# PETROGRAPHY AND GEOCHEMISTRY OF SOME PHOSPHATE BEARING SEDIMENTS IN EGYPT

## NADIA M.S. ABD EL-MAGUID
Geology Department, Faculty of Science, Menoufia University
Shebin El-Kom, Egypt.

## ABSTRACT

The Upper Cretaceous phosphate-bearing sediments in Egypt, generally referred to as the Duwi or Phosphate Formation, were investigated in terms of their petrographical and geochemical characteristics. The study is carried out on alternating phosphate and non-phosphate beds at three localities namely Gebel El-Topog at the Bahariya Oasis, Mohamed Rabah mine near Safaga and Mahamid, about 140 km from Aswan.

The Bahariya phosphates are deficient in $P_2O_5$ compared to the other two localities which are characterized by the presence of large bone fragments, dolomite intraclasts and glauconite minerals. In addition, the Bahariya phosphates are also enriched in angular, coarse-grained quartz and other clastic minerals. In Mohamed Rabah section, the phosphorites includes several types: calcareous phophorite, sandy phosphorite, siliceous phosphorite and grey fine-grained phosphorite. Most calcareous shells are totally replaced by fine to coarse-grained silica. The phosphorites at Mahamid are characterized by ill-sorted phosphatic and non-phosphatic grains cemented mainly by microcrystalline silica in the form of chalcedony.

Diagenetic processes such as glauconitization, silicification and dolomitization played a major part in the present lithologies. Glauconitization is considered as of early diagenetic origin developed under weakly reducing environment. Similarly, the presence of carbonaceous matter in the black shales at Mohamed Rabah section reflects the prevalence of reducing conditions during deposition. Silica also replaces the bone fragments, groundmass, some ca-apatite pellets and fossil intraclasts. Dolomite is considered as being diagenetic in origin in Gebel El-Topog section characterized by dissolution fabrics, but in both Mohamed Rabah and Mahamid sections dolomite is presented as early (syngenetic) documented by microcrystalline crystals of dolomite and evaporite.

From the vertical distribution of the elemental chemical composition in addition to petrography, lithology and field observations in the present studied sections; the investigated sediments can generally be classified into three main categories, shales, phosphorites and carbonates assemblages which were deposited

in alternating littoral and shallow marine environments and affected by diagenetic processes.

**Key words:** phosphorites, Ain Giffarra, diagenesis.

## INTRODUCTION

The Duwi (Phosphate) Formation in Egypt comprises a number of phosphate horizons separated by shales, marls, dolostone, cherts, glauconitic sandstones and oyster limestone beds. These phosphate beds belong to the Late Cretaceous-Early Tertiary age. Mediterranean phosphate belt stretches from Morocco in the west to Turkey and Iraq in the east (Klemme, 1958; Sheldon, 1964). Similar to these regions, the Egyptian phosphates were deposited in the transitional zone between the stable shelf in the south and the Tethys Sea in the north as a result of upwelling currents (Bender, 1968; 1975).

In Egypt, phosphate deposits are widely distributed in the Eastern Desert, Nile Valley, Western Desert and Sinai. Most of these phosphorites belong to the upper most part of the Cretaceous (Campanian/Early Maastrichtian) based on macro- and nanno-fossils, and palynomorphs studies (e.g. Hermina, 1973; Dominik and Schaal, 1984; Schrank and Perch-Nielsen, 1985).

Several studies were performed on the Duwi or (Phosphate) Formation in Egypt by many authors. Among of these studies are Ball (1913); Hume (1927); Hussein (1954); Higazy and Hussein (1955); Rittman and Machu (1955); Youssef (1958, 1965 and 1975); Anwar and Tarabili (1960); Anwar et al.(1963); Higazy (1964); Tobia and Fekry (1964); Zaghloul and Mabrouk (1964); Omara (1965); Issawi et al. (1969); Philobbs (1964, 1969, 1975 and 1976a, b,c); Soliman and Amer (1969 and 1972); Tarabili (1969); El-Kammar (1970); Abdel Aziz et al. (1971); Abdallah et al. (1972); Attia et al. (1972); El-Mahrook (1972 and 1975); Guirguis (1974); Salman (1974); Kamel et al. (1976 and 1977); El-Aassy (1977); Gindy (1978); Mohamed (1979); Glenn (1990); Glenn et al. (1990); Morad et al. (2000); Abu Zeid et al. (2005) and Rifai and Shaaban (2007).

The aim of the present study is to provide a better understanding of the phosphorites and non-phosphate rocks through petrographical, geochemical and diagenetic studies, in addition to offer some help for exploitation purposes. For this purpose, the materials of the present study was taken from three different localities namely Gebel El-Topog in the Baharia Oasis, Mohamed Rabah Mine near Safaga along the Red Sea coast and Mahamid (about 140Km from south Aswan (Fig.1), three different stratigraphic successions (Fig.2) were measured. The following is a brief description of each stratigraphic succession:

## 1- Gebel El-Topog Section:

The studied section of Gebel El-Topog succession (13.3m thick) in the depression of Bahariya Oasis belongs to the Ain Giffara Formation (Campanian-Maastrichtian) which unconformably overlies the El-Hefhuf Formation and conformably underlies the Maastrichtian Khoman Chalk Formation (Khalifa, 1977; Khalifa et al., 2002). The Ain Giffara Formation consists of two main facies, phosphatic calcareous sandstone enriched with phosphatic minerals and ferruginous pockets at the base and a highly indurated, porous, dolomitic limestone with numerous shell debris and chert nodules at the top.

## 2-Mohamed Rabah Section:

The samples were taken from Mohamed Rabah Mine near Safaga along the Red Sea coast (Duwi Formation, 14m thick). This Formation conformably overlies the Quseir (variegated) Shale which is stratigraphically equivalent to the El-Hefhuf Formation. The lower part of the Duwi Formation consists of interbedded thin phosphate beds, marls and black shales with gypsum veinlets. The upper part consists of phosphorites interbedded with bioclastic limestone. The Duwi (Phosphate) Formation in Safaga district was previously assigned to Early Maastrichtian (Faris and Hassan, 1959).
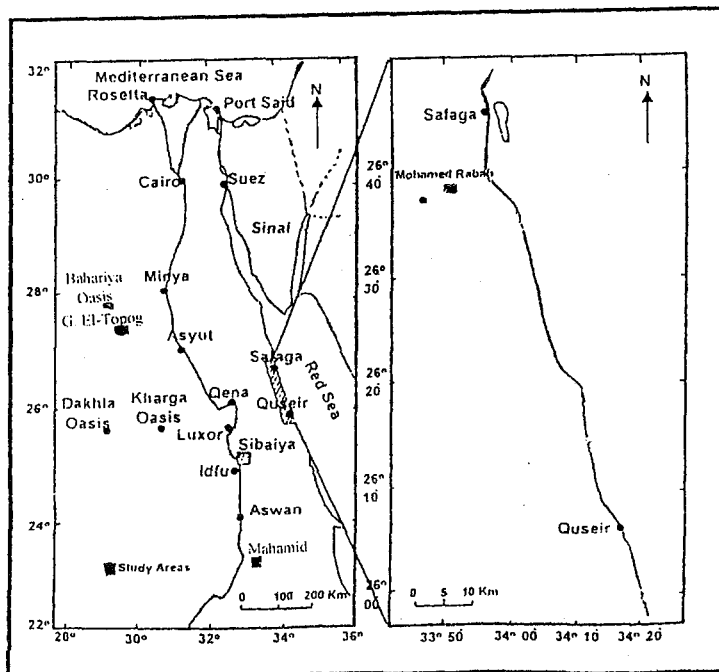


