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## **GEOCHEMISTRY OF THE PHOSPHATE DEPOSITS AT EL-RASHDA, EL-MAWHOOB AREA, DAKHLA OASIS, WESTERN DESERT, EGYPT**

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### **Abstract**

This work comprises an attempt carried out to throw light on the geochemical evaluation of the phosphorite deposits at El-Rashda, El-Mawhoob area, Dakhla oasis, Western Desert, Egypt. The work is based on the field and laboratory work. Fifty stratigraphic sections, 19 borholes representing the study area, where studied, measured, sampled and studied.

The laboratory work comprises 69 samples for determining the physical properties, 11 samples for XRD analyses, 27 thin sections and 133 samples for chemical analyses using XRF method to detect the major oxides, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO, MgO, Na<sub>2</sub>O, SO<sub>3</sub>, Cl, P<sub>2</sub>O<sub>5</sub>, F, L.O.I. as well as trace the elements, Ba, Sr, Cu, Pb, Zn, Mn, Ni, Co, Ti, V, Y, Ce.

According to the results of, chemical characteristics it can be concluded that the phosphorite deposits in the study area are suitable for fertilization used in the agriculture sector. As well as used in animal feed supplements, food preservation, anticorrosion agents, cosmetics, fungicides, ceramics, water treatment and metallurgy, very important in steel production, in the making of phosphor bronze, the thermal phosphorus used in the treatment of many surface minerals as, Aluminium, Copper, Iron.

### **Introduction**

The study area is located at the northern tip of Mute City, Dakhla Oasis, Egypt. It lies between

Latitudes; 25° 30' 00" – 25° 45' 00" N Longitude; 28° 30' 00" – 29° 00' 00" E (Fig. 1). Covering about 303.8 km<sup>2</sup>, where the phosphorite deposits cover an area about 265.5 km<sup>2</sup>. It is easily reached through high way of Kharga-Dakhla and Farafra Town.

The present work deals with the preliminary qualitative, quantitative evaluation of the phosphorite deposits from a geochemical point of view.

### **Geologic Setting**

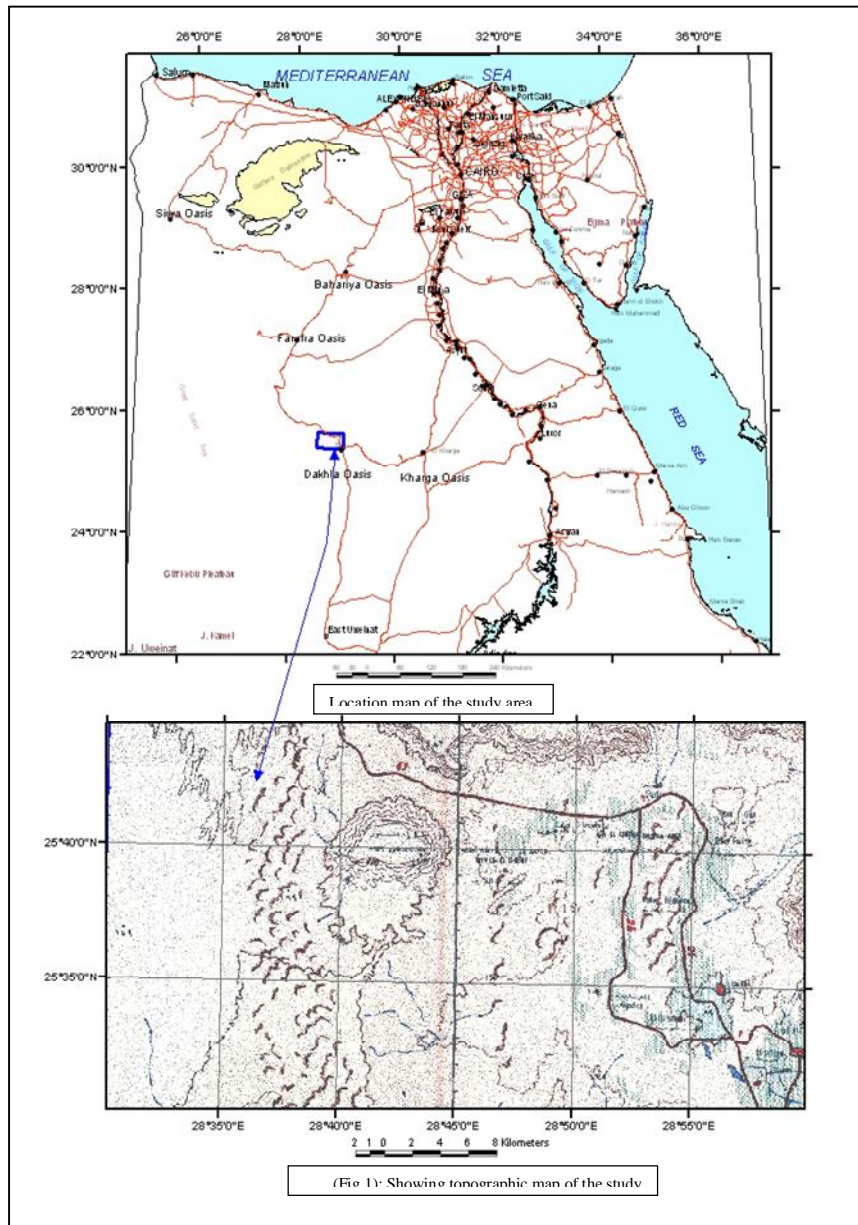
The sedimentary sequence ranges in age from Campanian to Upper Paleocene. The lithostratigraphic investigation allowed subdividing this succession into four rock units from oldest to youngest as follows, Qusseir Formation, Duwi Formation, Dakhla Shale, Tarawan Chalk as shown in geologic map (Fig. 2). The Duwi Formation overlies uncomfortably the upper part of Qusseir Formation with sharp facies change between them (El-Bakry et al, 2005).

The Duwi Formation consists of pale yellow to yellowish brown, medium to coarse grains, moderately hard with bone fragments and shark teeth, the phosphorite beds are intercalated with gypsumiferous claystone, alternated with shale beds. This Formation is distributed in many features such as hills, minor plateaus separated by wadis and low lands, generally dipping NE-NW.

### **Duwi Formation;**

The Duwi Formation was first used to describe the term Phosphate Formation at its type section, Gebel Duwi by Youssef (1949). The lower limit of this formation is

marked by the base of the lower most phosphate bed which rests conformably on the Qussier Formation and the upper limit of the formation is the top of the upper most phosphate bed in the succession. Later, Ghorab (1956), recognized it as a formation and named it the Duwi Formation. The base of this Formation is marked and limited by distinguishable bed named the Neara bed at the Dakhla Oases, (Hermina et al,



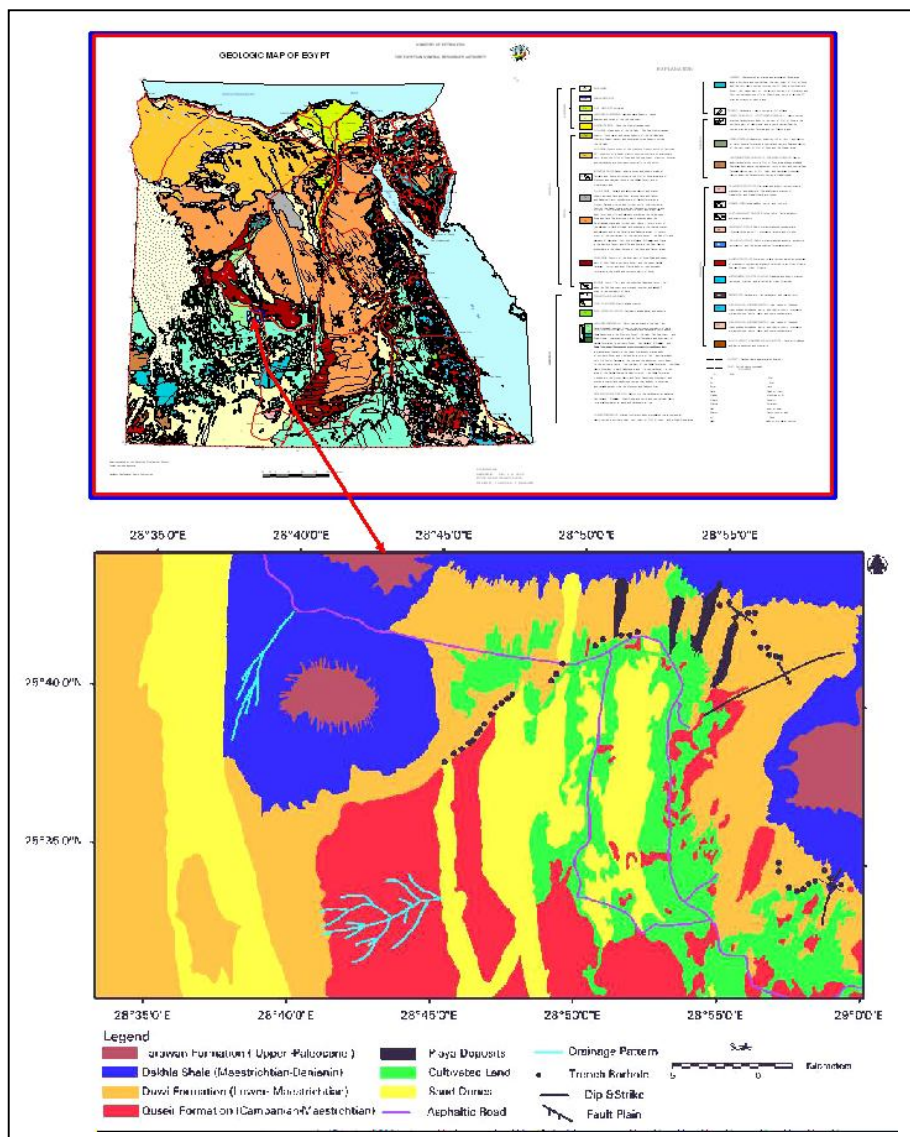
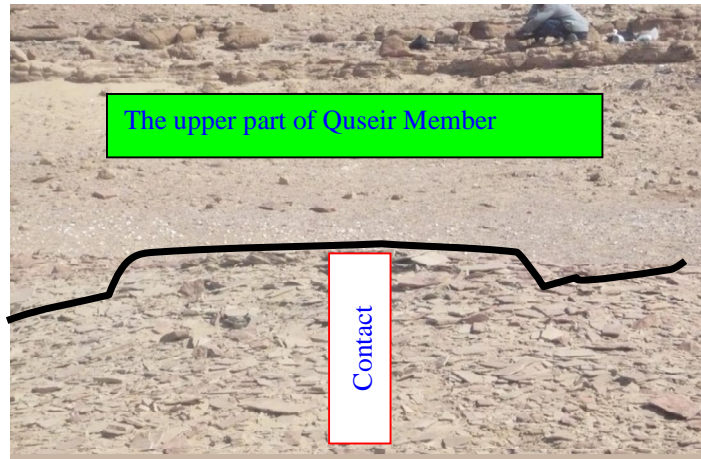


Fig. 2. Geological map of the studied area.



