

SWAB PHOSPHORITE DEPOSIT A GIANT DISCOVERY IN THE WESTERN DESERT, IRAQ

Khaldoun S. Al-Bassam *

ABSTRACT

Swab phosphorite deposit was discovered in 1986 in the Western Desert of Iraq. It is of Paleocene age and belongs to the Akashat Formation. The industrial phosphorite consists of (9 – 16) m thick bed of fine sand - size well sorted phosphate peloids and coated grains with calcite cement, occasionally rich in organic matter. The average P_2O_5 grade is about 22% and the average stripping ratio is about 3. The overburden consists of Paleocene and Eocene carbonate rocks. The strata are gently dipping towards north with little structural deformation. The new deposit, with its 3.5 billion tons of reserves, puts Iraq among the leading countries in proved phosphorite reserves.

راسب فوسفات صواب. إكتشاف عملاق في الصحراء الغربية، العراق خلدون صبحي البصام

المستخلص

أُكتشف راسب فوسفات صواب في عام 1986 في الصحراء الغربية العراقية وهو من عمر الباليوسين ويعود إلى تكوين عكاشات. يتكون الراسب الفوسفاتي من طبقة فوسفاتية سمكها (9 – 16) متر تتألف من دمالق وسرنيات فوسفاتية بحجم الرمل الناعم مرتبطة بملاط من الكالسيت وغنية بالمواد العضوية أحياناً. يبلغ معدل رتبة خامس أكسيد الفوسفور (P_2O_5) حوالي 22% ومعدل معامل الكشف حوالي 3. تتألف الطبقات الغطائية من صخور كربونانية من عمر الباليوسين والإيوسين. تميل الطبقات قليلاً نحو الشمال مع قليل من التشوهات التركيبية. يبلغ الاحتياطي في هذا الراسب الفوسفاتي الجديد 3.5 بليون طن ويضع العراق بذلك في دول المقدمة بالاحتياطيات الفوسفاتية.

INTRODUCTION

Iraq, as with most of the east and south Mediterranean countries, is rich in phosphorite deposits of Late Cretaceous – Early Tertiary age. These deposits are part of the huge Tethyan phosphorite province, which extends from the northern parts of South America to Pakistan and probably to India (Sheldon, 1987).

The Iraqi phosphorites show their best development in the Western Desert (west of longitude $40^{\circ} 30'$, Fig.1). On the contrary to most neighboring countries, the Late Cretaceous deposits in Iraq are of poor grade, usually thin and diluted by non-phosphatic detritals, whereas the Paleocene deposits are better developed as far as thickness, grade and extension. They are the source of phosphate raw material for the fertilizers industry at the present time.

Until 1985 Iraqi proved phosphorite reserves were given as 450 m.t. (Notholt, 1985), which is represented by the Akashat deposit (Paleocene). However, in view of the increasing demand to have an accurate estimation of the mineable phosphorite reserves in the country, extensive exploration survey began in 1986 to fulfill this target. This survey gave its first results in the discovery of Swab phosphorite deposit, which was investigated in detail during 1986 and early 1987. The deposit is situated west of the Akashat mines covering an area of about 500 Km².

* Chief Researcher, State Co. of Geological Survey and Mining, P.O. 968, Baghdad, Iraq

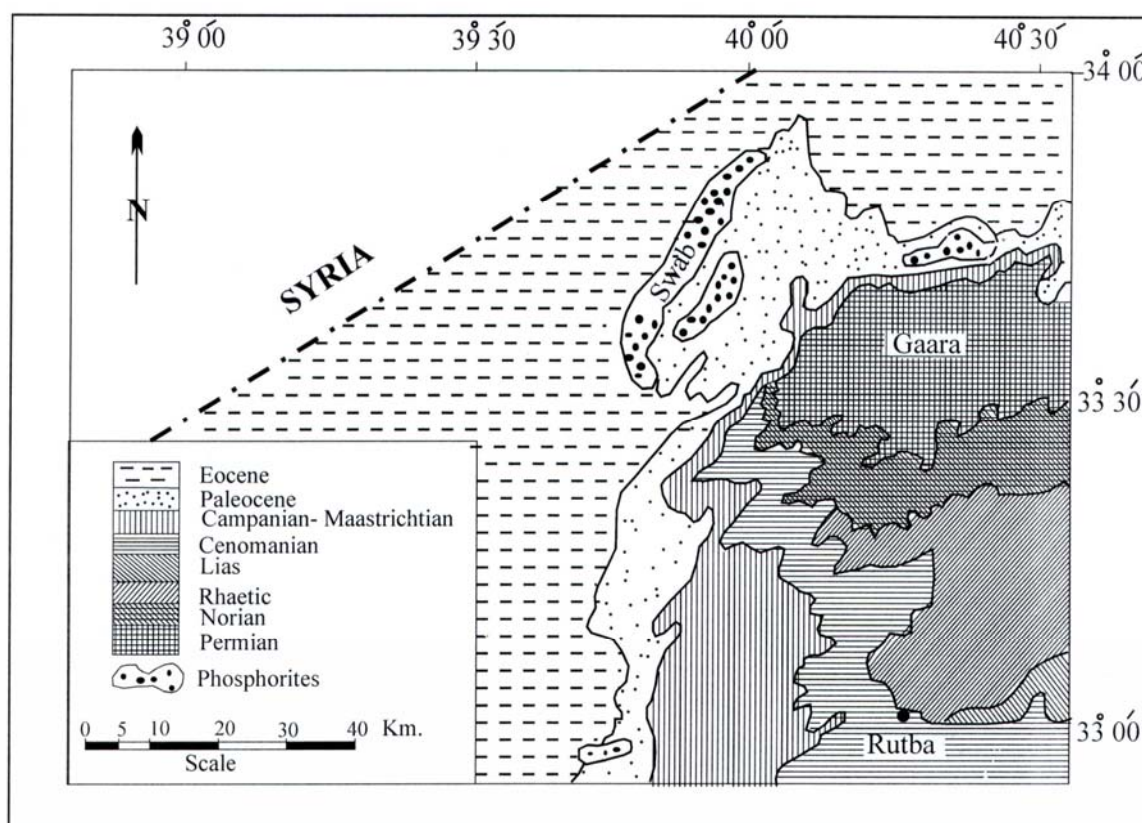


Fig. 1: Geological and Location map (modified after Jassim et al., 1990)

The investigated part of the deposit, however, represents an elongated strip extending in a NE – SW direction and is about 200 Km² in area (30 Km long and 6 – 7 Km wide). The area is a plateau, 640 m (a.s.l.) in its SW part and 540 m (a.s.l.) in the NE part. Two main desert vallies (wadi) bind the deposit from its eastern side, Wadi Hirri Al-Gharbi and from its western side, Wadi Swab (Fig.2). The exploration work was carried out by The Geological Survey of Iraq and included drilling of 153 boreholes (1×1 Km net), 60 trenches (0.5 Km intervals) and analysis of about 3000 samples. The reserves were estimated on category C₁ (economic demonstrated reserve).

REGIONAL GEOLOGY

Tectonically, the Western Desert of Iraq is part of the Stable Shelf, which is characterized by the absence of folds (only anticlinariums) and by the common presence of block tectonics (Buday and Jassim, 1984). The main tectonic feature is represented by the Horan High, which extends from Saudi Arabia in a NNE direction inside western Iraqi desert (Fig.3). It is a major positive zone since the Triassic (Al-Bassam et al., 1997) and has influenced the sedimentary pattern of the area since then. The main phosphorites of Iraq were deposited on the western side of this elongated uplift.