Figure 1 Location maps showing the location of the studied areas. ( Modified after Abu Zeid et al. 2005 )
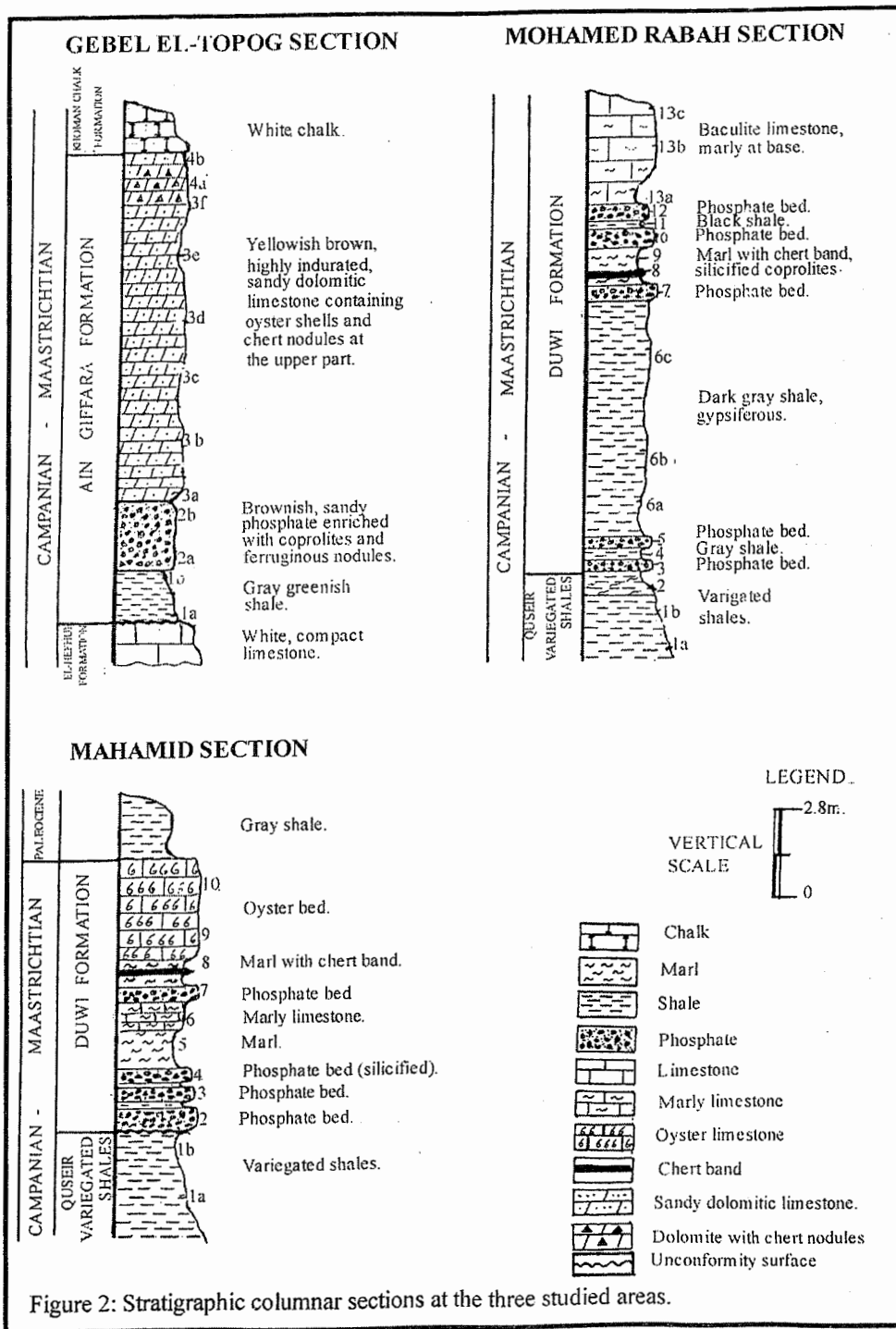
### 3- Mahamid Section:

The Duwi (Phosphate) Formation (7.7m thick) at this locality is enclosed between the variegated shale at the base and the Paleocene shales at the top. The Formation contains a number of phosphate beds separated by chert, marl and oyster limestone beds in the form of large scale low-angle cross-bedding.

## METHODS

The collected samples were examined by X-ray diffraction analysis technique (XRD) for bulk samples. Clay mineral associations have been studied using X-ray diffraction on oriented mounts. Defloccution of clays was done by successive washing with distilled water after decarbonatation of the crushed rock with 0.2N HCl. The clay fraction (<2um) was separated by sedimentation and centrifugation (Brindley and Brown, 1980).

Polarizing microscope, energy dispersive X-ray pattern (EDAX) was carried out using a JEOL 730 SEM and LINK-1000 system for both mineralogical identification and petrographical studies including modal composition using point counter (Table 1). The obtained samples are well examined for their gross structures and fabrics in the laboratory. Chemical analysis for some major, minor and trace elements was performed on some selected samples (Table 2) after digestion in inorganic acids following the technique used by Okmima (1961). Total organic carbon (TOC) and total sulphur (S) were analyzed by a LECO WR12 and LECO 532, respectively. Electron microprobe analyses were also carried out in the Electron Microprobe Laboratory using polished, carbon-coated thin-sections and a JEOL JXA-8900 super probe with five wavelength dispersive spectrometers, an accelerating voltage of 15 kV and beam current of 7 nA. A relatively large defocused electron beam (10 um) was used to minimize sample degradation. The detection limits of the microprobe were estimated at approximately 0.004 element%. It is to be noted that the above mentioned analyses were carried out in the Department of Earth and Atmospheric Sciences, University of Alberta, Canada.

Figure 2: Stratigraphic columnar sections at the three studied areas.

# PETROGRAPHYICAL INVESTIGATIONS

The petrographical investigations of phosphorites and non-phosphate rocks in the present work (12 rock samples from Gebel El-Topog section, 15 rock samples from Mohamed Rabah section and 9 samples from Mahamid section) will be dealt separately:

**Phosphorites:**

In hand specimens, the phosphorites are yellowish brown to grey in colour, semifriable but in part massive and hard. Microscopically, the main constituents of the phosphorites of the present study are: Ca-apatite, bone fragments, quartz, bioclasts, intraclasts, plagioclase, glauconite, carbonate minerals, iron oxides heavy minerals as well as gypsum (Table 1). These constituents are cemented by either calcareous or siliceous cement and/or frequently lithified by ferruginous, glauconitic ca-apatite groundmass.

Table 1: Constituents of phosphorites and non-phosphate contents using polarized microscope in thestudied areas.

| Area / Sample No | ALLOCHEMS | | | | | | | | Glauconite | Gypsum / Anhydrite | Dolomite | Micritic ground-mass or cement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Phosphatic Ca-apatite | Phosphatic bioclastic and bone fragments | Calcareous skeletal and other bioclasts | Carbonate intraclasts | extra - clasts | | | | | | | |
| | | | | | Quartz | Plagioclase | Heavy minerals | Iron oxides | | | | |
| Gebel El-Topog phosphorites 2 | 34.6 | 16.2 | 3.1 | 1.5 | 10.7 | - | - | 3.2 | 1.1 | - | 2.6 | 27 |
| 3 | 31.8 | 18.6 | 4.3 | 2.2 | 8.4 | 0.4 | 0.1 | 2.1 | 0.6 | - | 1.5 | 30 |
| Average | 33.2 | 17.4 | 3.7 | 1.85 | 9.55 | 0.2 | 0.05 | 2.65 | 0.85 | - | 2.05 | 28.5 |
| Mohamed Rabah phosphorites 3 | 38.6 | 15.4 | 7.6 | 6.9 | - | - | - | 1.6 | - | - | 1.9 | 28 |
| 5 | 34.8 | 19 | 5.6 | 4.2 | - | - | - | 1.4 | - | 1.2 | 0.8 | 33 |
| 7 | 36.2 | 18.6 | 5.2 | 5.0 | 14.5 | - | 0.1 | 4.6 | 0.8 | - | - | 15 |
| 10 | 31.8 | 17.6 | 11.4 | 3.8 | 3.9 | 1.0 | 0.2 | 2.8 | - | - | 1.5 | 26 |
| Average | 35.35 | 17.65 | 7.45 | 5.0 | 4.6 | 0.25 | 0.05 | 2.6 | 0.2 | | 1.05 | 25.5 |
| Mahamid phosphorites 2 | 38.9 | 19.2 | 8.3 | 3.2 | 8.3 | - | 0.4 | 4.5 | - | - | 2.2 | 15 |
| 3 | 42.6 | 25.4 | 4.6 | 2.1 | 9.5 | 0.4 | 0.5 | 2.1 | - | - | - | 13 |
| 4 | 44.0 | 20.4 | 8.9 | 6.3 | 6.2 | 0.6 | 0.1 | 1.5 | - | - | - | 12 |
| 7 | 36.8 | 20.5 | 9.1 | 5.4 | 8.8 | 0.2 | 0.1 | 3.1 | - | - | - | 16 |
| Average | 40.58 | 21.37 | 7.7 | 4.25 | 8.2 | 0.3 | 0.22 | 2.8 | - | - | 0.55 | 14 |

However, the relationships between phosphates, calcareous and cementing material in the studied phosphatic particles and cementing material in the studied phosphorite samples are shown in Figure 3 which shows that the studied phosphorites in the three studied sections are composed mainly of ca-apatite and bone fragments cemented by calcareous and/or siliceous materials but extra components are rare. The interrelation was interpreted as described by Pettijhon et al. (1973).The phosphate particles involve lithoclasts, pellets, skeletals (e.g. fish

debris, bones, teeth, cellular bone fragments) and diagenetic grains (epigenetic phosphatized particles, phosphatic nodules (Plate I-A). Ca-apatite is the most dominant constituent in the phosphorite samples where they range between 31.8% and 44% (Table 1).

