# EARLY LUTETIAN PHOSHORITES IN WADI AKASH, WESTERN DESERT, IRAQ

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## ABSTRACT

Phosphorites from the Ratga Formation (Eocene) exposed in Wadi Akash in the Western Desert of Iraq are studied from micropaleontological, petrological and geochemical aspects. They are the youngest among the phosphorite deposits of Iraq; index fossils of Middle Eocene (Early Lutetian) were identified in these phosphorites. The underlying rocks are composed of nummulitic limestone of Late Ypresian age, whereas the overlying rocks are basinal limestone of Late Lutetian age.

The Early Lutetian phosphorites are peloidal in texture with calcareous cement. Detrital fragments are of small amount, composed of quartz grains and fish scales. The phosphorite is of low $P_2O_5$ grade relative to other Iraqi phosphorite deposits, but is similar to most marine phosphorites in having high concentrations of F, Cd, U, V, Y and Zn and being dominated by francolite (carbonate fluorapatite) as the only phosphorite mineral. The Early Lutetian phosphorites represent the final stage of the Tethyan phosphogenic epoch in Iraq and are comparable in age to several North African deposits.

# فوسفوريت اللوتيشي المبكر في وادي عكاش، الصحراء الغربية، العراق

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## المستخلص

تتناول هذه الدراسة صخور الفوسفوريت من تكوين الرطكة ( الايوسين ) المتكشفة في وادي عكاش في الصحراء الغربية العراقية من نواحي المستحاثات الدقيقة والصخارية والجيوكيميائية . تعتبر هذه الفوسفوريت الاحدث عمراً من بين الرواسب الفوسفاتية العراقية حيث بينت المستحاثات الدالة على انها من عمر الايوسين المتوسط ( اللوتيشي المبكر ) وتعود الصخور الواقعة اسفل الفوسفوريت الى اليبريزي المتاخر وتلك الواقعة اعلاها الى صخور حوضية من عمر اللوتيشي المتاخر .

تتكون فوسفوريت اللوتيشي المبكر من نسيج دملقي مع ملاط كلسي وتحتوي على فتاتيات بكميات قليلة تتكون من الكوارتز وعظام الأسماك .يعتبر هذا الفوسفوريت ذو رتبة واطئة نسبياً من خامس اوكسيد الفوسفور بالمقارنة بالرواسب الفوسفاتية العراقية ، غير انه مشابه لمعظم رواسب الفوسفوريت البحرية في العالم باحتوائه على تراكيز عالية نسبياً من F ، Cd ، U، V، Y، و Zn وكون الفرنكوليت هو المعدن الفوسفاتي الوحيد فيه. يمثل فوسفوريت اللوتيشي المبكر المرحلة الأخيرة من حقبة تكون فوسفوريت التيثيس في العراق ويمكن مقارنته عمرياً بعدد من الرواسب الفوسفاتية في شمال أفريقيا .

## INTRODUCTION

Marine sedimentary phosphorites are wide spread in Iraq and other areas of the southern and eastern Mediterranean region. They range in age from Late Cretaceous to Eocene and together form one of the largest phosphorite provinces of the world; its main deposits extend from NW African coasts, in the west to Iraq

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in the east. Lutetian phosphorites were reported in North African countries such as those in Morocco, Tunisia, Algeria and Mauritania (Salvan, 1983, Boujo and Ould Jiddou, 1983 and Mostefai and Flicoteaux, 1983). The Early Lutetian is believed to be an important phosphogenic period due to the numerous deposits discovered of this age, especially in North Africa (Salvan, 1983).

Tethyan phosphorites of Iraq are known within Campanian, Maastrichtian, Paleocene and Eocene rock units in the Western Desert as relatively thick horizontal beds associated with limestone, marl, shale and chert (Al-Bassam et al., 1983). The Eocene phosphorites are part of the Ratga Formation (Damluk Member) which is one of the widely exposed rock units in the Western Desert of Iraq. The formation consists mainly of limestone.

The phosphorite – bearing units occur in two areas. The first and better developed Ethna deposit is located near the Iraqi – Jordanian borders and was reported as Late Ypresian in age (Al-Bassam and Hagopian, 1983). However, detailed paleontological investigation has shown some Early Lutetian fossils at the upper parts of the phosphorite sequence (Jassim et al., 1984) which may bring the age of the Ethna deposit to Late Ypresian – Early Lutetian. The other Eocene phosphorite occurrence is located near the Syrian borders, exposed at the banks of Wadi Akash, about 35 km NE of the Akashat Mines (Fig. 1). The exposure is relatively small, of limited extension and was discovered in 1972 during a stratigraphic study of the Eocene rock units in the area (Al-Hashimi, 1972).

The present work deals with the Early Lutetian phosphorites of Wadi Akash. Several aspects were studied including paleontology, petrology and geochemical characteristics to understand the depositional environment and to compare this occurrence with other phosphorites of Iraq.

