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Geo-Metallurgical Studies of Rampura Agucha Deposit

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Abstract

Rampura Agucha deposit which is the 5 th largest deposit in the world in terms of the reserves and 3rd largest in terms of metal production, is also one of the most complex deposit in the world in terms of its textural characteristics, due to its highly deformed nature. The paper details the results of Geo-metallurgical studies for identification of domains within the deposit with similar textural characteristics and their correlation with actual plant performance. As recovery performance of the valuable minerals directly impacts the profitability, the plant metallurgist would be very much interested in improvement of recovery performance of lead / zinc and the inputs of process mineralogy for understanding metallurgical process are very important and the insights provided by process mineralogy in understanding and improving the recovery processes are described.

INTRODUCTION

Rampura Agucha deposit is 5th largest deposit with a total of 75.03 Mt of reserves & resources with an situ grade of 1.86 % Pb and 12.65% Zn and 3rd largest in terms of production of contained Zinc metal in the world. Besides being a world-class deposit it also boasts of high complexity in terms of its geo-metallurgical characteristics i.e. textural characters, which makes it challenging for a metallurgist to achieve optimum recoveries and grade. The various mineralogical characteristics that directly impact the process parameters are described in the paper.

GEOLOGY AND MINERALIZATION

Host Rock

Graphite mica sillimanite schist /Gneiss but as in several portions of the ore body ore mineral concentration is more than 50 % it would be more appropriate to call the ore bearing rock as Sphalerite – pyrrhotite silliminite graphite gneiss

Shape and Extent of Ore Body

The ore body is lens shaped with a maximum width of 100m in the central portion and an average width of 58 m and extends for about 1550 m from S725 to N825. In the depth extent it is extending for more than 750 m below surface level.

Ore Minerals

Sphalerite, Galena, Pyrite, Pyrrhotite, Arsenopyrite & other Sulpho salts

Gangue Minerals

Quartz, Feldspar, Graphite, Sillimanite, Mica, Gypsum & Calcite

Modal Percentage Ranges

Sphalerite :15-20%, Galena: 1-2%, Pyrite:15-18%, Pyrrhotite : 12-14%, Graphite: 4-7-%, Gangue : 45-50%.

The above distribution gives a broad picture, but does not reflect thee varation along strike and dip. Though there is not much variation in dip (Table No 1), there is a lot of variation in the distribution of ore forming minerals and rock forming minerals especially along the strike. Pyrrhotite is more dominant in the southern portion and pyrite is more dominant in the northern portion of the orebody. Similarly the host rock varies from mica rich to quartz / feldspar rich.

Table 1: Levelwise Percentage Distribution of Ore Forming Minerals (OFM) and Rock Forming Minerals (RFM) in Ore Zone

Levels	360-310	310-260	260 - 210	210-160
Ore Forming Minerals (OFM)				
Sphalerite	21	19	22	20
Galena	2	2	3	2
Pyrite+ Pyrrhotite	20	22	20	23
Total	43	43	45	45
Rock Forming Minerals (RFM)				
Quartz	17	17	18	18
Felspar	17	18	17	16
Mica	15	17	16	14
Graphite	4	4	3	3
Miss	4	1	1	4
Total	53	57	55	55

Mineralogy of the Ore

Sphalerite

The sphalerite is of two types; Coarse grained granular variety with abundance of more than 60 % (>74 microns) (Fig No 2) having inclusions of submicroscopic size pyrrhotite (5-10 microns) and fine grained, cataclastic variety (Fig No 3)containing fine grained< 50 microns inclusions of gangue minerals which are thoroughly intermixed with sphalerite and other sulfides leading to poor liberation. Fine grained sphalerite is noted wherever it has been involved in cataclasis The rounded fragments of quartz – felspar occur in a fine grained ground mass of sphalerite, pyrrhotite, pyrite and silicates. The rounded porphyroclasts of quatzo-felspathic materials are coarse grained (Fig No 4) while the sphalerite rich matrix is fine grained having inclusions of pyrrhotite, pyrite, quartz, plagioclase and potash felspar. Pyrrhotite inclusions are common in both coarse and fine grained sphalerite. Minor amounts of gangue minerals are also present in sphalerite ex graphite, silliminite and biotite.

