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GEOLOGY OF THE PHOSPHORITE DEPOSITS OF IRAQ

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ABSTRACT

Phosphorite deposits of Late Cretaceous and Paleogene age are well known in the Iraqi Western Desert. They are part of the regional phosphorite belt of the Tethys which is best developed in North Africa and East Mediterranean countries and is considered to include the largest marine upwelling-type deposits in the world.

The phosphorites of Iraq, as with the other deposits of this belt, are marine sedimentary stratiform deposits, granular in texture, associated with limestone, shale, chert and occasionally sandstone. The phosphorite beds may reach several meters in thickness, and show common features of hardgrounds and bioturbation. Silicification is common in these deposits. They were deposited in several cycles of phosphogenesis, extended from Maastrichtian to Middle Eocene. Most of the Iraqi phosphorite deposits, except those in the Nukhaib area, were laid down west of the Horan High, in successive episodes, culminated in the Paleocene.

The phosphate components consist mostly of coated grains (cortoids and ooids), uncoated grains (peloids) and to a lesser extent phosphoclasts (mostly bones) and coprolites. The cementing material is commonly calcite; occasionally silicified. The only phosphate mineral identified is francolite. The P_2O_5 content of the Iraqi deposits is generally in the range of (18 – 25) %, but typically (20 – 22) %; the main diluent is calcite cement. The phosphorites, as with most upwelling marine deposits, are relatively enriched in F, U, Cd, Sr, Y and REE, which are associated with the phosphate phase.

The indicated phosphate resources of Iraq were estimated by about 10 billion metric tones, which put Iraq the second after Morocco in that respect. These resources are divided among several deposits; most of which are bordering the northern and western rims of the Ga'ara Depression. They are: Akashat, Swab, Hirri, Marbat, Dwaima, H3 and Ethna. The bulk of the phosphate resources is found in the Paleocene Akashat Formation. The H3 deposit includes parts of the Late Cretaceous sequence (Digma Formation), whereas the Ethna deposit is merely of Middle Eocene age (Ratga Formation). Among the Iraqi deposits, only Akashat has been developed and exploited since the early eighties of the past century.

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جيولوجية رواسب الفوسفوريت في العراق

خلدون صبحي البصام

المستخلص

توجد رواسب الفوسفوريت من عمر الطباشيري المتأخر والباليوجين في الصحراء الغربية العراقية وهي جزء من حزام الفوسفوريت الإقليمي لمحيط التيثيز الذي يمتد من شمال أفريقيا الى شرق البحر الأبيض المتوسط ويضم أكبر رواسب الفوسفوريت من نوع التيارات البحرية الصاعدة في العالم. إن الفوسفوريت في العراق، كما هو الحال في بقية الرواسب في هذا الحزام الإقليمي، بحرية الأصل، متطبقة وحبيبية النسجة مرتبطة مع رواسب من الحجر الجيري والسجيل والصوان وأحيانا مع الحجر الرملي. يبلغ سمك الطبقات الفوسفاتية عدة أمتار وتظهر خصائص شائعة مثل الأرض الصلبة والتعكر الاحيائي والتحول الى السيليكا. تكونت هذه الرواسب في عدة دورات ترسيبية متتابعة امتدت من الماستريختي الى الإيوسين المتوسط وتعاظمت في الباليوسين وتتموضع معظم الرواسب الفوسفاتية العراقية غرب نهوض حوران.

تتشكل المكونات الفوسفاتية من الحبيبات المغطاة (اللحائيات والسرئيات) وغير المغطاة (الدمالق) ونسب أقل من الحطام الفوسفاتي (العظام) وبراز الأسماك المتحجر. تتكون المادة الرابطة من الكالسايت المتحول أحيانا الى السيليكا ويمثل الفرنكوليت المعدن الفوسفاتي الوحيد في هذه الرواسب. تترواح نسبة (P_2O_5) في الرواسب العراقية بين (18% و 25%) ولكن المدى الشائع هو (20% الى 22%) ويمثل الفرنكوليت المعدن الرئيسي المتحكم بهذا التركيز. الصخور الفوسفاتية العراقية، كما الحال في مثيلاتها من الرواسب البحرية المتكونة بفعل التيارات الصاعدة، غنية نسبيا بالعناصر (F، U، Cd، Sr، Y و REE) التي تربط بالطور المعدني الفوسفاتي.

تم تقدير الموارد المعدنية الفوسفاتية بحوالي (10) بليون طن متري مما يجعل العراق الثاني بعد المغرب في هذا المجال وتتوزع هذه الموارد في عدة رواسب تقع معظمها في المناطق الشمالية والغربية المحاذية لمنخفض الگعرة وهي عكاشات وصواب والهري والمربط ودويمة و H3 والإثنى. إن معظم الموارد الفوسفاتية العراقية من عمر الباليوسين وتتموضع في تكوين عكاشات غير ان أجزاء من راسب H3 تقع ضمن تتابع الطباشيري المتأخر لتكوين الدگمة في حين أن راسب الإثنى يقع ضمن تتابع الإيوسين الأوسط لتكوين الرطگة ويعتبر راسب فوسفات عكاشات الوحيد الذي تم تطويره و استثماره منذ مطلع الثمانينات من القرن الماضي.

INTRODUCTION

The Iraqi phosphorites were discovered in the early fifties of the past century, by the Site Investigation Co. (UK) during a reconnaissance car-borne radiometric survey along Baghdad – Amman Highway (Cobbett, 1954). The H3 deposit was later investigated and assessed by Technoexport (former USSR) (Antonets and Aksenoy, 1962), whereas the Akashat deposit was discovered and investigated by Iraq Geological Survey in the sixties and seventies and started mining in the eighties of the past century (Dawood, 1965, Zainal, 1970 and Al-Khalil *et al*., 1973). The Ethna deposit was assessed in the early eightees (Abdul Raheem, 1983). The extensive detailed geological exploration in the area (1986 – 1990) led to the discovery and assessment of the giant deposits (Swab, Marbat, Dwaima and Hirri) (Al-Bassam *et al*., 1990). Some Paleocene phosphorite-bearing strata have been also reported in the Nukhaib area, but not assessed in detail (Jassim, *et al*., 1987; Mohamed and Jassim, 1992).

The phosphate-bearing strata are located in the Western Desert of Iraq and are of Late Cretaceous and Paleogene ages. However, most of the Iraqi economic phosphorite resources are of Paleocene age. They form a crescent around the northern and western rims of the Ga'ara depression (Fig.1). The Ethna deposit is of Eocene age and is located near the Iraq – Jordan boarders. Phosphorite showings have been reported and partly investigated elsewhere, such as the Nukhaib area (Paleocene) and Wadi Akash (Eocene).

The Iraqi phosphorites are well correlated with similar deposits in Jordan, Syria, Saudi Arabia, Turkey, Egypt, Tunisia, Morocco and Mauretania (Fig.2), both in age and in geological characters. However, the rich and producing deposits vary in age among these countries. In Syria, Jordan and Egypt they are mostly of Late Cretaceous age, in Iraq, Saudi Arabia and Mauretania they are of Paleogene age, whereas in Morocco and Tunisia, the Late Cretaceous and Paleogene strata are all productive.

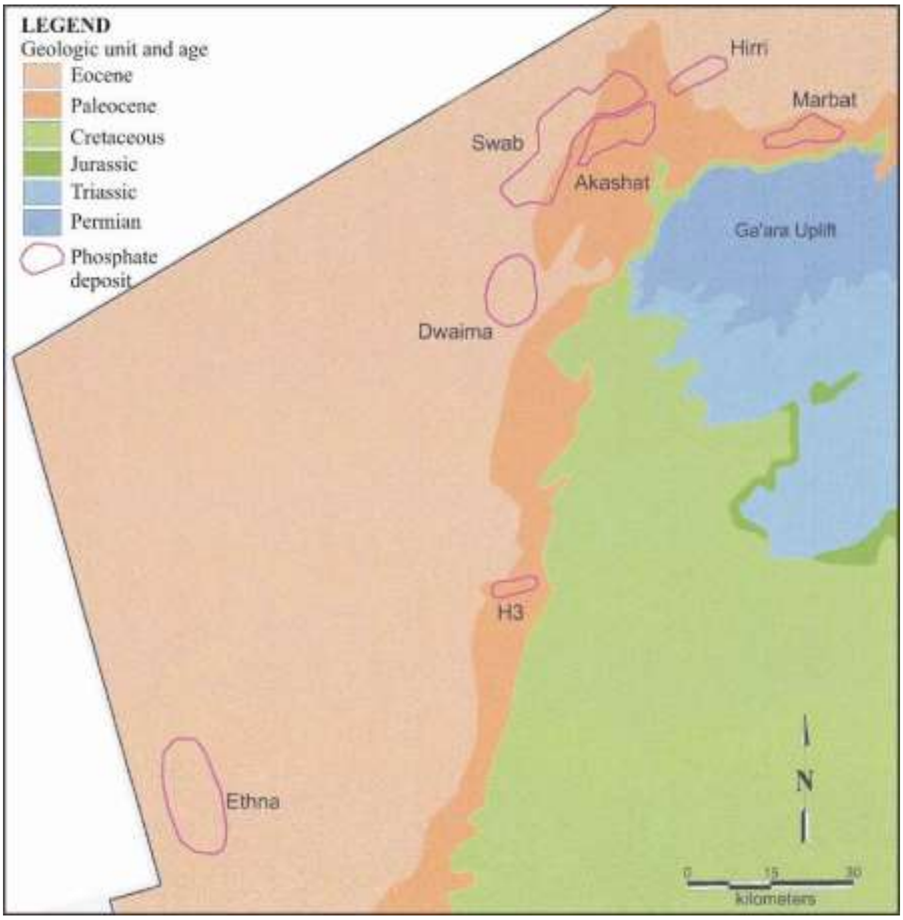

Fig.1: Geology and location of phosphorite deposits (Al-Bassam *et al*., 2012)

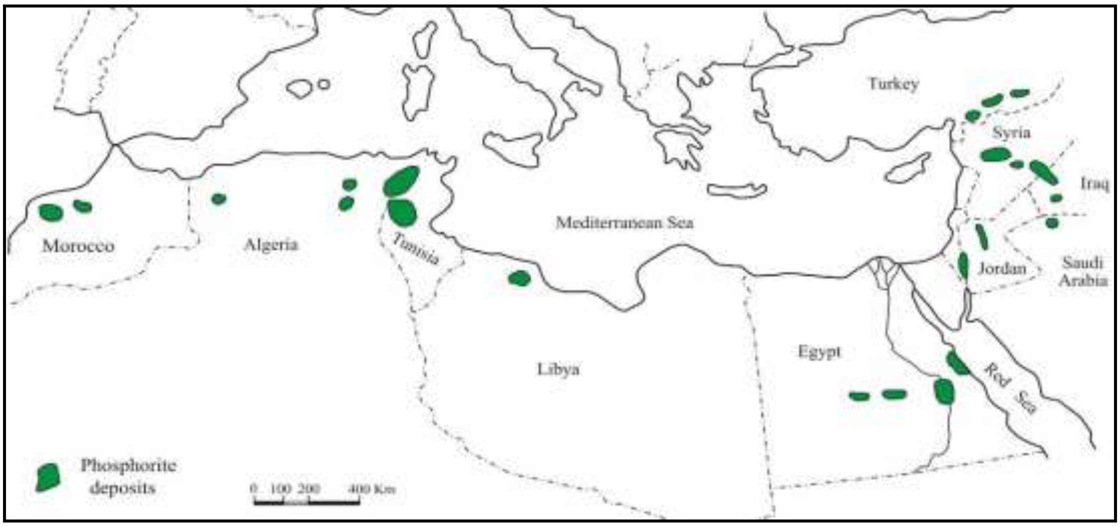

Fig.2: Phosphorite deposits of the Mediterranean area (Al-Bassam, 1974)

The phosphorites of Iraq have been the subject of extensive geological research that included stratigraphy, sedimentation, petrology and geochemistry. The research work was mostly accomplished by Iraq Geological Survey, but the Iraqi universities have significantly contributed to this effort through postgraduate research work which was published later.