1961). The Neara bed is hard to moderately hard pale, fossiliferous, mudstone. yellow to yellowish brown, Awad and Ghobrial (1965), described the Phosphate Formation from above the Varigated Shale Formation of their Nubia group while its bottom contact is marked by unfossiliferous phosphate bed, in Dakhla and Kharga Oases.



**Fig.3: Photograph showing the contact between the Qusseir Formation and the Duwi Formation at El- Rashda area. .**

El-Bakry (2005), recorded that the upper part of Qussier Formation at the west of Dakhla Oases is unconformable of Duwi Formation, demonstrated by sharp facies changes between the coastal to swampy, unfossiliferous facies of the Quseir Formation, and the fossiliferous, marine facies of the Duwi Formation. The author supports and agrees with El-Bakry view, where the contact between the upper part of Qussier Formation and the lower part of the Duwi Formation showing at (Fig.3).

The Duwi Formation is composed mainly of phosphorite beds alternated with shale beds (fig.4), where the number of phosphorite beds ranges from two to four but dominantly are two beds.



**Fig.4: Photograph showing excavated trench in the Duwi Formation at El- Rashda area.**

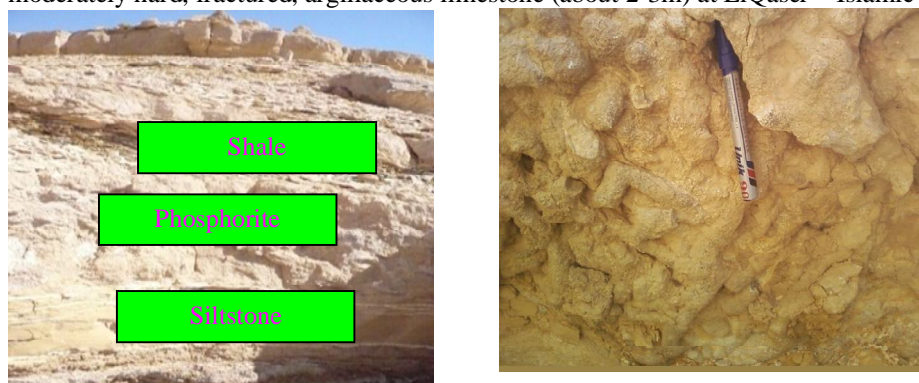
**Fig.5: Photograph showing the granular and coarse grained phosphorite at El-Qaser area.**

most of the phosphate beds in the study area are pale yellow to yellowish brown in colour, medium to coarse grained, moderately hard with bone fragments and shark teeth (fig.5), varies in thickness with an average from 0.25m to 2.10m. The phosphorite beds intercalation with gypsiferous claystone at the study area (fig.6), also the phosphorite beds based by bioturbation activity (fig.7). The thickness of phosphate beds observed are well developed in, El Dohose, El Rashda, and El Qaser Villages.

Also at the Eastern side of El Mzawaka and Dir El Hajar temple, the phosphate beds are well represented and occupying for stratigraphic positions (fig.8). In the Western side of the area the phosphate, bearing formation becomes hide.

The shale beds varies in colour from, greenish grey, yellow to yellowish white, black to blackish grey and comparatively Low to moderately hard .

The formation bearing phosphate is capped by pale yellow to yellowish brown, moderately hard, fractured, argillaceous limestone (about 2-3m) at ElQaser – Islamic



**Fig.6: Photograph showing the phosphorite beds intercalated with shale and based by siltstone at El- Rashda area.**

**Fig.7: Photograph showing the bioturbation activity at the base of phosphorite beds.**

Villages, this bed overlies red to brown mudstone changed west wards towards El Mzawaka and El Mawhoob villages, to very hard dolomite the cape of Duwi Formation.

The detailed field study allows classifying the Duwi Formation into four large sedimentary cycles according to facies changes shown upward as the follow;

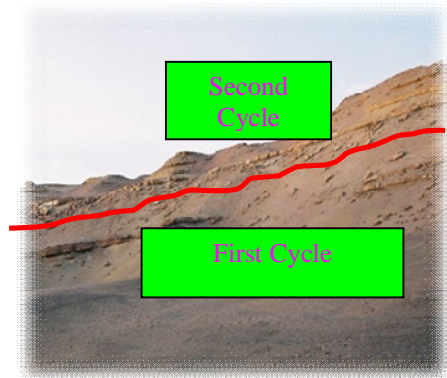
**-The first cycle:** Represents the lower part of the Duwi Formation it overlies the Qusseir Formation with a sharp contact. Lithologically; this cycle consists of shale, black, blackish grey, to greenish grey, moderately compacted intercalated with claystone, yellow to yellowish brown, silty clay, yellow to pale yellow , low to moderately hard, gypsiferous, occasionally interbedded with bands of phosphatic clay, yellow to yellowish brown and underlies the mudstone, yellowish brown, hard to moderately hard, fossiliferous, "**Neara bed**", and topped by yellowish brown, pale brown to blackish grey, moderately hard, bone fragments, phosphate.

The type section of first cycle is well developed at El-Rashda, El-Dohose, and El Qaser Villages.

**-The second cycle;** composed mainly of claystone, silty clay, brown to pale yellow, moderately hard, laterally changed at Mawhoob village into shale, greenish grey to black, fissile, with pockets of limonitic oxides, phosphatic at the base and topped by pale brown to yellow, moderately hard, shark teeth, phosphate (fig.9).



**Fig.8:Photograph showing the development of the phosphorite thickness bed at El-Rashda area**



**Fig.9: Photograph showing the first, and the second cycles .**

**-The third cycle;** contains of a thick bed of shale, grey to yellowish brown, gypsyferous, moderately hard , varieties laterally into claystone , yellow, moderately hard at western side of El-Mawhoob Village, topped by dark brown to yellowish brown, moderately hard, phosphate.

**-The fourth cycle;** consisted of shale, grey to greenish grey, fissile and claystone, yellow to light yellow, gypsyferous, concoidal fracture, representing in most of the study area, absent of the phosphate beds.

#### **Geochemistry;**

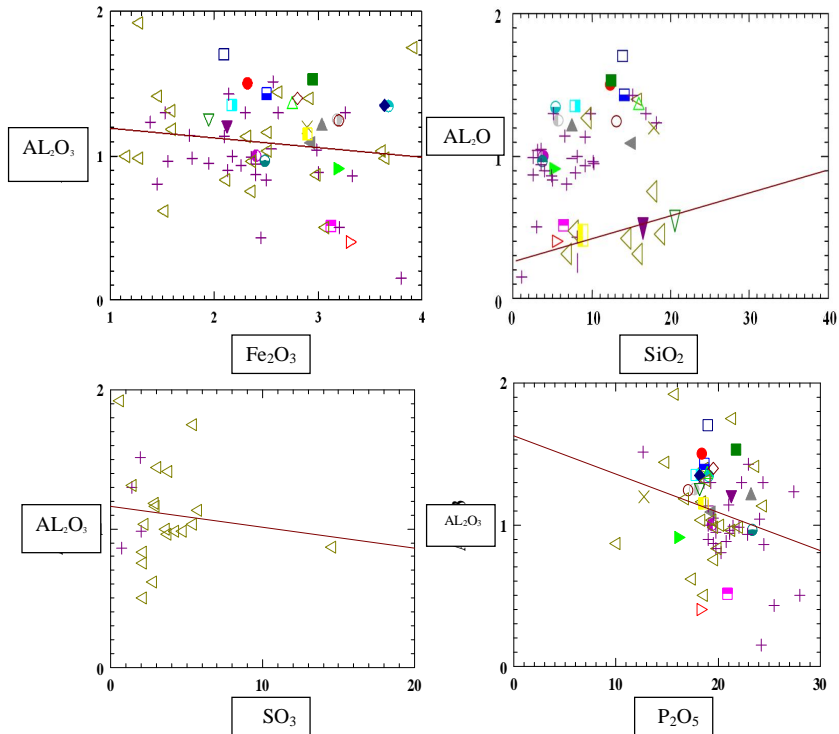
In order to study the chemical composition and geochemical evaluation of the El-Rashda, El-Mawhoob phosphorite, 133 samples representing the main phosphorite beds of this area are selected for this study; 122 samples are analyzed for major elements,they were chosen from 69 trenches and boreholes. Eleven samples were chosen from 4 trenches and analyzed for trace elements.

**Chemical Characteristics and geochemical evaluation of the major elements :  
Aluminium :**

Aluminium is an essential constituent of the clay minerals. It is the principal element in gibbsite and is associated with potassium in muscovite mixed-layer clay minerals.

The Aluminium content in the studied samples ranges from 0.15 to 1.92% with an average of about 1.09%, (table.5).

