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The Sulphidic Ores and Their Metamorphism in Rajpura-Dariba Deposit, Rajasthan: Textural Evidences

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Abstract

Rajpura-Dariba Belt is one of the important lead zinc deposits of India and was rediscovered on the basis of the large scale gossan present in the area. The belt has suffered regional metamorphism. The ores along with the host rocks have been metamorphosed to a middle to higher grade amphibolite facies along with the host rocks at an ambient temperature of ~ 550°C and pressure of ~ 5.4 kbar. Main ore minerals present in the deposit are sphalerite, pyrite, pyrrhotite and galena which are mainly concentrated along two lodes, hosted by calc-silicate dolomite and graphite mica schist. The ore reserve was estimated at ~ 20 × 106 tons grading 6-7% Zn + Pb. Cu and Ag also occur at economic concentration. Textures representing deformation, metamorphism and replacement are well reflected in the ores. Petrographic study depicts that the ores and host rocks have been metamorphosed.

Keywords: Sulphidic Ores, Deformation, Metamorphism, Amphibolite, Textures.

Introduction

Rajasthan is unique and have a fascinating geology with rocks ranging in age from one of the oldest feature (morethan 3,500 million years) to recent, displaying a wide range of rocks and mineral deposits (both metallic and non-metmetallic). Many stratiform base metals deposits are distributed in the Proterozoic Aravalli-Delhi orogenic belt which are commercially viable in India. The largest ore deposit amounting to 607.53 Million tonnes is endowed in Rajasthan. These include the important mines of the Rampura-Agucha, Rajpura-Dariba and Zawar.

The Rajpura-Dariba-Bethumni belt which forms a part of Bhilwara plateau is located at about 125 km from the Zawar mine and 88 km from Udaipur. The area is included in the Survey of India Toposheet No. 45 L/l. The ancient mines are located in a series of north-south trending low ridges extending from Dariba (24°57':74º08') to Rajpura (24°59: 74º08'). The work is mainly confined to random sampling of rocks both from surface exposures(Fig.1) as well as underground mines and their textural study. Ore mineralisation have taken place in "pull-apart basin". A unique gossan hill is present over the massive Pb-Zn deposits. The area have undergone at least three phases of deformation and the last deformational phase is responsible for the regional crescent shaped structure. The Rajpura-Dariba Belt have undergone an isofacial metamorphism of medium to high grade amphibolite facies. Calc – silicate dolomite and Graphite mica schist of Rajpura – Dariba group are the main host rocks for the sulphide ore bodies. The ore bodies in Dariba are blanket to lensoid shaped and are conformable with the host rocks. Dariba main lode shows clear vertical zonation from Cu in the footwall through Pb-Zn in the middle to Fe in the hanging wall. This work involved the study of ore petrography as well with thin section petrography. Primary sedimentary fabric is evident in the rocks by the occurrence of conformable layers of sphalerite, pyrite and occasionally galena interbedded with the host rocks. The ore minerals reflects both effects of deformation as well as metamorphism. Textures indicating deformation and metamorphism are well acquainted by replacement textures. The sulphide ores show sedimentary diagenetic features, overprinted by later deformational structures. Evidence of deformation is well reflected in both the ores and the silicates.

Aim of the Study

How did the ores behave due to metamorphism? What are the imprints of metamorphism preserved? What has been the behaviour of the ore minerals during the phase of metamorphism? Are there any relict features preserved in ore minerals as well as in the host rocks? Are there any evidences of metamorphism in the ores to conclude that they have also been metamorphosed? What are the changes, textural and mineralogical took place due to metamorphism? Is there any compatibility in records of metamorphism between the ores and the gangue minerals? How the ores equilibrated with the silicates during and after metamorphism? Did there any new mineral formed because of ore-gangue equilibration? What are the changes in chemical composition of ore minerals as well as silicate assemblages?

These are the possible questions that haunt me to get involve myself to the Rajpura-Dariba deposit. I have tried my best to answer at least some of the questions mentioned above.

Review of literature

The geological details of the area and adjoining parts are studied by several workers basically for establishing the lithostratigraphy. Heron (1917a, 1923) classified the rocks of the Delhi ‘System’ on the basis of lithology into the Alwar ‘Series’ and the Ajabgarh ‘Series’. Both open cast and underground methods of mining are carried out for many centuries. The occurrence of the deposits was realized in 1934 with the help of gossan zones in the southern part, ancient workings, heaps of mine debris and slag which serve as guides to sulphide mineralization in this belt. The systematic exploration of the belt was initiated by Geological Survey of India (GSI) in 1962 at the southern end of the belt. Jhanwar et al (1969) in the southeast area of Nim ka Thana, reported a few old workings which were assumed to be for copper. Ore forming processes of sulphides and their relationship with volcano-sedimentary succession have been studied in Sindesar Khurd, Rajpura Dariba belt, Rajsamand District, Rajasthan by Chaudhary et. al. (1984), Nair and Agarwal (1976),Chauhan (1977), Mishra (2000), Misra and Mookerjee (1986), Yadav and Sharma (1989), Deb and Pal (2004).

Sampling

The samples were collected from the country rock at a distance from the ore body(Fig.1). A sample map has been prepared in the field (Fig. 1). The samples of host rocks and ores were collected from the ore-mine and from the mine-dump. Excluding the samples of the country rocks all together fiftytwo (52) samples of host-rocks and ores were collected. Thirtythree(33) samples were collected from the mine and . the rest nineteen(19) were collected from mine-dump.

Methodology

Thin section slides and polish section blocks of different samples were made out in the department. Etching methods were administered to study the ore petrography in intricate detail. Different etchants were applied for different ore minerals through trial and error methods. Etchants such as thio-urea, dilute hydrochloric acid, dilute and concentrated chromic acid, concentrated nitric acid were applied. However, most successful was the application of chromic acid, both dilute and concentrated. Photomicrographs were taken in the department by the camera, model ‘NIKON ECLIPSE E200MV POLE’.

Regional geology

The Aravalli-Delhi Proterozoic belt is 30-200 km wide and extends in a NNE-SSW direction for about 700 km, covers the Aravalli mountain ranges from Palanpur in northern Gujarat to Delhi and the adjoining parts of the eastern Mewar region and parts of the western Marwar region of Rajasthan(Fig.2). The sedimentary supracrustals rocks consists of two main cratonic blocks of BGC and the Sarara inlier, wrapped by several lineaments (Deb, 1989, Ramakrishnan & Vaidyanadhan, 2008).