Most Ca-apatite is generally rounded nodules, sometimes elongated but others are packed irregular shape due to compaction. The nodules are predominantly simple, although the composite ones are observed, and they have different internal concentric textures and structures. Most of these nodules are homogenous and formed of fine, dark brown Ca-apatite; micro-fractures observed are probably related to contraction effect which normally occurred prior to their lithification.
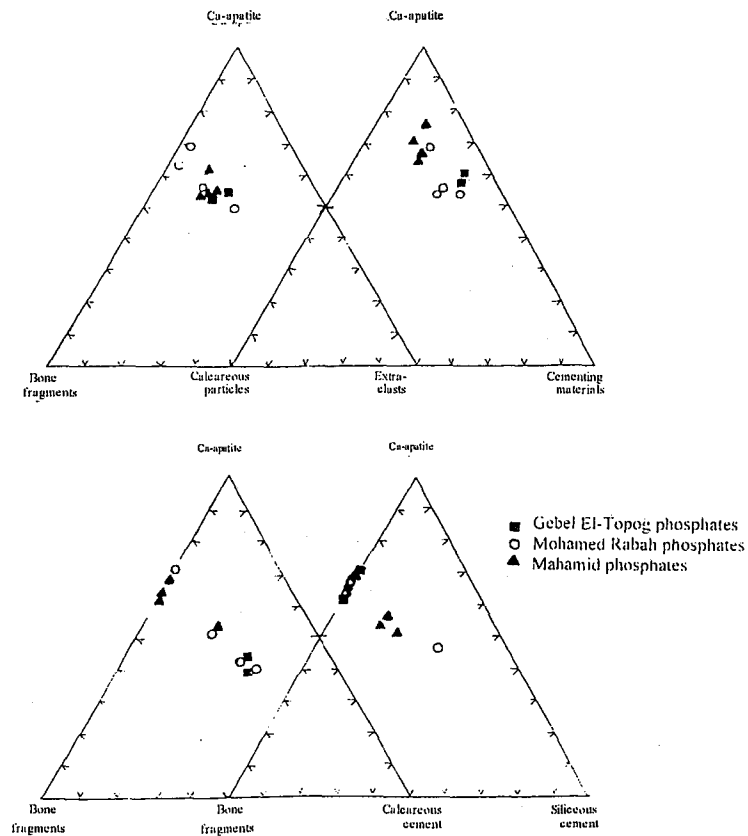


Figure 3: Ternary diagrams showing the relationship between phosphatic particles, calcareous particles, and cementing material in the studied phoesphorite samples using the technique proposed by Pettijhon et al. (1973).

Bone fragments present in all phosphorite samples (Table 1) have different types and forms. They are usually elongate in shape and commonly fractured and sometimes stained with Fe-oxides. Complete shark teeth are rarely recorded but most vertebrate bones are fragmented.This fragmentation is probably related to vigorous energy generated by strong waves or currents (Plate1-B). X-ray diffraction data (Fig.4) and Scanning Electron Microscope (Plate 1- C) and EDAX (Figs.5A and B) indicate that the apatite minerals are present in the form of carbonate apatite.

Clastic minerals such as quartz, feldspars (Table 1), iron oxides, and heavy minerals are also detected in the studied phosphorites. The variability of quartz mineral in the present samples depends on the degree of contribution from nearby terrain. It is generally ill-sorted and angular to subround and sometimes shows wavy extinction. Feldspars plagioclase (Table 1).

In addition to the above mentioned clastic minerals, glauconite granules are mainly observed in the Gebel El-Topog section (Bahariya phosphates) as small pellets in the groundmass and they are probably formed as a result of authigneic and/or diagenetic origin. The groundmass is represented by sand, Ca-apatite and argillaceous matrix. Diagenetic minerals including calcite, dolomite, glauconite as well as microcrystalline siliceous cement are particularly abundant in most phosphate samples while ferruginous, glauconitic, Ca-apatite groundmass is usually encountered in some phosphorite samples (plate 1- A). Petrographic investigation of the studied phosphorite samples revealed that there are several types of phosphorites including siliceous phosphorite, calcareous phosphorite and sandy phosphorite.

In the Ain Giffara Formation at Gebel El-Topog (Bahariya Oasis), the phosphorite samples are characterized by a very coarse-grained bone fragments, Ca-apatite nodules, coprolites and dolomite and glauconite minerals. They are also enriched in angular to sub angular quartz grains and other clastic minerals embedded in ferruginous, glauconitic Ca-apatite groundmass (Plate1- D). Because the environment in which phosphate grains form is apparently similar to that in which gluaconite forms (Weaver and Wampler, 1972), the phosphorites and glauconitic facies are often described to be found together in marine formation of various ages (Odin and Letolle, 1980).

At Mohamed Rabah Mine, near Safaga area, the phosphorites of the Duwi Formation includes several types: calcareous phosphorite, sandy phosphorites and siliceous phosphorites (Plate1- E and F and Plate 2-A). The calcareous phosphorites are characterised by ill-sorted, highly fractured bone fragments, ca-apatite pellets, calcareous skeletal intraclasts embedded in sparry calcite cement.
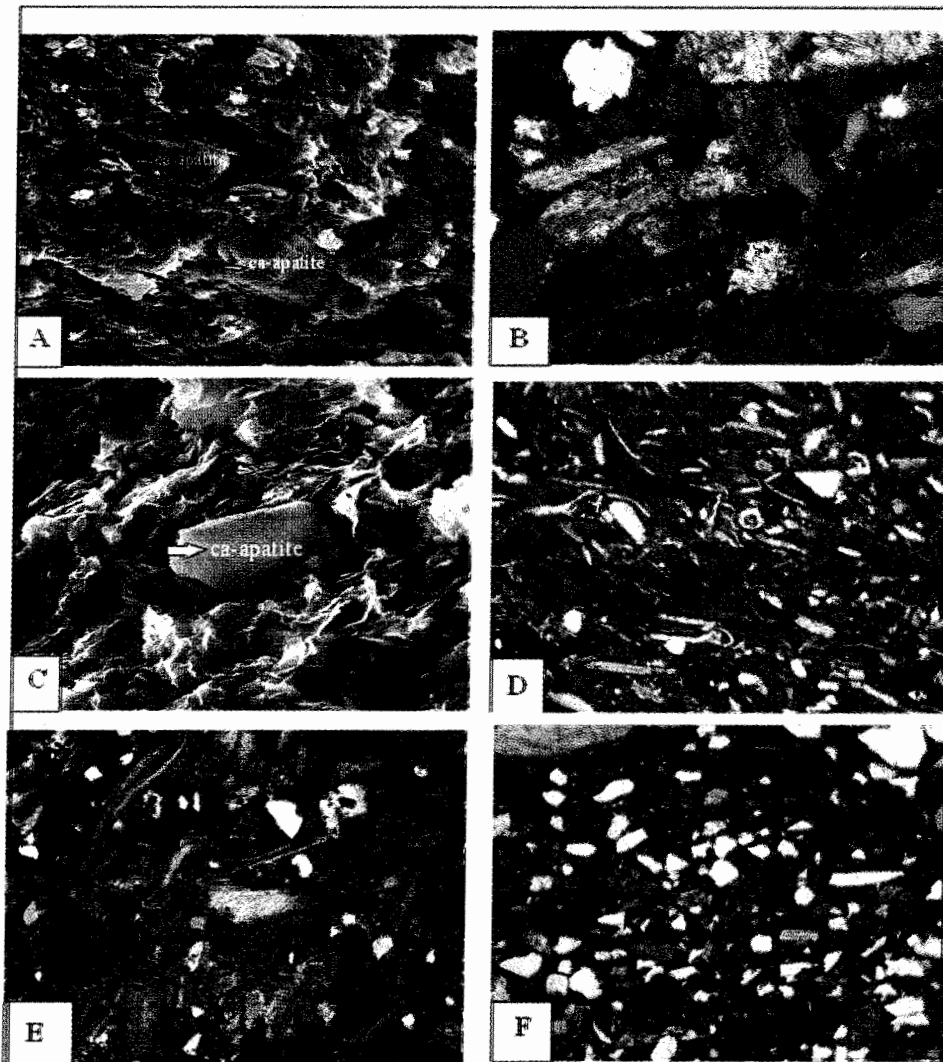
Plate 1. A SEM photomicrograph of phosphate nodules embedded in micrite and argillaceous intercalations. Mohamid.

B. Photomicrograph showing highly indurated grey with rounded to subrounded, fractured ca-apatite phosphorite nodules, bone fragments and quartz grains embedded in microcrystalline silica, Sample no.7, Mohamed Raboh., PPL., X50

C. SEM photomicrograph of apatite and argillaceous intercalations. Mohamid

D. Same sample no.7, showing elongated bone fragments, most particles and groundmass are replaced by secondary microcrystalline silica, Mohamed Raboh, PPL., X50

E. Photomicrograph showing coarse-grained phosphorite showing a very large, highly fractured bone fragment stained with iron oxide and dispersed in microsparry calcite cement. Sample no.5, Mohamed Raboh, PPL, X50.

