

Geology and Mineralogy of Jabal Kabid Phosphorite Deposits, Southeastern Jordan

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Abstract

The phosphorites of *Jabal Kabid* (Campanian-Maastrichtian), crops out along the southeastern extension of Ras En Naqab - Batn Al Ghul escarpments, are up to 20 m thick and unconformably overlie the Upper Cretaceous-Batn Al Ghul Group. The phosphorite sequence in the study area shows lateral variations in lithology, thickness and distribution of the phosphorite beds. Generally, phosphates at these localities form approximately 50% of the sequence and occur as beds, up to 1.4 m thick. The petrographic studies indicate the presence of phosphate pellets, bone fragments, fish teeth, and phosphate intraclasts. The main phosphate mineral is francolite. Chemical results indicate that P₂O₅ content of the phosphate beds increases upwards in the sequence from 8.0 to 26.42 %. The SEM-EDS results indicate that the P₂O₅ content ranges between 36.98-41.67%. The phosphorites, in the study area, were deposited in a marginal marine environment close to the shore line.

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1. Introduction

Economic phosphorite deposits are present in Jordan in Rusiefa, Qatrana, Al Abyad, Al Hasa, and Ash-Shidiya areas (Fig. 1). The phosphorites in Jordan are found in the phosphorite member of Bender (1974), the topmost of Amman Formation of Masri (1963), and Maastrichtian in age according to Burdon (1959). The term Al Hisa Phosphorite Formation (AHP) (Campanian-Maastrichtian) is adopted by the National Geological Mapping Project (Natural Resources Authority).

New deposits were discovered in northwest Jordan (Mikbel and Abed, 1985). The phosphate of Jordan is part of the Upper Cretaceous-Eocene Tethyn Phosphorite Belt stretching from Morocco to Turkey, Syria, Iraq, Saudi Arabia, and Palestine (Klemme, 1958; Sheldon, 1964; Notholt *et al.*, 1989). The belt belongs to South Tethyn Phosphogenic Province (STPP); a carbonate-dominated phosphorite giant that is composed of greatest accumulation of known sedimentary phosphorites and hosts 66% of the world's phosphate reserve base and accounts for approximately 30% of global phosphate rock production (Pufahl *et al.*, 2003). The Jordanian phosphorites were deposited in the transitional zone between a stable shelf in the south and the Tethys Sea in the north Jordan due to the upwelling currents (Bender,

1974). Details on the geology, petrology, mineralogy, chemistry and genesis of phosphate deposits are found in Reeves and Saadi (1971), Khalid (1980), Khalid and Abed (1982), Abed and Khalid (1985), Al-Agha (1985), Mikbel and Abed (1985), Abed and Ashour (1987), Abed and Al-Agha (1989), Abed and Fakhouri (1990, 1996), Abed *et al.* (1992), Tarawneh (1997), Pufahl *et al.* (2003), Tarawneh and Moumani (2006), Tarawneh (2006), and Abed *et al.* (2007).

The following work is the first detailed study of the phosphorite deposits along the southeastern part of Batn Al Ghul Escarpment (Jabal Kabid/Naqab Etaiq area) in southeast Jordan (Fig. 1). The aim of this research is to investigate the petrology, mineralogy, chemistry and genesis of phosphates at this locality.

2. Geological Setting

The phosphorite deposits crops out in the southeastern part of Jordan along the southeastern extension of Batn Al Ghul Escarpment (Jabal Kabid /Naqb Etaiq area). The area is situated to the southeast of Ash Shidiya Phosphate Mine; close to the Saudi Arabia border (Fig. 1).

The phosphorite deposits (20m thick) rest unconformably on the Upper Cretaceous of Batn Al Ghul Group (Fig. 2).

The phosphorite sequence shows lateral and vertical variations in lithology, thickness and distribution of the phosphorite beds (up to 1.4m thick). The phosphorite beds occur at several levels, increase upward and intercalate

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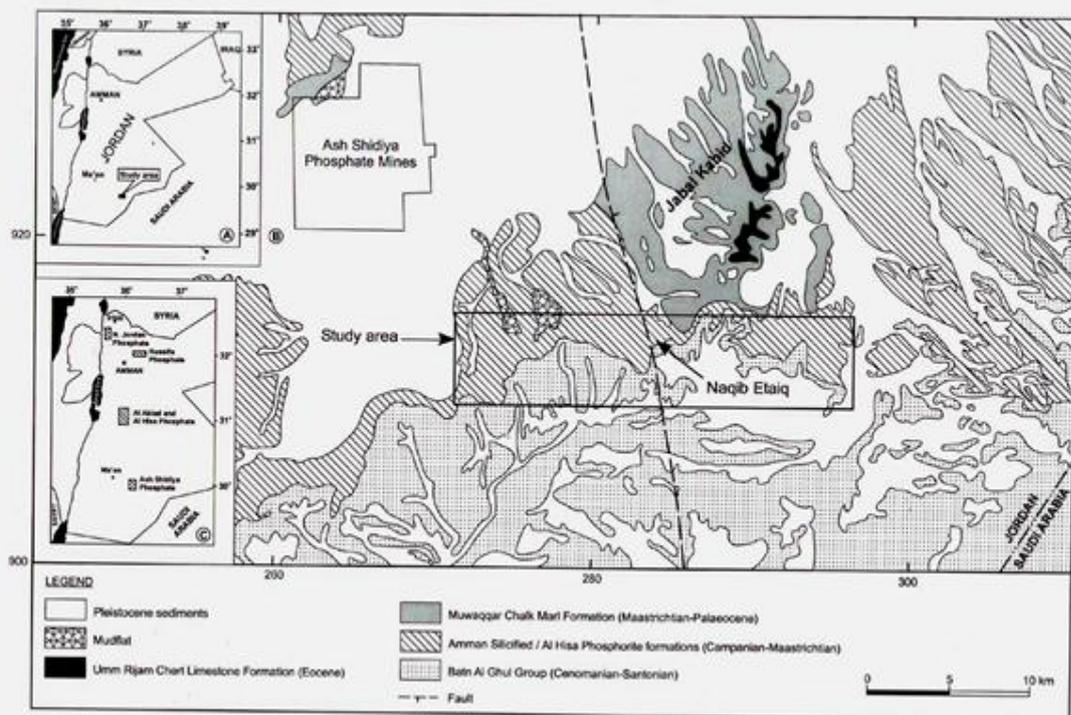


