Journal of Geography, Environment and Earth Science International

Volume 27, Issue 9, Page 122-139, 2023; Article no.JGEESI.104228
ISSN: 2454-7352

A Case Study of Phosphorite Investigation in Jhabua District, Madhya Pradesh, India: By Barefoot Geologist

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2023/v27i9711

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104228

Original Research Article

Received: 03/06/2023
Accepted: 09/08/2023
Published: 22/08/2023

ABSTRACT

The Jhabua phosphorite is the second largest deposit in India after the famous Jhamerkotra deposit of Rajasthan. Though geographically they are separated by state boundaries but geologically they belong to the same domain. The Jhabua deposit is hosted with in the Proterozoic meta-sediments of Aravalli Supergroup. The host litho-units for the stromatolite bearing phosphate mineralization are limestone and chert. The limestone is siliceous in nature and has large variation in terms of impurities and grades to dolomite. The phosphate content is higher in cherts compared to limestone. The stromatolites are the important field guides to locate the phosphate mineralization.

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But need of geochemical investigation method arises in locating the non stromatolite bearing rock phosphate mineralization. The paper demonstrates very vividly the methodology of exploration for rock phosphate mineralization. This can be seen here as how the basic and conventional techniques of exploration are effectively utilized to first locate the geochemical anomalies on the ground followed by drilling the anomalies and establishing the resources. This is significant here to observe that no state of art technology has been used here during the entire course of exploration, in establishing the resources. This is to underline the importance of conventional exploration techniques which is getting a beating by the frequent use of AI in geology. This case study demonstrates as how the time tested conventional methods are still very much valid and can yield fruitful results if utilized meticulously.

Keywords: Jhabua; phosphorite; aravalli supergroup; stromatolite; case study; conventional exploration.

1. INTRODUCTION

The world reserve base of phosphate rock is about 71 billion tonnes, located mainly in Morocco and Western Sahara 70% , China (5%), Egypt 4%, and Algeria 3% and remaining 18%nof world resources of Phosphate are located in countries like, Australia, Brazil, Russia including India. (USGS Mineral Commodity Summaries 2021). India's Total resources of rock phosphate as per the national Mineral inventory 2015 are 312.68 million tons. Large deposits have been identified on the continental shelves and on seamounts in the Atlantic Ocean and Pacific Ocean but cannot be mined economically with present technology. India meets its requirement by mostly imports and has only a minor production. Within the country the important deposits are Jhamarkotra phosphorite and Jahbaua phosphorite. Both these deposits are located within the Aravalli Supergroup of rocks. The Aravalli Phosphogenic belt is exposed from Udaipur (Rajasthan) in north to Jhabua (M.P.) in the south. Economically workable deposits are located only at two places, around Udaipur in Rajasthan & Jhabua district in Madhya Pradesh. The Phosphorite shows a distinct lithological affinity with Stromatolite bearing dolomite. The presence of algal structure in the phosphatic dolomite indicates shallow depositional condition under warm climate.

The exploration has been revolutionized in the recent times with the flooding of the exploration world with plethora of new technology. The portable XRF is gradually replacing the conventional sampling and reducing the time required for evaluation of the ground for mineralization of economic grade. The conventional techniques are now becoming almost obsolete to the extent that the new generation of exploration geologist are not even aware of these very basic techniques which are very low cost and yet very effective in delineation of the mineralized zone reasonably well with systematic approach. In the present paper this has been demonstrated that how a very basic tool; The Shapiro's kit was used for delineation of the mineralized zone which led to proving of some resources in the Piploda and Khatama blocks in Meghnagar Tehsil of Jhabua district of Madhya Pradesh, and the extension areas of the known phosphorite bearing areas in the very famous Jhabua phosphorite belt, have been delineated. It is very easy to recognize the stromatolite colony where ever they are present and hence provide a direct evidence of phosphate zones, but the areas where these direct evidences are missing it is difficult to trace mineralization of phosphate without chemical analytical procedure. Here the Shapiro's kit comes handy in delineating the mineralized zone in the field itself with a very minimum expenditure and on a fast pace. With experience in the matching the shades of the precipitate received from the samples with the shades of the pre-prepared standard solution from the known concentrations., fairly accurate results can be obtained with the help of this basic yet very effective exploration tool for phosphorite.

The Jhabua Phosphorite is the largest and well known Phosphorite deposits after Jhamarkotra in in India. The Phosphorite here in Jhabua is confined to the dolomitic limestone and cherty horizons of the Proterozoic sequence of rocks of Madhya Pradesh, which forms the southern extension of the Proterozoic rocks exposed and named as Lunawada Group of Rocks of Aravalli Supergroup in Rajasthan. The phosphorite deposits in Rajasthan are also hosted within similar rocks and it is nearly a physical continuation of the host package to Jhabua from Rajasthan. The rock phosphate mineralization

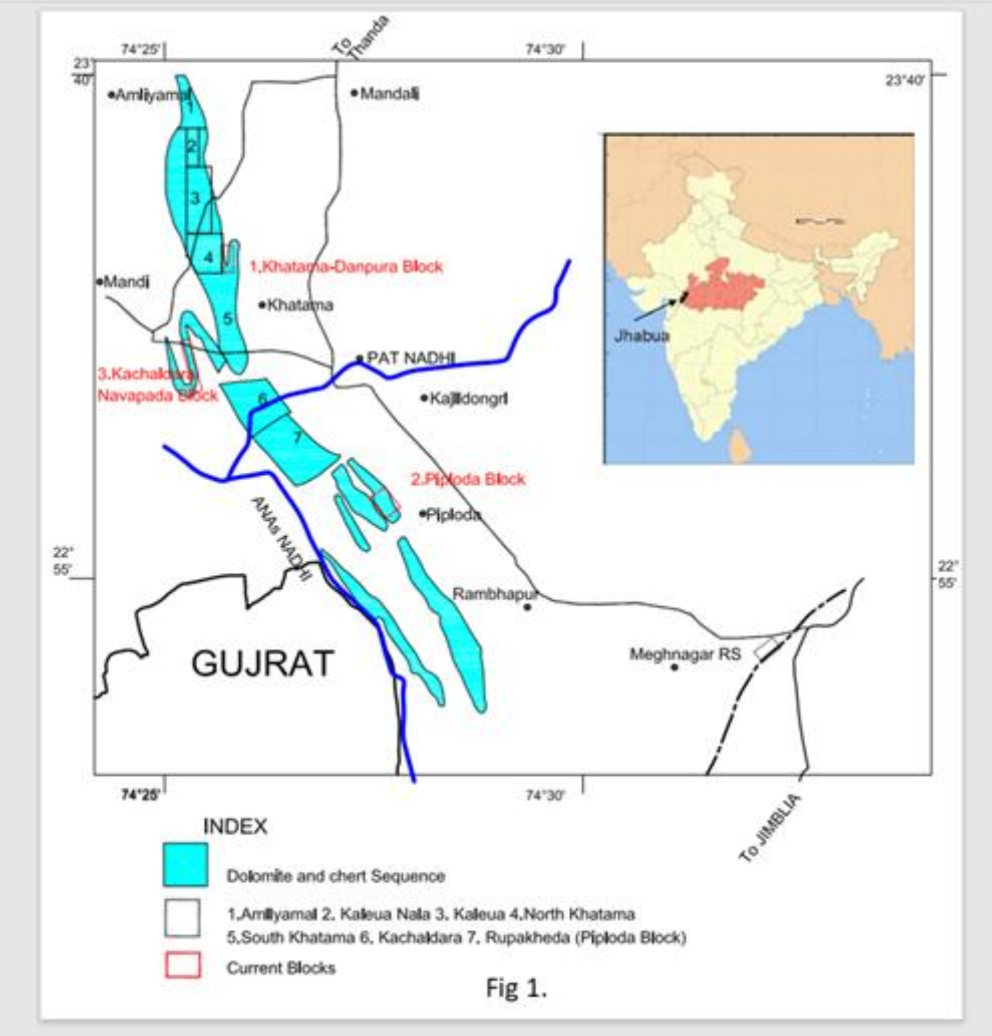

Fig. 1. Location map of the area. Indicating explored blocks, within dolomite sequence

