

PHOSPHORITES IN SINJAR FORMATION OF SULAIMANIAH AREA, IRAQ

I. AL-FADHLI and KHALIL AHMED MALLICK

ABSTRACT

Phosphorites in Sinjar Limestone Formation of Paleocene age have been discovered and investigated for their petrographic and geochemical characters. The study of the rocks associated with the phosphorites was also made to determine the sources of the phosphorites and the degree of correspondence with the associated limestone beds.

The two horizons of phosphorites in the same stratigraphic succession are separated by 43 feet thick limestone beds which are completely non-phosphatic. The maximum content of P_2O_5 in lower phosphorite horizon is 4.061% and the minimum is 1.460%. The upper horizon of the phosphorite has a maximum of 5.947% and the minimum of 1.360% P_2O_5 at the top of this horizon.

It is concluded that the layered phosphorite beds are recycled sedimentary deposits from the near by source. No effects of phosphatization could be observed on the associated rocks.

Five phases of sedimentation representing different physico-chemical controls have been established on the bases of physical properties, chemical composition, petrographic characteristics and the fossils present in the beds. This discovery of phosphorites appeared very helpful in establishing the yet not reported linkage in the regional distribution of phosphorites of Paleocene age in Zagros Mountains of Iran in the east and Syria and Turkey on the west of Iraq.

INTRODUCTION

Informations regarding the phosphate deposits of Iraq are found in many of the records of the Geological Survey of Iraq. J. A. SMITH an English geologist is considered pioneer in discovering the phosphate deposit of Paleocene age in Rutba area. His discovery was followed by a group of geologists in collaboration with Soviet specialists in 1960—62, to prospect over a larger area and to make a detail geological exploration and exploitation of Rutba phosphate deposit.

Later on, in 1964—65 investigation for phosphate deposits in Akashat area was made and ultimately suggestions were made for the exploitation of the reserve.

In spite of the fact that numerous occurrences of phosphorites in the Cretaceous, Paleocene and Eocene rocks of the Zagros folded belt have been found in Iran, Syria and Turkey but no attention was paid to prospect the continuation of the same rock units exposed in north eastern part of Iraq. Moreover, the available reports regarding the phosphate deposits of Akashat and Rutba do not provide any informations regarding the genesis of the phosphorites. Keeping in view the above facts, the present authors became more inquisitive to investigate Sinjar Limestone Formation of Paleocene age from Zagros Mountains of Sulaimaniah area in north eastern Iraq, with the possibilities of finding phosphorites in this formation. Although the phosphorites discovered during the present work are not of high grade but are useful enough to trace the continuation of phosphorites deposited in the Zagros trough

extending from Iran in the south east to Syria and Turkey in the north west of Iraq during Paleocene period.

The present paper is to report the discovery of phosphorite beds in Sinjar Limestone Formation of Paleocene age exposed in Sulaimaniah area of Iraq. Effort has also been made to discuss the genesis of the phosphorite in the light of chemical analysis data, petrographic investigations and the content of acid insoluble residues in addition to field evidences. This attempt is first of its kind for the study of Sinjar Formation.

GEOLOGICAL DESCRIPTION OF THE AREA

The areas under present investigation are Kani Jinnah, Bazyan and Dukan of Sulaimaniah county in north eastern Iraq (*Fig. 1*). These areas are on the western flank of a major anticline in this region, trending northwest southeast in the Zagros Mountain belt of Iraq. The rocks exposed in the areas are of Sheranish and Tanjero Formations, Sinjar and Kolosh Formations, and Gercus Formation of upper Cretaceous, Paleocene and Miocene ages, respectively.

The rocks of Sheranish Formation are thinly bedded limestone and blue marl of transgressive cycle which tongue into the reef and fore reef deposits of Campanian age. Tanjero Formation is of clastics such as siltstones, shales and marls of various shades of colours, compactness and hardness. It is contemporaneous of Sheranish Formation.

Sinjar Formation is composed of a varieties of limestones which differ in colours, compactness, argillaceous matter contents and hardness. The total thickness of the formation in the areas of study is 530 feet. The content of microfossils in the beds increases in the upper part. Kolosh Formation of clastics is contemporaneous of Sinjar Limestone Formation and the main rocks of this formation are silstones, marls and shales of dark brown, grey and black colours. The shale is gypsiferous to some extent. A-aliji Formation is another contemporaneous formation of Sinjar and Kolosh Formations but it is not exposed in the areas under present investigation. It is well exposed in Sinjar Mountains which represents the type area for Sinjar Forma-

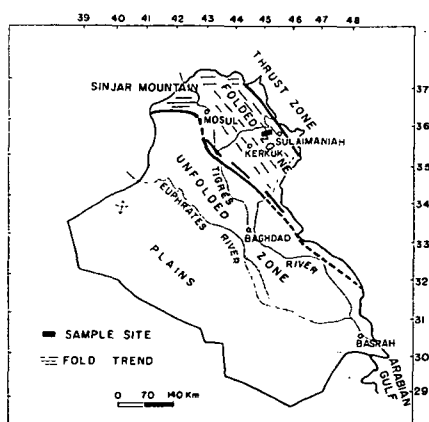


Fig. 1. Tectonic map of Iraq showing location of sample site

tion of Paleocene age in Iraq. It is mainly composed of shale, argillaceous marls and marly limestones. A-aliji Formation is considered to be off shore deposit of Paleocene age on the basis of fossil contents and intertonguing with Sinjar Formation.