## METHODS

The phosphorite exposure was investigated in the field and two measured sections were sampled at about 0.5 m interval. About twenty samples were collected from the two sections covering the whole thickness of the phosphorite bed, together with samples from the underlying and overlying rocks. The samples were reduced and analysed for the following major and trace components and elements: $SiO_2$, CaO, MgO, $P_2O_5$, $Fe_2O_3$, $Al_2O_3$, $SO_3$, $Na_2O$, $K_2O$, Cl, C, $CO_2$, $H_2O^+$, U, V, Y, Yb, Zn, Cu, Ni, Cr, Pb, Cd, Sr, Mn, and B. Standard wet chemical analytical techniques were used in addition to atomic absorption spectrophotometry, ion selective electrode, colorimetry and carbon – sulfur analyzer. The chemical analysis was carried out by the chemists of the Geological Survey of Iraq. Duplicate samples were thin sectioned and studied from petrological and micropaleontological aspects by the authors. Several fossiliferous samples were treated in order to separate microfossils for hand picking and detailed microscopic examination. One composite sample was subjected for selective grinding, sieving, heavy liquid separation (bromoform) and citrate

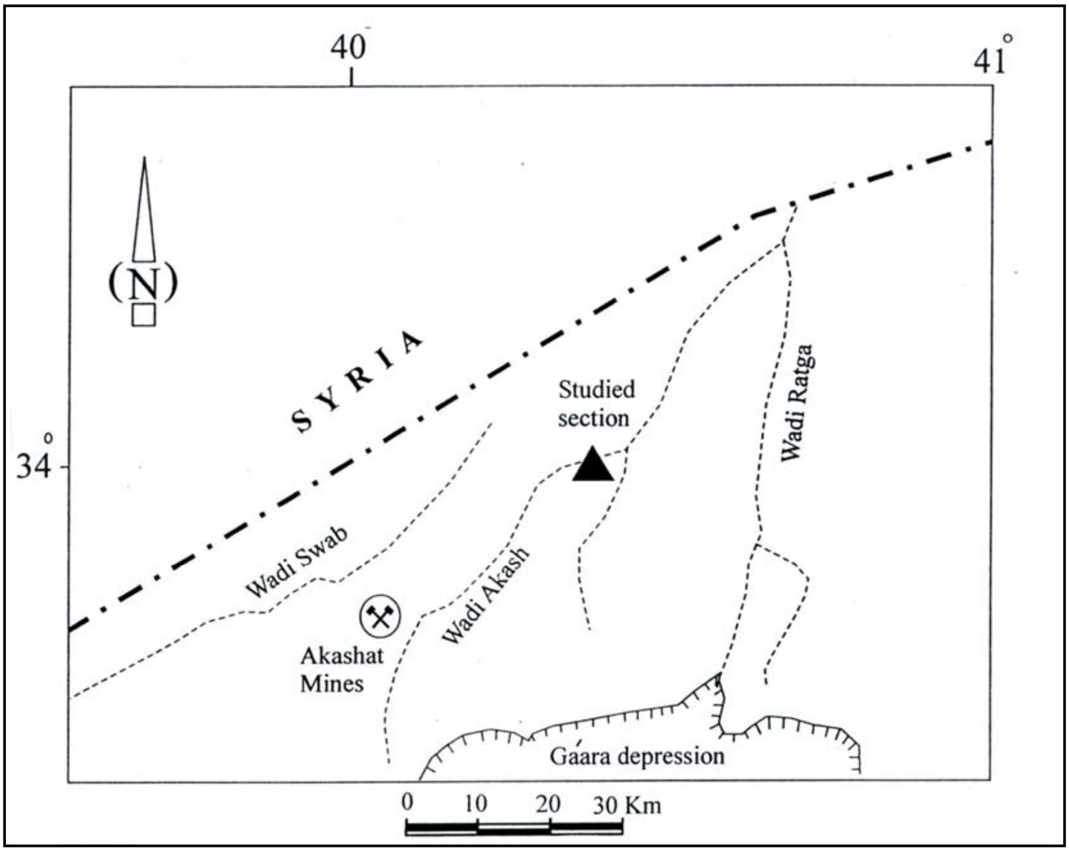

Fig. 1: Location Map

(Silverman et al., 1952) to extract a pure francolite fraction for crystal chemical study.

## STRATIGRAPHY

The studied Early Lutetian phosphorite occurs as (3.5 – 4.0) m thick horizontal beds overlain by siliceous chalky limestone with a sharp but conformable contact and underlain by nummulitic limestone. The paleontological study of the phosphorite bed yielded, in part, common planktonic foraminiferal assemblages of planktonic and small benthonic species. The significant planktonic species recognized from this phosphorite horizon are: *Globorotalia bullbrooki* BOLLI, *G. centralis* CUSHMAN AND BERMUDEZ, *G. bolivariana* PETTERS, *G. aspensis* (COLOM).The associated small benthonic genera and species include: *Bulimina* spp., *Lenticulina* spp., *Nodasaria* spp. and *Dentalina* spp. (Figs.2,3 and 4). The presence of these planktonic species permits satisfactory correlation of