here in Jhabua is confined to a 12 km long belt between Amliyamal in the north and Rambhapur in the south, located in the Survey of India Toposheet No 46J/5 (Fig. 1) and is closely associated with stromatolitic development within dolomitic limestone, besides occurring in chert bodies and cherty dolomite. The presence of algal strands, as thin laminated grayish bands within the dolomite and limestone are also observed, whereas the chert and cherty dolomite do not contain visible stromatolites. The History of exploration in the area dates back to 1972 when Geological Survey of India carried out preliminary investigation for Phosphorite in Jhabua district, Munshi et al. [1] reported occurrences of phosphorite in 8 km strike length between Amliyamal and Rambhapur in the dolomitic limestone band extending for 12 km in the strike length. (Fig. 1.). The chert and dolomite limestone lenses in the area form conspicuous hills in an otherwise pediplained area mostly comprising gneisses and phyllite. The major phosphorite bodies were located near Amliyamal, Kelkua, and Khatama, while minor occurrences were located by these authors at west of Rassori, west of Piploda near Kachaldara and Nawapara. These authors observed during their study that the phosphorite bodies range in length from few meters to more than 700m in strike length and are less than 1m to 25m in width, with some of the bodies varying up to 100m in width. The authors observed that the phosphate content is more in the phosphorite associated to the stromatolitic colonies, and the percentage of P2O5 is also more in these phosphates than the phosphates associated with the carbonate rocks. Extensive exploration followed this find and resources were proved [1] Balasubramanium; Soni and Sonakia; [2]; Khan (1979); Khan Mathur; Jain Srivastava; [3]; in Kelua and

Khatama north and south blocks. Khan carried out detailed investigation in 5 km strike length, which included Amliyamal block, Kelkua *nala* block, Kelkua block Khatama north and south blocks were assessed. A total of 26.559 million tons, of resources were proved with an average grade varying differently in various blocks from 12% to 32% P_2O_5.The Stratigraphic succession evolved and established after a detailed work by Munshi, et al. [1] and other workers is as Table 1.

The origin of these phosphatic deposits has been discussed by [4, 5, 6]. There has been very scanty work on the Jhabua phosphorite post GSI's extensive exploration during 1973 to 1978. However there are some recent publications, not exectly on Jhabua,but dealing with the use of ASTER data [7] for phosphatic rock mapping in Aravalli belt. Another paper by possibly same first author (Guha et al, 2022) also described importance of reflectance and its use in exploration. Similarly Occurrence of rare earth has been described by Samsuddin Khan [8] in Sallopat area, which is located just south of the Jhabua deposit, in the same set up and falls in Rajasthan part of the same host package, of Aravalli meta sediments. The present work was aimed at tracing the extension areas of the already exiting mineralization with the help of Shapiro's kit, detailed and large scale mapping. Sinha Chouhan [9].carried out preliminary studies by remote sensing and limited field check. Sharma et al. [10] effectively used the basic techniques of random and systematic sampling of the various horizons by testing the P_2O_5 content in field and were able to delineate the surface mineralized / anomalous zones successfully followed by drilling and made some contributions to the national inventory of Phosphorite reserves.

It is demonstrated here that how a very basic technique of mapping and proper and systematic sampling using the low cost conventional methodology can lead to successful exploration.

Table 1. Stratigraphy of the area. [1]

Group	Formation	Rock type	Dscription
Lunavada group		Intrusive	Intrusive quartz feldspathic rock with granite,granite gneisses, gneissic granite traversed by aplite, pegmatite, amphibolite and quartz veins.
	Mandli formation	Quartzite	Massive quartzite locally flaggy and conglomerate at the base with current ripples and cross bedding showing at places mineralization of manganese.
	Kelwa formation	Phyllite (upper):	Chlorite-quartz-sericite-phyllite at places schistose and calc-phyllite.
		Chert	Massive brown chert with fragments of phosphatic stromatolite, at places bedded and non stromatolitic chert
		Phosphorite	Chert based phosphorite with stromatolites
		Dolomitic Limestone	Dolomitic limestone with broken and reworked stromatolites
		Phosphorite-	Carbonate based phosphorite with stromatolites
		Dolomite	Impure dolomite (siliceous) with some limestone (calcite), quartz vein and stringers of phosphate.
	Thandla dhara formation	Phyllite (lower)	Chlorite-biotite-phyllite with silica bands
----------------Unconformity----------			
Udaipur group Base		Gneisses, amphibolite and granitised amphibolites etc.	

