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A Note On The Geology And Geological Model Of Rajpura Dariba, Rajsamand, Rajasthan

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Abstract
Geological map of Rajpura Dariba area has been produced and discussed by earlier workers but this paper produces a revised geological model of Rajpura Dariba-Banera belt based on litho-structural data acquisition and interpretation by the authors. Four phases of deformation are evident in the area and their signatures in the form of small-scale structures are conspicuous.
The lead-zinc bearing Proterozoic rocks of Rajpura Dariba, Rajasthan, show classic development of small-scale structures resulting from superposed folding and ductile shearing. The most penetrative deformation structure noted in the rocks is a Cleavage (S-1) axial planar to a phase of isoclinal folding (F1). The lineations which parallel the hinges of F-1 folds are deformed by a set of folds (F2) having vertical or very steep axial planes. At many places a crenulation cleavage (S-2) has developed subparallel to the axial planes of F-2 folds, particularly in the psammopelitic rocks. There is a penetrative shear plane parallel to F-2 Axial plane which can be traced from Banera in North to Dariba in South. The plunge and trend of F-2 folds vary widely over the area. The structural evolutionary model worked out to explain the chronology of the deformational features and the large-scale out-crop pattern envisages extreme east-west shortening following formation of F I structures, resulting in the formation of tight and isoclinal antifoams (F 2) with pinched-in synforms in between. These latter zones evolved into several ductile shear zones (DSZs). The east-west refolding of the large-scale F 2 isoclinal antiforms seems to be the consequence of a continuous deformation and resultant migration of folds along the DSZs. The main shear zone which wraps the Rajpura-Dariba folds followed a curved path. Deformation of F 2 folds into hook-shaped geometry and development of another set of axial planar crenulation cleavage are the main imprints of the third-generation folds (F 3) in the region. In addition to these, there are at least two other sets of cleavage planes with corresponding folds in small scales. More common among these is a set of recumbents and reclined folds (F1)
Preferential sulphide mineralization is observed from West to East which may be mainly on account of differential mobility characteristics of the elements.
Keywords *– Lithological Setup, Host rock, Sulphides, Structure, Recumbent Fold*

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I. Introduction:

The **Rajpura-Dariba** zinc, lead and copper deposit is located about 86 km to the north-east of Udaipur in Rajasthan at approximately 24° 57'N, 74° 08'E. It is approximately 110 km to the south-west of the Rampura- Agucha Zn-Pb deposit, and around 100 km to the north-east of the Zawar group of mines (Figure 1).