According to Kolodny (1981) table 6, the average value of aluminium content is lowest than that reported by Kolodny values, this may be attributed to the little abundance of clays in the matrix of these deposits, and according to El Hazeq, et al (1980), who considered the correlation value below 0.35 as low, from 0.35 to 0.49 as moderate, from 0.5 to 0.74 as strong ,and above 0.74 as very strong, the correlation coefficient (r) data of the analyzed major, trace elements, then the aluminum has a low positive correlation with SiO<sub>2</sub>, which may be explained by that SiO<sub>2</sub> is strongly attached with Al<sub>2</sub>O<sub>3</sub> as clay minerals that present in the matrix of the whole rock, and aluminum is low negative correlation with P<sub>2</sub>O<sub>5</sub>, Fe<sub>2</sub>O<sub>3</sub>, SO<sub>3</sub>, that may attributed that it is located outside the apatite latic, or the differentiation in environment deposition of these elements (Fig.10).



**Fig10: Correlation coefficient relationship of Al<sub>2</sub>O<sub>3</sub> and SO<sub>3</sub>, P<sub>2</sub>O<sub>5</sub>, Fe<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>.**



**Phosphorus:**

Phosphorus content in the studied samples ranges from 9.85 to 28% with an average of about 19.91%. The average value of phosphorus content is lower than that reported by Kolodny (1981), this may be attributed to the high value of impurities as,  $\text{Fe}_2\text{O}_3$ ,  $\text{SO}_3$ ,  $\text{MgO}$ , in the phosphorite deposits. The negative correlation  $\text{P}_2\text{O}_5$  may be attributed to substitution of  $(\text{PO}_4)$  by  $\text{CaO}$ ,  $\text{CO}_3$ ,  $\text{Al}$ ,  $\text{Si}$ . The phosphorus has low negative correlation with,  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ , which may be attributed to the occurrence of these elements outside of lattice of a patite, or resulted from the substitution of  $\text{Si}^{4+}$ ,  $\text{Al}^{3+}$ , by  $\text{P}^{5+}$  (McConnell 1938), the low negative correlation with  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ , moderately negative correlation with  $\text{SO}_3$ , low positive correlation with  $\text{F}$  may be attributed to the presence of free carbonate in bulk sample or the different precipitation between  $\text{P}_2\text{O}_5$ ,  $\text{F}$  and  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{SO}_3$ , where the phosphorus and fluorine precipitated at the same pH 7-7.8 .

The author reported the lowest value of  $\text{P}_2\text{O}_5$ , and the highest value of  $\text{Al}_2\text{O}_3$ , at El-Mawhoob area, while the highest value of  $\text{P}_2\text{O}_5$ , and the lowest value of  $\text{Al}_2\text{O}_3$ , at El-Mzawaka area, which supports the above interpretation (Fig.11).

**Calcium Oxide:**

Calcium oxide content in the studied samples ranges from 27.89 to 43.76% with an average of about 37.69%.

The average value of calcium oxide content is lower than that of Kolodny , this may be attributed to the presence of a negative correlation between it and  $\text{MgO}$  where the later is higher than that of Kolodny value at the studied area. The calcium oxide has low negative correlation with  $\text{P}_2\text{O}_5$ , moderately negative correlation with  $\text{F}$ , which may be attributed to the substitution of  $\text{Ca}^{2+}$  by  $\text{P}^{5+}$  (McConnell 1980) or due to the different precipitation between  $\text{P}_2\text{O}_5$ ,  $\text{F}$  and  $\text{CaO}$ , moderately negative correlation with  $\text{SiO}_2$ , that may be attributed to the deposition of silica, together with phosphates at the pH from 7 to 7.8. at this pH, the conditions are not favorable for the deposition of  $\text{CaO}_3$ , when it tends to be dissolved till the pH increases and reaches its field of stability, low positive correlation with  $\text{SO}_3$ ,  $\text{Fe}_2\text{O}_3$ , that may be attributed to the similarity of pH value deposition for  $\text{CaO}$ ,  $\text{SO}_3$ ,  $\text{Fe}_2\text{O}_3$ , low positive correlation with  $\text{Al}_2\text{O}_3$ , that may be indicated to the presence of  $\text{Al}_2\text{O}_3$  outside the lattice of apatite at the studied are (Fig.12).

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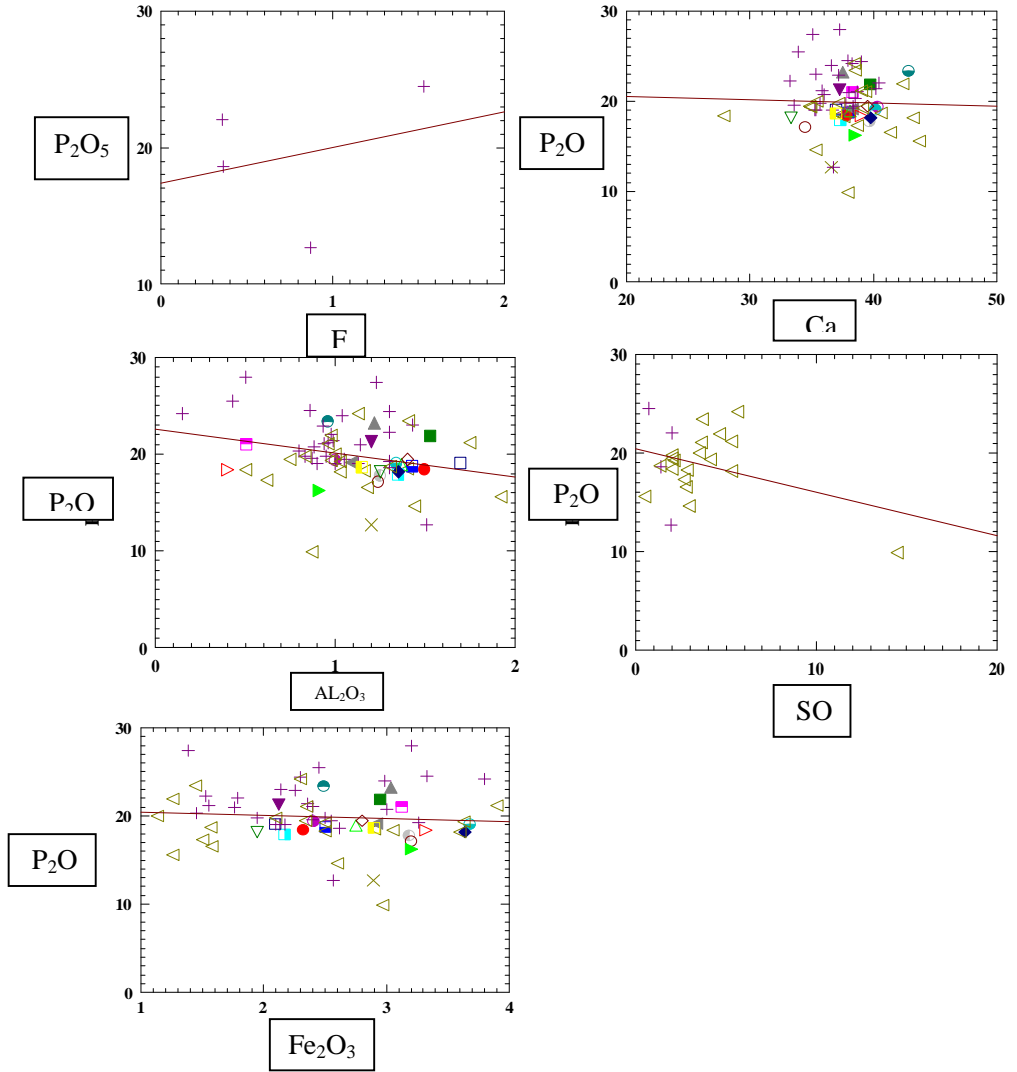
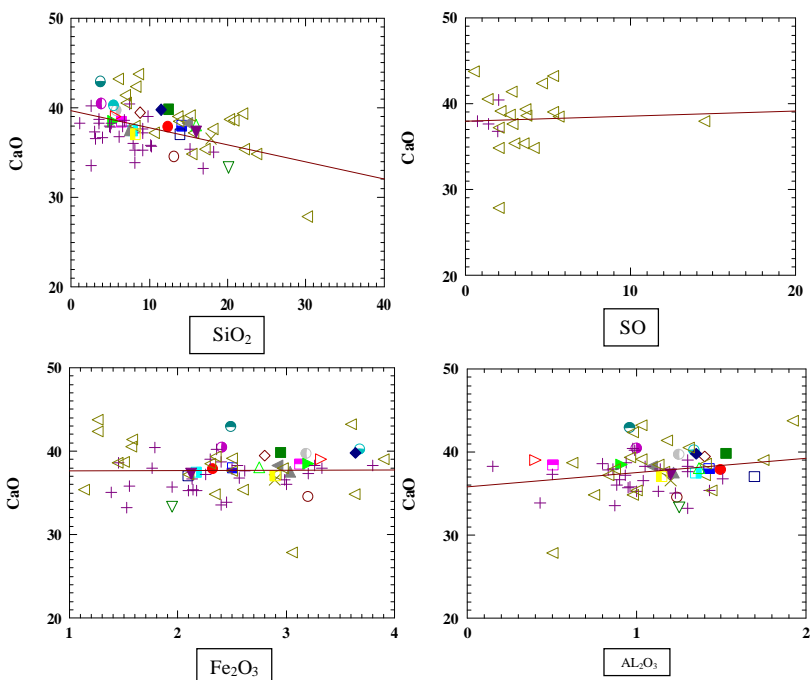


Fig.11 ; Correlation coefficient relationship of  $P_2O_5$  and  $Fe_2O_3$ ,  $Al_2O_3$ ,  $SO_3$ ,  $CaO$ , **F**.



**Fig.12: Correlation coefficient relationship of CaO and  $P_2O_5$ ,  $Fe_2O_3$ ,  $Al_2O_3$ ,  $SO_3$ ,  $SiO_2$ , F.**

### Fluorine:

Fluorine content in the studied samples ranges from 0.36 to 1.53% with an average of about 0.78%.

