CHAPTER VII

GENESIS OF PHOSPHORITES

HISTORICAL DEVELOPMENT

Phosphorites have formed periodically, through geological time, in response to specialized oceanic conditions. The prerequisites and processes leading to the origin and accumulation of the phosphorites are poorly understood. In spite of the innumerable attempts in understanding the complex but specific geological settings responsible for phosphorite formation, no suitable and unequivocally acceptable genetic model has so far been proposed.

Voluminous literature on phosphorite has been generated, mostly dealing with the genesis. Excellent review articles on
phosphogenesis have come up during the past one and a half decade, some of them among others are: Cook (1976), Riggs (1980), Sheldon (1981), Cook (1984), Cook and Shergold (1986). In the following paragraphs, the historical development in understanding of phosphorite genesis has been briefly summed up.

Existing hypotheses on the origin of marine phosphorite can be grouped into four general categories: (1) Special events such as catastrophic destruction of life (Murray and Renard, 1891) or volcanic addition of fluorine to the sea (Mansfield, 1940); (2) Direct interaction of land and sea processes such as introduction of phosphate to the sea from rivers (Pevear, 1966; Bushinskii, 1964); and the formation of phosphorite due to sea bottom flow of brines from shoreline salt pans to the continental shelves (Hite, 1978); (3) Models based on the concept of upwelling (Kazakov, 1937; McKelvey, et al., 1953) leading to the deposition of apatite either at sediment water interface or diagenetically within the sediments from interstitial waters (Baturin, 1971) and (4) Models developed as a result of influence of IGCP 156 Phosphorites on Scientific Community (Riggs, 1979b, 1980, 1984; Sheldon, 1980; Cook and Shergold, 1986). A comprehensive list of the models proposed by Riggs (1986) is presented in Table XVI.

The above (Table-XVI) reveals that in many of the models role of organisms and organic productivity is considered as one of the most important prerequisite in
Table-XVI : Models of Phosphogenesis

1. Buckland (1829) Coprolites and fossil faeces.

2. Seeley (1866) Gelatinous phosphate of lime with the phosphorus derived from the decomposition of marine plants and animals plus skeletal material.


4. Cornet (1886) Keypserling (in Permo., 1888) Mass mortality of fish as a major source of phosphorus which was dissolved and subsequently redeposited.

5. Shaler (in Penrose, 1888) Formed at the bottom of swamps associated with peat.

6. Kazakov (1937, 1938) Upwelling of deep phosphorus-rich waters into geosynclinal basins and shelf platforms leading to an increase in T and decrease of P and CO₂ in solution causing apatite to precipitate below euphotic zone (between 50m and 200m).

7. Mansfield (1940) Time and space association of volcanism with phosphate deposition; the rapid dissolution of volcanic glass supplies increased concentrations of P, F, and Si resulting in increased organic productivity including silica-utilising organisms.

8. Brongersma-Sanders (1957) Marine mass mortalities occur in regions of phosphorus-rich upwelling currents and high organic productivity. These are often areas of bituminous-rich sediments, diatomaceous oozes, and occasionally phosphate sediments.


11. Bushinsky (1966) Dead organisms are the immediate source of P. The rate of supply of organisms must be high and in a warm and shallow environment to facilitate rapid deposition and decomposition of the organism.


13. Rooney & Kerr (1967) Initiation of mass mortalities as a result of massive ash falls.

14. Baturin (1971) Diagenetic formation of a low-grade phosphorite immediately below the sediment-water interface, followed by a period of mechanical reworking and concentration to form a high-grade deposit.


17. Influence of IUGCP 15o-Phosphorites upon scientific community (1978 to present) Recognition of the inter-relationships of global tectonism upon palaeoceanographic and palaeoclimatic conditions has led to the understanding that there are many variables interacting to produce different types of phosphate deposits episodically in variable oceanographic settings and environments.