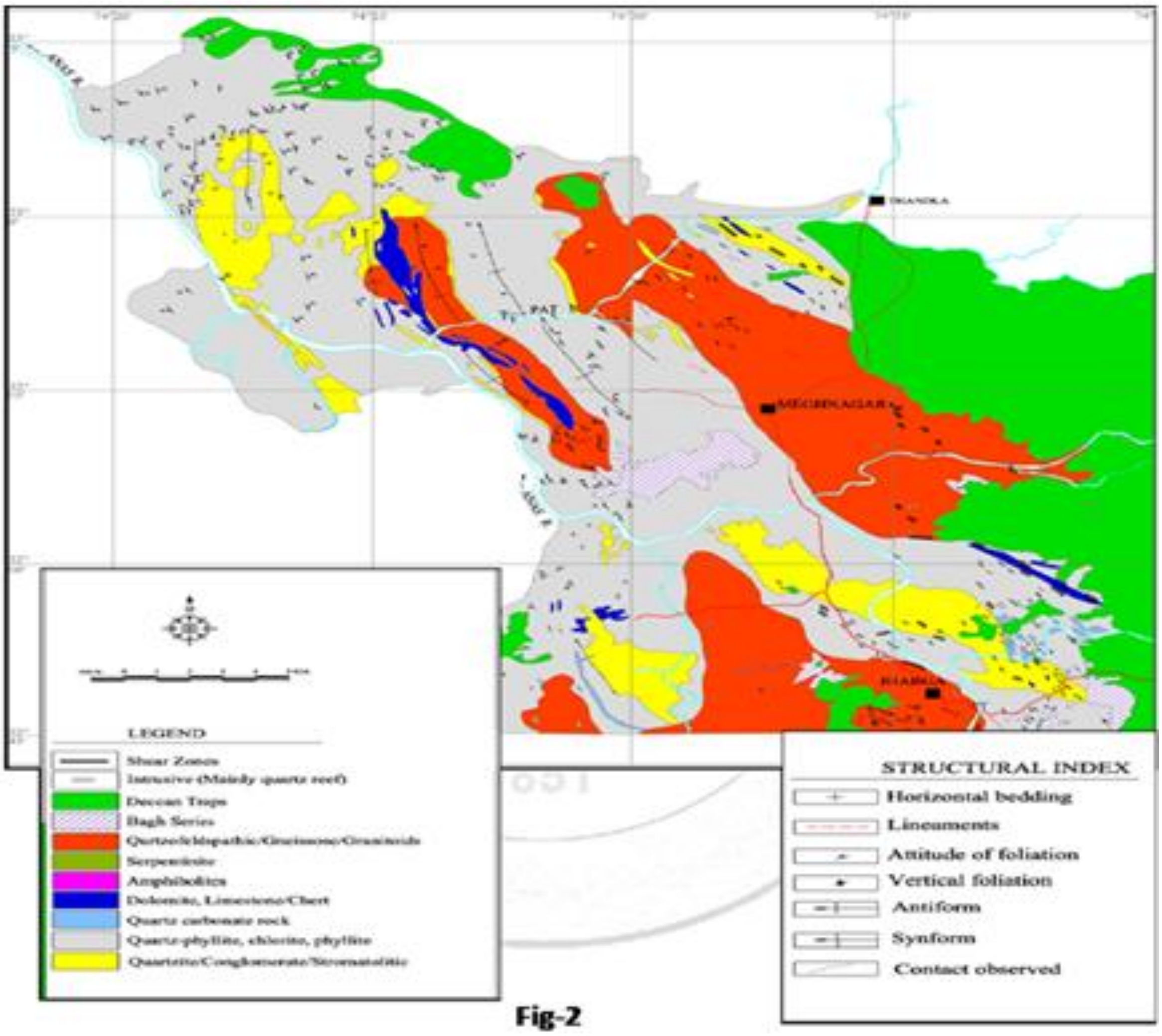

Fig-2

Fig. 2. Regional Geological Map of the Jhabua District Madhya Pradesh

1.1 Regional Structure of the Area

The study area falls in the core of a doubly plunging synformal structure, which has a width of more than 10 km and length over 25 km as described by Munshi et al. [11,1]. The southern end of this synform plunges due north and is steeper as compared to northern end which plunges at shallower angle comparatively, of the two but otherwise both the ends plunge at moderate to steep angle to the tune of 45° to 70°.The axial plane of this mega fold runs NNW-SSE and the hinge zone is very wide/ large. The central part of this map scale fold is characterized by presence of many synformal and corresponding antiformal closures. The mineralization of Phosphorite is wholly confined to the central axial zone to western part of the eastern limb of the fold. While the western limb of the fold does not have any known mineralization though the litho-pack remains to be the same [2].

1.2 Local Geology

The geological succession erected by Munshi et al. [1] holds good till date, as far as the regional geological setup is concerned, however the current team of authors observed certain localized variations in the chert and phyllite litho units. Though the changes have not been suggested in stratigraphy due to comparatively smaller area covered during the latter studies however the details have been incorporated.

Large scale mapping on 1:12,500 scale, in and around Khatama, Dhanpura Kalikhet,Kachaldara, Nawapara and Mandli falling in C1 and B1 quadrants of parts of 46J/5 toposheet was carried out [10] in order to locate phosphatic band if any in the area adjacent to the mining areas of MPSMC. (The lease areas of Madhaya Pradesh Mining Corporation). The mapping has revealed that dolomite in the area is the most important and extensively exposed lithology, which has variations as phosphatic stromatolite bearing dolomite and the siliceous dolomite with thin sandy/quartzitic layers. The dolomite is extensively exposed in parts of Dhanpura-Khatama and Piploda block and also in Kachaldara block. Stromatolite bearing dolomite is the most important unit of dolomite and is the host of phosporite mineralization in the area. The profuse development of stromatolites can be observed in Khatamba south Dhanpura village where mining is being carried out, besides stretched stromatolites are also recorded from kachaldara block. The stromatolites in the newly located band in Kachaldara- Kalikhet (Fig. 3.) vary in distribution and concentration and are patchy in occurrence, though the total strike length of the band containing the algal strands and stromatolites is about 1000m. The band starts from Kalikhet and extends due south (Fig. 3.) Another band which was located during the large scale mapping, north of Mandli has not been found exposed between Nawapara and Mandli due to thick soil and scree cover. The stromatolitic limestone samples from the band north of Mandli (Random 2 samples tested) indicate P_2O_5 about 10% to 12% by Shapiro's kit. Subsequent systematic sampling of the band reflects 15m thick zone with 6 to 10% P_2O_5 by Shapiro's kit testing. This band extends discontinuously for about 250 to 300m in strike length. The western part of the area mapped contains mostly quartzite and phyllite except for the small dolomite band north of Mandli. The quartzite exposed north of Mandli is feldspathic, very well bedded containing well developed current bedding, ripple marks of both wave and current origin are well preserved besides containing graded bedding. The quartzite also contains intra-formational conglomerates suggesting local hiatus between the deposition of the quartzite sequence. A small band of manganese-quartzite inter-layered unit, contained within the phyllite has been located south of Kelkua. Though the phyllite and quartzite are exposed at various places in the Granite occurs both as intrusive and as basement for Aravalli meta sediments in various parts of studied area including in Piploda, Khatama and Kachaldara blocks. The undulating basement terrain has been responsible for highly variable thickness of the Aravalli metasediments which are host of phosphatic mineralization. Besides large scale mapping detailed mapping was also carried out in all the three blocks including Dhanpura- Khatama, Piploda and Kalikhet-Navapara blocks. The DM maps of Piploda and Kalikhet are contained in the reports of these blocks and the interested reader can refer to these reports. However the Detailed Geological map of Khatama block is enclosed for reference (Fig. 4) studied area but are not discussed in detail because they are not the host for the phosphatic mineralization.

The large scale mapping in the 10 sq.km area carried out during the course of present work, has indicated large number of synformal doubly plunging mesoscopic folds sympathetic to the regional F_2 fold, preserved in dolomite and quartz veins contained within the dolomite [10]. The mapping also revealed that the eastern part of the area mapped comprising the working mines of the MPSMC in Khatama as well as Kelkua blocks, are located within the axial zone of the major fold. This axial zone is represented by the preferredly stretched stromatolite colonies defined by strong north – south alignment besides occurrence of stretched and brecciated quartz veins, and autoclastic brecciation of the veins emplaced within the chert (Fig. 5a to 5f). Besides this axial zone, shearing has also been observed in the western limb of this major fold which is represented by Mandli quartzite with subordinate dolomite; The shear zone can discretely be demarcated by a prominent silicified zone, stretching of the fragments of quartz veins, besides sigmoidal bodies of quartz, and development of crude S-C fabric, besides large scale ferruginized zones.

1.3 Primary Structures

Colour banding has been recorded from the thin as well as thick quartzite band in the area**,** this could also be seen in a thin folded band exposed east of the Trench T-1.The bedding in dolomite is only recognizable wherever it is in contact with the thin quartzite intercalations. Vugs *and cavity-* Vugs, cavities and comb quartz could be observed preserved within the quartz veins emplaced within the cherty sequence in the mapped area. *Stromatolites:- development of crude stromatolytes but non phosphatic in nature has been observed in the thin quartzite bands exposed in the area kachaldara block.* The stromatolites, algal as well as silicified are preserved here, contained within the limestone/ dolomite limestone. These are mostly columnar in nature and show concentric ring like structures, without much branching. The stromatolites are concentrated in the northern part more and become sparse in the southern part. These structures depict a strong preferred alignment due N-S and due E-W in various parts indicates their growth during sedimentation.

1.4 Deformational Structures

Deformational structures of the planner and non-planner type are profusely developed here as the area has suffered three phases of recognizable deformation.

Foliation/Schistocity:-

Three foliation surfaces have been recorded in the dolomite as well as in the cherty horizon. The S_0 is largely parallel to $S_1$and is generally runs in N-S direction with moderate to steep dips due east, which keeps changing due to folding. The S_2 has a very acute interfolial angle of 10° to 15° degrees with $S_1$and also dipping steeply the direction of dip keeps changing due to folding. The S_2 foliation also occurs as crenulations cleavage at places. While the S_3 surface which is more of a fracture / disjunctive cleavage is oriented in N70° W-S70 ° E direction with northerly dip of 75°. Foliations are also developed in granite and amphibolite which are exposed in the area.