The average value of Fluorine content is lower than that reported by Kolodny, this may be attributed to the substitution of  $F^{1-}$  by  $CO_3^{2-}$ ,  $Cl^{1-}$ , (McConnell 1980), where the environment of the studied area is characterized with a highly carbonate deposit, that is supported by

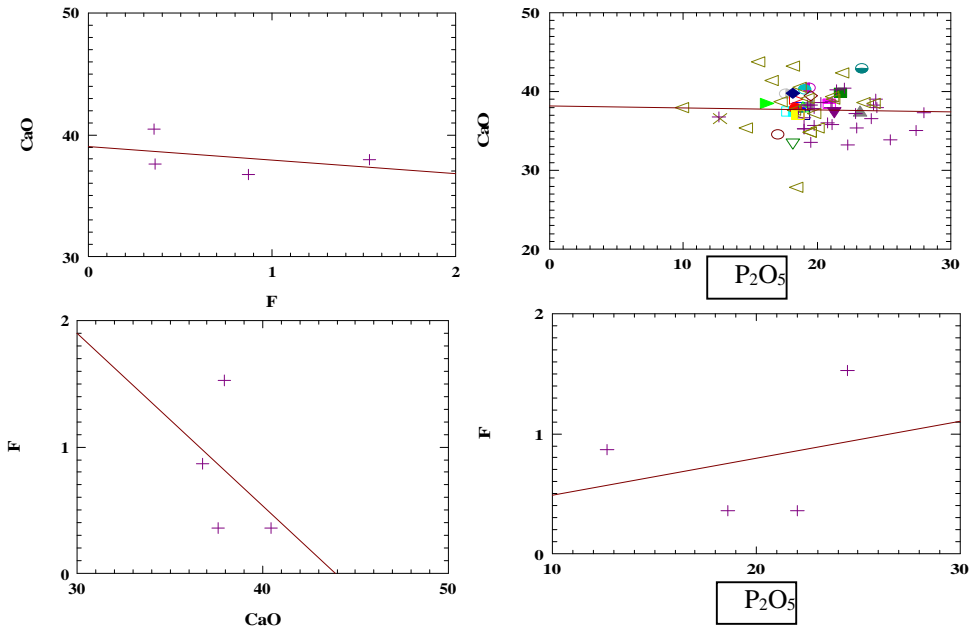
XRdiffraction, where Ankerite mineral recorded at El-Rashda area as major constituent, the lowest value of Fluorine reported at El-Rashda. The Fluorine has a low negative correlation with  $SiO_2$ , which may be attributed to the highly free amount of Silica in the bulk sample or the substitution of  $P^{4+}$  by  $Si^{4+}$  (McConnell 1980). Also Fluorine has a moderately negative correlation with  $Al_2O_3$ , which may be attributed to the substitution of  $P^{4+}$  by  $Al^{3+}$ . The very strong positive correlation with  $Fe_2O_3$  may be attributed to the similarity of sources of iron between the pellets and the other iron phases in the rock, or the area is a good evidence of the above interpretation. possibility of its presence in the Clay components of pellets. The low positive correlation with  $P_2O_5$ , where the highest values of F and  $P_2O_5$  are recorded at El-Mzawaka area, shown a moderately negative correlation with CaO, and a strong negative correlation with  $SO_3$ , which may be an indicative to the substitution of  $PO_4$  by  $SO_4$  (Mc Connell.1973) or may be attributed to the fact that fluorine and

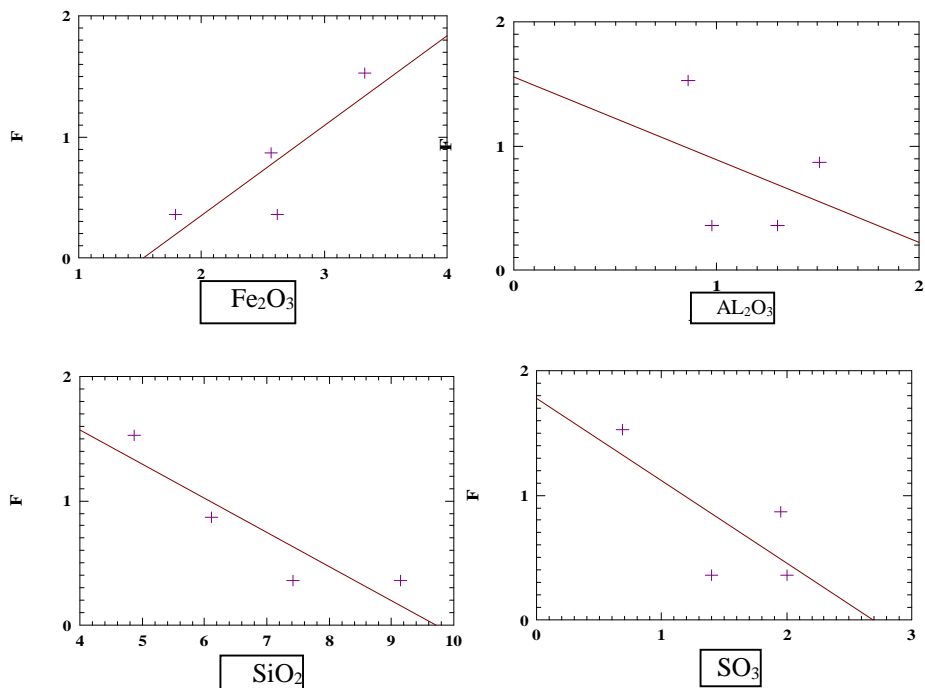
the phosphorus deposited at pH-value lower than that of deposits of the carbonate and evaporites, ( Krumbein and Garrels 1952) considered phosphates could be formed with a relatively low pH{7-7.8}, but the precipitation from normal sea waters{PH  $\geq$  7.8 } saturated with CaCO<sub>3</sub> and apatite would develop a sediment with a very small amount of phosphorite. (Degens 1965), also concluded that one of the essential conditions required for the carbonate apatite is pH higher than 7, that supported the similarity of carbonate and evaporites at the environment deposition (Fig.13).

**Magnesium Oxide: (MgO)**

MgO content in the studied samples ranges from 0.85 to 9.18% with an average of about 3.65%. The average value of magnesium oxide content is higher than Kolodny values that may be attributed to the derivation of (MgO) from dolomite by the oxidation processes, where dolomite is of a secondary origin detected by petrographic studies or that resulted from the negative relationship of MgO, CaO where Ca<sup>2+</sup> substitute by Mg<sup>2+</sup> (McConnell 1980).

The highest magnesium content in the phosphorites due to a high content of dolomite, (Germann et al. 1984), The Magnesium recorded as dolomite form detected by microscopic investigation and XRdiffraction.





**Fig.13: Correlation coefficient relationship of F and  $Fe_2O_3$ ,  $SO_3$ ,  $SiO_2$ ,  $Al_2O_3$ ,  $P_2O_5$ ,  $CaO$ .**  
**1= average shale (Turekian&Wedepoth 1961)**  
**2= average world phosphorite (Kolodny 1981)**  
**3= average Dakhla phosphorite (studied area)**

many authors {Strakhove,1962; Friedman and Sanders, 1967; Pettijhon, 1975 and others} the dolomite can form in shallow evaporite basins within the intertidal zone of carbonate environment, and the chemical sedimentation of Mg in the form of dolomite can only take place under conditions of high temperature and high salinity and magnesium-ions concentrations {Friedman and Sanders 1967}.

Magnesium Oxide has a low negative correlation with  $CaO$ , that may be attributed to the substitution of  $Ca^{2+}$  by  $Mg^{2+}$ , low negative correlation with  $Al_2O_3$ , moderately negative correlation with  $SiO_2$ , that indicate that Mg not derived from Montmorillonite mineral {Mg-rich}, low negative correlation with F,  $SO_3$ , moderately negative correlation with  $P_2O_5$ , that may be attributed to the variation of pH value at environment of deposition, low positive correlation with  $Fe_2O_3$ , that supported the above interpretation that MgO is derived from dolomite by the oxidation processes (Fig.14).



| Tr. No. | S. No | Thick. (m) | Chemical analysis(mean average) |                                |                                |       |       |                   |                  |                               |      |      |                 |       |       |  |  |  |
|---------|-------|------------|---------------------------------|--------------------------------|--------------------------------|-------|-------|-------------------|------------------|-------------------------------|------|------|-----------------|-------|-------|--|--|--|
|         |       |            | SiO <sub>2</sub>                | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | MgO   | CaO   | Na <sub>2</sub> O | K <sub>2</sub> O | P <sub>2</sub> O <sub>5</sub> | Cl   | F    | SO <sub>3</sub> | L.O.I | T.C.P |  |  |  |
| 1       | 1     | 0.50       | 6.13                            | 0.56                           | 3.55                           | 2.62  | 35.46 | 1.08              | 0.05             | 16.75                         | 2.93 | -    | -               | 21.43 | -     |  |  |  |
|         | 2     | 0.30       | 9.78                            | 1.92                           | 3.31                           | 4.11  | 36.21 | 3.16              | 0.12             | 21.16                         | 4.18 | -    | -               | 11.51 | -     |  |  |  |
|         | 3     | 0.35       | 10.02                           | 1.24                           | 1.71                           | 1.77  | 40.03 | 1.28              | 0.03             | 19.05                         | 1.30 | -    | -               | 19.14 | -     |  |  |  |
|         | Av    | 1.15       | 8.30                            | 1.15                           | 2.90                           | 2.60  | 37.00 | 1.70              | 0.06             | 18.60                         | 2.76 | -    | -               | 18.00 | -     |  |  |  |
| 2       | 4     | 0.20       | 5.7                             | 0.5                            | 3.5                            | 2.60  | 35.4  | 1.00              | -                | 15.60                         | 2.8  | 0.3  | 1.12            | 20.5  | -     |  |  |  |
|         | 5     | 0.40       | 9.5                             | 1.8                            | 3.2                            | 4.11  | 36.1  | 3.1               | -                | 20.1                          | 3.5  | 0.4  | 1.2             | 11.20 | -     |  |  |  |
|         | 6     | 0.40       | 10.5                            | 1.20                           | 1.6                            | 1.8   | 40.20 | 1.2               | -                | 18.6                          | 1.2  | 0.35 | 1.8             | 18.9  | -     |  |  |  |
|         | Av    | 1          | 9.14                            | 1.3                            | 2.62                           | 2.88  | 37.6  | 2.08              | -                | 18.6                          | 2.44 | 0.36 | 1.40            | 16.4  | -     |  |  |  |
| 3       | 7     | 1.70       | 3.19                            | 0.88                           | 2.49                           | 5.34  | 41.25 | 1.64              | 0.01             | 19.62                         | 2.03 | -    | -               | 20.15 | -     |  |  |  |
|         | 8     | 0.35       | 7.29                            | 1.62                           | 2.06                           | 3.71  | 36.42 | 2.62              | 0.11             | 18.54                         | 2.85 | -    | -               | 21.68 | -     |  |  |  |
|         | Av.   | 2.05       | 3.89                            | 1.0                            | 2.41                           | 5.06  | 40.40 | 1.8.0             | 0.02             | 19.40                         | 2.17 | -    | -               | 20.41 | -     |  |  |  |
| 4       | 9     | 0.50       | 7.78                            | 1.54                           | 2.25                           | 13.61 | 30.75 | 0.75              | -                | 12.3                          | 0.54 | 0.41 | 2.52            | 36.15 | -     |  |  |  |
|         | 10    | 0.50       | 4.44                            | 1.49                           | 2.89                           | 4.77  | 42.8  | 0.76              | -                | 21.97                         | 0.22 | 1.34 | 1.39            | 17.18 | -     |  |  |  |
|         | Av    | 1          | 6.11                            | 1.51                           | 2.57                           | 9.18  | 39.77 | 0.75              | -                | 17.3                          | 0.38 | 0.87 | 1.95            | 26.66 | -     |  |  |  |

