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The Metamorphic Evolution of the Base Metal Sulphide Deposit of Rampura-Agucha, Rajasthan: Petrographical Evidences

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Abstract

Located adjacent to the Banded Gneissic Complex, Rampura-Agucha is the only sulphide ore deposit discovered within Precambrian basement gneisses of Rajasthan. The deposit is the largest Pb--Zn deposit in the country producing 9* 10^5 tons per annum. The main ore minerals are sphalerite, pyrrhotite, galena and graphite. The deposit occurs in a doubly plunging synformal strucuture and in a transverse section it appears as a slab that wedges out towards the bottom. The ores are metamorphosed along with the graphite-bearing metapelitic host rocks. Petrographical study of the ores and the silicates reveal that ores, silicates and ore-silicates togetherly recorded the imprints of metamorphism and deformation and document it without undergoing resetting by later geological processes.

Keywords: Sulphide Ores, Basement Gneiss, Metamorphism, Deformation, Petrographical Evidences.

Introduction

The Rampura-Agucha lead-zinc deposit (Fig.1) is located 15 km southeast of Gulabpura in the Bhilwara district, Rajasthan. The deposit is significant because of its large potential and geological setting. The deposit is the largest Pb-Zn deposit in the country (Gandhi, 2003). Rampura-Agucha base metal sulphide deposit (Fig.1) is metamorphosed along with host rock that is graphite bearing metapelitic rocks.

Metamorphism and deformation of sulphide deposits is a subject that evoked all along a great deal of scientific interest.The aim of study is to find how did the sulphide ores behave during mtamorphism? What are the records of metamorphism of ores preserved? Or do the ores totally reset themselves to the later retrograde phase of metamorphism? And also how the ores equilibrated with the silicates? Are new minerals formed due to the ore-silicate equilibration? Is there any change in the chemistry of the silicates? Is there any change in the composition of the ores? Is it possible to distinguish the prograde phase and retrograde phase of metamorphism from ore-silicate textures as well as the changes underwent due to successive phases of metamorphism?

The ores vis-à-vis the silicates of Rampura—Agucha deposit have recorded the imprints of prograde phase of metamorphism and document the events of metamorphism through textural evidences. Sulfides are non-quenchable; rarely do the sulphide ores preserve the imprints of earlier phases of metamorphism and easily readjust them to the later retrograde phase. This deposit is one of those rare metamorphosed sulphide deposits that occurs in Mewar gneiss and has preserved the evidences of metamorphism without being altered by later geological processes.

The deposit has drawn the attention of many workers. Deb (Deb and Sarkar, 1990) studied the deposit with the detailed REE geochemical analysis. Deb (Deb et.al, 1990B) concluded that the REE patterns of the metasediments are suggestive of continental (BGC) derivation of the sediments. Deb (Deb and Sehgal, 1997) had studied in detail the metamorphism of ores vis-à-vis the silicates and calibrated the metamorphic pressure and temperature from silicate assemblages. Holler (Holler etal., 1996) studied the fluid composition of the ores with the aid of microspectrometry. Roy (Roy etal., 1981) got into the structural aspects of the deposit and concluded that the rocks underwent multiple phases of deformations. Gandhi (Gandhi etal., 1984) suggested that the deposit occurred in a deformed synformal structure. The model Pb-age of the deposit is 1800 Ma (Deb etal.1989).Absense of coherent element dispersion halo around the ore orebody led some workers to suggest that the ore body was allochthonous in origin (Shah,2004). But origin of such a huge deposit by allochthonous origin is difficult to explain.Viswanath etal (2006) studied the geometallurgical aspects of the deposit and identified the domains within the deposit with similar textural characteristics and their corelation with actual plant performance. Hazaika etal (2013) made a comparative study of geochronology of metamorphism of Rampura-Agucha deposit and Rajpura-Dariba deposit of Aravalli-Delhi belt, India. He concluded that Rampura-Agucha deposit suffered metamorphism during 1.65 Ga and again in 1.0 Ga. Misra and Bernhardt (2009) studied the metamorphism of the silicates as well as the sulfides and tried to make a comparative study of their recorded history of metamorphism.

The samples were collected from the country rock at a distance from the ore body. 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 altogether fortyeight (48) samples of host-rocks and ores were collected. Fifteen (15) samples were collected from the mine and the rest thirtythree (33) were collected from mine-dump.