(After Riggs, 1986)
phosphogenesis. However a major change in the development of theories of phosphogenesis took place after the introduction of the concept of marine upwelling by Kazakov (1937). The Kazakov's hypothesis, in essence, invokes deep, cold, phosphorus rich ocean water as a source of phosphorus in phosphorites. The ascent of phosphate rich water upwards into the shallow photic zone involves a decrease in partial pressure of CO₂, with a consequent rise of temperature and pH resulting in supersaturation of sea water relative to carbonate fluorapatite, and its direct inorganic precipitation. He suggested a concurrent and a consecutive precipitation of first of all calcite and then apatite. Kazakov discarded a number of the then current hypotheses and provoked for chemogenic precipitation as against biogenic hypotheses, and asserted that precipitation of apatite could be accomplished by the physico-chemical processes alone.

The Kazakov's hypothesis was strongly favoured by Dietz et al. (1942), Emery (1960), McKelvey et al. (1953), however it was vehemently opposed by Bushinskii (1964, 1966, 1969) on the very basis of unnatural investigations underlying the Kazakov's hypothesis.

The main objection to his upwelling hypothesis is based on the fact that in the regions of modern upwelling no primary phosphates are reported, instead the phosphorite has been forming diagenetically below the sediment-water interface. On these grounds, Baturin (1971) and Burnett (1977) supported to some extent the importance of upwelling, though not necessarily
for the original Kazakov's mechanism of inorganic precipitation. Baturin (1971) proposed an hypothesis "Upwelling current - diagenetic precipitation - low sea level reworking", which invokes that low grade phosphate pellets formed diagenetically immediately below the sediment-water interface followed by a period of reworking and concentration to form a high grade deposit. Baturin's (1971) hypothesis got support from Cook (1976) and Kolodny (C.F. Sheldon, 1981), however later Sheldon (1980) questioned this as a mechanism of producing major phosphate deposits (Sheldon, 1981).

All researches during pre 70's were not influenced by Kazakov's upwelling hypothesis. Bushinskii (1964, 1966), Pevear (1966) favour a riverine source and shallow water shelf of estuarine deposition to explain the source and palaeogeography of ancient phosphorites. Some workers proposed volcanic emanations as the source of phosphorites (Brodskaya, 1974; Riggs, 1979b, 1980), while others believed in that volcanic tuff fall killed large number of organisms whose decay contributed as a source of phosphorus (Rooney and Kerr, 1967). Ames (1959) proposed phosphatisation of preexisting carbonates due to replacement processes, while Gibson (1967) propounded that the mixing of cold water currents with the warm waters could contribute towards the deposition of phosphorites. The direct precipitation of apatite from sea water as proposed by Kazakov (1937) was questioned by Atlas (1975) on the basis of kinetics of crystallisation of apatite.
After 1937, much interest arose in understanding the physical chemistry of apatite precipitation and a number of workers synthesized apatite experimentally. Gulbrandsen (1969) pointed out that the optimum condition for the formation of large amount of apatite seems to be the coincidence of a special steady supply of phosphate, originally driven from organic matter and a decreased capacity of sea water for phosphate. He suggested that these conditions were best met in the shallow part of seas and continents where large amount of organic matter accumulates in oxygenated waters of higher than normal temperature, pH and salinity. The mechanism faces the problems pointed out by Martens and Harris (1970) that the Mg/Ca ratio in sea water is sufficiently high to inhibit apatite precipitation from the ocean. To overcome the problems of Mg inhibition effects, Burnett (1977) proposed a model which involves inorganic precipitation of apatite within pore waters of anoxic sediments and subsequent concentration of the apatite by physical processes. He asserts that oxidation of organic materials during $\text{SO}_4^{2-}$ reduction is the main source of dissolved phosphate. Apatite precipitation is favoured within the sediments by the high phosphate concentration in the interstitial waters, by the availability of suitable nucleation sites, and by diagenetic reactions that remove interfering Mg ions from the pore solutions. Relatively recent experiments by Gulbrandsen et al. (1984) on the crystallisation of apatite
have led them to conclude that the factor of time overcomes the well known inhibiting effects of Mg upon the crystallisation of apatite. Gulbrandsen et al. (1984) are of the opinion that given an adequate supply of phosphate, apatite can form in the most ocean environments and likely plays a major part in the control of phosphate content of sea water. Lucas and Prevot (1985) experimentally synthesized apatite from ribonucleic acid (RNA) by bacterial activity with different Ca sources such as aragonite, calcite and gypsum, and propose that apatite formation can be explained by the breaking of RNA into three parts by the bacteria, viz. sugar (d-ribose), nitrogenous base and phosphoric acid. They assert that apatite precipitates directly and is practically unaffected by Mg inhibition effects.