The Horan High is an important structural feature in the area and has locally, but continuously influenced the sedimentary system in this part of Iraq. Rocks of Permian age are exposed at the core of this uplift, which is represented by a topographic (erosional) depression at the present time (Ga'ara Depression). The Akashat plateau is an extension of this uplift, and seems to have been a submarine high in the Late Cretaceous and Early

Tertiary protruding in a NW direction towards the Iraqi – Syrian borders. Anah Graben was opened in the Upper Cretaceous (Lovelock, 1984) and brought about basinal sedimentation in some parts of the Western Desert. The regional dip of the Late Cretaceous – Early Tertiary units in the Akashat area is generally towards N and NW, influenced by the Horan High.

Step like E – W normal faults have influenced the area extending from Akashat in the west to Anah in the east. They are of the same character and origin as the Anah fault system. They were probably activated in the Campanian and influenced the sedimentary basin significantly by controlling facies distribution including the phosphorites (Fig.4). They are syn-sedimentary growth faults (Al-Bassam, 1992).

The phosphorites - bearing sequence in the Western Desert consists of three formations: Digma (Campanian – Maastrichtian), Akashat (Paleocene) and Ratga (Eocene). These were previously called Tayarat, Umm Er Radhuma and Dammam Formations, respectively (Al-Naqib, 1963).

The phosphorites are associated with shale, marl, dolostone, shelly limestone and chert in the Late Cretaceous – Early Tertiary sequence. The Late Cretaceous units contain relatively thin (1 – 2) m occasionally reaching 4 m in thickness, bioclastic and lithoclastic phosphorites, often pass laterally to phosphatic sandstones or phosphatic limestones. They are interbedded with dolomitized limemudstone, smectite and palygorskite - bearing marls and shales and oyster limestones. Chert nodules, porcelanite and silicified limestones are common.

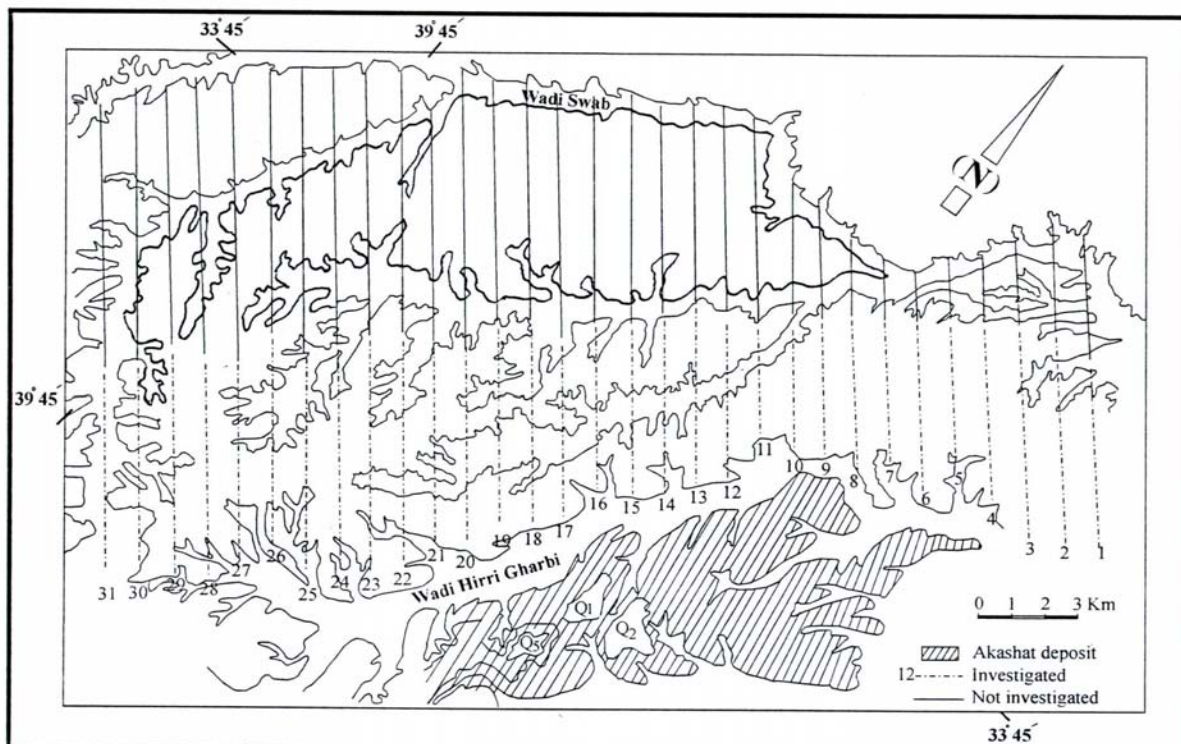


Fig. 2: Swab phosphorites deposit (Al-Bassam,1988)

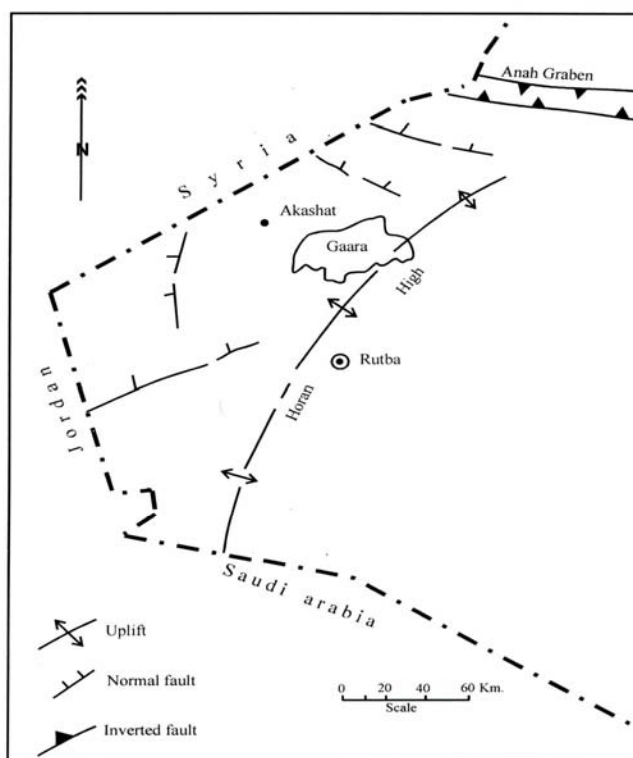


Fig. 3: Main structural elements (modified after Al-Bassam, 1992)