Gercus Formation overlies Sinjar and Kolosh Formations unconformably. The rocks are reddish brown and maroon coloured shales, siltstones and sandstones of different grades.

DESCRIPTION OF PHOSPHATIC BEDS

The phosphatic beds of Sinjar Limestone Formation are attributed to Paleocene in age on the basis of fossil evidences. The phosphatic beds of Sinjar Formation are contemporaneous to the phosphatic sediments of Akashat and Rutba areas which are in analogy with geological section of the adjacent regions in Jordan and Syria (open file report No. 1 and 2, 1961 & 1963, Geol. Surv. of Iraq).

Sinjar Formation has eight phosphatic beds which differ from each other in P_2O_5 contents ranging from 1.615% to 5.930% and the petrographic characteristics. The percentage of acid insoluble residues is also not similar. Kolosh Formation which is mainly composed of siltstones, shales and marls intertongues with Sinjar Limestone Formation.

The descriptions of the phosphatic beds of Sinjar Limestone Formation are given according to stratigraphic succession and represent the beds from the lower part to the upper part of the section sampled for the present investigation. The number shows to the phosphatic bed exposed and the number in bracket is the actual number of the same bed in the section.



Fig. 2. Phosphatic limestone bed in Sinjar Formation of Kinn Jinnah area showing weathering effects similar to argillaceous limestone.

Phosphatic bed No. 1 (SK—3)

The first phosphatic bed encountered in the section measured for the present work, overlies light grey and brown banded limestone of variable hardness. Megascopically the phosphatic bed is buff coloured, dense and hard limestone. Calcite grains segregation appearing colourless to light grey under higher magnification of

hand lense can be seen. The bed is 6 feet thick and the texture of the limestone is clastic. The content of P_2O_5 in the sample of this bed was 1.766%.

In thin section of the rock, cluster of sparry calcite grains with random orientation are quite prominent. Some of the fossil fragments which are partly or completely micritized can be seen. Partial micritization is in the inner parts of the fossil fragments. Peloids and argillaceous intraclasts of cylindrical to triangular shape are also present.

Phosphatic bed No. 2 (SK—4)

This immediately overlies phosphatic bed No. 1 and is marked by pronounced bedding. The colour of the rock is light grey with brown patches of ferruginous and argillaceous matters. The sample of this bed exhibits clastic texture due to the presence of calcite and aragonite seggregations and brown specks of ferro-argillaceous matters. The clastic texture is very easily visible with the aid of a magnifying lense and in thin section. The thickness of the bed is about 6 feet and P_2O_5 content is 3,601%.

In thin section of the rock an aggregation of collichane and dahllite in pellets and lithic grains of variable sizes and shapes, embedded in calcareous matrix are observable. The corners and edges of the argillaceous grains are sharp and indicate very little effects of transport. Few lumps containing argillaceous fragments and microfossils exhibit micritization effects quite prominently. Development of sparry calcite and micrites due to recrystallization and diagenetic effects can easily be seen in calcareous matrix. It appears that the rock was porous in the beginning as a result of which intergranular spaces became the centre for the development of sparry calcite and micrites. Micritization is also visible in the argillaceous pellets, the clastics and microfossils (*Fig. 3-A*).

Phosphatic bed No. 3 (SK—5)

This bed overlies phosphatic bed No. 2 with well marked bedding plane and the characters like colour, hardness and to some extent the texture of the rock. The bed is mottled by light and dark brown shades and exhibits medium grained clastic texture. The light brown patches appeared to be clusters of calcite grains and darker parts in the rock specimen were found to be argillaceous matter when examined with the help of magnifying lense. The thickness of the bed is 21 feet and the P_2O_5 content is 4.061%. In thin section it appears as lithic pelleted limestone which is highly micritized. Small clusters of calcite grains with random orientation are also present in argillaceous parts. Microfossils are not common but algal characters are visible.

Phosphatic bed No. 4 (SK—7)

It is not immediately above phosphatic bed No. 3 but a bed of light grey limestone of 10 feet thickness and free from phosphatic content is present between the two phosphatic beds.