Several workers have recognised partly rhythmical laminations and cyclical arrangements of phosphorites on scale ranging from thin sections to field sections. Even ideas of Kazakov (1937) represented one of the first attempt to explain the spatial distribution of phosphorites. Sheldon (1964) showed that phosphorites preferentially formed at low palaeolatitudes i.e. within 40° of equator. Freas and Eckstrom (1968) further developed this idea to show how palaeolatitudes and palaeoceanography can be used to explain the location of many phosphate deposits. Cook and McElhinny (1979) assembled the evidence to show that the major episodes of phosphogenesis occurred during the Miocene, Late Cretaceous-Eocene, Late Proterozoic (at 620 m.y.) Late Proterozoic (700-800 m.y.),
Middle Proterozoic (1200-1600 m.y.) and Early Proterozoic (1800-2200 m.y.) times. Phosphorite formation is not only episodic but is generally of global extent when it occurs. This is well documented for the Cambrian and various Proterozoic sequences by Notholt (1979) and in other episodes as well (Riggs, 1986).

Cook and McElhinny (1979) proposed that underlying cause for this phosphogenic episodicity lies in the changing global palaeogeography and palaeoceanography due to plate tectonic processes. They also believed that phosphorites are not formed as a direct result of tectonism, whereas Riggs (1979b, 1986) asserts that tectonism has a direct and definitive control on phosphogenesis and that a change in global tectonics causes a major fluctuation in global sea level, oceanographic current regimes and world climatic conditions. The result of these changes is reflected in the pattern of associated sedimentary units of the stratigraphic column. Most phosphorite sequences appeared to have formed at times when the pattern of sedimentation were changing from one type to the other. Banerjee (1985) has also recognized five phosphogenic sedimentation cycles in Proterozoic Indian platform corresponding to the global phosphogenic episodes of Cook and McElhinny (1979) and Cook and Shergold (1980).

During the early 80's when the concept of upwelling was revived, although with some modifications in the light of new emerging concept of plate tectonics (Cook and McElhinny, 1979; Sheldon, 1980, 1981; Riggs, 1979b, 1984; Cook and Shergold,
1980) a somewhat dissatisfaction arose among the workers as regards with the applicability of upwelling Model for the Proterozoic phosphorite provinces. Although both Cook and McElhinny (1979) and Sheldon (1981) pointed out that many of the phosphorites particularly those formed in shallow intracontinental epicontinental seas and those occurring along eastern continental margins do not fit to these two phosphogenic models.

For Proterozoic phosphorites of India and China, Banerjee (1971a), Banerjee et al. (1980), Riggs (1980), Sheldon (1979, 1981) opine that these stromatolitic phosphorites have formed as a result of removal of CO$_2$ from Precambrian atmospheres and oceans, with consequent increase in pH due to the increased biological activity, resulting in saturation of sea water with respect to apatite and its precipitation.

