

Lithofacies and Depositional Model of the phosphatic bearing rocks, Ain Giffara Formation (Campanian), Bahariya Oasis, Western Desert, Egypt

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ABSTRACT

The Campanian Ain Giffara Formation is distributed from southern escarpment (east and west of Naqb es Sillim, Ain Ris and southwest of Gebel El-Heiz) to the middle of the Bahariya depression (Gebel El-Hefhuf, Gebel Fagget El-Harra and Gebel El-Tobog) with total thickness ranging from 15 to 45 m. The Ain Giffara Formation consists of two members, the lower member has high abundance of phosphorite in clastic facies whereas the upper member has low abundance of phosphorite in dolostone facies. The phosphorites are remarked within the synclinal structures and the flanks of anticlines with trends NE-SW direction. Petrographic examination, SEM and elemental analyses resulted francolite reach to 25 % in sandstone and 5-10 % in dolostone lithofacies as pelloids and skeletal remains (teeth and bone fragments) associated with organic matter and pyrite.

The depositional model of Ain Giffara phosphorites is different from the phosphorites of Nile Valley, Abu Tartur and Red Sea due to lack of chert bands, Oyster banks, glauconite and black shales. The transgression of Upper Cretaceous was associated with terrigenous sediments in shallow marine environment. The high stand of sea level, chemical-biological mechanism affected by decomposition of organic matter in reducing conditions and accumulation of phosphorites. Falling of sea level, bioturbation and strong waves winnowed and concentrated phosphorites in clastic deposits.

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INTRODUCTION

The Bahariya Oasis lies in the heart of the Western Desert between latitudes 28° and 28° 50' North and longitudes 29° 10' and 28° 20' East (Fig. 1). The Upper Cretaceous rock units in the Bahariya Oasis are classified from base to top as follows:-

- Khoman Chalk (Kerdany, 1969)

Maastrichtian

- Ain Giffara Formation (Khalifa, 1977)

Campanian

- 3- El-Hefhuf Formation (Said, 1962)

Turonian-

Santonian

- 2- El-Heiz Formation (El-Akkad and Issawi, 1963)

Late

Cenomanian

- 1- Bahariya Formation (Stromer, 1914)

Early

Cenomanian

The structures and tectonics of the Bahariya Oasis were studied by many authors. Shukri (1954) mentioned that the Bahariya Oasis is one of the main structural highs of the Syrian Arc System in the Western Desert. Yalious and Knetsch (1954) reported that the Bahariya depression follows a structural orientation trending in a northeast- southwest direction. El-Bassyouny (1978) recorded two periods of deformation in the Bahariya Oasis. The first period is a part of Syrian Arc System (Post Cenomanian to Pre-Campanian) and the

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second is a part of the Alpine cycle which affecting during Eocene to Oligocene. In the present work, the Campanian phosphorite of Ain Giffara Formation will be study on the basis of field observation, petrographical examination and elemental analyses of phosphatic bearing rocks to observe the depositional model of phosphorite.

STRATIGRAPHIC POSITION

The Campanian Ain Giffara Formation was introduced in the Upper Cretaceous stratigraphic sequence in Bahariya Oasis by Khalifa (1977) at Gebel El-Hefhuf within the Bahariya depression (Fig. 1). He observed that the phosphatic beds occurring in the upper part of the El-Hefhuf Formation exhibit unconformable contact with the underlying glauconitic clastic rocks of the El-Hefhuf Formation. Consequently, Khalifa (op. cit) separated the phosphatic rocks into one independent rock unit under the term "Ain Giffara Formation". Many authors have used this formational name "Ain Giffara Formation" in the Bahariya Oasis such as Franks (1982), El-Mansy (1983) and Khalifa and Zaghoul (1985). Khalifa (1977) subdivided the Ain Giffara Formation into two members as follows: 1-) Lower phosphatic sandstone member and 2) Upper phosphatic dolostone member.

In the present work, Ain Giffara Formation represents the only phosphatic rock unit in the Bahariya Oasis which has a maximum thickness of 45 m at its type locality of Gebel El-Hefhuf (Fig. 2). It decreases in thickness to 22m and 19 m at Ain Ris and south of Gebel El-Heiz respectively. Seven stratigraphic sections (Fig. 3) of the Ain Giffara Formation were measured along the eastern and western

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escarpments and in the depression of the oasis (Fig. 3). The lower contact of Ain Giffara Formation with the underlying El-Hefhuf Formation is always unconformable. The lower unconformable contact is dominantly calcrete and ferricrete with phosphatic cobbles and boulders (Fig. 4A). The upper contact of Ain Giffara Formation with the overlying Khoman Chalk is gradational at west and east of Naqb es Sillim, Gebel El-Hefhuf and Gebel El-Tobog sections (Fig. 4B&C).

Lithologically, the Ain Giffara Formation is subdivided into two members. The lower phosphatic sandstone member is yellowish brown in colour, hard with vertical to oblique burrows in the basal part of sandstone beds. The phosphatic beds are intercalated with thin beds of marl and clays (5-10 cm) (Fig. 4D). The coprolites and shark teeth in phosphatic sandstone are relatively high in abundance (reach to 25 %) in the synclinal structures (Gebel El-Hefhuf, Gebel El-Tobog and Fagget El-Harra synclines) while on the eastern and western escarpments and in the southern part of the Oasis (Naqb es Sillim area) they are relatively less in abundance (5-10 %). The upper phosphatic dolostone member consists of dolomitic limestones which are commonly creamy white and hard with snow white calcrete between them (Fig. 4E). Some empty vugs occur in the dolostone which are most probably formed from the dissolved organisms (Fig. 4F). The dolomitic limestones are occasionally phosphatic coprolites with Exogyra overweigi , Ostrea villi. Most of these shells were recrystallized to calcite filling vugs.

On the basis of lithological variation, the Ain Giffara Formation (Campanian) in the Bahariya Oasis is correlated with the Duwi

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Formation in Nile Valley, Red Sea and Abu Tartur (Fig. 5). Duwi Formation (Ghorab, 1956) has age assigned to Middle Campanian to Early Maastrichtian (Hendriks and Luger, 1987). In Nile Valley, Red Sea and Abu Tartur, Duwi Formation unconformably overlies the Senonian Qusseir Formation (Said, 1962) and unconformably underlies the Danian Dakhla Shale (Said, 1961 and Abdel Razik, 1968). The lithological characters of Duwi Formation in Nile valley are heterogenous shallow marine rocks consists of phosphatic beds (tens of centimeter thick) concentrated in the upper part intercalated with shales, sandstones, marls, limestones and oyster beds. In the Red Sea, Duwi Formation comprises of phosphatic beds (5-25 cm thick) in lower and upper part of section intercalated with marly limestone, shales, oyster beds and chert bands (few centimeter in thickness). In Abu Tartur Plateau (Western Desert) the phosphatic beds appears in the basal part with thickness of each bed 20 to 150 cm intercalated with thin beds of grey clays (3-15 cm), green glauconite and black shales in the upper part.

The lithological characters of Ain Giffara Formation in the Bahariya Oasis (Fig. 5) are changed from Nile Valley, Abu Tartur and Red Sea. The phosphatic beds of Ain Giffara Formation attains thickness from 20 to 50 cm in the lower member intercalated with thin beds of claystone and sandstone and the upper member changed to grey dolostone with pelecypod molds. High sea level is deposited black shales and glauconitic claystone of Duwi Formation (Glenn and Arthur, 1990). Falling of sea level is affected by progradational wedge of

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glaucopitic sandstone in Abu Tartur, siltstone and marls in Nile Valley, reefal debris in Red Sea and dolostone in Bahariya Oasis.

METHODS

One hundred thin sections were prepared from representative sandstone and dolostone samples that were collected wherever the lithological changes were seen in the studied rock unit at different localities. These thin sections were examined using an optical microscope. Some of the uncovered thin sections were stained by Alizarin Red S and potassium ferrocyanide (Dickson, 1965) to differentiate between dolomite and calcite. SEM used for the analyses of the texture of the phosphatic bearing rocks. Geochemical analyses used XRF and mineral chemistry for dolomite rhombs and phosphatic grains to measure the major elements (CaO, MgO, Fe₂O₃, Na₂O, Al₂O₃, SiO₂, F, P₂O₅ and SO₃) and trace elements (Ti, V, Cr, Mn, Zn, Y and Ba). The chemical analysis have been made for thirty samples of phosphatic sandstone in lower member and phosphatic dolostone in upper member selected with high concentration of phosphorites. Organic carbon was determined after acidifying the powder by 5 % HCl to remove the inorganic carbon and drying at 75 °C one day. The dried residue was measured by LECO analyzer to result the total organic carbon. All analyses were carried out in the Mineralogical Institute, La Sapienza University, Roma, Italy.

PETROGRAPHIC INVESTIGATION

The following is a list of the main facies recognized from the study of about 100 thin sections. The petrographic terminology of sandstone will be dealt according to classification of Pettijohn (1973)

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and Friedman (1965) respectively. Petrographic investigation of the phosphatic sandstone (lower member) and phosphatic dolostone (upper member) are represented by different types of lithofacies (*Quartzarenite, phosphatic litharenite, siliceous quartzarenite and dolomitic quartzarenite*)

1- Sandstone lithofacies

Sandstone lithofacies are encountered only in the lower member of Ain Giffara Formation. The petrographical studies led to identify four sandstone lithofacies as follows:-

a) Quartzarenite lithofacies

Quartzarenite lithofacies occurs in the lower member of the Ain Giffara Formation with an average thickness of 1m. It appears as brownish colour, massive and very hard. In thin section, this lithofacies consists of detrital quartz grains (85-95 %) and silica cement (10-15 %).

