars and mafic minerals in conglomerates. Mineral variations in conglomerate composition are related to the different rock fragments (pebbles) and the alteration products in weathered conglomerate rocks.

Generally, X.R.D analysis reveals that hematite, calcite, apatite, kaolinite and anhydrite are present in most weathered conglomerate samples. The dominance of quartz, alkali feldspar, forsterite, calcite and clay minerals may reflect the derivation of rock fragments of conglomerate from igneous rocks, metamorphic rocks and recycled sediments exposed in Central Eastern Desert of Egypt.

The high salts concentration plays many roles in the deterioration processes in the area, the most effective of them is anhydrite. Calcium sulphate can appear as two distinct minerals: gypsum (dehydrate) and anhydrite (anhydrous). It is possible that the dehydration-hydration reaction plays a critical role in the deterioration mechanism[31]. Commonly, clay and calcite minerals are replacing feldspar and quartz minerals along the intercrystalline, boundaries and fill the cracks which commonly dissected the rock fragments (pebbles).

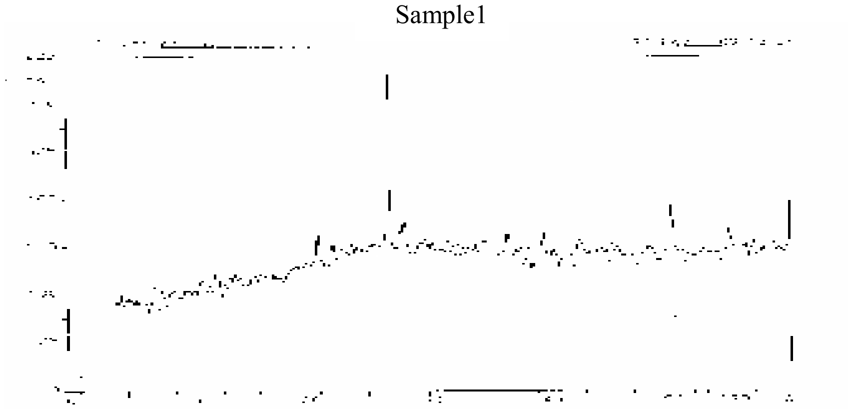
Also, ferromagnesian grains are susceptible to replacement by clay. Kaolinite is the main alteration mineral with subordinate nanotronite(montmorillonite group) occurs as a result of transformation feldspars and mafic minerals. Moreover, silhydrite (opal) contains more water than chalcedony and is considerably softer than quartz. Opal occurs mainly as secondary deposit, formed by the action of percolating groundwater.

[31] Charola, A. E., and Centeno, S.A. : Analysis of gypsum containing lime mortars:possible errors due to the use of different drying conditions, Journal of the American Institute of Conservation, (2002),41, 269-78.

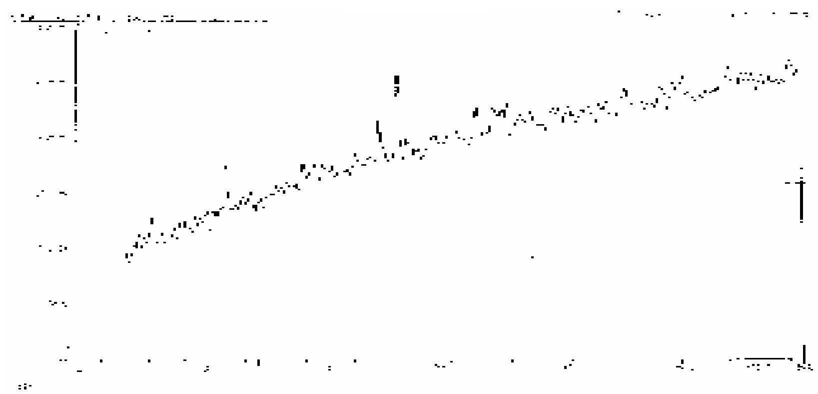
Table (1) Results of X – ray diffraction analysis