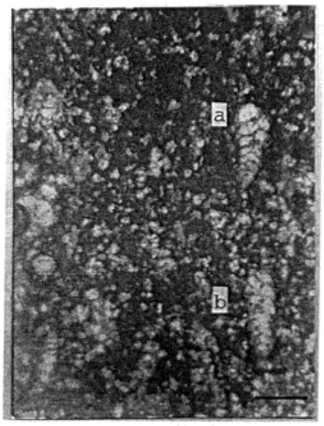

Fig. 2(a): *Bolivina* sp.
(b): *Bolivina alata* (SEGUNEZA)
with other assemblage of planktonic
and benthonic fauna (bar = 0.2 mm)

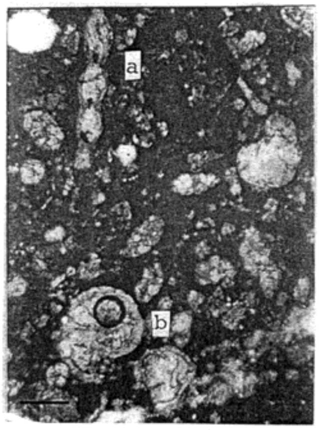

Fig. 3(a):*Dentalina communis* (D′ORBIGNY)
(b): *Cibicides* sp.
with *Bolivina* spp., *Bulimina* spp.
and planktonic fauna (bar = 0.2 mm)

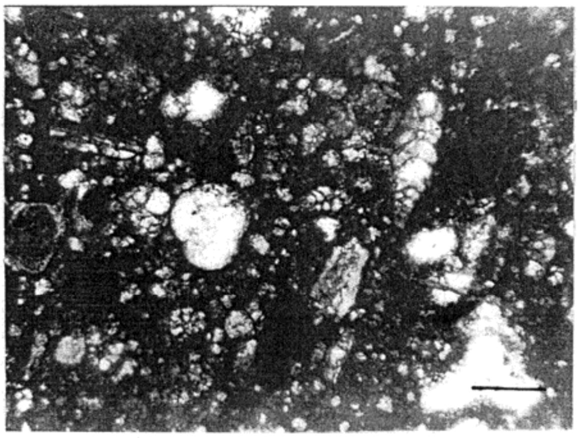

Fig. 4: Assemblages of planktonic and benthonic fauna (bar = 0.2 mm)

this assemblage with that of early Middle Eocene ( Early Lutetian ) of the *Hantkenina aragonensis* Zone and *Globigerapsis Kugleri* Zone of Trinidad (Bolli, 1957), Syria (Ejel , 1969 ), India ( Samanta, 1969) and *Globorotalia bullbrooki* Zone of Egypt (Fahmy et al., 1969).

Al-Hashimi (1972, 1973 and 1980) examined samples from this phosphorite bearing horizon, but found them devoid of fossils. However, he recognized late Lower Eocene (Late Ypresian ) rocks underlying the phosphorite unit. The fossils in these rocks are characterized by larger species of *Nummulites planulatus* (LAMARK), *N. globules* LEYMERIE, *N. atacicu*s LEYMERIE, *N. lucasanus* ( D́ ARCHIAC ) and *N. murchisoni* ( RUTIMEYER ). The rocks immediately overlying the phosphorite were found by Al- Hashimi (1972, 1973 and 1980) to be of late Middle Eocene (Late Lutetian) age. These rocks belong to the *Globorotalita lehneri* Zone.

## PETROGRAPHY AND MINERALOGY

Almost all the phosphate present in the form of peloids, represent (20−50)% of the phosphorite constituents, whereas phosphatic bones are few (5−10)%. The phosphate peloids (Fig. 5) are usually without internal structure, rounded, spherical, about (0.1 – 0.2) mm in diameter, usually rich in black organic matter and iron oxides. Some peloids may contain a nucleus (Fig. 6) such as a fragment of bone, shell, smaller peloid, or silt size quartz grain. Larger phosphate grains, up to 5 mm in diameter, are present, but rare. The phosphate peloids are cryptocrystalline and isotropic under crossed nicols, but bone fragments are anisotropic with wavy extinction (Figs. 7 and 8).

The other constituents of the phosphorite are fossil shells (about 5%), composed of calcite, and to a lesser amount quartz grains (less than 3%), which when present appear to have been recycled several times and have the same size range as the phosphate grains. The cementing material is composed of micrite with sparite nests. Clay, organic matter and iron oxides are occasionally present in very small amounts (1 – 3) %. Secondary gypsum occurs in small amounts (2 – 3) % in the upper part of the phosphorite bed.

Partial leaching of the original calcareous cement occurs especially at the middle of the phosphorite bed. The contact between the cement and the phosphate grains is sharp and well defined. The cementing calcite account for (30 – 40)% of the rock constituents in the middle part of phosphorite bed, but increases to about 80% in the lower and upper parts, where the content of the phosphate grains generally decreases. At the uppermost part of the sequence the rocks become more fossiliferous and less phosphatic.