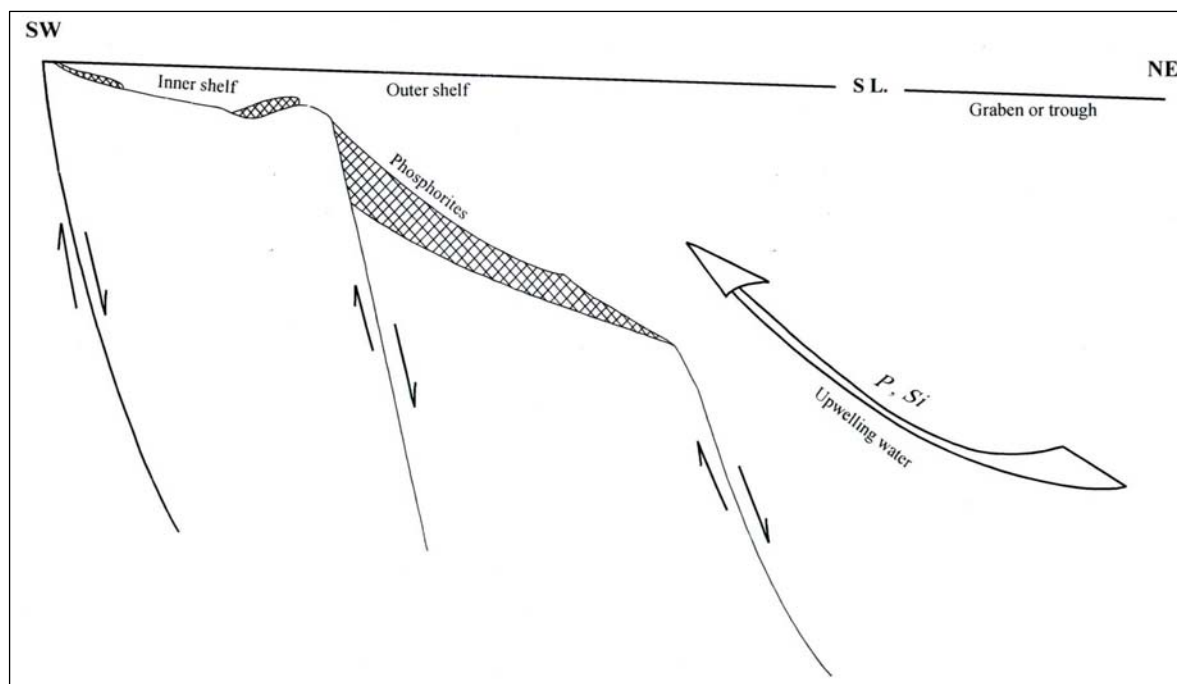


Fig. 4: Structural control on basin configuration (Al-Bassam, 1992)

The Paleocene phosphorites contain relatively thicker phosphorite beds in the middle part (up to 13 m), mostly of peloidal and ooidal texture, associated with shelly limestone, with thinner horizons of phosphoclastic and coprolitic phosphorites in the lower and upper parts associated with bioturbated dolostone, marl and shale.

The Eocene phosphorites are relatively of thin to medium thickness (maximum 4 m) having either peloidal and coated grain texture or coprolitic and intraclastic texture. They are highly associated with chalks and bedded chert or silicified limestones. Occasionally the phosphorites are partly silicified themselves (cementing material only).

The whole phosphorite - bearing sequence of Late Cretaceous – Early Tertiary age shows a well - defined cyclic pattern of sedimentation. This is represented by rhythmic alternation of deep and shallow facies and reflects sea level fluctuations on the shelf (Al-Bassam, 1987).

GEOLOGY OF SWAB PHOSPHORITE DEPOSIT

Three formations were recognized in the Swab phosphorite deposit, the oldest is of Maastrichtian age (Digma Formation) and was encountered by drilling in subsurface sections only, the Paleocene (Akashat Formation) which includes the industrial bed and is partly exposed along the cliffs of wadi Hirri Al-Gharbi, and the Eocene (Ratga Formation, Swab Member, Early Eocene), which covers most of the surface in this area. The strata show a gentle dip towards North by about (0.5 – 1.0)°. Apart of slight deformation, in the structural contours, which could be due to minor faults, the deposit is structurally simple and was influenced by the Horan High and synsedimentary growth faults (Fig.5). Based on drilling data the stratigraphy of the deposit can be given as follows (Fig.6):

Digma Formation (Maastrichtian)

Only the uppermost part of the Digma Formation was encountered by drilling. It is composed of dark gray marl or calcareous shale. The contact with the overlying Akashat Formation was determined by macro and microfossils, as there is no lithological break.

This contact is marked by a characteristic oyster limestone, which tops the Digma Formation in the shore - ward direction. Micropaleontological studies (Karim, 1986) showed complete sequence (complete faunal zones) from Late Cretaceous to Early Paleocene (Danian) in subsurface sections of this area.

Akashat Formation (Paleocene)

This formation was divided into three mapable members (Al-Bassam et al., 1986). Significant increase in thickness of this formation takes place in the Swab deposit, caused by an increase in the carbonate facies in the upper part of the formation. The total thickness of the formation reaches up to 45 m, in Swab deposit relative to about 15m only in the near - shore sections, around Ga'ara Depression .

■ Traifawi Member (Early Paleocene)

It lies conformably and without apparent break over the Maastrichtian rocks. It consists of the following beds (bottom to top):

(0.0 – 0.2) m phosphorite, sandy, poorly sorted and consists of bio and lithoclastic phosphate grains.

(1.5 – 1.9) m shale, dark brown or dark gray with poorly sorted phosphate lenses in the middle.

2.0 m limemudstone, gray, dolomitic, bioturbated at upper surface, with chert nodules.

(0.3 – 0.7) m phosphorite, gray, moderately sorted and consists of coated phosphate grains, mostly filling borings in the underlying bed.