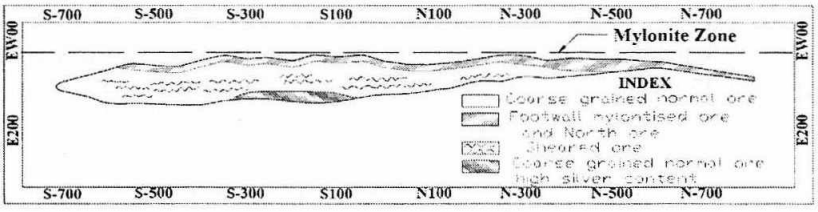

Fig. 1: Distribution of Different Ore Types in the Ore Zone

Galena

Occurs as medium to fine grained intergrowths with sphalerite, pyrite, pyrrhotite also as inclusion in other sulphides and entrapped in grains within graphite and micaceous minerals (10 – 20 microns) due to which recovery may not exceed 65 % (Fig No 3). Coarse-grained Galena is found in hanging wall area. Normally galena does not contain inclusions of other minerals but graphite occurs as inclusion in galena. Besides occurring as granular aggregates galena is found as infilling along cleavages of mica

and graphite. Galena displays deformation in the form of flowage, shearing out, emplacement along cleavage, fractures and as fine thin lamellar form.

Fig. 2: The Normal Type is Coarse Grained Which Simple Inter-Granular Relationship and Consequently Good Liberation Characteristics. (100X PPL)

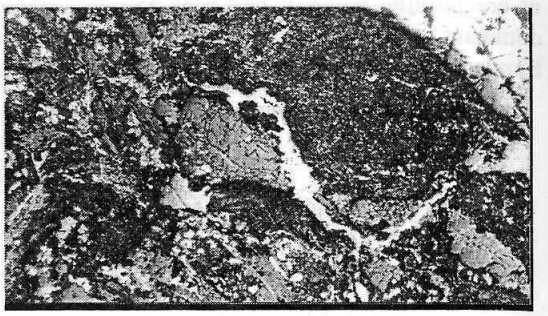

Fig. 3: View of Mylonitized Ore Which is Very Fine Grained and with Complex Textural Characteristics and Poor Liberation Characteristics. the Galena Has Migrated Into the Interstices of Mica and Would be Difficult to Recover. (100X PPL)

Fig. 4: the Sheared Ore (Durchbegweng Type Ore) Comparatively is Intermediate in Grain Size with Medium Textural Characteristics Liberation and Inter Mediate Textural Characteristics. (100X PPL)

Pyrite

Pyrite occurs as coarse grained aggregates intergrown with pyrrhotite and represents about 15-18 % by volume. Large porphyroblasts of pyrite show brittle fractures filled with other sulfides.

Pyrrhotite

Pyrrhotite occurs as granular medium grained aggregates associated with sphalerite and pyrite and galena and represents about 12-14 % by volume. It also occurs commonly as 5- 10 micron inclusions in Sphalerite.

Graphite

It is the commonest gangue mineral in association with ore minerals. It occurs as coarse 150 microns by 50 microns long grains showing bent and kinked flakes and fine grained fracture fillings encircling other gangue and ore minerals and represents about 7- 10 % by volume and is interlocked with Sphalerite and galena to form a sandwich like texture.

TEXTURAL FEATURES OF THE ORE BODY AND THEIR BEARING ON METALLURGICAL PERFORMANCE

Distribution of different ore types in the ore zone: The ore body is flanked on the foot wall side by a sheared mylonitic zone (Fig No 1), with a number of parallel shears within the ore body and thus

the ore zone is a predominantly sheared massive sulfide breccia. The ore body is distinctly different in texture from that of hanging wall and footwall. The ore in the hanging wall side is coarse grained and has good liberation characteristics while the on foot wall side because of the mylonitic shear zone the mineralisation is fine grained and has poor liberation characteristics (Fig No 3) In addition to this because of the number of shear zones traversing the ore body, the mineralisation within the shear zones is also sheared (Fig No 4) which has poor liberation characteristics.