Fig. 5: Phosphate peloids rich in organic matter and iron oxide, cemented by calcite; (polarized light) (bar = 0.2 mm)

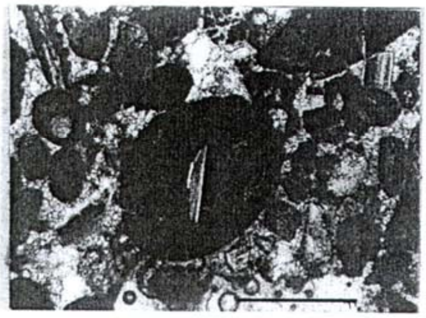

Fig. 6: Phosphate ooid with a nucleus of a bone fragment (crossed nicols) (bar = 0.2 mm)

Fig. 7: Skeletal phosphate cemented by calcite (polarized light) (bar = 0.2 mm)

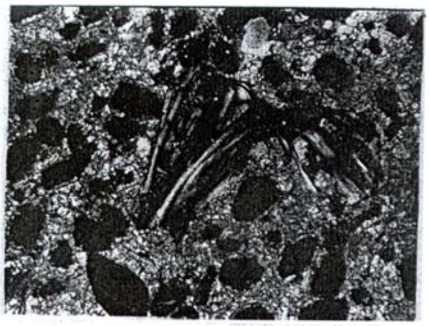

Fig. 8: Same as Fig.7 (crossed nicols)

The overlying rocks are chalky siliceous limestones, micritic in texture, fossiliferous, slightly phosphatic at the lower parts (5 – 7% phosphate grains) with relatively large amounts (up to 10%) of chalcedony. Clay minerals constitute up to 5% of the constituents. The underlying rocks are composed of highly fossiliferous, nummulitic limestone, which is non – phosphatic and devoid of any detrital material. The only phosphate mineral detected by X– ray diffraction is francolite. Other minerals in the phosphorite samples identified by this technique include calcite, palygorskite, gypsum and quartz.

## GEOCHEMISTRY

The results of chemical analysis (Table 1) indicate a relatively poor phosphorite with an average of about 12.8% $P_2O_5$. Silica ($SiO_2$) content, is relatively highly increasing upwards (average 2.73%) compared with the other Eoccene deposit (Ethna) and the Paleocene deposit (Akashat), but may be similar to the Late Cretaceous phosphorites, in this respect (Al-Bassam, 1976 and Al- Bassam et al., 1983).

Most of the alumina and magnesia appear to be present in palygorskite, as suggested by the positive correlation between $SiO_2$, $Al_2O_3$ and MgO (Table 2). The correlation coefficients also suggest that part of Fe is related to clay minerals, whereas the remaining part may be present as oxides. The elements that are associated with phosphorous in apatite include S, Na, K, F, Sr, U, Y, Yb, Cd and Cu. All of which are capable of substituting in the francolite structure (Kreidler and Hummel, 1970).

The F/ $P_2O_5$ ratio varies within a narrow range (Table 3) with an average of 0.14, which is similar to those found in the other phosphorites of Iraq. The U / $P_2O_5$ is similar in average to that of Akashat deposit (Paleocene), but higher than in the other deposits of Iraq. Other significant ratios include Sr/ $P_2O_5$ and Y/ $P_2O_5$, which generally vary within a limited range (Table 3) suggesting the close association of these elements with apatite. These ratios tend to be higher near the top of the phosphorite bed and are two to four times higher in the overlying basinal limestone.

Generally, the studied Early Lutetian phosphorites are characterized by high Y, Ni, Cd and B and low Sr relative to the world wide phosphorites ( Tooms et al., 1969). The correlation coefficients suggest that V, Zn and Ni are mainly associated with Fe in its oxides. Zinc, Cr and Ni may be present in clay minerals. Sulfur appears to be shared between francolite, gypsum and organic matter, whereas sodium is mostly present in francolite. Among the Iraqi phosphorite deposits the Early Lutetian of Wadi Akash is the highest in the average content of Mn, Y and V concentrations and the lowest in Sr and organic C concentrations. The other elements analysed fall within the reported ranges of other deposits.

Some variation in the geochemical components and elements occurs with depth (Fig. 9). Silica, Mg, Mn and B generally increase at the upper part, whereas, phosphorus and the associated elements have their highest concentrations at the middle part of the section. The only elements that generally tend to decrease towards the top are K and Cu. The overlying basinal chalky limestone is characterized by high concentrations of Cr, Ni, V, Fe and Zn relative to the average carbonates (Graf, 1960), which is typical for basinal limestones (Al-Bassam and Saeed, 1980).