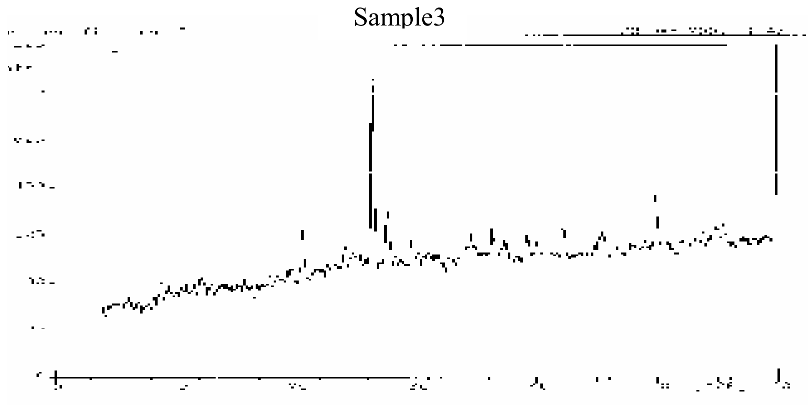
| Sample No. | Material type | Sample site | com position |
|---|---|---|---|
| 1 | Altered conglomerates | Hammamat quarry | Quartz – Kaoinite-Orthoclase-Calcite-Anhydrite-Apatite-Brucite- Forsterite |
| 2 | Altered conglomerates | Hammamat quarry | Hematite - Quartz – Kaolinite-Magnetite-Calcite-Nontronite-Apatite-Iron silicate-Silhydrite- |
| 3 | Altered conglomerates | Hammamat quarry | Quartz – Kaoinite-Orthoclase-Calcite- Nontronite-iron silicate |

Sample1



Sample2






Sample (1, 2, 3) The altered conglomerate rocks from the Hammamat quarry.

## Quarrying Technology

The quarries at wadi Hammamat were without any doubt exploited from the earliest dynasties until the end of Roman period. Usually, it is described by Egyptologists as Bekhen stone and breccias verde antico. These have been heavily used for architectural, stone-vessel caring, sculptural and other application.

The studied area affected by a set of left lateral strike-slip faults and thrusts, first mentioned by Andrew[41] are well exposed on both sides of the Qift-Quseir road at k 94 (from Quseir) immediately west of the entrance to wadi Atalla. Joints also, dissected the whole Hammamat hills in the wadi Hammamat into many rhomboidal blocks more than several meters in long and 2 meters in width. The spacing and frequency of joints and fractures are important factors in quarrying stone, the widely spaced joints

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[41] Andrew, g. : The greywakes of the Eastern Desert of Egypt. Bull. Inst. Egypt, (1939), 21, 153 - 90.

[51] Edwards, I.E.S. : The pyramids of Egypt. London, (1985).

[61] Röder, Zur Steinbruchsgeschichte des Rosengranits von Assuan. Archäologischer Anzeiger, (1965), 3: 467-552.

[71] Klemm, R. and Klemm, D. : Die steine der pharaonen. ( exhibit. Cat.), Munich, (1981).

yield large blocks of stone, while closely jointed rock is broken up into small pieces.

The hard stone was worked with dolerite hammers (PL.6, Fig.1). The technique was certainly known in ancient Egypt, one inscription refers to that. The inscriptions present in wadi Hammamat, dates from the eleventh dynasty (reign of Monthuhotep IV). Dolerite is a greenish stone, found in the Eastern Desert. The stone is much harder than greywackes or conglomerates. This explains why the Hammamat rocks is crushed and pounded with dolerite stone.[51],[61],[71]. Moreover, wedges were used to split the hard rocks in the Roman time. This method was used to extract obelisks, statues, pillars and sarcophagus. The earliest step for splitting the blocks from the parent rocks was drawing a sketch of the required block using ochre to make a channel along the boundary of the block from all sides by chisel about 2cm deep (PL.6, Fig.5). After that, a series of holes were cut along a straight line. Wedge-shaped pieces of iron were then inserted into the holes and hammered until the rock split. Opinions differ widely on the dating of wedge holes. In 1965, Roeder formulated the idea that the great variety in the spacing of the wedge holes reflects a chronological evolution.
This chronological typology consists of successive phases. It covers the whole period from 500 B.C until the present. Each phase can be distinguished by the diminishing space between the wedge holes until all wedges were placed together in a continuous groove. After investigation many traces of wedge holes and tool marks in the wadi Hammamat quarries. We think that the quarrymen were not sure yet how to use the wedging technique in the beginning of quarrying. The quarrymen placed two wedges at each end of the block. In addition, supplementary holes were cut in between by chisels. This feature means that the wedge –holes must date from