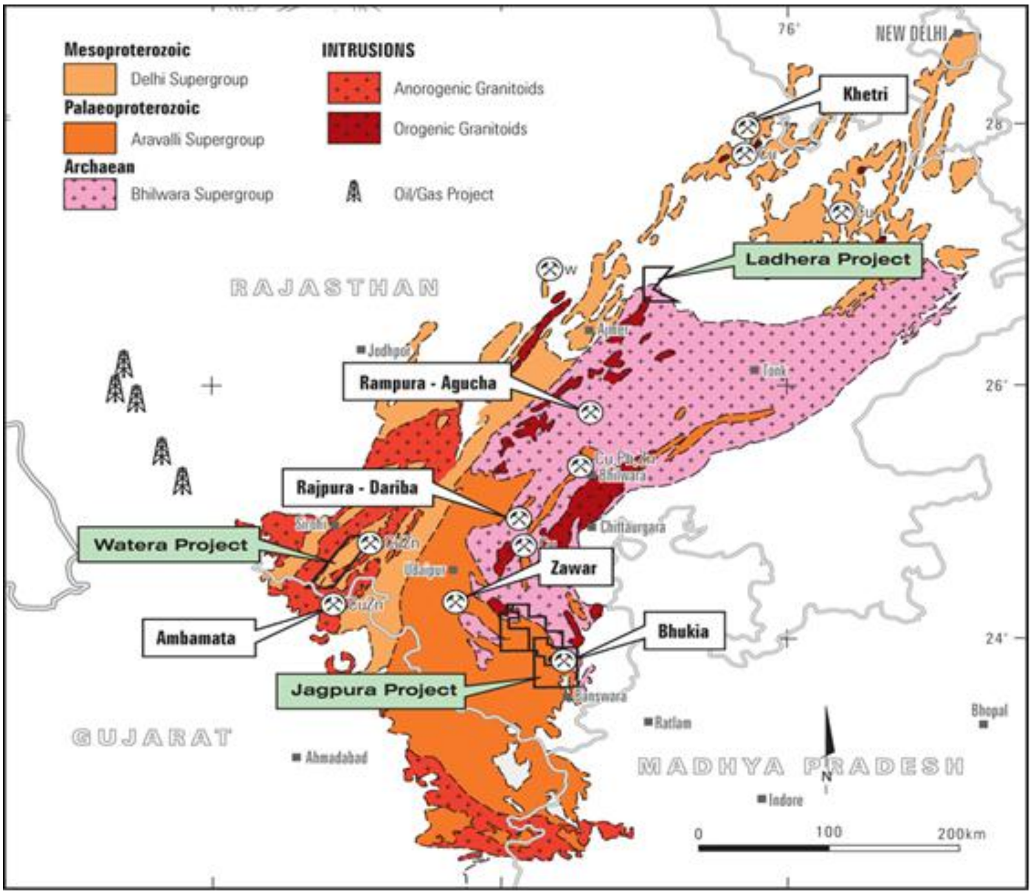

Figure 1 : Regional geological map (Modified after GSI)

The area lies within a plain, with isolated low ridges which protrude from the sandy cultivated land. The mineralized zone features an in-situ ridge cap of yellowish-brown gossan that forms a distinct physiographic unit. Ancient workings, including 'large pits and deep shafts', are evident over a strike length of 4.8 km, from the village of Dariba in the south, to the village of Rajpura in the north, and again at Bethumni about 8 km to the NNE of Rajpura extending up-to Banera in North.

Significant work has been done by earlier workers including Geological Survey of India and Hindustan Zinc Limited on the Base metal Mineralization in the area and regional framework but, the structural architecture has not been fully conceptualized controlling the Base metal mineralization. A geological model has been conceptualised and the same has been supported by field data acquisition during the author’s earlier work.

Brief regional geology: The geological assemblage of Rajasthan includes a multi-litho-association representing the basement complex (BGC of Heron, 1953), Proterozoic fold belts (Aravalli & Delhi belts) and late – Proterozoic igneous suit (Malani, Jalore and Siwana). Banded gneissic complex being the basement, underlies the Proterozoic supracrustal of Aravalli and Delhi supergroups. On the east BGC is truncated by the Great Boundary Fault (GBF), which marks the western limit of the Vindhyan system (Fig 1). Heron’s (1953) proposition that the BGC (with its meta-sedimentary and meta-igneous component) was already a deformed and metamorphosed rock suit during Archaean event was supported by Sharma (1988) based on petrological and geological evidence. However, it is generally agreed that both basement and cover sequence of Aravalli and Delhi supergroups were subsequently deformed and recrystalised during the Aravalli orogeny thus because Aravalli and Delhi supergroup participated in the orogeny although their sedimentation was not contemporaneous. The recrystalised early crust subsequently rifted to develop basins of Proterozoic supracrustal of the Aravalli and Delhi supergroups. The sediments and the volcanics were deformed and metamorphosed to produce the Proterozoic fold belts of Aravalli’s and Delhi’s. Reworking of the middle Archaean rocks is evidenced by the recurrent events of granitic plutonism. There had been a continuous effort from the academicians and professionals to define the sequence of events chronologically, but still there are certain Gray areas to be resolved. Based on Pb-Pb model ages of stratiform galena occurrences which lie in the Bhilwara area South of Banas River; showed that they are all around 1.8 Ga old (Deb and Thorpe,1989,2004) it was supported by Roy et al. (1981) based on tracing the structural and physical continuity of the Aravalli supracrustal into Bhilwara rocks. Roy et al. (1981) have claimed that they have traced continuity of band of quartzite from southeast of Nathdwara, Nathuwas, and Dhanera (south of Rajpura Dariba mines) to the west and south of Bhinder. (Naha and Roy, 1983; Roy 1988, 1999) an idea originally mooted by Heron (1953) and Crookshank (1948) and have indicated that the rocks of Rajpura-Dariba rest on Aravalli's. Rocks of Rajpura-Dariba are thus equivalent to the Aravalli Supergroup of rocks formations of Aravalli. Gupta *et al.,* (1980) described the Rajpura-Dariba Group as dolomitic marble, graphitic kyanite-staurolite-mica schist, bedded chert, quartzite, calc-biotite schist, actinolite schist and garnetiferous-biotite schist. Workers reported that these sediments have undergone metamorphism to epidote-amphibolite and amphibolite facies grades which indicates that the sequence has been metamorphosed to grades ranging from a quartz-albite-biotite assemblage of the greenschist facies to staurolite-almandine of the amphibolite facies.