Banerjee (1971a), Banerjee et al. (1980) and Chauhan (1979) have well documented the affinity of algal structures with Aravalli phosphorites, however as regards with the role that algae have played, Chauhan (1979), Pandya et al. (1984) and Chauhan and Sisodia (1984) are of the opinion that phosphorites have originated due to coeval and progressive replacement of initially developing carbonate stromatolites by collophane as a result of their interaction with phosphate bearing waters. Contrary to this Banerjee (1971a), Banerjee et al. (1980) stressed for algal induced biochemical origin of these phosphorites, this view is also supported by Verma and Barman (1980) and Verma (1984).
Relatively recently, Banerjee and Klemm (1985) on the basis of organogeochemical studies have concluded that phosphate is precipitated within the pore water under anoxic conditions through the activity of biological agents. The isotopic studies by Banerjee et al. (1986) on Aravalli phosphorite although led them towards a diagenetic (replacement) nature of phosphate deposition, nevertheless they conclude that the available geological and petrographic evidences, and organogeochemical evidences (Banerjee and Klemm, 1985) strongly suggest that the phosphate had been directly scavenged by original microbial carpets from the surrounding sea water with the isotopic composition of their structural carbonate components identical to that of the associated carbonates. Likewise, for the nonstromatolitic phosphorites of Hirapur-Bassia area, Saugar district, M.P. (Bijawars), Banerjee et al. (1982) stress for their primary precipitation in epicontinental seas.

It is beyond the scope of this thesis to favour or negate the primary phosphorite precipitation hypothesis for Aravalli phosphorites, rather their mention is made to have an idea of prevalent views about the different genetic models so far proposed for the other Indian Proterozoic phosphorites.

From the above prevalent models, it is evident that (1) phosphogenesis is intimately associated with tectonism, (2) there are many different types of phosphorites which formed in response to different sets of oceanographic conditions and processes, and in different environments of deposition.
(3) phosphogenesis requires more than just upwelling or organisms alone, and (4) there are many types of upwellings, each of which resulting in phosphogenesis, if all other prerequisite variables are correct (Riggs, 1986).

Cook and Shergold (1986) erected a phosphogenic model, which is based upon the above discussed prevalent models, and have designed a series of questions to test that for Proterozoic Phosphogenic systems. They have rightly pointed out that phosphorites formed in response to factors ranging in scale from the depositional conditions in an area, a few square kilometers in extent to changes in oceanic conditions which may be global in extent. In this scenario, the author has collected sedimentological, petrological, geochemical and mineralogical evidences to formulate a suitable genetic model for these phosphorites.

**GENESIS OF LOHARA PHOSPHORITES**

The geological setting suggests that the Chhattisgarh basin was an intracraticonic epiric sea, developed over the Archaean and Early to Middle Proterozoic supracrustals, probably following the Khairagarh Orogeny.

As Proterozoic records all over India show characters of shallow water sediments (Singh, 1980), the possibilities of the presence of any E-W or N-S sea ways as suggested by Cook and McElhinny (1979) for Phanerozoic time are not feasible, consequently, presence of upwelling related to such
openings is remote. Moreover in this area of study, presence of black shale - chert - phosphorite assemblage - generally taken as indicative of upwelling (Cook and Shergold, 1986 p. 375) is not developed, instead an association of polymictic conglomerates - arkoses - glauconitic sandstones - siliceous clays - carbonates - phosphorites is recorded, which is indicative of prevalence of shallow marine environments. In addition to this, the petrofacies data (Fig. 9) of the Chandarpur Group sandstones clearly indicate that the terrigenous material was derived from stable cratonic block.

Several episodes of sea level changes have also been inferred from the sedimentologic record of the area. The profuse development of authigenic glauconitic pellets and sedimentary structures in Chaporadih sandstones collectively suggests its deposition in tidal flat environments resulting from marine transgression. Above could be imputed to local tectonism. The coarse grained, clean washed quartz arenites of overlying Kansa Pathar/Kondkera sandstones suggest a change in the depositional environment from tidal flat to beach environment, possibly as a result of reactivation in the provenance and concomitant marine regression.