of subangular quartz grains F. Photomicrograph showing sandy phosphorite showing abundance associated with ca-apatite of subangular quartz grains associated with ca-apatite
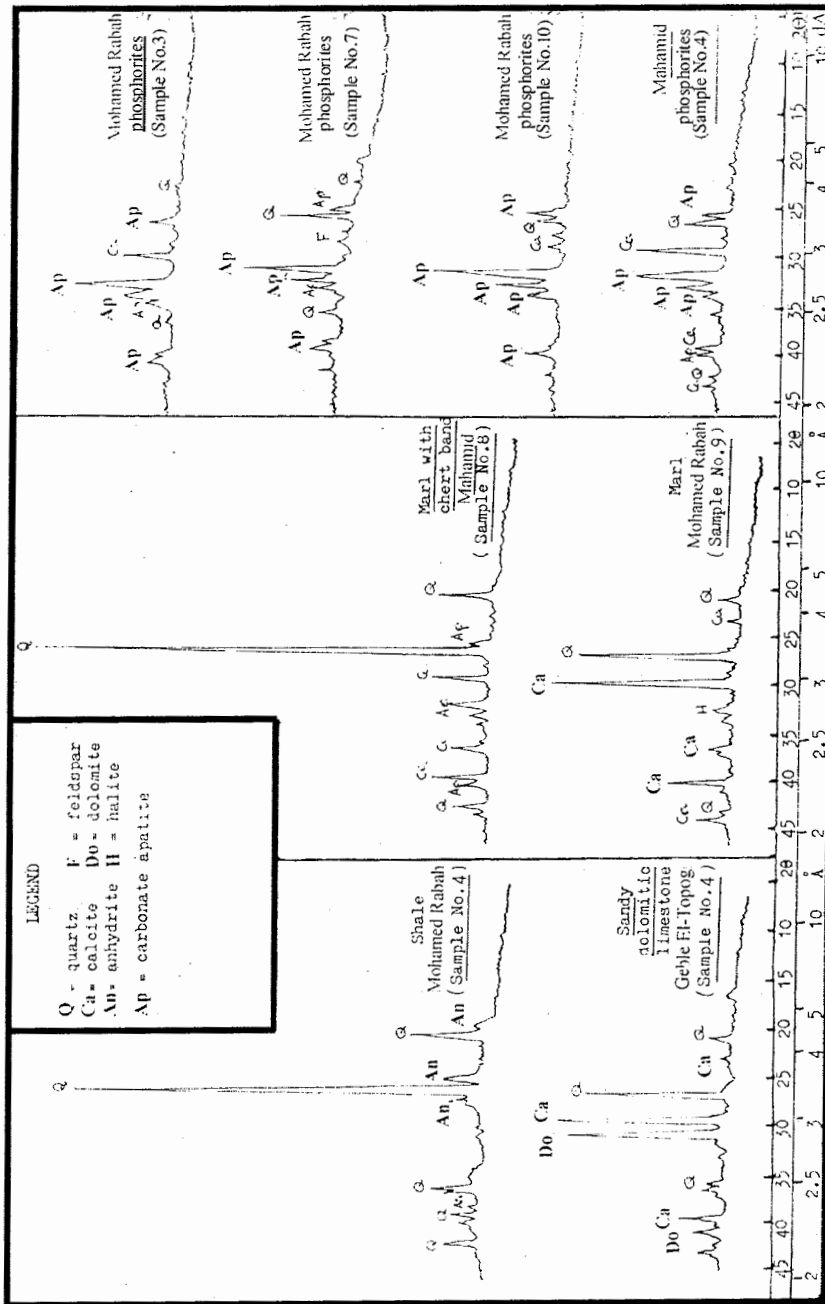: Sample no 3, Mohamed Raboh, PPL, X50. nodules and clay minerals

Figure 4. X-ray diffractograms of some selected phosphorite and non-phosphate samples.
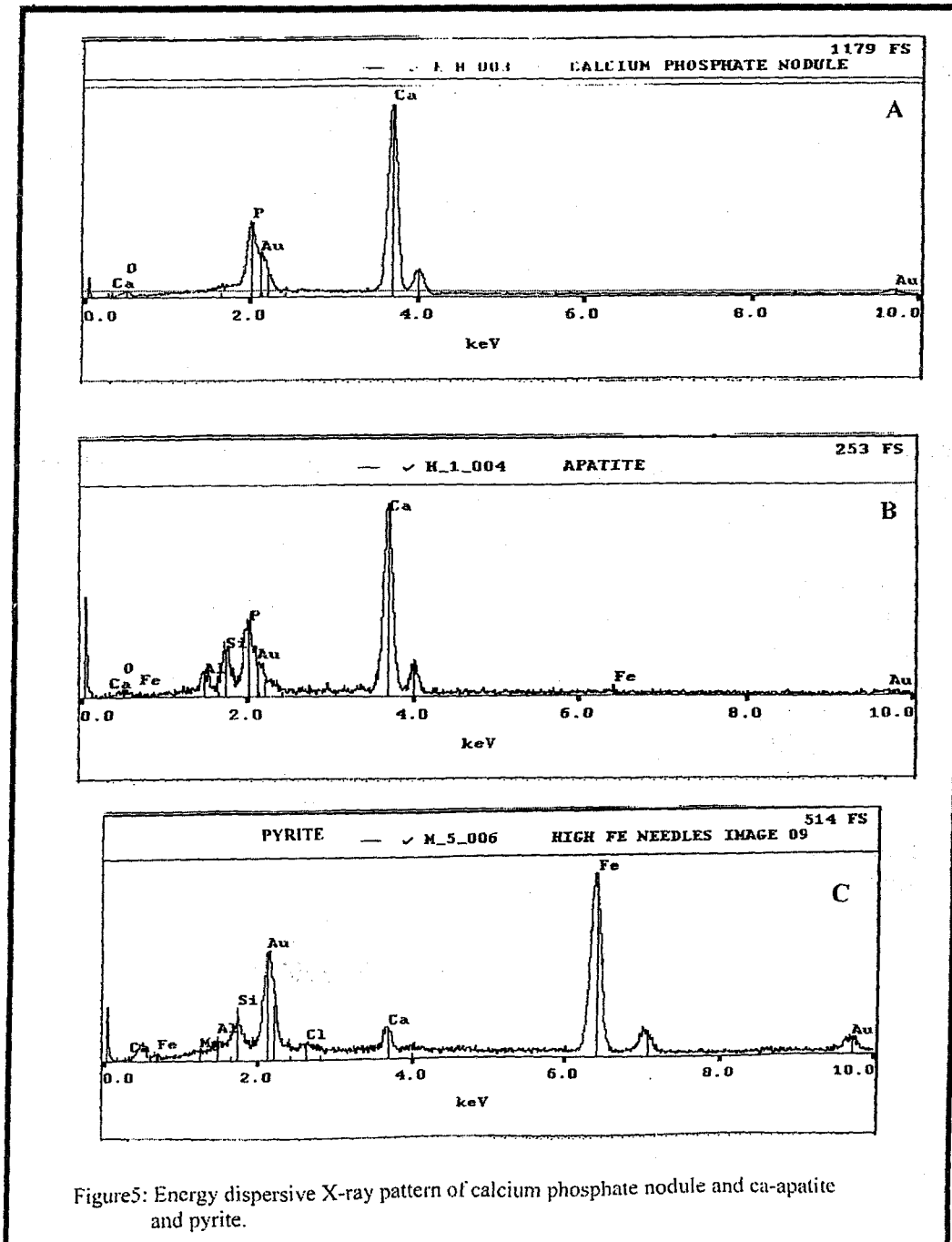
Figure5: Energy dispersive X-ray pattern of calcium phosphate nodule and ca-apatite
and pyrite.

Calcareous shells and shell fragments are mostly replaced by silica and pores are filled with gypsum. The sandy phosphorite (Plate1- F) is very rich in subangular to subrounded, fractured quartz grains, Ca-apatite nodules and a high content of Fe-oxides (Fig.5C). It is also characterized by highly fractured bone fragments, Ca-apatite groundmass and iron oxide filling fractures at later stages. The siliceous phosphorite type on the other hand, is characterized by partially replacement of calcareous particles by silicification process (plate 2 - A and B).

The phosphorites of Mahamid are characterised by ill-sorted grains composed of Ca-apatite, bone fragments, quartz, opaque minerals and chlorite (Plate 2 - B.). Some quartz grains are polycrystalline, others show a wavy extinction. Grains are cemented by fine-grained silica in the form of chalcedony. Most calcareous shells are totally replaced by fine to coarse-grained quartz grains (plate 3 - A).

### Non-Phosphate rocks:

The non-phosphate rocks are represented by shales, marls, mollusca limestone and dolomitic limestone as well as chert. The shales are of two types, light-grey calcareous shale and carbonaceous shale varieties. The former is laminated or even fissile and this lamination is mainly due to variation in grain size and/or mineralogical composition. It consists of alternations of silt-grade quartz, calcite, and anhydrite and clay-grade material. Naturally, the percentage of carbonates in these shales depends principally upon the amount of detrital supply and/or biological activities.