Aravalli craton is divided into some tectono-stratigraphic categories (Ramakrishnan & Vaidyanadhan, 2008). From older to younger they are as follows (Fig.2):

1. Archaean Mewar Gneiss with Ancient Supracrustal Enclaves
2. Bhilwara Supergroup consisting of Hindoli Group, Mangalwar Complex and Sandmata Complex.
3. Mineralised Supracrustals Belts of Rajpura-Dariba, Pur-Banera, etc.
4. Aravalli-Delhi Orogen
5. Neoproterozoic Basins

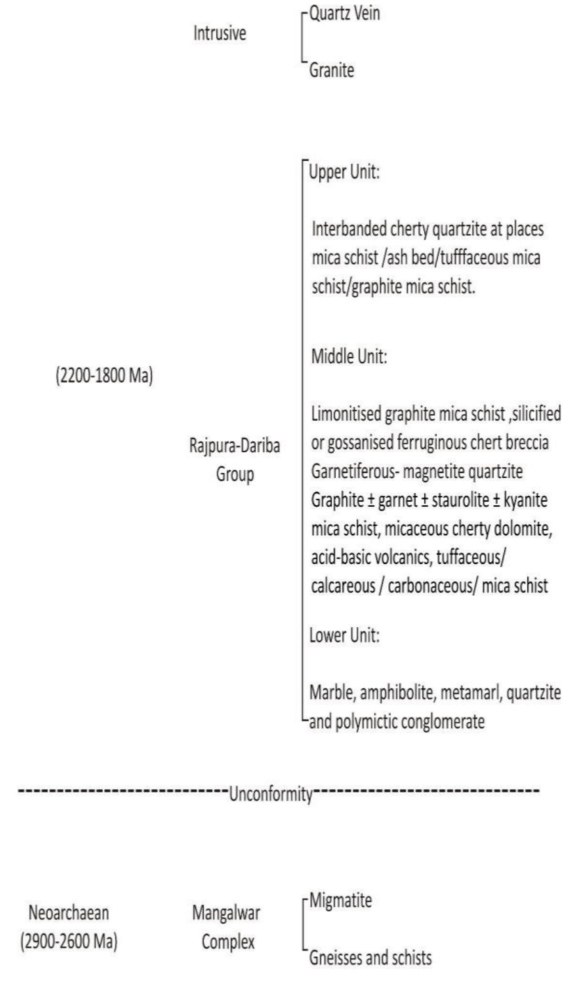
Mewar Gneiss which was considered as Banded Gneissic Complex (BGC) by Heron (1953), forms the basement to Aravalli Supergroup and consists of the migmatites and gneisses of Lasaria Formation of Mangalwar Complex. Gupta (1934) considered those gneisses that form clear basement to Aravalli Supergroup as BGC-I or BGC (south) and those that are reworked extensively during later deformational events as BGC-II or BGC (north). BGC-I roughly corresponds to the Mewar Gneiss of Roy (1988). Mewar Gneiss consists of three principal components as follows-(i) basement tonalite-trondhjemite- granodiorite (TTG) gneisses, (ii) basement granitoids including the TTG gneisses (e.g., Untala and Gingla granites), (iii) basement granitoids occurring as inliers within the Aravalli Fold Belt (e.g., Sarara, Mando and Ahar River granites).

GSI proposed a classification of the Bhilwara Supergroup and included both Achaean and Lower Proterozoic components. The carbonate bearing volcano-sedimentary sequences exposed in the linear mineralised belts of Bhilwara Province are considered of Lower Proterozoic age based on recent evidences. Mangalwar Complex consists of the vast stretch of varied gneisses occurring between the Banas Lineament which bounds the Hindoli belt in the east and the Delwara Lineament which bounds the Sandmata Complex in the west. The complex is again divided into Lasaria, Potla, Suwana and Kekri Formations by Gupta et. al. (1997).

Proterozoic rocks in the Bhilwara Province Overlying the Hindoli Group of rocks and Manglwar Complex with an unconformity occur the next younger groups of rocks classified as the Rajpura- Dariba, Pur-Banera, Jahazpur and Sawar Groups which are exposed in a series of isolated linear belts. The important lead-zinc deposits of India include Rampura-

Agucha and Pur-Banera (Bhilwara district), Rajpura-Dariba-Bethumni and Sindesar (Rajsamand district), Zawar (Udaipur district), Sawar and Kayar-Ghugra (Ajmer district), Basantgarh and Dehri (Sirohi district) in Rajasthan. The mineralized zone under discussion is a part of the metasedimentary zones lying within Bhilwara supracrustal belt, which overlies the basement of the Archean Banded Gneiss Complex in Rajasthan. The linear belts at Jahazpur, Sawar, Rampura-Agucha, Pur-Banera and Dariba-Rajpura-Bethumni consists sediments of carbonate- sand-shale facies associated with euxinic black shales, stratiform Pb-Zn sulphides with felsic tuffs in some areas. However, there is a doubt regarding the contemporaneity of the Jahazpur belt in the east. Sinha-Roy in 1984 considered the individual mineralized zones as 'pull-apart' basins that developed along strike-slip faults during the Aravalli orogeny. The confinement of the zone along a NE-SW direction, presence of linear oxide zones, sulphide facies of iron-rich exhalative rocks and sporadic occurrences of mafic bodies with N-MORB chemistry, deciphered near Agucha (Deb, 1992), bear evidences of intracontinental rift related development of the Bhilwara metasedimentary basin. Rifting of the basement rocks within the linear belts developed a series of half-grabens in which the volcano-sedimentary supracrustal rocks were deposited in linear zones. Later on, some of these individual linear zones became sites for the exhalation of metal-rich fluids, including the Dariba-Rajpura belt. Presumably the rifting has ensued through the developed closely spaced fractures. Movement along these fractures resulted in considerable tilting of the blocks with respect to the rift axis and cause basement slices to intervene between adjacent supracrustal rocks (Deb and Pal, 2004, Ramakrishnan and Vaidyanadhan, 2008, Sarkar and Gupta, 2012, Deb, 1986).

Rajpura-Dariba Group is a crescent-shaped NNE-SSW belt (Fig.3) extends from Bharak in the north to Dariba in the south which unconformably overlies garnet-staurolite-mica shist, feldspathic schist, gneisses and migmatites belonging to the Mangalwar Complex of Archaean age with a major unconformity. The rocks at South of Dariba closure, extend in west up to Gavardi. The unconformable relation with the underlying Lasaria Formation of the Mangalwar Complex and the overlying Rajpura-Dariba Group of rocks, is clearly seen here. The Mangalwar Complex is exposed on either side of the metasedimentary cover at Rajpura-Dariba. Rajpura-Dariba Group of rocks has been further sub-divided into Lower, Middle and Upper units and consists of basal conglomerate and quartzite, dolomitic marble with amphibolite bands, calc-silicate rock, carbonaceous and argillaceous schist (tuffaceous containing-graphite-garnet-staurolite-kyanite-chloritoid), calcareous schist and interbanded ferruginous and manganiferous cherts. The rocks are metamorphosed to medium grade amphibolite facies and are flanked by a thick monotonous sequence of meta-argillites. Synsedimentary Pb-Zn-Cu mineralisation is prominent in this belt. The Group has been further subdivided into the Bhinder, Malikhera, Dariba, Sindesar and Satdudhia Formations. The Rajpura-Dariba belt was designated as the western limb of Banera-Bhinder synform. The overall map pattern of the belt is crescent shaped and extends over 19 km in North-South direction which represents a regional synform with a closure situated to the south of Dariba and the fold limbs continue in the North. The synformal closure exhibits a steeply plunging axis of 55°-60° towards ENE. The regional trend of the formations varies from north-south between Dariba and Rajpura in the south, to N15°E-S15°W between Sindesar Khurd and Sindesar Kalan in the middle, and finally to N50°E-S50°W around Bethumni in the north. The rocks are generally moderate to steeply dipping towards ESE and bear evidences of at least three phases of deformation. The first phase folds (F1) are rare, tightly appressed, symmetrical and overturned and the axial trace trends NE to SSW. Folds of F2 phase are co-axial to F1 and have NNE to SSW axes. They are asymmetrical, tight to open with easterly dipping axial planes. The limbs are steeply dipping with shorter length and are Z-type folds. The regional synformal structure with NNE to SSW axial trace and overturned eastern limb belongs to this second deformational phase. The F3 folds are large and open with WNW to ESE axes, and caused the crescent shape of the regional structure. East-west trending small faults are noted in the belt. The most prominent one is a regional dextral strike-slip fault which transects the southern end of the belt. And is thought to be an eastward extension of the Banas dislocation zone . Four sets of joints are noted . The most conspicuous and penetrative set trends N 20°-40° W and dips 25°-30° towards southwest . Zircon Pb -Pb dates suggest a range of ~2350 to 1800 Ma, for the ages of the source and mobilisation of ores (Deb and Pal, 2004, Sarkar and Gupta, 2012, Ramakrishnan and Vaidyanadhan, 2008).