During the end stages of deposition of Kansa Pathar/Kondkera sandstones, the hinterland became peneplained and climates were changed. Although Murti (1987) records a disconformable contact between Chandarpur and Raipur Group, however, in this area no concrete evidence could be gathered to support a disconformable contact.
Deposition of Charmuria Formation commenced in response to transgression of Chhattisgarh sea over the Chandarpur Group sandstones, resulting in the development of a series of embayments and lagoons. In these embayments and lagoons the chemical and biochemical sedimentation ensued and produced a mosaic of facies represented by siliceous clays, carbonates and phosphates.

It is also expected that a number of large and small rivers might have poured very fine terrigenous mud into this (Chhattisgarh) shallow sea. This assumption is based on the mineralogical characters of the lowermost facies (siliceous clays) of Charmuria Formation. Mineralogically these are composed of silt size quartz, amorphous silica, kaolinite and illite, which were derived from the peneplained hinterland, most probably as a result of intense chemical weathering under warm humid climates. The absence of such features as volcanic glass shards, subhedral feldspar grains or bentonites in these siliceous clays further supports to their terrigenous origin.

These siliceous clays were laid down in the proximal areas in shallow lagoons. However, a decreased supply of fine detritus and a change in the physicochemical milieu of the basin, resulted in the commencement of carbonate precipitation in subtidal environments over the siliceous clays. These carbonates are characterized by evenly laminated micrites and micrograded micrites. Above characters collectively suggest their development in subtidal low energy environments. High
sodium content in these sediments indicates restricted sea water circulation and high palaeosalinity.

The development of phosphatic siliceous clays and phosphorites over limestones may be a reflection of disturbance in chemical system. In this phosphatic siliceous clayey facies phosphorites are distinctly recognized (Fig. 24).

Mineralogically these phosphorites are composed of carbonate fluorapatite in which appreciable amount of carbonate substitution has taken place. The apatites recorded in phosphatic siliceous clays are mineralogically same as those of phosphorites. These phosphorites characteristically reveal thin micro-laminations, specks of brown to grey colour, desiccation cracks typical of shallow water conditions. Petrographically, these phosphorites are microsphorites (mudstone phosphorite) showing irregular gas bubble cavities and occasional micrograded lamination like features (Plate XVI-B, XVII-A and B). Above characters are indicative of their primary precipitation. Absence of any clastic quartz grains in addition to their laminated nature also supports the above view, that they are in-situ and have formed authigenically above the sediment water interface—a common mode of formation of ancient sediments (Sheldon, 1980; Southgate, 1986). Abundant recrystallisation and replacement features of diagenetic origin are also recorded in the mudstone phosphorites. The ultrafine textures observed in phosphorites
are (i) dense, smooth mat-like structures and (ii) radially growing aggregates of fibrous apatite grains. The mat-like structures have been interpreted as a result of precipitation of phosphate from gel like substances (Boiko and Yaskolko, 1984). In contrast, apatite grains in phosphatic siliceous clays reveal ultrastructures like (a) minute radially growing crystallite aggregates and (b) smooth microgranular structures. The minute radially growing crystallites also show euhedral and pyramidal terminations in individual apatite crystals, indicating their growth during diagenesis (Russell and Trueman, 1971).

It is unequivocally accepted that there is a relationship between biological activity and phosphogenesis at all epochs (Cook and Shergold, 1986; Soudry, 1987). However, in present area of investigation, although no algal stromatolites are reported, the presence of burrow tubes in these sediments provide sufficient evidences in favour of biological activity. Moreover profuse development of anastomosing microlaminations and microdomal structures in the carbonates of lithofacies 'D' provide evidences to add in support of the biological activities—possibly algal activities. The tube like features (Plate XX-B) in these phosphorites most probably are a result of phosphatization of burrow tubes.
As regards the genesis of these phosphorites is concerned it is opined that perhaps best clues to unravelling it lie in their peculiar ultrastructures. The mat like dense ultrastructures in microphorites is believed to be a result of direct precipitation of apatite by bacteria, above sediment - water interface. Recent studies by Froelich et al. (1988) have revealed that leaching of phosphate from the decay of organic matter and its accumulation at the sediment-water interface may be possible under reducing conditions in a mixed oxic - anoxic environment under the influence of bacteria. Niedermeyer and Langbein (1989) and Soudry (1987) have reported pyritised organic forms representing fossilised cyanobacteria and have interpreted such features as microbially mediated ultrastructures responsible for phosphate accretion. Although in these phosphorites no such features are observed, however, presence of abundant pyrite specks in microphorite mud and limonitized pyrite laminae, by analogy to the above perhaps favours the influence of sulphate reducing bacteria.