Microscopically, the clay minerals appear intimately mixed with quartz in a finelly dispersed manner (plate 3 - B). X-ray diffraction analysis shows that the clay mineral contained in the present shales are represented mainly by kaolinite and minor illite (Fig.6). Kaolinite was formed by alteration of feldspars, transformation of smectites and/or direct crystallization from acidic solutions (Abu Zeid et al., 2005) and as a product of weathering in humid zones (Tucker, 1981). Illite was developed through transformation of smectite by addition of $Mg^{+2}$ provided by partial dissolution of dolomite (Abu Zeid et al., 2005).
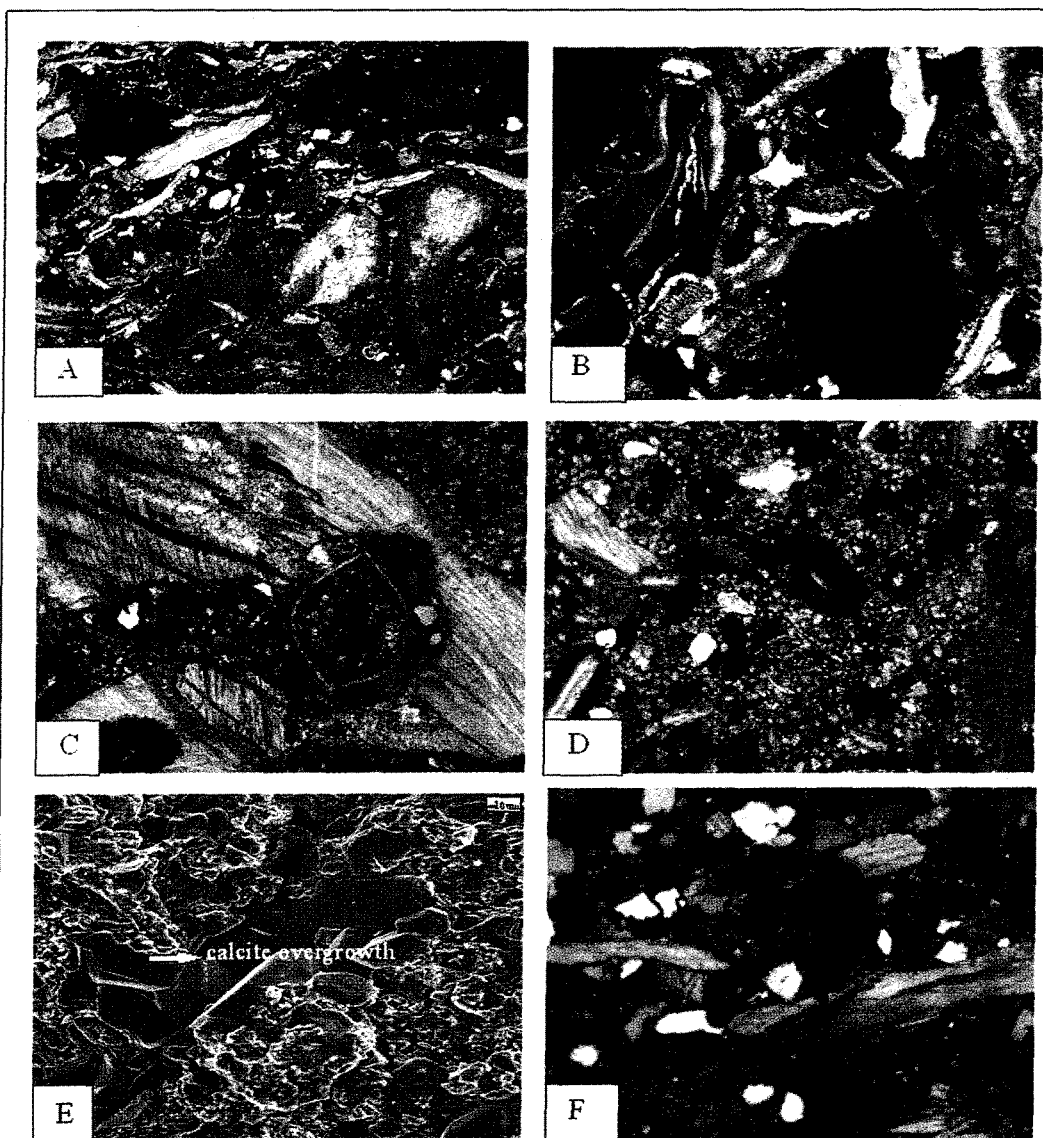
Plate2. A &B. Photomicrographs of siliceous phosphorite showing ill-sorted ca-apatite nodules, bonfragments, opaque minerals and polycrystalline quartz. Grains and groundmass are wholly replaced by secondary microcrystalline silica in the form of chalcedony; Sample no.4, Mohamed Rabah phosphorite, PPL, X50
C.Oyster packstone, characterized by abundance of large oyster shells and shell fragments sit inrfe silty, argillaceous, micritic lime groundmass; Sample no.9, Oyster bed, Mahamid, PPL, X0.
D. Dolomitized phosphorite showing ill-sorted bone fragments and apatite nodules embedded in dolotmi groundmass, Sample no.3a, Gebel El-Topog phosphate, PPL, X50.
E. SEM photomicrograp showing calcite pore filling in micrite, Sample no.3b, Gebel El-Topog phospha
F. photomicrograph of sandy phosphate, rich in subangular fine to medium-grained dispersed in mitrj ferruginous, glauconitic, collophane groundmass; Sample no.3, Gebel El-Topog phosphate, PPL. X50.

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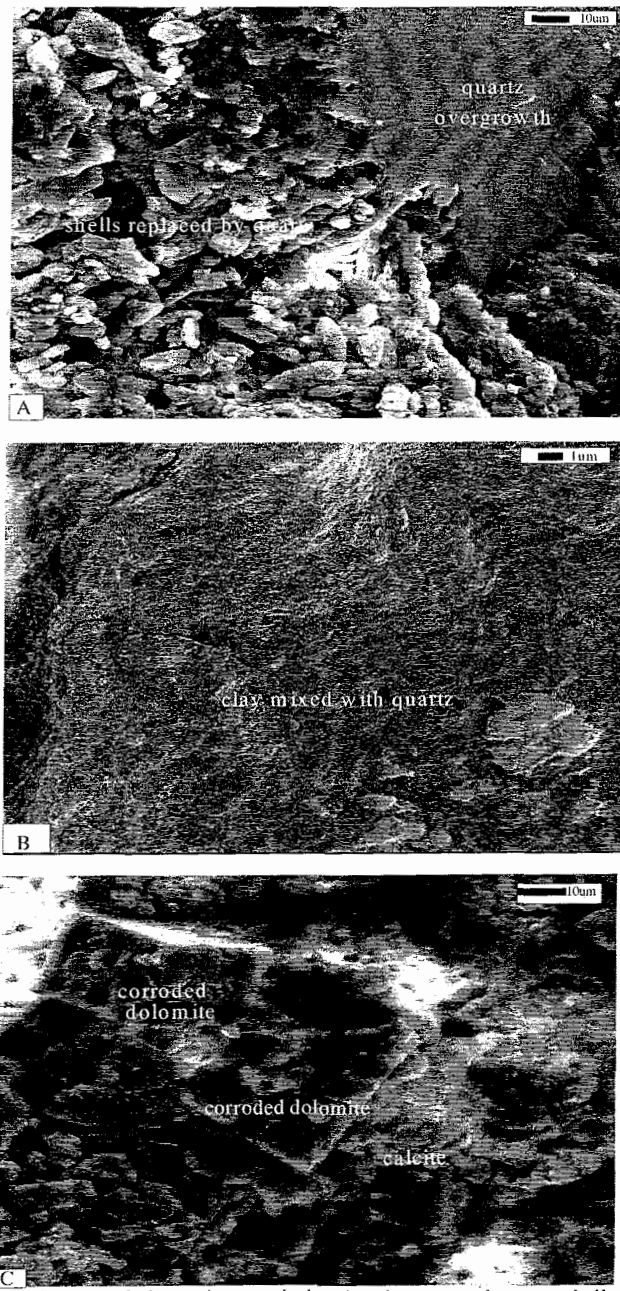Plate 3: A. SEM photomicrograph showing that most calcareous shells
are totally replaced by fine to coarse quartz grains. Mohamed Rabah section
B. SEM photomicrograph showing that the clay minerals appear intimately
mixed with quartz in a finely dispersed manner. Mahamid section.
C.SEM photomicrograph showing dolomite rhombs exhibit sharp edges.
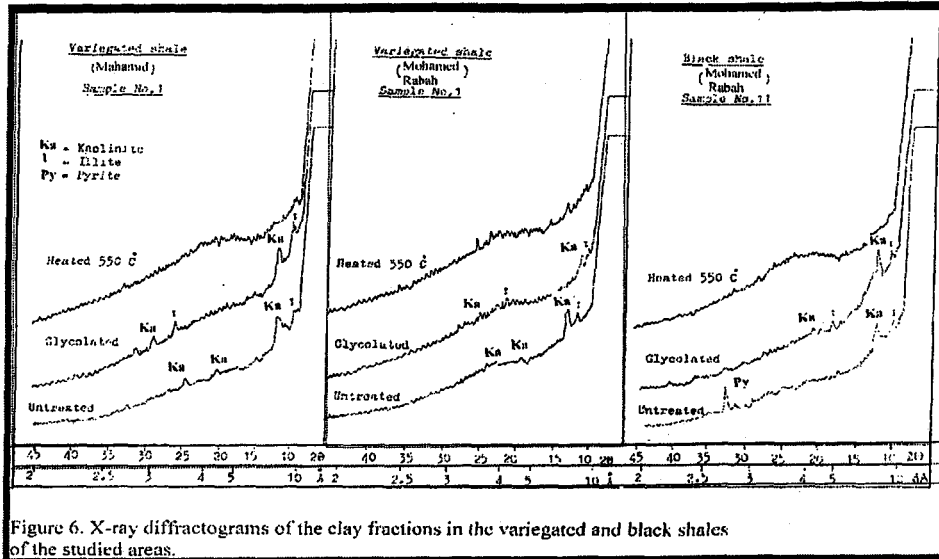dissolution fabrics associated with calcite. Gebel El- Topog section.

Figure 6. X-ray diffractograms of the clay fractions in the variegated and black shales of the studied areas.

The limestones of the present study are represented by oyster beds and sandy dolomitic limestones. The former is a mollusca packstone (Plate 2- C) rich with calcitic pelecypod allochems and embedded in a fine-grained ferruginous micrite with silty detrital sub-angular quartz grains. The dolomitic limestone is fine-grained mosaic with microsparry calcite resulting from recrystallization (Plate 2 - D). SEM examination reveals that carbonate cement is present mainly as calcite which may exhibit different stages of recrystallization. In some samples, sparry calcite has grown out in large crystals to replace most of regional micritic matrix (Plate2 - E). Dolomite is commonly encountered as cementing material especially in the studied samples in the top of the Ain Giffara Formation. It occasionally occurs as well-developed rhombohedral crystals which frequently display distinct cleavage. The mineral displays a zonal texture. Dolomite is characterized by fine to coarse crystalline nature (plate 2 - C) exhibits sharp edges. Dissolution fabrics are distinguished surrounding the dolomite rhombs (Plate 3 - C).It has grey brown or red colour, which is probably due to impregnation by iron oxides or coated by organic matter. The dolomite cement in the Upper horizon of the Ain Giffara Formation is mainly controlled more or less with sea level fluctuations and the prevailing near circulation system (cf. Rifai and Shaaban, 2007 in Western Desert).

