Revista Brasileira de Geociências 12(1-3): 94-104, Mar.-Set., 1982 - São Paulo

CRUSTAL EVOLUTION AND PRECAMBRIAN METALLOGENESIS IN WESTERN INDIA

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ABSTRACT Proterozoic supracrustal rocks of continental derivation form the major rock groups in Rajasthan and adjacent states in western India and act as repositories for conspicuous base metal mineralization. The continental crust in this region evolved through three main cycles: the Bundelkhand-Berach granite pluton intruded during the Archaean-Proterozoic transition and formed the continental nuclei. Extensive migmatization of early volcanics and associated sediments during the process of cratonization brought about the evolution of the Banded Gneissic Complex. Stabilization of this basement took place around 2.0 Ga. when two slowly sinking major littoral basins received the huge pile the Aravalli sedimentary package through almost a billion years and the subsequent clastogenic Delhi sedimentation.

The recurrent syn-sedimentary metallogenesis in the Precambrians of western India has been examined by presenting the salient characteristics of six, economically important, metamorphosed, sediment-hosted, stratiform, base metal sulfide deposits: one massive, early Proterozoic, Zn-sulfide deposit in the migmatized sediments, probably related to initial basement volcanism; two mid-Proterozoic Pb-Zn-(Cu) deposits emplaced in the Aravalli sequence through rift-fed exhalations related to basic-felsic volcanism; three late Proterozoic Pb-Zn-Cu/Cu/Fe sulfide deposits which formed through sea water – basalt interaction or through basinal brines enriched by convective circulation.

INTRODUCTION The Precambrian rocks of Western India are mostly confined to the state of Rajasthan and only small parts occur in Gujarat, Haryana and Delhi. The most widespread and conspicuous mineralization in these rocks is that of base metals – only minor occurrences and deposits of manganese, tungsten and uranium are known in the region. Further, all the major base metal mineralizations are located in Rajasthan, and except for one – the Ambaji deposit, no base metal occurrence of exploitable size is known in Gujarat or elsewhere. In view of this the present contribution endeavours to provide a comparative review of only the major base metal deposits/prospects in Rajasthan and relate their formation to the crustal evolution of this segment of the Indian shield. The other metals mentioned have been left beyond the scope of this treatment.

Initially attention is focussed on the moot points regarding the Precambrian stratigraphy of the region, based on the contributions of previous workers. This is followed by a proposed scheme of Precambrian crustal evolution in Rajasthan. The latter part provides a comparative picture of base metal mineralization in the region with particular reference to their salient characteristics. Finally relevant comments are made on metallogenesis in terms of the crustal evolution model already proposed. The distribution of the major stratigraphic units in the region, as mapped by Heron (1935), is shown in Fig. 1. The locations of all important base metal deposit/prospects including the major ones considered in the present contribution, are also shown on this map.

PRECAMBRIAN STRATIGRAPHY Supracrustal rocks of continental derivation form the major rock groups in the Precambrians of Rajasthan followed in terms of areal extension, by migmatites and sialic magmatic rocks. The major part of the base metal mineralization is localized within these supracrustals whose basement forms a major issue in the controversy on the Precambrian stratigraphy of Rajasthan.

The regional statigraphic sequence, as suggested by the different workers, is summarized in Table 1. Regional correlation between major stratigraphic units has been attempted (Sen, 1970; Raja Rao *et al.*, 1971; Naha and Halyburton, 1974), though all these studies have suffered from a conspicuous dirth of systematic geochronological data as well as widespread cover of soil and alluvium in the region.

Recent studies in several sectors have revealed that pre-Aravalli basement *does* occur in the region but there is no unanimity on the question of its geographical extent. Geochronological studies by Crawford (1970) have indicated an age of 2,580 Ma. for the "Berach granite" (Pascoe, 1950) or the Bundelkhand gneiss along the eastern tracts and thus confirmed this to be the oldest rock in the region. The Sarara granite, south of Udaipur, which is overlain by the type Aravalli rocks with a profound unconformity denoted by a thick conglomerate horizon in between, is believed (Naha and Halyburton, 1974) to be its time equivalent. It is significant in this context that Pb-isochron method pursued by Vinogradov *et al.* (1964) for the Aravalli schists which contained a lot of detrital zircon, enriched with radiogenic lead, had provided an enormous value of

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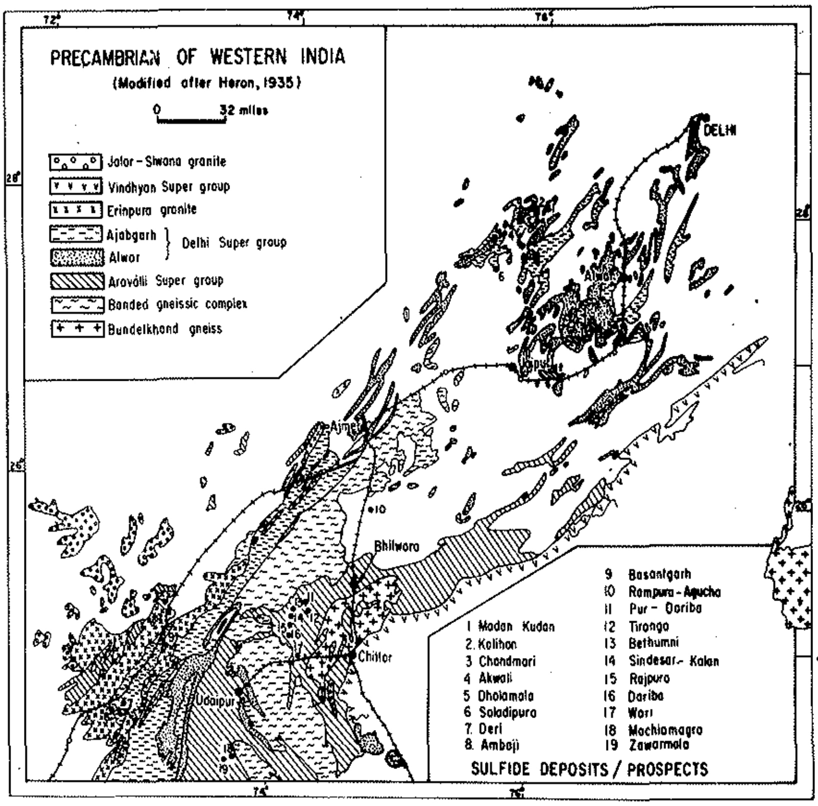

Figure 1 – Map showing distribution of different rock formations in south-central Rajasthan (modified after Heron, 1935). The locations of important base metal deposits prospects are also shown

Table 1 – Proposed simplified schemes of Precambrian succession in Rajasthan

B.C. Gupta (1934) Heron (1953)	**Raja Rao** *et al.* **(1971)**	**Naha and Halyburton (1974)**	**G.S.I (1980)**
Erinpura Granite			Erinpura Granite
Delhi system: *Ajabgarh* *Alwar*	Delhi system	Delhi group	Delhi supergroup: *Pali gr. Sindereth gr.* *Sirohi gr.* *Kumbhalgarh gr.* *Godunda gr.*
– unconformity –			
		Post-Aravalli granite	
Raialo series – unconformity – Aplogranites			
		Banded Gneissic Complex by migmatisation	
Aravalli system	Aravalli group	Aravalli group	Aravalli supergroup: *Champret gr.* *Lunavada gr.* *Jharol gr.* etc. *Bari Lake gr.* *Udaipur gr.* *Debari gr.*
	Bhilwara group		Bhilwara supergroup: *Ranthambor gr.*
Banded Gneissic Complex	Banded Gneissic Complex		*Rajpura gr. Pur-Banera gr.* etc. *Hindoli gr.*, etc.
Berach granite = Bundelkhand Gneiss	Berach granite	Berach granite = Sarara granite	

3,500 Ma. Inspite of the possible experimental error, this data is at least a pointer to the antiquity of the Archaean basement which was eroded during the development of the supracrustal cover.

