

## Re-exploration of Rajpura Dariba Belt for Zn-Pb

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**Abstract.** In the recently drilled deeper boreholes by HZL new intersection of lead and zinc ores have established depth ward continuity of ores of previous boreholes and have thus augmented reserves considerably. It has suggested revision of ore forming concepts and also that in the Rajpur Dariba area further search for Zn-Pb should be carried out using new innovative techniques. Success often requires supplementing standard procedures with the effective use of new exploration methods: the kind that can see deeper, are more definitive, and more efficient to ore discovery. The conventional methods have their place, but these are proving to be less effective as new terrains are increasingly more difficult to explore. Present studies have helped in searching new controls of mineralisation and in formulation of new ore guides for future search of new ore bodies. On the basis of present studies like facies of volcano-sedimentary sequence, textures, structures, ore microscopy, environment of ore deposition, characters of mineralisation, ore facies, sequence stratigraphy, airborne and ground geophysics new evidences for ore genesis have been collected. In Sindesar Khurd these studies have suggested vent complex type of hydrothermal sedex deposit. Rajpura Dariba deposit displays biphasic mineralisation including stratiform sulphides and post metamorphic epigenetically melt introduced independently. Salient features of vein ores such as occurrences as pods, segregation veins or open space fillings traversing the banded ores, absence of deformation and recrystallisation textures indicate that these veins are post-metamorphic and could have formed from a different ore fluid. The cavity filling nature of vein ore and their occurrence in irregular shear planes suggest their environment of ore formation was different than imprints of metamorphism in banded ores. The source of this fluid could be intrusive granite located during present studies. Now with an objective of searching new ore zones more evidences like faults and shear zones which are loci for ore in volcanoclastic rocks and calc silicate marble is the best host. Other evidences of ore forming processes and characters of volcanic rocks are also helpful in ore search. These strategies are discussed in this paper to search new local targets for selecting new drill sites.

**Keywords:** Rajpur-Dariba, volcano-sediments, volcanic textures, faults, ore guides, new ore bodies, alteration, zoning, hydrothermal, bimodal

### 1 Introduction

Massive sulfides associated with volcano-sedimentary rocks are important source of base metals. It has been presumed that preliminary exploration has been completed but present study has shown that still more work can be attempted to locate new deposits. Once an area has been defined using standard exploration procedures, stream/soil/rock geochemical sampling, geologic mapping, and geophysical surveys, success often requires supplementing these standard procedures with the effective use of new exploration methods: the kind that can see deeper, are more definitive, and more efficient to ore discovery. The conventional methods have their place, but these are proving to be less effective as new terrains are increasingly more difficult to explore. Study of ore forming processes of sulfides and their relationship with volcano-sedimentary succession in Sindesar Khurd, Rajpura Dariba belt, Rajsamand District, Rajasthan was taken up by Samaddar (1987), Yadav and Sharma (1989), Misra, B and Mookerjee, A.(1984), Deb and Pal (2004). Present studies were taken up on drill cores of Sindesar Khurd drilled by Geological Survey of India (GSI) and Crown Mining Private Limited (CMPL). On the basis of studies like facies of volcano-sedimentary sequence, ore facies, ore microscopy, environment of ore deposition, characters of mineralisation and sequence stratigraphy evidences for ore genesis have been collected. These studies have suggested vent complex type of hydrothermal sedex deposit. Earlier

Deb and Pal (2004) have given views of sedex ore genesis. Now with an objective of identification of ore guides for searching new ore zones more evidences have been collected on ore forming processes and characters of volcanic rocks. In the recently drilled deeper boreholes by HZL new intersection of lead and zinc ores have established depth ward continuity of ores of previous boreholes and has thus augmented reserves. It has suggested revision of concepts and also that in the Sindesar Khurd further search for Zn-Pb should be carried out in soil covered area. Author of present paper had a feeling that more studies regarding controls of mineralisation could be carried out which can serve as ore guide. For discovery of deeper and new locales of massive sulfide deposits detailed geological studies were required to be done to formulate guides for searching ore in the Rajpura-Dariba belt. In Rajpura Dariba in major part host rocks are not exposed. Therefore, for searching ores dependency increases on indirect methods. Since ore formations are hosted in graphite mica schist electro-magnetic method of geophysical survey has not been found very useful. Alternative strategy has been thus suggested. Interpretation of environment of ore deposition has been carried out to understand new geological set up which may help in searching more locales of massive sulfide deposits.