Fig. 1: A) Location map, B) Simplified geological map of the study area, C) Distribution of the phosphate deposits in Jordan.

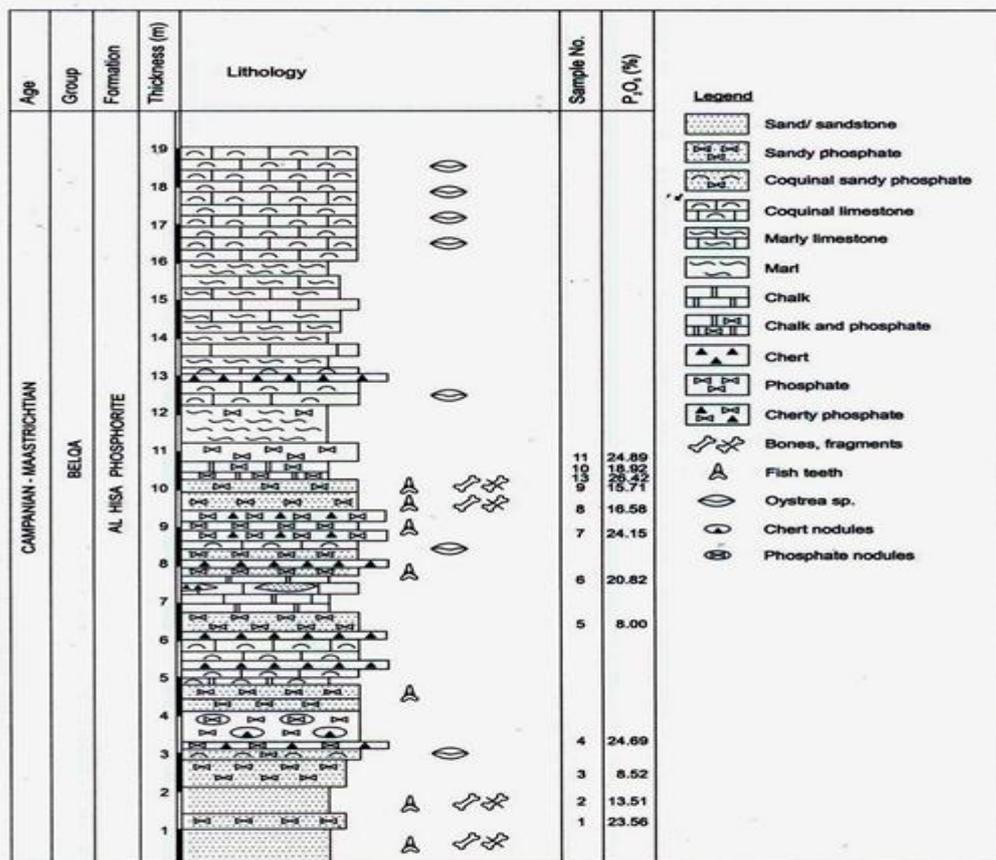


Fig. 2: Graphic log of Al Hisa Phosphorite Formation in Naqib Etaiq area.

with fine to medium-grained sand and sandstone, limestone, coquina, chert, cherty phosphate, marl and chalky limestone with macrofossils in the basal and upper parts of the phosphate sequence. The coarse-grained granular sandy phosphate occurs in the basal and in middle parts of the formation. This bed is characterized by enrichment of fish teeth and bones. Generally, the contact between the phosphate beds and the interbedded lithologies are usually gradational. The P_2O_5 content is variable and increases upward in the sequence (Fig. 2). Generally, phosphates form more than 50% of the formation. Field observations indicate the presence of different phosphate fragments, as well as, bone fragments, reptile carapaces, and different types of fish teeth intensively occur in the friable sandy phosphate of the lower part of the geological section.