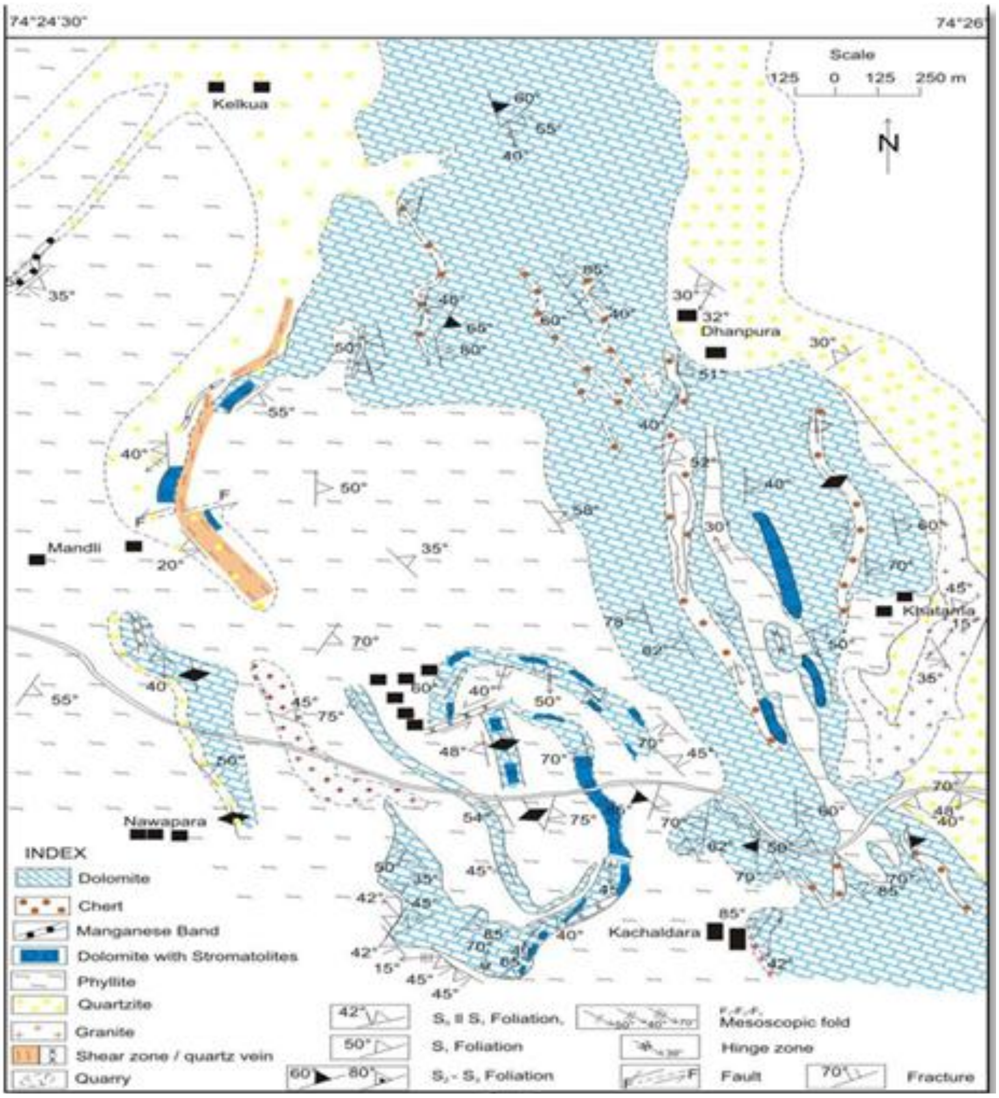

Fig. 3. Large scale Geological map of Kalikhet –Nawapara area, Jhabua district Madhya Pradesh depicting disposition of stromatolite bearing dolomite [10]

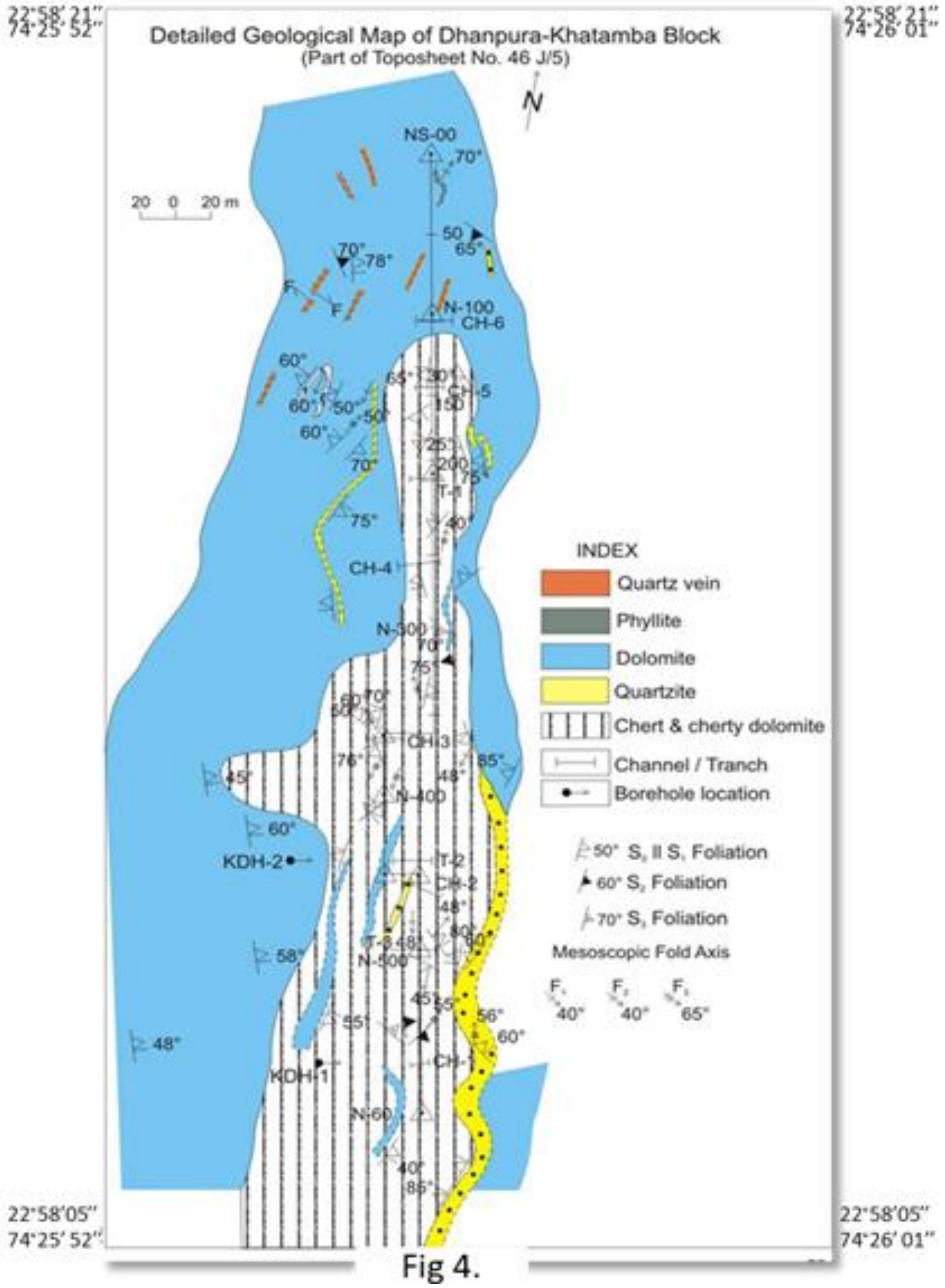

Fig. 4. Detailed geological map of Dhanpura Khatama block, Jhabua District, M.P. Depicting disposition of chert in the area which is phosphatic in nature [10]