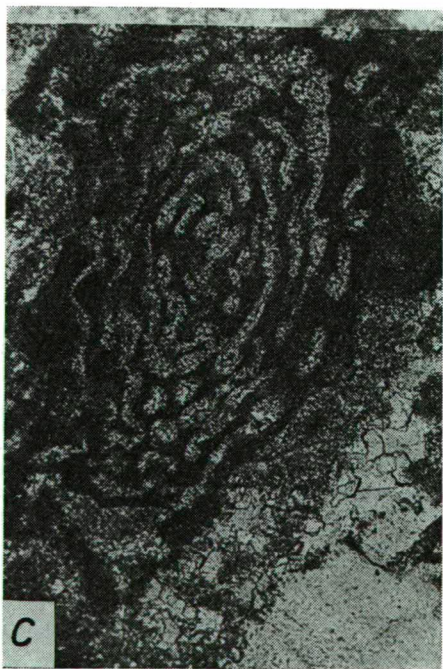
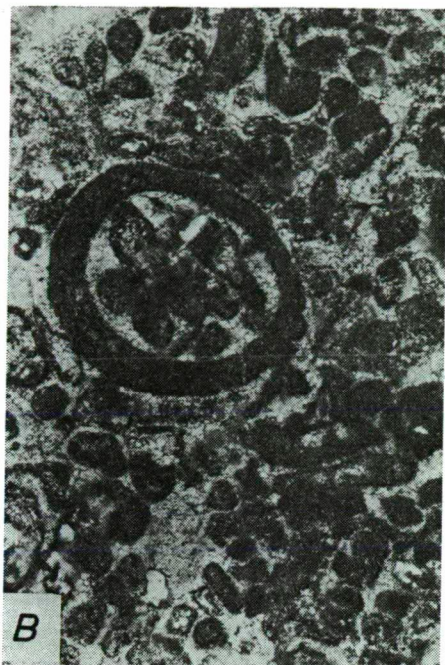
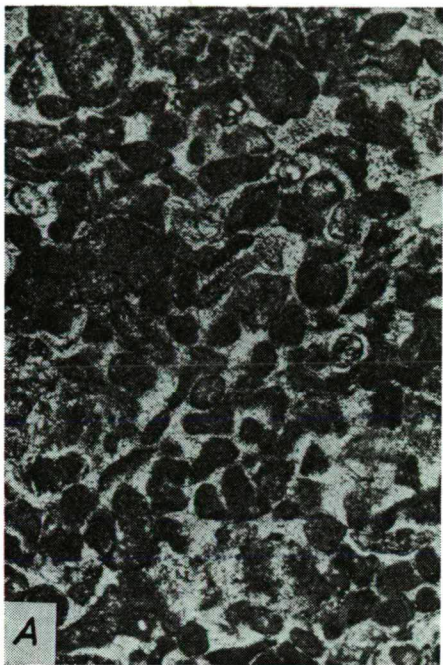
Fig. 3. Photomicrographs from phosphorite deposits, Sulaimaniah area, North Eastern Iraq

A) An aggregate of argillaceous intraclasts, pellets and some microfossils embedded in calcareous matrix. Micritization specially in the central parts of the microfossils. Pressure solution effects are also visible. Polarized light, $\times 50.4$

B) Ooid showing concentric layers containing micrites, sparry calcite, collichane and dahllite are visible. Sparry calcite developed due to pressure solution effects is also observable. Polarized light, $\times 50.4$

C) Lump, intraclast and peloids embedded in calcareous matrix. Micritization prominent. Collichane and dahllite and pressure solution effects can be seen. Polarized light, $\times 50.4$

D) Phosphatic pisolite containing collichane and dahllite is embedded in algal and calcareous matrix. Micrites prominent. Polarized light, $\times 50.4$



This phosphatic bed is reddish brown hard and compact. It appears like a lithic limestone but under higher magnification of hand lens, recrystallization effects are observable. This bed is 5 feet thick and the P_2O_5 content is 1.466%.

The thin section of the rock exhibits an aggregate of intraclasts, peloids and microfossils embedded in calcareous matrix and is recrystallized to a great extent into sparry calcite and micrites. Lumps encircling intraclasts were also found. Micritization is also well pronounced in the peloids, intraclasts and microfossils (*Fig. 3-B*).

Phosphatic bed No. 5 (SK—12)

Phosphatic bed No. 5 is separated from No. 4 by 43 feet thick limestone beds which are completely devoid of phosphatic contents. The limestone beds between the phosphatic beds are of different colours and textures and are marked by bedding planes. The phosphatic bed is mottled with light yellow and brown shades of colours. The texture of the rock is fine-grained. Under higher magnification of the hand lens, the light yellow patches show cluster of aragonite grains and the brown shades are dominated by argillaceous material. The bed is 19 feet thick and the P_2O_5 content is 2.291%.

In thin section ooids with concentric structure marked by micritized stringes and darker rings of argillaceous and organic matters are quite pronounced. Sparry calcite and micrites can also be seen around the ooids (*Fig. 3-C*).

Phosphatic bed No. 6 (SK—13)

The colour of the rock is reddish brown and overlies phosphatic bed No. 5. It is very hard, compact and fine grained. However, under higher magnification of the hand lens reddish brown calcite grains and pink patches of argillaceous matter are easily observable. The thickness of the bed is 18 feet and P_2O_5 content is 3.166%.

In thin sections, peloids, lumps and microfossils in calcareous matrix can easily be seen. It appears similar in characters to bed No. 4. Micrites and sparry calcite are well pronounced in the matrix. Some of the fossil fragments are completely micritized. The effects of micritization in the peloids and lumps can also be seen.

Phosphatic bed No. 7 (SK—14)

It is light brown, hard and massive calcareous bed and overlies bed No. 6. Clusters of calcite grains are visible with the help of magnifying lense. The thickness of the bed is 20 feet and P_2O_5 content is 5.947% which is the highest content in all the phosphatic beds of this area (Table 1).

Fig. 4. Photomicrographs from the non-phosphatic beds associated with the phosphorite deposits of Sulaimaniah area, North Eastern Iraq.