3. Field Work and Analytical Methods

The results presented in this work are based on detailed measurements of the phosphate sequence and sampling from typical localities in the study area. Petrographic studies were performed by using polarizing optical microscope type (Leica- DMLP). Thin and polished sections were prepared for detailed petrographic studies. X-ray fluorescence (XRF), X-ray diffraction (XRD) using Philips 1370 X-ray diffractometer, and Scanning Electron Microscope (SEM/EDS) using Jeol 6060 instrument were used to characterize the collected samples. Selected areas of the phosphates in thin and polish sections were investigated. The later utilized a Jeol 6060 instrument-high vacuum, equipped with a link 10000 Energy Dispersive Spectrometry (EDS) system. SEM coupled with back-scattered electron (BSE), and secondary electron image (SEI) microanalyses.

4. Results and Discussion Petrography

Petrographic examination has revealed that the phosphate grains, as peloids (pellets), constitute most of the phosphatic particles., particularly in the high-grade phosphorite beds. The pellets are structureless, sometimes oval in shape and uniform in size with smooth boundaries, dark in color with 0.060-0.5 mm in diameter grains (Fig. 3). Pellets are part of peloids which might be fecal in origin (Abed and Fakhouri, 1996). Through burial processes, peloids will become cemented and preserved (Bogg, 2006).

Intraclasts are also common in the studied phosphorites. They have irregular shape (up to 1cm in diameter) with internal microstructure. Some of these intraclasts are composed noncrystalline apatite or amorphous phosphate (Fig. 4). Skeletal fragments include bones and teeth of various sizes up to 1 mm in diameter. They made an important component of the phosphorite grains and concentrated mostly in the lowermost part of the sandy phosphate beds and in the friable quartzarenites in the basal part of the phosphate beds. Petrographically, the internal part of the phosphate particles is made of microcrystalline translucent apatite to noncrystalline (amorphous) type (Fig. 5). Many pellets show a relict structure of organic material. Some of the skeletal

fragments are replaced by microcrystalline quartz, indicating silicification. Coated grains of phosphate and microaggregates are present. They are generally larger than 0.25 mm, and are made of translucent apatite at the center and at the rim of these grains (Fig. 5).

Detrital quartz is abundant in the studied samples. The grains are rounded, subrounded to subangular with various sizes. It occurs as siliceous matrix, usually fine to medium grains. Silicification of some phosphate particles can be noticed in cherty phosphate horizon (Fig. 6). The cement is siliceous and is locally calcareous as a result of diagenetic silicification and partial calcitization. Silicification of phosphate particles has previously been reported by Kolodny (1969) from the northern Negev phosphorites. Cryptocrystalline dolomite and calcite (sparite) are present as cement, whereas secondary gypsum occurs in some micro-veins in thin sections.

In general, Jordanian phosphates are made up of four types of phosphatic particles; as peloids (pellets), intraclasts, skeletal fragments and coated grains (Abed and Al Agha, 1989; Khalid and Abed, 1982; Abed and Fakhouri, 1996; Pufahl, 2003; Tarawneh, 2006; Abed *et al.*, 2007). The composition of the phosphate in this study is similar to other Jordanian phosphates, with small differences in the amount of phosphatic particles in some parts of the phosphate beds.

5. Mineralogy and Chemistry

XRD results indicate that the major phosphate mineral is francolite (carbonate fluorapatite). The Calcite, quartz, dolomite are detected and trace of gypsum has been indicated (Fig. 7).

In general, the phosphate beds in the study area compared with the Upper Cretaceous phosphorite horizons in central and northern parts of Jordan. The beds are richer in SiO_2 and poorer in CaO, whereas the P_2O_5 content has a relatively wide range.

The P_2O_5 content ranges from 8.0 to 26.42%. This wide range of P_2O_5 content, in the studied samples, is mainly due to the admixture of non-phosphatic minerals such as quartz, calcite and dolomite. That is the reason of the weak relationship between the P_2O_5 and most of the oxides associated phosphatic facies. Most of the relationships are randomly oriented (Fig. 8). The positive relationships have been noticed between P_2O_5 with CaO and F, ($r=0.46$ and 0.32), respectively, whereas the negative relationships have been seen between P_2O_5 with CO_2 , SiO_2 , SO_3 and F/P_2O_5 ($r= -0.11, -0.51, -0.08, -0.71$), respectively.

The average content of SiO_2 in the study area is 29.91% and is mainly detrital quartz. In some cases, microcrystalline silica appears in the form of chalcedony filling some shells or as cement. According to Cathcart and Gulbrandsen (1973), silicon could replace phosphorous in the apatite lattice.

The CaO content ranges between 12.74-41.76%. Chemical analyses and microscopic investigations indicate that the major part of the carbonate materials is made of sparite and microsparitic calcite.

The MgO content in the studied samples ranges between 0.13 to 2.34%. Dolomite is only present in a few samples in the dolomitic sandy phosphate.

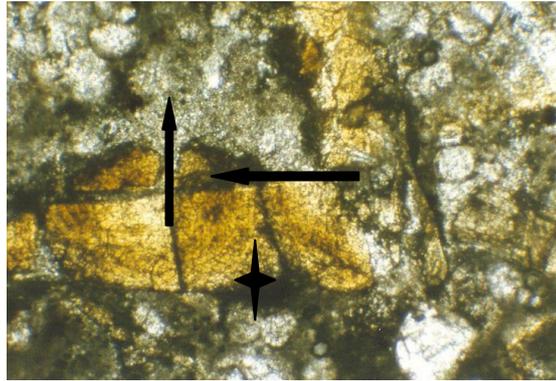


Fig. (3): Phosphate intraclast filling with translucent and amorphous phosphate (V-shape showing with an arrow) in sparitic to microsparitic cement and subrounded grains of quartz showing in stars, and fine-grained dolomite (PPL, X150).