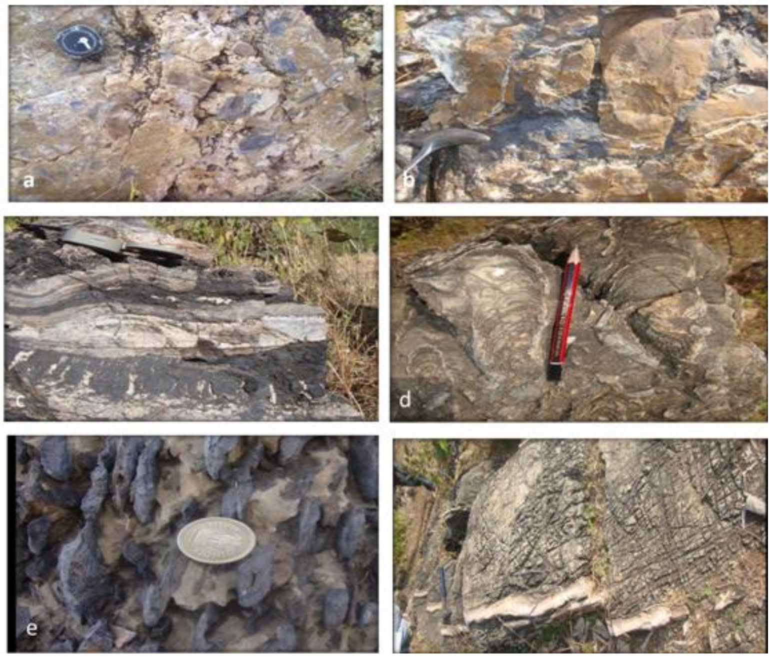

Fig. 5. Salient features of the lithounits in various blocks

A. Brecciated chert often phosphatic in nature , Khatama Block, Jhabua ; B. Cherty dolomite with manganese fillings along the fracture planes, Piploda area, Jhabua C. Thin and thickly bedded Quartzite, exhibiting sandwiched lensoid bodies of Manganese, south of Kelua,Jhabua;. D. Large columns of Stromatolites in Dolomite , South Khatama block, Jhabua; E. Stretched stromatolites hosted with in dolomite , depicting post depositional shearing evidences; F.Non Phosphatic dolomite with elephemt skin weathering and depicting step faulting , from Khatama area,Jhabua

Fig. 6. Different types of mesoscopic folds recorded from the area

a. Tight Isoclinal fold in inter layered quartzite in dolomite, Piploda block, Jhabua;.b. Rootless first fold in quartzite within dolomite, Piploda block, Jhabua; c. Mesoscopic Z shaped second fold in dolomite chert sequence in Khatama block, Piploda; d. M W folds marking hinge of a second generation exposure scale fold in Piploda block, Jhabua; e. Nuetral folds preserved in inter layered quartzite dolomite package, exhibiting shear zone, piploda block, Jhabua; f. Doubly plunging synformal F_2 fold in dolomite in Kachaldara block

Folds: Mesoscopic folds of three generations are found preserved and observed in the Khatama and other blocks during detailed mapping. The first fold F_1 is preserved in chert band with very steep plunge due south has been recorded from the area. The F1 has also become neutral in the shear zones due to overturning of the same. The second fold F_2 controls the outcrop pattern in the entire area and is doubly plunging upright to steeply inclined in nature. The attitude of plunge of the F_2 folds exhibit large variations due to predominantly two reasons, one due to progressive deformation and second the moderate thickness of the sediments over lying the basement in the entire area. The plunging nature of second fold has also controlled the depth continuation of the phosphorite bands. The F_3 fold is broad open type steeply plunging towards NW and is accompanied by development of fracture cleavage axial planar to $F_{3.}$ (Fig. 6a to 6e).

Faults / Slips

Mesoscopic slip planes have been recorded trending in East-West direction within the quartz veins. A prominent shear zones can be clearly observed in N-S direction. Along the shear plane silicification is developed. Quartz veins disposed in enechlon pattern along N-S direction and also along the E-W direction are common. Step faulting has also been recorded from the northern Khatama block during the large scale mapping The shear planes developed in the phyllite just south of the mapped block has been recorded .Various mesocopic faults observed are depicted in Fig. 7a to 7f.

Surface indications of the rock phosphate mineralization: The rock phosphate mineralization is different than the metallic mineralization and hence does not have any particular colour or any other guide as surface shows of mineralization. The only direct evidence is the presence of stromatolite colonies. The stromatolite colonies are contained within the cherty dolomite and limestone while the chert does not contain visible stromatolites, though the cherty horizons also contain phosphatic values. The mapping revealed that the major phosphatic cherty horizons are restricted to the eastern part of the mapped area and the chert bands are disposed in an en-echlon pattern and contain thin inter layered quartzite partings associated with them. The detailed mapping also indicated that the phosphatic chert is not as massive as non phosphatic, is more yellowish in colour and less ferruginous than the non mineralized chert.The dolomite / limestone horizons also contain dark grey coloured phosphatic algal strands as surface guide to the mineralization. In the present study only the Kalikhet- Kachhaldra –

Fig. 7. Various mesoscopic structures in the area

a. Z folds preserved as parasitic folds to the major antiformal folds in the kachaldara area, Jhabua. b. Shifting of the hinge of a mesoscopic F_2 fold Piploda block, Jhabha; c. Axial planer meso-scopic faults in Piploda block Jhabua; d. Crenulation cleavage in intrusive granite exposed in Pat River, Jhabua; e. Minor drags in Phyllite sympathetic to third deformation, Khatama block, jhabua; f. Shifting of Quartz veins along E-W direction , sympathetic to third deformation, Khatama block, Jhabua

Nawapara block contained stromatolites as a field guide, while in the Dhanpura Khatama and Piploda block it is the chert which is phosphatic in nature. The mineralized zones in these blocks could be identified and delineated after the field test by Shapiro, s kit was done.

The Shapiro's kit and methodology of use: Shapiro and Brannock [12] developed a method of dissolving P_2O_5 content in dilute nitric acid so as to form yellow coloured molybdo-vanado phosphoric acid complex. The solution is prepared in the chemical lab by taking0.3 g. Ammonium meta benedate + 200 ml of distilled water +50 ml concentrated HNO_3 this is solution 1 , another solution is prepared by weighing 12.5 g. Ammonium molybdate + 100 ml of distilled water + 25 ml of NH_3 solution. This is solution 2. Now solution 2 is poured in to solution 1 and after stirring it gently it is made up to 500ml. This makes Shapiro's solution ready for use.

Once this solution is prepared in the lab some standards are made from the known concentration of 5, 10, 15, 20% of P_2O_5 .The sample with known concentrations are dissolved in the Shapiro's solution by taking 0.1gm of sample in a graduated test tube and 5ml of Shapiro solution and 10 ml of distilled water is added to the sample. Yellow precipitate results. The different concentration samples will have different intensity and varying opacity of the yellow precipitate. Standards of are kept ready in camp to compare and match the colour to estimate the P_2O_5 in then samples tested. These standards are changed/ replenished every 10 days to avoid variation in colour intensity due to evaporation.

The samples from field are powdered (-60 mesh) and 0.1 gm of sample is used (standard measurement was carried out at chemical laboratory and approximately same quantity was taken for all samples) with a plastic spatula and was put into the test tube. 5ml of the Shapiro's solution was added into test tube and shaken well for proper mixing. Double the amount of distilled water is to be used for diluting the solution. If the sample is positive for phosphate a yellow colour appears. The variation in intensities of yellow colour and its degree of opacity is directly proportional to the concentration of P_2O_5 in the rock. The darker yellow and opaque solution indicates more concentration of P_2O_5 then the lighter yellow transparent solution. The yellow coloured precipitate is known as molybdo-vanado phosphate. For random checking on site itself the graduated test tube and Shapiro' s solution is carried to the field and the rock is just powdered with the hammer and 0.1 gm of power is collected and tested as per standard procedure.

a. In field test of stromatolitic Limestone with Shapiro. S kit. The yellow colour suggests presence of P2O5.
b. Different intensity of yellow indicates varying percentages of P2O5 in the rock.