The quartz grains are subangular to subrounded, moderately to well sorted and have medium to fine sand sized (Fig. 6A). Quartz grains are monocrystalline and few of them are polycrystalline. The monocrystalline quartz grains exhibit straight extinction. Silica is the abundant cement in the quartzarenite lithofacies. Most of which occur as quartz syntaxial overgrowths and in the pores between quartz grains. The overgrowths were incomplete and marked by the dust rims of iron oxides and/or clays that separate the overgrowths from the detrital grain (Fig. 6B). These syntaxial overgrowths show irregularities in thickness around the detrital grains.

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b) Phosphatic litharenite

The phosphatic litharenite is the dominant lithofacies in the lower member of Ain Giffara Formation at Gebel El-Hefhuf, Gebel Fagget El-Harra and west and east of Naqb es Sillim sections. This lithofacies appears as dark brownish colour with thin thickness (20-70 cm) alternatively with thin beds of green clays (5-10 cm in thick). In thin section, this lithofacies consists of quartz grains (75-85 %), phosphorite (15-20 %), glauconite and calcite (5%). The quartz grains are monocrystalline and exhibit uniform extinction. They are fine to coarse grains, poorly sorted and subrounded to subangular in shape.

The phosphorite is an apparently amorphous and isotropic variety of apatite often termed "collophane". However, modern studies show that this apparently isotropic substance is in fact cryptocrystalline or microcrystalline and is made up of the apatite family (Slansky 1986). The phosphorite in the litharenite lithofacies appears as peloids and skeletal materials. The term peloid will be used here to designate the most common and characteristic phosphatic material being microcrystalline or cryptocrystalline. Peloids are usually cryptocrystalline but some show weak birefringence (Fig. 6C). Texturally, the peloids possess different shapes and sizes. They may be spheroidal or ovoid, irregularly or lath-shaped. Ovoid-shaped grains resemble phosphatized fecal pellets. Most are well-rounded to subrounded. The internal structure of the peloids is also quite variable ranging from structureless to varieties possessing a mottled texture. Irregularly shaped grains possess relatively irregular borders. Lath-shaped grains are prismatic, with rounded to subrounded borders. Under plane polarized light, the peloids are mottled or even appear

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opaque and vary in colour from cloudy through amber, yellow, brown to grey or translucent. Peloids of phosphorite are occasionally stained by inclusions of ferruginous material, organic matter and small spheres of black pyrite (Fig. 6C). Around the peloids there are thin rim of calcite which replaced the peloids.

The skeletal materials are vertebral bone fragments, teeth and fish debris. The skeletal materials occurs as anisotropic prismatic with sharp edges, and some of them show irregular shape. Small fragments of broken bones and teeth are more or less angular to subangular (Fig. 6D). Teeth fragments exhibit distinct internal structure and giving bluish to grey, grey to pale grey interference colours of the first order. Commonly, they display undulator extinction due to their fibrous or spherulitic structure.

c) Siliceous quartzarenite

This lithofacies is less abundant in the Ain Giffara Formation. It occurs especially in Gebel El-Hefhuf and Fagget El-Harra sections and appears in the field as thin bed (less than 0.5 m), hard, brownish and yellow in colour. In thin section, siliceous quartzarenite is mainly composed of quartz grains (80-95 %) and microcrystalline quartz cement (10-15 %) in addition to glauconite and phosphatic grains (less than 5%). The quartz grains are medium sand size, rounded to subrounded and moderately sorted. Most of the quartz grains are monocrystalline exhibiting straight to slightly undulose extinction. Few quartz grains are polycrystalline to smicocomposite. The microcrystalline quartz crystals are fine to very fine grained. Microcrystalline silica is

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filled the pore spaces between the detrital quartz grains as a cement (Fig. 6E). It shows syntaxial overgrowth around the quartz grains.

d) Dolomitic quartzarenite

This lithofacies abundant dominantly in the all studied sections in the lower member of Ain Giffara Formation except at Gebel El-Tobog the dolomite cement is not recorded in sandstone. Dolomitic quartzarenite is massive, hard and brownish in colour and is recorded in the upper part of the lower member of Ain Giffara Formation.

In thin section, the dolomitic quartzarenite is composed of quartz grains (80-85 %) and dolomite cement (15-20 %). The quartz grains are fine to medium size, poorly sorted and monocrystalline exhibiting straight extinction. The dolomite cement consists of fine dolomite rhombs (20-80 μm). The dolomite rhombs are ferroan, idioblastic to hypidioblastic texture and are represented by small dark core surrounded by yellowish brown outer zone (Fig. 6F).

2- Carbonate lithofacies

The carbonate lithofacies are recorded in the upper member of Ain Giffara Formation. These lithofacies are phosphatic dolostone, sandy dolostone, siliceous dolostone, sucrosic dolostone and dedolostone.

a) Phosphatic dolostone

This lithofacies is the dominant in the upper member of Ain Giffara Formation. It is represented by two to three beds in Gebel Fagget El-Harra and Gebel El-Hefhuf with an average thickness of 1.5

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m. At Ain Ris, East and West of Naqb es Sillim in the southern escarpment, the phosphatic dolostone reduces in thickness with thickness of 0.5 m. It is grey to brownish in colour, massive, very hard with porous morphological appearance. In thin section, the phosphatic dolostone is composed of dolomite rhombs (75-80 %) and phosphatic materials (15-20 %) and quartz grains and glauconite (5%).

Dolomite rhombs are hypidiotopic texture with fine to medium grained (80-120 μm). Dolomite rhombs are represented by clear calcian core surrounded by dark hematitic zone (Fig. 7A). Some dolomite rhombs intergrowth together as twin crystals. Phosphatic grains are scattered randomly between the dolomite rhombs with different sizes varying from 1 to 3 mm. Phosphatic grains are peloids and skeletal materials. The peloids is isotropic, brownish yellow in colour, oval and pellets grains and serrated outer periphery (collophane). The peloids have dark materials of organic matter on the outer surface and the calcite cement penetrated the phosphatic peloids from the outer periphery. The skeletal materials are bone fragments and teeth having a grey interference colour with wavy extinctions (Fig. 7A). The skeletal materials appear as prismatic shads with sharp edges with preserved internal structures.

b) Sandy dolostone

This lithofacies is of low abundance in the upper member of Ain Giffara Formation. It is only recorded as one bed with thickness 1.5-2 m only at Gebel El-Hefhuf, Fagget El-Harra and east and west of Naqb es Sillim localities. It is characterized by yellowish grey in colour,

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massive and filled by molluscan molds which are sometimes reworked by weathering to give empty vugs.

In thin section, This lithofacies is composed of dolomite rhombs (80-90 %) and quartz grains(10-20%) (Fig. 7B). The dolomite rhombs are hypidiotopic to xenotopic, equigranular fabric and ferroan in composition. The dolomite rhombs are zoned with dark spots of hematitic iron oxides core surrounded by thick clear outer rim. The outer zone of dolomite rhombs in most case were replaced by calcite. Quartz grains are angular to subangular, moderately sorted, fine-grained and scattered randomly between the dolomite rhombs. Most of these grains have striaght extinctions. However, some quartz grains are wavy extinction or slightly undulose extinction. The outer periphery of the quartz grains are uneven and replaced by the calcite cement. Also, the dolomite rhombs penetrated the detrital quartz grains.

c) Siliceous dolostone

This lithofacies is recorded only at Gebel Fagget El-Harra and Gebel El-Hefhuf in the depression of the Bahariya Oasis. It is represented by one or two beds with an average thickness of 2 m and is geryish yellow in colour, with brownish nodules of chert.

The siliceous dolostone is composed of dolomite rhombs (75-85 %) and microcrystalline quartz cement (20-25 %). Dolomite rhombs are fine to medium grained (120-200 um), hypidiotopic texrutre and equigrtanular fabric. Zoning in the dolomite rhombs are clear core surrounded by successive zones of thin streaks if iron oxides with thick clear outer zones. The outer zone of rhombs are mainly calcite cemented the dolomite rhombs. The pore spaces between the

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dolomite rhombs are filled by microcrystalline quartz (Fig. 7C). Some quartz grains are generally uniform extinction, but irregular or shadow extinction may occur. The microcrystalline quartz was replaced the outer edges of rhombs and filled the empty pores in the dolomite rhombs indicating a later stage of silicification.

d) Sucrosic dolostone

This lithofacies have a regional distribution in all stratigraphic sections of Ain Giffara Formation in the Bahariya Oasis. It is represented by two to three beds with total thickness reach to 5 m at Gebel El-Hefhuf, Fagget El-Harra and west of Naqb es Sillim sections. It is characterized by geyish yellow in colour, massive very hard and sucrose like shape.

In thin section, this lithofacies is composed of dolomite rhombs (90-95 %) and calcite cement (5 %). The dolomite rhombs are fine grained (80-100 μm), idiotopic to hypidiotopic texture, and equigranular fabric (Fig. 7D). Zoning is represented by thick clear calcian core. The sucrosic dolomite is calcian dolomite zones cemented by calcite overgrowths (Fig. 7D). The calcite cement deposited in the pore spaces and due to the replacement on the outer peripheries of dolomite rhombs.

d) Dedolostone

This lithofacies is recorded in the upper dolostone member which capped by calcrete and ferricrete. This lithofacies is recognized at Gebel El-Hefhuf and Gebel El-Tobog in the depression and in the southern escarpment of the Bahariya Oasis (southwest of Gebel El-Heiz and east and west of Naqb es Sillim).