## 2 Tectonic Setting

The findings of geophysical studies indicate that a narrow gravity high of lower amplitude is noticed in the areas of RD lead-zinc deposits; representing rift sites of deposition of cover rocks. These geophysical studies also indicate faulted boundary of the basin (Reddi, A.G.B. and Ramakrishna, T.S., 1987).

The Bhiwara Supergroup has been considered pull-apart basins, linked with regional strike slip faults responsible for opening of main basin (S.Sinha Roy; 2004). These features suggest that Bhilwara Supergroup of rocks, Rajpura Dariba (RD) belt and Pur-Banera belt are first order intracatonic type and Dariba-SindesarKhurd-Bamania kalan areas are sites of second order systems formed by synsedimentary vertical tectonism and sites of ore deposition.

Multiple parallel lineaments in the center of RD belt characterize RD basin. Lineaments were active during deposition of the host volcano-sedimentary sequences.

Dariba belt is a major geofracture with several large-scale oblique and parallel fractures (conjugate faults/shears) in the central part which were reactivated. This type of tectonic and synsedimentary volcanic setup is broadly ideal locale for mineralisation of lead and zinc. Most such deposit settings are intercontinental rifts or rifted margins, and deposits are best developed in the youngest of sag basins overlying older rift-sag cyclic sequences. Intercontinental rifts or rifted margins are common regional sites for deposition of host lithologies formed in both emergent and sub-wave base settings but generation of local reduced facies through differential and reactivated movement on orthogonal sets of growth faults is a key factor in locating the ultimate repository for Pb-Zn mineralisation. Sequence stratigraphy and seismic imaging of concealed prospective packages are bringing new insights into basin architecture and area selection. Even the most controversial research becomes more explicable when it is clear that a system of rift-related structures may be continuously reactivated resulting in recrystallisation and extensive retexturing of pre-existing Pb-Zn mineralisation, similar for example to Cambrian to Devonian events at Rosebery VMS in Tasmania (Derrick, 2000).

It has been noticed that terrain between Rajpura to Sindesar Kalan of Rajpura-Dariba belt is flat except Sindesar ridge. Lead-zinc mineralisation in this area is hosted by graphite mica schist, calcareous mica schist, meta-marl, dolomitic-marble, calc-silicate and autoclastic acid volcanic rocks. The host rocks for mineralisation of lead and zinc are not exposed and situated 150m below surface. These metamorphic rocks are intruded by synkinematic granite.

Sites of mineralisation are longitudinal fault or conjugate shear with NNE-SSW trend which extend almost parallel to the bedding plane and on surface number of parallel faults are manifested by ferruginous gossanised cherty breccia. The cross faults with ESE-WNW trends are also observed at various places and have shifted ore lenses along strike.

In Sindesar Khurd area drill data has indicated major acid volcanic activity and minor basic volcanics associated with mineralisation. Volcanoclastics are observed around massive ore and volcanics are associated/interlayered with sedimentation. Hydrothermal alteration zone surrounds pipe like massive ore.

Massive ores are associated with faulting and kinematic granite intrusive acted as heat source to drive

ore bearing fluids. Massive ore encloses blocks of dolomite, milled round quartz fragments and pieces and blocks of banded ores of Pb and Zn. Granite has been noticed in the BH's of the study area. Fault developed favorable conduits where ore got precipitated. Ore fluids permeated through fractured and faulted rocks to the favorable sites where ore gets deposited under suitable conditions.

**Hydrothermal alterations** around ore zone are characteristic features and comprise sericite, quartz and carbonate (siderite).