Table 1: Chemical composition of Early Lutetian phosphorites and overlying limestone

| Wt.% | Early Lutetian phosphorites | | overlying limestone |
|---|---|---|---|
| | Range | Mean | Mean |
| $SiO_2$ | 1.00 – 5.94 | 2.73 | 8.75 |
| CaO | 48.51 – 52.85 | 50.93 | 46.65 |
| MgO | 0.56 – 1.50 | 0.88 | 1.89 |
| $P_2O_5$ | 6.50 – 18.0 | 12.85 | 1.16 |
| $Fe_2O_3$ | 0.18 – 0.60 | 0.31 | 0.56 |
| $Al_2O_3$ | 0.46 – 0.61 | 0.49 | 1.02 |
| $SO_3$ | 0.18 – 2.20 | 1.18 | 0.13 |
| $Na_2O$ | 0.30 – 0.91 | 0.54 | 0.20 |
| $K_2O$ | 0.04 – 0.10 | 0.06 | 0.05 |
| O.M | 0.10 – 0.21 | 0.16 | 0.16 |
| F | 0.80 – 3.04 | 1.78 | 0.19 |
| Cl | 0.02 – 0.82 | 0.27 | 0.11 |
| L.O.I. | 22.01 – 34.01 | 28.24 | 38.06 |

| ppm | | (a) | (b) |
|---|---|---|---|
| U | 19 – 58 | 37 ( 8 – 1300 ) | 18 ( 2.1 ) |
| V | 92 – 400 | 175 ( 20 – 500 ) | 365 ( 15 ) |
| Y | 82 – 208 | 155 ( 0 – 50 ) | 39 ( 13 ) |
| Yb | 4 – 11 | 8 ( ? ) | 3 ( ? ) |
| Zn | 69 – 150 | 105 ( 4 – 345 ) | 135 ( 26 ) |
| Cu | 17 – 40 | 29 ( 0.6 – 394 ) | 19 ( 14 ) |
| Ni | 20 – 60 | 34 ( 1.9 – 30 ) | 48 ( 12 ) |
| Cr | 60 – 100 | 86 ( 7 – 1600 ) | 118 ( 9 ) |
| Pb | 40 – 70 | 56 ( 0 – 100 ) | 40 ( 8 ) |
| Cd | 14 – 66 | 27 ( 1 – 10 ) | 16 ( 0.1 ) |
| Sr | 258 – 507 | 434 ( 1800 – 2000 ) | 215 ( 475 ) |
| Mn | 27 – 39 | 31 ( 0 – 10000 ) | 38 ( 500 ) |
| B | 30 – 74 | 53 ( 3 – 33 ) | 30 ( 12 ) |

Number of samples analysed 13 4

Values of trace elements between parentheses are:
(a) World phosphorites after Tooms et al. (1969), and (b) Average carbonates after Graf (1960)
O.M.: Organic matter
L.O.I: Loss on ignition (1000 ºC)

Table 2 : Interelement correlation coefficients ( 17 samples)

| | $SiO_2$ | CaO | MgO | $P_2O_5$ | $Fe_2O_3$ | $Al_2O_3$ | $SO_3$ | $Na_2O$ | $K_2O$ | O.M | F | Cl | U | V | Y | Zn | Cu | Ni | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CaO | - 0.82 | | | | | | | | | | | | | | | | | | |
| MgO | 0.54 | -0.62 | | | | | | | | | | | | | | | | | |
| $P_2O_5$ | -0.87 | 0.63 | -0.62 | | | | | | | | | | | | | | | | |
| $Fe_2O_3$ | 0.81 | -0.67 | 0.44 | -0.76 | | | | | | | | | | | | | | | |
| $Al_2O_3$ | 0.86 | -0.70 | 0.22 | -0.63 | 0.63 | | | | | | | | | | | | | | |
| $SO_3$ | -0.49 | 0.36 | -0.23 | 0.75 | -0.52 | -0.34 | | | | | | | | | | | | | |
| $Na_2O$ | -0.55 | 0.10 | -0.0 | 0.59 | -0.47 | -0.64 | 0.45 | | | | | | | | | | | | |
| $K_2O$ | -0.27 | 0.45 | -0.65 | 0.34 | -0.04 | -0.15 | 0.09 | -0.17 | | | | | | | | | | | |
| O.M | 0.01 | -0.00 | 0.21 | -0.00 | -0.29 | 0.00 | 0.37 | 0.05 | -0.37 | | | | | | | | | | |
| F | -0.72 | 0.54 | -0.64 | 0.95 | -0.65 | -0.47 | 0.82 | 0.44 | 0.39 | 0.11 | | | | | | | | | |
| Cl | -0.16 | -0.30 | 0.36 | 0.09 | -0.14 | -0.37 | -0.03 | 0.82 | -0.49 | -0.01 | -0.08 | | | | | | | | |
| U | -0.79 | 0.58 | -0.53 | 0.90 | -0.81 | -0.59 | 0.73 | 0.55 | 0.15 | 0.06 | 0.86 | 0.12 | | | | | | | |
| V | 0.17 | -0.28 | 0.21 | -0.14 | 0.55 | -0.07 | -0.05 | 0.22 | -0.03 | -0.20 | -0.12 | 0.29 | -0.22 | | | | | | |
| Y | -0.58 | 0.19 | -0.15 | 0.72 | -0.43 | -0.48 | 0.65 | 0.75 | -0.02 | 0.11 | 0.64 | 0.45 | 0.56 | 0.35 | | | | | |
| Zn | 0.64 | -0.41 | -0.04 | -0.42 | 0.64 | 0.64 | -0.21 | -0.52 | 0.51 | -0.24 | -0.23 | -0.47 | -0.46 | 0.09 | -0.48 | | | | |
| Cu | -0.49 | 0.55 | -0.68 | 0.59 | -0.31 | -0.28 | 0.32 | -0.05 | 0.81 | -0.31 | 0.64 | -0.47 | 0.37 | -0.29 | 0.09 | 0.24 | | | |
| Ni | 0.32 | -0.42 | -0.16 | -0.11 | 0.54 | 0.39 | -0.18 | 0.02 | 0.43 | -0.51 | -0.08 | 0.03 | -0.35 | 0.40 | 0.10 | 0.65 | 0.21 | | |
| Cr | 0.23 | -0.39 | -0.19 | 0.19 | -0.05 | 0.47 | 0.23 | -0.01 | 0.13 | -0.03 | 0.33 | -0.10 | 0.28 | -0.00 | 0.15 | 0.38 | 0.10 | -0.32 | |
| Sr | -0.49 | 0.09 | 0.02 | 0.61 | -0.37 | -0.38 | 0.67 | 0.70 | -0.21 | 0.33 | 0.56 | 0.44 | 0.44 | 0.24 | -0.91 | -0.52 | 0.03 | -0.01 | 0.01 |