Geological set-up:

The local geological setting of Rajpura Dariba provides a metasedimentary package comprising the following stratigraphic sequence:

- **Quartzite/Vein Quartz**
- **Dolerite Dyke**
- **Eastern Calcsilicate/Carbonate/Variants**
- **Graphite Mica Schist (GMS)**
- **Central Calc Silicate/Carbonate/Variants**
- **Western Silicious Dolomites & Cherts**
- **Calc Biotite Schist (CBS)**
- **Basement (Not Seen) (Untala granite?)**

Sulphide Mineraliation (Zn, Pb, Cu & Ag)

Calcsilicate and para-amphibolite: The Calcsilicates are mainly Para amphibolite which is carbonatized and silicified at places. This lithology hosts Sphalerite, Galena and associated sulphide mineralization.

Graphitic and sulphide-bearing mica-schist, with local sulphidic calc-silicate marble/chert lenses at the lower contact. This unit hosts the ore.

Quartzite/chert interbedded with graphitic mica schist It is observed that the chief lithologies within this broader sequence, that are exposed along the Dariba Main Lode, from the footwall to hanging wall are: **i).** Biotite-muscovite schist, which is occasionally argentiferous and has thin bands of intercalated dolomite; **ii).** Siliceous dolomite and calc-silicates; **iii).** Ferruginous quartzite; **iv).** Graphitic mica-schist; **v).** Dolomitic marble and calc- silicates; **vi).** Quartzites, usually with intercalated chert bands; **vii).** Calc-silicates; **viii).** Graphitic mica-schist; and **ix).** Graphitic staurolite- kyanite schist. It appears that all are probably within the 'graphitic and sulphides-bearing mica-schist' unit detailed by both Jain & Rakesh, (1984) and Roonwal & Lowhim, (1986), as listed above.

Graphitic mica-schist and kyanite-staurolite schist - containing mostly pyrite with some sphalerite, although in zones, as described below, the ore is also within the graphitic mica-schist, above and/or below the mineralized siliceous zones. According to Raja Rao *et al.,* (1972), the graphitic-schists are composed of graphite, talc, sericite, kyanite and staurolite and occur as bands in the central part of the area from Dariba, north-wards to Bethumni. The mica-schists are calcareous near the dolomites, with a narrow gradational contact (Yadav 2015).

Banded quartzite-cherts - which contain the major zinc mineralization, present as sphalerite, usually associated with pyrite and occasionally galena (Chauhan 1977). According to Raja Rao *et al.,* (1972), the ortho-quartzite is brown, well banded and slabby, and contains partings of graphite schist. The joints are mostly well-formed and often filled with milky quartz. One continuous band is traced from Dariba to Bethumni and beyond, attaining a 'considerable' thickness in some sections. Some sections of the quartzite garnetiferous black meta-cherts have been documented in the main ore zone as well by earlier workers and some authors refer to the quartzites and cherts as being the main host to ore, however significant sulphide mineralization is hosted by Calcsilicates / carbonatized Calcsilicates and graphite mica schist.

Calc biotite Schist: This lithounit comprises mainly biotite rich calcareous unit with few feldspars at places and it forms the oldest rock unit in the metasedimentary package of the area. This unit appears as Greywacke and has been described as Schistose Greywacke in 'south of Banas area' by Heron (Heron 1953).