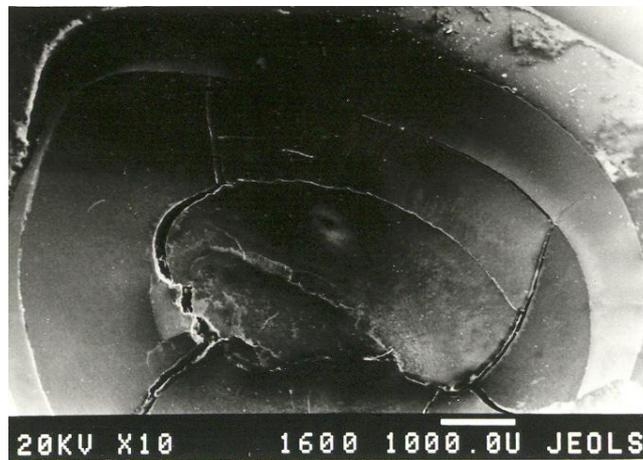


Fig. (4): Fish teeth with rounded smooth boundaries, filling with translucent anisotropic phosphate.

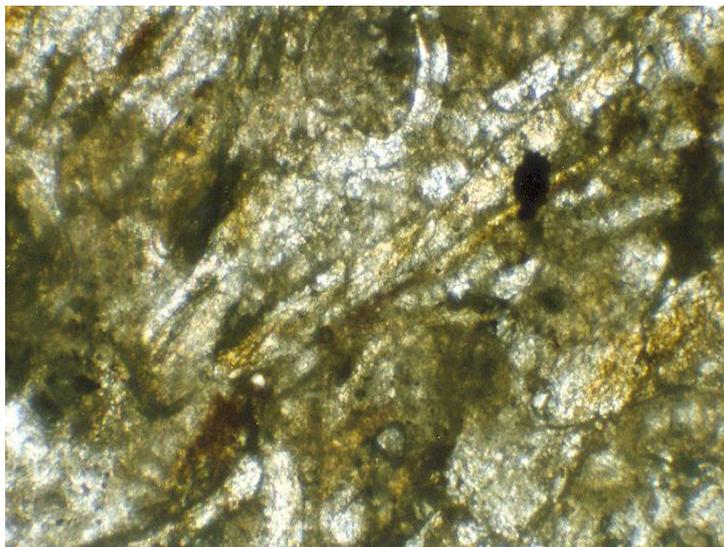


Fig. 5: microcrystalline to translucent apatite at the center and at the rim of skeletal fragments and noncrystalline phosphate (amorphous) filling them (PPL, 50X).

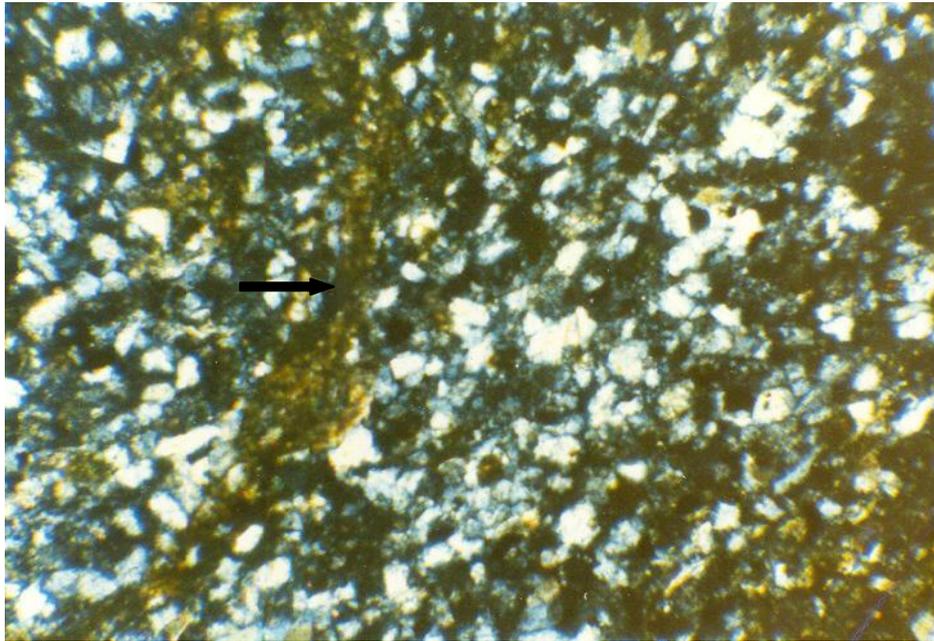


Fig. (6): Noncrystalline apatite (amorphous) filling the cavities (showing with arrow), surrounded with detrital quartz and chalcedony (.XPL,50X).