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

Rampura-Agucha deposit falls on Bhilwara supergroup vis-à-vis mineralized supracrustal Belts consists of Jahajpur Sawar, Pur-Banera, Rajpura-Dariba, Rampura-Agucha and Bhinder deposits (Fig. 2). The Bhindwara litho-tectonic belt lies between the banded gneissic complex in the west and Vindhyan supergroup to the east consists of several subparallel and sub-linear zones of differently metamorphosed sedimentary (volcanic) rocks, the metamorphism increasing from east towards the west. It is 200km in lenth. It is about 100km at its widest in the northern part, narrowing down to about 10km in the south, near Bhinder.

Several ore deposits, ore belts occur within the Bhilwara belt, including Rampura--Agucha deposit. The mineralisations are associated with the supracrustal rocks that were deposited on the continental rifts (Deb and Sarkar, 1990: Sinha-Roy, 1984). According to Roy (Roy etal.1981) and Deb (Deb and Sarkar, 1990) these supracrustals are time equivalents of the Aravalli sediments (supergroup). However Rao (Raja Rao, 1970) and his co-workers (Rao etal.1976) suggested an older age of the supracrustal rocks of the Bhilwara belt. Gupta (Gupta etal.1997) included the mineralized belt under the youngest unit of Pre-Aravalli equivalent isolated cover sequences deposited in pull-apart basins within Mangalwar complex. Aravalli Craton is broadly divided into the following categories according to Ramakrishnan and Vaidyanathan (2008) (Fig. 3):

1. Archaean Mewar Gneiss.
2. Bhilwara SuperGroup-Mineralised supracrustal belts (Rampura-Agucha, Rajpura-Dariba etc.)
3. Mineralised supracrustal belts (Rampur-Agucha, Rajpura-Dariba etc.)
4. Aravalli-Delhi orogen

Mewar gneiss forms the basement of Aravalli supergroup, It consists of migmatites, gneisses and granitoids. Heron (1953) termed them as Banded Gnessic Complex (BGC). Extensive mapping by the Geological Survey of India(Gupta etal.,1980) led to the divison of BGC, renamed as Bhilwara SuperGroup into three tectono-stratigraphic units viz. 1) Hindoli Group at the bottom, 2) Mangalwar complex with isolated mineralized belts at middle and 3) Sandmata complex at the top. The Rampura-Agucha belt located close to Delwara lineament at the contact of Mangalwar and Sandmata complexes to the west of Sawar belt.

The orebody, the Ores and Their Metamorphism

The orebody

The Rampura—Agucha deposit explored by State Department of Geology and Mines,. Geological Survey of India and HZL is one of the most important Zn—Pb—(Cu) deposit in India producing $9*10^5$ tons per annum.Total ore reserve is 63.7 mt (proven 39.2mt + probable13.8 mt + possible 10.7 mt) with an average grade of 13.6% Zn, 1.9%Pb and 45ppm Ag (HZL, 1992), quoted by Holler (Holler and Gandhi, 1995).

The rock types in and around RA deposit, proceeding east to west (Fig.4) are 1) Garnet—Biotite –Sillimanite—Gneiss (GBSG) with bands of amphibolite and calc-silicate rocks, intruded by aplite and pegmatite. 2) Graphite—Mica—Sillimanite schist containing the ores. 3) GBSG with lenses of amphibolites, quartzo-felspathic bands and calc—silicate rocks intruded by pegmatite aplite veins. 4) granite gneiss.5) banded gneiss. Using garnet—biotite and garnet –hornblende geothermometers and garnet—plagioclase-sillimanite-quartz geobarometer, Deb (Deb and Sehgal, 1997) determined the T_{max} and P_{max} of metamorphism to be 650^0 C and 6Kb respectively. Almost all the rocks in and around the deposit contain garnet. Mg-enrichment of the silicates in the ore zone that is characteristic of metamorphosed sulfide deposit is also present here. The deposit occurs in a doubly plunging synformal structure (Gandhi etal., 1984) and in a transverse section it appears as a slab, which wedges out towards the bottom (Fig. 5).Bhatnagar (Bhatnagar and Mathur, 1989) and Roy (Roy etal., 1981) concluded that three successive phases of deformation took place in the belt. The first phase produced NNW-SSE trending isoclinals, reclined folds (F1), while the 2^{nd} phase also produced isocline to tight folds and trending NE-SW, the third phase of deformation was weak.

The Ores

The main ore minerals i.e. opaque phases in the ores are sphalerite, pyrrhotite, pyrite, galena and graphite. Minor phases include chalcopyrite, arsenopyrite and tetrahedrite—tenantite. Sphalerite dominates over other sulphides (Deb and Sarkar1990; Ranawat etal., 1988; Genkin and Schimdt, 1991; Holler and Gandhi, 1995; Holler and Stumpfi, 1995; Mukherjee etal., 1991). The gangue minerals comprise quartz, feldspar, sillimanite, graphite and phyllosilicates. Sulfosalt has also been reported as trace phases from the deposit. In lump ores the grain sizes vary widely, the largest grains could be several mm in size. Overall fabric of the ore in hand specimen is schistose.