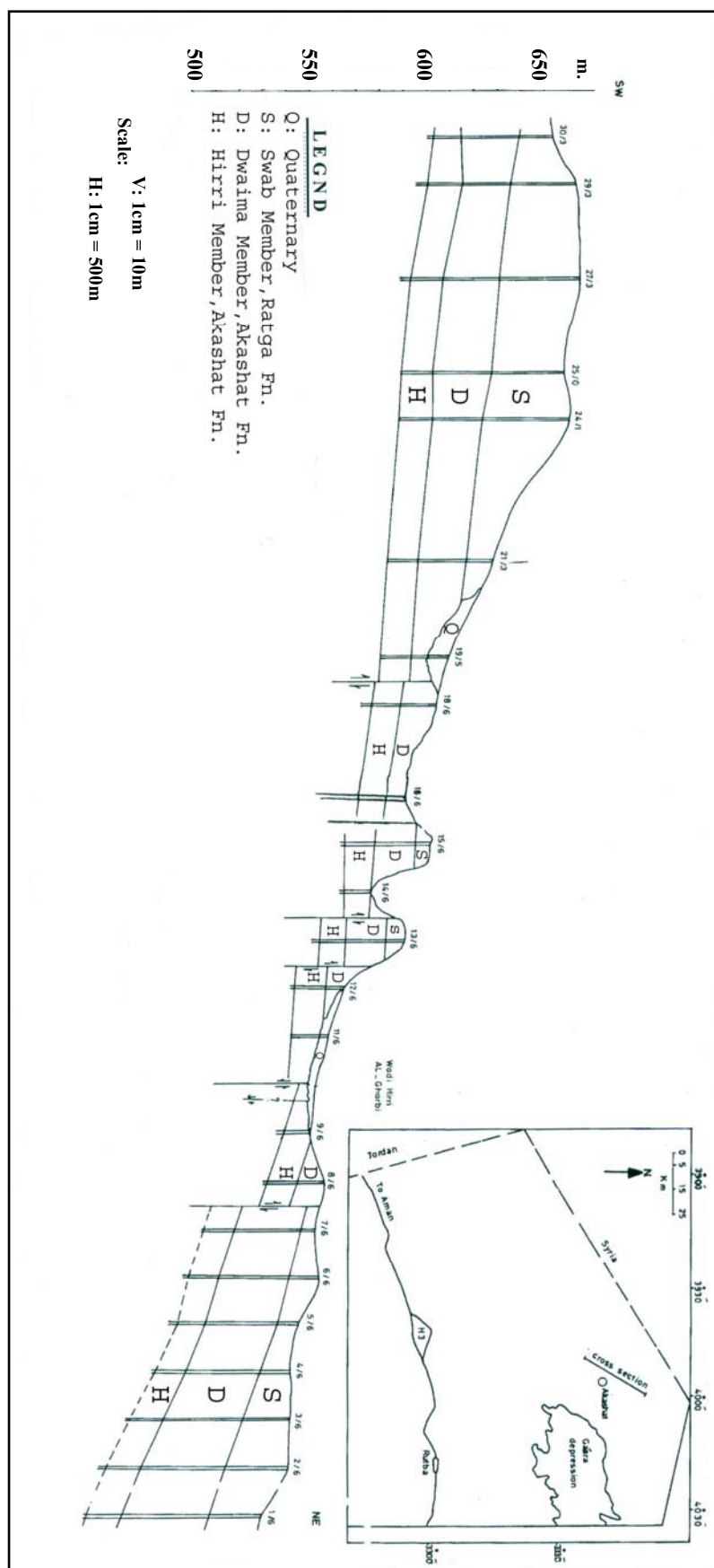


Fig. 5: Geological cross section in Swab deposit (Al-Bassam, 1988)

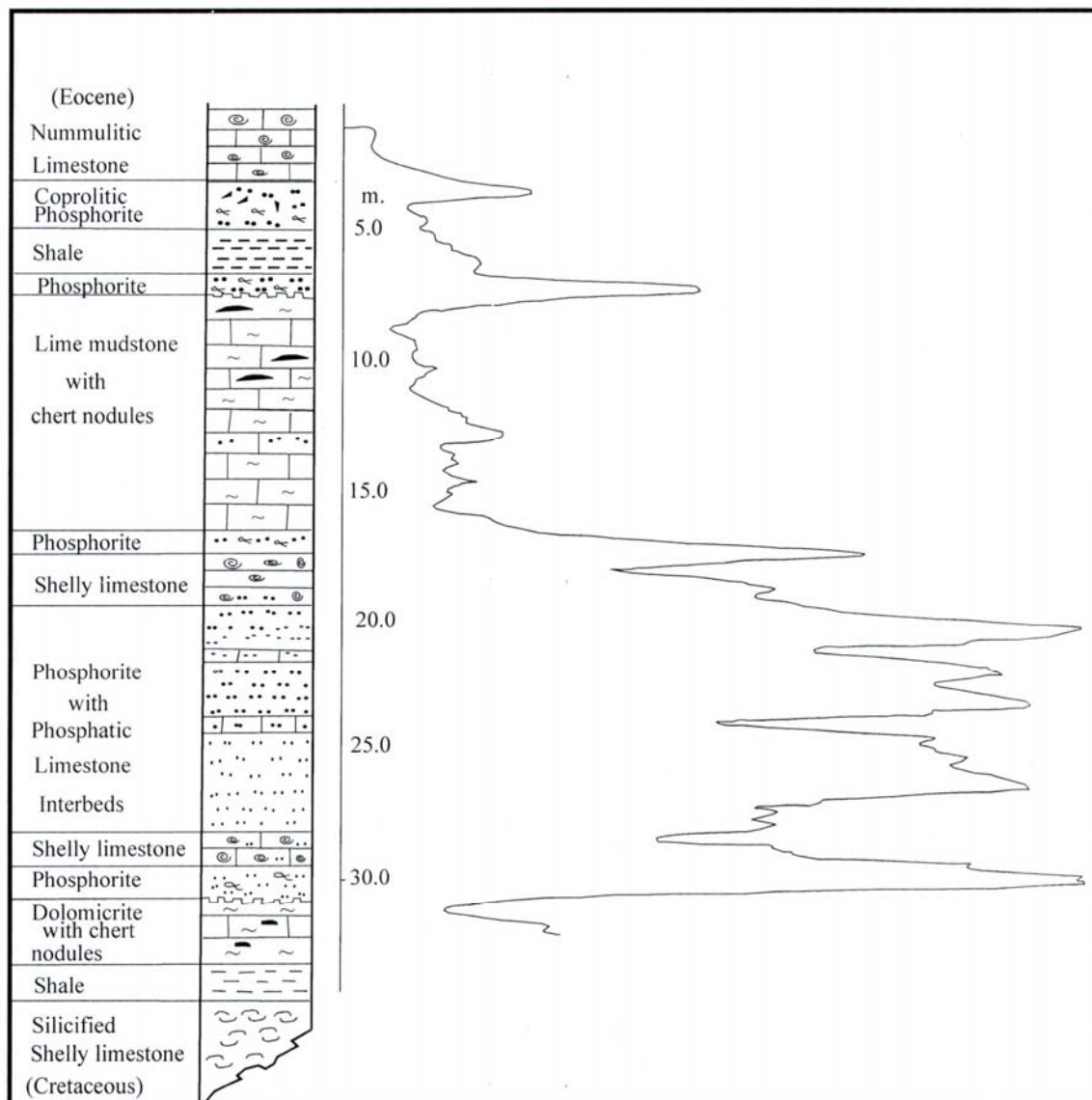


Fig. 6: Lithological columnar section and γ log of the phosphorites - bearing sequence

■ Hirri Member (Middle Paleocene)

It consists of the following beds (bottom to top):

(0.2 – 0.5) m limestone, shelly and phosphatic.

(4.5 – 8.0) m phosphorite, gray, peloidal, well sorted, cross-laminated, medium tough, with calcite cement (mostly micrite) and includes (1 – 2) thin phosphatic limestone interbeds (globigerinal).

(4.5 – 5.5) m phosphorite, gray, peloidal, well sorted, with calcite cement, friable at the upper part, and occasionally bioturbated.

(0.5 – 1.5) m limestone, shelly and phosphatic.

■ Dwaima Member (Late Paleocene)

It is characterized by the presence of banded chert nodules in lime mudstone thick beds, with occasional presence of oyster-bearing limestones. It consists of the following beds (bottom to top):

(0.2 – 0.5) m phosphorite, poorly sorted (bio and lithoclasts).

(4.0 – 6.0) m limemudstone, bioturbated at top.

(0.5 – 4.0) m phosphorite, moderately sorted, consists of coated grains and intraclasts, usually friable.

(0.3 – 0.5) m limestone, shelly (oysters) and phosphatic.

(10.0 – 14.0) m limemudstone, chert-bearing as nodules (up to 5 horizons), bioturbated at top.

(0.2 – 0.3) m phosphorite, sandy, moderately sorted (bio and lithoclasts).

(1.0 – 2.0) m shale, light gray, papery, carbonatic at lower part, and bioturbated at top.

(0.5 – 1.0) m phosphorite, coprolitic and poorly sorted (coprolites, bio and lithoclasts), gypsiferous and silty.

Ratga Formation (Eocene)

It is represented, here by its Swab Member (Early Eocene), which consists of (20 – 30) m thick limestone, nummulitic and recrystallized, shelly at lower and upper parts, and the top is silicified. The contact with the underlying Akashat Formation is marked by a coprolitic phosphatic limestone.