Table.1; Chemical analyses of the surface phosphorite deposits at the study area.

| Tr. No. | S. No | Thick. (m) | Chemical analysis(mean average) |                                |                                |       |       |                   |                  |                               |      |      |                 |       |      |  |
|---------|-------|------------|---------------------------------|--------------------------------|--------------------------------|-------|-------|-------------------|------------------|-------------------------------|------|------|-----------------|-------|------|--|
|         |       |            | SiO <sub>2</sub>                | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | MgO   | CaO   | Na <sub>2</sub> O | K <sub>2</sub> O | P <sub>2</sub> O <sub>5</sub> | Cl   | F    | SO <sub>3</sub> | LOI   | T.C. |  |
| 5       | 11    | 0.30       | 10.23                           | 0.86                           | 2.04                           | 0.90  | 33.23 | 6.13              | 0.04             | 20.76                         | 9.45 | -    | -               | 11.73 | -    |  |
|         | 12    | 0.30       | 10.23                           | 1.21                           | 1.78                           | 4.85  | 34.23 | 3.55              | 0.12             | 15.85                         | 5.17 | -    | -               | 20.12 | -    |  |
|         | 13    | 0.30       | 4.11                            | 1.03                           | 2.70                           | 4.92  | 38.54 | 2.23              | 0.07             | 20.32                         | 3.44 | -    | -               | 19.54 | -    |  |
| Av      | 0.90  | 8.19       | 1.00                            | 2.17                           | 3.60                           | 35.30 | 4.00  | 0.08              | 19.00            | 6.02                          | -    | -    | 17.13           | -     |      |  |
| 6       | 14    | 0.70       | 2.53                            | 0.67                           | 3.69                           | 7.37  | 34.65 | 3.52              | 0.04             | 20.25                         | 5.26 | -    | -               | 14.23 | -    |  |
|         | 15    | 0.50       | 18.23                           | 0.84                           | 2.27                           | 2.17  | 34.23 | 3.11              | 0.03             | 22.11                         | 3.69 | -    | -               | 9.23  | -    |  |
|         | 16    | 0.30       | 3.21                            | 1.42                           | 2.54                           | 5.05  | 38.23 | 3.19              | 0.07             | 19.72                         | 4.28 | -    | -               | 18.56 | -    |  |
| Av      | 1.50  | 7.90       | 0.88                            | 3.00                           | 5.17                           | 36.00 | 3.40  | 0.55              | 20.80            | 4.20                          | -    | -    | 13.40           | -     |      |  |
| 7       | 17    | 0.30       | 9.58                            | 1.63                           | 1.66                           | 0.6   | 41.67 | 2.23              | -                | 27.35                         | 1.02 | 0.06 | 0.78            | 2.3   | -    |  |
|         | 18    | 0.50       | 7.57                            | 0.96                           | 1.66                           | 4     | 40.11 | 2.2               | -                | 21.53                         | 2.1  | 0.34 | 2.2             | 16.68 | -    |  |
|         | 19    | 0.50       | 4.92                            | 0.76                           | 1.99                           | 4.33  | 40.00 | 2.1               | -                | 19.84                         | 2.03 | 0.43 | 1.12            | 21.7  | -    |  |
| Av      | 1.30  | 6.99       | 1.02                            | 1.77                           | 3.23                           | 40.38 | 2.17  | -                 | 22.2             | 1.8                           | 0.35 | 2.05 | 17.04           | -     |      |  |

Table 2: Chemical analyses of the surface phosphorite deposits at the study area.

|    |             |             |             |             |             |              |             |             |              |             |             |             |              |          |
|----|-------------|-------------|-------------|-------------|-------------|--------------|-------------|-------------|--------------|-------------|-------------|-------------|--------------|----------|
| 21 | 0.40        | 10.23       | 0.90        | 1.76        | 2.34        | 34.23        | 5.50        | 0.04        | 23.97        | 7.33        | -           | -           | 11.23        | -        |
| 22 | 0.30        | 2.12        | 0.97        | 2.30        | 4.94        | 39.54        | 2.32        | 0.06        | 21.31        | 2.84        | -           | -           | 21.11        | -        |
| Av | <b>1.20</b> | <b>5.00</b> | <b>0.83</b> | <b>2.50</b> | <b>5.40</b> | <b>37.80</b> | <b>3.18</b> | <b>0.10</b> | <b>19.80</b> | <b>3.70</b> | -           | -           | <b>18.30</b> | -        |
| 9  | 0.30        | 1.09        | 0.15        | 3.80        | 3.42        | 38.23        | 3.42        | 0.02        | 24.23        | 4.20        | -           | -           | 18.23        | -        |
| 10 | 0.30        | 4.11        | 0.31        | 3.12        | 1.68        | 33.23        | 5.59        | 0.23        | 24.57        | 8.62        | -           | -           | 11.23        | -        |
| 25 | 0.60        | 10.23       | 0.80        | 2.12        | 2.03        | 34.23        | 3.65        | 0.08        | 25.94        | 6.11        | -           | -           | 11.51        | -        |
| Av | <b>0.90</b> | <b>8.19</b> | <b>0.43</b> | <b>2.45</b> | <b>1.90</b> | <b>33.90</b> | <b>4.30</b> | <b>0.13</b> | <b>25.50</b> | <b>7.00</b> | -           | -           | <b>11.40</b> | -        |
| 11 | 0.4         | 1.99        | 0.64        | 3.19        | 5.47        | 37.21        | 2.26        | 0.16        | 20.90        | 3.45        | -           | -           | 20.42        | -        |
| 26 | 0.60        | 3.56        | 0.32        | 3.35        | 0.58        | 37.37        | 3.11        | 0.09        | 32.63        | 4.84        | -           | -           | 10.95        | -        |
| 27 | 0.60        | 3.00        | 0.50        | 3.20        | 2.50        | 37.30        | 3.00        | 0.12        | 28.00        | 4.15        | -           | -           | 14.70        | -        |
| Av | <b>1.0</b>  | <b>3.00</b> | <b>0.50</b> | <b>3.20</b> | <b>2.50</b> | <b>37.30</b> | <b>3.00</b> | <b>0.12</b> | <b>28.00</b> | <b>4.15</b> | -           | -           | <b>14.70</b> | -        |
| 12 | 0.70        | 2.38        | 0.77        | 4.18        | 0.31        | 37.12        | 4.02        | -           | 25.85        | 5.57        | 1.63        | 0.84        | 17.4         | -        |
| 28 | 0.30        | 10.58       | 1.08        | 1.45        | 3.34        | 39.85        | 1.12        | -           | 21.33        | 1.33        | 1.32        | 0.38        | 17.38        | -        |
| 29 | 0.30        | 4.87        | 0.86        | 3.33        | 1.22        | 37.93        | 3.14        | -           | 24.49        | 4.29        | 1.53        | 0.69        | 17.11        | -        |
| Av | <b>1</b>    | <b>4.87</b> | <b>0.86</b> | <b>3.33</b> | <b>1.22</b> | <b>37.93</b> | <b>3.14</b> | <b>-</b>    | <b>24.49</b> | <b>4.29</b> | <b>1.53</b> | <b>0.69</b> | <b>17.11</b> | <b>-</b> |

Table-3: Chemical analyses of the surface phosphorite deposits at the study area.