This article is a compilation of the extensive literature on the geology of the Iraqi phosphorite deposits. Emphasis on published work is justified to facilitate further reading, but main technical reports of Iraq Geological Survey are also considered in addition to important postgraduate research work. Discussion of the various aspects of the Iraqi phosphorite deposits is considered separately for each topic within the article.

STRATIGRAPHY

Three main phosphorite-bearing formations are recognized in Iraq. These are Digma (Maastrichtian), Akashat (Paleocene) and Ratga (Eocene), developed west of the Horan High, extreme west of Iraq (Al-Bassam *et al*., 1990). They are marine sedimentary rock units, where carbonates are dominant, followed by phosphorite, shale, chert and sandstone. Several horizons of phosphorite and phosphatic rocks are interbedded with carbonates and shale. Silicification is common, especially in the Eocene rocks. The whole phosphorite-bearing sequence is cyclic with the phosphorites showing at the onset of transgressive cycles, usually topping hardgrounds in carbonate rocks (Al-Bassam and Karim, 1992). However, not all the units of the Late Cretaceous-Paleogene sequence are phosphorite-bearing, and the main phosphogenic episode in Iraq was manifested in the Paleocene.

The Late Cretaceous – Paleogene phosphorite-bearing sequence in Iraq was described as follow (Al-Bassam *et al*., 1990):

- **Digma Formation** (Maastrichtian)

It is exposed along the northern and western rims of the Ga’ara depression as narrow belt, but shows wide exposures south of Rutba town. The thickness varies from a few meters along the Ga'ara northern and western rims to about (40) m south of Rutba town. Greater thicknesses have been reported in subsurface. It is dominated by shale, dolomitic marl and limestone. The phosphorite is present as thin and discontinuous horizons at the upper part (Fig.3).

Three main phosphorite-bearing cycles can be recognized in subsurface sections (Fig.3). In exposed sections the lower part consists mostly of fissile shale (black in subsurface and ocher or green in surface exposures), dominated by smectite, gradually overlain by a middle part, which consists of dolomitic marl, creamy in color, chert-bearing and bioturbated, with clastic phosphorite horizons at top, 0.5 m – 2 m thick, sharply overlying hardgrounds and filling borings. The upper part consists of a remarkable shelly (bivalves) limestone bed (shell hash) interbedded with thin marl beds. Thicker phosphatic horizons have been reported in deeper subsurface sections north and south of the Ga'ara depression.

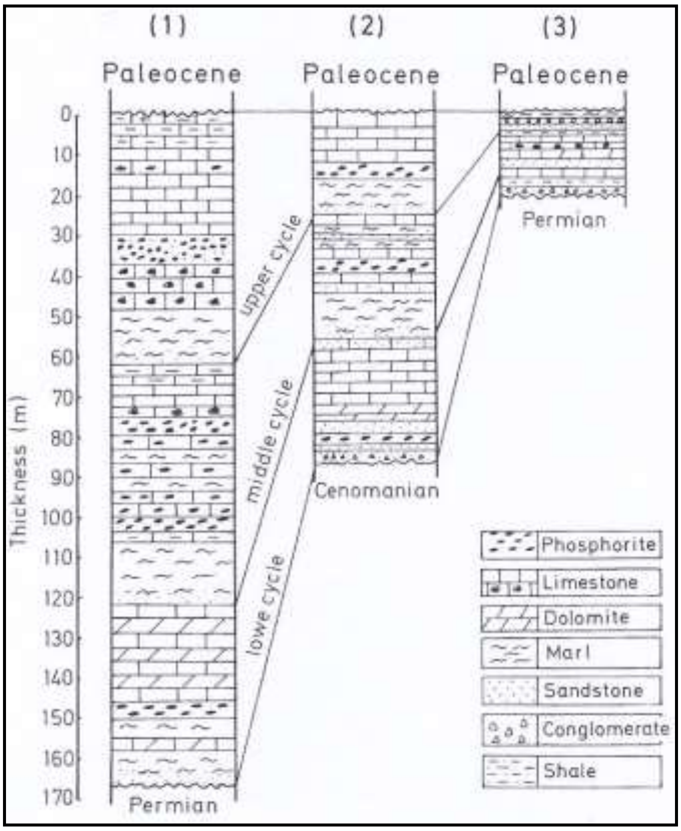

Fig.3: Columnar lithostratigraphic sections of the Campanian – Maastrichtian sequence in the western desert of Iraq. **1)** Subsurface section, H3 area, **2)** Subsurface section at Swab area and **3)** outcrop section at NW rims of the Ga'ara depression (Al-Bassam *et al*., 1983)

- **Akashat Formation** (Paleocene)

This is the main phosphorite-bearing rock unit in Iraq. It is exposed north, west and south of the Ga’ara depression (Fig.4) and was encountered in subsurface west of the Horan High. It varies in thickness from about (15) m near the Ga'ara depression to about (25) m at Akashat area, (50) m in Wadi Swab and up to (70) m south of the highway (Al-Bassam *et al*., 1990). The lithology is dominated by phosphorite, marl, limestone and shale (Fig.5). The Akashat Formation overlies the Digma Formation with a conformable, but sharp contact and is divided into three members:

– **Traifawi member** (Lower Paleocene)**:** it overlies the Digma Formation with an erosional contact, but the Danian index fossils have been first identified in this unit on the basis of microfossils (S. Karim, in: Jassim *et al*, 1984) and were ascertained lately by Al-Ganabi, (2004). It is missing in the northern rims of the Ga'ara depression, but was encountered elsewhere in the area. The thickness generally varies from about (5) m in Akashat area to about (21) m in Traifawi area. The lithology consists of interbedded shale, marl and phosphorite. The shale is ocher in color (black in subsurface), dominated by smectite and includes thin horizons of phosphorite. The marl is dolomitic and bioturbated and the phosphorite is granular (sand-size), rich in bioclasts (bone remains), coated grains and coprolites with calcite cement. It occurs in relatively thin horizons, less than (0.25) m thick, and often tops hardgrounds, bioturbated and indurated surfaces in the marl beds.

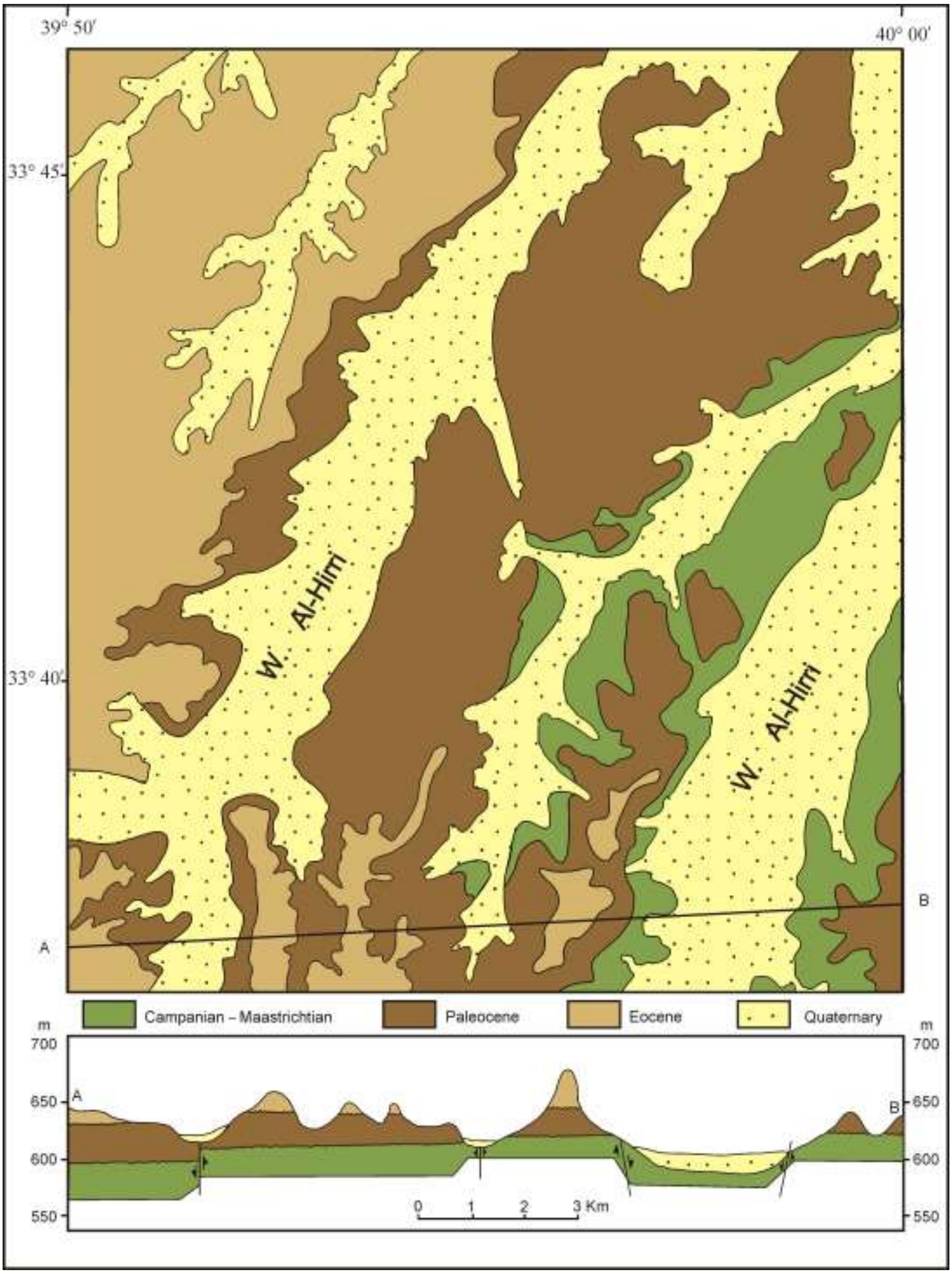

Fig.4: Geological map of the Akashat area (Dawood, 1965)