	Intrusive	Quartz Vein Granite
(2200-1800 Ma)	Rajpura-Dariba Group	Upper Unit: Interbanded cherty quartzite at places mica schist /ash bed/tufffaceous mica schist/graphite mica schist.
		Middle Unit: Limonitised graphite mica schist ,silicified or gossanised ferruginous chert breccia Garnetiferous- magnetite quartzite Graphite ± garnet ± staurolite ± kyanite mica schist, micaceous cherty dolomite, acid-basic volcanics, tuffaceous/ calcareous / carbonaceous/ mica schist
		Lower Unit: Marble, amphibolite, metamarl, quartzite and polymictic conglomerate
---------------------------Unconformity-----------------------------		
Neoarchaean (2900-2600 Ma)	Mangalwar Complex	Migmatite Gneisses and schists

Table 1. Generalized stratigraphy of the study area (Alam et al., 2015 and Yadav, 2015)

Host rocks and the country rocks

The Geological Survey of India, in collaboration with Hindustan Zinc Limited, have declared the Rajpura-Dariba Gossan as National Gossan Monument because of its unique nature and its educative value to the students of earth sciences as a type area for study of oxidized ores.This gossan zone was recognized as the principal guide and indicator of base metal mineralisation in the area and eventually led to the re-discovery and detailed exploration of the Rajpura - Dariba mineralized belt by the Geological Survey of India. The exploration brought to light two ore bodies designated as ‘Dariba main lode’ and ‘Dariba east lode’ carrying reserves of about 11.57 million tonnes (proved), 12.665 million tonnes (probable) and 27.00 million tonnes (possible) ore, averaging 5.5% zinc and 1.2 % lead at a cut off of 3 % (Zn + Pb).

The Rajpura-Dariba mine area is predominantly constituted of metasedimentary rocks. from footwall to hanging wall of Dariba main lode they are recrystallized dolomitic marble, metamarl with bands of amphibolite (probably mafic sills), calcareous biotite schist, recrystallized siliceous dolostone, quartzite interbedded with chert bands, calc-silicate rocks and (graphite)- mica schist with garnet, staurolite and less commonly, kyanite porphyroblasts, grading to a calcareous biotite schist. . Calc– silicate dolomite and Graphite mica schist of Rajpura – Dariba group are the main host rocks for the sulphide ore bodies, shows contact with the calcareous biotite schist in the footwall and grades to pure quartzite at places. Intercalations of host rocks with black chert-sulphide rhythmites in specific zones are present.. Deb and Kumar (1982) first described that the graphite mica schist contain metamorphosed water-lain tuff bands. A 2-10 m wide barren part of meta-basic dykes is present in the middle of the Dariba main lode. A thin-ferruginous-siliceous breccia layer in contact with the gossan can be found to the south of footwall side of the Dariba lode. This layer is 150m wide which extends northwards into the major sites of concentration for the Sulphide lodes are the hinges of F2 folds.

The richer lodes are hosted by marble and mica schist but the felsic volcanics also contain appreciable Zn and Pb sulphides. Minerals in the marble are pyrrhotite, sphalerite and galena with minor pyrite and arsenopyrite. The major mineralization of zinc in the form of sphalerite associated with some pyrite and occasionally galena is usually confined to the banded quartzite-cherts. Dolomitic marble and the calc-silicate rocks mainly contain chalcopyrite and galena with occasionally some sphalerite. Graphitic mica schist and kyanite- staurolite schist mostly contain pyrite with some sphalerite. Banded quartzite-cherts, dolomitic marble, calc-silicate rocks, graphitic mica schist and kyanite-staurolite schist are the principal host rocks in the deposit. The pelitic metasediments in the area are characterized by biotite, muscovite, sericite, chlorite, quartz, garnet, epidote, kyanite, and staurolite. The carbonate metasediments are represented by the mineral assemblages of calcite, tremolite, dolomite, diopside, plagioclase and quartz. Sometimes barite and fluorite are also present in the carbonate metasediments (Chauhan, 1977, Yadav and Avadich, 2014).

Findings

The ore Body and the Ores

Four orebodies numbered one to four are distributed in six prominent well-defined blocks with varying average width from few metres to 34 metres extending along strike up to 900m. The Geological Survey of India continued exploration and identified other large, sub-economic graphitic schists hosted deposits at Sindesar Kalan (94 Mt with 0.6% Pb, 2.1% Zn) and Mokhanpura (63 Mt with 0.7% Pb, 2.2% Zn) areas. The total resource of the belt is around 261Mt grading 3-4% Pb+Zn or 45 Mt of 2.4% Pb and 6.5% Zn. The ore reserves or resources of the Dariba main lode which is at the southern end of the belt are estimated to be about 18 Mt grading 2.1% Pb, 7.9% Zn and 90-100 gm/t of Ag. The Dariba east lode has a potential of 6 Mt with 1.3% Pb and 6.9% Zn. The estimated probable reserves of in situ gossan, to a depth of 40-50 m, developed over Rajpura-Dariba ore bodies was estimated at 31.82 Mt, analysing up to 1.2% Zn, 0.4% Pb, 0.27% Cu, 200 ppm Ag, 500 ppm Hg, 1000 ppm Sb and As, and less than 0.5gm/t Au.

Two distinct blanket to lensoid ore bodies present at Dariba are conformable to the host rocks within a narrow stratigraphic horizon at Dariba (Fig.4.). The ore body corresponding to the gossan at the crest of Dariba hill in Dariba 'A' block is called the Dariba main lode. It is 1-47 m wide. The Dariba Main Lode or South Lode, the larger and economically more important of the two has a lenticular outline and tapers northward and extends over a strike length of 3.7 km. the occurrence of the ore body is typically stratiform though some discordant veins due to remobilization are also present. This lode shows clear well-defined mineralogical, compositional, and morphological zoning. Chalcopyrite is the predominant mineral in the footwall (Cu zone) along with minor galena and sphalerite within the recrystallized dolostone as stringers, irregular massive patches, and rarely as conformable layers, and has a mosaic texture with occasional subhedra of pyrite and aggregates of pyrrhotite and sphalerite, wormlike mackinawite, and rare blades of cubanite. The previous one is followed by a Pb-Zn zone in the same rock type and the contact between the two zones being diffused. Galena, sphalerite, and pyrite are the predominant minerals with minor chalcopyrite and sporadic patches of massive tennantite in this zone. A Fe-rich zone follows through a sharp contact. This zone is hosted by graphitic schists and is characterized by pyrite-rich, and less commonly by pyrrhotite-rich bands (Deb, 1986). The East Lode is highly pyritic (Sarkar and Gupta, 2012).

The presence of folds, foliation and other deformational characteristics of the primary structures such as pinching of quartz veins marks the effect of deformation during regional metamorphism.

The common mineral assemblages in the ores as opaque phases are sphalerite, pyrite, pyrrhotite and galena in order of decreasing abundances. We begin our discussion successively with the most abundantly occurring ore minerals to the least.