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## GEOCHEMICAL INVESTIGATIONS

The results of the chemical analyses of the studied samples (5 rock samples from Gebel El-Topog section, 13 rock samples from Mohamed Rabah section and 10 samples from Mahamid section) are given in Table 2. The interrelation between the different constituents of the studied samples is given in Figure (7) and the vertical distribution of the major, minor and trace constituents is in Figure (8), the elemental major analyses (Table 2) reflected the composition of the dominant mineral ca-apatite (Figs 5A and B).Whereas, the specific composition of apatite is obscured in some samples by the presence of other components principally quartz and calcite (plate 1-B and D). The composition of apatite in sedimentary phosphatic rocks can be adequately described by their six components ($P_2O_5$, CaO, $CO_2$, $Na_2O$, MgO and F) (Lehr et al., 1967 and McClellan and Lehr, 1969).

### $P_2O_5$, CaO, F and L.O.I. (Loss on ignition)

The interrelation between $P_2O_5$ and CaO (Fig. 7A) reflected a direct relation with some anomalies. The interrelation between $P_2O_5$ and F (Fig.7B) reflects no distinct relation. Strontium shows a strong direct relation with $P_2O_5$ (Fig. 7C) which suggests that at least part from it were formed inside the apatite lattice (Rooney and Kerr, 1967). Strontium was persisted in samples where no free carbonates were detected especially in samples of Mohamed Rabah and Mahamid sections (see Figure 3). The relationship between L.O.I and fluorine (Fig.7D) shows an axial intercept, which mostly represents unsubstituted fluorine ions in apatite ions structure as well as a proportion that might be associated with organic matter.

So, from the above mentioned relations, $P_2O_5$ was affected with CaO and strontium.

### $P_2O_5$ and organic Carbon.

Organic carbon (Table 2) shows a direct relation with $P_2O_5$ (Fig.7E), implying the possible genetic relationship between the two components.

### MgO and $Na_2O$

The relative high MgO content especially in the upper part of Gebel El-Topog section (Table 2) may be referred to the presence of Mg-carbonate (Rooney and Kerr, 1967)) or authigenic phase (Burnelt, 1974). The relative high sodium oxide content in some samples may be attributed to detrital contributions or halite (Table 2). This indicates that the upper part of Gebel El-Topog was affected by diagenetic processes.

Table 2:Major, minor and trace elements in the studied areas.

| Locality / Sample No. | | SiO₂ | Ti⁺ | Al₂O₃ | Fe₂O₃ | MgO | CaO | K₂O | Na₂O | MnO | P₂O₅ | F⁺ | SO₃ | Org.C | H₂O⁺ | H₂O⁻ | L.O.I | Total | I.R | Sr⁺⁺ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Geble El-Topog | 1 | 44.12 | 0.01 | 10.26 | 3.22 | 0.63 | 18.22 | 1.15 | 2.14 | 0.71 | 1.15 | N.D | 2.12 | N.D | N.D | 1.60 | 14.23 | 99.61 | 46.82 | 0.05 |
| | 2 | 29.50 | 0.04 | 2.85 | 3.25 | 0.88 | 22.25 | 0.08 | 0.18 | 0.53 | 15.60 | 0.96 | 1.38 | 3.20 | 1.60 | 0.29 | 17.35 | 92.53 | 30.22 | 0.08 |
| | 3 | 26.16 | 0.05 | 2.13 | 2.12 | 1.16 | 24.12 | 0.18 | 0.36 | 0.62 | 16.18 | 1.12 | 2.18 | 2.15 | 1.09 | 0.25 | 18.12 | 99.94 | 29.15 | 0.06 |
| | 4 | 28.55 | 0.002 | 1.86 | 2.26 | 8.05 | 23.12 | 0.36 | 0.63 | 0.01 | 1.36 | N.D | 1.09 | 0.29 | N.D | 0.48 | 30.16 | 99.36 | 31.50 | 0.04 |
| | 5 | 30.92 | 0.006 | 2.19 | 3.11 | 9.36 | 22.18 | 0.26 | 0.02 | 0.02 | 1.12 | N.D | 0.46 | 0.36 | N.D | 0.36 | 28.25 | 99.51 | 32.15 | 0.05 |
| Mohamed Rabah | 1 | 31.95 | 0.04 | 20.56 | 0.82 | 0.28 | 24.30 | 0.19 | 0.75 | 0.06 | 1.15 | N.D | 2.05 | 1.36 | N.D | 2.18 | 13.21 | 98.74 | 32.23 | 0.05 |
| | 2 | 33.98 | 0.003 | 9.18 | 0.63 | 0.34 | 28.12 | 1.96 | 0.62 | 0.08 | 12.25 | 1.79 | 0.39 | N.D | 1.73 | 0.39 | 8.39 | 99.21 | 36.23 | 0.09 |
| | 3 | 16.56 | 0.04 | 4.12 | 0.18 | 2.29 | 36.51 | 0.13 | 0.51 | 0.11 | 23.87 | 1.60 | 3.90 | 0.21 | 1.60 | 0.35 | 9.06 | 100.83 | 19.25 | 0.21 |
| | 4 | 32.80 | 0.008 | 10.12 | 0.16 | 0.26 | 29.16 | 1.87 | 0.34 | 0.07 | 2.54 | N.D | 0.16 | N.D | N.D | 0.82 | 22.05 | 100.28 | 33.16 | 0.07 |
| | 5 | N.D | 0.03 | 3.12 | 0.32 | 2.25 | 47.25 | 0.14 | 0.58 | 0.03 | 25.98 | 1.12 | 2.92 | 0.33 | 1.12 | 0.25 | 13.11 | 100.65 | 1.95 | 0.27 |
| | 6 | 39.99 | 0.04 | 12.15 | 0.09 | 0.29 | 32.55 | 0.05 | 1.18 | 0.01 | 2.24 | N.D | 2.80 | N.D | N.D | 0.63 | 8.11 | 100.07 | 41.73 | 0.07 |
| | 7 | N.D | 0.15 | 2.85 | 0.19 | 3.18 | 44.24 | 0.16 | 0.58 | 0.08 | 27.58 | 0.04 | 4.68 | 0.18 | 0.94 | 0.31 | 11.39 | 100.05 | 0.27 | 0.19 |
| | 8 | 86.85 | 0.04 | N.D | 0.06 | 0.16 | 4.24 | 0.38 | 0.23 | 0.04 | N.D | N.D | 3.15 | N.D | N.D | 0.05 | 1.12 | 99.26 | 91.13 | 0.02 |
| | 9 | 29.16 | 0.05 | 12.55 | 0.13 | 0.39 | 41.90 | 0.11 | 0.56 | 0.07 | 3.55 | N.D | 0.86 | N.D | N.D | 0.82 | 9.22 | 98.49 | 30.52 | 0.25 |
| | 10 | N.D | 0.06 | 3.82 | 0.38 | 3.42 | 42.18 | 0.08 | 0.35 | 0.03 | 28.24 | 0.53 | 3.88 | 0.19 | 0.53 | 0.52 | 15.27 | 100.82 | 0.53 | 0.28 |
| | 11 | 38.85 | 0.003 | 9.25 | 0.36 | 0.28 | 27.24 | 0.04 | 2.85 | 0.07 | 0.21 | N.D | 0.19 | N.D | N.D | 0.35 | 20.25 | 99.67 | 41.20 | 0.04 |
| | 12 | N.D | 0.04 | 2.13 | 0.24 | 1.32 | 43.61 | 0.06 | 0.46 | 0.04 | 27.13 | 0.34 | 6.05 | 0.26 | 0.34 | 0.49 | 17.64 | 100.64 | 1.14 | 0.25 |
| | 13 | 10.22 | 0.05 | 14.18 | 0.34 | 0.28 | 36.60 | 0.09 | 0.03 | 0.01 | 4.98 | N.D | 0.92 | N.D | N.D | 0.62 | 27.28 | 98.33 | 11.45 | 0.16 |
| Mahamid | 1 | 39.62 | 0.009 | 18.30 | 1.62 | 12.69 | 20.60 | 1.18 | 0.25 | 0.11 | 2.19 | N.D | 0.89 | 3.12 | N.D | 3.45 | 5.12 | 96.59 | 40.03 | 0.08 |
| | 2 | 18.15 | 0.04 | 2.44 | 0.49 | 3.22 | 35.20 | 0.64 | 0.15 | 0.08 | 20.42 | 0.36 | 3.22 | N.D | 0.36 | 0.12 | 14.72 | 100.37 | 23.95 | 0.19 |
| | 3 | 6.25 | 0.04 | 1.95 | 1.16 | 2.04 | 39.38 | 0.45 | 0.38 | 0.06 | 25.04 | 0.65 | 5.12 | 1.28 | 0.65 | 1.35 | 13.29 | 99.39 | 7.15 | 0.24 |
| | 4 | 12.15 | 0.05 | 1.28 | 2.12 | 1.58 | 40.46 | 0.92 | 0.39 | 0.07 | 24.66 | 0.98 | 4.12 | 1.11 | 0.98 | 0.89 | 3.12 | 99.98 | 13.82 | 0.27 |
| | 5 | 40.55 | 0.004 | 10.58 | 1.83 | 1.58 | 20.66 | 0.82 | 1.22 | 0.03 | 2.13 | N.D | 1.11 | N.D | N.D | 1.18 | 17.46 | 99.12 | 43.16 | 0.04 |
| | 6 | 43.62 | 0.005 | 8.25 | 0.68 | 1.12 | 29.44 | 0.63 | 0.95 | 0.04 | 1.96 | N.D | 0.98 | N.D | N.D | 1.05 | 19.83 | 100.19 | 45.83 | 0.07 |
| | 7 | 4.12 | 0.04 | 1.50 | 1.13 | 0.098 | 43.99 | 0.82 | 0.18 | 0.08 | 27.13 | N.D | 3.20 | 2.04 | N.D | 0.89 | 10.66 | 100.15 | 6.62 | 0.30 |
| | 8 | 76.25 | 0.006 | N.D | 0.36 | 0.29 | 6.15 | 0.28 | 0.28 | 0.13 | 0.36 | N.D | 2.12 | N.D | N.D | 0.08 | 7.45 | 99.62 | 82.15 | 0.04 |
| | 9 | 7.50 | 0.006 | 2.16 | 2.16 | 1.16 | 45.58 | 0.18 | 0.28 | 0.05 | 3.16 | N.D | 4.11 | N.D | N.D | 0.34 | 31.76 | 98.41 | 8.12 | 0.25 |
| | 10 | 34.15 | 0.03 | 17.22 | 2.29 | 1.05 | 20.19 | 1.35 | 0.95 | 0.04 | 2.36 | N.D | 4.12 | N.D | N.D | 1.39 | 14.19 | 99.19 | 36.22 | 0.04 |