500 B.C., according to Roeder, 1965. Moreover, the third phase is represented in the Hammamat quarries. We found several blocks with a series of wedge holes placed together closed in a continuous groove, which means that the wedge-holes must date from the $2^{nd}$-$1^{st}$ century B.C(PL.6, Fig.3).. Also, the 5 and 6 phases represented in the Hammamat quarries. A typical profile of flat and funnel shaped wedge holes, which means that the wedge-holes must date before 50 A.D(PL.6, Fig.4). Finally, the late phase of Roader's typology appear in the 19th century (phase 10) represented in the Hammamat quarries (PL.6, Fig.7).

**DISCUSSION**

The quarries which produced the famous green ornamental stone known in antiquity as breccia verde antico and Bekhny stone are located in the area of wadi Hammamat and since Roman times produced those rocks. Egyptian commonly employed a crops of professionals know as Sementyou or pioneers. Their task was to roam the land in search of stone and minerals. They brought back specimens in leather satchels hung on the ends of their staffs[81].

The field observation revealed that, the Hammamat rocks dissected by large extensive and widely spaced joints with a distance separating the joints reaching about 2-3meters or less. The blocks between the successive joints were usually of roughly rhomboidal shape.

During early dynastic when Bakhen stone was quarried, the labourers simply let the blocks of stone roll down the mountain sides and kept only those which reached the foot of the mountain intact. One interesting form is called carbonate nodules, spherical or overall shaped, commonly scattered in several places in the Hammamat rocks. When Bekhen stone subjected to the chemical weathering, the carbonate nodules were dissolved and produced

[81] Hillier, A., 2003.Ancient rock quarries: the Ravine of inscriptions. TourEgypt. http://www.touregypt.net/featurestories/inscription.htm.

spherical holes carved into the Hammamat bedrock. This phenomenon often developed as a series of wedge holes cut a long a straight line within the Hammamat rocks. Accordingly, we suggested that at the beginning of quarrying the ancient quarrymen probably concentrated on those parts of Hammamat layer, exploited many carbonate nodules with aid of joints and fractured to extract the bekhen stone from the parent rocks. Hammer stone, copper and flint tools were used to cut stone, until stone broken and fractured along the line of carbonate holes.

In addition, a significant feature of the Hammamat site is the evidence for the use wedging technique and iron quarrying tools in Roman times. The use of a conglomeratic variety of rock, the so-called "Breccia Verde Antico" became fashionable in Roman period. According to Roader's typology (Roder, 1965) and field observation such as many wedge holes, tool marks and unfinished objects, we conclude that the Egyptian quarrymen and sculptors were able to drill, carve and pound the Hammamat rocks with chisels and pounders in pharaonic time, whereas in the late period iron wedges and chisels were used. Finally, several broken sarcophagi and numerous stone fragments scattered in Hammamat site, this indicate that these objects were mostly dressed at the quarry site and transported over 90 km through the desert until they were shipped on the river Nile to their final destination.

The famous green breccias or conglomerates were extracted from Wadi Hammamat quarries in the Eastern Desert on Qena-Quseir road. It always slightly metamorphosed, mainly quarried in the $20^{th, 25th}$ and $30^{th\ dynasties}$. It contains rounded pebbles and cobbles of different colors and compositions, in fine groundmass and is greenish due to the contents of epidote and chlorite.

This unique heritage is at immense risk from damage and destruction by modern quarrying or "theft of stone", weathering and erosion. Salt weathering, wind action and rock-fall are also main risks in some areas. Naturally, after several thousand years, partial collapse of exterior quarry faces and rock-fall from such faces will certainly take place from time to time. Collapse of quarry faces, flash floods impacting on Hammamat quarries and weathering of inscriptions and tool marks may lead to serious loss of cultural heritage values. In the mountainous of Eastern Desert localized torrential rains may occur from time to time, which form the basis for Bedouin life[91], [02], but can lead to serious destruction of ancient quarry infrastructure.