A pivotal issue in the controversy is the position of the Banded Gneissic Complex (BGC). The different views in this regard may be summarized as follows: 1) This gneissic basement underlies with a prominent erosional unconformity, a sedimentary sequence of early Precambrian age – the argillaceous and arenaceous rocks of the Aravalli "system" and the predominantly calcareous Raialo "series", with a supposed unconformity between the two (Gupta, 1934; Heron, 1953). Metasedimentary inclusions of older, unspecified age and significance were recorded within the BGC by Heron (*op. cit.*). This basement-cover relationship received recent support from the studies by Roy and his co-workers (Roy and Paliwal, 1981; Roy *et al.*, 1981) on the type Aravalli rocks around Udaipur as well as those towards east, around Bhinder. *2)* The status of the BGC as the basement for Aravalli sedimentation is in general untenable, as the BGC, by and large, represents the migmatised derivative of the Aravalli sediments (Crookshank, 1948; Sharma, 1953; Naha and Halyburton, 1974). Naha and his associates, through studies spanning over a decade concluded that the BGC is a migmatite and both the Aravalli and the Raialo rocks have undergone synkinematic migmatization during the first folding and the migmatized front transgressed the stratigraphic boundaries. Radiometric dating of the banded gneisses from the type area (cf. Naha and Halyburton, 1974) by Crawford (1970) gave age between 1,935 and 2,060 Ma.

Another controversial issue has developed recently due to the redefinition of the Aravalli-Pre-Aravalli boundary (Raja Rao, 1970; Raja Rao *et al.*, 1971; Raja Rao, 1976). Raja Rao and his co-workers while largely supporting Heron's contentions on the stratigraphic sequence, had suggested that the metasedimentaries in the eastern tract of the Aravalli rocks (of Heron, *op. cit.*) are older than the type Aravallis around Udaipur and had redesignated them as Bhilwara group. In the context of metallogenesis this revision would imply a different metallogenic epoch for the Zawar deposits from that of the mineralization along Rajpura-Dariba belt. In a recent re-examination of the structural-stratigraphic status of these so called pre-Aravalli rocks (Bhilwara group of Raja Rao) around Bhinder, Roy *et al.* (1981) have provided convincing field evidence against the suggestion and have also shown that the Aravalli--pre-Aravalli boundary suggested by Raja Rao and his associates is clearly a time-transgressive plane.

In recent years the Geological Survey of India (1976, 1980) has published maps of the region showing the stratigraphic sequence, with regrouping and renaming within the framework of Raja Rao's scheme.

Scanty radiometric dating, as pointed out earlier, has provided only a broad idea of the absolute ages of the different formations and has also left considerable uncertainty regarding the base and top of the different groups. Rb/Sr age determinations by Crawford (*op. cit.*) suggests that the Aravalli system of Heron (*op. cit.*) spans approximately the interval between 2,500-1,900 Ma. The base of the Aravallis is determined (at 2,585 Ma) on the doubtful assumption that the Berach granite is the time equivalent of the BGC. The same study also indicates that the BGC contains components of ages varying from atleast 2,000 Ma to less than 1,000 Ma – which appears to corroborate Naha's contention of syn- to late-kinematic migmatization of the Aravallis at different stratigraphic levels. But still, surely there are components in the BGC which are older than these. According to Sarkar (1972) the base of the Aravallis appears to be younger than ~ 2,500 Ma and some post-Aravalli granites are less than 2,000 Ma (cf. Naha and Halyburton, *op. cit.*). On the other hand earlier studies of Vinogradov *et al.* (1964) had indicated an age of 1,500 Ma for the Aravalli schists on the basis of isotopic composition of lead extracted from them. The upper limit of the Aravalli "system", according to these workers, is defined around 1,100 Ma by the ages of the Sivala granite and Bhivarla pegmatites.

Heron (*op. cit.*) believed in the presence of a first order unconformity, corresponding to the "Eparchaean interval", between the Aravalli group and the overlying Delhi group, which was taken to be late Precambrian in age. Preliminary radiometric studies of minerals in pegmatites within Delhi rocks giving age between 700 Ma and 835 Ma (Holmes, 1955) as well as comments on the structural relationships present in rocks of Delhi group by Naha and Halyburton (1974) point to a considerable younger age for the rocks of the "Delhi system", as implied in Heron's correlation.

PRECAMBRIAN CRUSTAL EVOLUTION IN WESTERN INDIA Against this brief background of the important issues concerning the Precambrian stratigraphy of western India, a scheme of crustal evolution is now proposed. This scheme and the comments that follow are based on the observations made by the author in different sectors of the region over the last decade as well as on the contributions of earlier workers discussed above.

A broad perusal of the bulk composition of the rocks in the region indicate that the decipherable Precambrian crust in Rajasthan was continental rather than oceanic. This continental crust evolved through complex events of sialic magmatism, sedimentation, migmatization, volcanism, polyphase deformation and regional metamorphism – all in three main recognisable cycles/stages.

The relic of continental nuclei is represented by the Berach granite-Bundelkhand gneiss pluton which intruded during the Archaean-Proterozoic transition. Whether an older Archaean basement, as old as 3,500 Ma (?) or somewhat younger (cf. Vinogradov *et al.*, 1964; Sarkar, 1972) was present or this cratonic mass itself, atleast in parts, represents recycled mafic material by partial melting, remains doubtful in the absence of further data either supporting or challenging the age.

The closely associated Banded Gneissic Complex – comprising high grade granulite to upper amphibolite facies quartz-feldspathic gneisses striped with amphibolites and containing enclaves of mica schists, calc-silicate rocks, quartzites, etc. – despite their suggested early Proterozoic age have characteristics more in keeping with their counter--parts of Archaean age (cf. Anhaeusser, 1981) and probably evolved during the process of cratonization. Anhaeusser (*op. cit.*) has suggested that the emplacement of the early sial was largely driven by gravitative overturning so that primitive continental masses were tectonically unstable. Diachronous nucleation of soda-rich granitic rocks during the Archaean is also seen (Glikson, 1979) as a major process effecting a transformation of an early Archaean sima into sial and the intimate interaction triggering the formation of complex migmatites that are prevalent in all the oldest granitic terrains. Otherwise passive emplacement of K-rich magma to higher crustal levels produce marginal migmatites and gneisses representing zones of interaction between the granite massifs and the intruded crust. It is apparent that much of the amphibolites in the BGC were originally volcanics and a thin veneer of shelf-type sediments had accumulated on the evolving Archaean basement. Extensive migmatization and high grade metamorphism transformed the volcano-sedimentary cover into the "BGC" by processes broadly similar to that mentioned above. Stabilization of the craton took place in the early Proterozoics around 2,000 Ma – a fact evidenced by the development of two large slowly sinking basins on the undulatory topography of this peneplained basement.

These two contiguous epicontinental basins of Aravalli sedimentation – the eastern one defined by the Bhinder--Bhilwara tract and the western one around Udaipur (Fig. 1) – received enormous finegrained shallow water clastics and widespread chemical sedimentation, and were intermittently connected in space and time. Basic lava poured out along the basin margins (Roy and Paliwal, 1981; Roy *et al.*, 1981; Deb and Kumar, 1982) probably through deep cracks in the increasingly brittle craton, providing access to deep seated heat and probable mantle--derived ingredients – a feature common in many mid--Proterozoic basins the world over (Milanovskiy, 1976). The eastern basin is characterized by oxide facies of Banded Iron Formations in the Pur-Banera belt (Basu, 1971) and its sulfide facies in the Rajpura-Dariba belt (Deb and Kumar, 1982) – a rock type conspicuous by its absence in the western basin. Together with Pb-isotope ages of syn--sedimentary sulfide deposits (discussed later) and other field relationships, this indicates that the more argillaceous eastern basin with linear zones of platform-type carbonates and higher grades of metamorphism was filled up earlier and thus form the basal part of the Aravalli sequence.