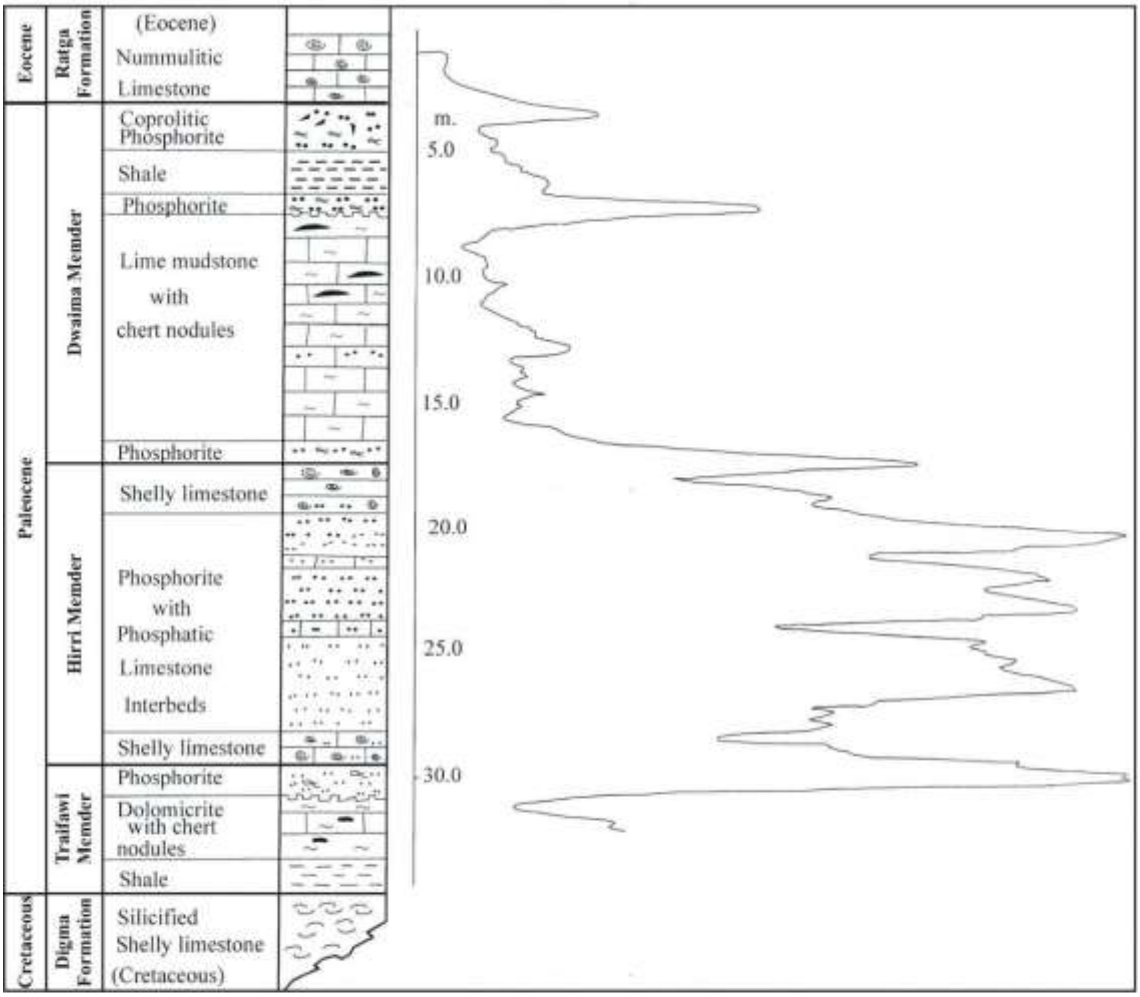

Fig.5: Lithological columnar section and γ log of the Paleocene phosphorites-bearing sequence at Swab area (Al-Bassam, 2007a)

– **Hirri member** (Middle Paleocene)**:** This is the main phosphorite-bearing rock unit in Iraq; it consists of an alternation of granular phosphorite and phosphatic lime mudstone, topped by a shelly limestone. The thickness of the Hirri Member is about (15) m at Akashat, (35) m in Wadi Swab and reduced to (45) m in the Traifawi area. The base consists of shelly (bivalve), phosphatic limestone of variable thickness; usually not exceeding (1) m and occasionally missing. The main body of this member is peloidal-ooidal, well sorted sand-size phosphorite, interbedded with phosphatic marl and reach up to (12) m in thickness at Wadi Swab, but may be reduced to (1 – 2) m thick along the Ga'ara rims and south of the Baghdad – Amman highway. The cementing material of the phosphate grains is calcite. The phosphorite is topped by another shelly (bivalve) phosphatic limestone, which may reach up to 10 m in thickness.

– **Dwaima member** (Upper Paleocene)**:** It consists of up to (20) m thick chert-bearing lime mudstone occasionally with quartz geodes, interbedded with multiple (0.2 – 4.0) m thick granular phosphorite and shale horizons. The thickest of the phosphorite interbeds in this member, (up to 4.0 m thick), is considered economically feasible for mining and exploitation (the Hirri deposit) (Al-Bassam and Saeed, 1989). The upper part consists of a remarkable, (0.5 – 1.0) m thick bed of coprolitic phosphatic and clayey limestone, rich in bone remains and shark teeth. This bed marks the uppermost part of the Paleocene sequence in the region.

- **Ratga Formation** (Eocene)

The phosphorite-bearing units are found in the middle part of the formation (Fig.6), which is divided into three members: **1)** Swab Member (Lower Eocene), about (20 – 40) m thick and consists of recrystallized nummulitic limestone throughout with a sharp contact with the underlying unit. **2)** Damlouk Member (Middle Eocene), it is generally a nummulitic limestone, (40 – 50) m thick, comprising two transgressive cycles, with phosphorite, up to (8) m thick, at the base of these cycles, especially the upper cycle. Extensive silicification of several horizons of this member is common at the Ethna and Traibeel areas. **3)** Mugur Member (Upper Eocene), it is the upper part of the Eocene sequence in western Iraq. It is (30 – 40) m thick and contains no phosphate showings.

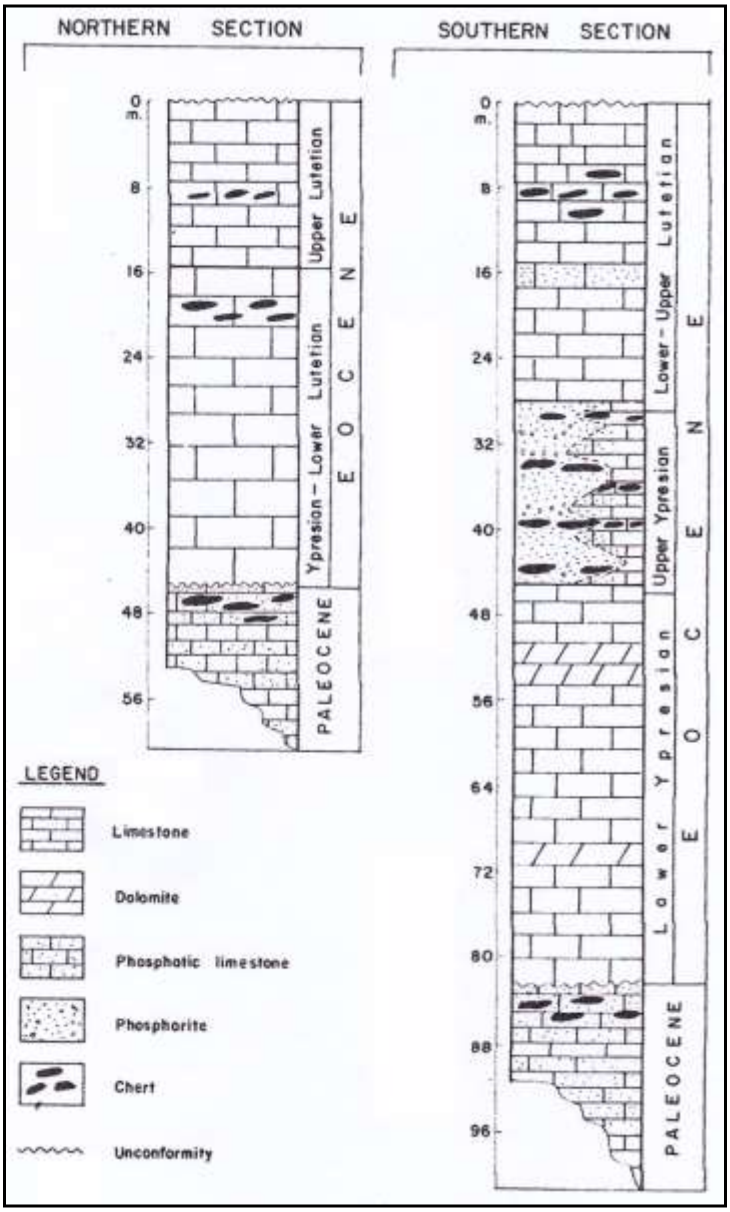

Fig.6: Columnar stratigraphic sections of the Eocene sequence in the extreme western part of Iraq (Al-Bassam and Hagopian, 1983)

PALEOGEOGRAPHY

The Late Cretaceous-Paleogene phosphorite deposits of Iraq are part of the extensive phosphorite belt of the Tethys Sea; best developed in North Africa and East Mediterranean, from Mauretania and Senegal in the west to Iraq, Iran and Turkey in the east, including deposits of Morocco, Algeria, Tunisia, Egypt, Saudi Arabia Syria, Palestine and Jordan (Fig.2). They all have the same age span and share similar sedimentological characteristics.

In about 25 million years of geological history, the largest and most extensive phosphorite deposits of the world were laid down. It was a regional event that lasted from the Campanian to the Lutetian, initiated and controlled by specific regional paleogeography of the Tethys, in its concluding episodes, and by local basins and troughs, of tectonic origin, which represented favorable sites of phosphogenesis.

By Late Cretaceous, the New Tethys Ocean was developed into an elongated narrow seaway, as a result of the continuous northward movement of the African Plate towards Eurasia (Fig.7). Upwelling deep oceanic cold currents were active along the southern margins of the Tethys, bringing P- and Si-rich waters from deeper parts of the sea to the shallow warm shelf (Fig.8). The anomalously phosphorus-rich bottom waters, welling up to shallow local basins, represented the regional controlling factor that initiated this extensive phosphogenic event.

Local basins along the southern margins of the Tethys Sea were developed tectonically, as a result of the extensional forces acting effectively in the region at that time. In Iraq, the Anah Graben is one of the examples on the results of such extensional forces. Locally, normal E – W faults initiated basinal troughs west and east of the Ga'ara depression, which was an elevated area, occasionally submerged in periods of high sea level stand. A series of step normal faults in the eastern part of the area, approaching and simulating those of Anah Graben, created troughs and left the uplifted Ga’ara area and its northern and western extensions, a relatively elevated, but submerged hanging block, known as the Akashat Platform, which was terminated from the west by the simultaneously developed Tinif Trough (Fig.9). The deposition of Paleocene phosphate-bearing strata in the Nukhaib and surrounding areas, provides evidence on free connection of the basin in those areas with the open sea in the Paleocene. These deposits are comparable to those deposited in the Akashat area and are equivalent to those found in Northern Saudi Arabia of the same age.

Most of the important Iraqi phosphorite deposits were laid down on the Akashat Platform including Akashat, Swab, Dwaima, Marbat and Hirri. The troughs located to the east and west facilitated access to the open marine and consequently to the phosphorus-rich upwelling waters to reach these local basins (Al-Bassam and Al-Allak, 1985). Deeper carbonate and chalky facies were developed in these troughs while shallower phosphorite facies were developed in the elevated shallower margins (Al-Bassam and Karim, 1992). The area south of the Tinif trough formed another platform for phosphorite deposition in the Middle Eocene, where the Ethna deposit was developed (Al-Bassam and Hagopian, 1983 and Kettaneh *et al*., 1986).