The field observation and the primary investigation show that greater number of tool marks (wedge holes and other traces of stone cutting) and rock inscriptions on the conglomerate surfaces already have partially and sometimes completely disintegration. it is easy to note, variations in color (PL.1, Fig.3), a lack of cohesion between the various components of the rock, detachment of portions of material(such as pebbles), formation deep cavities due to the growth of salt crystals (PL.1, Fig.4) and appearance of many fractures and fissures (PL.1, Fig.8)in the conglomerates. Moreover, the high load of traffics on the Qift-Qusier road especially by trucks may increase the strain along the active fault and joint plains and eventually may increase the weakness zones. Also, the quarry face is coated with a reddish brown oxidized film, consists of iron oxides, which fills cracks and penetrates into crystals (PL.1, Fig.10).

Thin section examination of the rock samples shows them to be composed of different pebbles within a groundmass. The conglomerates are fine to coarse, greenish grey in color and massive. Microscopically, the weakly metamorphosed

[91]Hobbs, J.J.: Bedouin Life in the Egyptian Wilderness. The American University in Cairo Press, Cairo, (1989), 165 pp.

[02]Krzywinski, K. and Pierce, R.H.: Deserting the Desert: a Threatened Cultural Landscape between the Nile and the Sea. Alvheim & Eide Akademisk Forlag, Bergen, (2001).

conglomerates are composed mainly of subangular to rounded clastic grains of quartz, plagioclase and rock fragments (including granites, andesite, metabasalt, greywacke and siltstone) embedded in a silty clayed groundmass composed mainly of chlorite, sericite, muscovite, calcite, recrystallize quartz, epidote and iron oxides. Generally, petrograpic description of the examined pebbles from the Hammamat conglomerates including the following:-

I -Volcanic pebbles include: metabasalts, and porphyritic andesites
II – Granitic pebbles include: graphic granites and tonalites
III – Reworked Hammamat clasts include: Siltstone

Conglomerate quarry faces in wadi Hammamat are subject, with the passing of time, to more or less intense deterioration which may even only be evidenced by macroscopic analysis. The petrographic photographs are showing subrounded to rounded different rock fragments. Some rounded plagioclase fragment appears with zigzag boundaries as a result of largely corroded by groundmass and chemical alteration. Also, plagioclase grains are partially kaolinitized, commonly replaced by calcite crystals, bent of twin lamellae as a result of stress and deformation in conglomerates (PL.2, Fig. 4).

Moreover, some plagioclase grains are highly weathered, partially or completely altered to kaolinite, epidote, sericite, calcite and tiny muscovite flakes mask its twining (PL.3, Fig. 1). SEM photomicrograph reveals that plagioclase grains have etched pits and a large number of cracks compared with quartz (PL.4, Fig. 1). Many cracks were observed running along cleavages in the plagioclase and run between mineral grains (PL.2, Fig. 5). In addition to these cracks, others run parallel to the surface of the rock and across cleavage planes at depths less than 0.5mm, which may be called "micro-sheeting" as reflected from SEM microphotographs and field observation (PL.4, Fig.3) (PL.1, Fig.8). Optical observations also show that most of the kaolinite in the weathered rock derives from the weathering of plagioclase and muscovite. Numerous micropitting and kaolinite spots scatered on feldspar surfaces along the edges or along narrow zones in the interior of the feldspar crystals (PL.2, Fig.4). Keller [12] stated that "micropitting of feldspar, presumably by incongruent dissolution, is a common pre- or early-stage, of kaolinization of feldspar. Berner and Holdren [22] also said no doubt, that the dissolution of feldspar proceeds by selective etching of the surface, probably along dislocations."

The weathering started in the plagioclase crystals in the peripheral parts of the crystals. The clay minerals are formed as secondary clay products after plagioclase along the network of intergranular micropores. The intermineral cracks were filled with fine dust and small granules of iron oxides, while several grains coated with brown iron oxides (Pl3. Fig.5). Calcite occurs as irregular patches and shreds dispersed in the groundmass or filling the fractures dissecting the conglomerate rocks.