| BH. No          | Samp. NO.       | Thick. m | Main Component   |                  |                                |                                |      |      |       |                   |                  |                               |                 |                 |                 |       | Cl | L.O.I |
|-----------------|-----------------|----------|------------------|------------------|--------------------------------|--------------------------------|------|------|-------|-------------------|------------------|-------------------------------|-----------------|-----------------|-----------------|-------|----|-------|
|                 |                 |          | SiO <sub>2</sub> | TiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | MnO  | MgO  | CaO   | Na <sub>2</sub> O | K <sub>2</sub> O | P <sub>2</sub> O <sub>5</sub> | SO <sub>3</sub> | SO <sub>2</sub> | CO <sub>2</sub> |       |    |       |
| 1               | 1               | 0.3      | 8.16             | 0.06             | 0.87                           | 2.97                           | 0.37 | 4.4  | 37.94 | 0.03              | -                | 9.85                          | 14.48           | 0.41            | 19.31           |       |    |       |
|                 | 2               | 0.3      | 6.18             | 0.05             | 1.39                           | 0.52                           | 0.08 | 3.56 | 42.65 | 0.05              | -                | 16.53                         | 4.53            | 0.1             | 23.12           |       |    |       |
|                 | 3               | 0.8      | 13.89            | 0.04             | 1.1                            | 1.25                           | 0.06 | 1.02 | 41.53 | 0.04              | -                | 24.85                         | 4.01            | 0.11            | 10.41           |       |    |       |
|                 | 4               | 0.4      | 4.72             | 0.02             | 0.88                           | 2.31                           | 0.27 | 3.15 | 42.55 | 0.04              | -                | 20.6                          | 5.09            | 0.08            | 19.03           |       |    |       |
|                 | 5               | 0.6      | 4.03             | 0.01             | 0.7                            | 2.21                           | 0.28 | 3.27 | 43.38 | 0.04              | -                | 21.44                         | 5.13            | 0.07            | 18.05           |       |    |       |
| Aver. Wet. Mean |                 |          | 8.22             | 0.03             | 0.98                           | 1.26                           | 0.17 | 2.43 | 42.41 | 0.04              | -                | 21.88                         | 4.61            | 0.09            | 16.05           |       |    |       |
| 3               | 6               | 0.2      | 8.13             | 0.05             | 1.38                           | 1.16                           | 0.07 | 3.1  | 42.94 | 0.03              | -                | 18.25                         | 1.38            | 0.07            | 22.06           |       |    |       |
|                 | 7               | 0.4      | 20.82            | 0.05             | 1.41                           | 1.44                           | 0.05 | 0.85 | 38.55 | 0.04              | -                | 23.43                         | 3.67            | 0.08            | 8.19            |       |    |       |
|                 | 8               | 0.4      | 11.42            | 0.12             | 2.24                           | 6.31                           | 0.13 | 0.71 | 38.22 | 0.17              | -                | 23.74                         | 8.11            | 0.06            | 7.07            |       |    |       |
|                 | 9               | 0.3      | 10.75            | 0.13             | 1.79                           | 5.79                           | 0.36 | 2.61 | 38.27 | 0.16              | -                | 16.69                         | 6.25            | 0.07            | 15.61           |       |    |       |
| Aver. Wet. Mean |                 |          | 13.65            | 0.09             | 1.75                           | 3.9                            | 0.15 | 1.56 | 39.06 | 0.11              | -                | 21.17                         | 5.3             | 0.07            | 11.69           |       |    |       |
| 4               | 10              | 0.7      | 23.21            | 0.05             | 1.10                           | 1.84                           | 0.06 | 1.71 | 38.12 | 0.33              | 0.2              | 19.48                         | 1.69            | 0.51            | 9.52            |       |    |       |
|                 | 11              | 1.0      | 14.57            | 0.10             | 1.2                            | 2.97                           | 0.33 | 4.3  | 37.23 | 0.35              | 0.32             | 17.5                          | 3.66            | 0.73            | 14.85           |       |    |       |
|                 | Aver. Wet. Mean |          |                  | 18.13            | 0.08                           | 1.16                           | 2.5  | 0.22 | 3.2   | 37.60             | 0.34             | 0.27                          | 18.30           | 2.85            | 0.64            | 12.65 |    |       |
| 5               | 12              | 0.8      | 30.12            | 0.21             | 0.5                            | 3.05                           | 0.1  | 4.8  | 27.89 | 0.31              | 0.71             | 18.42                         | 1.98            | 0.61            | 19.46           |       |    |       |
|                 | 13              | 0.7      | 8.54             | 0.06             | 1.92                           | 1.26                           | 0.03 | 2.88 | 43.76 | 0.01              | 0.35             | 15.55                         | 0.5             | 0.32            | 39.2            |       |    |       |
| 7               | 14              | 0.6      | 24.54            | 0.08             | 1.75                           | 3.3                            | 0.1  | 1.4  | 34.23 | 0.46              | 0.26             | 18.92                         | 3.79            | 0.8             | 7.83            |       |    |       |
|                 | 15              | 0.8      | 11.54            | 0.07             | 1.2                            | 2.1                            | 0.15 | 7.73 | 36.21 | 0.23              | 0.19             | 11.43                         | 2.32            | 0.52            | 24.53           |       |    |       |
| Aver. Wet. Mean |                 |          | 17.11            | 0.075            | 1.44                           | 2.6                            | 0.13 | 5.02 | 35.36 | 0.33              | 0.22             | 14.64                         | 2.95            | 0.64            | 17.37           |       |    |       |
| 8               | 16              | 0.45     | 20.82            | 0.05             | 1.41                           | 1.44                           | 0.05 | 0.85 | 38.55 | 0.04              | 0.01             | 23.43                         | 3.67            | 0.08            | 8.19            |       |    |       |

Table.4; Chemical analyses of the subsurface phosphorite deposits at the study area.

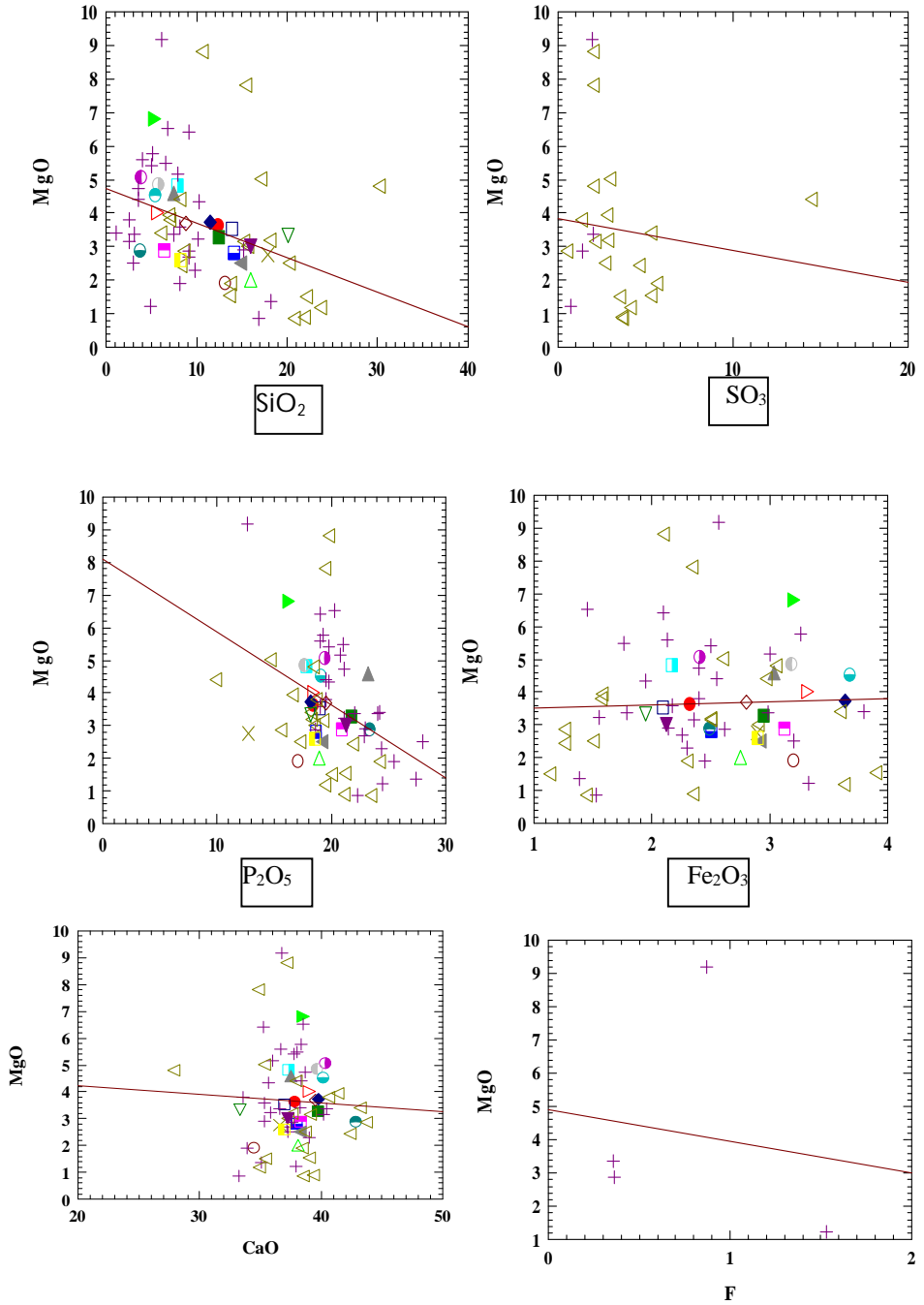
**Table.5; Total a verage mean of El-Rashda, El-MawhoobPhosphorite at major elements composition.**

|                |                                   |                                    |                                    |
|----------------|-----------------------------------|------------------------------------|------------------------------------|
|                | <b>K<sub>2</sub>O</b>             | <b>Al<sub>2</sub>O<sub>3</sub></b> | <b>Fe<sub>2</sub>O<sub>3</sub></b> |
| <b>Minimum</b> | <b>0.01</b>                       | <b>0.15</b>                        | <b>1.13</b>                        |
| <b>Maximum</b> | <b>0.71</b>                       | <b>1.92</b>                        | <b>3.9</b>                         |
| <b>Mean</b>    | <b>0.13</b>                       | <b>1.09</b>                        | <b>2.49</b>                        |
|                | <b>MgO</b>                        | <b>CaO</b>                         | <b>Na<sub>2</sub>O</b>             |
| <b>Minimum</b> | <b>0.85</b>                       | <b>27.89</b>                       | <b>0.01</b>                        |
| <b>Maximum</b> | <b>9.18</b>                       | <b>43.76</b>                       | <b>11.5</b>                        |
| <b>Mean</b>    | <b>3.65</b>                       | <b>37.69</b>                       | <b>1.88</b>                        |
|                | <b>P<sub>2</sub>O<sub>5</sub></b> | <b>SO<sub>3</sub></b>              | <b>SiO<sub>2</sub></b>             |
| <b>Minimum</b> | <b>9.85</b>                       | <b>0.5</b>                         | <b>1.09</b>                        |
| <b>Maximum</b> | <b>28</b>                         | <b>14.48</b>                       | <b>30.12</b>                       |
| <b>Mean</b>    | <b>19.91</b>                      | <b>3.37</b>                        | <b>10.61</b>                       |
|                | <b>F</b>                          | <b>MnO</b>                         |                                    |
| <b>Minimum</b> | <b>0.36</b>                       | <b>0.03</b>                        |                                    |
| <b>Maximum</b> | <b>1.53</b>                       | <b>0.6</b>                         |                                    |
| <b>Mean</b>    | <b>0.78</b>                       | <b>0.18</b>                        |                                    |