The upper part of the Aravalli sequence in the western basin is characterized by terrigenous sediments like arkose, grit, orthoquartzite interbanded with dolomites/stromatolitic phosphorite horizons, deposited in a turbulent tidal to intertidal environment (Banerjee, 1971). This phase of sedimentation was followed by rather quiescent conditions when more argillaceous sediments were deposited with thin stratifications in relatively deeper parts of the basin. In the last phase tidal dolomites formed in patches and lenses to give rise to the "Raialos" of Heron (*op. cit.*). The Aravalli sediments were intruded by later granites and also underwent lit-per-lit migmatization locally at higher stratigraphic levels.

After a considerable hiatus sedimentation of the Delhi supergroup commenced with clastics of terrigenous derivation deposited along erosional channels. The upper part of the sequence is markedly argillaceous and is accompanied by co-eval shallow marine volcanism in different sectors. The Delhi Supergroup all along its trend was intruded extensively by the Erinpura granite batholith and its related stocks and bosses in the last magmatic phase in the region.

MINERALIZATION The prime objective of this contribution is to relate mineralization of base metals in Rajasthan to the three decipherable cycles of crustal evolution discussed above. To this end, six major economically important deposits have been chosen – one from the earliest cycle, two from the next and three from the youngest cycle (Table 2; see Fig. 1). Interestingly all the deposits fall under the sediment hosted stratiform class of copper, lead and zinc deposits reviewed recently by Gustafson and Williams (1981), though curiously, have been totally overlooked by these authors. Salient characteristics of these six deposits have been succinctly presented in a comparative manner in Table 2 in abbreviated language, whose explanations follow in Table 3.

The metal content of these deposits has been plotted in a triangular diagram (Fig. 2) in terms of weight percent of Cu, Pb and Zn. The well known separation of Cu from Pb and Zn and the absence of any deposit on the Cu-Pb join (Stanton, 1972) is well exemplified here. Polymetallic deposits are only Ambaji and Deri though copper occurs in considerable amounts in the copper-rich footwall zone at Rajpura-Dariba. It is significant that on the basis of their metallic constitution most of the deposits under consideration either fall in or skirt the field of volcanogenic massive sulfide deposits, chalked out by Pelissonnier (1972 *in* Gustafson and Williams, 1981).

The deposit at Saladipura is of iron sulfide, with pyrite predominating over pyrrhotite. In all other deposits iron sulfide, mainly as pyrite is present ubiquitously. At Khetri, pyrrhotite and magnetite are also present in the ore, locally in substantial quantities. Pyrrhotite-rich ores also occur at Deri within amphibolites. At Rampura-Agucha pyrrhotite is subsidiary to pyrite in a total iron content of about 10%. In the Dariba lode pyrite is highly concentrated in the hanging wall Fe-rich zone of the polymetallic sulfide orebody. The smaller lode at Dariba is mainly pyritic. Silver is present in almost all deposits – in the copper ores of Khetri, Pb-Zn ores of Zawar as well as in the polymetallic ores of Ambaji, Deri and Rajpura-Dariba. Gold however is reported from Khetri and Rajpura-Dariba. In the latter, the precious metal is localised in the remobilized massive sulfides (Deb, 1982). As expected cadmium is concentrated in all Zn-rich ores and cobalt is present in some of the Khetri prospects.

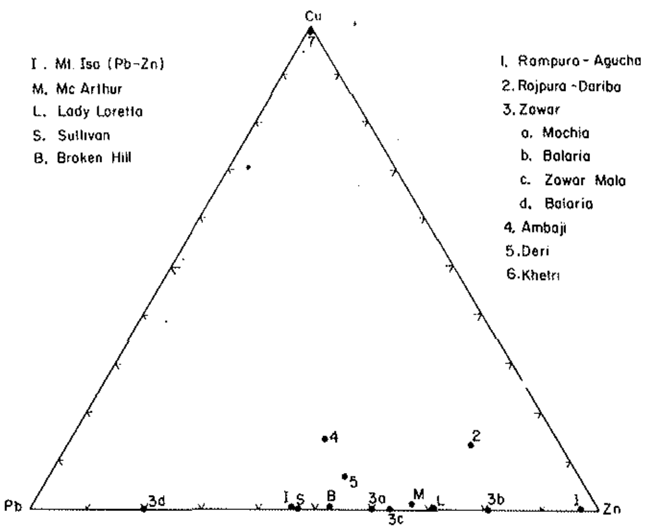

Figure 2 – Triangular plot of metal content (in terms of Cu, Pb and Zn) of the base metal deposits/prospects discussed in the paper. Plot of other similar Proterozoic also shown for comparison (data for these taken from Gustafson and Williams, 1981)

Except for minor shows no base metal occurrence of exploitable size has so far been recorded in the Bundelkhand-Berach granite basement. However, only recently a large Zn-rich massive sulfide orebody has been discovered in the metasedimentary enclaves within the Banded Gneissic Complex at Rampura-Agucha. Unfortunately, not enough information is available on this deposit as exploration and geological studies are still in progress. The long lensoid orebody appears to be doubly plunging and is enclosed by garnetiferous sillimanite biotite gneiss with intermittent bands of calc-gneiss and amphibolites in the hanging wall and a dark grey mylonitic rock and feldspathic quartzite in the footwall. Biotite schist forms the host (Raghunandan *et al.*, 1981).

Table 2A – Characteristics of selected stratiform sediment hosted Cu, Pb and Zn deposits in western India (Abbreviations used are listed in table 2)

Name	Reserves + Grades t × 10^6 Zn% Pb% Cu%	Associated metals	Age (Approx.)	Metamorphism
(1) *KHETRI(B)* D: Jhunjhunu & Sikar. (from N-S)				
Madan-Kudan (M) Kolihan (M) Chandmari (M) Dholamala (Pr) Akwali (Pr) Satkui (Pr)	43.8 — — 0.91 28.6 — — 1.50 3.5 — — 0.88 1.5 — — 0.91 1.65 — — 1.50 3.9 — — 1.00	Au 0.6-0.8 g/t, Ag Au 0.5-0.6 g/t, Ag 6-8 g/t + Co, Zn as by-products Co 200-300; Ni 50-150; Au 0.5-1.5; Ag 2-8 (in ppm)	L Prot. (~ 900 Ma?)	Low P Int. facies sr, attained <5.5 kb/550 °C-600 °C, followed by retr.
(2) *SALADIPURA* (Pr) D: Sikar	115 Fe sulfide deposit S content 22.5%	Zn (<.5-2%)	L Prot. (~ 900 Ma?)	Low P Int. facies sr culminating at 5.5 kb/600 °C
(3) *AMBAJI-DERI* (B) D: Banaskantha		Mo 5-250; Ag 2-130; Cd 50-100; Ni 10-150; Co 10-220 (all in ppm)	L Prot. (~ 900 Ma?)	Green sch. facies regn. metm suimp by hbl hornfels facies therm metm around 3.4 kb/575 °C
Ambaji (Pr) & Sirohi Deri (Pr) Basantgarh (Pr)	8.2 5.5 4.9 1.7 1.0 7.3 5.5 1.9 3.5 1.2 1.7			
(4) *ZAWAR (D)* D: Udaipur	Cumulative strike l 8.6 km			
Mochia (M) Balaria (M) Zawarmala (Pr) Baroi (Pr)	26.77 3.8 1.7 — 18.97 5.6 1.1 — 18.03 3.72 2.1 — 11.33 1.23 4.3	Ag 300-550 g/t in Pb conc Cd 0.2-0.3% in Zn conc.	L Prot. (~ 1,500 Ma)	Green sch. facies
(5) *RAJPURA DARIBA (B)* D: Udaipur				
Dariba (M) + Rajpura (Pr)	51.00 5.1 1.2 1.08 (in 0.6 t 0) In situ gossan 31.62 1.2 4.0 0.27	Ag 122 g/t; Cd 170 g/t As 180 g/t; Sb 69 g/t Hg 18 g/t; In 7 g/t Ag 200; Hg 500; Sb & As 1,000 each in ppm; Au < 0.5g/t	L Prot. (~ 1,700 Ma)	Amph facies 5.4 kb/555 °C
Sindesar-Kalan (Pr)	70.00 2.1 0.5			
(6) *RAMPURA-AGUCHA (Pr)* D: Bhilwara Note: All geol. info tentative.	60 14 1.5	?	E Prot. (> 2,000 Ma)	Granulite facies