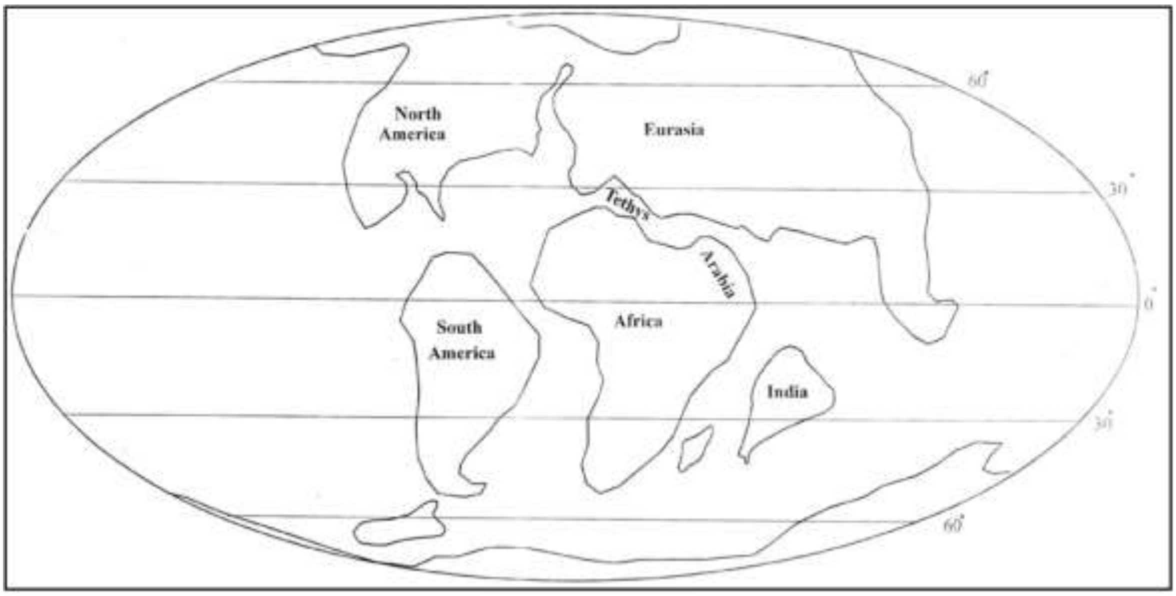

Fig.7: Late Cretaceous paleogeography (after Ziegler *et al*., 1982, in Sheldon, 1987)

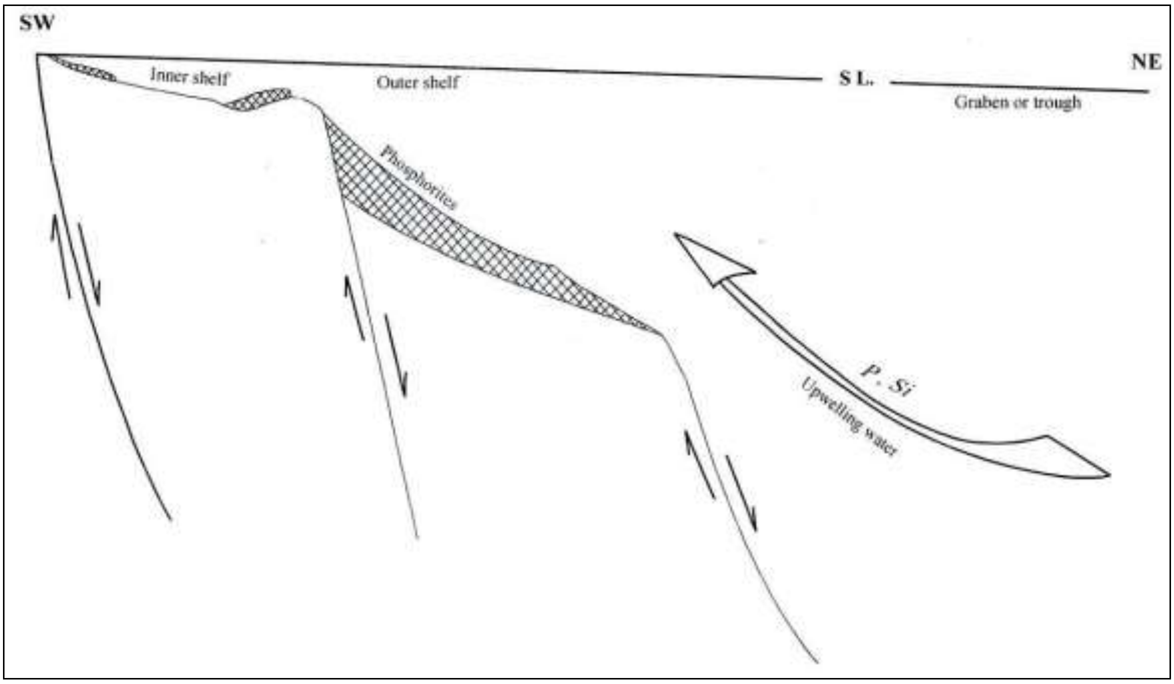

Fig.8: Structural control on basin configuration and phosphorite deposition
(Al-Bassam, 1992)

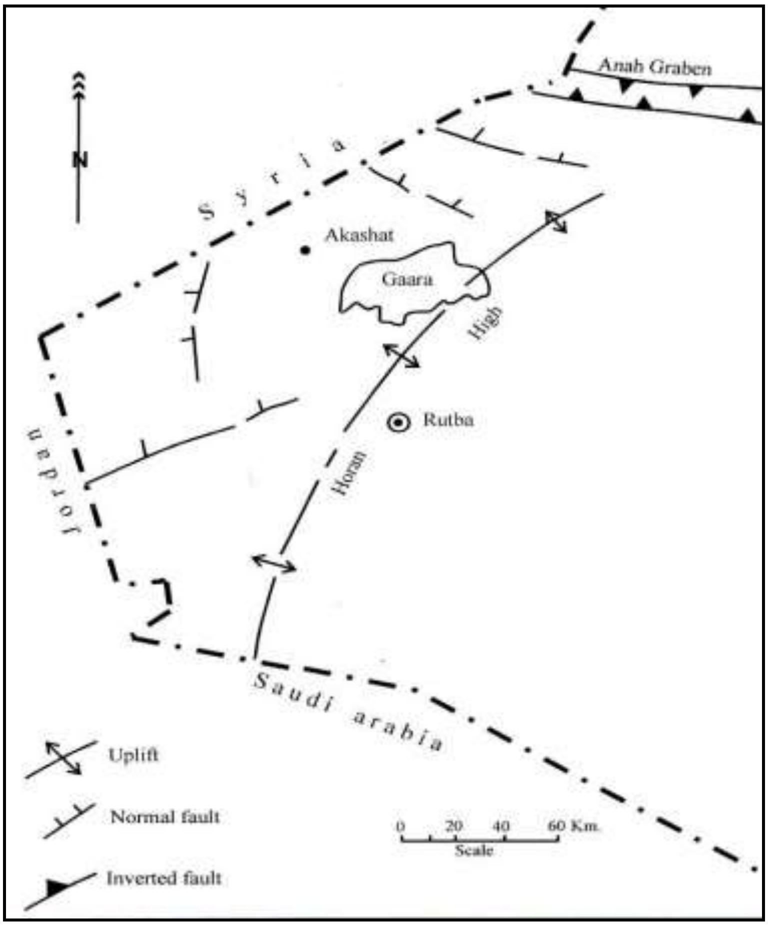

Fig.9: Main structural elements of western Iraq (Al-Bassam, 1992)

FACIES AND DEPOSITIONAL ENVIRONMENT

The package of associated lithotypes (phosphorite-shale-limestone-chert) is a typical character of the Tethyan phosphorite-bearing sequence in the region. It represents a signature of peculiar oceanographic as well as continental conditions. The whole sequence is cyclic, with numerous pauses in sedimentation (expressed as hardgrounds with borings) (Figs.10a and 10b). A typical transgressive cycle in this sequence begings with granular phosphorite topping the older indurated lime mudstone surfaces and filling borings, passing upward into phosphatic limestone, marl and/ or shale, phosphorite, shelly limestone, phosphorite, shale and limemudstone. These are usually complete cycles, range in thickness from less than one meter to several meters and may be missing one or more of its members.

These facies were deposited in rapidly changing marine environments, ranging from basin slope (globigerinal chalky limestone) to peritidal mudflats (lime mudstone with chert nodules and quartz geodes) (Fig.11). The peloidal-ooidal phosphorites were deposited in the outer shelf (ooids-dominant) to slope environment (peloids-dominent) (Al-Bassam *et al*., 2010). However, occasionally shallower environments have occurred, where clastic phosphate components (bones and intraclasts) are admixed with detrital quartz-sand, suggesting near-shore agitated environment, or when they are composed of coarse grained coprolites and phosphoclasts, but no detritals, suggesting a shallow off-shore environment, such as a mid-shelf shoal (Al-Bassam, 1992 and Al-Bassam and Karim, 1992).

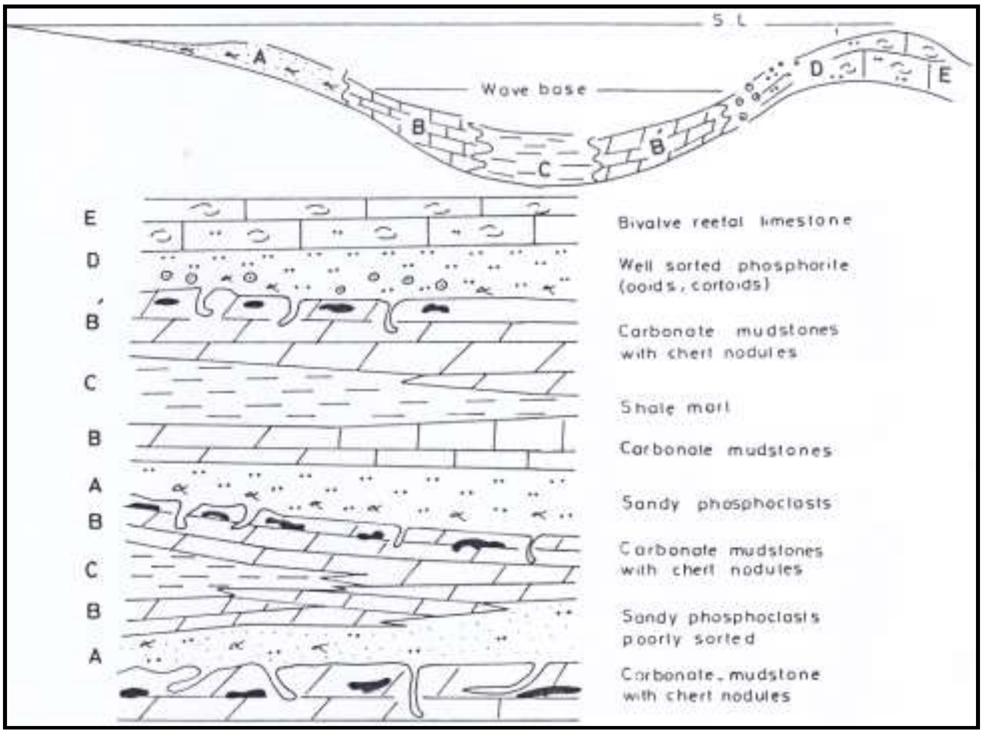

Fig.10a: Inner shelf cyclicity in the Late Cretaceous and Paleocene sequences (Al-Bassam, 1992)