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In thin section, this lithofacies is composed of dolomite rhombs (75-85 %) and calcite cement (20-15 %) and less than 5 % evaporites. Dolomite rhombs are medium to coarse grained (150-200 μm), xenotopic to hypidiotopic texture (Fig. 7E). The dedolomitization processes affecting on the dolomite rhombs are partially and complete. The partial or incomplete dedolomite is represented by calcite replaced the outer periphery of rhombs (Fig. 7E). The complete dedolomite is represented by intensive replacement of dolomite rhombs by calcite where there is a relics of dolomite in calcite cement.

GEOCHEMISTRY AND ORIGIN OF PHOSPHORITE

Lehr et al (1967) and McClellan and Lehr (1969) have reported that the composition of apatites in sedimentary phosphate rocks can be adequately described by their six elements e.g P_2O_5 , CaO, CO_2 , Na_2O , MgO and F components. According to Cook (1972), there are essentially two groups of major elements: those which are located predominantly within the apatite lattice (CaO, P_2O_5 , CO_2 , F) and those located outside the lattice in minerals, either of detrital origin (SiO_2 , Al_2O_3 , K_2O , TiO_2) or introduced by weathering (Fe_2O_3 , MgO ?, MnO). **Therefore major and trace elements** have been analysed from the phosphorite grains selected from the associated rocks (Table 1)

Major elements

P_2O_5 content falls in the range from 2 to 20 % (Table 1) of the analysed bulk samples by XRF. The electron microprobe analyses (Table 2) gave P_2O_5 average values 33.68 %. **CaO** in the phosphatic carbonate samples depends only the carbonate content in these

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Table (1) XRF for the phosphatic sandstone and phosphatic dolostone selected from the stratigraphic sections of Ain Giffara Formation.

Sampl.	MgO%	P2O5%	CaO%	Fe2O3%	SiO2%	K2O%	Al2O3%	Mn ppm	Ba ppm	S ppm	V ppm	Y ppm	Cr ppm	Zn ppm	Ti ppm	C _{org} %	CO ₂ %	Total %
1	16.3	0.21	36.97	4.79	3.36	0.1	0.25	2200	300	400	5	20	0	300	60	0.04	38.72	98.7
2	19.75	0.22	30.47	3.38	4.71	0.06	0.21	1400	700	4600	0	30	0	300	80	0.08	40.02	98.82
3	16.73	0.17	36.1	5.8	1.44	0.08	0.15	2200	300	1100	10	50	10	300	60	0.04	39.12	99.59
4	16.6	1.14	32.78	2.79	4.78	0.13	0.16	500	600	1000	4	0	5	300	50	0.05	40.22	98.60
5	20.85	0.16	34.29	3.89	0.09	0.05	0.14	1100	90	800	15	40	0	290	60	0.09	40.15	99.62
6	22.58	0.03	33.85	2.78	2.2	0.08	0.21	600	80	100	0	90	10	310	40	0.03	37.42	99.15
7	19.15	0.67	35.36	3.19	4.2	0.15	0.11	1100	600	2800	0	40	0	300	30	0.08	36.85	99.68
8	21.41	0.43	32.75	3.5	2.17	0.13	0.08	1300	100	1200	5	50	20	280	40	0.06	39.22	99.69
9	18.85	0.41	30.53	4.23	2.2	0.04	0.18	1700	80	2700	0	110	0	300	300	0.07	42.34	98.78
10	16.84	1.71	33.19	3.19	1.74	0.06	0.19	900	2700	5400	10	10	15	300	500	0.1	41.44	98.36
11	19.75	0.22	30.47	3.38	4.71	0.06	0.21	1400	700	4600	0	20	10	300	80	0.06	40.22	99.02
12	7.74	4.44	29.81	5.11	13.64	0.06	0.09	2100	1400	1800	15	60	0	300	400	0.2	34.52	98.41
13	9.92	1.68	33.58	4.42	2.91	0.11	0.09	600	200	800	10	10	15	280	690	0.04	39.65	98.36
14	0.42	20.16	36.39	6.11	1.22	0.09	0.35	900	600	2800	5	30	0	300	400	0.25	32.12	96.86
15	0.43	18.25	0.67	3.22	70.32	0.08	3.4	3300	500	3800	50	200	20	500	250	0.3	—	97.08
16	0.81	15.12	1.32	4.24	73.52	0.11	2.94	2100	600	7200	70	300	55	650	400	0.45	—	98.99
17	0.21	8.27	2.76	5.94	75.83	0.09	1.84	1100	450	18200	60	250	30	400	350	0.29	—	96.87
18	0.33	12.45	0.89	3.45	74.85	0.85	2.38	800	600	15200	20	400	10	750	400	0.18	—	96.8
19	0.10	22.54	1.32	2.98	64.23	0.89	5.04	4000	550	7200	30	550	25	820	550	0.5	—	98.22
20	0.90	16.44	2.87	4.70	67.77	0.91	3.65	1800	750	900	45	250	100	620	600	0.8	—	97.51
21	1.02	12.98	3.54	4.04	73.87	0.45	2.85	1200	430	2900	75	450	90	500	450	0.75	—	99.16
22	1.43	3.65	0.76	5.12	85.75	0.09	0.99	400	620	800	25	700	40	490	290	0.6	—	97.91
23	0.12	7.63	2.54	6.44	79.87	0.15	1.02	2200	650	3900	15	650	35	530	390	0.9	—	98.38
24	0.98	8.90	1.43	3.12	79.21	0.18	2.11	5200	570	9800	5	280	25	620	420	0.8	—	97.43
25	0.87	18.43	6.71	4.28	60.85	0.49	4.75	8200	590	11400	10	350	110	550	550	0.27	—	98.43
26	2.42	12.55	4.62	5.32	70.22	0.09	3.65	420	220	9650	17	460	80	650	340	0.18	—	—
27	1.45	2.24	3.22	10.12	78.54	0.3	2.99	430	540	1200	20	620	75	540	420	0.35	—	—
28	0.41	3.56	1.32	3.87	85.65	0.24	2.76	450	340	6900	60	350	35	600	500	0.46	—	—
29	0.07	2.98	0.78	11.29	80.98	0.12	1.78	550	400	8000	55	560	65	450	250	0.66	—	—
30	0.87	13.22	2.39	5.89	75.44	0.55	0.69	620	350	900	35	450	70	400	350	0.75	—	—

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samples. Electron microprobe analyses (Table 2) showed that CaO content of the phosphorite grains in sandstone (Fig. 7F) and carbonate samples have an average values 47.94 %. CaO is one of the main components of phosphorite and the microprobe analysis gave lower values (47.04 %) than that reported by McClellan (1980) for a pure fluorapatite (55.6 %). More likely, this is caused by the substitution of Ca by Na and Mg in the apatite lattice (McConnell 1973). CaO/P₂O₅ ratio of the phosphorite of the Ain Giffara Formation is 1.4. This ratio is greater than the ideal ratio 1.38 reported by McClellan (1980) for fluorapatite. This is most likely related to the substitution of CO₃ for PO₄.

Fluorine ranges from 0.18 to 3.4 % with an average of 1.8 % (Table 2). According to McClellan (1980), the ideal fluorine content for pure fluorapatite is 3.77%. The F content of the Ain Giffara phosphorites is less than the ideal value and this means that this phosphorite not lies in the range of fluorapatite but is francolite. On the other hand, Price and Calvert (1978) pointed out that a small proportion of fluorine might be associated with the organic matter and other constituents.

CO₂ content of 40 samples of clastic and carbonate facies showed that, the CO₂ content in phosphatic sandstone ranges from 1.5 to 18 % and in phosphatic carbonate lithofacies ranges from 25 to 40 % (Table 1). Generally, the relationship of total CO₂ to the other major and minor constituents are difficult to asses due to the presence of extraneous phases, especially accessory carbonates and

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aluminosilicates. The organic carbon was measured in phosphatic sandstone and phosphatic dolostone of Ain Giffara Formation. Table (1) showed the enrichment of *organic carbon* in phosphatic sandstone (0.3-0.75 %) and low abundance or traces in phosphatic dolostone (0.03-0.09 %). This means the increase of organic matter with increasing phosphatic grains in the sandstone rock indicating the genetic relationship between the two components.

Na₂O and MgO values (0.7 to 1.5 % and 0.4 to 22 % respectively) by XRF analyses are higher values relative to those obtained by microprobe analysis (0.44 % and 0.08 % respectively) (Tables 1&2). High values measured by XRF are thought to reflect the contributions from mother mineral impurities. The high MgO content in these samples resulted from the presence of Mg-glaucinite and Mg-carbonate (Rooney and Kerr 1967) or authigenic phase (Burnett 1974). The high Na content, on the other hand, may be attributed to detrital contributions or halite.

According to the hypothesis cited by McArthur (1978), all marine apatite form with a constant initial composition containing 2.9 % of *SO₄*, which is reduced in a systematic manner by weathering to low concentration. In comparison with the bulk analysis (Table 1) showed the average value of *SO₃* reach to 1.5 % and the microprobe analysis showed average value of *SO₃* is 1.33 % (Table 2). Sulphur occurs in phosphorites in four different forms: a) organic sulphur, b) gypsum and anhydrite, c) sulphides, mainly pyrite, and d) sulphate within the apatite structure (Rooney and Kerr 1967, Stow

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1969; Powell et al. 1975). The substitution of PO_4 by SO_4 has been suggested by some researchers (McConnell 1973; Gulbrandsen 1966; McArthur 1978). In the present work the substitution probably occurs between S and P contents. The petrographic examination for the samples confirmed the occurrence of organic matter and black points of pyrite (Fig. 6C and 7F). S content is associated with the presence of organic matter and pyrite.