Sphalerite commonly occurs as irregularly shaped grains with pointed angular ends. Sphalerite crystals, with discernable twinning possess a polycrystalline internal texture. Both growth twin lamellae which is confined to a single grain and deformation twin lamellae passing through adjacent grains are observed. Etched surfaces of sphalerite show granoblastic- polygonal texture. Wide variation in grain size is very well noticed within short limits of microscopic scale which is apparently constrained by recrystallization due to deformation (Fig.5). The illustration behind the occurrence of smaller grains and larger grains together can be that, some of the smaller grains have recovered their strain to form larger grains while most of them are not. Due to the presence of soft mineral such as sphalerite and gangue minerals in the interstices kinking of twin lamellae due to deformation, is also observed (Fig. 6). Bending of twin lamellae in sphalerite adjacent to the silicate gangues may be an effect of rheological contrast between the two. Preferred morphological orientation of sphalerite and pyrite can be systematically related to the preferred orientation of quartz, calcite, and micas in the schistosity plane of the host rocks as the rocks have undergone intense deformation. Dominant effect of cataclastic deformation include' healed' breccias and fractures are often found in layered sphalerite quartzite- chert. Sphalerite and galena being amenable to stresses appears to be mobilized from the matrix into the fractures and have replaced to varying degrees, not only the fracture walls, but the outer edges of the pyrite grains and recrystallized in the newly formed spaces between the fragmented layers in such structures. They have moved along the cleavage planes and occupy pressure shadow areas around the harder sulphides (pyrite) (Fig.7). Softer sulphides; sphalerite are annealed and generally developed equilibrium texture due to metamorphism. Large sphalerite grains are resorbed at the expense of smaller ones in a single photographic view. Another interesting feature is the presence of small sphalerite grains within the matrix of the same mineral. The host and the guest grains are only partially co-herent, or are apparent under the microscope as a result of fast growth. Replacement is also another phenomena that results from metamorphism. Sphalerite have moved from the matrix into the fractures and show heavy replacive relations to varying degrees to the cataclastically deformed metablastic pyrite. Reaction relationship is also found to occur between sphalerite and galena.

The pyrite assumes a euhedral, usually cubical shape. The pyrite in Dariba is characterized by non-framboidal pyrite as the dominating form. Large elongated crystals of pyrite are often found (Fig.8). Massive pyritic bodies because of the hardness and brittleness of the pyrite underwent metablastic growth, display considerable amounts of cataclasis under dynamic metamorphism (Fig.7). Bands of equigranular pyrite occur in massive sphalerite. Porphyroblasts of pyrite tend to have elongated parallel to the deformation direction (Fig.8). Pyrite porphyroblasts within a matrix of sphalerite, galena and gangue is a very common feature so observed. Euhedral pyrite grains without having any reaction relationship with galena seems to float in matrix of galena. The fracture- infillings and eventual replacement in metablastic, often porphyroblastic pyrite suggest that the mobilisation processes must have taken place during or subsequent to the prograde phase of metamorphism in which the metablasts formed. Fracturing is considered to have occurred during continuing movements affecting the whole sulphide mass, and at the prevailing temperature the mass have deformed in a ductile or plastic manner.

Pyrrhotite being less refractory in nature exhibits annealing texture through development of triple junctions of monomineralic aggregates. However the triple junctions have opened up during deformation and the space is then filled up by sphalerite. Pyrrhotite grains show triple junction and equilibrium texture with interstices occupied by sphalerite.

Galena shows high reflectance and a network of triangular pits. Galena is typically present as cusps oriented in a particular direction in a sphalerite groundmass (Fig.9). Curved cleavage traces from the recrystallized galena results from late stage deformation. Galena in the conformable layers occurs either as small elongated grains or aggregates of elongated grains often with smooth outlines. The corrugated boundary in galena, seems that galena have replaced sphalerite along the grain boundaries. Martensitic lamellae is generally considered to form at a later stage. Here, it occurs as thin lath shaped or spindle shaped tapering lamellae, often curved themselves and occupying some part of galena. These structures are abundant in galena, but require etching to be made readily visible (Fig.10).

Textural relationships of the ore minerals with the silicates are equally interesting as we shall see later, important in the interpretation of evolution of the ores. The mineralogical and textural relationships of the metamorphic minerals of the host rocks demonstrate interesting relationships.

First of all, we refer to the occurrence of ore minerals within and at the interstices of gangue minerals suggesting that the ore minerals co-existed with these minerals. Mutual grain boundary adjustment between galena and gangue minerals are commonly visible. Graphite grains are kinked and broken apart due to deformation (Fig. 11). Euhedral shaped pyrite mineral embedded within the matrix of quartz in siliceous dolostone with no hydrous minerals occurring nearby (Fig.12). Sphalerite grains occurring within the interstices of clinopyroxene (Fig.13). Sphalerite are found as small grains that appear to be protruding in the adjacent boundaries of the clinopyroxene grains. This suggests their arrested growth within the matrix of silicates. Alignment of sulphide grains along with kyanite, muscovite and graphite was observed. Sulphide grains embedded within a matrix of blades and needles of kyanite suggests that kyanite has still higher force of crystallization than sulphides (Fig.14). Sulphides replacing deformed calcite or dolomitic grains indicate the post-deformation replacement. In some cases, silicate minerals also show inclusion of sulphide minerals (Fig.13). Another feature is the intricate network structure of gangue minerals and ore minerals where polygonised quartz grains, biotite, ore minerals and graphite grains are making a 3-dimensional network structure (Fig.15). Somewhere allignment of small blebs of ore minerals along with the gangue minerals are present in a fine grained rock (Fig.16).

Veinlets of ore into the individual silicate grains and their aggregation constitute another interesting feature under the microscope. Complex network formed by criss-cross quartz rich veinlets are common in the rocks. However, many of the veinlets exhibits parallelism. Ore veins displaying minor folds are present and is cross cut by veinlets of quartz, probably a result of deformation. Minute grains of ore minerals occur as parallel bands within the recrystallized siliceous dolostone. This suggests that the intrusion of quartz veins is a very latter phenomenon that took place after the deformation and recrystallization of the host rocks as well as the ore minerals. Under the microscope this veinlets show that they are dominantly constituted of sphalerite and are made up of recrystallized ore minerals. In most of the cases, they are likely to have been emplaced by plastic flowage during a tectonothermal event. This is a case of dynamic recrystallization. However, very thin veinlets controlled by micro fracture in individual minerals are supposed to be formed by secondary hydrothermal fluids may be generated during retrogressive phase. In some cases, ore minerals make banding within dolostones and they are supposed to be primary banding that remained intact even after metamorphism.

Disscussion & Conclusion

Production of elongation effects, chaotic folding and foliation development, together with flowage structures and ductile injections of sulphides, coarse-grained sulphide fabrics are characteristic of deformation in high-grade metamorphic environments. Later events result in preferred orientations, kinking and related evidence of crystal-plastic behaviour of the minerals.

The sulphide minerals which were studied reflect overprinting effects of deformation as well as metamorphism and show recrystallization. Minerals deform plastically under the influence of thermal energy and differential stress. Stress and deformation are two accompanying processes and deformational effects are quite observable in the rocks. Straining within the crystals modifies the grain boundary and increases the imperfection density. When the rocks are subjected to stress beyond its plastic limit, fracturing or plastic deformation of rocks occur. Both inter- and intra- granular adjustments occur as a result of plastic deformation of the rocks. Generally, sulphides are more reactive and thus respond more readily to deformation than silicates. There is a great competency differences between sulphide and silicate rocks, so sulphide rocks will undergo more flow relative to silicate rocks during deformation. The response to deformation among sulphides decreases in order galena, sphalerite and pyrite. Sulphides which easily gets deformed, sometimes intrude along the grain boundaries. Difference in degree of deformation is reflected from the variation in grain size of metamorphosed ore zone.