There are numerous roundish to elliptical rock fragments within the ore, the size of these bodies range from <1mm to few cm in diameter (fig. 6). These bodies may consist of feldspar, sillimanite, graphite, phyllosillicates and quartz. Many minute bodies may consist of a single mineral or two. Here the ball structure is constituted of plagioclase feldspar and phyllosilicate. This is 'ball' or 'knead' 'durchbewegung structure' described from many ore deposits around the world (Geizer, 1971; Vokes, 1973; Sarkar et.al., 1980).

Although some of the above workers differed in details, the overall explanation is that when sulphidic (Pb-Zn-Cu-Fe- sulphides) ores interlayered interwoven with silicate rocks, quartz veins are subjected to shearing during dynamo-thermal perturbations, the sulphide will generally behave as a ductile material and the silicate will yield by brittle deformation. With continual movement, the fragments of the rigid members will be rolling (may be also broken into smaller pieces), ultimately shaping into roundish bodies in a sulphidic matrix. Sometimes even phyllosilicate patches may roll into sigmoidal to rounded bodies.

The Ores and Its Metamorphism

A moderately rich ore under the microscope may be virtually monomineralic particularly sphalerite (Fig. 7) or dominantly sphaleritic with a little or another phase such as pyrrhotite (Fig.8). There are situations where other phases such as pyrite, galena also are present in considerable proportions. Sphalerite can even be locally unimportant. In polished section with considerable proportions of silicate gangue minerals, the silicates may be shattered (Fig.7) with the sulphides having penetrated along the fractures (Fig.9) or the specimen may represent a domain where the ore is virtually strain free. Evidence of late high unmitigated strain may ofcourse be conspicuous in virtually gang free sulphidic aggregates.

In low strain domain the overall fabric is one of annealing with the major phase polygonised and the minor phases occupying triple points. In (Fig.10) sphalerite is polygonised and pyrrhotite occupied the triple point or interstices of sphalerite.

Speaking exclusively of the sphalerite fabric, its grain size vary widely within the limits of single photomicrograph (Fig.10) controlled by deformational recrystallisation constraints. Twinning is a common feature in Rampura—Agucha sphalerite ores. They are both growth (annealing) and deformational in type, distinguished mainly on the morphology of the twin lamellae. Sphalerite deforms at all temperatures by twinning and slip on (111) and (112-)(Clark etal.,1973). The interesting feature is the presence of small sphalerite grains within the porphyroblast of the same mineral. The guest and the host are only partially coherent, or are apparent under the microscope. Is it a result of fast growth?

Pyrrhotite and sphalerite grains show their relative strength under deformational constraints (Fig.10). Often Small droplets of pyrrhotite grains are included within the sphalerite. Symplectitic texture between sphalerite and pyrrhotite are not uncommon. It also shows their relative characters to negotiate during deformation. The aggregates of the pyrrhotite commonly show equilibrium texture with 120^0 angle with interstices occupied by sphalerite. The grains are virtually strain free and may be crystallized during retrogression.

Graphite is present rarely though in the ores as distorted sheaves of flakes (Fig.11). It also occurs with other silicate mineral forming ball structures (Fig. 6).

Pyrite grains are framboidal and often replaced either by sphalerite or pyrrhotite.

Chalcopyrite may show partial polygonisation and growth (annealing) twin and deformational twins. Chalcopyrite as small mineral grains occurs at the triple points in a sphalerite matrix.

Galena shows advanced recovery and recrystallisation and is included and replaced by sphalerite. This is in consonance with the available result of experimental studies. Clarke (Clark etal., 1977) showed that galena developed recovery and annealing features at temperature in which sphalerite and chalcopyrite will little response. In contrast to sphalerite, deformation twins are absent in galena as in most of the galena bearing deposits. It may be worthwhile to recall that Lyall (Lyall etal.,1986) studied the development of deformation twins in galena at various strain rates. His conclusion was that, natural deformation twinning in galena developed only at very high strain rate is not normally expected in normal situation. Therefore twinning is not normally expected to be an active deformation mechanism in galena under normal tectonic evolution. It was noticed in Rampura—Agucha ores either.

Textural relationship of the ore minerals with the silicates are equally interesting and as we shall see later, important in the interpretation of the evolution of the ores.