N.B. For abbreviations used see Table 3

Table 2B –

Geologic setting	Host lithology	Volcanics	Organic assoc.
(1) Up. Ajabgarh gr of Delhi super gr: feld qte, b m q, cord-anth-cumm rk, b amph qte, gar chl sch & m qte, L kin gran. 2 ph of def prod 3 gent of buckle folds. No Sh Z. Some transverse F.	Gar chl sch, b amph qte. Other rks in close assoc: andl mic sch, cord anth rk. O asmbl: cp, po, py, mt, cb. Also sl, ilm, aspy, mack, moly, pn, cobl. G: qtz chl, gar, amph, bt, scap, plag, grap.	None rep. Nearest 50 km S – amph at Saladipura	Carb matter (grap) closely assoc with O
(2) Up. Ajabgarh gr of Delhi super gr: Gran intr(top), qte, carb phyl, chl qtz sch, amph with intercalated metased, 0, phyl & mic sch, imp marb, calc sil rk, b amph qte; base not exposed. 3 ph of suimp folds. No F/Sh Z	m amph & phyl mic sch. Common asmbl: hbl, act, plag, qtz mt, po or anth, cord, qtz, cumm, py, po ± sl. W rks: cord, anth, qtz ± scap or ms, bt, qtz ± andl. Inv py, po, aspy asmbl present.	Precursor of amph could be water laid volc contamina ted with sed.	Carb matter (grap) is present in small but var amt in O asmbl.
(3) Up. Ajabgarh gr of Delhi super gr: paragns, bt, qtz sch intlyd with conf m amph enclose lenses of chl hornfels (with var prop of cord, anth, tc, tr), fors marb, tr qte. Pegm & gran at Ambaji, alk syen at Deri are intr. 3 ph of suimp def. No F/Sh Z.	chl hornfels & diop fors marb. Some OB in bt qtz sch & rly in amph. G: cord, anth, Mg-chl, spinel, phl, tc, cumm, calc, tr, bt, qtz, diop, fors. O: sl, gn, cp py. Also: po, aspy, cb, moly, mack, mt, ilm, sulfosalts, Bi, Ag.	m amph repr basaltic flows. Pillows rep from Basantgarh	Insignificant carb matter rep from bt qte.
(4) b gns complex overlain unconf by type Aravalli supergr seq: congl + grit, qte (oft ark), phyl + grwke, imp dol (locally carb marly ark). Cataclastic gran. 4 gent of folds. First two most penetrative.	Fine grained grey dol, commonly gritty/ark. Asmbl incl: sl gn, py, aspy, po, mt, cp, argt, Ag, qtz, dol, gyp (rare).	None rep	HR carb at places
(5) b gns complex (at some distance to W) overlain by Aravalli supergr. seq: calc bt sch grading to rexl, X bedded dol with conf amph, sil carbonate rk, carb chert, grap mic sch with gar, staur, ky, m qte. Ferr breccia & gar rk in OZ. 3 ph of def & folding. No Sh Z	Rexl sil dol, carb chert, grap mic sch. O:sl, gn, cp, py, po, tn, aspy, cb, mack – host of rare sulfo-salts, electrum, As etc. G: calc, qtz, tr, diop, phl, bt, grap, gar, staur, ky.	Thin tuff bands rep in grap mic sch. Chert repr exhalites	Carb matter (grap) intimately assoc with Pb-Zn & Fe rich O
(6) b gns complex: striped amph, diop gar amph, gar sill mic gns, calc gns, aplite, feld qte & pegm.	bt mic sch with sill. O:sl, py po, aspy. G:qtz, grap, K-feld, tr, diop etc.	Probably present though modified totally.	Big flakes of grap ubq in O

Table 2C –

Ore bodies	Ore structure-fabric	Zonation
(1) Conf lensoid, 1-2 orders of mag larger along strike. "Stratabound" in single lithounit. No of OB in an OZ	b, m, stringers & dism. O texture & O-sil reln ind metm of O.	None rep.
(2) 4 synformal OB with parabolic outcrop. Biggest – a pl synform, 7 km along strike. 5th OB linear. Conf with S_0 in metased.	m O 40%; dism O minor; O-sil rhyth. Prim str abound. Sec def str & equilibrium tex ind metm of O. Locally pegm O.	None rep.
(3) Stratiform lenses or tabular OB in lensoid HR. Conf with S_0/S_1. Cu & Pb-Zn ob gen separate. Cu in more arenaceous HR, Pb-Zn in more Ca-Mg facies in narrow strat Z. OB strike 1:250-400 m, downdip extent & thickness 40--80 m & 5-55 m resp. 3 major stratiform lodes at Basantgarh.	m, b sl-py O, b in cp-rich O with sil, minor discordancy in cp-rich O. O co-folded with HR. Polymetm of O fabric	In composite OBs no strat zoning of metal obvious. In some OB Pb conc at lr levels

Table 2C — (continuated)

Ore bodies	Ore structure-fabric	Zonation
(4) OBs stratabound in dol: as conf layers, as ill defined shoots along pl of fold axes, as repl & fr filling along subparallel strain slip cl. At Mochia composite sheeted veins grading to m repl OB and stockwork.	m & b. Prim, penecontemporaneous def, diag and metm str, solid & fluid state mobilisation common. Stromatolites, bands of native S, py framboid with chert rep. Mega & micro fabric ind O metm.	At Mochia sharply defined Zn rich and Pb rich lateral zones present, themselves aligned vert.
(5) 2 OBs conf with S_0/S_1. Stratabound in narrow strat Z. Dariba main lode 3 700 m strike l, width 1-47 m Smaller HW lode 600 m strike l, width 2-35 m	cp O stringery/m, conf in rexl sil dol; sl-py rhyth in carb chert; gn-sl O commonly b. m gn withAg-As sulfo-salts in diop rk. m tn common. Prim, diag & def strwell preserved Fabric metm. Remobilization common. Stromatolites in Pb-Zn O rep.	Conspicuous mineral/ /comp vert zoning. FW-HW: Cu-Pb/Zn- -Fe. Lense of Ag-As in Pb-Zn Z. Smaller HW lode is pyritic
(6) Single OB, doubly pl lense. 1.5 km along strike. Max width 100 m. Conf with S_1	m sl O. Rare b ore in calc gneiss. Metm microfabric	Not rep. gn apparently conc along FW contact