**Table.6; Average chemical composition of El-Rashda & El-Mawhoob phosphorites relative to shale and globale marine phosphorite (Queted in Mullins&Rash 1985).**

| Oxide (%)                      | 1     | 2     | 3     |
|--------------------------------|-------|-------|-------|
| P <sub>2</sub> O <sub>5</sub>  | 0.16  | 23.01 | 19.91 |
| CaO                            | 3.09  | 40.38 | 37.69 |
| F                              | 0.07  | 2.55  | 0.78  |
| CO <sub>2</sub>                | -     | 4.92  | -     |
| SrO                            | 0.04  | 0.12  | -     |
| SO <sub>3</sub>                | 0.60  | 1.39  | 3.37  |
| MgO                            | 2.49  | 1.33  | 3.65  |
| Na <sub>2</sub> O              | 1.29  | -     | 1.88  |
| K <sub>2</sub> O               | 3.20  | 0.62  | 0.13  |
| MnO                            | 0.11  | -     | 0.18  |
| Al <sub>2</sub> O <sub>3</sub> | 15.12 | 1.80  | 1.09  |
| Fe <sub>2</sub> O <sub>3</sub> | 6.75  | 2.33  | 2.49  |
| SiO <sub>2</sub>               | 15.61 | 12.23 | 10.61 |





**Fig.14:** Correlation coefficient relationship of MgO and  $\text{SO}_3$ ,  $\text{CaO}$ ,  $\text{F}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{P}_2\text{O}_5$ ,  $\text{SiO}_2$ .

**Ferric oxide: (Fe<sub>2</sub>O<sub>3</sub>)**

The total ferric oxide content in the studied samples ranges from 1.13 to 3.9% with an average of about 2.49%. The average value of Ferric oxides content is higher than Kolodny, that may be attributed to the positive correlation of Fe<sub>2</sub>O<sub>3</sub> with MgO. It is low negative correlation with P<sub>2</sub>O<sub>5</sub>, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and low positive correlation with CaO, SO<sub>3</sub> that may be attributed to the presence of Fe<sub>2</sub>O<sub>3</sub> in carbonate phase, or the iron oxide in phosphorite which derived from weathering process of pyrite mineral, indicated by thin section investigation (Fig.15).

**Silica: (SiO<sub>2</sub>)**

The Silica content in the studied samples ranges from 1.09 to 30.12% with an average of about 10.61%. The average value of SiO<sub>2</sub> content is higher than Kolodny values, that may be attributed to the presence of highly free amount of silica in the bulk sample and P<sup>5+</sup> substitute by Si<sup>4+</sup>

(McConnell 1980). The silica recorded by thin section investigation as quartz form as well as supported by XRD diffraction.

The silica is low negative correlation with P<sub>2</sub>O<sub>5</sub>, very strong negative correlation with F, that may be resulted from the substitution of P<sup>5+</sup> by Si<sup>4+</sup>, low negative correlation with Fe<sub>2</sub>O<sub>3</sub>, SO<sub>3</sub>, moderately negative correlation with CaO, and low positive correlation with Al<sub>2</sub>O<sub>3</sub>, that means also its presence in clay phases (clay mineral) and not association with carbonate minerals (Fig.16).

**Sulphur: (SO<sub>3</sub><sup>2-</sup>)**

The Sulphur content in the studied samples ranges from 0.5 to 14.48% with an average of about 3.37%.

The average value of SO<sub>3</sub><sup>2-</sup> content is higher than Kolodny, where is the SO<sub>3</sub><sup>2-</sup> content may be derived from the weathering processes (oxidation of pyrite), the SO<sub>3</sub><sup>2-</sup> content recorded in gypsum form detected by thin section, also anhydrite mineral supported by XRay diffraction.

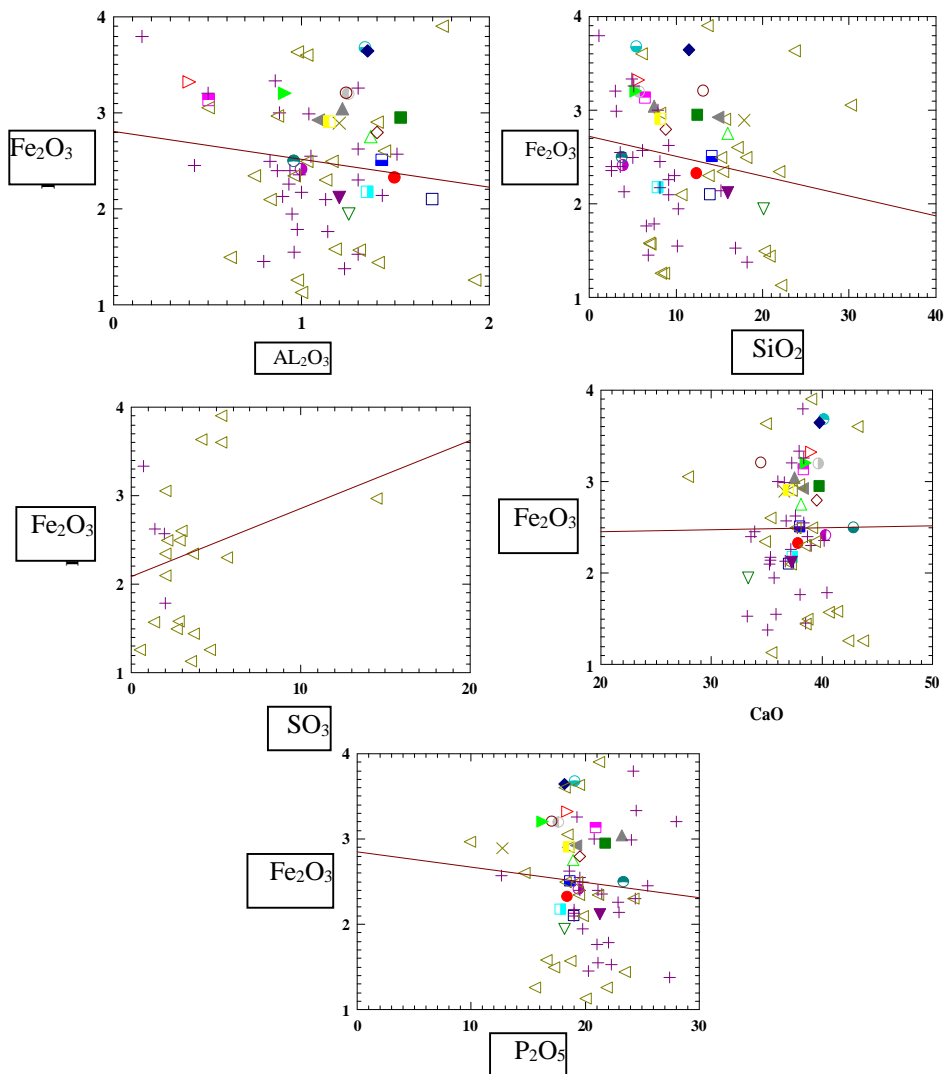
The SO<sub>3</sub><sup>2-</sup> has a low positive correlation with Fe<sub>2</sub>O<sub>3</sub>, and moderately negative correlation with P<sub>2</sub>O<sub>5</sub>, and low positive correlation with CaO, strong negative correlation with F, that resulted from the differentiation of pH value at environment of deposition, low negative correlation with SiO<sub>2</sub>, that means its presence in carbonate phase (Fig.17).

-The study and calculated of F/P<sub>2</sub>O<sub>5</sub> ratio, were found to be 0.03 at El-Rashda sector while it is 0.02 at El-Qaser, El-Mzawaka areas, which indicates that El-Rashda area is more shallower than El-Qaser, El-Mzawaka areas .

-The high content of sulphate at the phosphorite beds of the studied area indicated that the phosphorite beds are deposited in a more saline, isolated and warm water environment.

-Mg<sup>2+</sup> ions depletion in the environment of deposition. Experimental work by (Martens and Harris 1970) has shown that Mg<sup>2+</sup> ions have an inhibiting effect on the precipitation of apatite, perhaps because Mg<sup>2+</sup> competes with Ca<sup>2+</sup> for sites in the apatite lattice, that may be also revealed to the high content of MgO at the study area.

- Silica is one of the components which transported from deep parts of the basin to the shallow shelf by upwelling currents (Al-Bassam – Al-Allak, 1985). The deposition of the phosphorites took place under avariable Eh factor. These variations are often due to irregularities in the bottom of the depositional basin and the nature of water-sediment interface.