Average values for *Fe* (3.8 %, Table 1&2) is about six times that obtained by microprobe analysis (0.62 %). The iron in phosphorite is known to be in the pyrite phase, the occurrence of which in the samples has been supported by thin section examination (Fig. 5C). *Mn* in the bulk samples is enriched to an average of about 0.17 % (Table 1) but by using the electron microprobe analysis of phosphorites it reaches to the half value with average 0.042 % (Table 2). According to Tooms *et al.* (1969), Mn is considerably enriched in phosphorite relative to sea water, but is depleted in comparison with crustal abundances. Mn may be contained in the apatite phase (Altschuler et al. 1958 and McClellan 1980). In the present work the values of Mn is lower value in the microprobe analysis relative to its value in the samples analysed by XRF due to the effect of some impurities as an additional source of Mn in the samples.

Al_2O_3 , SiO_2 and K_2O were measured by microprobe analysis for the phosphorite grains (Table 2). These compounds have an average values 0.14 %, 0.41 % and 0.09 % respectively. These elements are reported by Cook (1972) as a major elements tied

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primarily to the detrital contaminants in phosphorites and located outside the apatite lattice. Al_2O_3 and K_2O signifying the presence of an extraneous aluminosilicate phase, whereas K_2O and SiO_2 signifying the presence of glauconite.

Trace Elements

Barium content in the phosphatic samples have low value with average 75 ppm. Arrhenius (1963) have shown that Ba occurs in the lattice of pelagic fishbone apatite, its depletion in phosphorites may reflect the general impoverishment of sea water in this element. *Cr, V and Zn* occurred in the phosphorite with variable values 93 ppm, 186 ppm and 165 ppm respectively (Table 2) and approximately similar to the global phosphorites in the world ($\text{Cr}=125\text{ppm}$, $\text{V}=100\text{ ppm}$, $\text{Zn}=195\text{ ppm}$ according to Altschuler 1980). Cr, V and Zn are thought to be associated with organic matter (Krauskopf 1956 and Gulbrandsen 1966). Some of these elements may occur as sulphides or coprecipitated within pyrite in organic rich-sediments (Fleischer 1956), some are possibly retained by adsorption on clay particles or apatite crystallites, other possibly enclosed within the apatite lattice, or some are probably the result of epigenetic mineralization (Cook, 1972). V and Cr are included in the phosphorite of Ain Giffara due to its association with pyrite and organic matter in marine phosphorites (Bonnot-Courtois and Flicoteaux, 1989).

Y and Ti in the phosphorite of Ain Giffara Formation have an average values 736 ppm and 154 ppm respectively. The global values of these elements in the phosphorite of the world are $\text{Y}=260\text{ ppm}$ and $\text{Ti}=640\text{ ppm}$ (Altschuler, 1980). In Ain Giffara phosphorite Ti is

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abnormally depleted and Y enriched relative the global phosphorites. The depletion of Ti relative to the global phosphorites can be assigned to the occurrence of Ti in insoluble minerals as ilmenite (Altschuler 1980). The concentration of Y in phosphorites may be accounted for by fractionations in marine environment (Piper 1974b). The substitution of Y in apatite appears to be reasonable due to the similarity in its ionic size with Ca (Cruft 1966), which probably reflects its enrichment in marine phosphorites.

DEPOSITIONAL MODEL OF PHOSPHORITE

The hypotheses on the origin of marine phosphorites date back to the last century and considerable progress has been achieved during the last decades. Many attempts have been proposed by different authors (Youssef, 1965; Trudinger, 1979; McConnell, 1965; Lucas *et al.* 1977; Slanky, 1986 and Waples 1982) to review some of the various theories that have been proposed for the genesis of marine phosphorites. All of them gave a basis for further discussion concerning the possible mode of phosphorite formation. The question about the origin of sedimentary apatite can be approached from two directions (Kolodny 1980). The first direction is required to understand the stability field of francolite and the kinetics of its crystallization. The second direction to understand where, within the geochemical cycle of phosphorus. The answer on the first direction must be rely on experimental studies whereas the second problem is to identify the environments of deposition of phosphorites, must primarily be solved by analysis of field data.

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The origin of Egyptian phosphorites have been suggested by Ball (1913) who referred the origin of Egyptian phosphorite to the accumulation of bones and phosphate-bearing limestones through the dissolution of calcium carbonates by water enriched by CO₂. Youssef (1958) pointed that the most of the deposits of the Egyptian phosphorites are associated with synclines. Philobos (1985) is of the opinion that a biochemical, rather than upwelling origin of phosphorite sediments in Egypt. El-Kammar (1977) studied the mineralogical and geochemical characteristics of Gebel El-Hefhuf phosphate bearing rocks in the depression of the Bahariya Oasis. He concluded that the phosphorites of the Bahariya Oasis are composed of francolite deposited in shallow marine environments with prevailing reworking and stirring by waves. Abdel-Rahman (1992) studied the geochemical, mineralogical and sedimentological studies of the Nile Valley phosphorites between Qena and Idfu. He concluded that the Nile Valley phosphorite is fluorapatite deposited in shallow marine environment under reducing oxidizing conditions.

The summary given below is an attempt to review some of the various theories that have been proposed for the genesis of marine phosphorites to give a basis for further discussion concerning the possible mode of formation of the Ain Giffara phosphorites.

1- The first concepts of the origin of phosphorite deposits is a biochemical mode of formation, controlled by the configuration of the sea floor, being folded into shallow synclines and anticlines. This mode is suggested by Youssef (1965) to explain the genesis of bedded phosphorite. Decaying organisms on the bottom of depressions

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produce ammonium phosphate and ammonia which are oxidized by nitrogenous bacteria into nitrates. On death, the biota fall to the bottoms of the sea floor depressions, where the amounts of soluble phosphates increase beyond the needs of the animals and plants living above. The ammonium phosphate reacts with Ca ions or with precipitating CaCO_3 to give insoluble calcium phosphate.

Reviewing the role of organisms in the formation of phosphate, three hypotheses have been reported by Trudinger (1979):

- Biological reduction of phosphate to soluble hypophosphites followed by oxidation of the latter in aerobic environments with the formation of apatite (Gulbrandsen 1969).
- Modification of the CO_2 -bicarbonate-carbonate equilibrium which in turn controls phosphate deposition (McConnell 1965).
- Accumulation of phosphate by phytoplankton followed by incorporation of the plankton into sediments and the release and fixation of phosphate (Youssef 1965; Gulbrandsen 1969).

2- Replacement has been a rather well-accepted hypothesis to account for the phosphatization of calcareous material observed in the geological record. Observations on phosphate grains originating from the replacement of previous calcareous bioclastics or lithoclastics have led various authors (Lucas *et al.* 1977; in Slanký 1986 and in Waples 1982) to conclude that the epigenesis of carbonates plays an important role in phosphate formation.

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3- The interstitial water in the anoxic sediments may offer much more favourable conditions for apatite formation. The formation of apatite in this micro-environment is favoured in many aspects:-

- bottom conditions may expose the organic matter to an intensive microbial alteration which gives rise to phosphorus supersaturation in the interstitial waters (Baturin 1972).

- the high Mg^{+2} concentration in open seawater may inhibit the precipitation of apatite (Martens and Harris 1970). Drever (1971) has suggested that Mg^{+2} may replace Fe^{+3} in clays under anoxic conditions. Other mechanisms suggested to remove the interfering Mg^{+2} ions include substitution of Mg^{+2} for Ca^{+2} in carbonates (dolomitization) and the authigenic formation of Mg-rich silicates.

- the solubility of carbonate fluorapatite increase with decreasing temperature (Baturin (1971b).

The origin of Ain Giffara phosphorites in the middle and southern escarpment of the Bahariya Oasis depends upon field observation, petrographic examination and geochemical analyses. The field observations showed the high abundance and concentration of the phosphorite in sandstone of the lower members as thin beds (20 cm to 70 cm thick) with burrows in the basal part of beds which separated by grey claystone (5-15 cm thick). Phosphatic sandstone in the lower member changed to dolomitic sandstone in upper part. The upper member is mainly dolostone with very low abundance of phosphorites. Gebel El-Hefhuf is a synclinal structure in the depression but in the southern escarpment east and west of Naqb es Sillim sections lies on the flanks of the El-Heiz anticline. The high accumulation of phosphorite on the synclines (Youssef, 1958) and the flanks of

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structural highs increase the wave and storm current activity (Woodrow & Isley, 1983). The presence of burrows indicate the effect of storm wave actions and bioturbation.

Petrographic examinations subdivided the phosphatic grains into skeletal (bone fragment and teeth) and diagenetic. Diagenetic grains include structureless peloids. The oolitic grains have not been observed in these deposits. Peloid grains usually predominante and often contain clots of organic matter and pyrite (Fig. 6C & 7F).

Chemical analyses by using XRF for the phosphatic samples and the mineral chemistry of major and trace elements of peloids and skeletal particles of phosphorites resulted that the marine phosphorites and francolite dominant mineral according to the value of F element. CaO value in phosphorites indicate the pure francolite mineral which likely related to the substitution of CO_3 for PO_4 . High amounts of Cr, V, Zn and Y in Ain Giffara phosphorites are characteristic of marine phosphorites.