Table 2D —

Ore environment	Genesis/Comments	Major references*
(1) Sed env shallow marine occ subareal. Evap now repr by scap/cord- -anth rks, prod by isochem metm of halite bearing marly sed/magnesite. Basin partly stagnant, anoxic with biologic activity. No WR alter.	Epigen/syngen controversy. minzn premetm. No spatial/temporal reln with gran. Overall features ind sed-diag origin. Source of metals obscure. Volc-exhalative source possible: Fe & Cu-Fe sulfide predom & oxidic Fe facies in the neighbourhood.	Roychowdhuri and Dasgupta (1965) Sarkar and Dasgupta (1980)
(2) Sed env near shore anoxic, possibly lagoonal condition	Minzn pre-metm. No evidence of Sh Z, selective repl. All features point to sed-diag origin. Pegm O formed by volatiles emanated by L kin anatectic gran.	Dasgupta (1970) Ray (1974) Sarkar *et al.* (1980)
(3) Volc-sed env. OZ repr transitional near shore turbulent shelf env. HR resulted from isochem metm of Mg/Ca-Mg sed conc on basaltic flows	Consanguinous sed-diag origin with derivation of metals, conc of Mg-sed & non-bacteriogenic reduction of sea-water SO_4 by sea water- -basalt inter action. Volcanogenic source of metals	Deb (1973, 1974, 1979, 1980) Dhar (1980)
(4) Stagnant basin condition with slow sedimentation in an euxinic env	Epigen/syngen controversy for years. Undoubted sulfide rhyth & sed fabric of O establishes syn-sed/diag timing of minzn. Extensively remobilised by superposed tectonism. Possible volc-exhalative source	Mookherjee (1964, 1965) Smith (1964) Pereira (1964) Poddar (1965) Chakrabarti (1967) Straczek and Srikantan (1967) Chauhan (1970) Roy & Jain (1974)
(5) Intracratonic rifted basin. Litho seq repr platform type sedm. under low energy, intertidal, env over a linear Z of basement high. Platform shoaled at places & euxinic conditions in 2nd order basin. Volc-sed env.	Syn-sed timing of minzn, later diag & metm remobilization. Typical zoning chert-Fe/Zn sulfide rhyth, tuff inter calations in HW & petrogenesis of OZ rks ind formation as sea floor exhalites pouring out from basement linea ment. Early basic volc turned calcalk during & after minzn. Homogeneity of Pb isotope ratio marked	Raja Rao *et al.* (1972) Poddar (1974) Chauhan (1977) Deb and Bhattacharya (1978) Deb *et al.* (1978) Pandya *et al.* (1980) Deb (1982) Deb and Kumar (1982)
(6) Probably a mobile trough obscured by extreme def & metm.\	Probable syn-sed formation in localised restriction basin. Source could be early basic basement volcanism	Bhatnagar and Gandhi (1981) Raghunandan *et al.* (1981)

*All resource data from Raghunandan *et al.* (1981)

Table 3 – Abbreviations used in Table 2

General terms	General terms	General terms	Minerals
amt = amount	M = Mine	t = metric ton	ms = muscovite
asmbl = assemblage	m = massive	tex = texture	mt = magnetite
assoc = association	mag = magnitude	ubq = ubiquitous	phl = phlogopite
B = belt	max = maximum	var = variable	plag = plagioclase
b = banded	metm = metamorphism/ic	vert = vertical	pn = pentlandite
cl = cleavage	minzn = mineralization	W = wall	po = pyrrhotite
conf = conformable	O = ore	X = cross	py = pyrite
conc = concentrate (d)	OB = orebody	Z = zone	qtz = quartz
D = district	oft = often		scap = scapolite
def = deformation (al)	occ = occasionally	**Minerals**	silc = silicates
diag = diagenetic	Pr = prospect	act = actinolite	sill = sillimanite
dism = disseminated	pl = plunging	and = andalusite	sl = sphalerite
E = early	ph = phase	anth = anthophyllite/	staur = staurolite
env = environment	pot = potential	orthoamphibole	tc = talc
epigen = epigenetic	predom = predominant	argt = argentite	tn = tenantite
evap = evaporite	prim = primary	aspy = arsenopyrite	tr = tremolite
F = fault; FW = footwall	prod = producing	bt = biotite	
fr = fracture	prop = proportion	calc = calcite	**Rocks**
G = gangue	reln = relationship	cb = cubanite	AMPH+
g/t = gms per metric ton	regn = regional	chl = chlorite	amph = amphibolite
gen = generally	rep = reported	cobl = cobaltite	argil = argillites
gent = generation	repl = replacement	cord = cordierite	ark = arkose (ic)
gr = group	repr = represented	cp = chalcopyrite	b m q = banded
HR = host rock	retr = retrogression	cumm = cummingtonite	magnetite
HW = hanging wall	rexl = recrystallised	diop = diopside	quartzite
imp = impure	rhyth = rhythmites	feld = feldspar	carb = carbonaceous
incl = include	rks = rocks	fors = forsterite	congl = conglomerate
ind = indicate	rly = rarely	gar = garnet	dol = dolomite
info = information	Sh = shear	gn = galena	ferr = ferruginous
intlyd = interlayered	S_0 = primary statification	grap = graphite	gns = gneiss
intr = intrusive	S_1 = schistosity	gyp = gypsum	gran = granite
inv = invariant	sec = secondary	hbl = hornblende	grwke = greywacke
kin = kinematic	seq = sequence	ilm = ilmenite	marb = marble
L = late	sr = series	ky = kyanite	phyl = phyllite
l = length	str = structure	mack = mackinawite	pegm = pegmatite
lr = lower	strat = stratigraphic	mic = mica	qte = quartzite
	suimp = superimposed	moly = molybdenite	sch = schist
	syngen = syngenetic		sed = sediments/ary
			sil = siliceous
			syen = syenite
			volc = volcanics

*All resource data from Raghunandan *et al.* (1981)

In the Aravalli supracrustals polymetallic mineralization is localized along a 17 km belt running from Bethumni in the north through Rajpura to Dariba in the south. With a lean pyritic zone south of Dariba the belt continues southward for another 16 km between Wari-Bhopalsagar-Akola where the predominant metal is low grade copper. There is another belt of lean polymetallic mineralization to the north-east – running between Pur and Banera for 34 km. In the type Aravalli rocks around Udaipur, although minor shows of copper mineralization are known associated with phosphorites, the only concentration of Pb-Zn, the largest in the country, is located in the Zawar ore district (Fig. 1).

Pb-Zn-(Cu) mineralization in the Aravalli sequence shows a marked preference for nonclastic lithologies of carbonate and carbonaceous rocks. These lithologies probably developed in shallow first and second order basins of platform sedimentation along paleotopographic basement highs. Extensive preservation of primary sedimentary features in the ore rhythmites prove unequivocally that the metals were deposited as chemogenic sediments under euxinic conditions and concentrated syn (-dia)-genetically. The discordance seen at places in these otherwise stratiform ores, may, depending on situation, be attributed to mobilization/remobilization during late diagenesis or metamorphism. An apparent difference in the mineralization in the lower and upper parts of the Aravalli sequence lies in the conspicuous multimetallic character of the former. Analytical data (Deb, unpubl. work) and ore mineral assemblage (Deb, 1982) reveal a complex geochemical association of Zn-Pb-Cu-Ag-Sb-Cd-As-S-Ba-F with minor amounts of Au, In, Mo and Hg.

In the Delhi Supergroup which runs along the Aravalli trend (Fig. 1) from Gujarat in the south, through Rajasthan to Haryana and Delhi in the north, two distinct metallogenic provinces are recognizable – the copper province in northern Rajasthan and a polymetallic Zn-Pb-Cu (poor) province along southern Rajasthan-Gujarat border. The central sector, so far, appears to be devoid of any mineralization. Base metals in the Delhi Supergroup are restricted to the more argillaceous rocks of the upper Ajabgarh Group in the southern province. Along Khetri copper belt the host rocks are believed to occupy the transitional position between

The Alwar and Ajabgarh groups. Minor copper occurences at Kho-Dariba Bhagoni, etc. occur within arkosic quartzites of the Alwar Group. The typical sedimentary environment and close association of the ores with sediments of magnesian composition are conspicuous features. The metamorphic equivalent of such magnesian compositions – cordierite orthoamphibole rocks are present in both the ore provinces and the lithology thus, may well serve as a good exploration guide on a regional scale.