Martensitic transformations are diffusionless transformation, caused by change in crystal structure into another one and is being achieved by deformation of the parent phase. In order to avoid the enormous strains caused by deformation the martensite either slips or undergoes transformation twinning. In martensitic plate, not only a new orientation produces, but also a basically different crystal structure forms. The parent phase are realigned as new crystal lattices. This transformation involves relative atomic motion by smaller amounts than the interatomic spacing, and exhibits a lattice correspondence between the parent and product structures. The martensitic structures formed in galena are the product of thermotectonic perturbations, could not be depicted in other ore minerals. The ore bodies and ore minerals are deformed and metamorphosed.The ore minerals reflects both effects of deformation as well as metamorphism. Textures indicating deformation and metamorphism are well acquainted by replacement textures. Evidence of deformation and metamophism is well reflected in both the ores and the silicates.

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Fig. 1 A Sample-Location Map of the Area

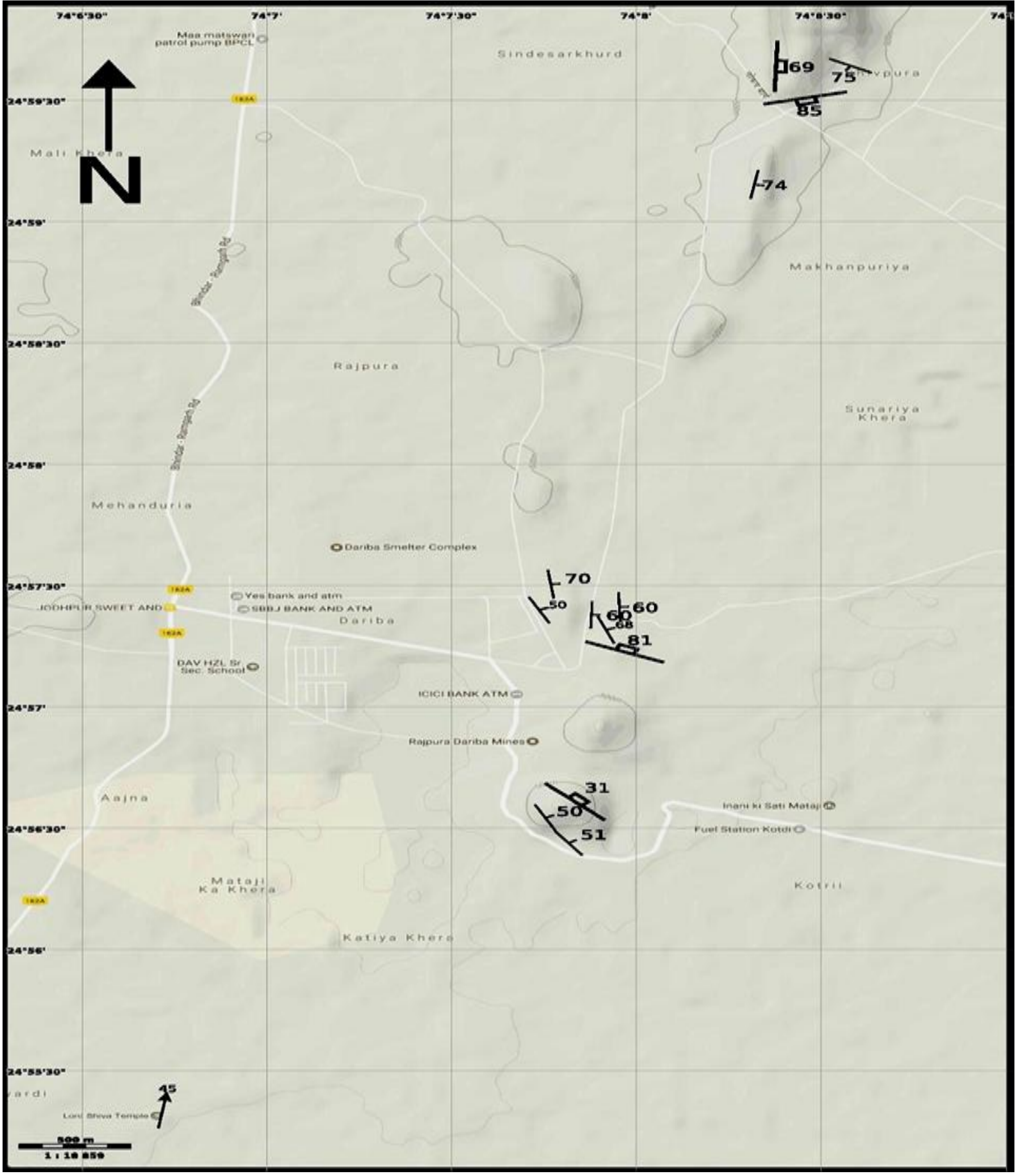

Fig. 2 Geological map showing distribution of major straigraphic units of the Aravalli craton. A-Alwar, BL- Bhilwara, Bw-Beawar, M-Mangalwar, N-Nathdwara, P-Pisangan, PH- Phulad, RA-Rampura-Agucha, RD- Rajpura-Dariba, S- Salumbar, SR- Sarara, Z- Zawar (after Ramakrishnan and Vaidyanadhan, 2008)