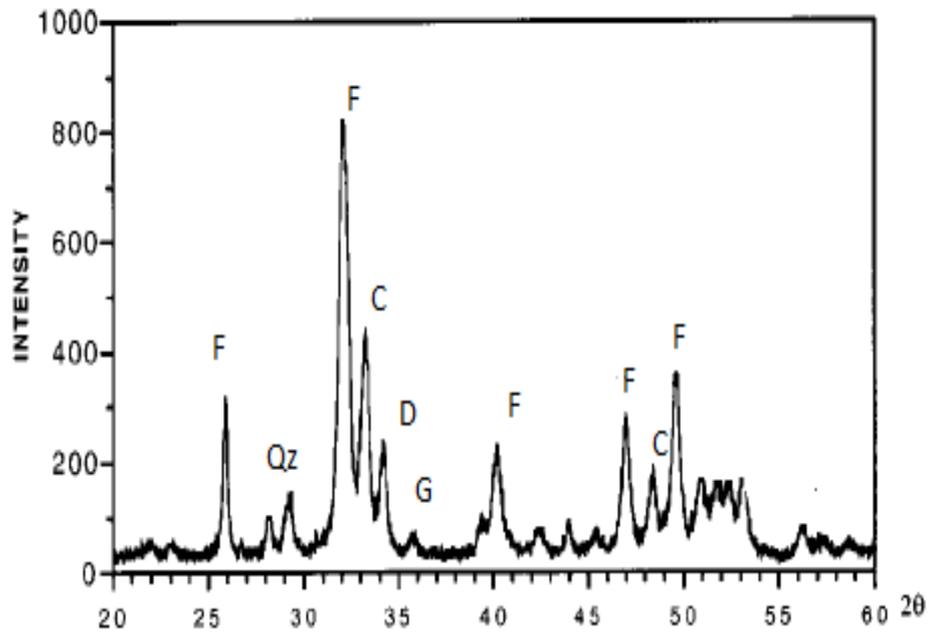


Fig. (7): XRD showing francolite (F), quartz (Qz), calcite (C), dolomite and gypsum (G) minerals.