First of all we refer to the occurrence of sphalerite within and at the interstices of feldspar and quartz grains (Fig.12) suggesting that sphalerite coexisted with these minerals. This holds good also for the inclusion of sphalerite and pyrrhotite within feldspar and cordierite. In some cases polygonised strained quartz grains include sphalerite within them. Blebs and droplets of sphalerite and pyrrhotite are included in plagioclase feldspar. Minute blebs of elongated sphalerite and pyrrhotite grains are included within prograde biotite grains and oriented parallel to the foliation along with biotite grain (Fig. 13). No hydrous or secondary mineral is seen nearby. Ball structure observed in lump-specimen and discussed earlier are common in the ores viewed under the microscope. There this could be monomineralic being formed of such minerals as cordierite, biotite, garnet(Fig. 6) or aggregates of all these (and other) phases. Another feature is the intricate network structure of silicates and ore minerals. Occurrences of ore minerals along the cleavages of biotite grains are common. The protomylonitic quartz grains and minute grains of ore minerals are oriented parallel to the direction of dynamic deformation. Often the silicate grains are broken apart or kinked within sulphide matrix may be owing to difference in rheologic property between the two. The pyrrhotite grains are elongated and parallel to foliation along with silicate grains and are a common feature (Fig.14).

Veinlets of ore into individual silicate grains and their aggregation constitute another interesting feature under the microscope. (Fig. 9) shows a transmitted light picture of sphalerite rich sulphidic veinlet in a plagioclase feldspar aggregates. Such veinlets in incident light microscope show that they are recrystallised ore minerals. They are likely to have been emplaced by plastic flowage during a tectonothermal event. This is a case of dynamic recrystallisation. However very thin veinlets controlled by micro-fractures in individual minerals, formed by secondary hydrothermal fluids generated during retrogression could be precipitant.

Conclusion of the ore petrographic studies discussed so far are, that the ores were metamorphosed.followed by recrystallisation in varying degrees. Large scale remobilization of ores during metamorphism is not evidenced except in the case of veinlets in the cleavages and fractures in the associated silicates.

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Figures

Fig – I : Rampura - Agucha deposit at Rajasthan , India

Fig:- 2: *M*ineralised Sedimentary Belts within BGC (after Sinha-Roy 1984).