Also, ferromagnesian grains are susceptible to replacement by clay minerals. Kaolinite is the main clay mineral with subordinate nanotronite ( montmorillonite group) formed as a result of alteration feldspars minerals. Kaolinite shows a variety of morphologies, including platy, pseudohexagonal particles and vermicular stack.

X-ray data (Table 1) of weathered samples reveals the presence of nanotronite ( montmorillonite group) and kalonilite. These swelling clay minerals cause stresses and weaken the consistency of the stone. Moreover, hematite, calcite, apatite, kaolinite and anhydrite are present in all weathered conglomerate samples. The dominance of quartz, alkali feldspar, forsterite, calcite and clay minerals may reflect the derivation of rock fragments of

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[12] Keller, W. E. :Scan electron micrographs of kaolins collected from diverse environments or origin--l: *Clays & Clay Minerals*,(1976), *24,* 107-113.

[22] Berner, R. A. and Holdren, C. R.: Mechanism of feldspar weathering: some observational evidence: *Geology,* (1977), 5, 369-372.

conglomerate from igneous rocks, metamorphic rocks and recycled sediments exposed in Central Eastern Desert of Egypt.

On the otherhand, salt weathering occurs on the faces of Hammamat quarry which naturally contains salts, especially halite and anhydrite, due to the influence of underground water, condensation, pollution and changes in relative humidity. Commonly, some salt such as *halite and gypsum* always covers the rock surface, originates from different sources as "Rocks, Soils or resulted through different chemical effects and drying cycles"[32]. This actually a problem when such surfaces display fine tool marks, inscriptions and rock-art. Accordingly, the high salts concentration plays many roles in the deterioration phenomenon in the Hammamat area. We can suggest that the sulphate that was found in some stone surfaces is formed by chemical reactions of $SO_2$ with $CaCO_3$, as reported by many researches as Fassina[42] and Russ, *et al.* [52]. This mechanism leads to the formation of some aggressive salty hard crusts of Gypsum on stone surfaces as a result of dissolution processes of calcite, originates from the conglomerate rocks. In addition, halite salts also are precipitated on the stone surface or in the pore space of the rock close to the surface [62] . According that,

[32]Abdel Hady, M.M. : Conservation problems of Islamic architectural heritage in Cairo[Egypt], Conservation, Preservation & Restoration, Traditions, Trends and Techniques, India., (1995), pp: 63-70.

[42] Fassina, V. :Environmental pollution in relation to stone decay, Air pollution and conservation-safeguarding our architectural heritage, Elsevier, Amsterdam, (1988).

[52] Russ, J., W.D. Kaluarachchi, L. Drummond and H.G.M. Edwards : The nature of a whewellite-rich rock crust associated with pictographs in southwestern Texas, Studies in conservation, (1999), 44(2): 91-103. 45.

[62]Fitzner, B., Heinrichs, K, and la Bouchardiere, D., , Limestone weathering of historical monuments in Cairo, Egypt, in Natural stone, weathering phenomena, conservation strategies and case studies Special Publication 205.The Geological Society of London, London, (2002).

[72]Wust, R. A. J., and SchluchterCh. : The origin of soluble salts in rocks of the Thebes Mountains, Egypt: the damage potential to ancient Egyptian wall art, Journal of Archaeological Science, (20002), 7, 1161-72.

salts mixed with cement between grains and inter inside pebbles and caused intensive deterioration. Moreover, rainwater and underground water dissolve halite first then gypsum, anhydrite and calcite in the stone [72] and cause granular disintegration of Hammamat rocks (lost cement and grains).

The scanning electron microscope micrographs on external deteriorated surfaces of conglomerate rocks from Hammamat quarry showing many microsheet fractures, etch pits, black spots, dissolving and removal of minerals due to weathering processes (PL.4, Fig.7). SEM micrographs showing numerous deep cavities and dissolving cement and removal of rock fragment (pebbles) as a result of physiochemical action (PL.4, Fig.8). The dissolution of different minerals and cement between grains and pebbles is the most conspicuous alteration feature in conglomerate rocks, where it produces vugs whose volume and shapes coincide with that of the dissolved mineral grains or pebbles. The vugs left after the dissolution of mineral grains and pebbles may be filled with authigenic minerals, such as calcite, kaolinite and iron oxides. According to Blum and Lasaga [82] the presence of etch pits suggests that defects in the crystal structure are sites of strong preferential dissolution during geochemical processes. The surfaces of some large plagioclase grains were covered with etch pits. Uniform distributions of etch pits have been described previously[92]. Various sizes of etch pits were noted. Some grains exhibited only one population of pits, whereas others showed two sizes (PL.4, Fig.1),

[82]Blum, A. and Lasaga, A. Monte: Carlo simulations of surface reaction rate laws: in *Aquatic Surface Chemistry*,W. Stumm, ed., Wiley-Interscience, New York, (1987), 520 pp.