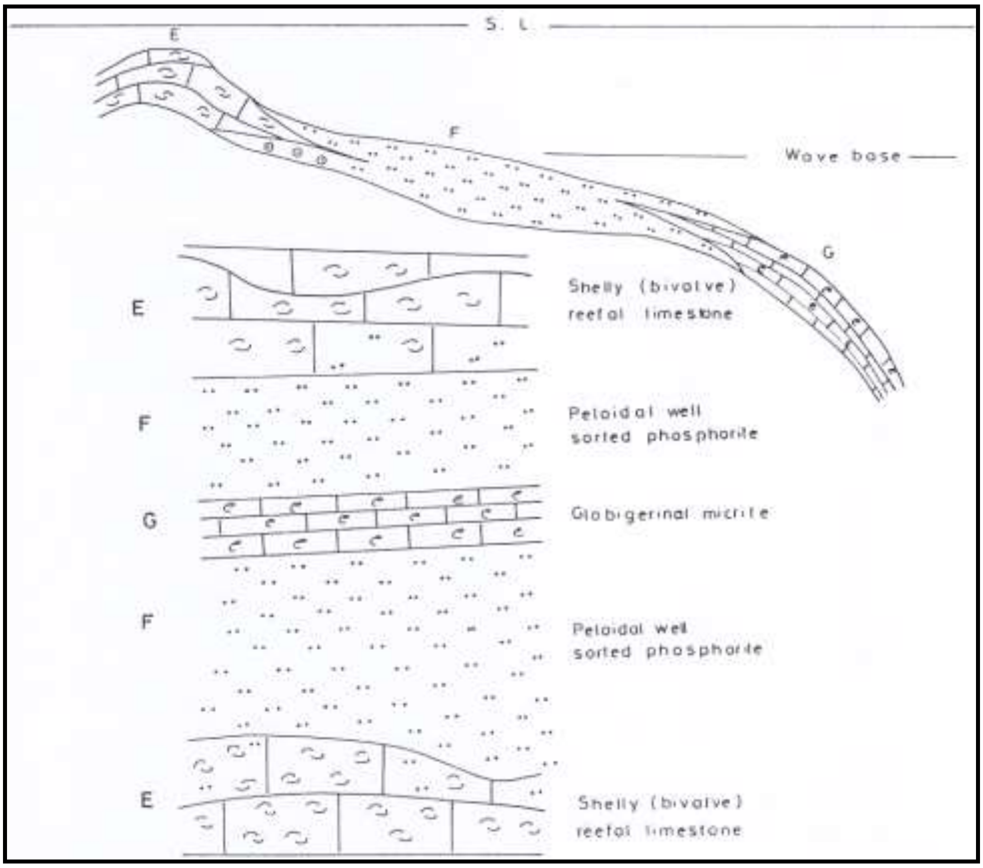

Fig.10b: Outer shelf cyclicity in the Middle Paleocene and Early to Middle Eocene sequences (Al-Bassam, 1992)

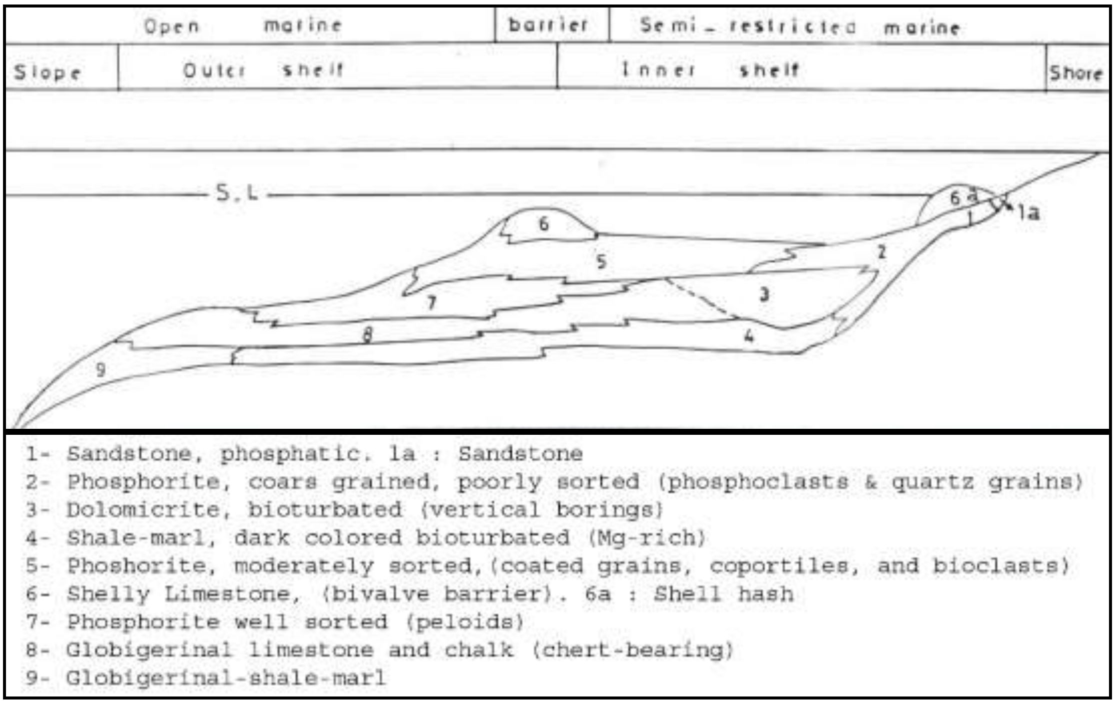

Fig.11: Facies model of the Paleocene phosphorite-bearing sequence
(Al-Bassam and Karim, 1992)

Phosphate intraclasts may suggest a microsphorite (phosphate mud) precursor phase, that was later reworked under waves and currents (Al-Jaleel, 1983). Coated phosphate grains, such as ooids, cortoids, composites and oncoids were formed by accretionary process (Mohamed, 1985 and Aba-Hussain, 1987). Bacterial mats were able to form one or more coat(s) in short lived non-depositional episodes of the grain growth history, leaving their signature as an internal core or as concentric rings of black organic residues (Al-Bassam, 1976). On the other hand, phosphate peloids with no internal structure, may have formed in the deeper environments of the outer shelf or slope (Al-Bassam and Karim, 1992). Most of the cementing material in the phosphorite facies is diagenetically precipitated including silicification and calcite cementation.

The ocher and green fissile shale encountered in exposures, is black in subsurface sections (Fig.12) and rich in carbonaceous material (Al-Bassam and Al-Haba, 1990). It is a typical black shale facies, deposited in an anoxic, restricted and quite environment within the inner shelf. Most of the clay is of detrital origin, brought to the basin by surface water (Al-Bassam and Al-Sa'adi, 1985). Smectite-rich shale is common at the Cretaceous/ Tertiary boundary in many parts of the world (Ortega *et al.*, 1998). This facies is usually less than 0.5 m in the phosphorite dominant area, but may reach more than 10 m in thickness south of the highway (Al-Bassam, *et al.*, 1990). The carbonate content increases gradually upward to form marl at the upper part.

The shelly (oyster) limestone was formed as a shoal, occasionally reworked by waves and currents, to form a near-shore accumulation of shell hash (Al-Bassam and Karim, 1992). This facies and the phosphorites are closely related and their contacts are transitional, whereas the contacts between phosphorites and lime mudstone are usually sharp with a pause in sedimentation marking the top of the latter.

Fig.12: Phosphorite-shale association, **Left:** oxidized by weathering (light color)
Right: original unoxidized (dark color)

The chert-and geodes-bearing lime mudstones are considered mudflat deposits, usually suffered early diagenetic dolomitization. The chert nodules and quartz geodes are believed to be silicified anhydrite nodules by Petranek *et al*. (1983), formed within the mudflat peritidal deposits, in an arid and warm climate. This facies usually makes the top of the sedimentary cycles, especially in the Paleocene sequence. It is rich in diatomite and occasionally silicified into an opal-CT (porcelanite) (Aba Hussain 1987 and Al-Bassam *et al*., 2000).

The chalky globigerinal limestones, usually found interbedded with the phosphorite horizons, represent the deepest facies in the Paleogene sequence, based on the faunal assemblages recognized (Karim; in Al-Bassam *et al*., 1990). They were deposited at the basin-slope and represent maximum sea-level stands in the Paleocene and Eocene sequences.

PETROLOGY

The Iraqi phosphorite deposits are generally granular in texture, as with all Tythyan deposits (Al-Bassam, 1976; Al-Dahan, 1977; Al-Jaleel, 1983; Mohamed, 1985 and Aba-Hussain, 1987). The phosphate components vary in type, size and origin and are cemented by calcite or cryptocrystalline silica. They include impurities such as detrital grains, fossil shells, bone fragments, carbonaceous remains, etc. They are generally sand-size, but coarser varieties are common, such as the phosphate intraclasts, bone remains, shark teeth and coprolites in the Ethna deposit (Eocene) and in the upper part of the Dwaima Member (Late Paleocene).

The Late Cretaceous phosphorites are generally poorly sorted, mixed with terrigenous clastics and consist of various types of phosphate components, including intraclasts, coated grains, coprolites and bone fragments (Figs.13a and 13b) (Al-Dahan, 1977; Mohamed, 1985 and Al-Bassam *et al*., 1983). The matrix is clayey, calcareous or dolomitic, but rarely phosphatic (Fig.13c). Diagenetic cementation is not common, but when occasionally present, the cement is calcareous.