Fig. 8. Surface Geochemical evaluation of the ground

After exploring the local lithological variations and structure by detailed mapping, surface geochemical sampling was carried out on grid pattern, in Khatama, and piploda blocks by laying a baseline and sample lines across it. In Khatama block a strike length of 600m was covered by laying the channels across the exposed host lithology at every 100m interval along the strike with every sample being of 1 meter length. The background information about the area indicated chert to be phosphatic host hence systematic sampling was done in chert while thicker dolomite horizon was also sampled by random sampling. Samples were also taken from the dolomitic intercalations within chert to ascertain, whether these contain any P_2O_5 content. Apart from the channels at regular interval some trenches were also sampled to get additional information. The geochemical sampling in the block was helpful in delineating an anomalous zone of 130m X 10m in this block. Litho-geochemical map. (Fig. 9.) of the area is enclosed. The details of sample length, rock type and analytical results can be found in the reports of Geological survey of India of respective blocks.

The geochemical surface contours drawn manually are depicted in Fig. 10, while the potential area within the 1sq.km area in Piploda block (Fig. 11.) was delineated by using Shapiro's kit in field. A large number of samples from dolomite and almost all the chert bands and cherty dolomite horizons exposed in the mapped area of 1 sq.km, were tested in field, to zero down the target area for detailed sampling. A total of 7 channels and pits were laid in the area, the location of these sample lines have been plotted on the map. The sampling methodology remains the same as adopted in the Khatama block. The spacing of trenches / channels was not uniform in Piploda block due the forest department issues. The chert band testing positive for Phosphorite, with Shapiro's kit were only sampled. Some check samples and channels were put in the thicker silicified dolomite to explore the possibility of phosphate content in that, but it was observed that the siliceous dolomite with coarsely crystalline nature without stromatolite is not suitable for phosphatic mineralization. More than 345 numbers of samples were tested by Shapiro's kit after powdering them to -60 mesh, but finally 191 samples were analysed. The results of these samples along with details of sample length and lithology can be found in the reports if the reader is interested. The surface geochemical sampling in the area could delineate an area of 340mX50m dimension, as anomalous for phosphate mineralization. The surface geochemical map is depicted in Fig. 10.

The surface geochemical sampling in Kalikhet Nawapahar block was guided by the presence of stromatolites in the limestone at an interval of 200m across the strike. The surface geochemical profile was laid in the northern part of the mapped block covering three major and minor bands of dolomite and lime stone. The sample of 1m length each composite samples of 5 m each were drawn. Though the surface geochemical evaluation done was positive the analytical results of the the core samples do not indicate any phosphate present in the samples. All the values are below 1% P_2O_5.

Pitting and Trenching: Besides carrying out detailed surface sampling by means of putting channels within the host lithology, trenches and pits were also laid to expose the geology and to collect the fresh samples, where ever the soil and scree was thick in various blocks. The details of the channels including the sample length, type of sample and chemical analytical results of the samples are provided in the tabular form in the reports of GSI for various blocks, the same have not been included here.

Preparation of the surface geochemical maps/ delineation of Mineralized zone: This is significant here to mention that no contouring software was used here to draw geochemical contours of different P_2O_5 assays, but the contouring was done manually (Fig. 9 & 10). Once more this is to stress the fact that the basic techniques are still valid and can effectively be used to carry out exploration in the times of high-tech gadgets and techniques, with precise accuracy.

Borehole planning – The boreholes were planned perpendicular to the geochemical anomaly, which is guided by the host lithology as the mineralization is litho controlled. The azimuth was fixed perpendicular to the strike of the lithology /geochemical anomaly (Fig. 9 &10). The angle of the borehole was fixed so as to get the near perpendicular intersection to obtain true thickness of the mineralized zones. In Khatama block the dip of the enveloping surface was considered for fixing the angle of the borehole as there were local variations in the dip of the partings of chert and dolomite. Two boreholes each in Khatama, Piploda and Kachaldara blocks were drilled. Both the boreholes in Piploda and Khatama blocks were positive while the kachaldara block though the surface shows were encouraging because of presence of stromatolites but results were not encouraging. The resources for both the blocks i.e Khatama and Piploda were calculated and contribution towards the rock phosphate inventory of the country was made. Subsequently the blocks were auctioned also for exploration.

Petrography of the host rock- The thin section study of the host litho units suggest large scale recrystallization of the dolomite depicted by different grain size of dolomite, sugary texture in quartzite (Fig. 12,a&b) and post depositional intrusive quartz veins emplaced with in the dolomite and chert. (Fig. 12 e). The rocks of the area have suffered a green schist facies metamorphism evidenced by the occurrence of chlorite, epidote and sericite (Fig. 12d and 12F). The petrographic study suggests that the rocks of the area contain a syn-sedimentary mineralization of phosphate as depicted in Fig. 13. (Note the co-folded nature of the algal matter with the host lithology). Sulfide mineralization evidenced by occurrence of pyrite and chalcopyrite besides profuse circulation of hydrothermal ferruginous fluids, resulted in grain boundaries pervasion by the fluid (Fig. 14 A to D).

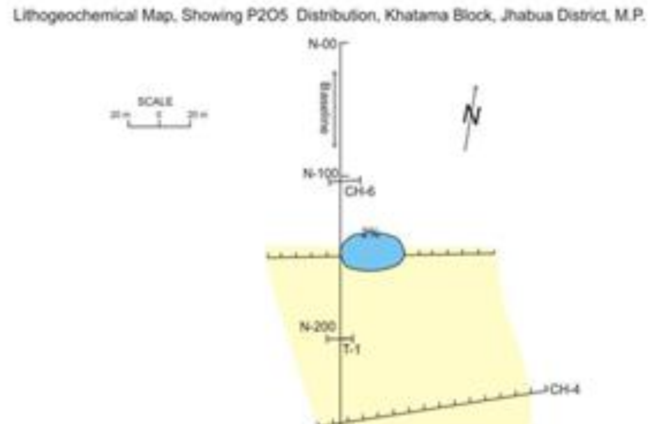

Fig 9.

Fig. 9. The detached and lensoid nature of geochemical anomaly, as could be seen here was confirmed in the subsurface drilling (depicted in Level plan Fig. 15.)

Fig. 10. The geochemical anomaly depicts consistency and continuity in assay values