Structural setting: Structures of three generations are decipherable in the metasedimentary rocks of the Rajpura Daribe area with an indication that structure of the first two phases are large in scale (Naha et.al 1990). The lead-zinc bearing Proterozoic rocks of Rajpura Dariba (RDMF), Rajasthan, show classic development of small-scale structures resulting from superposed folding and ductile shearing. The Rajpura Dariba belt extending from Dariba (Mata-Ji-Ka-Kheda) to Banera in North form a Synformal structure (F_2) plunging South while Rajpura Dariba Mine area forms a Recumbent fold showing reclined geometry plunging NEE (F_1) where plunge and dip of Axial plane are subparallel to North-East-East (NEE). The most penetrative deformation structure noted in the rocks is a Cleavage (S1) axial planar to a phase of reclined folding (Figure 2)). The lineations which parallel the hinges of F 1 folds are deformed by a set of folds (F2) having vertical or very steep axial planes (Figure 2). At many places a crenulation cleavage has developed subparallel to the axial planes of F2 folds, particularly in the psammite rocks (Figure 4). Shearing is mostly parallel to F_2 Axial plane . Stretching along Shear planes are quite common in the area (Figure 3,4,5,6,7). The map pattern of the carbonate unit suggests an enormous thickening at the hinge compared to the limbs, even taking into consideration the fact that the map provides an oblique view of the structure. If the small-scale folds with low wavelength/amplitude ratio (~ 0.35 to 0'37) and thickened hinges (~ ratio around 0-3) are taken as models, then the Rajpura Dariba Fold can be described as the result of flattening strain superimposed on buckle shortening (Roy 1978)

Figure2: A reclined fold (Mata-ji-ka-kheda)

Figure 3: Upright F2 Fold (S1 & S2)

Figure 4: Crenulation cleavage

Figure5: Shear fabric

Figure 6: Hook Shaped folds

Figure 7 Boudinage formation

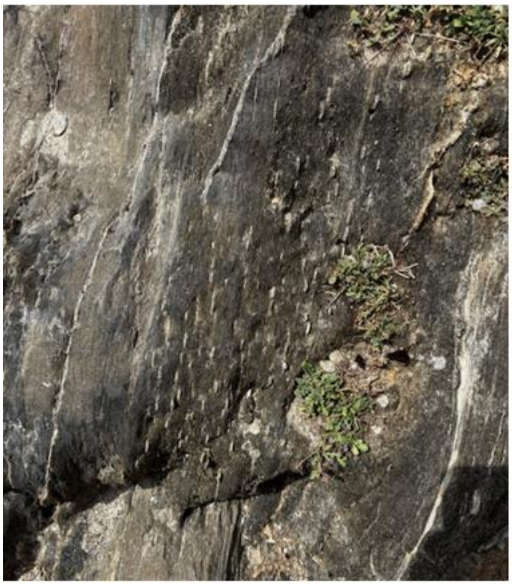

Figure 8: Penetrative S1 cleavage transposed parallel to bedding in metapelite with stretched pebbles

Figure 9: F2 fold on S1 cleavage Quartz veins are boudinaged

The plunge and trend of F_2 folds vary widely over the area. Deformation of F_2 folds into hook-shaped geometry and development of another set of axial planar crenulation cleavage are the main imprints of the third-generation folds (F_3) in the region. In addition to these, there are at least two other sets of cleavage planes with corresponding folds in small scales. More common among these is a set of recumbent and reclined folds (F_1) , developed on steeply dipping early formed planes. The larger of the two, the Main Rajpura Dariba Fold (RDF), shows a broad hook-shaped geometry. Both the major structures show truncation of lithological units along their respective east 'limbs', and extreme variation in the width of formations. The RDF is primarily the result of superimposition of F_2 on F_1. F_1 folds are recognizable in the Dariba Mine area which responded to deformation mainly by buckle shortening. Large-scale pinching-and swelling that appears in the outcrop pattern seems to be a pre-F2 feature. The structural evolutionary model worked out to explain the chronology of the deformational features and the large-scale out-crop pattern envisages extreme east-west shortening following formation of F I structures, resulting in the formation of tight and isoclinal antiforms with pinched-in synforms in between. These latter zones evolved into a few ductile shear zones (DSZs). The main shear zone which wraps traverses from Banera in North to Dariba in South followed a curved path because of the penetrative nature, the early lineations which were at high angles to the later ones (as is evident in the west of Rajpura Dariba), became subparallel to the trend of F2 folding over a large part of the area. The remodelled Rajpura Dariba Litho-structural stages are shown in Figure 10 & 11.