Recovery is a function of liberation which directly proportional to textural complexity. Simpler the textural characteristic better the liberation vice versa. Based on the textural characteristics the ore types can be classified as Normal, sheared and mylonitised. As can be seen from the Fig. No 2 the normal type is coarse grained which simple inter-granular relationship and consequently good liberation characteristics.

The mylonitised ore (Fig. No.3) is very fine grained and with complex textural characteristics and poor liberation characteristics.

The sheared ore (Figure No. 4) comparatively is intermediate in grain size with medium textural characteristics and liberation characteristics

Optimum Mesh of Grinding

As it is not possible to mine the different ore types and treat them separately an optimum Mesh of Grind (MOG)which takes into account the global abundance of ore has to be designed. Based on various studies on the optimum MOG for different types of ore and their abundance an optimum MOG was found to be be 80% passing 63 microns. (Table No 2)

Table 2: Optimum Mesh of Grind for Different Type of Ore

Ore type	Characteristics	% abundance	MOG (microns)
Normal	Coarse grained, simple locking	70%	74
FW contact and North ore	Fine grained and mylontised, complex locking	20%	37
Sheared ore	medium locking	10%	53
Optimum grind for a mixture of ores			63

BENCHMARKING OF ZINC RECOVERY OF RAMPURA – AGUCHA AGAINST OTHER MAJOR ZINC MINES

As can be seen from the Figure No.5 the Zinc recovery achieved at RA Mine is second highest in the world and exceeded only by Broken Hill deposit. But the comparison is not a true comparison and has

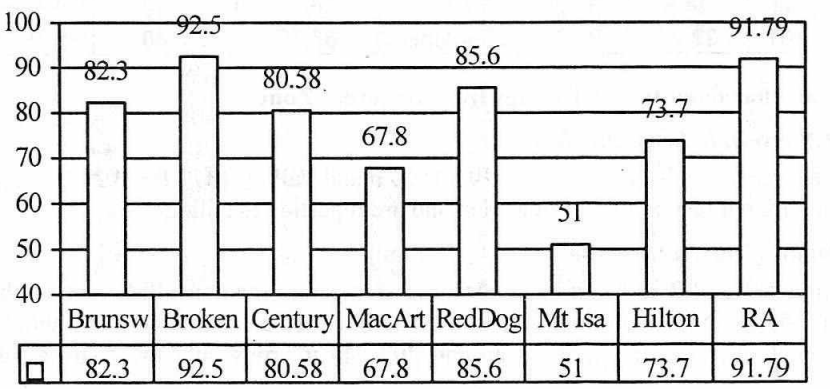

Fig. 5: Comparison of Zinc Recovery of Major Mines of the World

to be done on a textural basis. The ore at Broken hill is coarse grained with simple liberation characterstics while the ore of RA Mine has complex liberation characterstics, thus making the achievement more creditable.But keeping the benchmark of recovery attained at Briken Hill we want to achieve /exceed the performance and for this purpose a detailed mineralogical study was carried out to find out the mode of losses of zinc.

Metallurgical Characteristics of Different Zones of Ore

For operational purposes the ore based on the geographical distribution has been classified as North zone ore ie north of N150 grid and the ore South of it as South ore (Fig. No 1). As can be seen from Fig. No.6, the tailing values increase from the South to North.

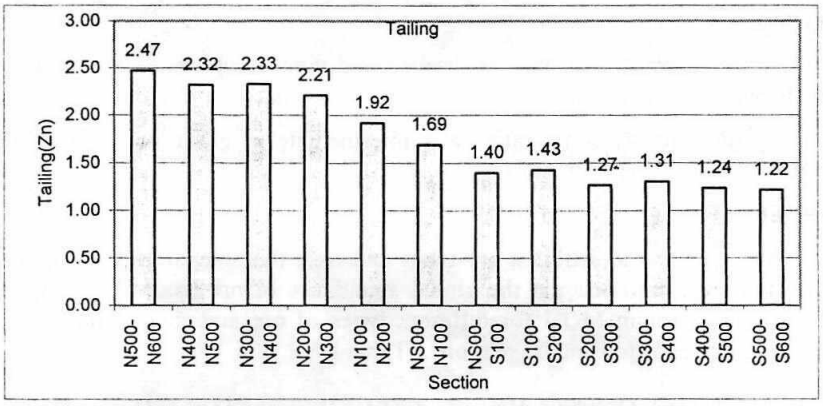

Fig. 6: Geographical Distribution of Zinc in Tailing Values Which Shows as Increase in Trend from South to North