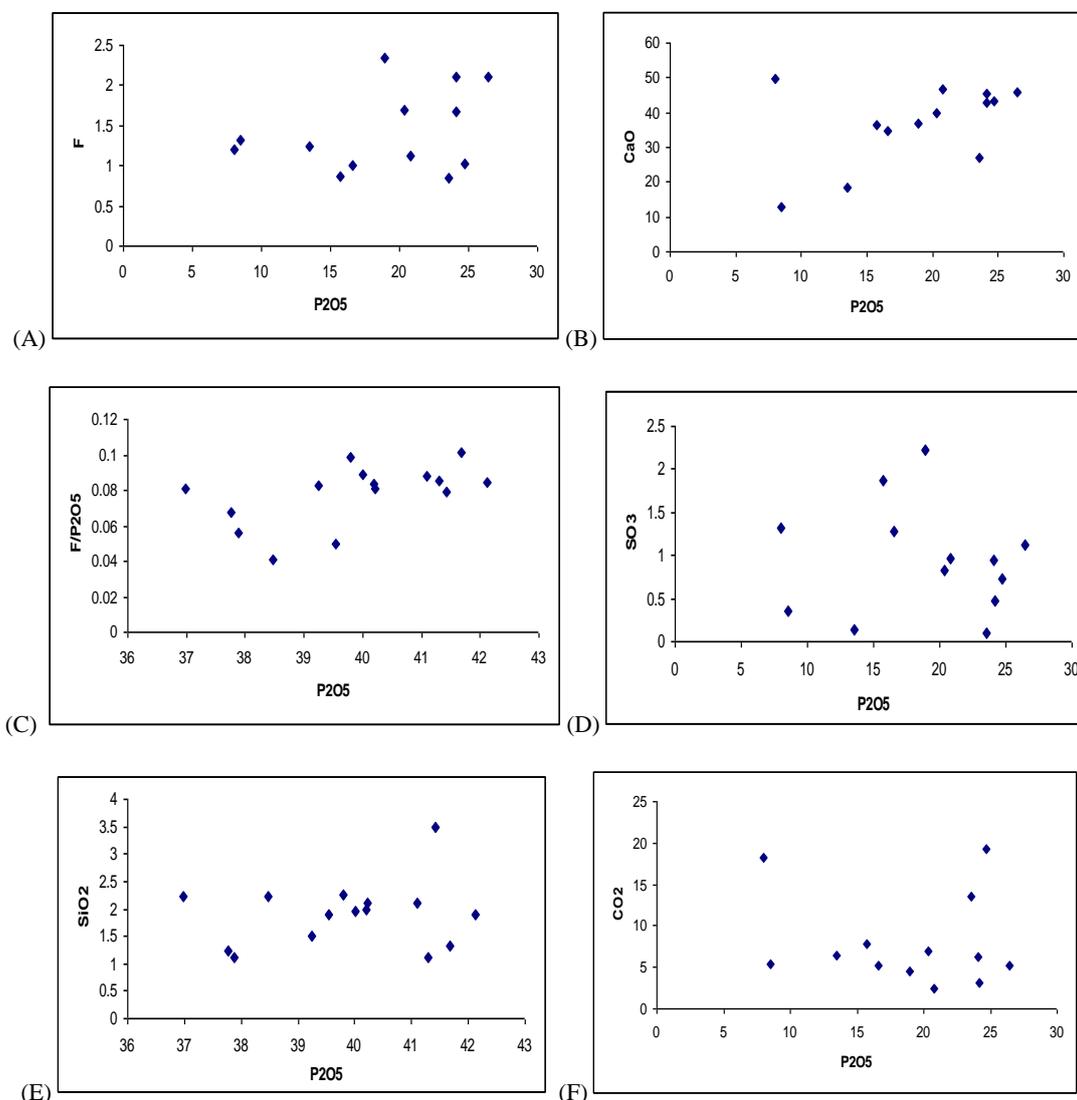


Fig.(8): Graphical representation demonstrating the relationships between: (A):P₂O₅:F; (B):P₂O₅:CaO; (C):P₂O₅:F/P₂O₅; (D):P₂O₅:SO₃; (E): P₂O₅:SiO₂; (F): P₂O₅:CO₂

Mg can replace Ca in apatite and calcite lattice (McClellan, 1980). The content of TiO₂, K₂O, Na₂O and Fe₂O₃ oxides is very low. The greatest amount of these oxides may be referred to the sandy facies.

The CO₂ content ranges between 1.28-18.29%. McConnell (1973) considered that the carbonate anionic group partly substitutes for PO₄ group. In the studied samples, CO₂ is mainly present in the carbonate and phosphate (francolite) facies.

The SO₃ content ranges between 0.10-1.87%. Sulphur may occur in the apatite structure as a normal constituent of phosphate lattice or in gypsum that was detected by X-ray diffraction as trace mineral. The (PO₄) group in the apatite can be also replaced by SO₄ (Stowasser, 1975).

The fluorine content ranges between 0.85-2.34%. Fluorine is present in the lattice and it occurs free or associated with (OH) and O-ions (McConnel, 1973).

The chlorine content in the studied samples varies from 0.04 to 1.31%. In the phosphates, chlorine may be present in the apatite lattice where it may replace F or OH group (Blatt *et al.*, 1972). The Cl may be associated with clay minerals, or partly incorporated in the apatite structure replacing F. The apatite PO₄-group may be partly replaced by OH-group (McConnell, 1965). Phosphorous may be partly replaced by the following elements As, V, Si, S, C and Cr (Cathcart and Gulbrandsen, 1973), whereas calcium can be partly replaced by Na, Sr, Ba, Cd, Rb, Re, Th and U (McConnell, 1973).

The EDS results for the *major* and minor elements are given in Table 2. These results indicate that the

groundmass of the studied phosphates consists of microcrystalline apatite, pellets, fish teeth, bone fragments and other unidentified phosphorite fragments. Apatite

occurs as dark envelops surrounding light cores of these components (Figs. 9, 10).

Table (1): XRF results in (wt %) of the phosphate samples collected from the study area

P ₂ O ₅	CO ₂	Fe ₂ O ₃	CaO	SO ₃	SiO ₂	Al ₂ O ₃	MgO	Cl	F
23.56	13.56	0.33	27.18	0.1	33.23	0.05	0.76	0.08	0.85
13.51	6.5	0.23	18.24	0.13	59.03	0.01	0.45	0.09	1.25
8.52	5.32	0.44	12.74	0.36	69.94	0.07	0.32	0.65	1.32
24.69	19.26	0.19	43.22	0.72	8.07	0.02	1.26	0.04	1.02
8.22	18.23	0	49.55	1.31	6.98	0.05	14.75	0.40	1.21
20.82	2.35	0.88	46.88	0.97	23.14	0.21	1.86	0.89	1.12
24.15	3.21	0.89	42.94	0.48	24.23	0.97	0.58	0.82	1.68
16.58	5.25	0.33	34.56	1.28	39.4	0.01	0.7	1.30	1.01
15.71	7.75	0.26	36.31	1.87	33.85	0	2.34	0.04	0.87
18.92	4.54	0.89	36.65	2.23	33.25	0.07	0.61	0.70	2.34
24.09	6.23	0.5	45.3	0.95	18.66	0.11	0.9	1.31	2.11
20.35	6.89	0.26	39.88	0.83	29.08	0	0.13	0.87	1.7
26.42	5.23	0.71	45.67	1.12	15.5	0	1.89	1.01	2.1

Table (2): Chemical analyses in (wt %) of the various types of phosphate particles using SEM-EDS method

Object of study	CaO	P ₂ O ₅	SiO ₂	Na ₂ O	F	Cl	F/P ₂ O ₅	CaO/P ₂ O ₅
Cement	51.1	41.7	1.32	0.88	4.2	0.8	0.1	1.22
Pellet core	48.5	40.1	1.93	1.04	3.6	1.1	0.08	1.2
Pellet rim	49.4	41.4	3.52	0.89	3.3	1.1	0.07	1.19
Skeletal material	52.3	40.2	2.22	1.18	3.4	0.9	0.08	1.3
Bone	51.1	41.3	1.12	1.12	3.5	1.3	0.08	1.23
Fish teeth	54.2	39.3	1.51	1.21	3.3	0.5	0.08	1.38
Intraclast	50.7	41.1	2.11	1.17	3.6	1.3	0.08	1.23
Bone	49.8	39.8	2.25	1.97	3.9	1.2	0.09	1.25
Isotropic phosphate	51.95	40.01	1.95	1.65	3.6	0.8	0.08	1.29
Anisotropic phosphate	48.5	37.8	4.23	1.98	2.6	1.8	1.8	1.28
Shell fragment	49.23	36.98	5.23	1.23	2.98	1.95	0.08	1.33
Cement	49.3	39.6	4.89	1.88	2	1.3	0.05	1.24
Coprolite	47.9	37.9	6.11	1.94	2.1	1.9	0.05	1.26
Fish teeth	49.9	40.2	4.12	1.25	3.3	1	0.08	1.23