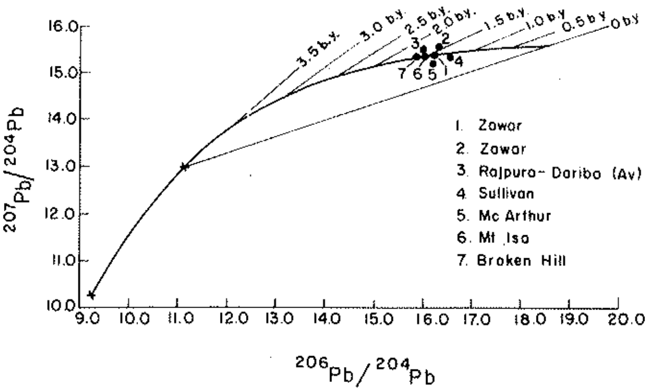

Figure 3 – Plot of ^{207}Pb ^{204}Pb against $^{206}Pb/^{204}Pb$ in galena samples from Zawar and Rajpura-Dariba on the two stage growth curve of Stacey and Kramer (1975). Pb-isotope values for other similar Proterozoic deposits are also shown for comparison. Refs.: **1** (*Venkatasubramanian* et al., *1982*); **2** (*Venkatasubramanian* et al., *1977*); **3** (*Chernyshev* et al., *1980*); **4** (*Koppel and Saager, 1976*); **5** (*Richards, 1975*); **6** *and* **7** (*Doe and Stacey, 1974*)

AGE OF MINERALIZATION Meyer (1981) has examined the evolutionary aspects of the earth's crust in terms of metallogenesis and concluded that major Cu-Pb-Zn deposits which formed prior to the mid-Proterozoic transition (1,800 ± 100 Ma) were mostly of the volcanogenic massive sulfide type. The transition was marked by the advent of stratiform, sediment hosted base metal sulfide deposits and the world's first economic concentration of lead. The largest known copper deposit of this class at Udokan and lead-zinc deposit at Broken Hill are also amongst the oldest – formed around 2,000 Ma and > 1,700 Ma, respectively (Gustafson and Williams, 1981). This period of transition between early and late Proterozoics was also marked by an abrupt decline of Banded Iron Formations which had reached climactic proliferation around 2,200-2,000 Ma. The reason is ascribed to subsiding volcanic activity and change in the chemical environment leading to a great evolutionary discontinuity in the history of the biomass (Cloud, 1973). This transition age correlates well with observed events in the evolution of the mantle and an important mantle release of lead to the crust could have taken place around this time through the emplacement of alkali-rich rocks, such as the red K-rich granites that characterise the Proterozoics (Meyer, *op. cit.*). After an extensive development in mid-Proterozoic, between 1,700-1,500 Ma lead assumed a subsidiary role to Zn and Cu in the later Proterozoics. Another conspicuous metallogenic epoch is noticeable in the late Proterozoics around 1,000 Ma, when large scale rifting events, igneous activity and mineralization took place in Africa, Australia and North America (Sawkins, 1976).

The phases of base metal mineralization recorded in the three cycles of Precambrian crustal evolution in western India correlate fairly well with these ore forming events on a global scale. The Rampura-Agucha deposit within the BGC is undoubtedly the oldest. As discussed earlier, the BGC evolved in the early Proterozoics and stabilized around 2,000 Ma. Therefore the Rampura-Agucha deposit can be compared with the oldest of the "stratiform, sediment hosted" class of sulfides, which first started forming around this time (Meyer, *op. cit.*).

Available Pb-isotope data of Zawar ores (Venkatasubramanian *et al.* 1977, 1982) and the average Pb-isotope data for seven galena samples from Rajpura-Dariba ores (Chernyshev *et al.*, 1980) were plotted on the two stage growth curve of Stacey and Kramer (1975) along with a few other well known Proterozoic sediment hosted deposits (Fig. 3). The plotting indicates an age of about 1,500 Ma for Zawar ores and about 1,700 Ma for the Rajpura-Dariba ores. These two Pb-Zn deposits thus formed during an epoch in the mid-Proterozoics when most of the stratiform, sediment hosted Pb-Zn deposits in the world with > 10 million tons of metal were generated. These ages also lend support to the inference made earlier that the eastern tract of the Aravalli basins developed first. The occurence of banded iron formations – which suffered a precipitous decline the world over around 1,800 Ma – along the Pur-Banera belt in this eastern tract is also significant in this context and indirectly suggests a late early Proterozoic age for the base of the Aravallis.

Mineralization in the late Proterozoic Delhi supergroup rocks, on the basis of the absolute ages of their hosts, discussed earlier, could also be correlated with the world wide event of rifting, igneous activity and mineralization around 1,000 Ma, when the famous Zaire-Zambian Cu belt, Ducktown deposit, Tennessee, etc. (Meyer, 1981) were formed.

METALLOGENESIS No deposit worth mentioning has so far been located in the Bundelkhand-Berach granite craton and as noted earlier, to-date only a single Zinc deposit has been discovered in the migmatized rocks of the Banded Gneissic Complex. Such marked absence of well represented ore deposits in the oldest, high grade gneissic terrains has been ascribed by Anhaeusser (1981) to one or a combination of the following reasons: *a*) Mineral concentrations may have been recycled/destroyed during the initial turbulent period of protocontinental development. *b*) Mineralization may have been destroyed by later tectono-thermal events that characterize the high grade mobile belt regimes. *c*) Mineralizing conditions may not have evolved sufficiently for metal concentration to have taken place in significant amounts. In the absence of any comprehensive petrogenetic study of the enclosing rocks of the Rampura-Agucha deposit any comment on the genesis of these ores would be premature and fraught with uncertainties. However, there are indications that the ore, as an intrinsic part of the original basement sediments/volcanics underwent the tectono-thermal evolution that characterized the local petrological environment. It is well known that high rate of energy transfer from the mantle to the surface took place in the Archaean with widespread emplacement of volcanics and as the crust grew and stabilized the high heat flow became localized along mobile belts (Windley, 1977) to transform the volcano-sedimentary lithologies into a gneissic complex similar to the BGC through extensive migmatization. Since zinc is generally accepted to be a geochemical indicator of recycling of basaltic crust (Hutchinson, 1973), it is tempting to suggest that the mineralization was related to early basement volcanism during the process of cratonization, discussed earlier.

There is no "tell-tale" evidence of volcanism associated with the syn-sedimentary mineralization in the Aravalli sequence. Therefore uncertainty is bound to prevail in the choice between two possible sources of the metals: *a*) Leaching of underlying sediments and volcanics by the mechanism of convective circulation of sea water (Russel, 1978). *b*) Juvenile derivation of the exhalations from magmatic sources. The linear zone of mineralization in the lower Aravalli sequence along belts of shallow platform-type sedimentation has been related (Deb and Bhattacharya, 1978) to the basement "highs" or lineaments in the epicontinental basins, probably representing intracontinental rift zones that characterize submarine, exhalative, sediment--hosted Pb-Zn deposits the world over (Large, 1981). The rifting is generally ascribed to hot-spot activity (Sawkins, 1976) and is closely followed by a compressive phase – all during the slow sinking of the cratonic basin while material beneath it was withdrawn from the mantle or lower crust or there was contraction by phase change or cooling (cf. Muratov, 1974). It has recently been pointed out (Deb and Kumar, 1982) that along the Rajpura-Dariba belt early basic volcanism turned calc-alkaline with time, the latter being represented by tuffaceous intercalations of dacitic affinity in the hanging wall of the ore zone. Restriction of the high grade polymetallic ore in a narrow stratigraphic zone, typical vertical metal zoning that characterize most volcanogenic massive sulfide deposits, chert association, Ba enrichment in shallower, distal (?) parts etc. have prompted these authors to suggest an exhalative origin of the deposits in a volcano-sedimentary environment of the "McArthur river" type (Lambert, 1976), where the paleogeography and the chemical environment of the restricted second order basins were conducive to precipitation and preservation of the metal sulfides. Similarly Mukherjee and Sen (1978) have adduced evidence for volcanogenic origin of the Zawar ores, which have comparable environmental setting, from trace element and REE studies. It is significant in this respect that acid volcanism has been reported from south of Zawar area, near Salumbar. Thus it seems probable that the mid-Proterozoic metallogenesis in the Aravalli sequence was related to an isotopically homogeneous magmatic source, which had undergone differentiation towards the felsic end.