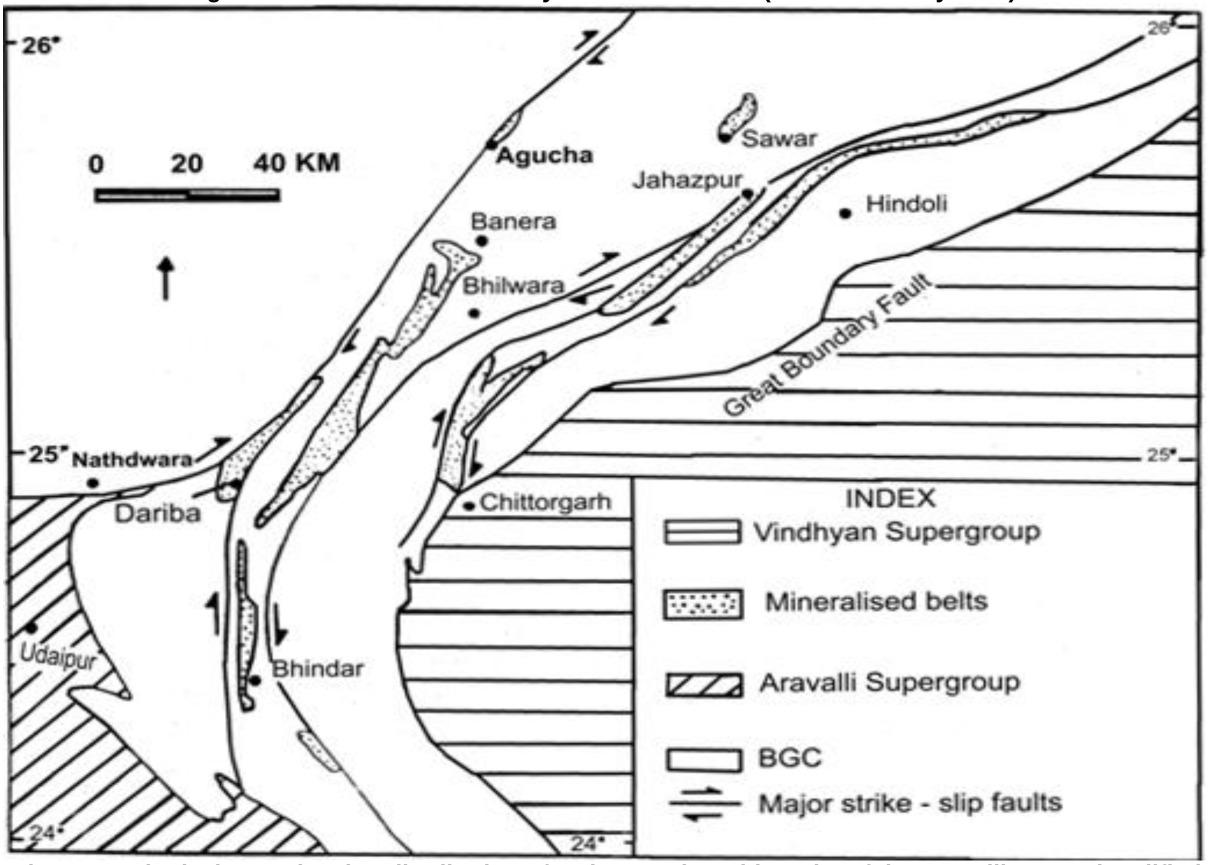

Fig -3 : Geological map showing distribution of Major Stratigraphic Units of the Aravalli craton (modified after Roy and Jakhar, 2002,p.40) A- Alwar ; Bl-Bhilwara; BN- Bhindar; BW- Beawar; M- Mangalwar; N-Nathdwara; P- Pisangan; PH- Phuad; RA- Rampura-Agucha; RD- Rajpura- Dariba; S – Salumbar; SR – Sarara; Z – Zawar.

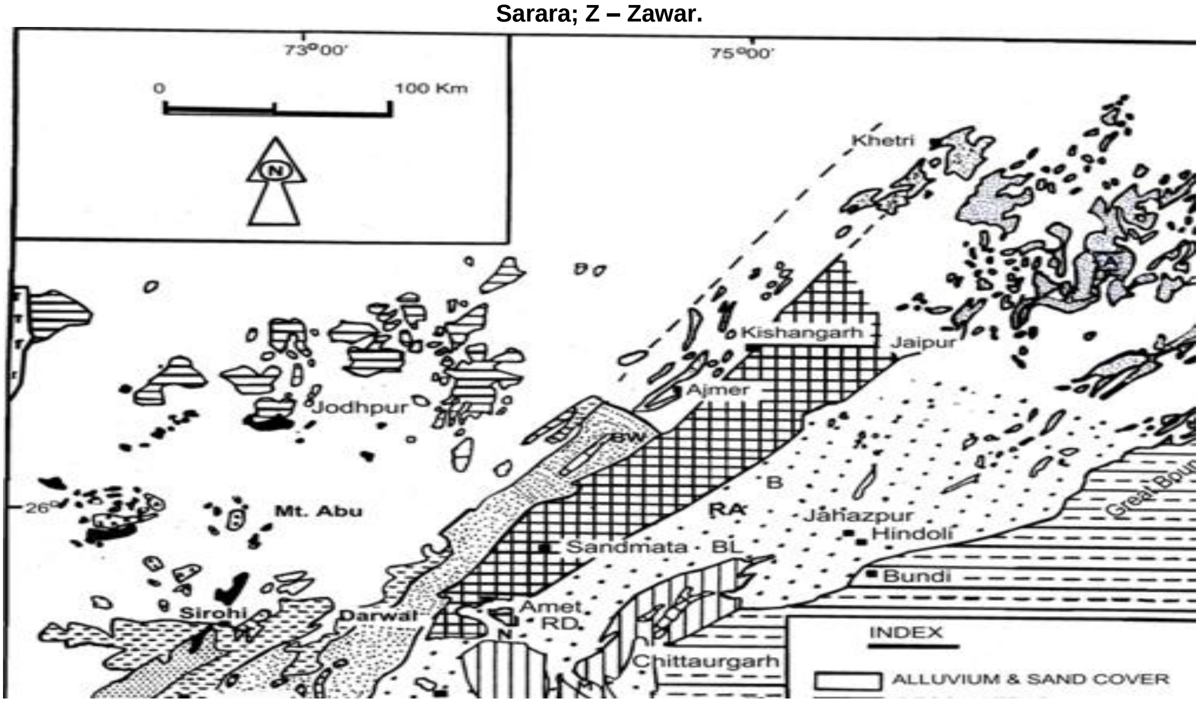

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Fig. 4: A Geoglogical Map of The Rampura- Agucha Area (After Deb And Sehgal, 1997).