**Metal zoning** is indicated by dominance of pyrite followed by pyrrhotite and then appearance of galena sphalerite and chalcopyrite. Pyrrhotite zonation is noticed above hydrothermal Pb-Zn massive ore zone in the vent.

In the Sindesar Khurd area **element zonation** is noticed from top to bottom e.g. Fe, Mn±Ba, Pb, Zn, Cu and Se. **Element zoning** comprises manganese forming an outer halo extending beyond zinc ores. Barite is present in either upper part or outer part or as cap overlying sulfides. Mn concentration is < 1ppm at 500m distance from vent and 100 to 1000 ppm in ore zones. Mn decreases away from ore. Abnormal higher content of Se, Hg is noticed in ore.

### 3 Depositional Environment of Sediments

Deposition of sediments started in basinal rift. Sediments of Rajpura Dariba Group indicates that the conditions of deposition were frequently changing. In the beginning these were different and by the time of closing of the basin conditions changed. Depositional environment was first reducing and later it changed to oxidizing.

In the beginning shallow water sediments like sandstone and conglomerate were deposited at the margin of shelf of rift where basic rocks had already deposited. Sediments like carbonaceous and quartz rich arenite and calcareous arenite of deep-water facies were deposited in the central part of the rift.

Subsequently the basin was filled with volcanic breccia and tuff derived from acid and basic volcanism. Contemporaneous with volcanics sediments like silt and arenites were continuously poured in the basin. These silty sediments were mixtures of calcareous, aluminous composition. Synsedimentary faulting accompanied deposition volcano sedimentaries.

Reduction of relative proportion of coarse arenaceous material characterize this period. Evidence of deepening of basin is reflected due to absence of sandy material. This character separates middle stratigraphic group from two other groups. Further during this phase presence of graphite indicates that in the environment reducing conditions prevailed. Volcanogenic rocks have disseminations of base metal suggests discharge of metals by hydrothermal solutions and precipitation in the argillites, volcanics and chemogenic carbonates.

At the end of this period basin conditions changed. Basin became shallow and oxidising. Shallowing would have been caused by basinal load coupled with tectonic subsidence. As a result alternate sequence of quartzite with mica schist and garnetiferous hematite quartzite (Yadav and Avadich, 2007) deposited in oxidizing environment.

### 4 Mineralisation

In the Sindesar Khurd area lead-zinc mineralisation occurs in metamorphosed volcano clastic, argillaceous and calcareous sediments.

In present study sphalerite, galena, pyrrhotite and pyrite occur as fine, medium and coarse grained minerals as disseminations, bands/layers, veins and massive ore.

The sulphide minerals of Rajpura-Dariba comprise pyrite ( $\text{FeS}_2$ ), pyrrhotite ( $\text{Fe}_{1-x}\text{S}$ ), sphalerite ( $\text{ZnS}$ ), galena ( $\text{PbS}$ ), arsenopyrite, tenantite  $(\text{Cu,Fe,Zn,Ag})_{12}\text{As}_4\text{S}_{13}$  and tetrahedrite (fahlore),  $(\text{Cu,Fe,Zn,Ag})_{12}\text{Sb}_4\text{S}_{13}$ . The other metallic minerals are chalcopyrite ( $\text{CuFeS}_2$ ) noticed in Dariba mines.

These sulphides occur as disseminated grains, layers and thin bands parallel to bedding and foliation; veins/stringers and rarely as replacement structures (replacing carbonate minerals). The fine and medium grained sphalerite, galena, pyrite and pyrrhotite minerals vary in size from 0.01 mm to 0.2 mm. These occur as disseminations and thin bands parallel to bedding in schist and marble. Discrete sulphide minerals occur as disseminations and elongated grains and in the banded form in the schist. Elongation of the minerals is parallel to  $S_1$  and  $S_2$ . Here the ores occur essentially as rhythmical sequence with

metamorphosed argillaceous sediments. These features and the relationship with gangue minerals indicate that the sulphides were deposited with the sediments.

The coarse grained galena and sphalerite vary in size from 0.25 mm to 2.0 mm and are mainly found as veins and stringers in the calc-silicate marble and calcareous schist and show better content of metals.