Glenn and Arthur (1988) have pointed out for Peru Shelf sediments that precipitation of apatite and pyrite appears to be nearly coincidental, with pyrite precipitation continuing after that of carbonate fluorapatite has ended. The petrographic evidences support the above, as pyrite and limonitized
pyrite often occurs in gas bubble cavities in these microsphorites, and occasionally replacing the latter.

As for the source of phosphorus, it is proposed, that either or both of the following two alternatives: (1) Organic phosphorus cracking (release of phosphorus from phospholipids and other high energy phosphorus compounds from the plankton debris by microbial action at sediment-water interface), or (2) Phosphate enrichment via the iron redox cycle, including microbially mediated pyrite precipitation, proposed by Froelich (1988) for modern Peru Shelf sediments may be the mechanisms in addition to the land derived phosphorus. It is believed that phosphorus was relieved by one or all of the above mechanisms and was precipitated under anoxic conditions, developed below bacterial mats.

According to Froelich et al. (1988) phosphate release and its precipitation in siliciclastic depositional environments without calcite may take place microbially in the presence of bacterial mats on surficial sediments. It is presumed that in Lohara area, phosphate accumulation took place on the shallow embayments or partly closed sounds in oxic-anoxic environments, which is sedimentologically supported by the presence of desiccation cracks and abundant pyrite. It is also suggested that the commencement of apatite precipitation took place at microenvironments within or below the bacterial mats. Such a mechanism is supported by the studies of Soudry and Champetier (1983) and Soudry (1987),
that cyanobacteria act as binding agents of phosphate and form cryptalgal laminations which often disappear during diagenesis resulting in undifferentiated cryptocrystalline groundmass. Thus on the basis of these observations, it is concluded that secondary diagenetic recrystallization destroyed most of the cryptalgal laminations in microspherite mud. The secondary diagenetic recrystallization is evident from the petrographic and SEM studies, and is also supported by the low contents of most of the trace elements in these phosphorites, which have probably leached out during diagenesis (McArthur, 1985). The diagenetic process probably took place in oxic conditions which have oxidized the primary organic material. This is evident from their light colour and presence of limonitized pyrite.

The apatites of the phosphatic siliceous clays reveal genetically different type of ultrastructures, and are supposed to be formed diagenetically below the sediment water interface, most probably at times of low concentration of phosphorus in sea water. The accumulation of mudstone phosphorite within the phosphatic siliceous clays suggest that mudstone phosphorites were formed at times of high concentration of phosphorus in sea water under decreased supply of terrigenous mud.
Evaluation of proposed model in context of Indian Proterozoic phosphorites

The Proterozoic sedimentary record in Indian subcontinent preserves well developed phosphogenic provinces. All these phosphorites (except Bijawars) are typical for their stromatolitic nature, and occur in association with carbonaceous shales, slates, chert or dolomite in condensed sequences (Banerjee, 1986).

The phosphorite occurrences of the study area (Chhattisgarh Basin) belong to one of the Proterozoic phosphogenic cycle (Banerjee, 1985) and bear great palaeogeographic significance. The absence of algal stromatolites, petrographic characters and their occurrence in siliceous host remarkably distinguishes them with other Proterozoic Phosphorites (Except Bijawars) of India. However their gross mineralogy, petrographic characters and lithoassociations are quite similar to the phosphorites of Volta Basin, S. Africa (Slansky 1986b) Minas Gerais, Brazil (Dardenne et al., 1985) Khubsugul Basin, Mongolian Republic (Ilyin et al., 1986) and Karatau Basin, USSR (Eganov et al., 1986).