Some authors applied the upwelling model to the genesis of Egyptian phosphorites (El-Tarabili 1969; Glenn & Mansour 1979; Kamel 1982; Schrotter 1986; and German, *et al.* 1987). The depositional model of the Ain Giffara phosphorites have been proposed for the development of the Cretaceous oceanic anoxic bottom conditions accordingly to Schanger and Jenkyns (1976), Fischer and Arthur (1977), Heckel (1977) and Jenkyns (1980). Also, Germann *et al.* (1987) drown a depositional model for the Upper Cretaceous

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phosphorite deposits in Egypt and showed the Bahariya affected by uplift of basement and upwelling current with prevailing wind action toward the west direction (Fig. 8). Based on a combination of the data presented in this study together with the above discussions on the different theories of phosphorite origin, a proposed depositional model for the formation of Ain Giffara phosphorite (Fig. 9), is postulated as follows:-

1- The Campanian Ain Giffara Formation deposited in a basin as sandstone in shallow and limestone in the in the deep-water basin of the Tethys where over millions of years phosphorites had accumulated in solution.

2- Apatite precipitated as soft colloidal microcrystalline mud either biochemically or physiochemically within the interstitial microenvironments under weakly to strongly reducing conditions along the OMZ (Oxygen Minimize Zone of Burnett et al., 1980 and Arthur and Jenkyns 1981). The skeletal material such as bones and teeth were rained into the sediment system. The phosphorite mud settled out under low-energy conditions (Riggs, 1979) and were subsequently broken up by biological and physical processes producing intraclasts. The phosphorite pellets may result from either abundance of nucleation sites in pore waters or from gentle agitation of sediments coinciding with apatite precipitation or both (Berg and Jack, 1982).

3- The reducing nature of the interstitial microenvironments of phosphorites and anoxic conditions are supported by the presence of:
1) Organic matter and 2) Pyrite. Field observations have indicated that

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basal contacts of the phosphorite beds are highly burrowed due to the bioturbated, a feature which suggests the storm currents periodically helped to aerate normally oxygen-deficient waters (Glenn and Mansour 1979).

4- During the high stand sea level, a zone of oxygen-poor water, possibly part of an expanded OMZ intersected with the sea floor. At the edge of this zone the conditions have favoured the precipitation of phosphorites. At this zone the low-oxygen water column might minimize decomposition of the organic material prior to burial and thus ensure maximum supply of dissolved phosphorus to the pore fluids. Decaying organisms on the bottom of the depressions produce ammonium phosphate and ammonia which are oxidized by nitrogenous bacteria into nitrate (Youssef, 1965). The ammonium phosphate react with precipitating CaCO_3 to give insoluble calcium phosphate.

5- During low stand sea level, mechanical enrichment and concentration of the phosphatic grains under oxic conditions in a shallow, high energy environment, the resulting allochems from skeletal materials were then transported as clastic particles along shoals with the associated terrigenous, carbonate and fossils inclusions during a periodic high energy conditions, upwelling current and bioturbation. The sediment were winnowed to concentrate the phosphorites (Cook, 1967) by remove fine mud by current and the coarse allochems remained.

CONCLUSIONS

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Ain Giffara Formation is Campanian age remarked in the south to middle part of the Bahariya Oasis and disappeared in the northeastern escarpments. Eight stratigraphic sections were measured and correlated with the Duwi Formation at Red Sea, Nile Valley and Abu Tartur. Different types of clastic and carbonate lithofacies of Ain Giffara phosphorites resulted the association of phosphorites with organic matter and pyrite spheres. Geochemical analyses aids with field observation and petrographic examinations concluded the following:-

- 1-) Ain Giffara phosphorites deposited in synclinal basin or on the flanks of anticlines and accumulation of phosphorites from deep water reservoir of Tethys over million years.
- 2-) The skeletal phosphorites settled out under low-energy conditions producing intraclasts transported by periodic high energy conditions. The phosphorite pellets may result from either abundance of nucleation sites in pore waters or from gentle agitation of sediments coinciding with apatite precipitation or both.
- 3- The presence of organic matter and pyrite indicated a reducing nature of the interstitial microenvironments of phosphorites and anoxic conditions suggested a storm currents periodically helped to the aerate normally oxygen-deficient waters.
- 4-) During low stand sea level, the concentration of the phosphatic allochem under oxic conditions in a shallow high energy environment which winnowed and concentrated the phosphatic grains.

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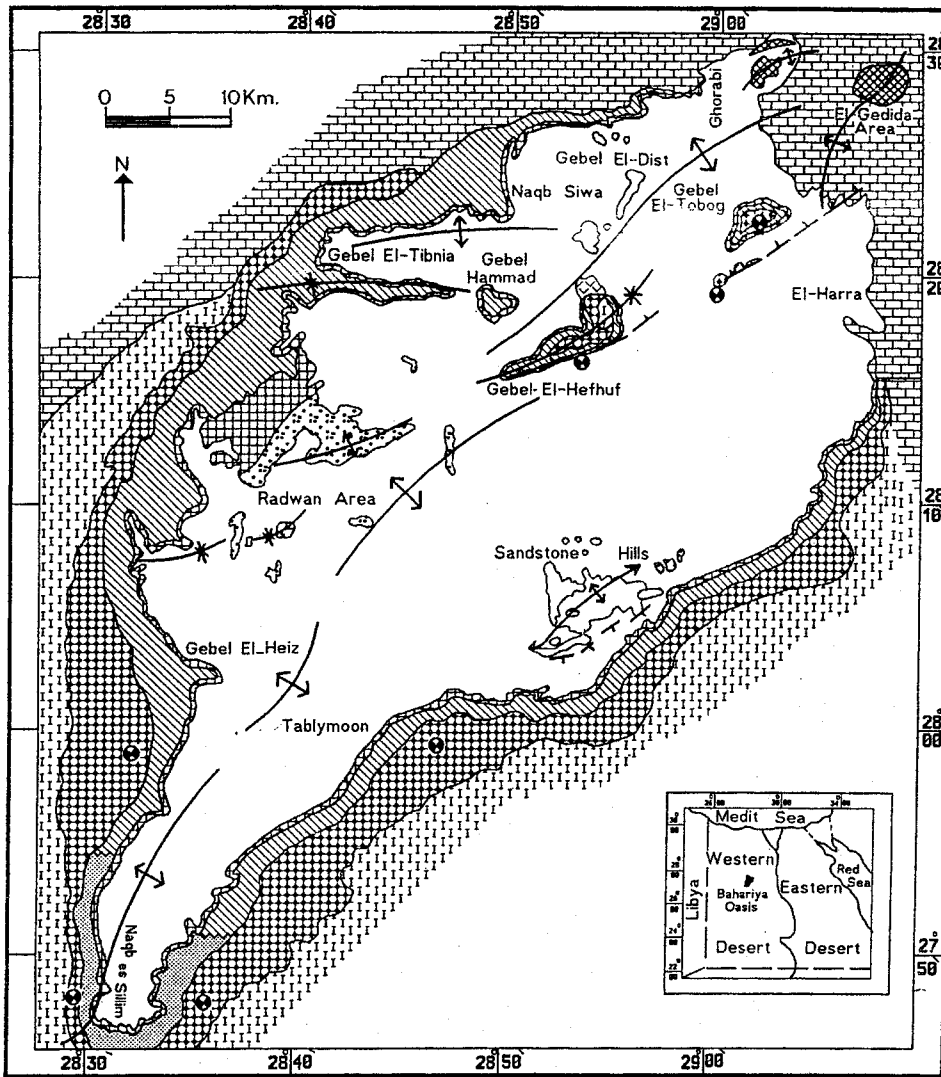
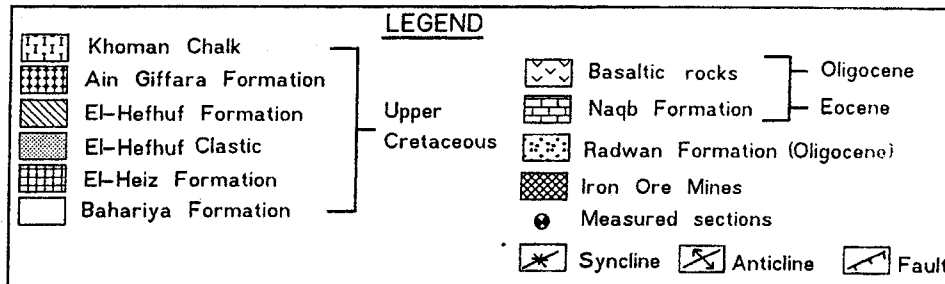


FIG. (1). GEOLOGICAL MAP OF THE BAHARIYA OASIS (El-Akked and Ismael 1953 with modification of Abu El-Heesan 1994)