Sphalerite with galena and pyrrhotite shows intergrowth texture indicating simultaneous crystallisation of these three minerals. Exsolution blebs or droplets of pyrrhotite are common in sphalerite indicating high temperature conditions (Ramdohr, 1980). Exsolution drops or lamelli of sphalerite are also observed in pyrrhotite but in rare case and this suggests that mineralisation continued for a longer period or occurred twice.

Exsolution features of sphalerite in galena and vice-versa are also observed but the blebs of sphalerite are more common in galena indicating sphalerite is younger than galena, however, reverse situation support the two stage mineralisation. At places, sphalerite has replaced pyrrhotite, pyrite and calcite/dolomite grains.

The well developed sphalerite grains are common in the tuffaceous schist and calcareous schist. The subhedral grains of sphalerite, pyrite and pyrrhotite varying in size from 1 mm to 2 mm occur in the fine grained ground mass of quartz, feldspar, biotite, muscovite and opaques. These show flow, emplacement, intergrowth and exsolution textures. Sulphides replacing deformed calcite grains indicate the post-deformation replacement. Sulphides replace and cut across the calcite grains.

The sulphides with vein, fracture filling and flow structures indicate recrystallisation and migration through the weak planes from rhythmic banding to nearest open space in schist and carbonate during metamorphism and post  $F_2$  deformations.

Coarse grained idiomorphic crystals of sphalerite and galena occur as massive pipe/lenses like band in the western part of Sindesar ridge. These ore bodies enclose fine rhythmites of sphalerite and galena and round quartz and dolomite fragments. Dolomite and quartz show effect of milling. Features of vein ores such as occurrences as pods, segregation veins or open space fillings traversing the banded ores, absence of deformation and recrystallisation textures indicate that these veins are post-metamorphic. Galena and sphalerite occur as of cavity filling nature and occur as vein ore in irregular shear planes. Flowage intergrowth and exsolved textures suggest that high temperature was required for development of these features. In the last stage hydrothermal solutions might have developed these features. Fine grained laminated sulphides occur with coarse sulphides. Both are discordant to each other. It is suggesting that coarse sulphides were filled by hydrothermal solutions through faults.

According to Rajawat and Sharma (1993) the ore mineralogy throws some light on the temperature of formation of the ore deposit. Cobaltite, globules of sphalerite and pentlandite in pyrrhotite indicate a high temperature of formation ( $>550^\circ\text{C}$ ). The presence of ore textures suggestive of the magmatic melt (presence of spheroidal sphalerite as inclusion in pyrrhotite) indicates an ultimate igneous source (deep seated). The textures indicative of hydrothermal nature (occurrence of ore minerals in quartz veins and fractures and coarse massive ore in fault zone and filling open space in brecciated rocks indicate that the metal has been derived from plutonic intrusions granite.

Ore occurrences as pods, segregated veins or open space fillings traversing the banded ores, absence of deformation and recrystallisation textures indicate that these veins are post-metamorphic and could have formed from a different ore fluid. The cavity filling nature of vein ore and their occurrence in irregular shear planes suggest that environment of ore formation was different than imprints of metamorphism in banded ores. The source of this fluid could be intrusive granite.

## 5 Ore Depositional Process and Nature of Volcanism

A single process which can explain all the characters, textures, mineral association is difficult to conceive because several processes can produce same type of features it is therefore, possible that more than one process would have produced a single deposit.

The presence of bedded sulfides in the finely laminated sediments like carbonaceous shales indicate anoxic environment at the sea floor.

Ore body is characterised by stratiform sheet like morphology of the ore body coupled with elliptical pipe like breccia filled ore zone. It indicates that discharge of ore fluids was through faults. Simultaneously volcanics were also extruding through such pipes and sediments were also deposited in

the rift. Convection currents thus deposited hydrothermal fluids of ore which was discharged through hydrothermal solutions.

Explosive acid volcanism has played a major role in fracturing the pile and opening up channel ways (Large et al, 2004) for ascent of ore fluids. Brecciated and blocky natures of host rocks also suggest explosive volcanism.