A) Mud supported micritized shell fragments with argillaceous peloids and intraclasts embedded in argillo-calcareous matrix. Pressure solution effects not very prominent. Polarized light, $\times 50.4$;

B) Skeletal limestone with argillaceous intraclasts. Effects of micritization and pressure solution prominent and sparry calcite present. Matrix argillo-calcareous. Polarized light, $\times 50.4$;

C) Banded algal structure with ooids and fine shell fragments. Micritization and pressure solution effects prominent. Matrix calcaro-carbonaceous. Polarized light, $\times 50.4$

D) Argillaceous pellets, intraclasts and shell fragments within tubicular part of a mud feeding organism and around it, micritization and pressure. solution effects prominent. Sparry calcite and dolomite can be seen. Crossed Nicols, $\times 50.4$

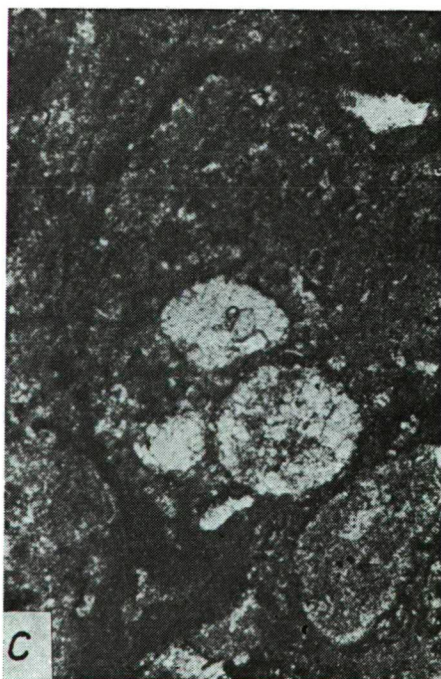
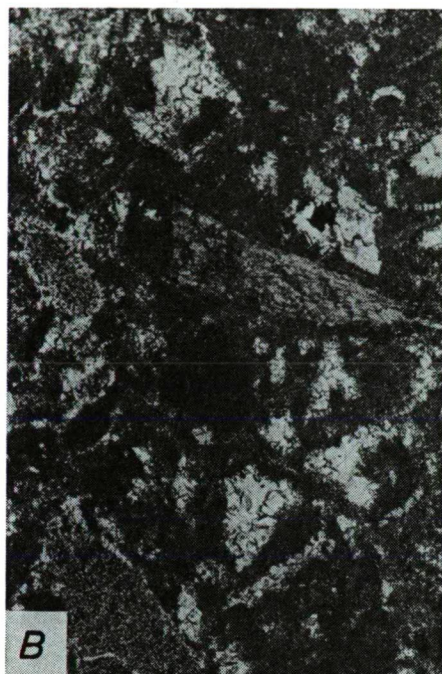


TABLE I

Chemical analysis data of the phosphorites and the associated rocks of Sinjar Formation

Bed No.	Thickness in feet	CaO %	MgO %	P ₂ O ₅ %	AIR %	SiO ₂ %
SK-2	10	49.532	6.341	ND	4.00	3.800
SK-3	6	51.301	4.634	1.766	5.40	2.373
SK-4	6	51.700	3.627	3.601	5.61	1.216
SK-5	21	54.008	3.573	4.061	7.79	2.929
SK-6	10	52.259	7.054	ND	3.82	0.328
SK-7	5	59.371	2.016	1.460	2.95	0.490
SK-8	2	48.290	8.920	ND	1.73	0.688
SK-9	16	46.111	5.524	ND	4.98	1.644
SK-10	17	47.566	7.039	ND	15.30	5.389
SK-11	8	48.686	4.735	ND	3.04	0.271
SK-12	19	54.935	3.526	2.291	4.59	0.980
SK-13	18	52.554	3.526	3.166	4.82	0.850
SK-14	20	53.275	9.120	5.947	6.38	0.329
SK-15	17	47.882	7.482	1.360	7.30	3.564
SK-16	51	53.701	6.517	ND	1.35	0.199

NB: AIR stands for acid insoluble residues and ND for not detectable.

In thin sections, argillaceous pellets of variable sizes are present in addition to argillaceous intraclasts which are angular and subangular in shapes. Other characteristics visible in thin sections are the same as in beds 5 and 6, except that sparry calcite appears to be more in percentage in this rock.

Phosphatic bed No. 8 (SK—15)

It immediately overlies the phosphatic bed No. 7. It is brown lithic limestone which is hard and massive in appearance. Dark brown specks can be seen in the rock samples. The thickness of the bed is 17 feet and P₂O₅ content is 1.360%. In thin section recrystallized fossil fragments in argillaceous matrix can be seen. Algal bands and micritization of matrix are prominent. (*Fig. 3-D*).

The associated limestone beds which are completely devoid of phosphatic contents were found to be prominently dissimilar in their petrographic characteristics also. The 43 feet thick beds of limestones present between the lower and upper phosphatic horizons are of variable petrographic characters. The colours of the rocks are light and dark brown, pink and mottled of various tint. Generally the rocks are dense, hard and break with sub-conchoidal fractures. Clastic texture is not well pronounced in hand specimens. Action with dilute hydrochloric acid is strong. Recrystallization effects are observable with the help of magnifying lense.

The study of the thin sections of these rocks show the presence of micritized fossil fragments and some lithic peloids embedded in calcareo-argillaceous matrix (*Fig. 4-A-B*). Algal limestones containing calcareous peloids, fossil fragments and exhibiting prominent banded algal structures were observed. The peloids and fossil fragments show variable degree of recrystallization and replacements (*Fig. 4-C*). Tubular structures containing lithic intraclasts and fossil fragments in calcareous matrix were also seen (*Fig. 4-D*). The tubular structure is, perhaps, of some mud feeding organism. The development of sparry calcite and dolomite were also observable in thin sections. Micritization effects in the components of the rocks are well pronounced.