In the Delhi supergroup submarine basic volcanism is clearly recognizable in the southern polymetallic province, and also at Saladipura, though with some reservations. Evidence for volcanism is much less convincing in the northern copper province of Khetri. Further, absence of biologic activity during ore formation is a conspicuous feature in the southern province. Based on these and other petrogenetic features Deb (1980) suggested a "consanguinous" origin (Routhier *et al.*, 1973) of the base metals and their magnesian host rocks through inorganic sulfate reduction by sea water-basalt interaction.

Lack of any direct affiliation to magmatic activity, presence of evaporitic and oxidised sediments give weight in favour of some mechanism of "basin pumping" (Gustafson and Williams, *op. cit.*) wherein cool sulfate rich brines derived at an early stage of basinal evolution, migrating up-dip probably through altered basic rocks, deposited the metal sulfides in reducing sites. Free oxygen in the environment was widely available in the late Proterozoics as was the biomass which controlled the ore precipitation in restricted anoxic zones. If the circulating brine poured out of some fracture or feeder vent the prevailing hydrostatic pressure in the shallow water basin, amongst other factors (Large, 1981) determined the style of mineralization.

The broad picture of Precambrian metallogenesis in western India is thus one of recurrent syn-sedimentary Pb-Zn-(Cu) mineralization through a time span of ~ 1,200 Ma. Periodicity of metal supply through rift-fed exhalations related to volcanism characterized the early and mid--Proterozoic ore forming epochs while sea water modified by interaction with basic volcanics or basinal brines enriched through convective circulations in the underlying sediment pile produced the syn-sedimentary mineralizations in the late Proterozoics.

Acknowledgement I am thankful to my colleague, Dr. D.M. Banerjee for hours of stimulating discussion on the subject and to Dr. S.C. Sarkar of Jadavpur University, Calcutta, for commenting upon a first draft of the manuscript.

REFERENCES

ANHAEUSSER, C.R. – 1981 – The relation of mineral deposits to early crustal evolution. Econ. Geol. 75th Anniv. Vol.:42-62.

BANERJEE, D.M. – 1971 – Precambrian stromatolitic phosphorites of Udaipur, Rajasthan, India. *Geol. Soc. Am. Bull.* **82**:2319-2330.

BASU, K.K. – 1971 – Base metal mineralisation along the Pur-Banera belt, Bhilwara district, Rajasthan. *Geol. Surv. India, Misc. Publ.* **16**(1):153-159.

BHATNAGAR, S.N. and GANDHI, S.M. – 1981 – Domestic reserves and resources of lead-zinc – future prospects. Int. Symp. on Pb-Zn-Cd prospect and retrospect, New Delhi. Pt. I A.

CHAKRABARTI, A.K. – 1967 – Genesis of lead-zinc deposit at Zawar, Rajasthan, India. *Econ. Geol.* **62**:554-556.

CHAUHAN, D.S. – 1970 – Some evidences about synsedimentary nature of lead-zinc-pyrite deposit of Zawar. *Jour. Min. Metals & Fuels*, March:81-86.

CHAUHAN, D.S. – 1977 – The Dariba main lode of Rajpura-Dariba zinc-lead-copper belt, Udaipur district, Rajasthan. *Jour. Geol. Soc. India* **18**:611-616.

CHERNYSHEV, I.V., SAFONOV, Yu. G., RADHAKRISHNA, B.P., KRISHNA RAO, B., VASUDEV, V.N. and DEB, M. – 1980 – Study of lead isotopes for investigating the origin of endogenic deposits with special reference to some ore deposits from India. *Jour. Geol. Soc. India* **21**:107-116.

CLOUD, P. – 1973 – Paleoecological significance of the banded iron formation. *Econ. Geol.* **68**:1135-1143.

CRAWFORD, A.R. – 1970 – The Precambrian geochronology of Rajasthan and Bundelkhand, Northern India. *Canadian Jour. Earth Sci.* **7**:91-110.

CROOKSHANK, H. – 1948 – Minerals of the Rajputana pegmatites. *Trans. Min. Geol. Met. Inst. India* **42**:105-189.

DASGUPTA, S.P. – 1970 – Sulfide deposits of Saladipura, Khetri copper belt, Rajasthan. *Econ. Geol.* **65**:331-339.

DEB, M. – 1973 – Some observations on the mineralogy and metamorphism of the Zn-Pb-Cu ores from Deri-Ambaji area, Banaskantha district Gujarat. *Jour. Geol. Soc. India* **14**:419-423.

DEB, M. – 1974 – Geological setting of the Deri-Ambaji base metal deposits in the Precambrians of western India. Int. Seminar on Tectonics & Metallogeny of SE Asia and far East (Abs.). *Geol. Surv. India. Misc. Publ.* **34**(2):85-86.

DEB, M., BANERJEE, D.M. and BHATTACHARYA, A.K. – 1978 – Precambrian stromatolite and other structures in the Rajpura-Dariba polymetallic ore deposit, Rajasthan, India. *Mineral. Deposita* **13**:1-9.

DEB, M. and BHATTACHARYA, A.K. – 1978 – Geological setting and conditions of metamorphism of Rajpura-Dariba polymetallic ore deposit, Rajasthan, India. Vth. IAGOD symp. Snowbird, Utah. Proc. 1, 1980. Schweizerbert'sche Verlagsbuchhandlung, Stuttgart, pp. 689-697.

DEB, M. – 1979 – Polymetamorphism of ores in Precambrian stratiform massive sulfide deposits at Ambaji-Deri, western India. *Mineral. Deposita* **14**:21-31.

DEB, M. – 1980 – Genesis and metamorphism of two stratiform massive sulfide deposits at Ambaji and Deri in the Precambrian of western India. *Econ. Geol.* **75**:572-591.

DEB, M. – 1982 – Rare minerals in Rajpura-Dariba ores – some further comments. *Jour. Geol. Soc. India* **23**:253-260.

DEB, M. and KUMAR, R. – 1982 – The volcano-sedimentary environment of Rajpura-Dariba polymetallic ore deposit, Udaipur district, Rajasthan. Symp. on Metallogeny of the Precambrian. IGCP proj. 91, Bangalore, August.

DHAR, A. – 1980 – Some observations on rock characters and ore mineralisation around Basantgarh, Sirohi district, Rajasthan. *Jour. Mines, metals & Fuels*, June:133-140.

DOE, B.R. and STACEY, J.S. – 1974 – The applications of lead isotopes to the problems of ore genesis and ore prospect evaluation – a review. *Econ. Geol.* **69**:757-776.

GEOLOGICAL SURVEY OF INDIA – 1976 – Know your district: Atlas of Rajasthan. Geol. Surv. India. Western region, Jaipur.

GEOLOGICAL SURVEY OF INDIA – 1980 – Geological map of Rajasthan. 26th. Int. Geol. Cong. Paris.

GLIKSON, A.Y. – 1979 – Early Precambrian tonalite-trondhjemite sialic nuclei, *Earth-Sci. Rev.* **15**:1-73.