PETROLOGY AND CHEMICAL COMPOSITION

The phosphorites in Swab deposit is granular as with most of the Tethyan deposits. Many types of phosphate grains were identified dominated by peloids and ooids of less than 0.5 mm in diameter (mostly 0.1 – 0.2 mm) (Fig.7 a and b), cemented with micrite and carbonaceous matter (in subsurface sections). Other phosphate components are phosphoclasts including bones and intraclasts (Fig.7 c), which are dominant in the basal part of the phosphate section (Traifawi Member) and coprolites (Fig.7 d), which are dominant, in large grain size (up to 1 cm in diameter) at the upper part of the section (Dwaima Member). Calcite is the major cementing material. Both micrite and sparite (secondary) are present.

Silicification is very common in the phosphorite and in the associated rocks. Opal - CT is found at the base of the section. Quartz - geodes and chert nodules are common in the upper part within the Dwaima Member. Carbonaceous (bituminous) matter is common in all types of rocks in the relatively deep sections (Fig.8).

Samples for chemical analysis were collected from the industrial bed every one meter (maximum) and less than that, when there is change in the lithology. Samples were also collected from above and below the industrial bed. About 3000 samples were analysed for: P_2O_5 , CaO, MgO, K_2O , Na_2O , SO_3 , Fe_2O_3 , Al_2O_3 , F, Cl, U, loss on ignition (L.O.I) and insoluble residue (strong acid) . Selected samples were analysed for: Y, V, Cd, Sr, Zn, Cu, Ni and Cr. In addition, about 10% of the total samples were examined by X- ray diffraction analysis.

The phosphorite chemical composition, as with all rock types, reflects its mineralogy. The X-ray diffraction analysis showed the phosphorite to contain francolite (Carbonate fluorapatite), calcite, dolomite, palygorskite and traces of quartz. In addition, high organic material (carbonaceous and bituminous) were encountered in a few deep boreholes. Mineral contents calculated from average chemical analysis suggest that the phosphorite consists of

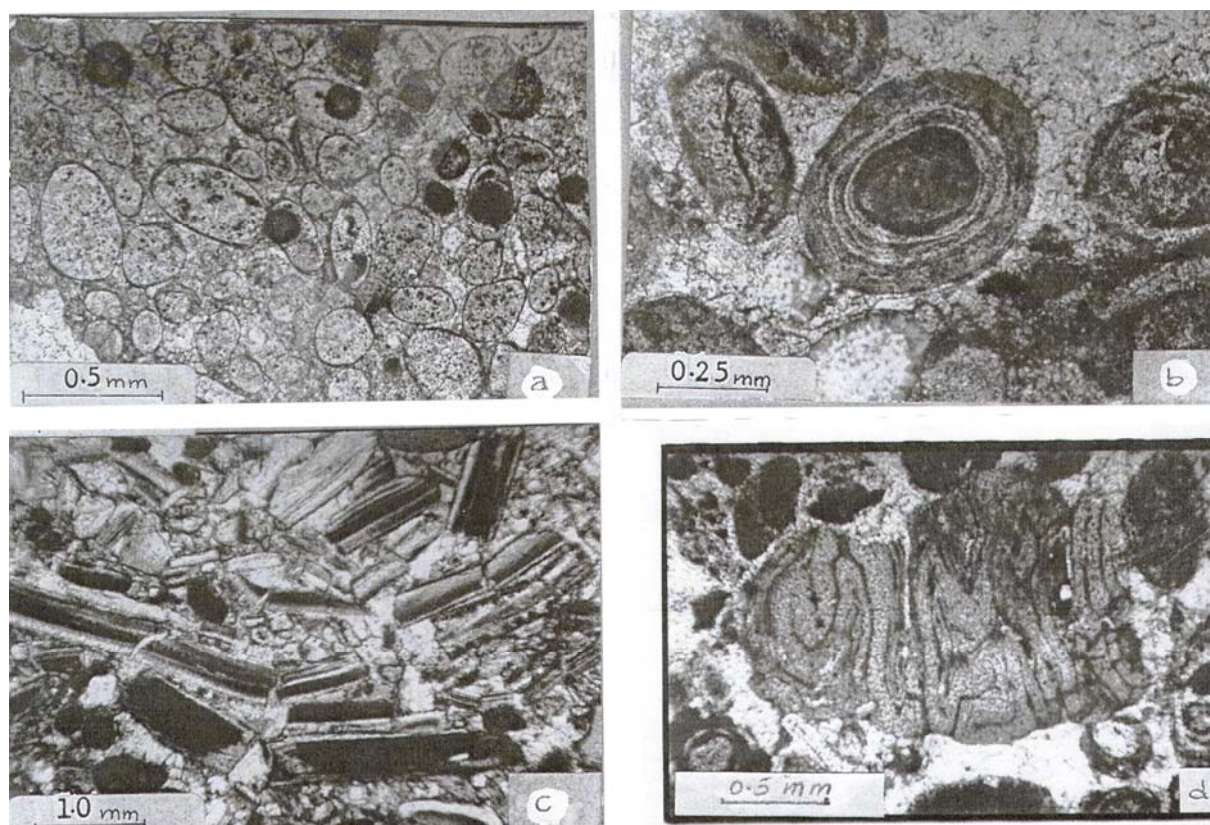


Fig. 7: Phosphate textural components in the Swab deposit (PPL):
(a) Peloids, (b) Ooids, (c) Phosphoclasts, (d) Coprolites

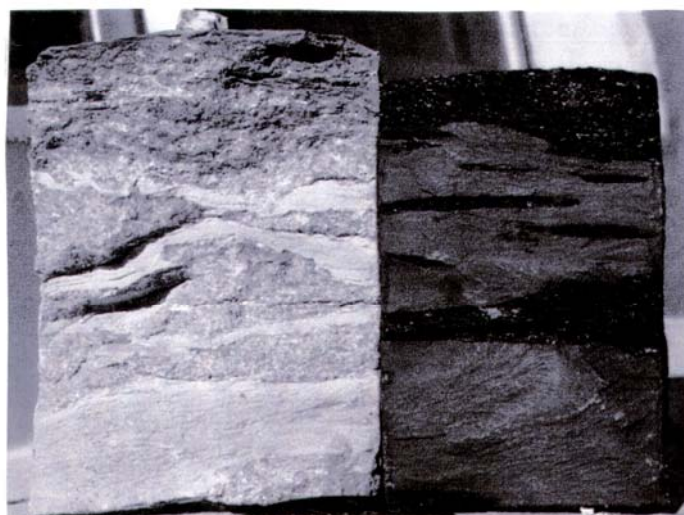


Fig. 8: Phosphorite - shale association
Left: oxidized by weathering (light color)
Right: original unoxidized (dark color)

65% francolite, 32% calcite, 2.5% palygorskite and 0.5% dolomite. The apatite is mostly present in the form of peloids and ooids, and the calcite forms the cementing material between the grains.

The average chemical composition of Swab phosphorite deposit is given in Table (1). The P_2O_5 and MgO contents are within the limits accepted by Al-Qaim fertilizers plant. The latter, however, is close to the maximum allowable limit of 1% MgO.

The variation in the major element concentration is a function of the variable proportions of the minerals constituents. The apatite includes all the phosphorus and most of the calcium, fluoride, sulfate and sodium. Magnesium is shared between dolomite and palygorskite, alumina and silica are proportional to their ratio in palygorskite and suggest no (or only traces of) free silica (except when chert is present). Iron is present as hydrated oxides (probably after pyrite).