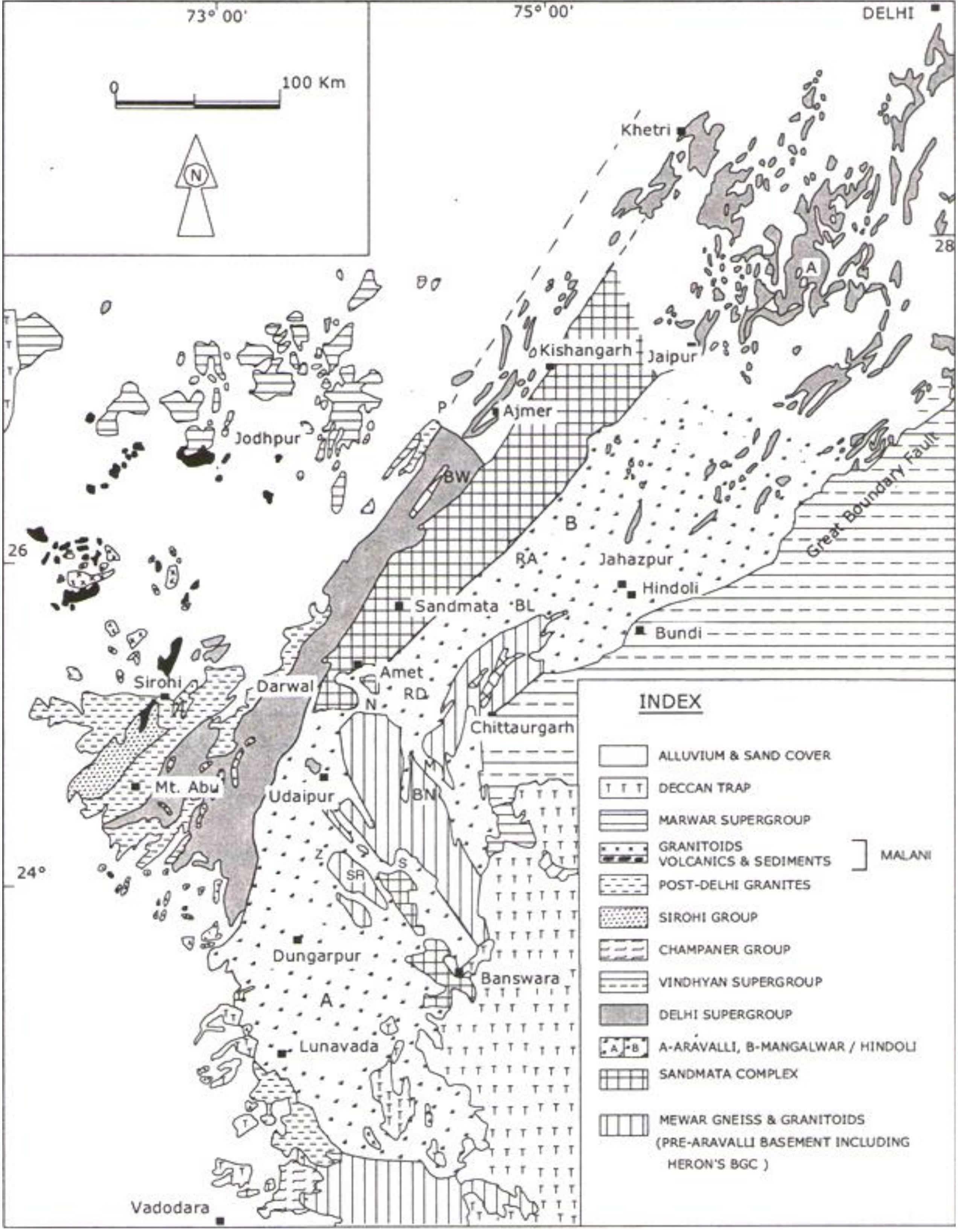

Fig. 3. Regional Geological Map of Rajpura-Dariba-Bethumni Belt (modified after Deb and Pal, 2004)