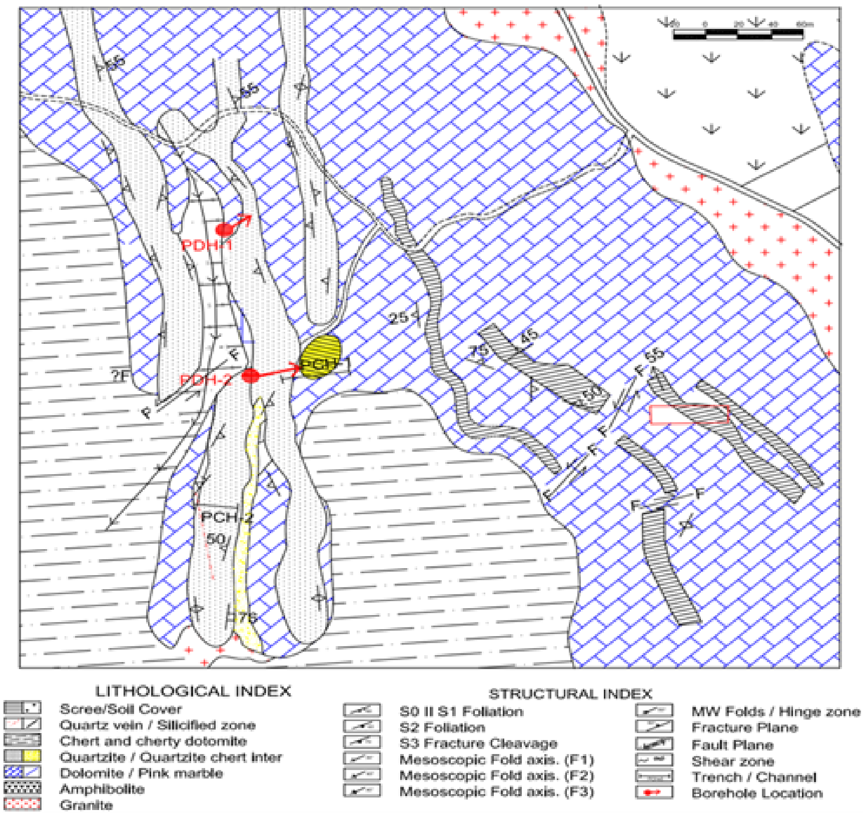

Fig. 11. Part of the Detailed Geological map of the Piploda block. [10] showing borehole locations in chert band. (The complete map could not be included because the area was large)

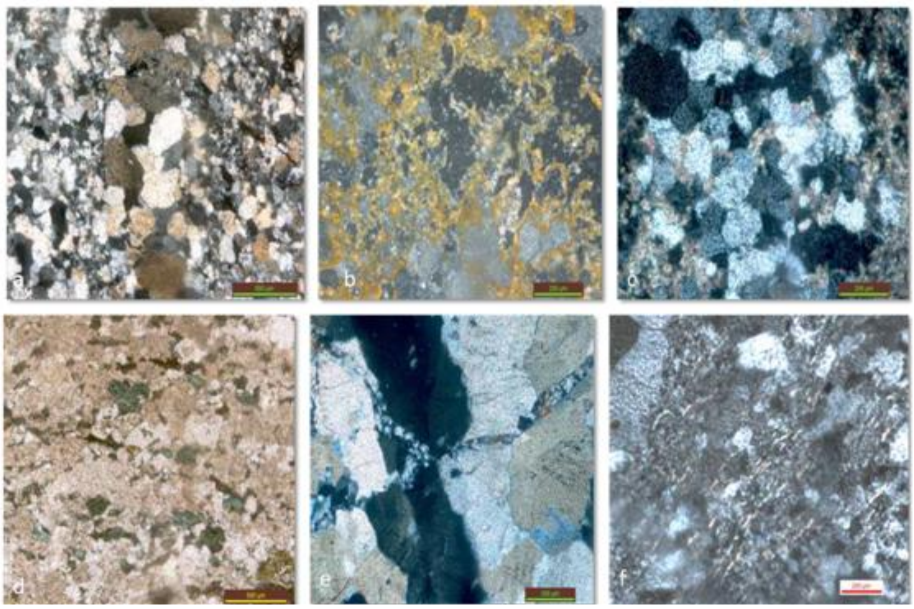

Fig. 12. Salient textural characters of various litho-units in the area

a. Different grain size in dolomite suggests recrystallization post deposition. (Under PPL). b. Profuse ferruginous fillings in Chert (Under CPL). c Sugary texture in Quartzite (Under CPL). d. Chlorite and Epidote clusters in dolomite (Under PPL), suggestive of green schist facies of metamorphism in the area. e. Microscopic shifting in the grain and fillings along the fracture plane suggests hydrothermal activity during metamorphism/ deformation (Under CPL). f. Sericitization in dolomite along the foliation plane might represent shearing. (Under CPL)

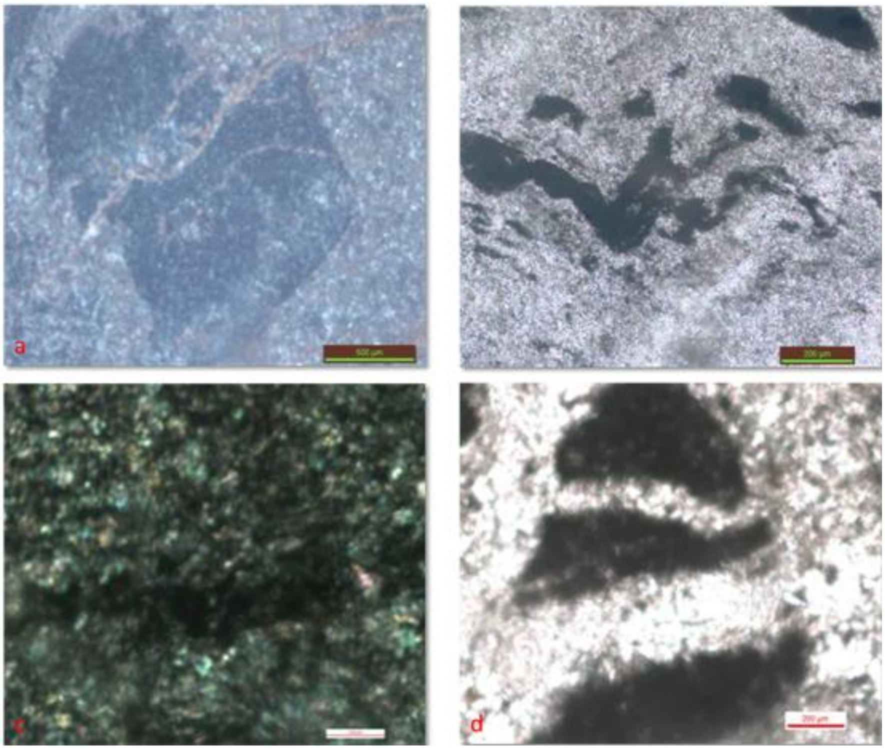

Fig. 13. Different mode of occurrence of algal matter in various host rocks.

a. Blocky fragments of algal matter in chert suggest fragmentation of the stromatolites on the tidal zone, (Under CPL). b. Beautifully folded algal matter strands suggest syn- genetic origin and alignment along the foliation of the same, (Under CPL). c. Alignment of Algal matter in dolomite along the foliation, (Under CPL). d. Partly aligned Algal grains in dolomite

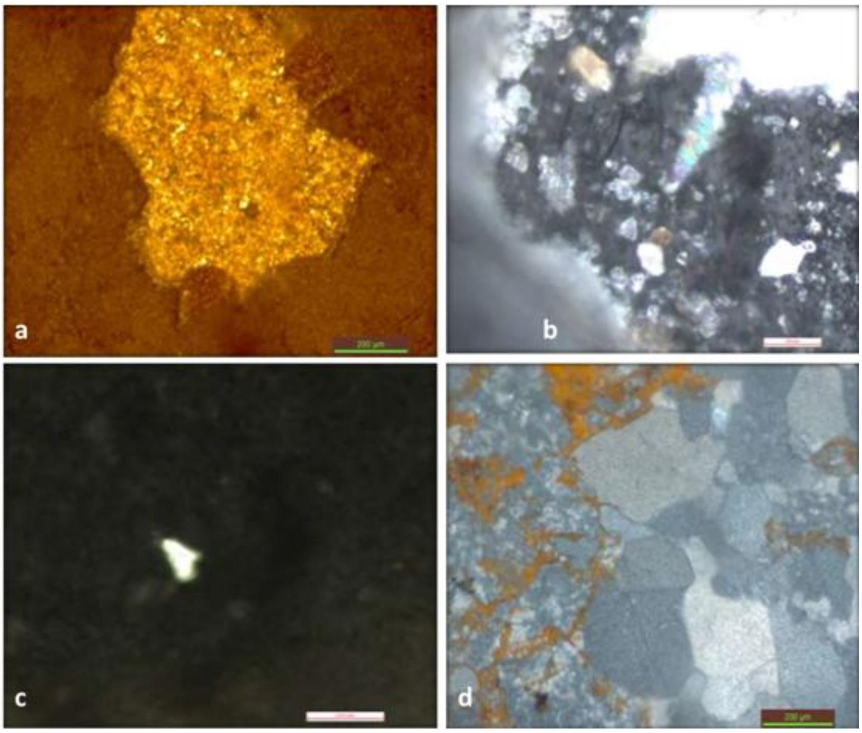

Fig. 14. Incidences of sulfide mineralization in the area

a. Pyrite grain with bold grain boundary in a quartz vein intruding the host rock, (Under PPL). b. Thin films of chalcopyrite with tarnishing and diffused grain boundary,(Under CPL). c. Solitary Chalcopyrite grain, (Under CPL). d. Circulation of ferruginous fluids along the grain boundaries in dolomite suggests mineralization by hydrothermal fluids in the area. (Under PPL)