As for the actual process of formation of phosphorites in India, two views exist, viz., (1) Direct precipitation of phosphates in the body of accreting algal stromatolites (Banerjee, 1971b, Banerjee et al., 1980, Banerjee and Klemm, 1985) and (2) Progressive replacement of initially developing
calcium carbonate structures (stromatolites) under the influence of microbial communities involved in their growth (Valdiya, 1972; Chauhan, 1979; Pandya et al., 1984; and Chauhan and Sisodia, 1984). Fairly recently Banerjee and Klemm (1985) on the basis of organogeochemical studies have stressed the role of biological agents in phosphate accumulation.

The present studies on the Lohara phosphorites have lead to propose that precipitation of phosphate took place at microenvironments, within or below the bacterial mats in shallow embayments, under anoxic conditions.

The secondary diagenetic recrystallization of apatite destroyed most of the cryptalgal laminations, and possibly also resulted in leaching of the trace elements.

The above proposed model for the Lohara phosphorite supports the earlier proposed models for mudstone phosphorites of Karatau Basin (Eganov et al., 1986) and is in agreement with a model proposed for mudstone phosphorites and stromatolitic phosphorites of Georgina basin, Australia (Southgate, 1986). This model also supports the views of Banerjee and Klemm (1985), and is probably equally applicable to the stromatolitic phosphorites of Aravalli and Pithoragarh and also may be considered for the laminated phosphorites of Hirapur-Basía, Sagar distt. M.P. and Sonrai area Lalitpur, distt. U.P.
SUMMARY AND CONCLUSION

The present thesis embodies mineralogical, petrographical and geochemical studies carried out on the phosphorites and associated lithologies occurring in the Lohara area, Durg district, M.P. These phosphorites belong to Upper Proterozoic Chhattisgarh Supergroup. These studies were initiated with an objective,

(i) to understand the phosphogenesis in Chhattisgarh sedimentary sequence and propose a phosphogenic model, and
(ii) to evaluate the proposed model in the context of other Indian Proterozoic phosphorites.

Since phosphorites are complex sediments, which developed under special set of conditions, therefore in order to understand phosphogenesis in Chhattisgarh sediments, an attempt has been made to correlate mineralogical, geochemical and petrographical data to sedimentologic, stratigraphic framework of Chhattisgarh basin. In the study area, rocks belonging to Chandarpur and Raipur Group of Chhattisgarh Supergroup are exposed. The phosphorites occur in the lowermost Charmuria Formation of Raipur Group in association with phosphatic siliceous clays.

The petrographic studies have led to classify the Chandarpur Group into three Formations, viz. Lohardih, Chaporadih and Kansa Pathar/Kondkera Formations in the younging order. Their mineralogical characters and sedimentary structures have provided sufficient evidences to speculate their depositional environments. It is ascertained that the sedimentation in Chhattisgarh basin commenced with the development of arkoses/subarkoses in beach environments, followed by a period of marine transgression and development of tidal flats under which Chaporadih sandstones were deposited. While Kansa Pathar/Kondkera sandstones were laid down in high energy shallow beach environments. The terrigenous supply was mainly from stable continental block provenance and early formed sediments.
The Charmuria Formation (Raipur Group) unconformably overlying the Chandarpur Group sandstones (Murti, 1987), has been divided into four lithofacies. The lowermost lithofacies 'A' is supposed to be equivalent of Sirpur clay Member of Murti (op. cit.), which is mainly composed of silt sized quartz and clay in subordinate amount. The presence of kaolinite and illite and absence of volcanic glass shards and bentonite together have been used to infer their terrigenous nature. White cherty limestones of lithofacies 'B' conformably overlying the siliceous clays of lithofacies 'A' were most probably developed in shallow subtidal environments in quiet water conditions. The phosphatic facies i.e. lithofacies 'C' comprising of phosphatic siliceous clays and phosphorites, conformably overlies the lithofacies 'B'. The thinly laminated, mudstone phosphorites, are lenticular in nature and form a subfacies of lithofacies 'C'. Their thinly laminated and microosphoritic nature indicates quiet water low energy conditions. Presence of abundant pyrites, micrograded laminations, tube like structures and mud cracks suggest that precipitation of apatite took place under shallow oxic-anoxic conditions in a restricted environment probably an embayment, under the influence of microbial activity. The flaggy limestones of lithofacies 'D' were probably formed under deeper protected shallow subtidal lagoonal environments in reducing conditions. Presence of anastomosing network of microlaminations and microdomal structures have been attributed towards the presence of algal activity within these limestones.
Mineralogically these phosphorites are composed of carbonate fluorapatite, with their general structural formula $\text{Ca}_9.2\text{Na}_0.3\text{Mg}_0.3(\text{PO}_4)_5(\text{CO}_3)_1\text{F}_{1.84}$, in which Na and Mg have replaced for Ca. Other diluent minerals present are quartz and calcite along with clay minerals. The apatite of phosphatic siliceous clays are more towards fluorapatite. The crystallite sizes measured for these apatites indicate their primary precipitation.