Table 3: Significant geochemical ratios in the Early Lutetian phosphorites of Wadi Akash

| Analysed samples | F/ $P_2O_5$ | $SO_3$/ $P_2O_5$ | U/ $P_2O_5$ | Sr/ $P_2O_5$ | Y/ $P_2O_5$ |
|---|---|---|---|---|---|
| Overlying limestone ( 4 samples) | 0.16 | 0.15 | 20 | 214 | 37 |
| Phosphorite, upper part ( 4 samples) | 0.13 | 0.13 | 3.0 | 53 | 18 |
| Phosphorite, middle part ( 5 samples) | 0.15 | 0.09 | 2.9 | 29 | 11 |
| Phosphorite, lower part ( 4 samples) | 0.13 | 0.05 | 2.8 | 31 | 10 |
| Concentrated francolite | 0.13 | 0.04 | 2.8 | 19 | 9 |
| Early Lutetian phosphorite ( average of 13 samples). | 0.14 | 0.09 | 2.9 | 34 | 12 |

Note: $P_2O_5$, $SO_3$ and F concentrations are in % and U, Sr and Y concentrations are in ppm

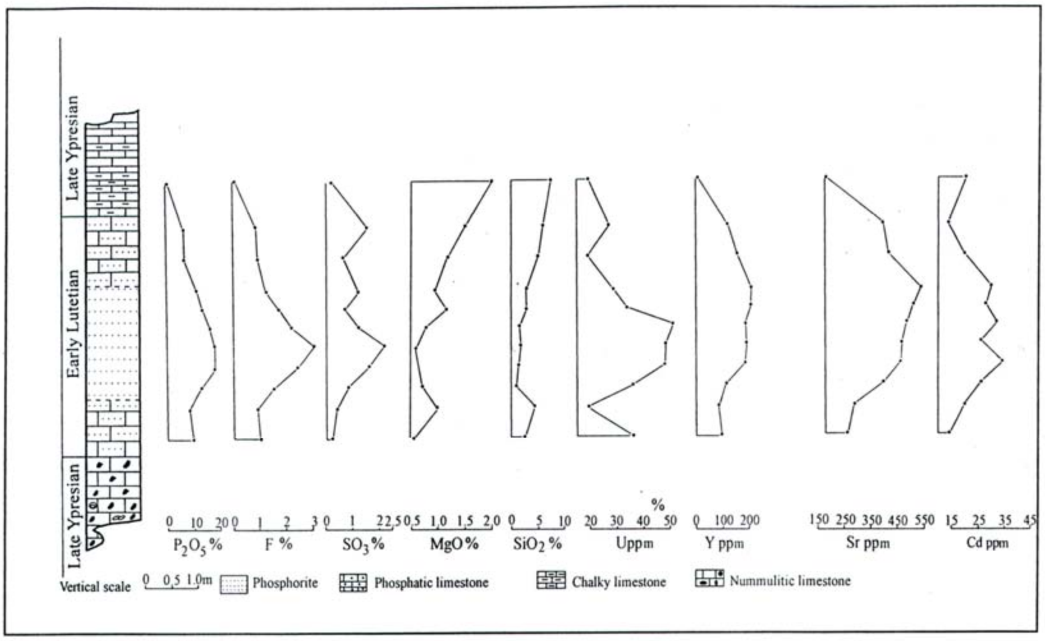

Fig. 9: Lithological columnar section of the studied sequence and vertical distribution of some chemical elements

## CRYSTAL CHEMISTRY OF FRANCOLITE

The chemical analysis of the purified apatite fraction (Table 4) shows a $P_2O_5$ content of 32.8 %, which is very close to that found in the other Eocene deposits, but lower than the Paleocene and Late Cretaceous apatites. The fluoride content of 4.28 % is also similar to the apatite from the Ethna deposit, but the $CO_2$ content is the highest in Wadi Akash apatite among all the other apatites from the Iraqi deposits**.** The uranium content is as high as 92 ppm similar in this respect to the Paleocene deposits of Akashat. The analysed apatite is also characterized by relatively low Sr content and low structural water content relative to other apatites from Iraq.