[29] Fung, P. C. and SanipeUi, G.: Surface studies of feldspar dissolution using surface replication combined with electron microscopic and spectroscopic techniques: *Geochim. Cosmochim. Acta*, (1982), 46, 503-512.

suggesting that the grains underwent one and two episodes of weathering, respectively. Other observations with SEM showing cone-shaped lamellae (chatter cones) (PL.5, Fig.7), conchoidal fractures, straight steps and adhering particles on quartz grains (PL.5, Fig.8). The observed abundant conchoidal fractures on the quartz grains from both areas indicate that the quartz grains were mainly derived from crystalline source rocks. Quartz was also easily identified by its conchoidal fracture and smooth surfaces.

In addition, one of the central topics within these studies is the relationship between air pollution and decay. Conglomerate decay can have many shapes in different grains, such as efflorescence, staining, cracking, alveolar erosion, scaling and micro-organisms growth. These alteration/deterioration and weathering phenomena are the result of interaction between conglomerates material and the atmosphere: water plays a decisive role, as well as atmospheric gases and the various particulate components. Moreover, the climate affects the weathering both directly and indirectly[03],[13],[23]. Temperature governs the rate of the chemical reactions, but heating and cooling are important which can cause physical disintegration of the mass rock.

A vital role is played by pollutants such as sulphur dioxide (SO2), nitrogen oxides (NO2) and carbon dioxide (CO2). In particular, sulphur dioxide (developed to a great extent by the combustion of fossil fuels) reacts with water to form sulphuric acid; contacts with calcite then forms $CaSO_4.2H_2O$ in conglomerates. Black crusts are major weathering forms on quarry surfaces exposed to sulphate pollution were detected by SEM

[03]Peliter L.: The geographic cycle in per glacial regions as it is related to climate geomorphology. Annals of Association of American Geologists, vol.,(1950),40, pp. 21.-t--236.
Oilier C. : Weathering, 2nd edition. Longman. London, (1984).[13]
[23]Saito T.: Variation of physical properties of igneous rocks in weathering. Proceedings of International Symposium on Weak Rock, Tokyo, (1981), pp. 191-196.

photomicrographs (PL.5, Fig.1). Until now black crusts are still a worrying problem in the conservation of cultural heritage.

Moreover, conglomerates essentially include calcite (calcium carbonate) as reflected from x-ray diffraction analysis that dissolve and respectively release ions of calcium. On the otherside, carbon dioxide, in the presence of water, transforms calcium carbonate into bicarbonate, that is soluble and inasmuch expelled from the rock.

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Plate (1)

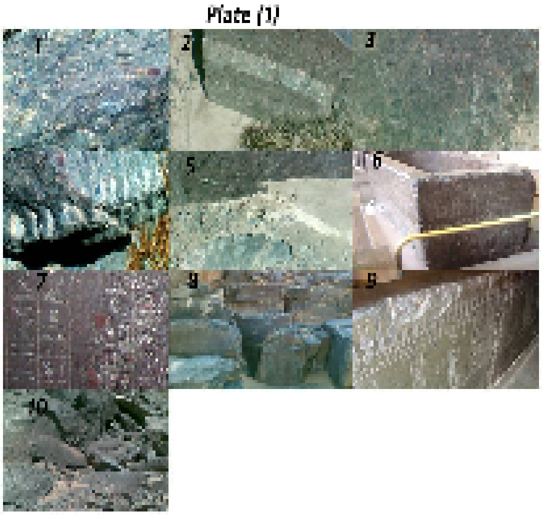

Plate (2)