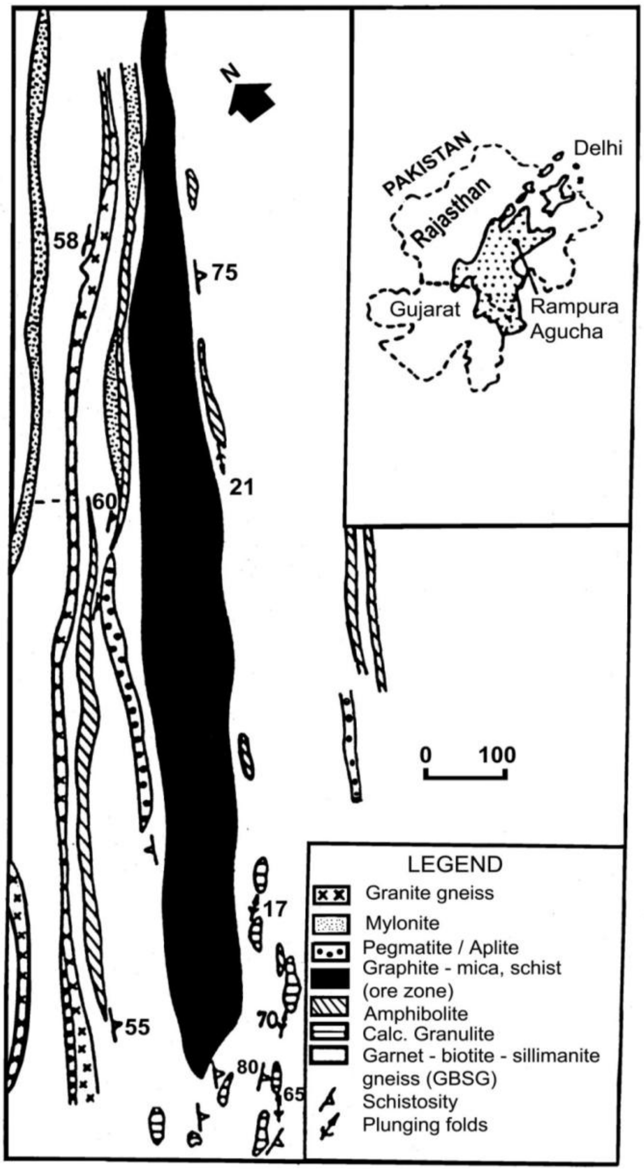

Fig. 5: A Generalized Transverse Section through the Ore Deposit at Rampura-Agucha (After Bhatnagar and Mathur, 1989).

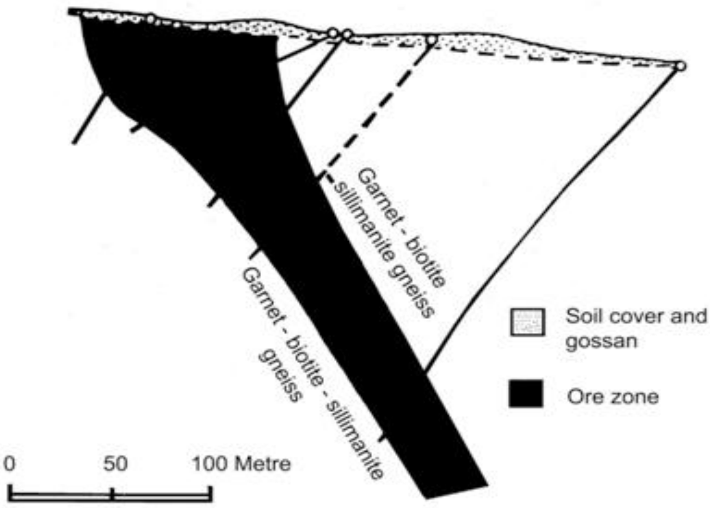

Fig. 6: Rounded Balls of Feldspar-Cordierite Float in Sphalerite (SP) Matrix. (Plane Polarized Light).

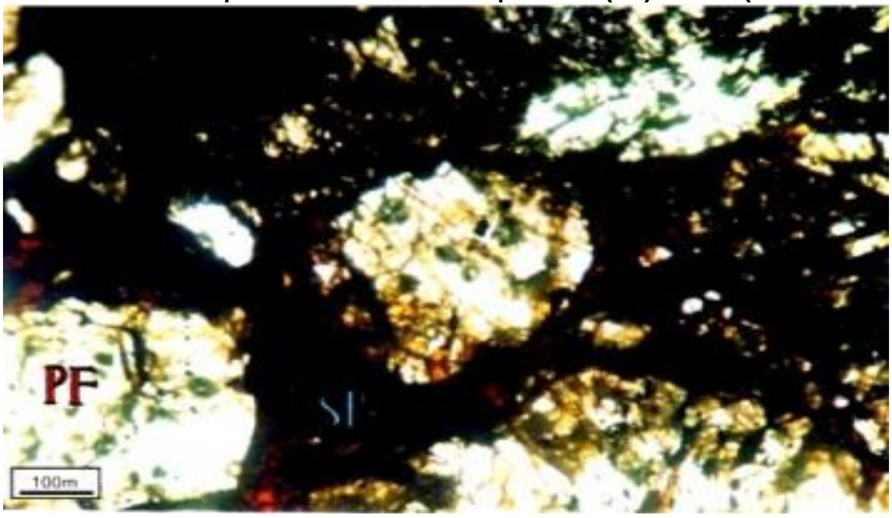

Fig. 7: The Phyllosilicate Grains (Psi) are fragmented and broken apart in sphalerite (SP) matrix. (Plane Polarized light).