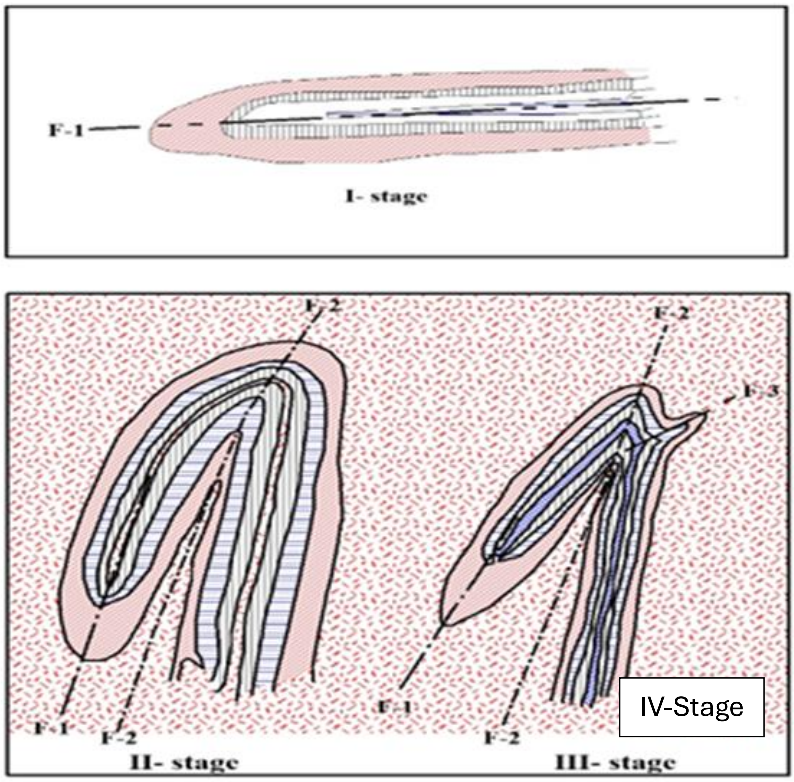

Figure 10: Conceptual stages of deformation (Not to Scale-Cartoon)

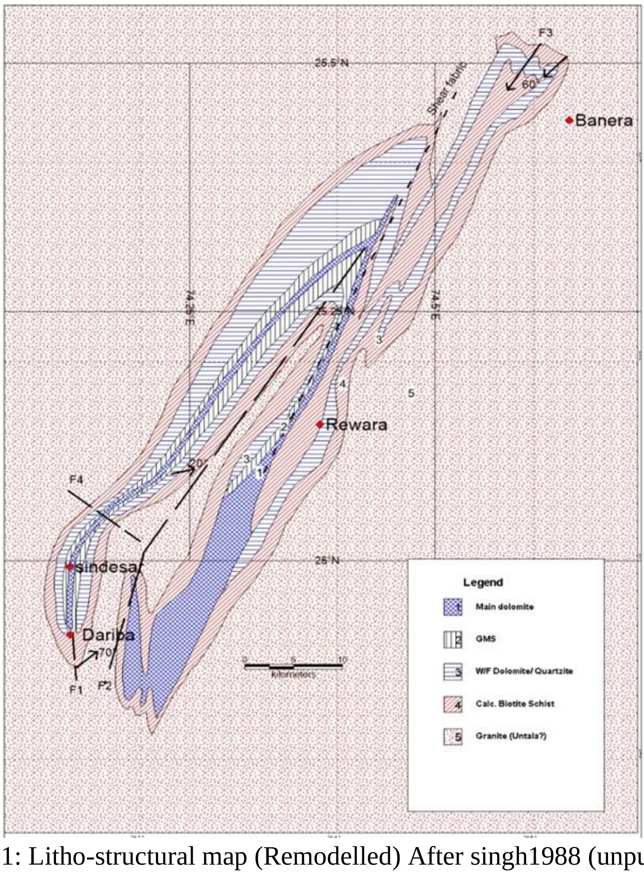

Figure 11: Litho-structural map (Remodelled) After singh1988 (unpublished)

Mineralisation: The Rajpura-Dariba ore deposit is visible as a gossan zone sporadically outcropping over more than 5 km. Chert zones on both sides of the gossan form low ridges up to 80 m above the plains. The limonite gossans form depressions between the siliceous ridges.