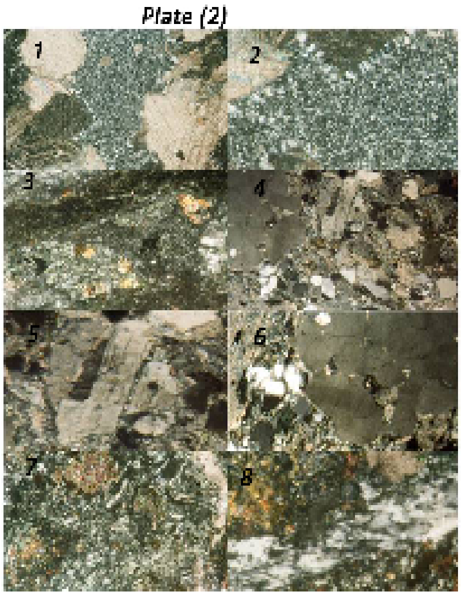

Plate (3)

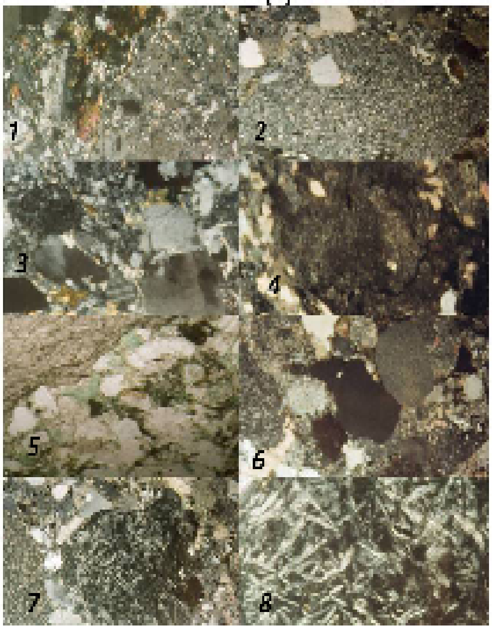


Plate (4)

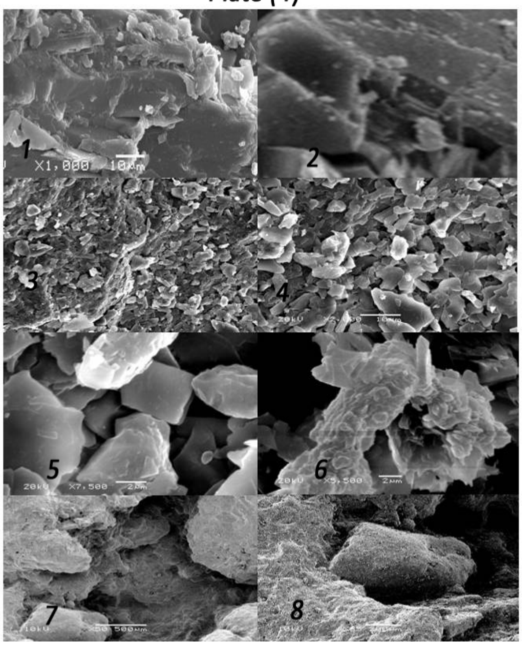

Plate (5)

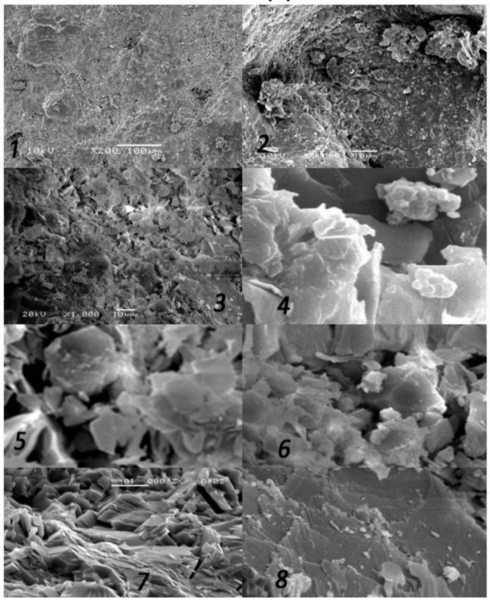

Plate (6)