Fig. (9): Apatite (microcrystalline to amorphous) occurs as dark envelopes surrounding light cores of phosphate particles (pellets)

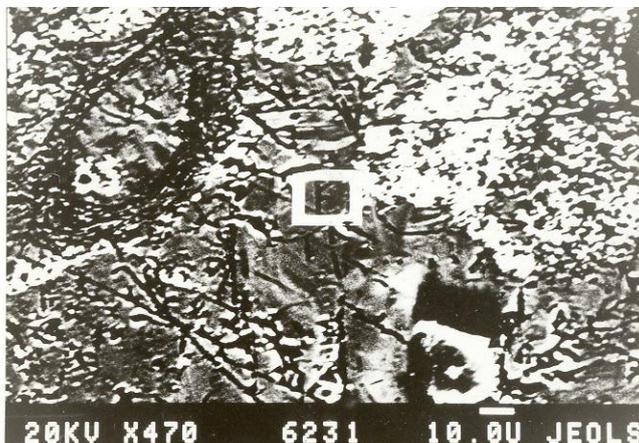


Fig. (10): Pellets are structureless, sometimes with oval forms and smooth boundaries.

SEM-EDS results of cement, core and rim of pellets, fish teeth, coprolite, and bone fragments indicate that the P_2O_5 content varies from 36.98 to 41.67 %. The content of other elements and oxides associated with the phosphorite facies is given in Table 2.

EDS results confirm that the phosphorite facies are mostly made up of P, Ca, F, Cl and partly of Si and Na, that could be involved in the apatite lattice (Fig. 11). Replacement of P by Si, Ca by Na and F by Cl, respectively, is more common in similar phosphates (Cheney *et al.*, 1979). Results of EDS indicates that the F/ P_2O_5 ratio ranges from 0.04 to 0.10, while CaO/ P_2O_5 value ranges from 1.23 to 1.38, which are similar to the values reported on the composition of francolite in other phosphate (Cheney *et al.*, 1979 and McClellan, 1980). Using the results of EDS, it can be assumed that positive relationships have been seen between P_2O_5 with CaO, F, SiO_2 and F/ P_2O_5 ($r=0.32, 0.65, 0.18, 0.54$), respectively.

6. Genesis

Field observations and experimental results have indicated that the phosphates of the study area are grain-supported type. Such type of phosphate in ancient strata are commonly viewed largely as a reworked product of syngenetic phosphatized mud generated in low-

energy and organic rich marine environments (Riggs, 1979; Glenn and Arthur, 1990). The processing of washing and transport would concentrate the phosphorite bodies "Pellets" generated as phosphorite beds within tectonic troughs in near shore setting (Soudry, 1992). Therefore, such phosphates could be formed due to a series of successive processes providing a final concentration of phosphorus (Baturin and Bezrkovis, 1979). These processes include winnowing of light and fine non-phosphatic fractions and residual concentration of coarser material, including phosphorite grains (Soudry and Nathan, 1980). The granular phosphorites of both southeastern Jordan and Negev (Soudry, 1987; Soudry and Lewy, 1988) are essentially grainstones to packstones, which are extremely porous and are situated near-surface in an arid area. Deposition of phosphorite deposits in arid zones has been long recognized by Strakov (1962). Formation of pelletal or granular phosphorites in Jordan, particularly in southeast Jordan and Negev and elsewhere appears to be diagenetic (Soudry and Nathan, 1980). Khalid (1980) recognized that Ash-Shidiya phosphates, which are close to the study area, were deposited in syntectonic depressions with high rate of sedimentation. Reworking could liberate internal molds and produce well-rounded phosphate mud particles, which may be

erroneously, interpreted as fecal pellets (Abed and Fakhouri, 1996).

The environment of deposition and early diagenetic processes are apparently reflected in the fabrics and grain

composition in such phosphate. The bioturbation features commonly associated with the granular phosphorites, and the high energy of character of these rocks, point to