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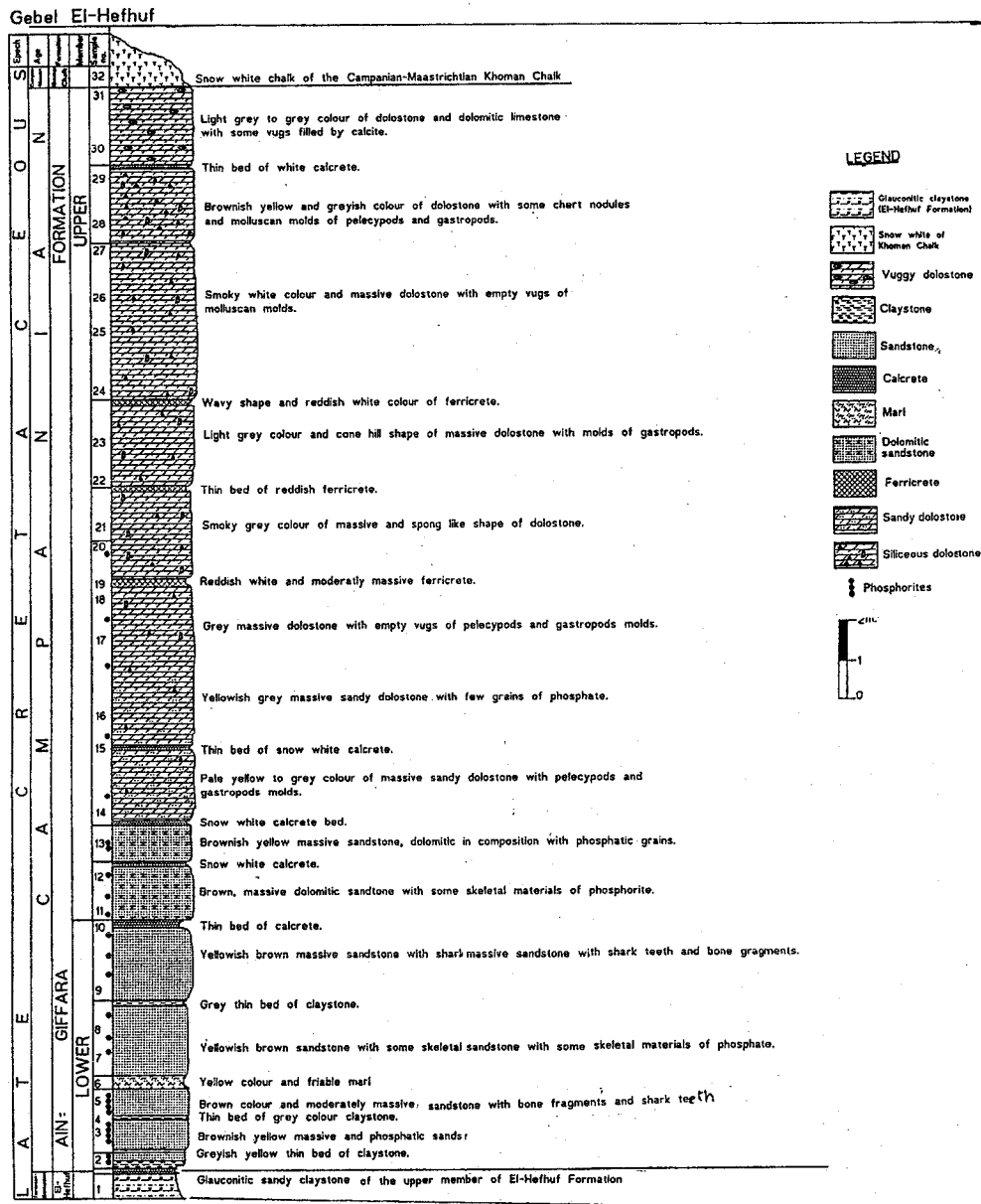


Fig. (2): Lithostratigraphic column of the Ain Giffara Formation at Gebel El-Hefhuf (type locality) in the Bahariya depression.

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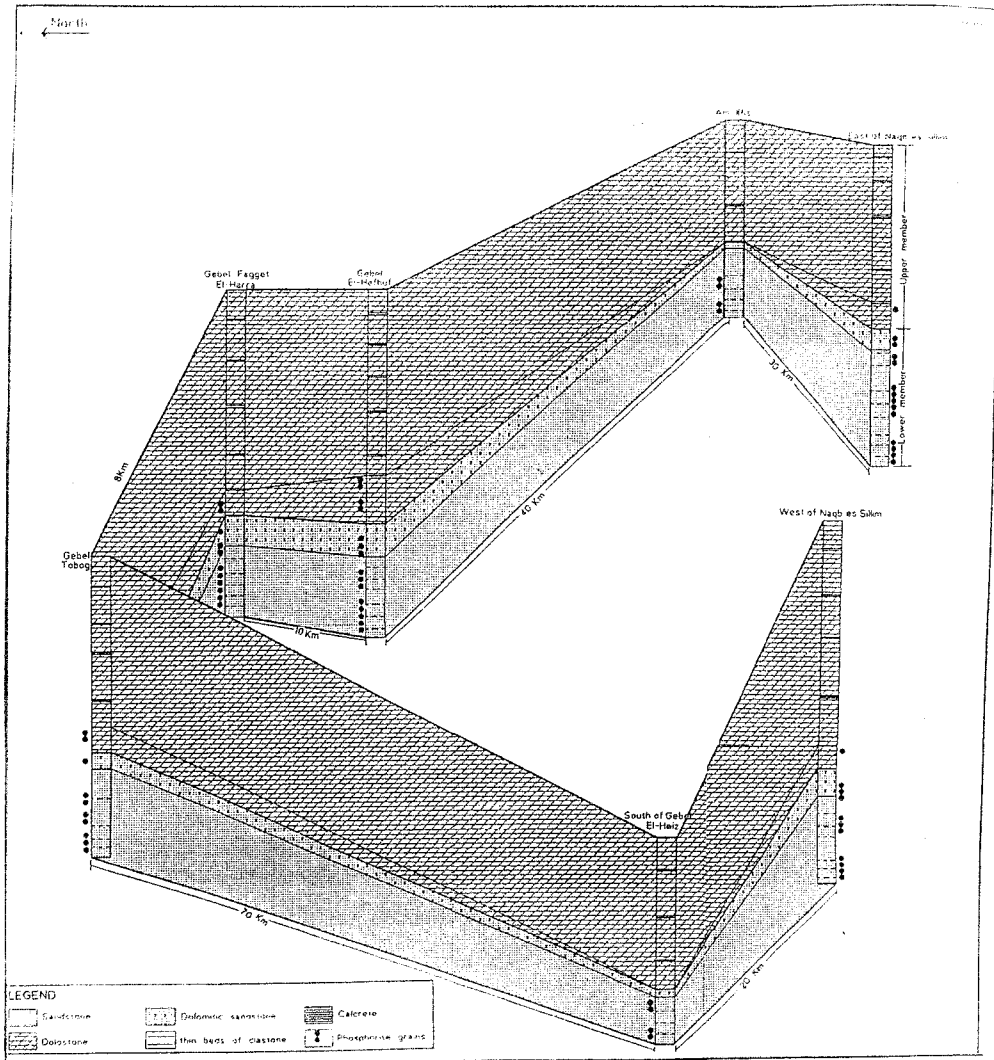


Fig. (3)-Panel diagram showing the lithofacies distribution of seven stratigraphic sections of Ain Giffara Formation allver the Bahariya Oasis.

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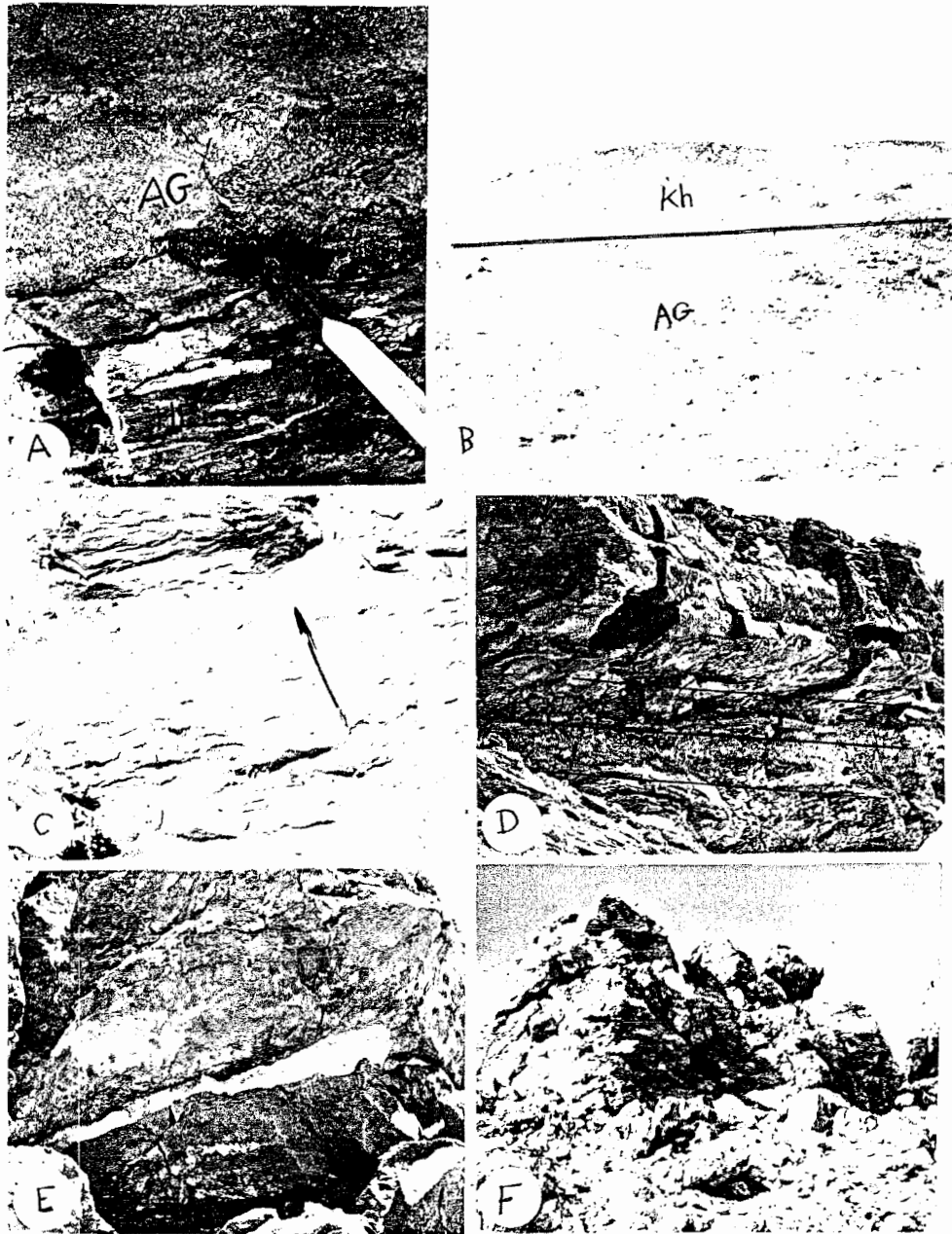