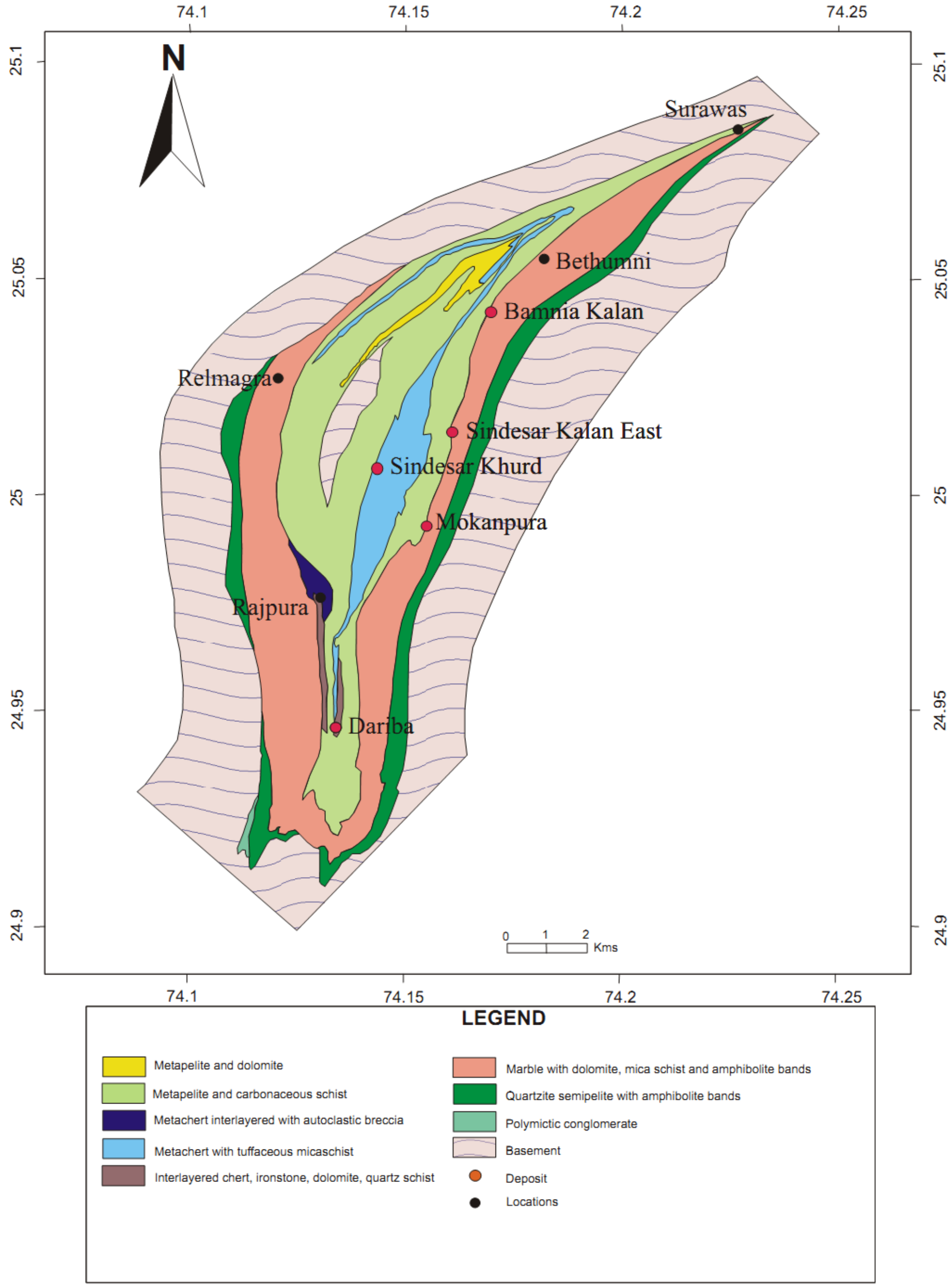

Fig. 4. Geological Cross-Section of Rajpura-Dariba Deposit

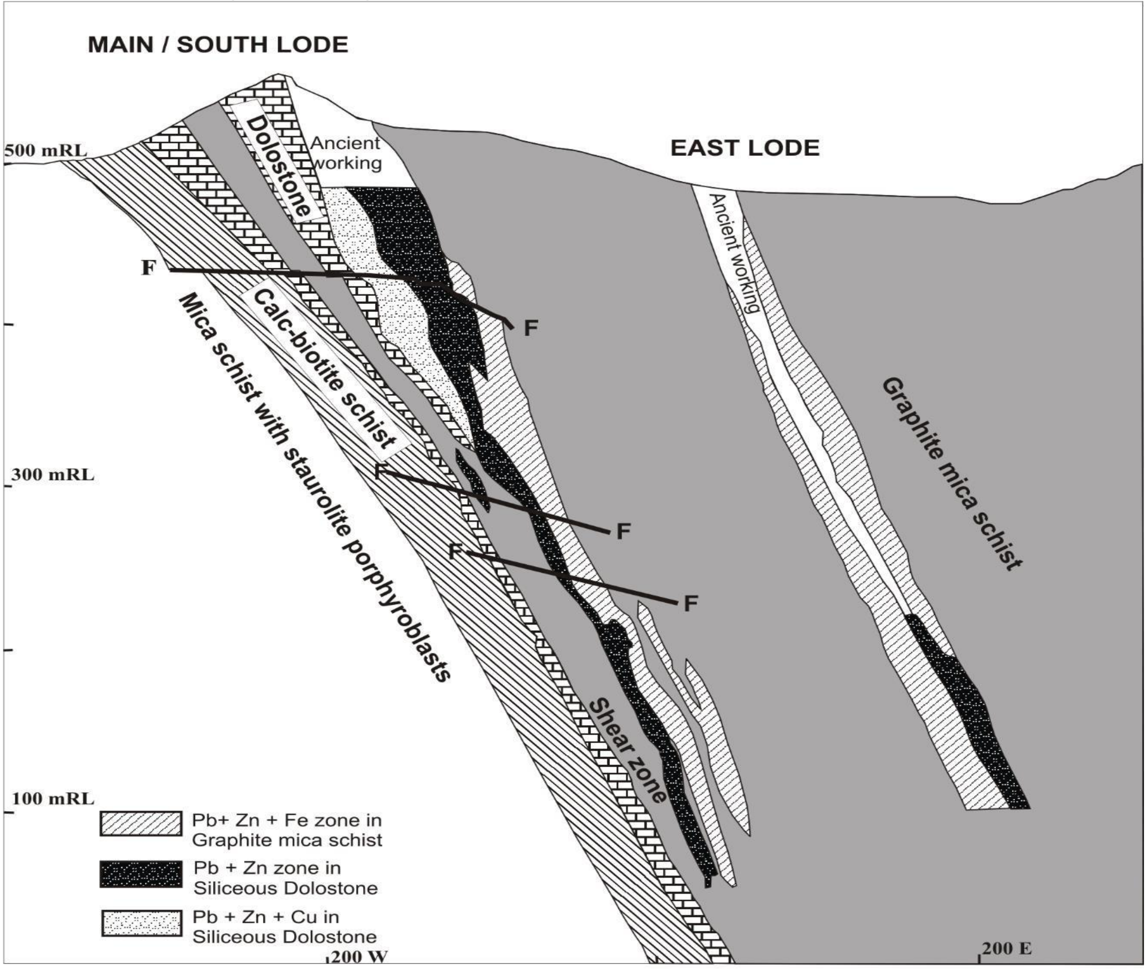

Fig. 5.Wide Grain Size Variation in Sphalerite Containing both Growth Twin Lamellae and Deformation Twin Lamellae, Within the Limits of A Single Photomicrograph. The Sphalerite Grains Show Granoblastic-Polygonal Texture with Differential Polygonisation. [Etched with saturated chromic acid solution. Sp-Sphalerite, PPL, Magnification 10X x 10]

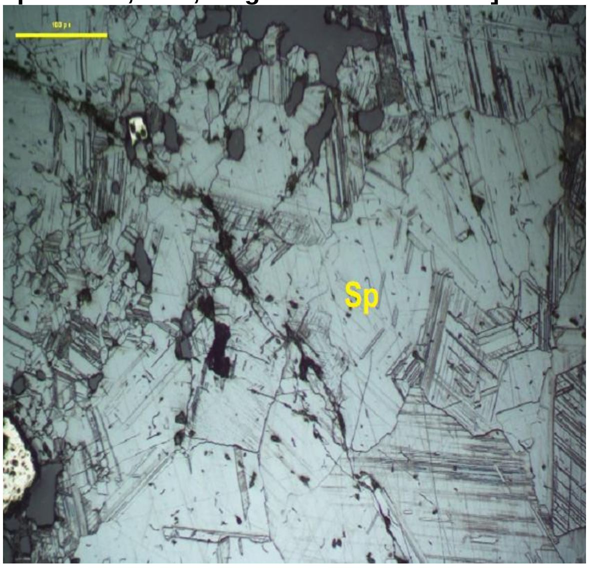

Fig. 6 Kinking of Twin Lamellae In Sphalerite Due To Deformation [Etched With Saturated Chromic Acid Solution; Sp-Sphalerite, PPL, Magnification 10X × 10]

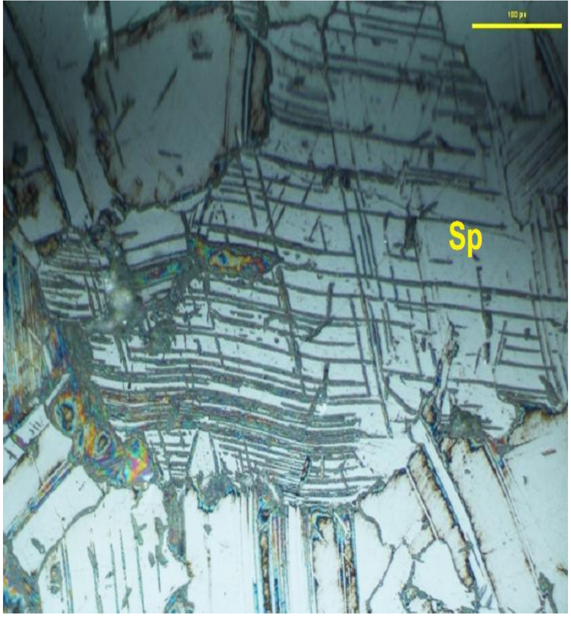

Fig. 7 Intensely Deformed Metablastic Pyrite Grains within Silicate Groundmass [Sp-Sphalerite, Ga- Galena, PPL, Magnification 10X × 10]

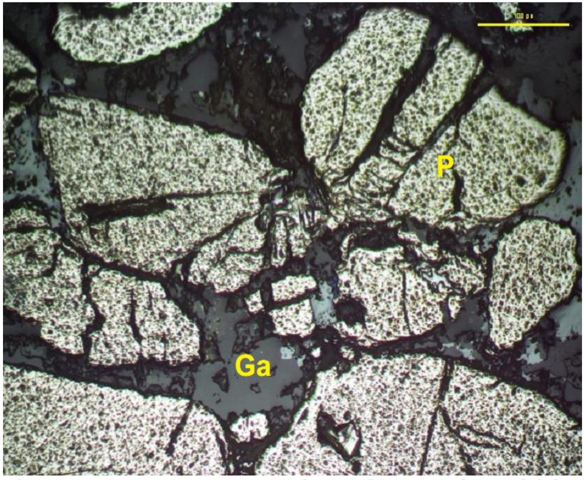

Fig. 8 Large Elongated Pyrite Grain within Gangue [PPL, Magnification 10X × 10]

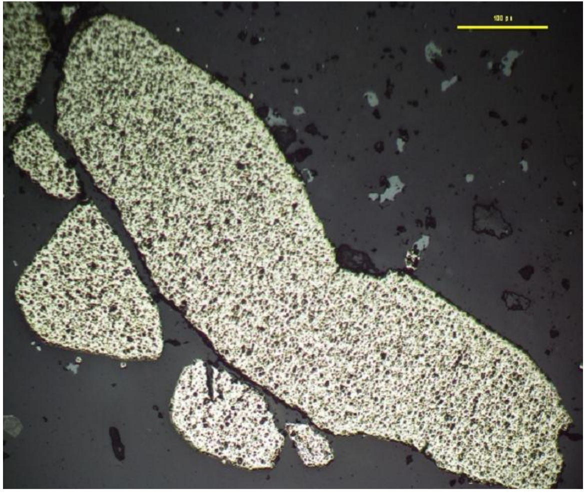

Fig. 9 Small Irregular Grains Of Galena Oriented In A Particular Direction Within Sphalerite Matrix [Sp-Sphalerite, Gl- Galena, PPL, Magnification 10X × 10]

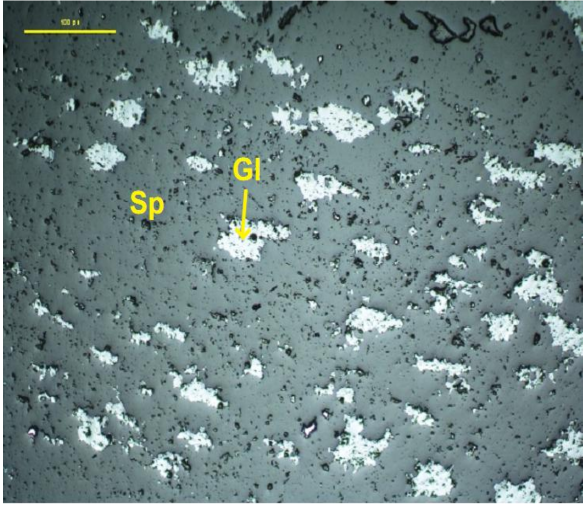

Fig.10 Martensitic Structures in Galena Formed Due Diffusionless Transformation [Etched with Saturated Chromic Acid Solution; Gl- Galena, PPL, Magnification 10X × 10]