Open space such as fractures and pore spaces of volcanic rocks due to high permeability served as conduits for ore forming fluids and caused quenching and deposition of ore fluids on the sea floor surfaces within volcano-sedimentary pile.

Laminated or bedded sulphides are thus interpreted as seafloor hydrothermal sediments. Hydrothermal fluids discharged through faults vent at the sea floor and associated sulphides precipitate in the volcano-sedimentary assemblage. Rajpura Dariba deposit displays biphasic mineralisation including stratiform sulphides and post metamorphic epigenetically introduced (Misra, B. and Mookerjee, A. 1984) along faults.

## 6 Ore Depositional Process and Nature of Volcanism

Search activities vary on scale of exploration. At the basin/regional scale for ore search understanding of basin architecture and distribution of organic rich sedimentary facies is required for defining area and selecting target for regional exploration. Most of the deposits are located adjacent to regional structures and determining the active syn-sedimentary faults and their potential to discharge ore fluids is a critical aspect of the exploration model. Geophysical data will elucidate basin structure and distribution of rock types below the cover. In poorly exposed and deeply weathered terrain airborne and ground electromagnetic methods may be used to locate faults, carbonaceous and pyritic sequences. At the prospect scale, geological mapping of structures and sedimentary facies will be important. Surface geochemical surveys and gossan studies give useful information but spurious anomalies and broad zinc dispersion can make interpretation difficult. Detailed gravity surveys have revealed presence of Pb-Zn ore bodies at depth of several hundred meters. Changes in carbonate chemistry like dolomite, ankerite and siderite occur in the host sequences near ore. Host sediments are anomalously rich in Zn, Fe, Mn, Tl, and Fe and Mn content of carbonates increases towards ore. Therefore, exploration involves different techniques for selection of target area on i) regional scale, ii) prospect scale and iii) detailed/local scale.

Selection of target areas for exploration for regional exploration may involve interpretation of land sat imageries for demarcation of regional and local structures and then followed by ground checks. Re-interpretations of structures may be done on results of ground check and data to be used as basis for finding out controls and guides of base metal mineralisation. These structures along with faults/shears located from airborne geophysical magnetic and electromagnetic data could be the basis of synthesis for finalizing controls and guides of base metal mineralisation. Integration of controls established as above along with airborne magnetic and electromagnetic data of GSI and ground geophysical data of GSI (Ram Gopal, 2004) have been used for synthesis and narrowing down of targets. Interpretation of such data may lead to identification of target areas for detailed exploration.

Environmental changes in the ore deposition could be guide for mineralisation. As brines moved from foreland folds to platformal carbonate sequences therefore, exploration could be restricted to dolomite in the areas of high limestone. Stratigraphically favourable sites are near basement, paleotopographic highs, rapid facies changes should be searched by geophysics/geological mapping, topographic highs, disconformities and highly permeable zones such as quartz reefs, large areas of sparry white dolomite, collapse breccia should be regarded as areas of high priority exploration.

The techniques used for predicting target areas for exploration are discussed below:

### **Regional Exploration:**

Satellite images and aerial photographs could be interpreted followed by field checks to update geological maps. The litho-structural contrasts to be used for the identification of faults, fractures and lineaments and confirmed by ground checks, if exposed. Concealed faults could be interpreted using magnetic breaks in the aeromagnetic maps. Satellite images to be used to interpret lineaments and lithological discontinuity on the ground. It may be difficult to interpret faults which are parallel to litho units with the use of airborne geophysical and imagery data. Such features can be however, interpreted using ground magnetic geophysical data. The faults which are oblique to regional structures can be

interpreted by aerial photographs.