Internal Benchmarking of Zn Recovery

In the quest for continual up gradation we have to bench mark actual v/s optimum metallurgical performances as determined by the mineralogy.

As a part of this study tailings from different zones of the deposit were studied (Table No.3)

Table 3: Mineralogical Characteristics of Tailings from Different Zone

Zone	Zn%	Tot Lib(%)	% Zn	Grain Size	Tot unlib (%)	% Zn	Grain Size
		Spl			Spl		
North	2.34	15.5	0.3	20-40 mic	84.5	1.7	5-30 micron, complex lock I
Mixed ore	2.41	34.5	0.72	20-40 mic	65.5	1.39	20-40 micron, complex locks
South zone	1..01	32.35	0.22	20-40 mic	67.75	0.48	20-40 micron, complex locks

Mineralogical Characterstics of Tailings from Different Zone

Behavior of Nonsulfide Lead and Zinc

The nonsulfde content in Feed : 0.19 % Pb, 0.30 % Zn and Tail : 0.18 % Pb, 0.29 % Zn indicating that the nonsulfdes are not responding to floatation and are reporting to tailing.

Results of Study of the North Zone

Out of a tailing value of 2.35 % zn from north ore subtracting the nonsulfide zinc of about 0.30% zn leaves about 2.05 % zn reporting to the tailings. The liberated sphalerite contains about 0.3 %, but as the grain size of liberated sphalerite is around 20 – 40 microns only the coarser particles can be recovered.

Recovery of Liberated Particles

- Assuming 50 % recovery of liberated fraction 0.15 % Zn can be recovered from the North area
- Present maximum recovery achieved from North Ore: 90 %.
- Saving in tailing by 0.15 % Zn increases zinc recovery from North ore from 90% to 90.75%

Recovery of Unliberated Particles

The grain size distribution of unliberated sphalerite indicates that it is between 5 – 30 microns and in an extreme case of N 500 it is between 5- 15 microns, in predominantly complex interlocking.

As can be seen from Figure No.7 the sphalerite grain which has reported in tailing is occurring in a complex interlocking with quartz/felspar gangue and as fine inclusions in gangue. Regrinding below 25 microns has to be done for liberation of this particle.

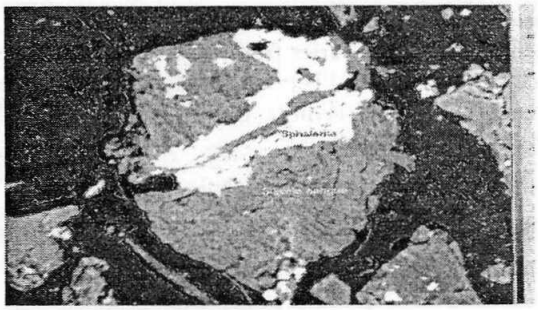

Fig. 7: Sphalerite Grain in Tailing as Complex Lock with Qtz/Felspar Gangue and as Fine Inclusions in Gangue Regrinding Below 25 Microns has to be Done for Liberation of this Particle

Option of Regrinding

As the sphalerite grains are contained in complex interlocking regrinding is not likely to be of much use and studies done earlier indicated that. negligible addition in liberated sphalerite in the northern part of the ore

Results of Study of the South Zone

Out of a tailing value of 1.01 % zn from south ore subtracting the nonsulfide zinc of about 0.30% zn leaves about 0.71 % zn reporting to the tailings. The liberated sphalerite contains about 0.22 % zn, but as the grain size of liberated sphalerite is around 20 – 40 microns averaging 30microns, only the coarser particles can be recovered by use of tank cells or column floatation. Assuming 50 % recovery of liberated fraction, % Zn recovered from liberated fraction: 0.11 %

- Present maximum recovery achieved from south Ore: 94 %
- Saving in tailing by 0.11 % Zn increases zinc recovery treating south ore from 94% to 94.55%

Recovery of Unliberated Particles

The Unliberated sphalerite particles constitute about (67%) with contained metal of 0.48% zn. The grain size distribution of unliberated sphalerite indicates that it is between 20 – 30microns, in predominantly complex interlocking.