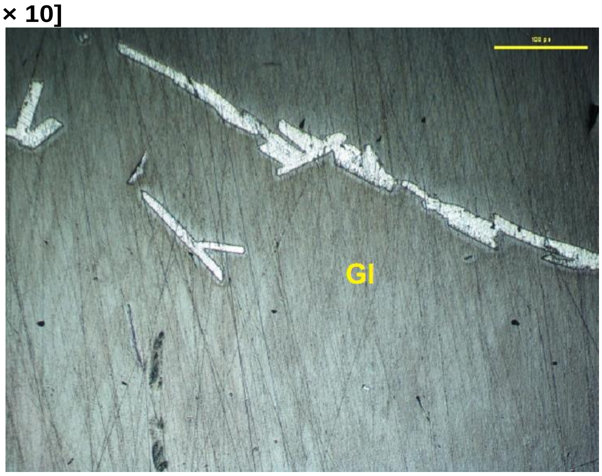

Fig.11. Deformed Graphite Grains Kinked And Broken Apart. [Gr-Graphite, PPL, Magnification 10X × 10]

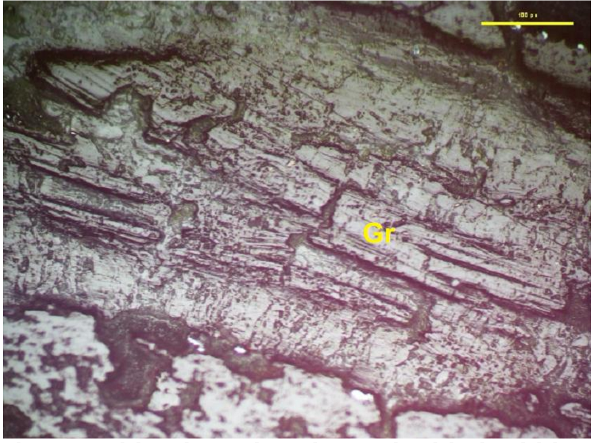

Fig.12 Cubic Shaped Pyrite Embedded Within Dolomite Rich Rock Lying Adjacent To Quartz Grains, With No Hydrous Mineral Occurring Nearby. [P- Pyrite, Q- Quartz PPL, Magnification 10X × 10]

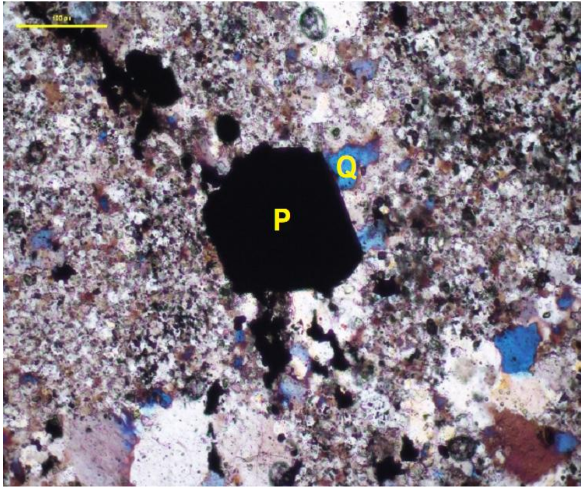

Fig.13 Sphalerite Present Within The Interstices Of Clinopyroxene Rich Dolomitic Rocks. Sulphides Also Present As Inclusion Within Clinopyroxene. [Sp-Sphalerite, S-Sulphides, Cpx- Clinopyroxene, XPL, Magnification 10X × 10]

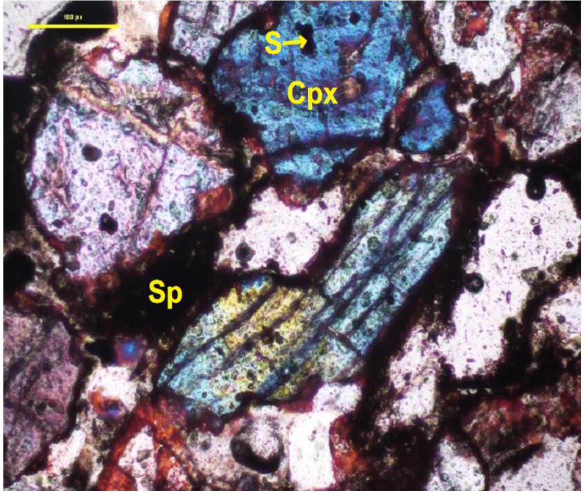

Fig.14 Kyanite and Graphite Aligning Parallel To Each Other in A Particular Direction With Sphalerite In The Interstices. [Sp-Sphalerite, Gr-Graphite, Ky- Kyanite, XPL, Magnification 10X × 10]

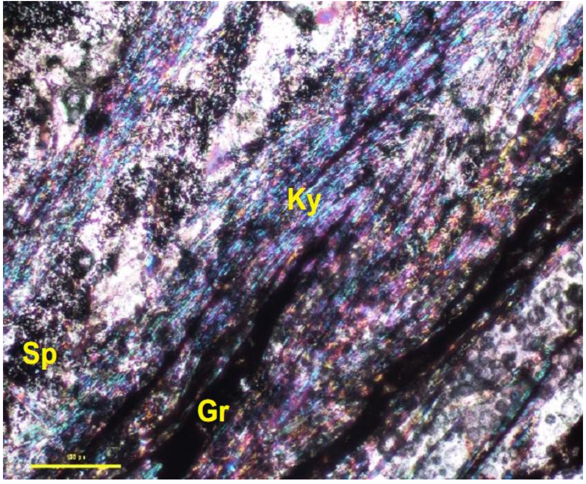

Fig. 15.Sulphide Minerals Present Within The Interstices of An Intricate 3-Dimensional Network Structure Formed by Strained Polygonised Quartz Grains, Biotite And Graphite. [S-Sulphide, Gr- Graphite, B-Biotite, Q- Quartz, XPL, Magnification 10X × 10]. [Sp-Sphalerite, Gr- Graphite, Ky- Kyanite, XPL, Magnification 10X × 10]

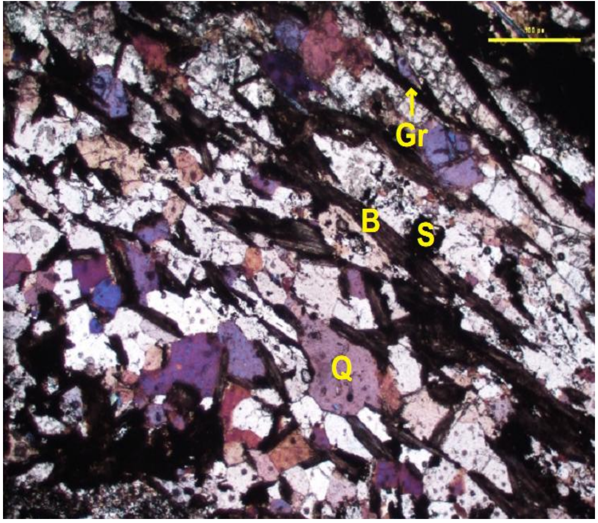

Fig. 16 Blebs Of Ore Minerals Oriented Along With Gangue Minerals In A Fine Grained Rock. [S- Sulphide Minerals, XPL, Magnification 10X × 10]