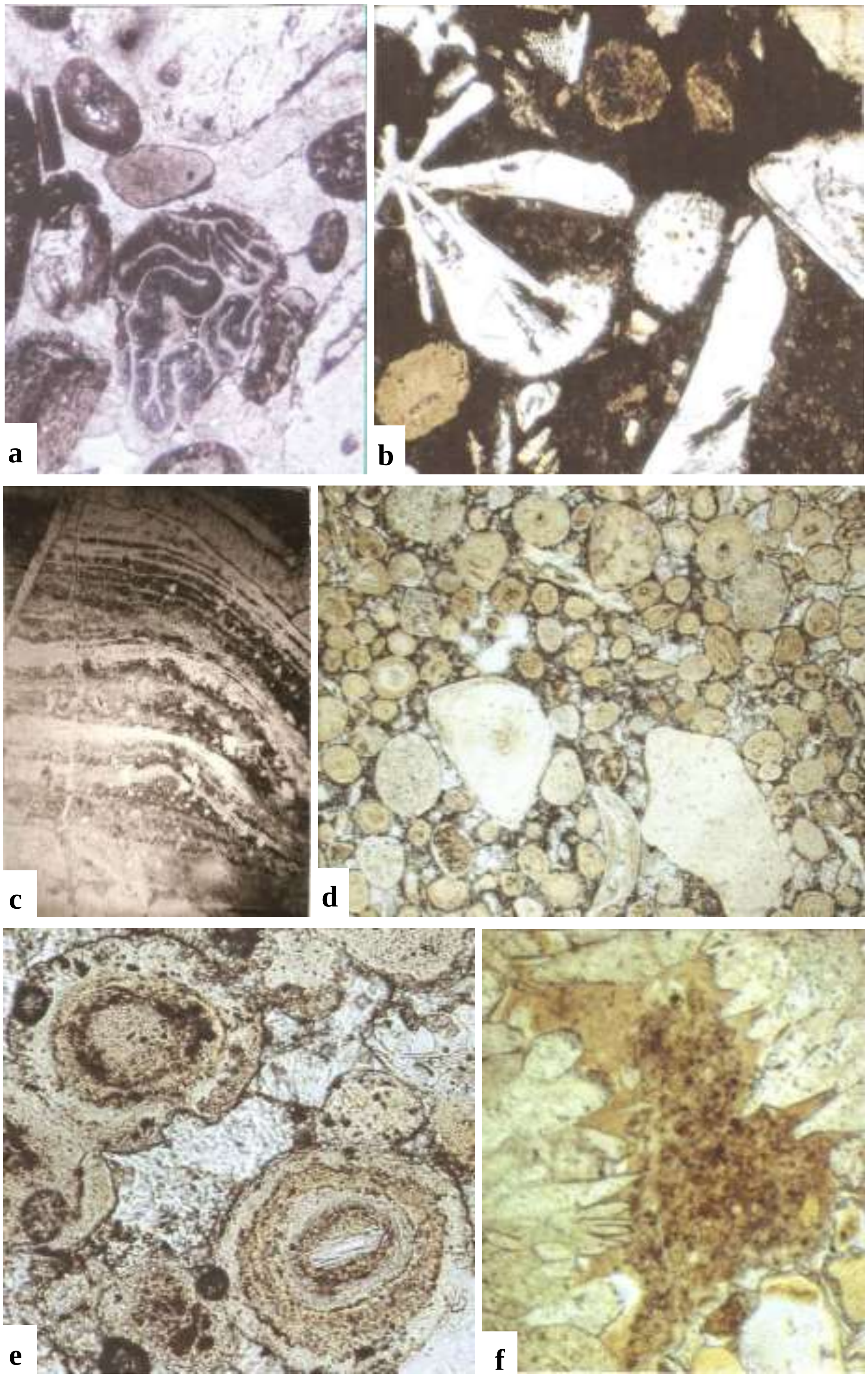

Fig.13: Microtextures of the Iraqi phosphorites
a) Phosphate coprolite, Late Cretaceous, Iraq, 1 cm = 1 mm, **b)** Phosphate fish scales, Late Cretaceous, 1 cm = 0.1 mm, **c)** Laminated phosphate matrix, Late Cretaceous, 1 cm = 0.25 mm, **d)** Coated and Non-coated phosphate grains (larger grains are phosphate lithoclasts), Paleocene, Iraq, 1 cm = 0.25 mm, **e)** Phosphate oncoids, Paleocene, Iraq, 1 cm = 0.1 mm and **f)** Intragranular phosphate cement, Paleocene, Iraq, 1 cm = 1 mm

On the other hand, the Paleocene phosphorites are mostly well sorted (except those at the upper part of the Dwaima Member), consist of sand size peloids, various types of coated grains (cortoids, ooids, oncoids), and minor amounts of bone fragments and coprolites (Figs.13d and 13e). In rare cases, phosphate cement was encountered in the Akashat Formation (Fig.13f). Otherwise, the dominant cementing material is coarsely crystalline calcite. However, silicification of the cementing material and the lime mudstone horizons is very common south of the Baghdad-Amman highway (Traifawi area). The phosphorite bed, marking the top of the Akashat Formation, is poorly sorted with phosphate components dominated by coarse grained (up to 1cm long) coprolites, shark teeth, bone fragments, as well as sand-size coated and non-coated grains (Fig.14). The matrix is clayey, calcareous and dolomitic.

The Middle Eocene phosphorites north of the Ga’ara depression, are generally moderately sorted and dominated by phosphate peloids, with accessory amounts of coated grains and rare phosphoclasts (Al-Hashimi and Al-Bassam, 2006). On the other hand, the age-equivalent phosphorites of the Ethna deposit are coarse grained, poorly sorted and consist mostly of phosphate intraclasts and coprolites, with rare bioclasts (Fig.15) (Al-Bassam and Hagopian, 1983 and Kettaneh *et al.*, 1986). The cementing material and most of the associated lime mudstone horizons are commonly silicified in that area.

The mineralogy of the phosphate is dominated by francolite (carbonate fluorapatite), which is cryptocrystalline, isotropic under crossed nicols (except bone fragments). The dominant clay mineral in the shale, as well as anywhere in the phosphorite-bearing Late Cretaceous-Paleogene sequence, is a high-Mg smectite; believed to be of detrital origin (Al-Bassam and Al-Sa'adi, 1985), followed by palygorskite (especially in the Akashat – Ga'ara area) and rarely sepiolite; both are believed to have originated from smectite transformation (Aswad *et al.*, 2000). Other clay minerals present are traces of detrital kaolinite and illite. Detrital quartz is commonly found associated with phosphorite in the Late Cretaceous sequence (Al-Dahan, 1977 and Mohamed, 1985), but it is rare in the Paleogene (Aba Hussain, 1987).

On the other hand, silicification of the associated lime mudstone and to a lesser extent the shelly (oyster) limestone is common in the whole sequence, especially south of the Ga’ara-Akashat area. The silica is present either as cryptocrystalline chalcedony, forming chert horizons, nodules or geodes, or it is crystallized as opal-CT forming porcelanite.

Quartz geodes (Fig.16) are believed to have formed diagenetically after vasnished evaporite nodules (Petranek *et al.*, 1983), hosted by diatomite-rich lime mudstone horizons, which were silicified into porcelanite (Al-Bassam, 1992). Secondary minerals of interest are carnotite and metatyuyamunite. The former is encountered in the shale, whereas the latter is found in the phosphorites and phosphatic limestones, as lining of joints and cavities (Al-Bassam, 2007b).

Fig.14: Coprolitic phosphorite with about 5 cm long shark tooth, Dwaima Member, Akashat Formation

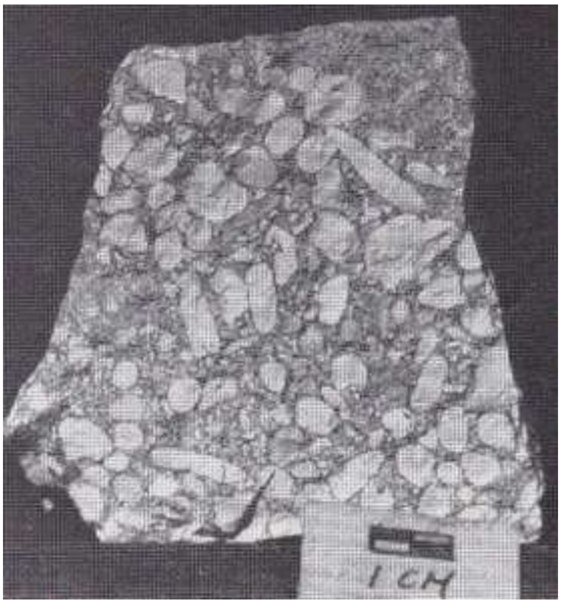

Fig.15: Coarse grained Eocene phosphorite
(Al-Bassam and Hagopian, 1983)

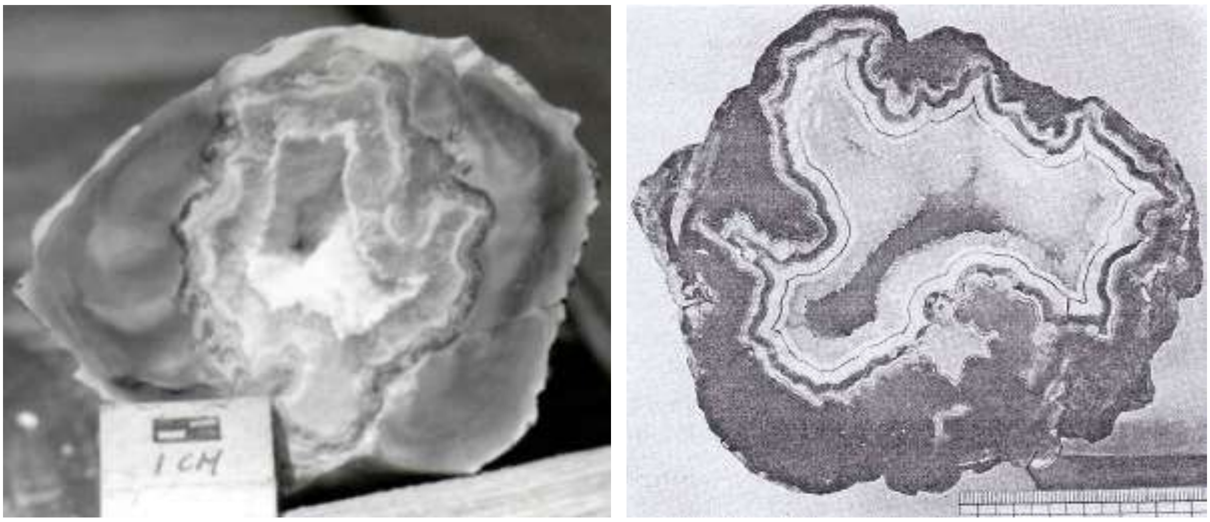

Fig.16: Quartz geodes, Late Cretaceous, (Petranek *et al*., 1983)

GEOCHEMISTRY

The chemical composition of the Iraqi phosphorite and phosphatic rocks is controlled by their mineral constituents, which are: francolite, calcite, dolomite, quartz, opal-CT, smectite, palygorskite and organic matter. The chemical composition (Table 1) of sedimentary rocks with such well-defined mineralogy is easily predicted. The francolite hosts all the phosphorus and the fluoride, and equally share calcium with the carbonate minerals.

Table 1: Mean chemical composition of phosphorites (Al-Bassam *et al*., 1990)

	Digma	**Traifawi**	**Hirri**	**Dwaima**	**Damluk**
	%				
P_2O_5	18.57	21.09	22.94	21.73	18.08
CaO	50.70	51.49	52.31	46.64	52.03
MgO	1.11	0.90	0.48	4.42	0.20
SrO	0.16	0.15	0.14	0.15	0.05
SiO_2	2.70	1.87	1.17	2.96	4.0
Al_2O_3	0.31	0.42	0.33	0.54	0.13
Fe_2O_3	0.70	0.21	0.15	0.32	0.08
Na_2O	0.65	0.76	0.74	0.77	0.44
K_2O	0.07	0.04	0.04	0.06	0.03
SO_3	1.77	1.28	1.88	1.19	0.89
F	2.17	2.51	2.78	2.69	2.61
Cl	0.07	0.14	0.17	0.10	0.08
LO1	21.91	19.92	17.50	19.08	21.52
	Ppm				
U	39	37	34	44	37
Y	37	88	75	n.a	179
V	150	95	183	n.a	176
Cd	8	29	62	22	37
Cr	112	39	240	n.a	96
Ni	40	5	43	n.a	38
Cu	6	7	13	n.a	34
Zn	n.a	124	611	n.a	110

n.a: analysed

The analysis of concentrated phosphate components from the Iraqi deposis show that the francolite contains about (33 – 34) % P_2O_5, (52 – 53) % CaO, (3 – 4) % F, (2) % SO_3, (1.5) % Na_2O, (4) % CO_2 and (2 – 3) % H_2O. Sodium and sulfate substitute for calcium and phosphate respectively, whereas, carbonate (CO_3) partially replaces phosphate (PO_4) in the francolite structure (Al-Bassam, 1976).