MAJOR CHEMICAL CONSTITUENTS OF THE PHOSPHORITE AND THE ASSOCIATED ROCKS

The concentration of Ca and Mg oxides in the phosphatic beds and the associated beds of limestones of Sinjar Formation have been plotted with the assumption that Mg concentration in the near shore water is more as compared to the off shore deep sea water and reverse is true for Ca. Any change or abnormal concentration of either of the elements would be the indication of varying physico-chemical conditions giving rise to enrichment or depletion of the elements through replacement of diagenesis. Thus the causes of an overall change in the chemical composition of the mother rock, diagenetic changes and solution actions are expected to be explained on the basis of enrichment and depletion of these elements.

Likewise the graphs plotted for the concentration of P_2O_5 , SiO_2 and acid insoluble residues are expected to help in describing the degree of correspondence, if any, between P_2O_5 and the major constituent of the rocks like Ca, SiO_2 , Mg and acid insoluble residues. The graphs plotted represent a cross section of the chemical constituents of the rocks of the area.

In the graph plotted for the concentration of CaO and MgO in the phosphatic beds and the associated rocks versus sample number, the sample No. 2 represents the non-phosphatic bed exposed at the bottom and lies immediately below the lower phosphatic horizon represented by sample Nos 3 to 7. Samples No. 8 to 11 having a total thickness of 43 feet are non-phosphatic limestone beds and separate the upper phosphatic horizon represented by samples Nos. 12 to 15. Sample No. 16 is from the non-phosphatic bed at the top of the uppermost phosphatic horizon exposed in the section.

The concentration of calcium and magnesium appear to show antipathic relationships with each other except in samples No. 9, 14 and 15 (Fig. 5). Bed No. 9 is non-phosphatic and bed Nos. 14 and 15 contain 5.947 and 1.360% P_2O_5 respectively.

The highest concentration of calcium (59.37%) was found in bed No. 7 which shows the presence of phosphorous (1.460% P_2O_5). The lowest content of calcium (46.11%) was present in bed No. 9 which is non-phosphatic. Bed No. 14 shows the

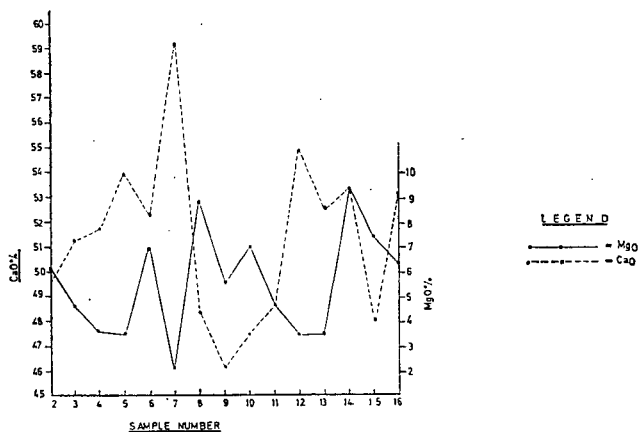


Fig. 5. Concentration of calcium and magnesium in phosphorites and associated rocks

maximum concentration of MgO (9.12%) and the lowest concentration of MgO was detected in bed No. 7, when both the beds are phosphatic.

The plot of Ca/Mg ratio versus Mg concentration for the samples under investigation show a fairly good inverse relationship in general (Fig. 6) but the beds from

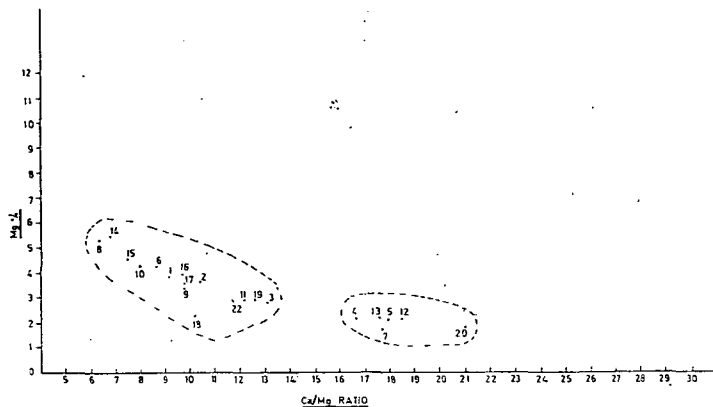


Fig. 6. Variation of Mg with Ca/Mg ratio in phosphorites and associated rocks

the bottom to the top of the section can not be separated as deep water or shallow water deposits. Since the concentration of Ca and Mg in the beds of the formation are variable, the symmetry in concentration of these elements can not be established. The variable and heterogeneous concentrations of Ca and Mg perhaps do not reflect to epigenetic percentages but are most probably caused by diagenetic factors and chemical conditions in the basin of deposition and afterwards.