All data calculated as %
I.R: Acid insoluble residue.
L.O.I.: Loss on ignition.
N.D: Not detected.

## SO₃, Fe₂O₃ and MnO

The data obtained from the analyses (Table 2 and Fig.7F) shows a direct relation between sulphur and phosphorous, this may be attributed partly to sulphate incorporated within the apatite structure (Powell et al., 1975). The petrographical examinations (Table 1) confirmed the occurrence of gypsum and anhydrite (Fig.4). This is in agreement with the works done by Rooney and Kerr (1967); Stow (1969) and Powell et al. (1975).

The iron in the present studied samples is referred to pyrite phase which has been supported by petrographical examination (Table 1 and Fig.5C). In addition to an appreciable amount of iron may be referred to glauconite (plate 1- B) or possibly the presence of clay minerals. Manganese is enriched in samples relative to sea water (Tooms et al. 1969), MnO appear to be related with $P_2O_5$ (Fig.8) which reflects its preferential uptake by apatite lattice (McClellan, 1980). So, sulphur may be present in association within apatite structure.

## Al₂O₃-SiO₂, K₂O

A strong relation was occurred between $Al_2O_3$ and $K_2O$ (Fig.8) signifying the presence of an extraneous silicate phase, $K_2O$ and $SiO_2$ in association with $Fe_2O_3$ and MgO signifying the presence of glauconite (Table1).

A large amount of silicon may present as free quartz (Plate 2 - D) or possibly as feldspar and clay minerals as detected by X-ray diffraction patterns (Figs 4 and 6).

So, from the data obtained (Table 2) , the vertical distribution of the elemental chemical composition (Fig.8), in addition to field observations, lithology and petrography in the present studied three sections, the investigated sediments can generally be classified into three main categories, shales, phosphorite and carbonate assemblages, affected by diagenetic processes.
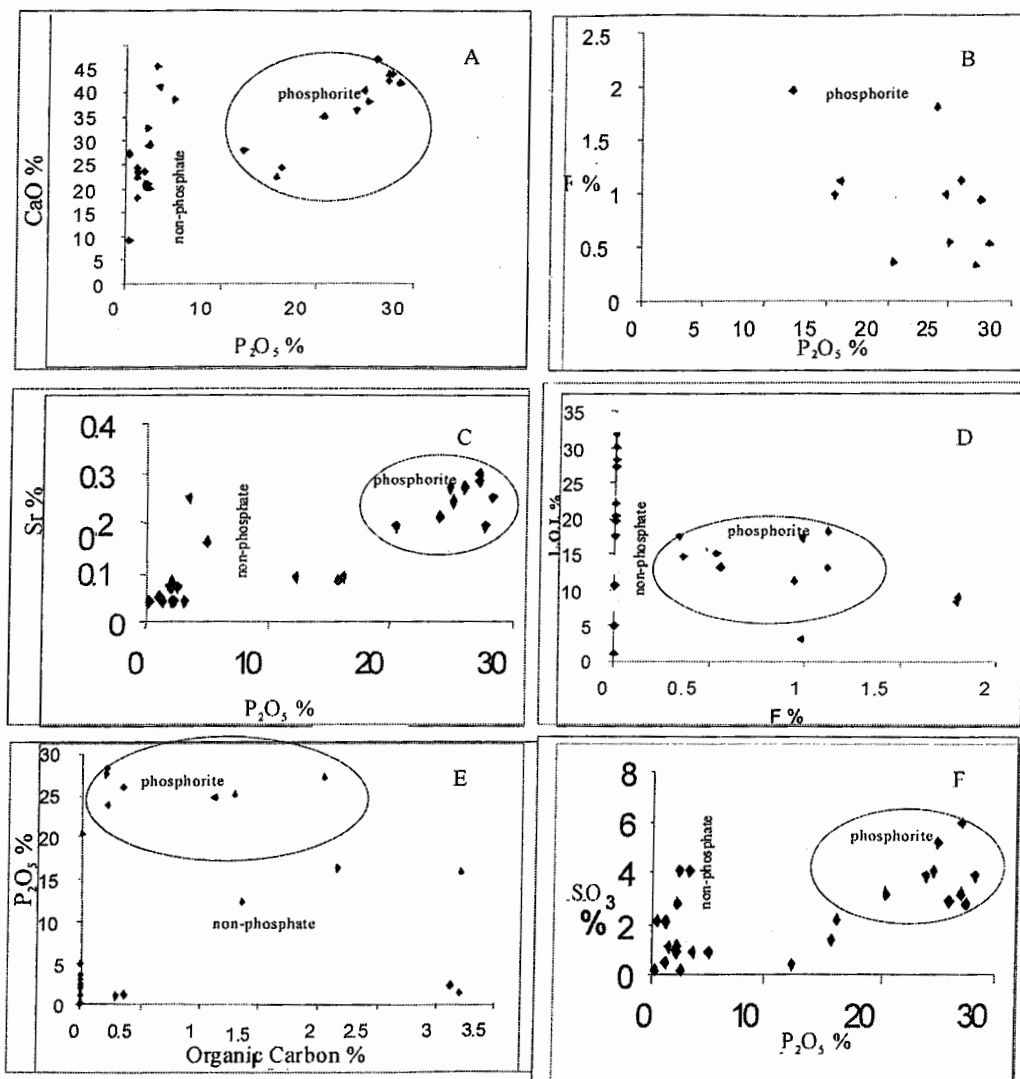
**Figure 7. Inter relations between the different constituents in the studied samples.**

A. CaO % vs. $P_2O_5$ %.    B. F % vs. $P_2O_5$ %.
C. Sr % vs. $P_2O_5$ %.    D. L.O.I. % vs F %.
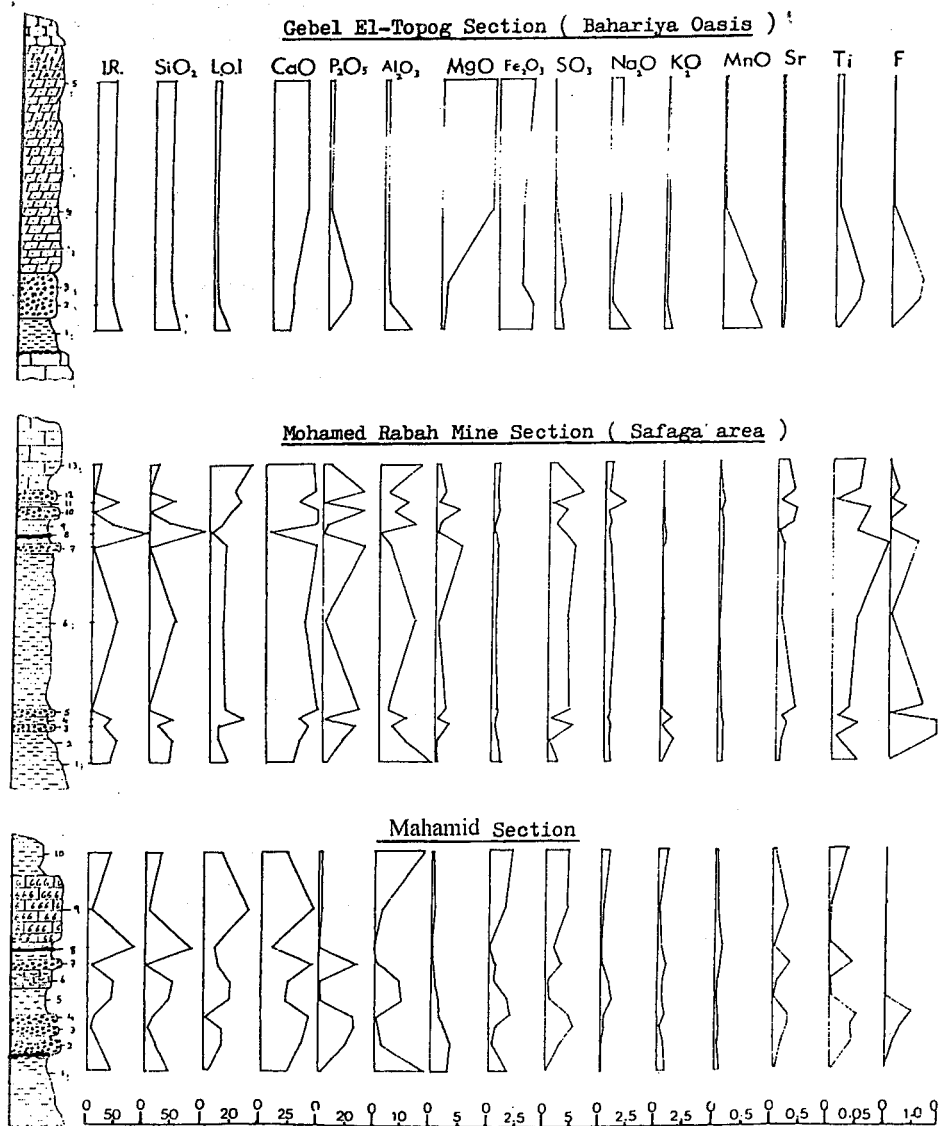E. $P_2O_5$ % vs Organic carbon %.    F. $SO_3$ % vs. $P_2O_5$ %.