**Fig.15: Correlation coefficient relationship of  $\text{Fe}_2\text{O}_3$  and  $\text{P}_2\text{O}_5$ ,  $\text{CaO}$ ,  $\text{SO}_3$ ,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ .**

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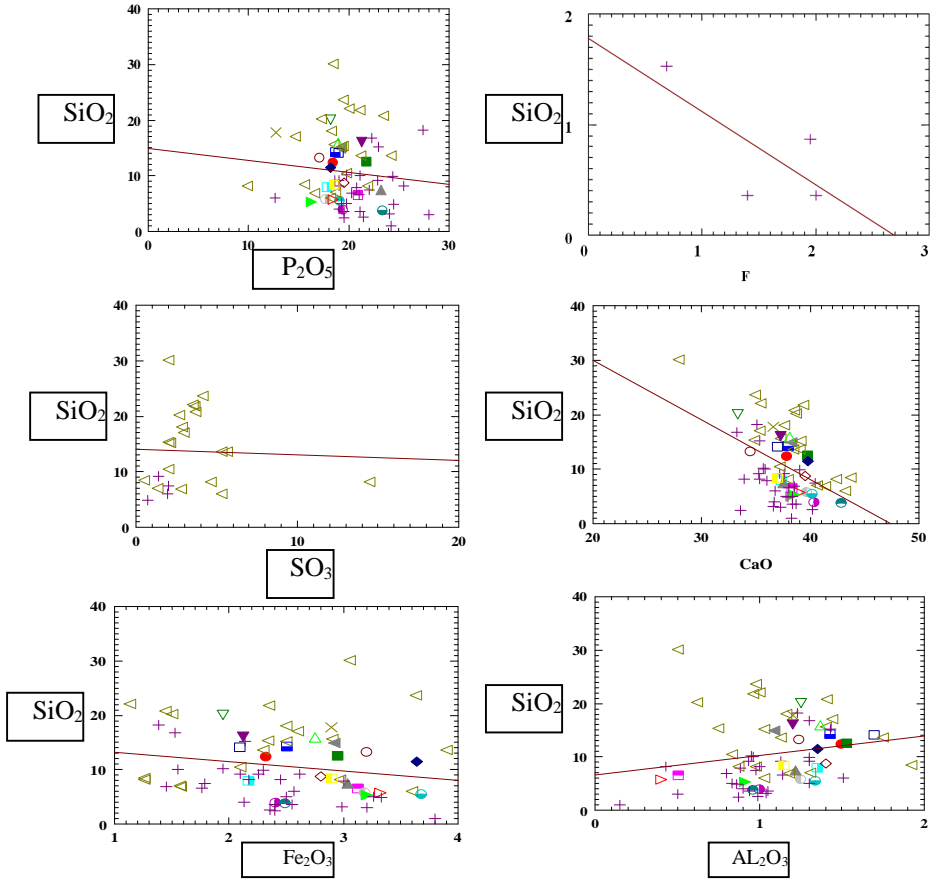
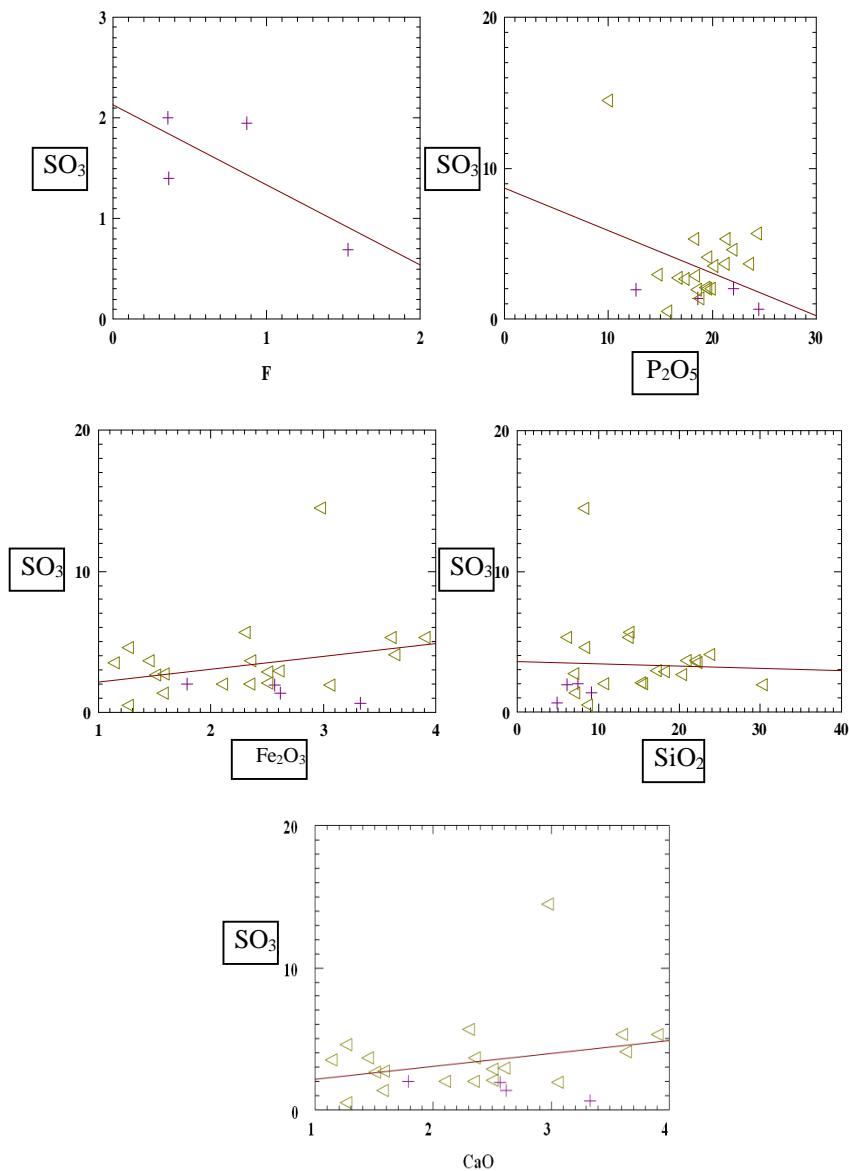


Fig.16: Correlation coefficient relationship of SiO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, SO<sub>3</sub>, CaO, F, P<sub>2</sub>O<sub>5</sub>.



**Fig.17: Correlation coefficient relationship of  $SO_3$  and  $Fe_2O_3$ ,  $Al_2O_3$ ,  $SiO_2$ , CaO, F,  $P_2O_5$ .**

### Summary

The studied area El-Rashda, El-Mawhoob lie between latitude;  $25^{\circ} 30'$  to  $25^{\circ} 45'$  N and longitude;  $28^{\circ} 30'$  to  $29^{\circ}$  E. The area subjected to several of subdivision of the Campanian –Maestrichtian phosphorite rocks.

Fifty stratigraphic successions were measured, 17 of them represented El-Rashda area, 17 also represented El-Qaser area, 16 represented El-Mzawaka area, 19



borholes represented El-Mawhoob area. According to El-Bakry (2005), the studied area contains the following rock units from base to top

|                   |                           |
|-------------------|---------------------------|
| Tarawan Chalk     | (Upper Paleocene)         |
| Dakhla Shale      | (Maestrichtian—Danian)    |
| Duwi Formation    | (Lower--Maestrichtian)    |
| Qussier Formation | (Campanian—Maestrichtian) |

- The average value of aluminium content is lowest at the phosphate samples, this can be attributed to the little abundance of clays. In the matrix of these deposits and the aluminum is low negative correlation with  $P_2O_5$ , that may attributed to its located outside the apatite lattice.
- The average value of phosphorus content is low that may be attributed to substitution of  $(PO_4)$  by  $CaO, CO_3, Al, Si$ .
- The average value of magnesium oxide content is high at the phosphate samples that may be attributed to the derivation of  $(MgO)$  from dolomite by the oxidation processes.
- The average value of calcium oxide content is low, that may be attributed to the presence of negative correlation between it and  $MgO$ .
- The average value of Fluorine content is low, that may be attributed to the substitution of  $F^{1-}$  by  $CO_3^{2-}, Cl^{1-}$ .
- The average value of ferric oxides content is high, that may attributed to the positive correlation of  $Fe_2O_3$  with  $MgO$ .
- The average value of  $SiO_2$  content is high, that may be attributed to the presence of highly free amount of Silica in the bulk sample and  $P^{5+}$  substitute by  $Si^{4+}$ .
- The average value of  $SO_3^{2-}$  content is high, where is the  $SO_3^{2-}$  content may be derived from the weathering processes (oxidation of pyrite).
- The average value of Barium content is high, that may be attributed to the  $Ba^{2+}$  associated with carbonate minerals and phosphorite minerals.
- The copper content in the studied samples ranges from 8.2 to 262.45 ppm with an average of about 73.49 ppm.
- The presence of Mn associated with iron oxides or adsorbed on the surface.
- The cobalt related to phosphorite minerals and as sulphid phase.

About 68 samples were selected for testing to determine some of its physical properties and the results of these physical properties as the follow; **El-Qaser area** characterized by observed of the radiations and the density than the other areas, while **El-Mzawaka area** included that the highest value of magnetic suitability than the other areas. The most of the phosphate beds with study area are varies in thickness with an average from 0.25m to 2.10m . and many can be found as impurities in the phosphorite deposits, these impurities contain clastic sediments as clay minerals and fine sands as well as chemical sediments such as dolomite, and evaporate minerals as gypsum, anhydrite. All of these impurities strongly effected about the quality and the grade of the phosphorite ore. And according to EGSMA, (1977) that classified the phosphorite ores into the main three categories of grade as the follow;

|                     |                                |
|---------------------|--------------------------------|
| 1- High grad ores   | $P_2O_5$ – not less than 26 %. |
| 2- Medium grad ores | $P_2O_5$ – 23 – 26 % .         |
| 3- Low grad ores    | $P_2O_5$ – under 23 %.         |

The results indicated that the percent of phosphorite is low grade where it is ranges from 9.85 % to 28 % with an average of 19.91 %.

Impurities in the phosphorite deposits found as clastic sediments as clay minerals and fine sands as well as chemical sediments such as dolomite, evaporate minerals as gypsum, anhydrite.

From all the field observation and detection of the petrographic, mineralogical, chemical studies the tabulated data revealed that the origin of the phosphorite deposits at the study area is shallow marine deposits and controlled with varies physico-chemical conditions.

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