The gossan shows dark brown, bright reddish-yellow, vermilion-red, brick-red, purple, yellow, pale-green, bluish-green, azure-blue, black, grey and white colours, indicating the presence of limonite, goethite, jarosite, jasper, malachite, azurite, turquoise, hematite, manganese oxides, clay minerals, etc., while siderite, covellite, chalcocite, chrysocolla, cerussite and smithsonite are also recorded. Cubic, cellular, honeycomb box works, and other voids are evident, as is dense limonite (Figure 12).

Figure 12: Gossan zone in North Lode Dariba

Relict galena, pyrite and chalcopyrite are seen within the gossan. Early grid soil and gossan sampling returned values of up to 4000 ppm Pb and 3000 to 4000 ppm Zn in the Dariba area (Raja Rao, et al., 1972). Near surface gossan to the north grades up to 3% Pb, 0.1% Zn and 200 g/t Ag, with traces of Cu, Sb, As, Au, Hg and Mo.

Three principal lode systems have been identified, the ***Dariba Main Lode (South Lode & North Lode), Western Lode (Foot wall copper zone)*** and the ***Dariba East Lode***. Mineralization extends over a strike length of 2 km with surface manifestation of ancient workings and gossan. South lode and North lode are the Main lode having an approximate strike length of 2.0Km with varying width of few meters to 25m.

Further north the zone has been deeply weathered with the gossan extending to depths of 300 to 400 m below the surface. In this area where the base of oxidation increases dramatically from around 40 m below surface, to about 300 m, some 34 mt of low-grade gossan have been indicated. The overall Dariba Main Lode, constitutes a series of blocks, including the Rajpura A and B blocks, and has a strike extent of 3700 m (Deb & Bhattacharya, 1980).

The ***East Lode,*** which has a strike length of 600 m, is developed 200 m to the east of the South Lode, the southern shoot of the Dariba Main Lode. It is generally 19 m thick and in 1984 was drilled to a depth of 300 m, but had not been closed (Jain & Rakesh, 1984). East Lode occupies the Eastern Limb of Dariba Main Fold (DMF) plunging 55^0-60^0.

The **West Lode** occupies the western Limb of DMF but due to tight isoclinal folding having reclined geometry this western limb does not show its entity though in North the Calc Silicate looks like Chert. This western limb hosts more copper zones than Zinc-Lead (Figure 13).

Each of these lodes pinches and swells along its length. The Dariba Main Lode varies between 1 and 47 m in width with an mean width of 25-30m, while the East lode ranges from 2 to 35 m in thickness.

Figure 13: Malachite (Cu mineralization) in Western Calc silicate/Carbonate near Malikheda

As described above, the economic mineralization is mainly hosted by the siliceous dolomite/calc-silicate rocks and the cherty quartzites, as well as locally, from 1 to 20 m of adjacent graphite-mica-schist. The primary north and south lodes are located at the boundary between dolomite or calc-silicate rocks and graphitic or carbonaceous schist. The North and East Lodes are essentially Zn-Pb lodes, while appreciably higher Cu levels are known towards the footwall of the South Lode, making it essentially a Zn-Pb-Cu lode. This Cu-rich footwall zone of the South Lode is represented by a 15 m wide zone of siliceous rock with splashy chalcopyrite, some tennantite, tetrahedrite, galena, sphalerite and a little fluorite.

The footwall of the South Lode is occupied by Fe zone characterized by biotite schist which is impregnated with graphite, and has an associated assemblage of pyrrhotite, pyrite and magnetite. Schists lower in the sequence contain disseminated hematite.

Within the Cu rich section of the South Lode, the host is a recrystallized siliceous dolomite, with stringers, irregular massive patches and rarely concordant bands chalcopyrite, all with subsidiary galena and pyrite. The western contact of this zone is marked by cherty Quartzite. Towards the hanging wall the Cu-zone has a diffuse assay contact with a Pb-Zn zone within recrystallized siliceous dolomite characterized by galena, sphalerite and pyrite, with little or no chalcopyrite. Towards the hanging wall of this zone, delicate bands of sphalerite and/or pyrite are intercalated with black carbonaceous cherts over widths of up to 20 m in places.