Fig. 8: Elongated Pyrrhotite (Po) Grains Are Oriented within the Sphalerite (Sp) Matrx. (Plane Polarized Light).

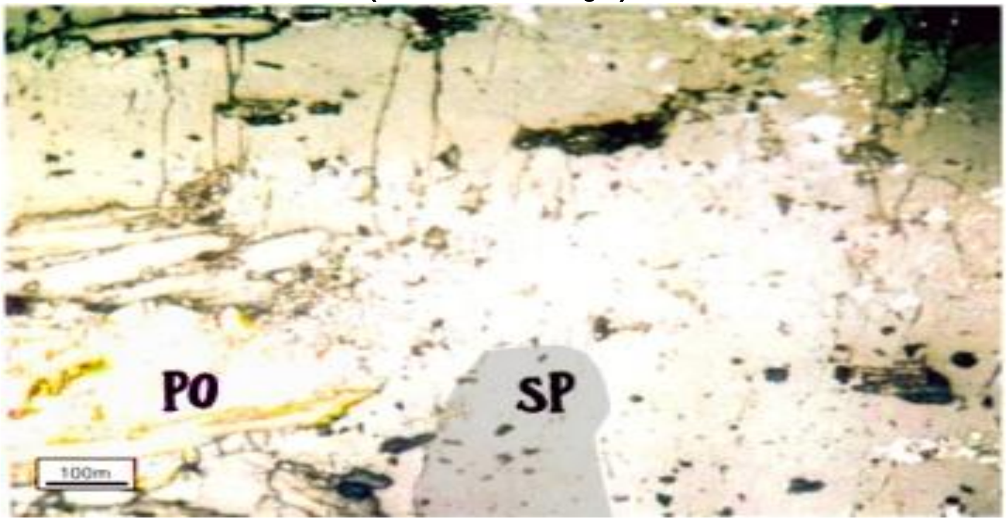

Fig. 9: Vienlets of Sphalerite (Sp) Have Protruded the Silicate Aggregates of Plagioclase Feldspar (PF) And Sillimanite(S). No Hydrous Mineral is Found Near by; Is It A Plastic Flowage? (Plane Polarized Light).

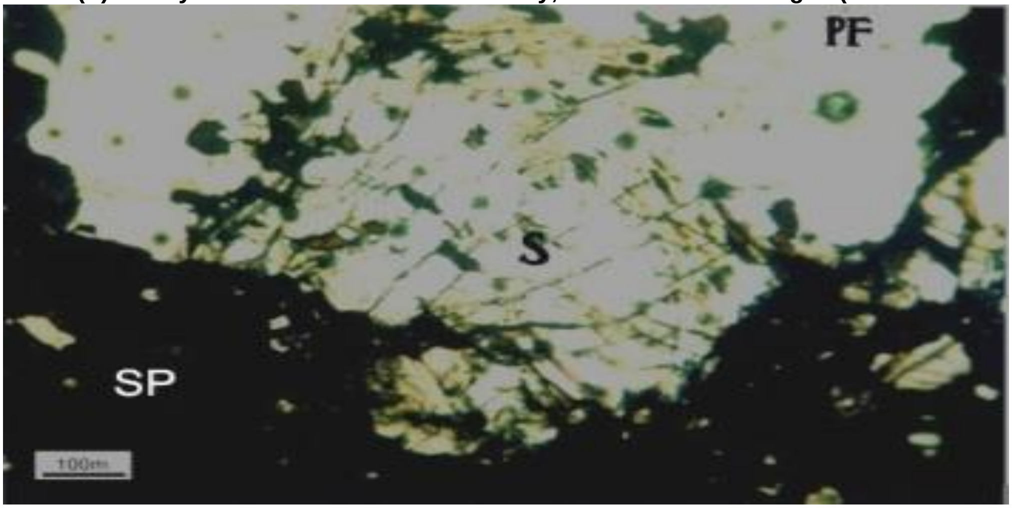

Fig. 10: Granular fabric in Sphalerite (Sp) Aggregate. Grain size varies widely within the limits of a single photomicrograph, apparently constrained by deformation recrystallisation. Grains contain growth and deformation twins. Polygonisation is differential. The section has been etched with saturated chromic acid solution. PO: Pyrrhotite,(Plane Polarized Light).