Option of Regrinding

Studies done earlier had indicated perceptible addition in liberation appearing in the southern ore body and considering that about 10 % metal contained in complex interlocking can be recovered, about 0.05 % zn can be recovered from the unliberated particles of sphalerite by fine grinding.

Thus an optimum of 0.15 % zn can be recovered from north zone tailings and 0.16 % zn can be recovered from south zone tailings, under optimum conditions of plant operations.

Recoverable from north zone tailings of 0.15 % Zn is equivalent to 0.75 % increase in recovery. Considering a maximum recovery of 90 % in exclusively north zone the maximum limit is 90.75 %. In case of south 0.16 % Zn is equivalent to 0.80 % recovery increase.Considering a maximum recovery of 94 % presently achieved recovery the maximum limit is 94.80 %. Considering a ratio of 30 : 70 North to South which represents the global abundance in the deposit ratio a recovery of **93.58 % is achievable as per mineralogy** as against the 91.31 % zn recovery being achieved currently.

GRADE OF THE ZINC CONCENTRATE

Ideally a grade of more than 54 % Zn with a silica content of less than 1.5 % is desirable from the view point of a smelter. Mineralogical studies indicated that as against an iron assay of 7.34 % in the zinc concentrate only 2 % Pyrite + Pyrrhotite is seen which is equivalent to about 1 % Fe and thus it can be postulated that the missing 6% Fe can be accounted by inter atomic substitution of iron within the Sphalerite atomic lattice. Electron microprobe studies (SM Gandhi 2001, Table No4) have indicated that the iron content in sphalerite varies from 6-10 %. As can be seen from Fig No-8 which shows a sample of Zn Concentrate with well liberated Sphalerite grains. Even though the iron content in zinc concentrate is around 8 % there is little pyrite/pyrrhotite and the iron is accounted by substitution in the lattice of Sphalerite

Table 4 : Microprobe Analysis of Sulphide Minerals From R a Mine

	Sph1	Sph2	Sph3	Sph4	Sph5	Sph6	Sph7	Sph8	Sph9	Sph10	Sph11
S	32.3	33.0	33.4	33.6	33.2	33.2	33.6	33.9	33.5	33.5	33.9
Fe	8.7	8.4	9.6	6.9	8.2	8.3	10.8	6.7	6.7	7.0	8.5
Zn	57.5	57.7	56.9	59.1	57.9	57.6	55.8	59.1	59.3	59.1	57.1
Cd	0.2	0.3	0.2	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.1
Mn	0.3	0.2	0.3	0.4	1.1	1.2	0.2	0.2	0.2	0.2	0.2
Total	99.8	99.6	100.4	100.3	100.5	100.4	100.5	100.0	99.9	99.9	99.8

Table 4: Silver Distribution in Mill Products

For the year 2004-05	Feed	Metal Distribution
Particulars	Ag (ppm)	Ag%
Feed	51	100.00
Lead Conc.	826	29.44
Zinc Conc.	72	31.98
Tailing	26	38.58

- Thus the Sphalerite is a marmatitic variety and the Atomic formula is (Zn : Fe, S) and the Fe substitutes for Zn in the lattice to the extent of upto 10 %. In a normal sphalerite the Zinc content is 65.34 %, subtracting 6. % Fe, the effective Zn content is 59 % Thus out of maximum 57 -59 % Zn content, even if 54 % is recovered in zinc concentrate it accounts for 91.50%-94.7% recovery. Thus it would be difficult to achieve more than 55 % zn in zinc concentrate.