Figure 8. Vertical distribution of the various constituents in the studied sections.

# DIAGENETIC PROCESSES

The petrographical and scanning electron microscope examination of the investigated rocks shows that they were subjected to a number of diagenetic processes. The main processes are gluconitization, silicification replacement in addition to dolomitization.

## Glauconitization:

Glauconite usually occurs as rounded to subrounded grains in the phosphate beds and intercalated shales of the three studied sections. It is most probably formed with coprolites which were formed by various sediment feeders.

Some collophane grains associated with glauconite grains are pitted and cracked. The cracks are devoid of any filling material and are generally narrow and filled with cementing materials. The cracks are replaced and filled with micrite and/or microsparite forming poikilotopic texture, (plate 2 - E). This type of cracks may refer to the effect of load of overlying sediments or to former fractures of these sediments that formed after consolidation of the rocks and before introduction of the epigenetic veinlets. Both phosphatic and glauconitic facies are often described to be found together in marine formations of various ages (Odin and Letolle, 1980). This is because the environment in which phosphate grains had been formed is apparently similar to that of glauconite environment (Weaver and Wampler 1972). The presence of glauconite in the studied samples probably reflects euxinic conditions favored by high organic matter (Hendriks, 1985).

## Silicification:

Silica exists mostly as replacement product in the form of chalcedonic silica that partly replaces to some extent the bone fragment, groundmass, some ca-apatite pellets and fossil intraclasts. Besides, sometimes random, irregular siliceous bodies (nodules) of microcrystalline quartz and also clear quartz crystals are found. (plate 2 - F).The presence of microcrystalline quartz with dolomite inclusions (plate 2 - D) in the studied samples of Gebel El-Topog section may argue for a possible interruption for the dolomitization process by a silicification event. It is assumed that the main source of the silica is the siliceous organic remains and clays of the lower shale beds in the studied section.

## Dolomitization:

Dolomitization process is dominated in the investigated samples of Gebel El-Topog section and rare in both Mohamed Rabah and Mahamid sections. The dolomite rhombs of Gebel El-Topog section have clear rhombs with sharp edges

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of 10-80 mm in diameter having dissolution fabrics surrounding the dolomite crystals (plate 3- D) and are considered as diagenetic dolomite but in both Mohamed Rabah and Mahamid sections dolomite is present as early (syngenetic) documented by microcrystalline crystals of dolomite and evaporate. The syngenetic dolomite is represented by the replacement of calcium carbonate by $Mg^{+2}$ ions either by capillary concentration or refluxion processes pen-contemporaneous with the deposition of carbonates (Friedman and Sanders, 1978).

## CONCLUSIONS

The Upper Cretaceous phosphate-bearing sediments, generally referred to as the Duwi or Phosphate Formation in Egypt, were investigated in terms of their petrographical and geochemical characteristics. The study is carried out on alternating phosphate and non-phosphate beds at three localities namely Gebel El-Topog at the Bahariya Oasis, Mohamed Rabah mine near Safaga and Mahamid, about 140 km from Aswan.

From the above mentioned discussions, the following conclusions are reached. The phosphates of Gebel El-Topog section are deficient in $P_2O_5$ compared to the other mentioned localities. They are characterized by the presence of large bone fragments, dolomite intraclasts and glauconitic minerals, in addition to enrich in an-angular, coarse-grained quartz and other clastic minerals.

In Mohamed Rabah section, the phosphorite includes several types: calcareous phophorite, sandy phosphorite and siliceous phosphorite and grey fine-grained phosphorite. The phosphorites at Mahamid are characterized by ill-sorted phosphatic and non-phosphatic grains cemented mainly by microcrystalline silica in the form of chalcedony. Most calcareous shells are totally replaced by fine to coarse-grained silica.

The diagenetic processes such as glauconitization, silicification and dolomitization played a major part in the present lithologies. Glauconitization is an early diagenetic origin developed under weakly reducing environment. Similarly, the presence of carbonaceous matter in the black shales at Mohamed Rabah section reflects the prevalence of euxinic conditions during deposition. Silica was also replaced to some extent the bone fragment, groundmass, some Ca-apatite pellets and fossil intraclasts. Dolomite is considered as diagenetic in Gebel El-Topog section but in both Mohamed Rabah and Mahamid sections dolomite is presented as early (syngenetic) documented by microcrystalline crystals of dolomite and evaporate.

From the vertical distribution of the elemental chemical composition in addition to petrography, lithology and field observations in the present studied sections; the investigated sediments can generally be classified into three main categories, shales, phosphorite and carbonate assemblages which were deposited in alternating littoral and shallow marine environments and affected by diagenetic processes.

The bedded nature of the phosphorites, supported by their occurrence with shales, marls and limestones and the presence of quartz, glauconite, fossils and shell fragments and oyster beds. The presence of the dolomite cement in the sediments of the Late horizon of the Ain Giffara Formation (Gebel El-Topog section) is controlled more or less with sea level fluctuations and the prevailing near circulation system (near shore currents).

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# بتروجرافية وجيوكيميائية لبعض الرواسب الحاملة للفوسفات فى مصر

## نادية محمد السعيد عبد المجيد

قسم الجيولوجيا - كلية العلوم - جامعة المنوفية - مصر

يتناول هذا البحث دراسة بتروجرافية وجيوكيميائية لبعض رواسب العصر الطباشيرى العلوى (متكون الضوى) الحاوى للفوسفات فى مصر. لهذا الغرض أختيرت ثلاثة أماكن هى جبل الطويج بالواحات البحرية و منجم محمد رباح بمنطقة سفاجا وكذلك منطقة محاميد .

ومن خلال الدراسات المعملية والمشاهدات الحقلية للتكوين الحاوى للفوسفات بهذه المناطق أمكن التعرف على بيئة ترسيب هذه الصخور حيث يعتقد أنها تكونت فى بيئة بحرية تراوحت فى عمقها ما بين الرصيف القارى والبيئة الساحلية الضحله .

وقد تميزت رواسب فوسفات الواحات البحرية بافتقارها الى عنصر الفوسفور اذا ما قورنت برواسب الفوسفات للمنطقتين الأخرتين , كما تميزت بوجود كسرات كبيره من عظام الفقاريات وفتات الدولوميت ومعادن الجلوكونيت , كما تتميز كذلك بغناها بحبيبات الكوارتز و غيرها من المعادن الفتاتيه الأخرى.

أمكن التعرف على عدة أنواع من رواسب الفوسفات بمنطقة سفاجا , منها الفوسفات الغنية بمعدن الكوارتز الفتاتى. وتتميز حبيبات رواسب الفوسفات بمنجم المحاميد الى الغرب من أسوان بأنها رديئة الفرز كما أن معظمها قد حدث له احلال ثانوى بالسليكا و تلتحم هذه الحبيبات عادة بالسليكا دقيقة التحبب فى صورة الكالسيدونى .

أوضحت الدراسه أن عمليات ما بعد الترسيب مثل عمليات الدلمته ومراحل تكوين الكالسيت و السليكا اضافة لتكوين الجلوكونيت كان لها أثر واضح على هذه الرواسب . كما يعتقد أن عملية تكوين الجلوكونيت بدأت فى المراحل المتقدمة لعمليات ما بعد الترسيب تحت ظروف مختزله قليلا. تلتها عمليات السليكا والتى أدت الى احلال السليكا لكسرات العظام و فتات الحفريات وحبيبات الأباتيت تحت ظروف بحرية . ثم تلى ذلك عمليات تطور الكالسيت والدلمته.

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