High resolution and high sensitivity aeromagnetic surveys are especially capable of detecting patterns in the distribution of opaque oxide minerals in a region in which geology is favorable for certain kinds of ores. Relationship occurs between magnetic minerals and depositional environments. There are many geological events other than ore forming processes which affect magnetite and these will tend to overprint ore environment magnetic signatures. The pitfalls and ambiguities that beset the interpretation of magnetic data are numerous. Sedex deposits of present area under study are having pyrite and pyrrhotite. The magnetic anomalies caused by the pyrrhotite tend to be extremely weak and erratic. In the present area behavior of ore texture, morphology, mineralogical association of constituent minerals and their ratio and geological setting is different in vent proximal and vent distal deposits interpretation of magnetic data is more challenging. The areas having outcrops could be surveyed geochemically.

Integration of geological, aeromagnetic and electromagnetic data could be done by transferring all the different layers on one scale. The geological layers contained lithological variations including gossan and host rocks. The structural layers to contain (a) faults, (b) fractures/lineaments, (c) shear zones, (d) fold axis and (e) trend lines. The airborne electromagnetic data and ground geophysical data acquired by GSI/RP holders may provide important input as they indicate conductivity of the rock formations and associated sulphide ore bodies. Magnetic high and low axes and discontinuities can be used as inputs for identification of faults. These data sets could be integrated.

#### **Detailed/local scale exploration:**

Ground Geophysical signature: Induced polarization (IP) methods can be applied in RD terrain as sufficient conductive minerals such as galena, pyrite, and pyrrhotite are present, and the chargeability of the host carbonates is low.

Ground electromagnetic (EM) methods may work for deposits sites with sufficient concentrations of iron sulphide minerals. Seismic, magnetic, and gravity methods can be used to identify some geological features associated with these deposits, such as basement highs beneath sedimentary successions, faults, sinkholes and carbonate/shale facies.

Airborne magnetic surveys were successfully used in delineating lineaments.

Since sphalerite and gangue minerals have different densities, gravity surveys could prove useful in exploring for sulphide bodies containing mainly sphalerite.

Geochemical anomalies: Zinc, lead, iron, silver, barium and manganese can be detected in residual soil samples and stream sediments.

Alteration: Clay minerals and chlorite, muscovite and sericite alterations are useful exploration tools when integrated with geological data and hydrothermal alterations around ore zone e.g. sericite, quartz and carbonate.

Element/metal zones: For local scale exploration element zoning consisting dominance of pyrite followed by pyrrhotite in the periphery of lead-zinc deposit. Appearance of galena and sphalerite is noticed after wide zones of pyrite and pyrrhotite are characteristic features. Pyrrhotite zonation is noticed above hydrothermal vent extending to Pb-Zn zone in the vent.

## **7 Conclusion**

Rocks of Bhilwara Supergroup are endowed with some of the best zinc resources of country. It has been presumed that preliminary exploration has been completed but present study has shown that still more work can be attempted to locate new deposits. The deposits are sediment hosted and include massive sulphides (SHMS) of Pb-Zn. SHMS deposits occur in intracratonic rift in half graben sediments. At the basin floor hydrothermal discharges were focused at the intersection of extensional and transform faults. Presence of mafic bodies in most of the ore environments suggests that hydrothermal convection systems were driven by high level magma bodies. In most cases low rigidity, permeability and thermal conductivity of host sediments helped to focus and prolong hydrothermal discharge to a number of limited sites. Rajpura Dariba deposit displays biphasic mineralisation including stratiform sulphides and post metamorphic epigenitically melt introduced independently. Salient features of vein ores such as occurrences as pods, segregation veins or open space fillings traversing the banded ores, absence of deformation and recrystallisation textures indicate that these veins are post-metamorphic and could have

formed from a different ore fluid. The cavity filling nature of vein ore and their occurrence in irregular shear planes suggest their environment of ore formation was different than imprints of metamorphism in banded ores. The source of this fluid could be intrusive granite located during present studies (Misra, B. and Mookerjee, A. 1984; Mishra, B., 2000).

Ore search would require identification of faults as sites of ore concentration in environment of favourable host rocks using magnetic and gravity geophysical data for selecting regional targets. Identification of volcanoclastic rocks, graphite mica-tuffaceous schist and, marble coupled with hydrothermal alteration and element/metal zones will demarcate local targets for selecting drill sites.

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