Apparently cluster of points in two groups with a boundary of Ca/Mg ratio gap from 13.5 to 16.5 separates the beds of shallow and relatively deep marine water deposits or at least the formation has faced fluctuating basin conditions. The numbers with the points show to the beds in the sections studied. Petrographically, the phosphatic beds which contain angular to sub-angular argillaceous fragments, pellets, concretions, lumps etc and the non-phosphatic beds with ooids, algal bands and pronounced recrystallization effects can not be differentiated. In the light of such evidences it appears more probable that differential post-depositional changes

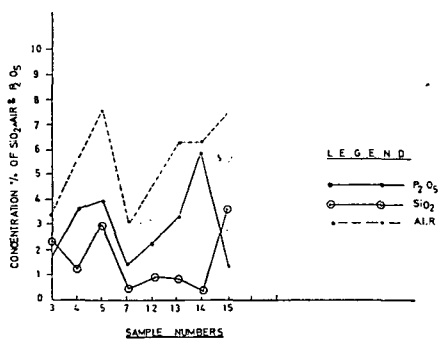


Fig. 7. Enrichment and depletion of P₂O₅, SiO₂ and A. I. R. in phosphorite beds

caused variable concentration of magnesium in the rocks under shallow sea condition.

The graphs plotted for the concentration SiO_2 , P_2O_5 and acid insoluble residues are only for the phosphatic beds found in Sinjar Formation. These graphs give a fairly good pictorial view of the relationships of P_2O_5 with respect to acid insoluble residues (Fig. 7). Similar enrichment and depletion of P_2O_5 with respect to acid insoluble residues suggest that the concentration of phosphate is with the argillaceous contents of the rocks. The present observation is in accordance with the petrographic studies. The graph for the concentration of SiO_2 does not show any conclusive positive or negative correspondence with the P_2O_5 contents in the phosphatic beds. The positive correspondence between P_2O_5 and acid insoluble residues can also be used as an important factor in making economic considerations and discussing the source of the layered phosphorites which appear to be of recycled sediments from near by source.

The variable concentrations of CaO and MgO in the beds of the formation are probably due to the fluctuation in conditions of the depth of the basin of deposition and influx of water from the open sea into the relatively restricted shallow part of the sea. The antipathic correspondence of Ca with Mg is probably an indication of period of calmness and turbulence in the sea. It appears probable that when the sea was oversaturated with Ca the precipitation of Ca took place in relatively agitating water condition but Mg remained in solution due to higher electronegative character. Chemical replacement of aragonite precipitate by Mg-iron in solution also appears as a reasonable cause of variable concentration of Mg in the rocks. Diagenesis may be considered as an important agent to cause variation in Mg contents.

As suggested by DEGENS [1965] that the variable concentration of Ca are a reflection of changing conditions such as temperature, agitation or aeration in the surrounding system by inorganic or organic means which cause removal of CO_2 and increases the pH and thus favours the precipitation of lime, seems partly compatible with the present observation but it is difficult to explain the antipathic relationship between Ca and Mg which is more pronounced in the samples under present investigation. The wide scattering of points along an inverse relationship line is a reflection of fluctuation in the content of calcium composition of the sea water, perhaps, due to influx of water from the open sea into the restricted shallow basin of deposition.

The plot showing the concentration of Mg versus Ca/Mg ratio indicates scattering of points probably due to variable contents of Ca because of the presence of organisms which consume Ca and the turbidity of the water at the time of deposition.

The graph of P_2O_5 content shows remarkably positive correspondence with the MgO content in the samples which are dominated by angular to subangular argillaceous fragments and pellets embedded in calcareous matrix (Table 1). The content of P_2O_5 and also the Mg concentration show a fairly positive correspondence with the acid insoluble residues with the exception of sample No. 15 which is the topmost bed of the phosphatic horizon and contains very little P_2O_5 (1.365%). It appears that the phosphate concentration is related to acid insoluble residues than to the fossils.

DISCUSSIONS

The alternate occurrence of limestones and the phosphorite beds, the variation in the physical and petrographic characters, the fossil types and their relative abundance in Sinjar Formation suggest that there were at least five phases of sedimentation. The possible phases of sedimentation under varying physico-chemical conditions

were *i*) deposition of limestone with sugary texture and little percentage of fossils, *ii*) deposition of phosphorites, *iii*) deposition of clastic limestones with fossils, *iv*) deposition of phosphorites, *v*) deposition of fossiliferous limestones.

KAZAKOV [1937, 1950] concluded from the studies of phosphorite facies and the genesis of Permian phosphorite deposits of U. S. S. R. in addition to his investigation on fluor-apatite system of equilibria under conditions of formation of sedimentary rocks that phosphorites are formed as chemical precipitate from supersaturated sea waters. MCKELVEY [1953] also came to the same conclusion as KAZAKOV from his studies of Permian phosphorites of Western United States.

The petrographic studies and the results of chemical analysis data of the phosphatic beds and the associated limestones under present investigations show no compatibility with the findings of those of KAZAKOV and MCKELVEY. Had there been chemical precipitation of phosphate, then the minerals of apatite group would have been found in thin sections. Moreover, the limestone beds lying below the phosphorite beds would have been phosphatized at least upto the detectable limits, but such evidences were not found.

CAYOUX [1936] supported biochemical origin of phosphorites and considered bacteria as the main factor in the formation of sedimentary phosphates.

The significant role played by micro-organisms or bacteria does not seem to be plausible in case of the phosphorites of Sinjar Formation because the fossiliferous beds were not found as a more phosphatic than the non-fossiliferous beds but reverse was true to a greater extent. Likewise, the limestone beds containing algal material which could be considered rich in bacteria and bacterial actions did not show any enrichment with respect to phosphate contents.