Silica in Zn Concentrate

Mineralogical studies indicate (Fig No.8) that though the size of the sphalerite is around 18 microns, interlocking with silicates is present to a very fine size and for this reason silica depressants like sodium silicate did not work. Thus it would be difficult to achieve a silica content of less than 1.75 % on a sustained basis.

BENCHMARKING OF LEAD RECOVERY

As can be seen from Fig No-9., The lead recovery in Lead concentrate is comparatively much lower as compared to other major mines. Here again the comparison has to be on a textural basis and because of the complex interlocking characteristics of the galena resulting in poor liberation the

recovery is also lower. Galena being a ductile mineral which flows easily, and because of the complex deformational history undergone by the deposit, it has migrated into the cleavages of graphite and mica and fractures of quartz/ feldspar as 15- 20 micron sized grains which are diffcult to liberate and report into the tailing (Fig No.10). But in an effort to increase the recovery mineralogical study of the tailing was done to ascertain the mode of losses of galena.

The study of tailing indicated that ;

- Total Liberated galena in the lead tailings = 0%
- Un-liberated galena in the lead tails is 100% and Grain size of un-liberated galena is around 15 microns as intergrowths with mica (Fig. No. 10).
- Thus there is only a limited scope for increasing lead recovery and can be done only by reducing the grade of the Concentrate.

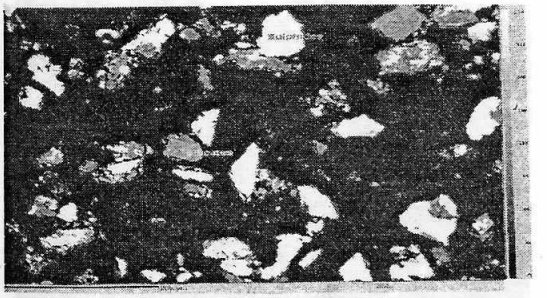

Fig. 8: Zn Concentrate Showing Well Liberated Sphalerite Grains. Though the P 80 is < 20 Microns Interlocking with Silicates is Present Even at This Level. Even Though the Iron Content is Around 8 % There is Little Pyrite/Pyrrhotite and the Iron is Accounted by Substitution in the Lattice of Sphalerite

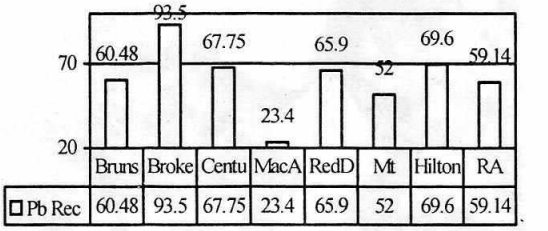

Fig. 9: Comparison of Lead Recovery of Major Mines of the World

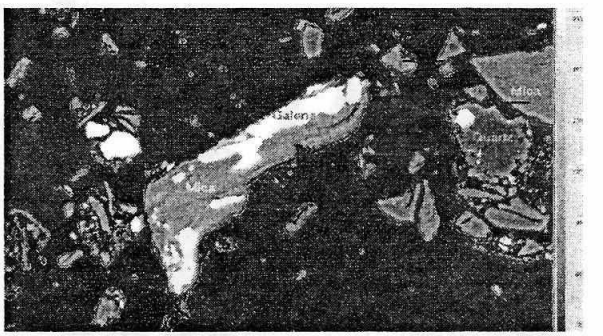

Fig. 10: View of Tailing Which Contains Locked Particle Within the Cleavages of Mica and has Escaped to the Tailing

SILVER RECOVERY

Silver is a valuable byproduct whose recovery can improve the financials of a project and thus it is important to search for ways of increasing the recovery but before which its mode of occurrence in various mill products has to be ascertained.