Towards the southern margin of the South Lode there is an elliptical patch of coarse diopside-rich rock, up to 75 m long, which is characterized by high Ag and As values in minerals such as geochronite and polybasite, together with massive tennantite-tetrahedrite and discordant veinlets of galena. There is a sharp contact between the Pb-Zn body in the hanging wall, with the Fe rich zone which occurs as pyrite and/or pyrrhotite interbedded with graphite-mica schist. Where banded pyrite occurs within graphite-mica-schist, the pyrite bands are generally 0.1 to 4 mm thick, rarely up to 1 cm.

According to earlier workers, accumulations of barite as pods and lenses, are found in the hanging wall of the deposit.

Large discordant veins of galena and chalcopyrite are recorded in the footwall dolomitic marbles and calc-silicates (mainly Western Limb of the Dariba Synformal structure). In addition, in the hanging wall calc-silicates there are accumulations of rare sulphosalts such as geohcronite, boulangerite, tetrahedrite, tennantite, which only occur in minor amounts elsewhere in the orebody.

The predominant sulphide minerals in the ores are sphalerite, galena, chalcopyrite, pyrite, pyrrhotite and tetrahedrite-tennantite. Minor minerals include arsenopyrite, cubanite, mackinawite, polybasite, geochronite, argentopyrite, pentlandite and enargite(?), as well as magnetite, ilmenite and rutile (Yadav 2015). The major minerals tend to be concentrated in defined zones, while the minor constituents are scattered sporadically throughout (Deb & Bhattacharya, 1980). Sphalerite is the most abundant sulphide, followed by pyrite. Pyrite is found associated with all of the other minerals in the deposit (Chauhan, 1974). Three common mineral associations at Rajpura-Dariba are, namely: **i).** pyrite-pyrrhotite-magnetite; **ii).** chalcopyrite-galena-pyrrhotite; and **iii).** Sphalerite-pyrite-galena.

Deformational fabrics are evident in the ore on all scales. These include: **i).** alignment of sulphides, mainly sphalerite, pyrite and pyrrhotite along strong penetrative Cleavage, S1; **ii).** The transposition of S1, along with the sulphides, into a well-developed crenulation cleavage; **iii).** stretching of sulphides layers to form boudins; **iv).** meta-blastic growth of pyrite and arsenopyrite, with associated pressure shadows, and rounded porphyroblasts that are rotated within the enclosing Cleavage; **v).** recrystallized granoblastic mosaics of softer sulphides enclosing clasts of more competent wall rocks.; and **vi).** the local mobilization of the sulphides to form massive galena and chalcopyrite-rich discordant veins, healed breccias and fractures. In addition to these textures, some authors claim to recognize syn-sedimentary sulphides textures.

Mesoscopic folds ranging from those with an amplitude of 1.5 m down to crenulations are observed in the sulphidic units, particularly the graphite-schist bearing pyrite bands. These folds are interpreted to represent flexural slip, flexural flow, shear and quasi-flexural folds. Within the chert hosts the sulphides have accommodated the strain. Cataclastic deformation is dominant in the layered sphalerite-quartzite-chert, where healed breccias are common. In these structures sphalerite and galena appear to be mobilized and recrystallized in spaces between clasts.

Prognostic approach: In view of the geological model and litho-structural control of mineralization it is conceptualized that:

- Copper-dominant sulphide mineralization may be concentrated in the Western Limb of the Dariba Synform from the Footwall of Dariba Main Lode to Malikhera-Devpura, while Zinc-Lead (and associated minerals) extends north from Dariba Main Lode to Lathion-Ki-Khedi. Zinc-Lead-Silver is present in the East Lode from Mataji-ka-Kheda to Sindesar and Bamnia.
- Keeping in view the structural architecture of Dariba belt as a whole occurrence of significant Sulphide mineralization of Copper-Zinc-Lead and Silver in Jasma-Bhupalsagar' Rewara area which forms the Eastern Limb of F2 Fold structure closing at Banera (Figure 11) cannot be ruled out.
- There may be a litho-variant from cherty carbonate in western limb to more carbonate-calcsilicate in main load while graphite-mica schist and calcsilicate in east load to Sindesar Khurd area-Bamnia.
- There may be a gradual increase in Iron content in the bed rock from Dariba South to Dariba Noth and Banera.
- There are structural basins and domes in the belt from Dariba to Banera. The plunge variation is seen at Bethumni where plunge is as shallow as 10^{0} - 20^{0}.
- Sulphide mineralization is expected to persist at depth with the host bodies, although width and grade may vary systematically.

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