The SEM studies reveal following ultrastructures (i) dense, smooth, mat like structures and (ii) radially growing aggregates of fibrous apatite grains. These structures evidently support the view that precipitation of apatite took place from gel like substances. In contrast, apatite grains in phosphatic siliceous clays reveal ultrastructures like (i) minute radially growing crystallite aggregates, and (ii) smooth microgranular structures. The minute radially growing crystallite aggregates show euhedral and pyramidal terminations in individual apatite grains a feature of probable diagenetic growth. These apatite grains of the two types are genetically different and indicate that the apatite precipitation in microsphorites took place at sediment-water interface, while that of phosphatic siliceous clays took place diagenetically below the sediment-water interface, in interstitial spaces.

The major element composition of these phosphorites and associated lithologies are evidently supported from
mineralogical and petrographic data. The $P_2O_5$ isochemical contour map (Fig. 23) clearly depicts one maxima, where phosphorites are occurring as lenticular beds in the phosphatic siliceous clays. The underlying and overlying carbonates do not reveal $P_2O_5$ enrichment, however they show high silica content compared to average carbonates. The vertical variation in CaO, $P_2O_5$, and $SiO_2$ in Kharkhara canal section (Fig. 24) clearly reveals a sharp change in the contents of these oxides. This suggests that phosphorites occur as distinct subfacies of the phosphatic siliceous facies and are not a result of weathering of phosphatic carbonates. The chemical characters such as CaO/$P_2O_5$ ratio, high Na$_2$O contents and absence of aluminous phosphates in these phosphorites further supports the above view. High $SiO_2$ content in these phosphorites is due to the presence of authigenic silica as a product of secondary diagenesis, whereas in phosphatic siliceous clays, it accounts for the presence of terrigenous silt size quartz and other clay minerals.

As regards with the abundance of trace elements in these phosphorites, it is observed that some of the trace elements (Co, Cu, Ni, and Se) if, are enriched or show normal abundance with respect to the averages of world phosphorites, are depleted with respect to average Indian Proterozoic phosphorites. This variation in concentration of trace elements suggests, either (i) the nonavailability of these elements in formational waters, or (ii) their leaching during diagenesis.
The trace elements of organic association, such as Ni, Cr, Zn in these phosphorites are characteristically depleted, except Zn. This depletion suggests that these elements were probably leached out during the early diagenesis.

The above studies have lead to propose that these phosphorites are primary in origin, and the precipitation of phosphate took place at microenvironments within or below the bacterial mats in shallow embayments under anoxic conditions. These phosphorites were later subjected to diagenesis under oxic environments, and during diagenetic processes most of the trace elements were probably leached out and the organic matter was oxidized to give them light colours.