Trace elements are differentiated into two main groups, one includes U, Y, Sr, Cd, V and is related to apatite, and the other includes Cr, Ni, Cu and Zn and seems to be related to palygorskite and to some extent organic material (when present).

Table 1: Average chemical composition of Swab phosphorite deposit

Wt. %		ppm	
I.R	1.65	U	37
Al ₂ O ₃	0.38	Y	89
Fe ₂ O ₃	0.20	V	172
CaO	51.25	Cd	55
MgO	1.09	Cr	269
SrO	0.19	Ni	72
K ₂ O	0.06	Cu	25
Na ₂ O	0.78	Zn	501
P ₂ O ₅	21.71		
SO ₃	1.15		
F	2.50		
Cl	0.05		
L.O.I	19.70		

FACIES ANALYSIS AND GENESIS

The genesis of Swab deposit is an integral episode of the Late Cretaceous – Early Tertiary phosphogenic system of Iraq and other areas of the Tethyan phosphorite belt. The Paleocene phosphorites are related to several episodes of upwelling currents, induced by specific paleoceanic conditions of the Tethys Sea during Late Cretaceous and continued to the Paleogene (Cook and McElhinny, 1979) (Fig. 9), and locally to the structural configuration of the area.

The Paleocene in Iraq, as with many other countries in the region, represents a transgressive phase (Jassim et al., 1984). In this part of Iraq, the sequence starts in the Early Paleocene with unstable conditions, suddenly changing from quiet environment (shale – marl – limemudstone) to a highly agitated environment (bioclastic and intraclastic phosphorite). The quiet water facies almost always ends up with a bioturbated hard ground and is highly enriched in Mg in the inner part of the shelf (sepiolite – palygorskite –

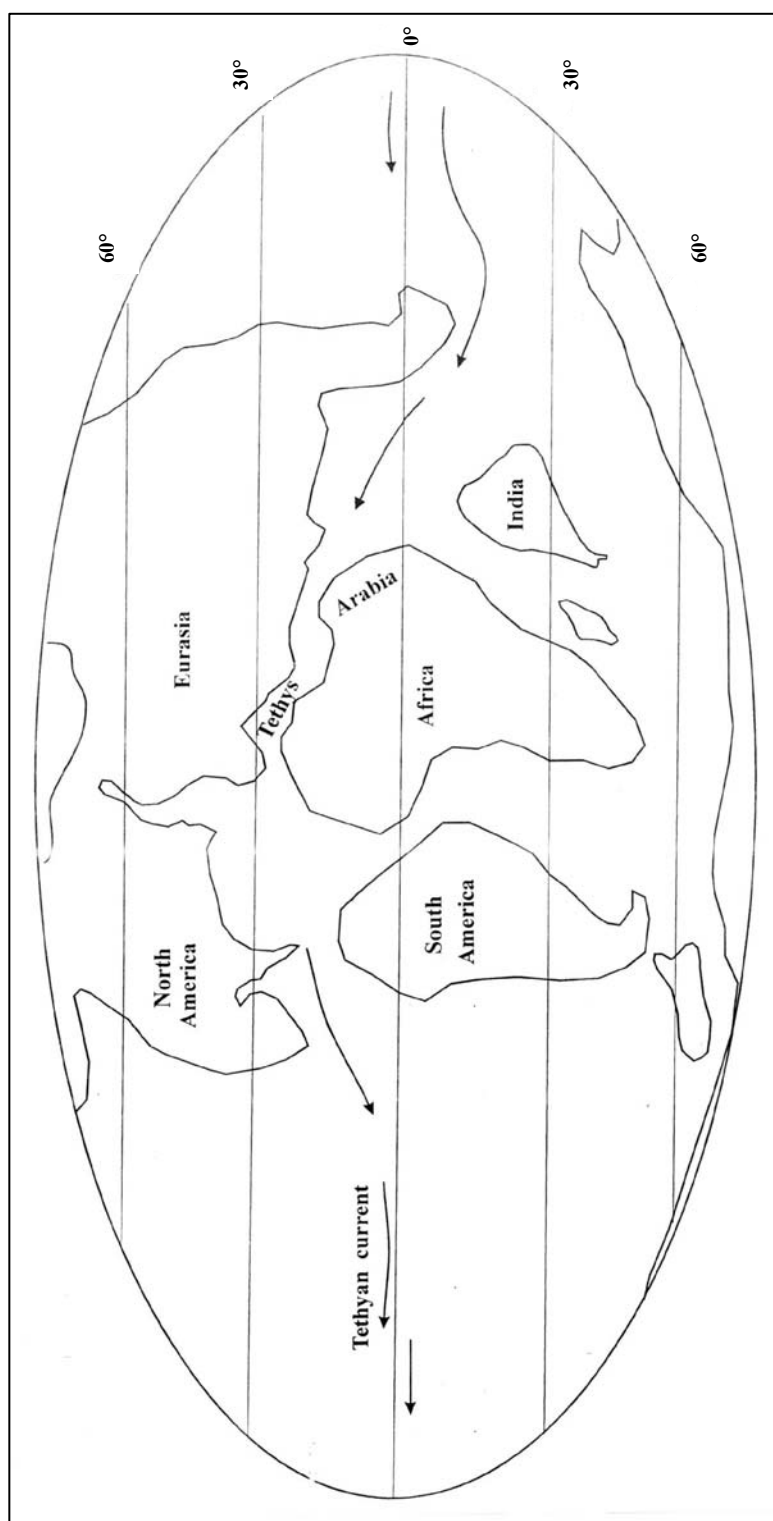


Fig. 9: Late Cretaceous paleogeography (after Ziegler et al., 1982, in Sheldon, 1987

dolomite). But, becomes more calcareous basin ward. These quiet - agitated duplets were repeated several times in the Early Paleocene.

This pattern of sedimentation may be explained by sea level fluctuation over a gently slopping shelf, which had no barrier and where free communication with open sea was available. The inner part of this shelf was richer in clays (mostly of detritals origin) and suffered low circulation and poor oxygenation (very quiet environment). This resulted in early diagenetic dolomitization, formation of Mg - rich clay mineral suite, low diversity of fauna and frequent breaks (poses) in sedimentation. The outer part of the shelf had better circulation, high diversity of fauna, less clays, more calcareous facies, and less or no breaks in sedimentation. The change in facies was noticed from E and SE (shore wards) to W and NW (basin wards). The poorly sorted clastic phosphorite represents a shallow water intertidal facies deposited in the inner shelf in shoaling events. The equivalent of this facies in the deeper outer shelf is a well - sorted peloidal phosphorite. The black color of unweathered samples suggests anoxic conditions.

The sequence passed to a lower sea level in the early Middle Paleocene where sand - size phosphate ooids and cortoids were deposited and developed into a shoal in the inner shelf. It was formed under moderate energy where algal mats frequently enveloped the growing grains forming later the common concentric rings, characteristic of these grains. Further shallowing had developed an off - shore shelly limestone barrier (bivalves) on top of the ooids shoal. This event was restricted to elevated parts of the inner shelf and was replaced by a phosphatic limestone or phosphorite in the deeper parts of the shelf.