Fig. (4): Field photographs of the Campanian Ain Giffara Formation describes in A) the unconformable lower contact between glauconitic claystone of El-Hefhuf (HF) and Ain Giffara Formation (AG). B&C) The unconformable upper contact between Ain Giffara Formation (AG) and Khoman Chalk (Kh) with angular fragment of phosphatic dolostone in white chalk matrix, D) The lower sandstone member showed intercalation of phosphatic sandstone with thin bed of claystone, E) White calcrete between phosphatic dolostone of the upper member and F) Cone hills of the upper dolostone member with empty vugs of molluscan molds.

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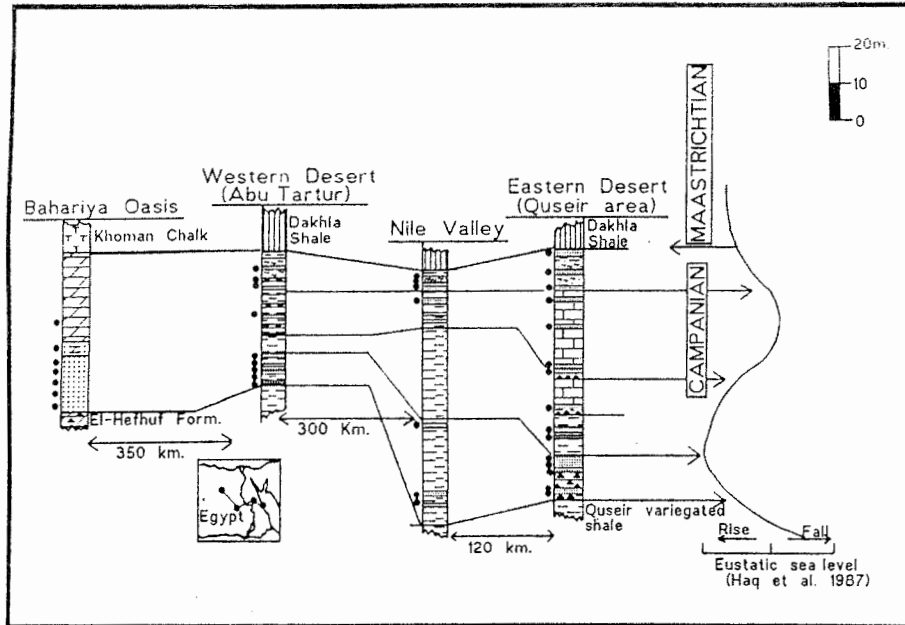
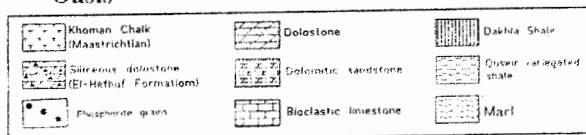


Fig. (5): Interpretive correlation diagram for Western Desert, Nile Valley and Eastern Desert phosphorite of Glenn and Arthur (1990) and its correlation with the Ain Giffara phosphorite in the Bahariya Oasis



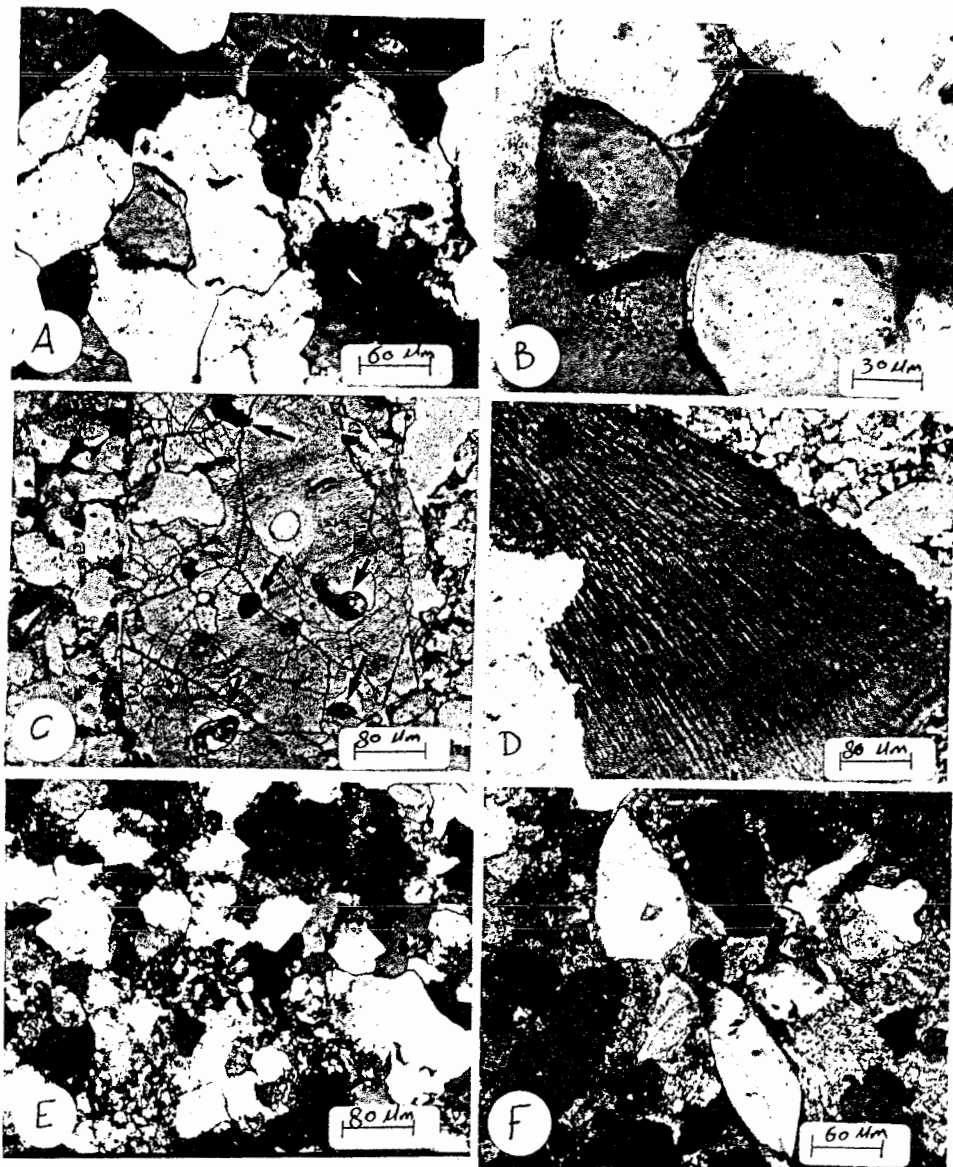


Fig. (6): Photomicrographs of the lower sandstone lithofacies of Ain Giffara Formation identified in A) quartzarenite lithofacies, B) high magnification of A) showed a concavo-convex contact between quartz grains, C) pelloids of phosphatic litharenite showed a black spheres of pyrite and organic matter (arrows), D) skeletal bone fragment in phosphatic litharenite, E) siliceous quartzarenite with microquartz deposited in pore spaces, and F) dolomitic quartzarenite lithofacies showed dolomite rhombs cemented the quartz grains.