Table 4: Chemical composition of a purified francolite fraction from Wadi Akash phosphorites

| | % | | ppm |
|---|---|---|---|
| $SiO_2$ | 0.39 | U | 92 |
| CaO | 52.71 | V | 120 |
| MgO | 0.28 | Y | 279 |
| $P_2O_5$ | 32.80 | Yb | 15 |
| $Fe_2O_3$ | 0.12 | Zn | 71 |
| $Al_2O_3$ | 0.19 | Cu | 17 |
| $SO_3$ | 1.30 | Ni | 20 |
| $Na_2O$ | 0.88 | Cr | 98 |
| $K_2O$ | 0.05 | Pb | 50 |
| F | 4.28 | Cd | 70 |
| Cl | 0.03 | Sr | 620 |
| $CO_2$ | 6.50 | Mn | 20 |
| $H_2O^+$ | 1.09 | B | 50 |
| | 100.62 | | |
| $- O \cong F + Cl$ | 1.81 | | |
| Total | 98.81 | | |

The structural formula was calculated according to McConnell's model (McConnell, 1970 and 1973) as shown in Table (5). The results show a francolite (carbonate – fluorapatite) very similar to that of the Ethna deposit, but had suffered more phosphate replacement by carbonate. However, the number of phosphorus atoms per unit cell is the same due to the lower hydration of Wadi

Akash apatite. The other constituents of the structure are very similar to the other Eocene apatites. The Eocene francolites in general (including the Ethna deposit) are characterized by high Ca and $CO_2$ and low P and F, as compared to the Paleocene and Late Cretaceous francolites of Iraq (Table 5).

Table 5: Crystal chemical composition of francolites from main phosphorite deposits of Iraq

| | Eocene | | Paleocene | Late Cretaceous |
|---|---|---|---|---|
| | Wadi Akash | Ethna | Akashat | Wadi Swab |
| Ca | 9.51 | 9.37 | 9.06 | 9.12 |
| Na | 0.14 | 0.13 | 0.45 | 0.17 |
| $H_3O$ | 0.35 | 0.50 | 0.50 | 0.72 |
| P | 4.68 | 4.63 | 4.71 | 5.03 |
| 3/4C | 1.12 | 0.91 | 0.74 | 0.72 |
| S | 0.16 | 0.12 | 0.25 | 0.19 |
| $H_4$ | 0.04 | 0.34 | 0.31 | 0.07 |
| F | 2.28 | 2.12 | 2.36 | 2.58 |
| O | 23.72 | 23.88 | 23.64 | 23.42 |

Values are in atoms / unit cell
Wadi Akash deposit: this paper
Ethna deposit: Al-Bassam and Hagopian (1983)
Akashat deposit: Al-Bassam (1976)
Wadi Swab deposit: Jamil et al. (1979)

## PALEOENVIRONMENTAL INTERPRETATION

The deposition of the Early Lutetian phosphorite – bearing rocks containing planktonic and small benthonic species, directly above the fore reef nummulitic facies of the late Lower Eocene (Late Ypresian) and below the basinal marls and chalky limestone facies containing rich assemblages of planktonic and small benthonic foraminifera suggests that the depositional basin had direct connection with the open sea. The study of the fossil assemblages indicates that the deposition of the Middle Eocene phosphorite took place in a shallow marine environment on the outer continental shelf (Fig.10). The dominant sand – size peloidal texture and the common presence of detritals (broken shells, detrital quartz and bone fragments) are further evidences of a shallow water facies.

The maximum rate of phosphorite deposition took place in the middle part of the phosphogenic cycle. The phosphorite was deposited at the early stages of a transgressive phase in the Early Lutetian that was culminated in the deposition of a basin – edge limestone on top of the phosphorite. The depositional environment becomes deeper at the concluding stages of the phosphorite deposition, as suggested by the rapid decrease in the phosphate content, increase in siliceous material and increase in the deep water fossil assemblages towards the top, where a basin – edge limestone facies replaced the shallower phosphorite facies (Fig.10).