BUSHINSKY concluded from the studies of structure and origin of the phosphorites of U. S. S. R. in 1935 and the shallow water phosphorite sediments of the same country in 1964, that the origin of phosphorite sediments is a result of simple replacement caused by the introduction of PO_4 units into pre-existing calcareous materials. AMES [1959] observations from the study of the genesis of carbonate apatite were also in accordance with those of BUSHINSKY's conclusions.

Phosphatization due to replacement caused by the introduction of PO_4 units into the pre-existing calcareous material means that fossils and fossil fragments, fish bones or teeth, Mg-calcite and aragonite would be the centres of replacement and enrichment of phosphorites. The present observation shows no relationships between the phosphate contents and the fossils or fossil fragments. On the contrary, more fossiliferous beds appeared to be devoid of phosphates. Similarly no correspondence could be found between the samples containing higher calcareous material and phosphate enrichment (Table 1). Under present observation the beds containing argillaceous pellets and fragments in calcareous matrix were found to be phosphatic.

DIETZ, EMERY and SHEPARD [1942] are of the opinion that nodules found abundantly in shallow areas of the sea were largely deposited inorganically from a colloidal suspensions. Further they suggested that stagnant waters, deficient in oxygen may allow the concentration of phosphorus in the absence of organisms which consume phosphorus and thus phosphate nodules or continuous bed or beds containing collophane and microcrystalline carbonate fluorapatite as main constituents are deposited.

The observations of DIETZ, EMERY and SHEPARD for the formation of nodules or beds of phosphate containing collophane and microcrystalline carbonate-fluorapatite appear in accordance with the results of the present investigation. Collophane and dahllite were observed as the common phosphatic minerals in the phosphatic

samples. The lumps encircling argillaceous fragments which are angular to subangular in shape were found to be promising for phosphate concretions. Pisolites and concretions showing concentric layering, micritization and the presence of collophane were found in the phosphatic beds. The absence of P_2O_5 in the fossiliferous and algal limestone beds which are in association with the phosphatic beds reveals that either the phosphorites are recycled sediments from the nearby source or the physico-chemical conditions were not favourable to keep the PO_4 in ionic state for a long time. However, the possibilities of recycling of phosphatic sediments appear more strong because of the fact that P_2O_5 could be found only in the argillaceous pellets and fragments embedded in calcareous matrix. The limestone beds present between the two phosphatic horizons are more calcareous but without any phosphate contents. Diagenetic changes like pressure solution effects, micritization and development of sparry calcite are observable both in the phosphorite and the associated limestone beds. The source of the recycled phosphatic sediments seems to be some older sedimentary phosphatic rock from the nearby area but the rock is not exposed. The phosphorites from the Devonian rocks in the neighbouring countries like Iran in the east and Turkey and Syria in the north west are well known, and therefore, there are great possibilities for the occurrence of phosphorites of Devonian age in Iraq. However, it requires more work to come to the final conclusion.

GOLDBERG and PARKER [1960] who studied phosphatized wood from the Pacific Sea floor; ADAMS *et al.* [1961] from the investigation of phosphatic pebbles of the Bright Seat Formation of Maryland and ARRHENIUS [1963] on the basis of his studies of pelagic sediments concluded that phosphatization of all kinds of organic residues such as shell materials, wood, fecal pellets, teeth etc is a common feature in marine environment.

No compatibility could be found between the present work and the observations of GOLDBERG and PARKER, ADAMS *et al.* and ARRHENIUS regarding the phosphatization of organic remains like shell materials, wood, fecal pellets etc because the phosphate deposit of the area under present study is not from ionic solution but it is considered an accumulation of recycled sediments from the near by source.

According to DEGENS [1965] phosphorite facies is restricted to marine environment when the areas are neither too shallow nor too deep with access to the open sea at one side. The author further suggests that the content of phosphorus increases upto a certain point in the off shore direction and then falls off, because the dead photosynthesizing marine organisms are carried to ocean floor via organic matters (tripton) and the phosphorus is released due to decay of the animals. The released phosphorus becomes active in deposition of phosphorites due to metasomatic replacement of calcite. The conditions required are *i)* alkaline geochemical condition with pH greater than 7; *ii)* presence of calcareous materials and a system that is Ca saturated with respect to HCO_3 content; *iii)* PO_4 concentration exceeding 0.1 ppm; *iv)* non-depositional environment.

The contemporaneous formations of Sinjar Formation in Iraq are the Kolosh clastics intertonguing with the Sinjar Limestones and the off shore equivalent known as A-aliji Formation which is mainly composed of argillaceous marls, marly limestones and shales with scattered glauconite grains in them. Since no informations are available regarding the occurrence of phosphorites in the contemporaneous formations, therefore, it requires more work to discuss the possibilities of phosphatization due to photosynthesizing organisms. Apparently there are no possibilities of such processes to be active because the newly discovered phosphorites are simply recycled sediments.

The changes in facies and thickness of Paleocene formations are probably the results of epirogenic movements in pre-orogenic times which caused gentle large scale undulations of the sea floor aligned partly parallel to the Arabian Shield. This belt can be considered as a marginal mobile sedimentary Zagros Trough superimposed on the platform. Later phases of movements caused gradual shift of the axis of the Zagros Trough in Iranian part to its present position in the Arabian Gulf and close relationship of the folded belt of Zagros was established with the Arabian Platform (Shield) in territories of Iraq, Syria and Turkey.