Uranium, yettrium and the REE are hosted essentially by francolite, whereas trace elements, such as Sr and Cd, are shared between phosphates and carbonates. The francolite structure is known to tolerate and host several other metals, such as As, Cr, Ni, V, and Zn in various sites of the structure (Al-Bassam, 1975).

Smectite hosts most of the alumina, magnesia, titania and iron, but shares silica with chert, porcelanite and quartz and shares magnesia with the carbonates. The smectite-dominated black shale is rich in carbonaceous organic matter and may host several trace metals (such as Cr, Ni, Cu, Cd and Zn) in structural or exchangeable sites of the smectite, as well as in organic complexes.

In the Iraqi phosphorites, the average (P_2O_5) concentration is generally in the range of (20 – 22) %, suggesting about (60 – 65) % francolite. The reminder is calcite or silica cement. In the phosphate-bearing rocks, the (P_2O_5) concentration varies according to that of francolite.

- **Uranium**

Uranium has been analysed in the bulk phosphorites and in the concentrated phosphate components. The results indicate that the Iraqi phosphorites are relatively poor in uranium relative to deposits elsewhere in the region (Al-Bassam, 2007b). Uranium mean concentration seldom exceeds (50) ppm in the bulk phosphorites and usually less than 100 ppm in the concentrates, being the highest in the Paleocene peloidal-ooidal phosphate concentrates.

The (U/P2O5) ratio in the bulk rocks generally has the range of (1 – 3); the Eocene phosphorites show the highest ratio of (> 2); the Paleocene show intermediate values of (1.5 – 2) and the Late Cretaceous phosphorites show the lowest mean ratio, but with the widest range of (1 – 2.7) (Al-Bassam, 2007b). Uranium is the source of gamma-ray activity of these rocks (Fig.17) and appears to be incorporated in the francolite structure (Fig.18).

Radiometric analysis of U_3O_8 and eU_3O_8 shows scattering around the 1: 1 equilibrium line (Fig.19), indicating that uranium is in a state of equilibrium with its daughter (Ra), except where weathering and diagenetic porosity in these rocks facilitated ratios in favor of Ra. It has been demonstrated that the uranium source is continental, transported, in ionic phase, by surface waters to the marine basin and was trapped by the newly formed phosphate mud and phosphate grains. Uranium uptake by the francolite from marine water could have been a continuous process of water-rock interaction before burial (Al-Bassam, 2007b).

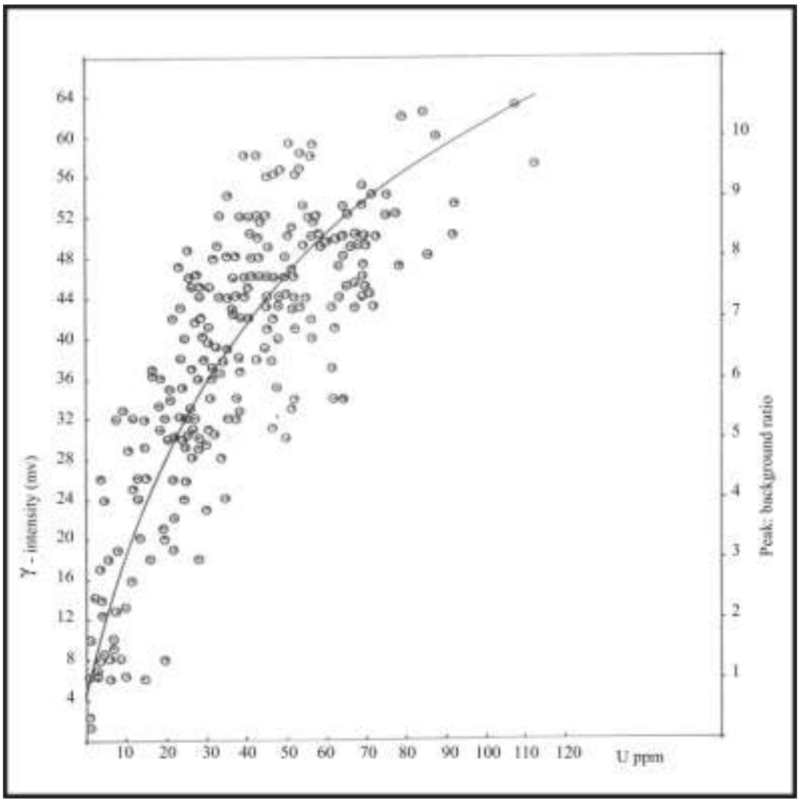

Fig.17: Relation of gamma intensity and uranium concentration
(Al-Bassam, 2007b)

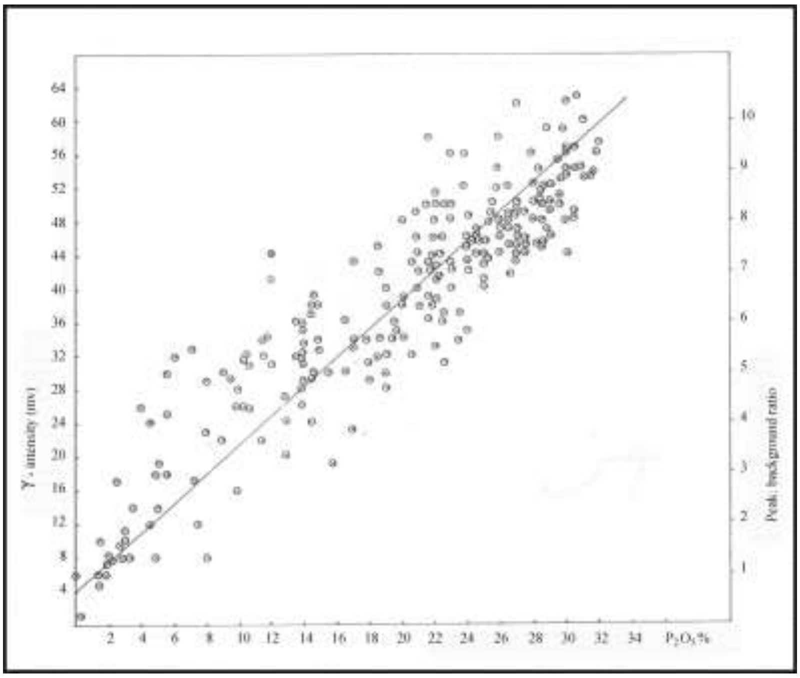

Fig.18: Relation of gamma intensity and phosphorus concentration (Al-Bassam, 2007b)

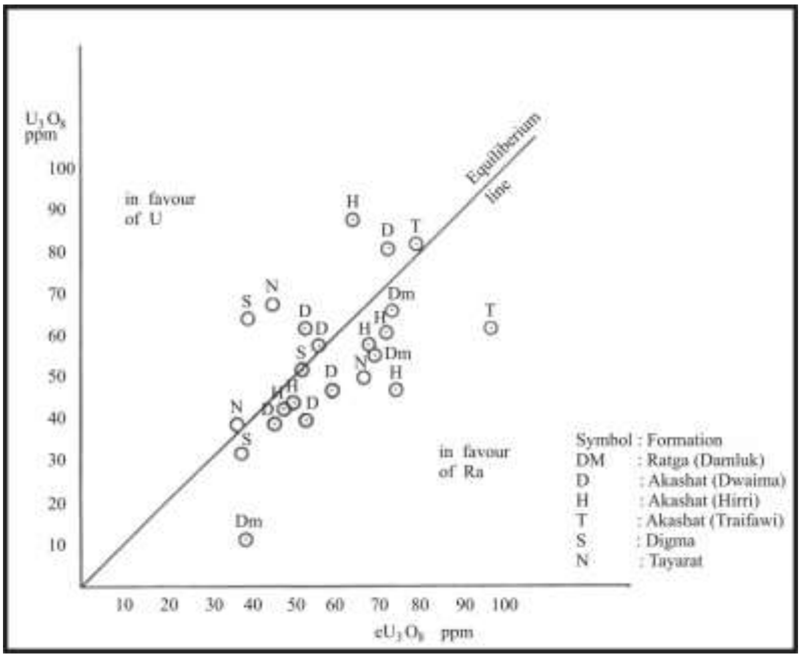

Fig.19: Uranium equilibrium state in some Iraqi phosphorites (Al-Bassam, 2007b)

- **Rare Earth Elements**

The REE analysis of concentrated phosphate grains (coprolites, peloids, coated grains and bioclasts) from the Paleocene phosphorites has revealed lower REE concentrations than average world phosphorites (Aba Hussain *et al.*, 2010). Coprolites show the highest concentrations in total REE (TR_2O_3) with a mean of (162.6) ppm, followed by coated grains and peloids with (82.1) ppm and the least concentration was found in the bioclasts (skeletal bones and teeth) with (66.2) ppm, compared to (457) ppm in world average phosphorites.

The mean of the shale-normalized REE analysis was compared with average marine upwelling phosphorites and with sea-water (Fig.20). The distribution patterns of REE in the Iraqi francolites are comparable to sea-water and to average world phosphorites patterns, with well defined Ce-anomaly, supporting the deep oceanic source of phosphorus (Aba Hussain *et al*., 2010). The variation in the REE concentration among the various phosphate grain types was attributed to genetic factors, contact time with sea water, mass/surface ratio of the grains and to diagenetic modifications.