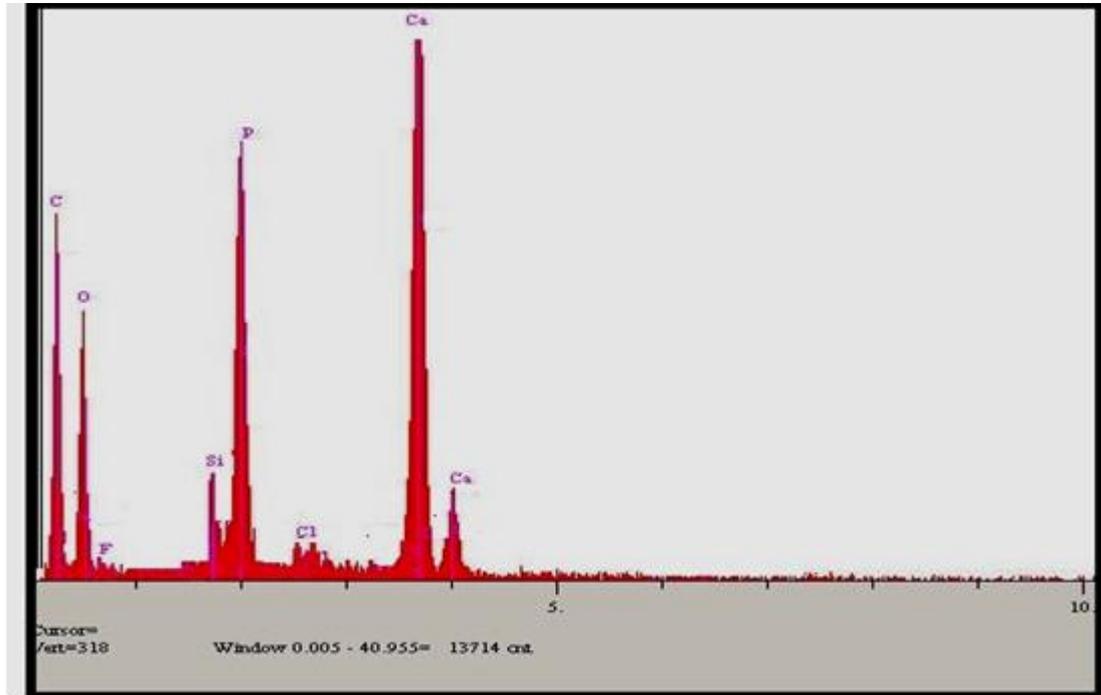


Fig. (11): EDS spectra of selected phosphate sample, showing the distribution of the major and minor elements associated in phosphatic facies.

deposition in arid environments with good mixing of waters that have chemical composition typical to sea-water (Nathan *et al.*, 1990). The abundance of bone fragments in the phosphate of this study is apparently related to onshore reworking of vertebrate remains from phosphatizing hemipelagic environment, as suggested by Anita and Whitaker (1978) and in Reif (1982). This model of deposition stands in contrast to the peloids of sandy phosphorites that are derived mainly from nearshore environments (Soudry, 1987). Pufahl *et al.* (2003) indicates that the southern Tethyan margin in Jordan was characterized by phosphogenesis in sedimentary environments spanning nearshore, mid-shelf, and distal shelf setting. Pufahl, *et al.* (2003) mentioned that the “phosphorite nursery” is a non-uniformitarian phenomenon reflecting phosphate precipitation across a broad paleoenvironmental spectrum. The former author described that the phosphogenesis on the Jordanian shelf was stimulated primarily by the microbial respiration of sedimentary organic matter. Phosphatic grainstones formed through the successive winnowing, transport and redeposition of phosphate grains and intraclasts derived from pristine phosphate facies via storm-generated currents as indicated by Pufahl *et al.* (2003). The relatively high abundance of biogenic forms may indicate high biogenic activity and accompanying phosphatization (Reisi, 1988; Tarwneh and Moumani, 2006). Abed *et al.* (2007) summarized that the deposition of Ashdiyya phosphorite platform in southern Jordan, near the study area, was deposited in open shelf conditions with

upwelling, shallow subtidal to inner shelf. He concluded that higher bioproductivity coupled with high rates of death and sedimentation; increase the P and Si concentration in the poor water of the sediments and lead to the authogenic formation of phosphorites, chert and porcellanite, as well as, mentioned by Birch (1980) and Burnett (1990).

From the previous discussion, it is concluded that the phosphates can be formed under a variety of depositional environments. However, it can be assumed that the presence of fauna and high abundance of biogenic forms as indicted in this study accompanying phosphatization process. The higher amounts of siliciclastics indicate that the phosphorites, in the study area, were probably deposited in a marginal marine environment; very close to the shore lines of the continent. It could be argued that the sedimentary structures, composition and thickness of the phosphorite deposits in the study area are closely controlled by the local palaeostructural relief.

7. Conclusions

This is the first detailed study to shed light on phosphorite deposits along the southeastern extension of Batn Al Ghul Escarpment (Jabal Kabid/Naqab Etaiq area) in southeast Jordan. The phosphorite deposits (~20m thick) overlie unconformably the Upper Cretaceous Batn Al Ghul Group. The composition of the phosphate in this study is similar to other Jordanian phosphates, with small differences in the amount of phosphatic particles in some

parts of the phosphate sequence. Petrographic examinations reveal that the phosphates are made up of four types of phosphatic particles; pellets, intraclasts, skeletal fragments and coated grains. The results of XRD indicate that the major phosphate mineral is francolite (carbonate fluorapatite). The XRF results of selected samples indicate that the P₂O₅ content ranges from 8.0 to 26.42%, whereas through SEM-EDS analyses, the P₂O₅ content ranges from 36.89 to 41.67%. It can be assumed that the presence of fauna, in addition to the higher amounts of siliciclasts indicate that the phosphorites in the study area were probably deposited in a marginal marine environment; very close to the shore lines of the continent.

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