Silver Distribution in Mill Products

As can be seen from the Table No 5 the silver is recovered equally between Lead conc. (29.44%) & Zinc Conc. (31.98%)and the total recovery is around 61.42%.But the silver reporting into the zinc

concentrate is recovered only in pyro -metallurgical process and in hydrometallurgical process it is not recovered. As the major smelters are based on the hydrometallurgical process the emphasis should be increasing the silver reporting to lead concentrate. For this purpose mineralogical study was carried our and the mineralogical study of the mill products indicated that ;

1. There is no native silver.
2. The Galena, Sphalerite and Pyrite do not have any Silver in Solid Solution.
3. Silver is occurring as Acanthite (AgS)(Fig No 11) and Tetrahedrite (Ag-Sb -S).)(Fig No 12)
4. While Acanthite is reporting to lead concentrate the Tetrahedrite is reporting lead/Zinc concentrate which explains the silver recovery in zinc concentrate. (Fig No. 12)
5. The Silver locked with gangue is reporting to tailings. (Fig No 13).

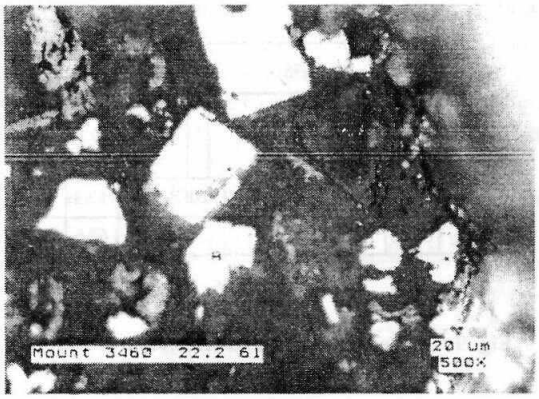

Fig. 11: A Liberated Grain of Ags (Acanthite (a)) in Lead Concentrate, Rest of the Grains are Galena

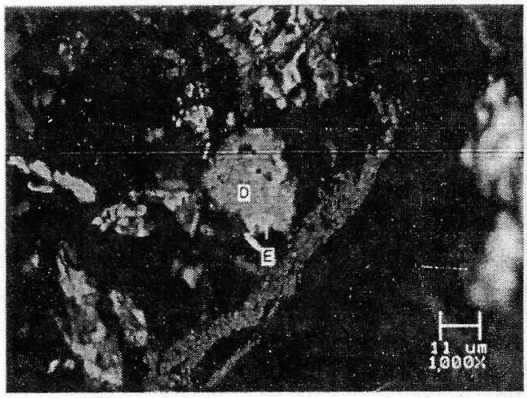

Fig. 12: Fine Grained Silver (Tetrahedrite E)Mineral Locked with Galena and Sphalerite (D) &Which Will Report to Zinc or Lead Concentrate

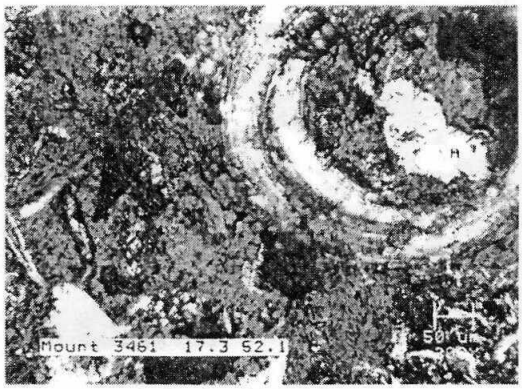

Fig. 13: Ags (Acanthite) Locked with Gangue Which in Tailing

Mineralogical Input for Increasing Silver Recovery

Based on the above mineralogical studies specific silver mineral collectors were tried but with a limited success. So another approach is being tried that by improving lead recovery it is hoped that silver recovery would be enhanced.

CONCLUSION

RA deposit being a complex deposit in terms of geo-metallurgical characteristics the inputs of process

mineralogy give a valuable insight into the metallurgical operation as have been described above. The study indicates that in case of zinc recovery the actual metallurgical performance has further scope of improvement but in the case of lead recovery the scope for quantum improvement is limited. Similarly, because of the inter atomic substitution of Iron in the lattice of Sphalerite achieving a conc. grade of more than 55% is difficult. Similarly because of intimate interlocking of silicates with sphalerite in the zinc conc even at a grain size of less than 20 microns it would be difficult to sustain a silica level of less than 1.75% on a consistent basis.

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