The peloidal phosphorite bed (main industrial bed) was deposited in a deeper environment, characterized by more stable conditions, under moderate energy and extended from the ooids shoal to the outer shelf, where some tongues of deeper globigerinal limestone were deposited in association with the phosphate peloids (Fig.10). These peloids were transported to some quiet environment of low circulation where micrite precipitated as a cementing material. Due to the poor oxygenation of such environment and the relatively high organic productivity, anoxic conditions prevailed and carbonaceous (sometimes bituminous) phosphorite facies were developed (Al-Bassam and Al-Haba, 1990). The Middle Paleocene ended with a shallowing event reflected in the development of another shelly limestone barrier, thickening in the inner parts of the shelf and thinning basin wards. This was followed by another phosphorite horizon of probably slightly deeper environment than the shelly limestone.

An oyster limestone, on top of these phosphorites, represents a shoaling event in the Late Paleocene. The environment went deeper in the remaining part of the Late Paleocene, where lime mudstone with chert nodules and shale with high fossil diversity (planktonic) were deposited in an open marine shelf environment (Al-Bassam and Karim, 1992). This deepening event, however, was interrupted by two poses in sedimentation marked by bioturbation and phosphorite deposition. The younger of these poses had terminated the Paleocene sequence in this area and is characterized by coprolitic bioclastic poorly sorted phosphorite.

The phosphate components appear to have formed by various ways; initially the phosphate was probably precipitated in the interstitial pore environment via a biogenic phase (Al-Bassam, 1976). However, later reworking and concentration by currents and waves have played an important role in the formation of the economic deposits. The phosphoclasts were formed by physical and biological breakdown of larger phosphate bodies, probably with contemporaneous phosphate enrichment during reworking. On the other hand, the peloids and

coated grains were mostly formed by accretion of minute phosphate particles. Some peloids, however, might be of faecal origin. In general, peloids reflect deeper environment than ooids and cortoids (Al- Bassam et al., 1988).

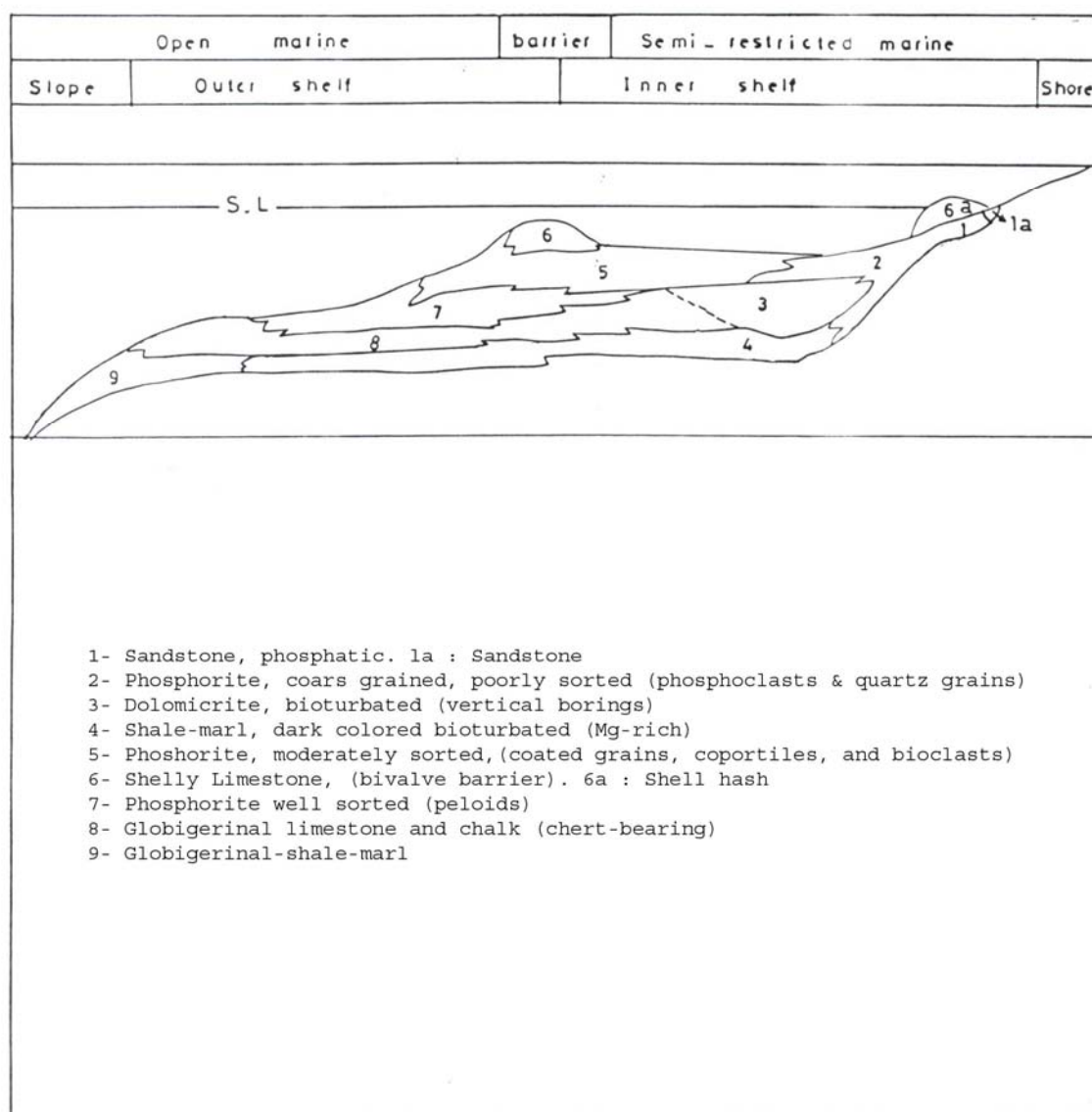


Fig. 10: Facies analysis model of the Paleocene phosphorite - bearing sequence

RESERVES

Swab deposit covers an area of about 500 Km². The investigated area however, is about 200 Km² only limited by a maximum allowable stripping ratio of 5. About 155 boreholes were drilled to study and accurately estimate thickness of industrial bed and overburden, lithological and petrographical characteristics, chemical composition, physical properties, etc. All boreholes were geophysically investigated by natural gamma logging to study the distribution and intensity of natural radiation and to control the accuracy of drilling and documentation. The drilling accuracy was better than $\pm 5\%$.

The thickness of the industrial bed ranges from (9 – 16) m (based on lithological description) and averages 11m. In most parts of the area, there is very little variation in thickness; the main thickness increase takes place in the extreme NE and SW parts. The middle part shows relatively reduced thickness, influenced by the structurally - controlled Akashat plateau.

The bulk density of the industrial bed was determined in about 400 samples representing various lithological types in 18 boreholes covering the deposit area. The weighted average is 1.665 gm /cm³ (range 1.478 – 1.901 gm/ cm³). This is typical for Paleocene phosphorites, which are characterized by relatively high porosity (30 – 40) % caused by partial dissolution of the cementing calcite.

The reserves were calculated according to the data above as 3556 m.t. of crude phosphorite (about 750 m.t. of P₂O₅). These reserves can be enlarged to twice this figure if the maximum allowable stripping ratio is increased to 10 instead of 5.

MINING CONDITIONS

The thickness, morphology and extension of the phosphorite industrial bed, in addition to the average stripping ratio of about 3 is suitable for an open pit mining. The overburden is composed of carbonate rocks and ranges in thickness from (0 – 70) m in the investigated part of Swab deposit, averaging about 30 m and increasing in the NE and SW parts. The overall stripping ratio in the investigated area is 2.9 (range 0.4 – 5.7). The distribution of stripping ratio is shown in Table (2).