Fig. 11: A graphite (G) Grain is being kinked within Sphalerite (SP) Matrix. Pyrrhotite (PO) Grains are included in Sphalerite. (Plane Polarized Light).

Fig. 12: Droplets of Pyrrhotite(po) are included within the Quartz-Feldspathic Matrix without any Hydrous Minerals occurring nearby. PF: Plagioclase Feldspar, (Plane Polarized Light).

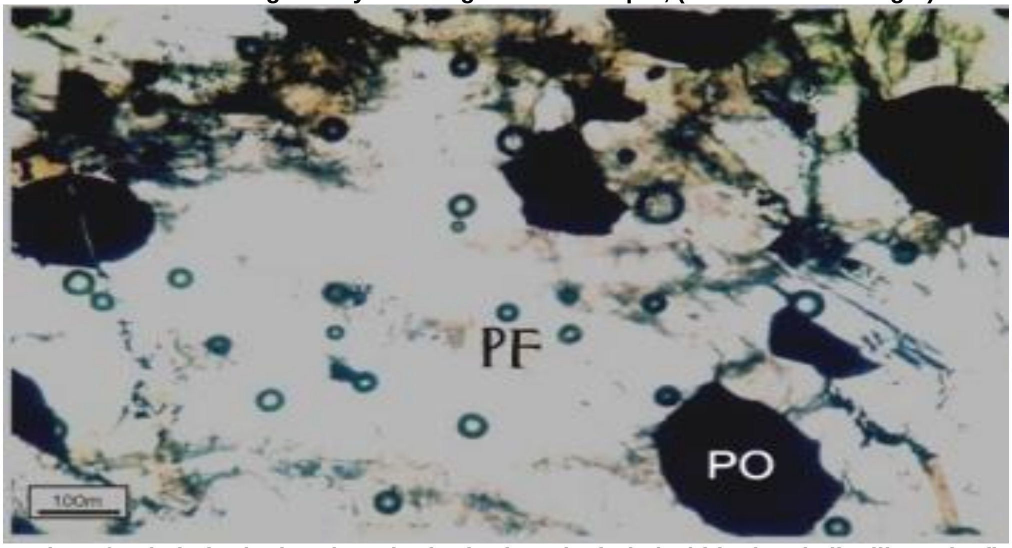

Fig. 13: Grains of Sphalerite (SP) and pyrrhotite (PO) are included within the phyllosilicate (PSi) and are oriented along with the silicate grains parallel to the Foliation. (Plane Polarized Light).

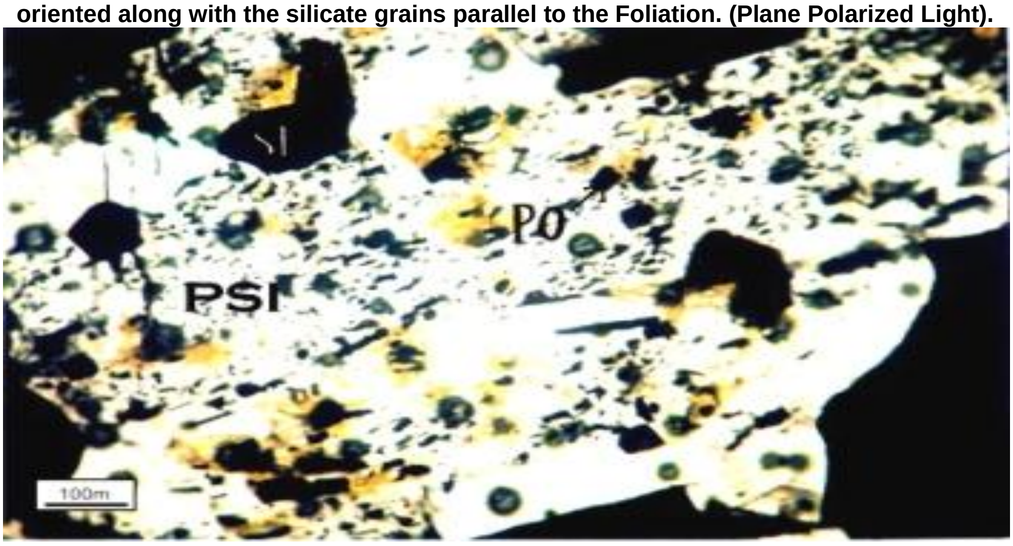

Fig. 14: The Silicate (Si) Grains and Pyrrhotite (Po) grains are Elongated Parallel to the Regional Foliation. (Plane Polarized Light)