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REFERENCES

- AL-KUFAISHI, F. A. M. [1977]: A geochemical study on Sinjar Limestone in a subsurface section (K—16). *Jour. Geol. Soc. Iraq*, Vol. X, pp. 47—51.
- AL-SAIGH, A. Y. and AL-OMARI, F. S. [1977]: *General Geology*. p. 377, University Mosul Press, Mosul, Iraq.
- AL-SIDDIQI, A. A. M. [1968]: *Stratigraphy and Microfacies of Sinjar Formation*. Unpub. M. Sc. Thesis, Baghdad, University, Baghdad, Iraq.
- AMES, L. L. JR. [1959]: The genesis of carbonate-apatites. *Econ. Geol.* Vol. 54, pp. 829—841.
- ARRHENIUS, G. [1963]: "Pelagic sediments". In *The Sea and observations on progress on the study of the sea*. Edited by M. N. HILL, N. Y. Interscience Publishers, Inc. pp. 655—727.
- BATHURST, R. G. C. [1976]: Carbonate sediments and their diagenesis. Elsevier Scientific Publishing Company, N. Y. p. 77—90.
- BROMLEY, R. G. (1967): Marine phosphorites as depth indicators. *Marine Geol.* Vol. 7, 1. 503—509.
- BUSHINSKY, G. I. [1935]: Structure and origin of the phosphorites of the USSR. *Jour. Sed. Petrol.* Vol. 5, p. 81—92.
- BUSHINSKY, G. I. [1964]: On shallow water origin of phosphorite sediments. *Development in Sedimentology* Vol. 1, Edited by L. M. J. U. VAN STRAATEN, Elsevier Publishing Co. N. Y.
- CAYEUX, L. [1939]: Phosphate sedimentaires et bacteries. *Compt. Rend.* Vol. 203, pp. 1198—1200.
- CONSULTANTS OF USSR and IRAQI GEOLOGISTS [1965]: Report on geological prospecting and investigation into phosphate deposits of Rutba and Akashat areas. Open file report, Geol. Min. Surv. Div. Baghdad, Iraq.
- DEGENS, E. T. [1965]: *Geochemistry of sediments*. pp. 144—146, Prentice Hall, Inc. N. Y.
- DIETZ, R. S., EMERY, K. O. and SHEPARD, F. P. [1942]: Phosphorite deposits on the sea floor of southern California. *Bull. Geol. Soc. Am.* Vol. 53, pp. 815—810.
- GOLDBERG, E. D. and PARKER, R. H. [1960]: Phosphatized wood from the Pacific sea floor. *Bull. Geol. Soc. Am.* Vol. 71, pp. 631—633.
- GULBRANDSEN, R. A. [1966]: Chemical composition of phosphorites of the Phosphoria Formation. *Geochem. Cosmochim. Acta*, Vol. 30, No. 8, pp. 769—778.
- KAZAKOV, A. V. [1937]: The phosphorite facies and the genesis of phosphorites. *Trans. Sc. Inst. of Fertilizers and Insect Fungicides*. Moscow, Vol. 142, pp. 95—113.
- KAZAKOV, A. V. [1950]: Fluorapatite system equilibria under conditions of formation of sedimentary rocks. *Akad. Nauk. Vyp.* 114, Geol. Ser. No. 40, pp. 1—21.
- MCKELVEY, V. E., SWANSON, R. W. and SHELDON, R. P. [1953]: The Permian phosphorite deposits of western United States. 19th Int. Geol. Congr. Algiers, *Compt. Rend.* X1, pp. 45—64.
- NOTHOLT, A. J. G. [1965]: Discussion on exploration for phosphorite in Turkey. *Econ. Geol.* Vol. 60, No. 4, pp. 822—823.

- NOTHOLT, A. J. G. (editor): [1977]: Phosphate rock in CENTO Region, CENTO Press, Ankara, Turkey.
- SAMIMI, M. and GHASEMIPOUR, R. [1977]: Phosphate deposits in Iran. Phosphate Rock in CENTO Region. Edited by NOTHOLT, A. J. G., pp. 1—40, Ankara, Turkey.
- SHAPIRO, L. [1952]: Simple field method for the determination of phosphate rocks. Am. Miner. Vol. 27, Mo. 3, pp. 341—343.
- SHELDON, R. P. [1964a]: Exploration for phosphorite in Turkey. Econ. Geol. Vol. 59, No. 6, pp. 1159—1175.
- SHELDON, R. P. [1964b]: Paleolatitudinal and paleogeographical distribution of phosphorite. Prof. Pap. No. 501—C, USGS Bull. pp. 106—113.
- SMITH, J. S. [1954]: Radioactive anomalies in the western part of the Republic of Iraq on the Syrian Desert. Open file report. Geol. and Mineral Surv. Division. Baghdad, Iraq.
- VAN BELLEN, R. C. [1956]: Lexique Stratigraphique International, Vol. 111, ASIE, Fascicule 100, pp. 108—112, 155—157, 274—285.
- YOUSEF, M. I. [1965]: Genesis of bedded phosphates. Econ. Geol. Vol. 60, No. 3, pp. 590—600.

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DR. I. AL-FADHLI and
DR KHALIL AHMED MALLICK
Department of Geology,
College of Science
University of Sulaimaniah
Sulaimaniah, Iraq.