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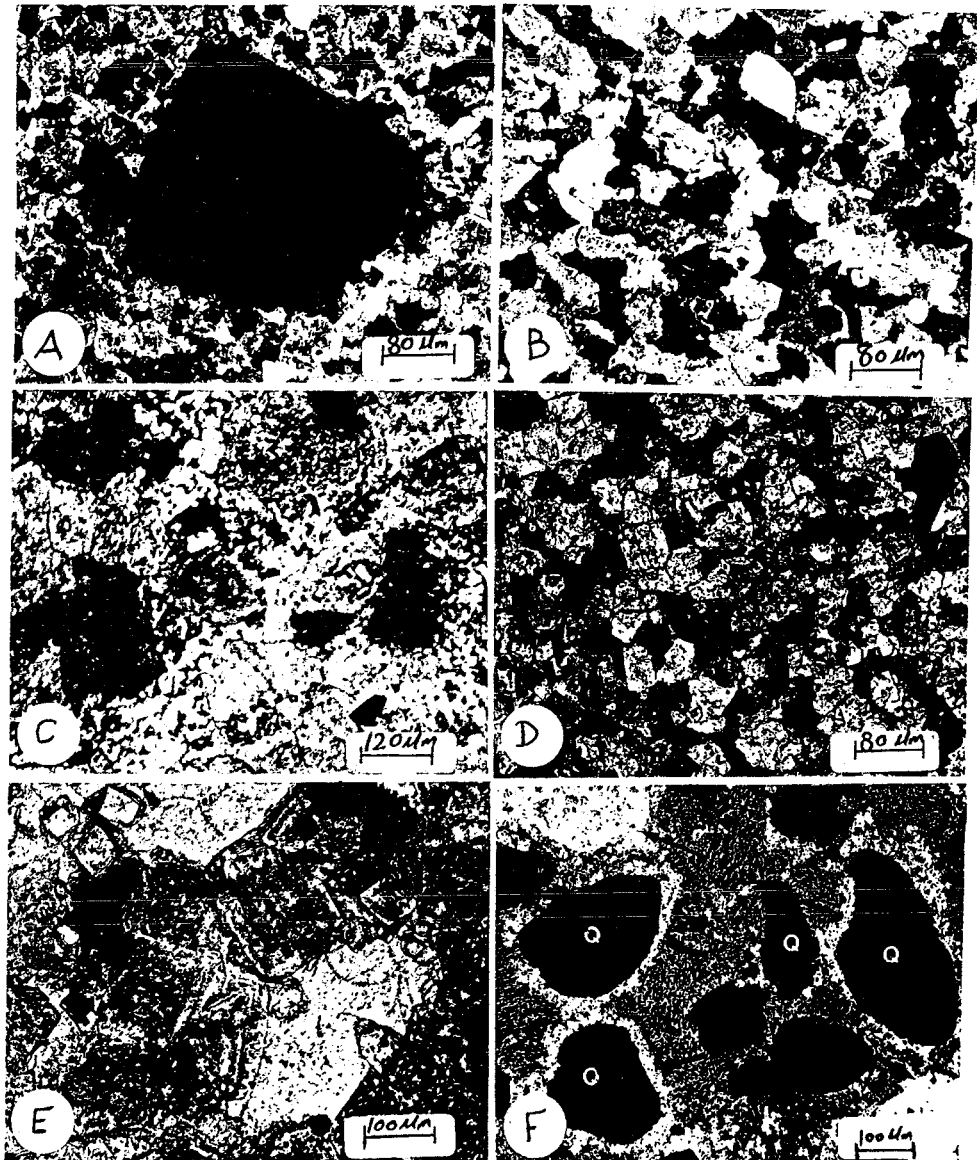


Fig. (7): Photomicrograph showing the dolostone lithofacies of the upper member of Ain Giffara Formation identified in A) Phosphatic dolostone lithofacies, B) Sandy dolostone lithofacies, C) Siliceous dolostone lithofacies showed the microcrystalline quartz in pore spaces, D) Sucrosic dolostone lithofacies, E) Dedolostone lithofacies showed relics of dolomite rhombs in blocky calcite cement and F) Backscattered image showed quartz grains (Q) surrounded by phosphate rims (arrows).

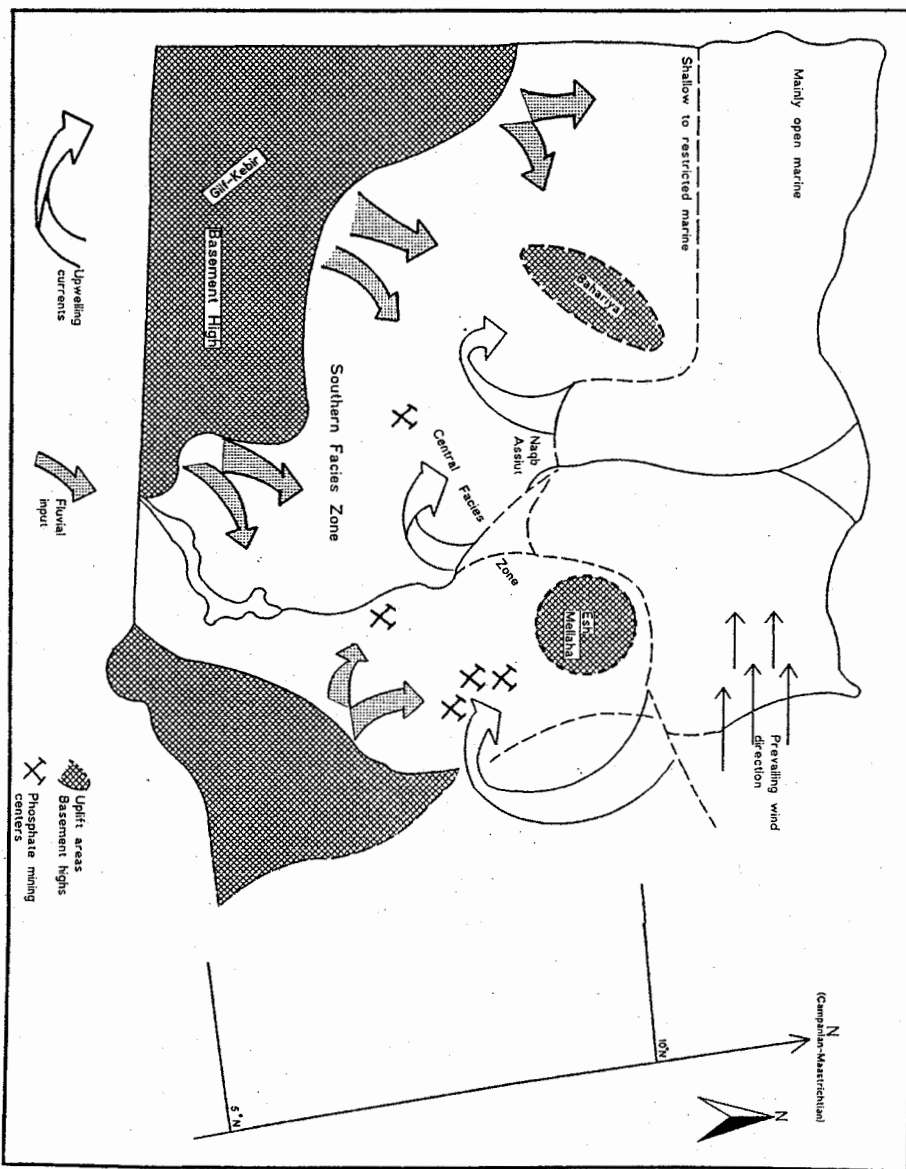


Fig. (8). The depositional model for the Upper Cretaceous phosphorite deposits in Egypt after German et al. (1987).

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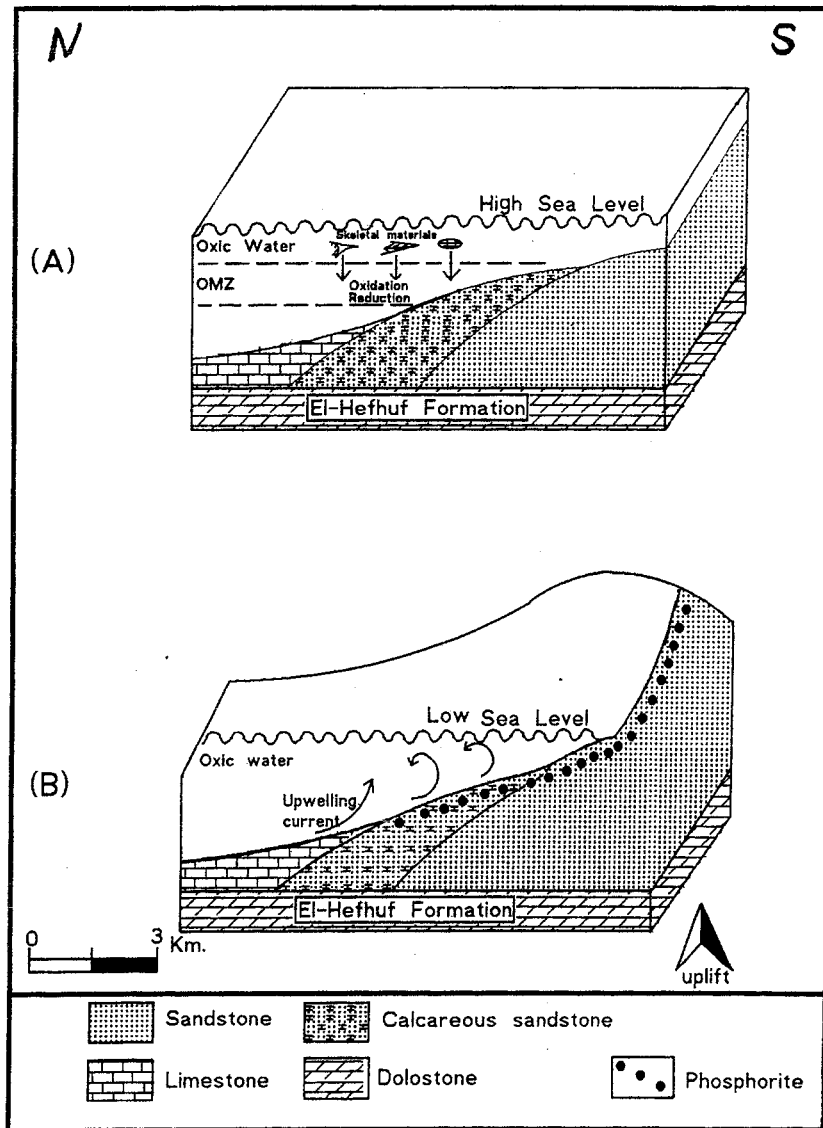


Fig.(9): Proposed depositional model for the Ain Giffara phosphorites