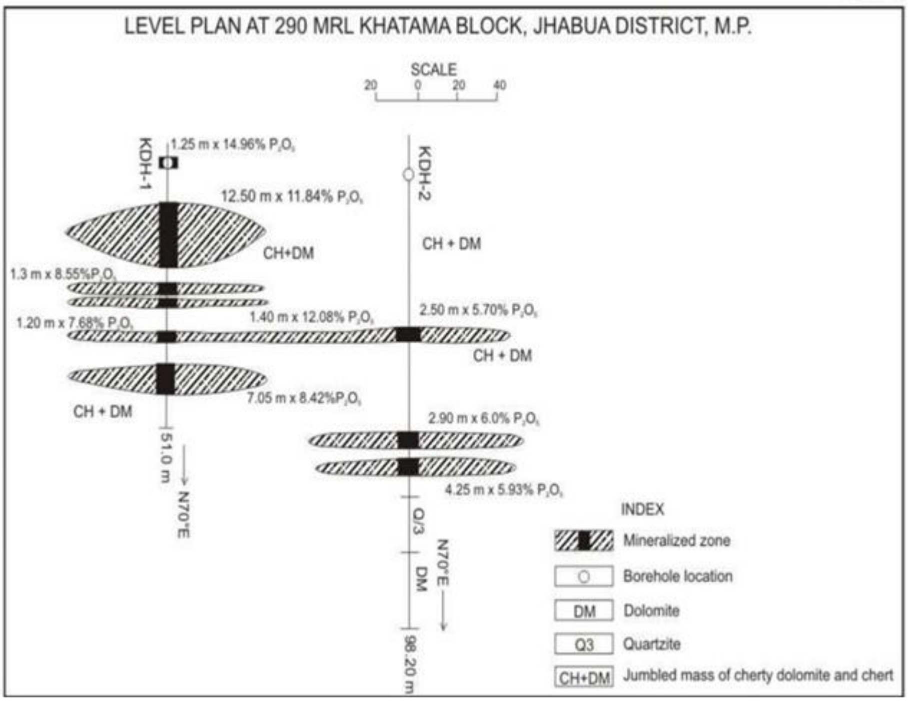

Fig. 15. Disposition of ore body in the Khatama block, based on the chemical analytical data, the lensoid nature of the phosphate zones suggests frequent facies variation in the chert during deposition

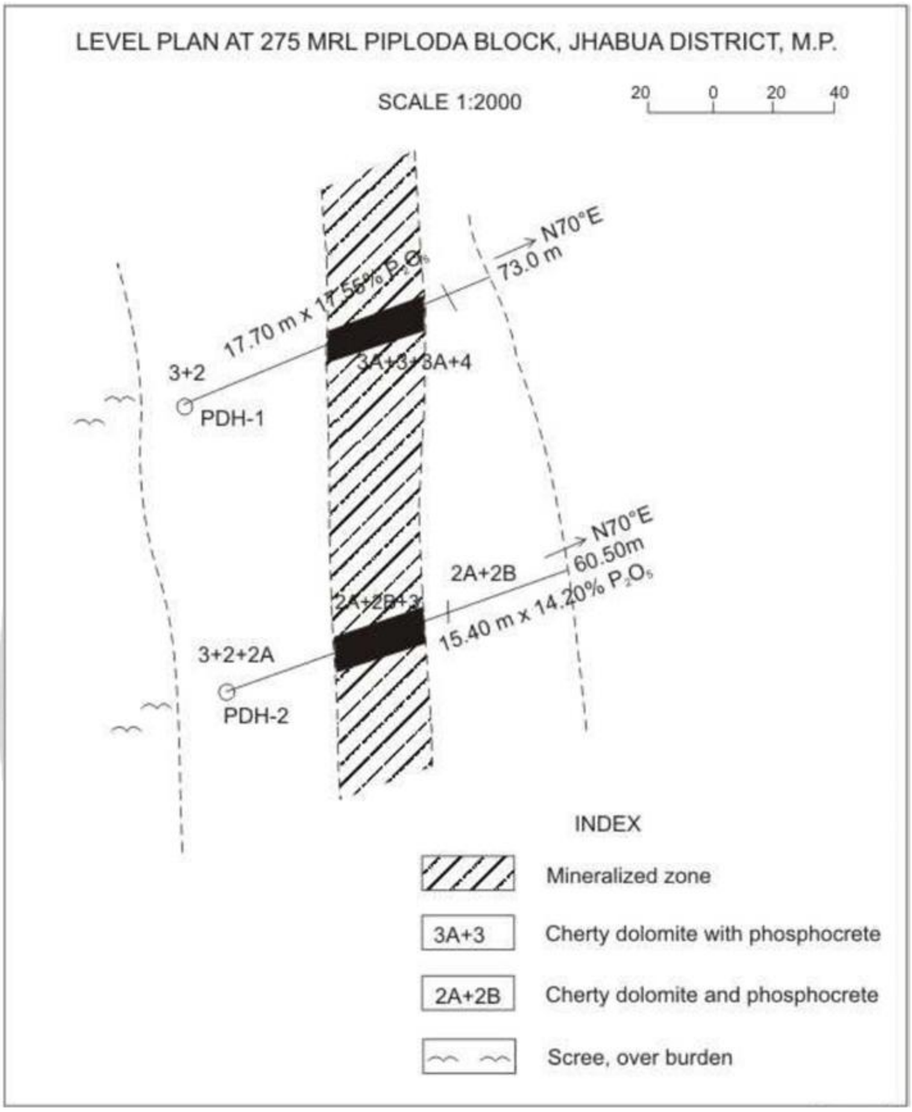

Fig. 16. The mineralized zone is more consistent and richer in P_2O_5 as compare to Khatama block, suggest stability of facies of deposition

Resources: Resources have been established in the area by using cross section method with the help of level plans prepared (Fig. 15 & 16) for both the areas which showed positive intersections.The level plans also demonstrate the shape of the ore body, which is lensoid in case of Khatama block (Fig. 15.), while is more tabular and consistent in Piploda block (Fig. 16.) This further can be interpreted that the Pioloda ore body represents the zone where there is consistent distribution of algal matter, while the Khatama ore body depicts that the deposit has more reworked stromatolite fragments which are irregular and scanty in distribution due to frequent change in depositional facies. Once again this is mentioned that the level plans have also been prepared manually [13,14].

2. CONCLUSION

The present case study has demonstrated very clearly that the conventional scheme of exploration of non-metallic as well as metallic minerals are still valid and can yield significant results if implemented systematically and meticulously. The use of software though it may help reduce the amount of effort required, cannot be a substitute for conventional exploration strategy.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Peer-review history:
The peer review history for this paper can be accessed here:
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