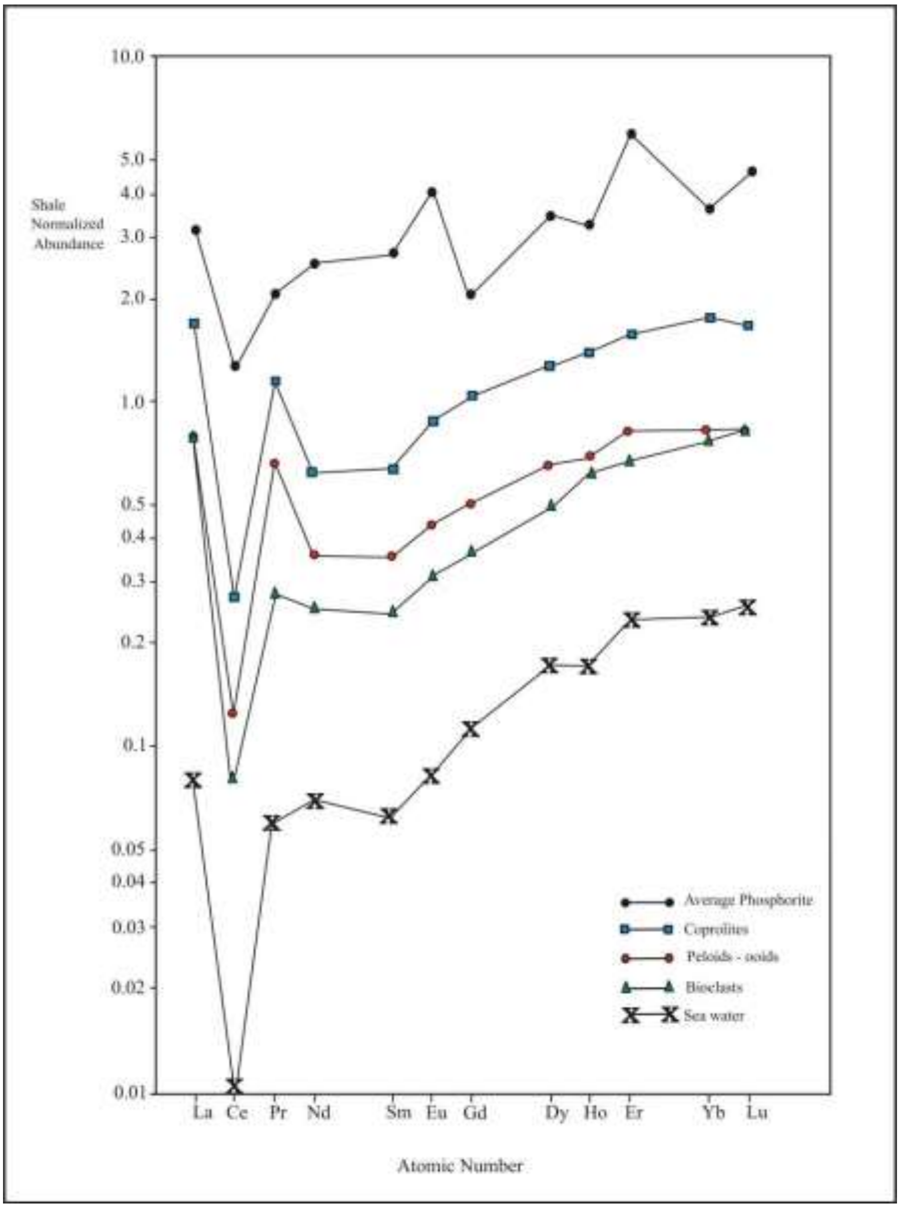

Fig.20: Shale-normalized REE patterns of Paleocene concentrated phosphate grains (Aba Hussain *et al*., 2010), seawater (Hogdahle *et al*., 1968) and average marine phosphorites (Altschuler, 1980)

- **Stable Isotopes**

Carbon and oxygen stable isotopes have been analysed in concentrated francolites from the Maastrichtian, Paleocene and Eocene Iraqi phosphorites and compared to their values in bulk phosphorites and associated carbonates (Al-Bassam, 1980). The results show a consistent decrease in the $\delta^{13}C$ from older to younger francolites. The former are more enriched in the heavy isotope of carbon relative to the latter (Table 3). Moreover, the phosphorites in general, are enriched in the light isotope of carbon relative to the associated carbonate rocks, which suggests precipitation from a lower-salinity waters and an organic source of carbon.

A significant microbial role in the phosphogenesis process has been indicated in the Iraqi phosphorite (Al-Bassam *et al*., 2005). Dissociation of organic remains, below sediment-water interface, had locally supplied phosphorus and organic carbon to these marine microenvironments (Al-Bassam, 1976). Organic carbon may have been the source of the light isotope of carbon detected in the francolite (Al-Bassam, 1980). The increase of the heavy isotope with age may be explained by diagenetic modifications.

Table 3: Stable isotopes of the francolites, phosphorites and associated limestones

Francolites			**Phosphorites and limestones**		
Age	$\delta^{13}C$	$\delta^{18}O$	**Lithology**	$\delta^{13}C$	$\delta^{18}O$
Maastrichtian	– 7.2 to – 7.0	– 6.1 to – 5.4	Phosphorite	– 5.8	– 7.9
Paleocene	– 8.5 to – 8.3	– 6.0 to – 5.1	Phosphorite	– 5.8	– 9.4
Eocene	– 9.6 to – 9.0	– 3.9 to – 4.2	Underlying limestone	– 3.2	– 3.8
			Overlying limestone	– 2.0	– 6.1

On the other hand, a relative increase in the heavy isotope of oxygen from older to younger francolites is noticed. This fits the general trend of marine carbonates and suggests higher temperature of the older oceans as well as recrystallization and isotopic exchange with continental waters. The Phosphorites are relatively enriched in the light isotope of oxygen relative to the associated limestones.

- **Organic Geochemistry**

The Maastrichtian and Paleocene phosphorites are black and carbonaceous in subsurface and are associated with black carbonaceous fissile shale, which is oxidized into green and ocher colors by weathering (Fig.12). The phosphorites themselves, turn gray in exposures.

The analysis of organic carbon in phosphorite and shale samples from Paleocene and Maastrichtian sequences (Al-Bassam and Al-Haba, 1992) shows Total Organic Content (TOC) up to (6.28) % in the Early Paleocene (Danian) shale, whereas, the Middle Paleocene phosphorites contains lower (TOC). The hydrocarbon produced by Kerogene-cracking, reaches up to (29.28) kg (hydrocarbon)/ ton rocks) and the Petroleum Potential (PP) up to 30 kg/ton in the Danian black shale.

However, the organic analysis and tests show that the organic matter in these rocks is of a very low maturity. The maximum free-state hydrocarbon content is only (0.26) mg/gm, recorded in the Paleocene shale. The organic matter in these rocks is of marine origin, generated from an anomalous accumulation of marine organisms in a poorly circulated anoxic environment.

RESOURCES

The phosphorite resources of Iraq are ranked as the second largest in the world after Morocco (Al-Bassam *et al*., 2012). The total indicated resources is about 10 billion tons; more than 50% of which are considered reserves by the USGS. The world phosphate resources are estimated by the USGS to be about 300 billion tons; of which the Iraqi resources represent about 3.3%. The inferred phosphorite resources are several times higher according to the detailed exploration works of the (1986 – 1990) campaign carried out by Iraq Geological Survey (Al-Bassam *et al*., 1990).

The Iraqi indicated reserves/resources are distributed in seven explored deposits: Akashat, Swab, Hirri, Marbat, Dwaima, H3 and Ethna (Fig.1). The H3 deposit was the first to be investigated in the sixties of the last century (Antonets and Aksenoy, 1962), whereas the giant deposits of Swab, Marbat and Dwaima were the fruits of the later more comprehensive exploration campaign of the eighties (Al-Bassam *et al*., 1990). Mining has been active since the early eighties from the Akashat deposit only. All the investigated resources are of Paleocene age, except the Ethna deposit, which is Eocene.

The P_2O_5 grade in the Paleocene deposits is typically 20 – 22 %, but in some horizons it may reach higher values of up to 30% P_2O_5. However the Eocene deposits show slightly lower grade (Table 4). The P_2O_5 content is controlled by the proportion of phosphate components to the non-phosphatic cementing material; whether it is calcite, as in most deposits, or chert as in some Eocene horizons. The phosphate grains contain 33 – 34 % P_2O_5. The P_2O_5 grade, however, depends on the phosphate-poor interbeds included within the mineable sequence.

Table 4: Indicated phosphate reserves/ resources of Iraq (Fig.1)

Deposit and age	**Reserve (m.t)**	**P_2O_5 (%)**	**Exploration category* and reference**
Akashat (Paleocene)	430.0	21.52	A + B + C1 (Al-Khalil *et al*., 1973)
Swab (Paleocene)	3502.9	21.71	C1 (Al-Bassam, 1988)
Dwaima (Paleocene)	2758.0	20.56	C1 + C2 (Al-Bassam and Saeed, 1990)
Marbat (Paleocene)	2114.2	21.17	C1 + C2 (Gulli, 1989)
Hirri (Paleocene)	193.0	21.94	B (Al-Bassam *et al*., 1989a and b)
H 3 (Paleogene)	313.0	17.50	A + B + C1 + C2 (Antonets and Aksenoy, 1962)
Ethna (Eocene)	430.0	17.50	C2 (Abdul Raheem, 1983)
TOTAL	9741.1		

*Russian norms

The mining conditions of the Iraqi deposits are relatively easy and feasible by open cast miming. The rocks are soft to medium tough and the average stripping ratio varies from 1, as in the Akashat deposit, to 3 as in the Swab deposit.

The presence of about 40% calcite cement and the toughness of the phosphate rocks have favoured the present beneficiation route for the Akashat phosphates. Crushing and grinding are carried out at the mining area, but beneficiation is carried out at the fertilizers plant, near the Euphrates River. The beneficiation requires calcinations (at about 1000 °C), hydration, lime removal by washing and phosphate concentration. A concentrate of about 30 – 32 % P_2O_5 is obtained, ready for phosphoric acid production.

The Hirri deposit is unique among the Iraqi phosphorite deposits. The phosphate components are cemented by a friable dolomicrite which enables concentration of the phosphate to more than 30% P_2O_5 by size separation only. The phosphorite horizon is up to 4.0 m in thickness and is overlying the main phosphorite bed of the Swab deposit in its NE part, allowing for multistage mining.

CONCLUSIONS

- The phosphorite deposits of Iraq are part of a geological event, regionally controlled by the paleogeography of the Tethys Sea from Late Cretaceous to Middle Eocene. The narrow and long E – W seaway facilitated upwelling of phosphorus-rich deep marine waters along its warm southern shelf. Locally, the phosphorite deposition was controlled by block faulting of extensional character, which initiated troughs and submerged platforms connected to the open sea and served as depositional traps in the Akashat, Ethna and Nukhaib areas.
- The phosphorite-bearing sequence is developed west of the Horan High in the Digma, Akashat and Ratga formations. It is characterized by alternations of phosphorite, limestone, black shale, chert and porcelanite. The whole sequence was deposited on a gently sloping ramp, extended from basin slope to peritidal mud flats with occasional development of mid shelf shoals. Deeper facies were encountered in the Paleogene compared to the Late Cretaceous sequences.
- Almost all the Iraqi phosphorites are granular in texture, mostly with calcite cement and to a lesser extent silica cement. They are associated with detrital quartz in the Late Cretaceous units. The phosphate constituents are mostly sand-size cortoids, oncoids and pelloids. Skeletal bones, shark teeth and coprolites are common, especially in the Late Paleocene and Middle Eocene phosphorites.
- Francolite is the only phosphate mineral identified. Other minerals include calcite, dolomite, quartz, opal-CT, high-Mg smectite and palygorskite. The whole sequence is carbonaceous in subsurface; the total organic content (TOC) exceeds 6% in the Paleocene black shale and the Kerogene-cracked hydrocarbon is more than 29 kg/ton.
- The phosphorites show geochemical affinity towards F, U, REE, Cd, Sr, Y, Zn and Cr. The main hosts are francolite, smectite and organic matter. Uranium is present in near-equilibrium with Ra, whereas the REE pattern of the Paleocene francolites show resemblance to world marine upwelling phosphorites and to sea-water.
- Phosphorite enrichment in the light isotope of carbon, compared to the associated limestones, is attributed to organic source of the francolite carbon. On the other hand, the increase in the heavy isotope of francolite oxygen from older to younger conforms with the general trend in carbonates.
- The Iraqi phosphorite reserves and resources are in the range of 10 billion tons, which represent, together with sulfur and natural gas, the pillars of a strong and sustainable fertilizers industry in Iraq.

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