Table 2: Distribution of phosphorite reserves and stripping ratio

Stripping ratio	% of phosphorite reserves
0.0 – 1.0	8.6
1.0 – 2.0	19.3
2.0 – 3.0	26.4
3.0 – 4.0	23.6
4.0 – 5.0	17.9
>5.0	4.3

Table (2) shows that more than 50% of the deposit reserves is with a stripping ratio of less than 3.0 and more than 25% of the deposit is with less than 2.0 stripping ratio. The maximum allowable stripping ratio of 5 was determined on the basis of excavation cost, grade and current prices of phosphate rocks.

The industrial bed and overburden rocks are relatively soft to medium tough and can be easily excavated by dragline and electric shovel. Selective blasting and excavation should be easy for industrial and overburden beds as they have well defined physical parameters and

sharp lithological boundaries. The surface morphology and gradient of the upper and lower surfaces of the industrial bed are suitable for dragline operations, since they do not exceed 5 m / Km in the whole area.

The phosphorite industrial bed is much higher than the main groundwater aquifer, which is found deep in the Permocarboniferous rocks of the Ga'ara Formation. However, lenticular bodies of perched ground water may be found in some parts of the deposit, but these are influenced by seasonal fluctuations and should not create any mining problem in the future.

BENEFICIATION POSSIBILITIES

The relatively medium P_2O_5 grade of Swab deposit requires several steps of concentration to remove the diluents components, which is mainly calcite here. The ore of Swab is similar to that of Akashat, which is presently mined and used in Al-Qaim plant. The similarity is in the textural features of the ore (sand - size peloids and ooids), cementing material (calcite) and grade (about 22% P_2O_5).

The phosphate rocks should undergo several stages of crushing and grinding, followed by calcinations at about 1000°C to remove moisture, CO_2 and H_2O^+ (weight lost at this stage is 18 – 20%). This is followed by wetting, washing and disliming to remove $Ca(OH)_2$ (weight lost at this stage is 15 to 20% depending on the efficiency of the process). The dry concentrate with about (30 – 31)% P_2O_5 is then introduced for sulfuric acid attack to produce phosphoric acid, on one hand and phosphogypsum (as byproduct) on the other hand. However, magnesium content, being on the maximum allowable limit for such process of 1% MgO, may cause some problems in the filtration stage, but this problem is not likely to occur very often as the mining can be carried out from more than one working face to ensure that the MgO content in the produced raw phosphate does not exceed 1% in all cases.

CONCLUSIONS

- Swab phosphorites deposit is the largest in Iraq and the region. It is part of the huge Tethyan phosphorite belt of North Africa and East Mediterranean. It is of Paleocene age and can be correlated in every respect with the well - known Akashat phosphorite deposit.
- The phosphorite is part of the Akashat Formation of Paleocene age. The phosphatic sequence is associated with shale and limestone with frequent silicified rocks as chert and porcelanite. The strata dip gently towards north and the deposit was influenced by E – W normal step faults as well as the activity of the Horan High. The thickness of the phosphorite bed is (9 – 16) m.
- The phosphorite is granular in texture, peloids, ooids, intraclasts, bioclasts and coprolites are the main components. The cementing material is calcite (micrite), occasionally recrystallized or silicified. The mineralogy of the phosphate is dominated by francolite. The associated shale consists of smectite and palygorskite. The average chemical composition shows P_2O_5 21.7 %, CaO 51.25% and F 2.5%.
- Mining conditions are relatively simple with average stripping ratio of about 3.0 (range 0 – 5.0) and relatively soft rocks with gentle dip and little structural deformation.
- Beneficiation is feasible via calcinations and disliming processes, leading to a phosphate concentrate of about 30% P_2O_5 .

REFERENCES

- Al-Bassam, K., 1976. The mineralogy, geochemistry and genesis of Akashat phosphorite deposit, Western Iraq. J. Geol. Soc. Iraq, Vol.9, p. 1 – 33.
- Al-Bassam, K.S., 1987. Facies and depositional environment of the Upper Cretaceous – Lower Tertiary phosphorite - bearing sequence of Iraq. 10th IGCP meeting, Tunis.
- Al-Bassam, K.S., 1988. Geology and reserve estimation of the Swab Phosphorite deposit . Western Desert, Iraq. GEOSURV, inter. report no. 1940.
- Al-Bassam, K., 1992. Genesis of the Late Cretaceous – Early Tertiary phosphorite in Iraq. Iraqi Geol. Jour., Vol.25, p. 80 – 103.
- Al-Bassam, K. and Al-Haba, Y., 1990. The geology and organic geochemistry of the Upper Cretaceous and Lower Tertiary black shales and associated phosphorites and limestones from the Western Desert, Iraq. Iraqi Geol. Jour., Vol.23, p. 1 – 15.
- Al-Bassam, K. and Karim, S., 1992. Depositional history and paleogeography of the Upper Cretaceous – Paleogene phosphorite - bearing sequence, Western Desert, Iraq. Iraqi Geol. J., Vol.25, p. 142 – 167.
- Al-Bassam, K.S., Jassim, S.Z., Karim, S.A. and Mahmoud, K., 1986. Phosphorite project, annual stage report, 1986. GEOSURV, int. rep. no. 1550.
- Al-Bassam, K., Aba Hussain, A., Mohammad, I. and Al-Rawi, Y., 1988. Petrographic classification of phosphate components in phosphorites. Preliminary proposal for east Mediterranean deposits. IGCP – 156. News letter, no. 19, p. 22 – 23.
- Al-Bassam, K., Al-Badaiwi, J. and Al Kadhim, J., 1997. A study on the extension of Hail Arch inside Iraq. New findings from the Nukhaib area, Southern Iraq. Geosciences and Arab Development Jour., no.1 and 2, p. 12 – 23 (In Arabic).
- Al-Naqib, K. 1963. Geology of the Arabian Peninsula, Southwestern Iraq. USGS prof. paper, 560 – G, G1 – G54.
- Buday, T. and Jassim, S.Z., 1984. Tectonic Map of Iraq, scale 1: 1 000 000. GEOSURV, Iraq.
- Coo, P.J. and McElhinny, M.W., 1979. A re-evaluation of the spatial and temporal distribution of sedimentary phosphate deposits in the light of plate tectonics. Econ. Geol., Vol.74, p. 315 – 330.
- Jassim, S.Z., Karim, S., Al-Mubarek, M., Basi, M. and Munir, J., 1984. Final report on the regional geological mapping of Iraq. V.3: Stratigraphy .GEOSURV, int. Rep. no. 1447.
- Jassim, S.Z., Al-Hashimi, H.J. and Hagobian, D.H., 1990. Geological map of Iraq, scale 1: 1 000 000 2nd edit. GEOSURV, Baghdad, Iraq.
- Karim, S.A., 1986. Micropaleontological results. In: Al-Bassam et al., 1986, Phosphorite project, annual stage report, 1986. GEOSURV, int. rep. no. 1550.
- Lovelock, P.E.R., 1984. A review of the tectonics of the northern Middle East region. Geol. Mag., Vol.121, p. 577 – 587.
- Notholt, A., 1985. Phosphorite resources in the Mediterranean (Tethyan) phosphogenic province, a progress report. In: Lucas, J. and Prevot, L. (eds.), 1985. Phosphorites, Sci. Geol. Mem., Vol.77, p. 41 – 44.
- Sheldon, R.P., 1987. Tethys and paleotethys phosphatic provinces. IGCP project 156. 10th International field workshop and Symposium, Tunisia.