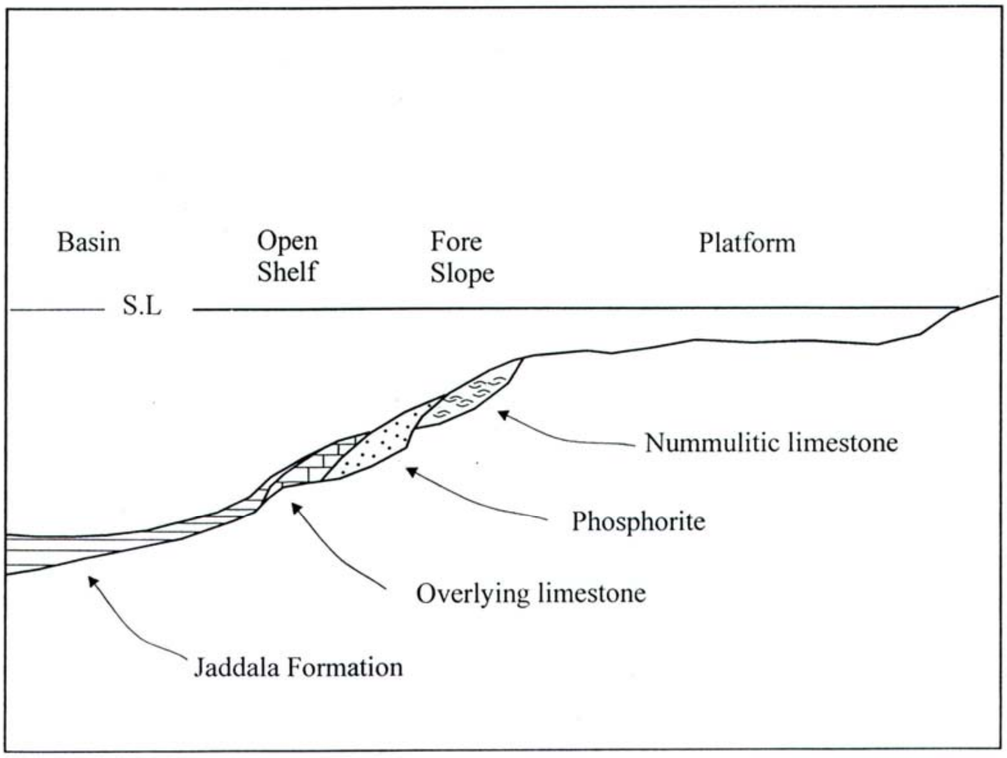

Fig. 10: Facies distribution in the Early Lutetian sedimentary basin of the Western Desert

The well rounded and spherical shape of the phosphate peloids and the distribution of impurities within these peloids together with the frequent presence of nucleating centers suggest growth from solution as the main mechanism of peloids formation. Most of the phosphate peloids appear to have formed at the sediment – water interface, since most of the petrographic and geochemical parameters suggest precipitation in an open environment. The consistency of many geochemical parameters such as F/ $P_2O_5$, Y/ $P_2O_5$ and U/ $P_2O_5$ within the total length of the phosphorite section is in favour of an open system of deposition, where the geochemical parameters and physical conditions can be more homogeneous relative to a closed system, where these parameters can vary significantly following the chemistry of the pore solution. Precipitation of phosphate in the interstitial environment, via a biogenic phase, was suggested for the Paleocene phosphorite (Al- Bassam, 1976). However, such process does not seem to be dominant in the studied phosphorites. Reworking and redistribution of the phosphate grains might have played some role in the formation of these deposits. The frequent presence of black carbonaceous material inside the phosphorite peloids suggests high organic productivity and relatively reducing conditions during phosphate deposition. This close association of phosphate with organic matter may suggest an organic local source of dissolved phosphorus and probably a biologic (bacterial) influence in the phosphate deposition. Bacteria are believed to be an important local agent in the deposition of carbonate apatite in marine environments (Lamboy, 1990).

Early and late diagenetic modifications have occurred and influenced the Early Lutetian phosphorites. The cementing material suffered recrystallization in some samples. Weathering partly leached the calcite cement leaving more friable sand – size phosphate grains. Sulfur released by oxidation of organic matter and probably mobilized from the apatite structure was redeposited as secondary gypsum in the upper parts. Similarly, sodium seems to have been partly leached from apatite by weathering and was redeposited as secondary halite, as suggested by the strong positive correlation between Na and Cl. In addition, most of the iron oxides in the phosphate peloids and in the cementing material appears to be oxidation product of an original pyrite.

## CONCLUSIONS

- The phosphorite occurrence in Wadi Akash is well – dated in this paper as Early Lutetian, on the basis of fossil assemblages and correlation with international biozones.
- The investigated phosphorites are mainly peloidal in texture with calcite cement. They were deposited, in the early stages of a transgressive cycle, in an open shelf environment.
- The phosphate peloids are fine sand – size (0.1 – 0.2) mm, well sorted with organic inclusion. They were mostly formed at sediment – water interface, with frequent agitation and redistribution.
- The mineralogy and chemical composition are comparable with other phosphorite deposits in Iraq with minor variations. Francolite is the only phosphate mineral. Uranium, Sr, Cd, Y and Yb are related to francolite, wheras Zn, Cr, V and Ni are shared between Fe – oxides and palygorskite.
- The Early Lutetian phosphorites of Wadi Akash can be compared, as a well – dated phosphogenic cycle, with other phosphorites of the same age in many North African countries. These phosphorites represent the concluding episode of the Tethyan phosphogenic event in Iraq.

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