GUPTA, B.C. – 1934 – The geology of central Mewar. *Mem. Geol. Surv. India* **65**:107-169.

GUSTAFSON, L.B. and WILLIAMS, N. – 1981 – Sediment hosted stratiform deposits of copper, lead and zinc. *Econ. Geol.* 75th. Anniv. Vol.: 139-178.

HERON, A.M. – 1935 – Synopsis of the pre-Vindyan geology of Rajputana. *Trans. Nat. Inst. Sci. India* **1**:17-33.

HERON, A.M. – 1953 – The geology of central Rajputana. *Mem. Geol. Surv. India* **79**:389 pp.

HOLMES, A. – 1955 – Dating the Precambrian of peninsular India and Ceylon. *Proc. Geol. Assoc. Canada* **7**:81-106.

HUTCHINSON, R.W. – 1973 – Volcanogenic sulfide deposits and their metallogenic significance. *Econ. Geol.* **68**:1223-1246.

KOPPEL, V. and SAAGER, R. – 1976 – Uranium, thorium and lead isotope studies of stratabound ores. *In*: K.H. Wolf (ed.), Handbook of Stratabound and Stratiform Ore Deposits, Elsevier, **2**:267-316.

LAMBERT, I.B. – 1976 – The McArthur river zinc-lead-silver deposit: features, metallogenesis and comparisons with some other stratiform ores. *In*: K.H. Wolf (ed.), Handbook of Stratabound and Stratiform Ore Deposits, Elsevier, **6**:535-585.

LARGE, D.E. – 1981 – Sediment-hosted submarine exhalative lead-zinc deposits – a review of their geological characteristics and genesis. *In*: K.H. Wolf (ed.), Handbook of Stratabound and Stratiform Ore Deposits, Elsevier, **9**:469-507.

MILANOVSKIY, Y.Y. – 1976 – Rift zones of the geologic past and their associated formations. *Internat. Geol. Rev.* **18**(1):515-532; (2):619-639.

MOOKHERJEE, A. – 1964 – The geology of the Zawar lead-zinc mine, Rajasthan, India. *Econ. Geol.* **59**:656-677.

MOOKHERJEE, A. – 1965 – Regional structural framework of the lead-zinc deposits at Zawar, Rajasthan, India. *Jour. Geol. Soc. India* **6**:67-80.

MUKHERJEE, A.D. and SEN, R. – 1978 – Geochemical implications in the genesis of Zawar lead-zinc deposit, Rajasthan, India. Vth. IAGOD symp. Snowbird, Utah. Abstr.:131.

MURATOV, M.V. – 1974 – Principal types of basins of ancient platforms and the problem of their origin. *Internat. Geol. Rev.* **16**:125-130.

NAHA, K. and HALYBURTON, R.V. – 1974 – Early Precambrian stratigraphy of central and southern Rajasthan. *Precambrian Res.* **1**:55-73.

PANDYA, M.K., SOLANKI, S.L. and PANDYA, T.K. – 1980 – Diagenetic features in sulfides of Dariba-Rajpura deposits, Udaipur district, Rajasthan. *Jour. Geol. Soc. India.* **21**:425-431.

PASCOE, E.S. – 1950 – A manual of the geology of India and Burma. 1 (3rd. ed.), Calcutta.

PEREIRA, J. – 1964 – Zawar lead-zinc deposit: hypogene-hydrothermal or remobilised? *Econ. Geol.* **59**:1603.

PODDAR, B.C. – 1965 – Lead-zinc mineralisation in the Zawar belt, India. *Econ. Geol.* **60**:636-638.

PODDAR, B.C. – 1974 – Evolution of sedimentary sulfide rhythmites into metamorphic tectonites in the base metal deposits of Rajpura-Dariba, Rajasthan. Golden Jub. Vol. Quart. *Jour. Geol. Min. Met. Soc. India.* **46**:207-221.

RAGHUNANDAN, K.R., DHRUVA RAO, B.K. and SINGHAL, M.L. – 1981 – Exploration for copper, lead and zinc ores in India. *Bull. Geol. Surv. India.* Sr. A. **47**:222 pp.

RAJA RAO, C.S. – 1970 – Sequence, structure and correlation of the metasediments and the gneisses of the Banded Gneissic Complex of Rajasthan. *Rec. Geol. Surv. India.* **98**(2):122-131.

RAJA RAO, C.S., PODDAR, B.C., BASU, K.K. and DUTTA, A.K. – 1971 – Precambrian stratigraphy of Rajasthan – a review. *Rec. Geol. Surv. India* **101**(2):60-79.

RAJA RAO, C.S., PODDAR, B.C. and CHATTERJEE, A.K. – 1972 – Dariba-Rajpura-Bethumni belt of zinc-lead-copper mineralisation, Udaipur district Rajasthan. *Misc. Publ. Geol. Surv. India* **16**(2):617-626.

RAJA RAO, C.S. – 1976 – Precambrian sequences of Rajasthan. *Misc. Publ. Geol. Surv. India* **23**(2):497-516.

RAY, S.K. – 1974 – Structural history of the Saladipura pyrite-pyrrhotite deposit and associated rocks, Khetri copper belt, Rajasthan. *Jour. Geol. Soc. India* **15**:227-238.

RICHARDS, J.R. – 1975 – Lead isotope data on three north Australian galena localities. *Mineral. Deposita* **10**:287-301.

ROUTHIER, P., BROUDER, P.R., MACQUAR, J.C., PAVILLON, MELLE, M.J., ROGER, G. and ROUVIER, H. – 1973 – Some major concepts of metallogeny: consanguinity, heritage, province. *Mineral. Deposita* **8**:237-258.

ROY, A.B. and JAIN, A.K. – 1974 – Polyphase deformation in the Pb-Zn bearing Precambrian rocks of Zawarmala, district Udaipur, southern Rajasthan. Golden Jub. Vol. Quart. *Jour Geol. Min. Met. Soc. India* **46**:81-86.

ROY, A.B. and PALIWAL, B.S. – 1981 – Evolution of lower Proterozoic epicontinental deposits: stromatolite-bearing Aravalli rocks of Udaipur, Rajasthan, India. *Precambrian Res.* **14**:49-74.

ROY, A.B., SOMANI, M.K. and SHARMA, N.K. – 1981 – Aravalli-pre-Aravalli relationship: a study from the Bhinder region, southern Rajasthan. *Indian Jour. Earth Sci.* **8**(2):119-130.

ROY CHOWDHURY, M.K. and DASGUPTA, S.P. – 1965 – Ore localisation in the Khetri copper belt, Rajasthan, India. *Econ. Geol.* **60**:69-88.

RUSSEL, M.J. – 1978 – Downward-excavating hydrothermal cells and Irish type ore deposits: importance of the underlying thick Caledonian prism. *Trans. Inst. Min. Metall.* **87**(B):128-133.

SARKAR, S.C. and DASGUPTA, S. – 1980 – Geologic setting, genesis and transformation of sulfide deposits in the northern part of Khetri copper belt, Rajasthan, India – an outline. *Mineral. Deposita* **15**:117-137.

SARKAR, S.C., BHATTACHARYA, P.K. and MUKHERJEE, A.D. – 1980 – Evolution of the sulfide ores of Saladipura, Rajasthan, India. *Econ. Geol.* **75**:1152-1167.

SARKAR, S.N. – 1972 – Present status of Precambrian geochronology of the peninsular India. 24th Internat. Geol. Congr. Sec. I:260-272.

SAWKINS, F.J. – 1976 – Metal deposits related to intracontinental hot spot and rifting environment. *Jour. Geol.* **84**:653-671.

SEN, S.N. – 1970 – Some problems of Precambrian geology of the central and southern Aravalli range, Rajasthan. *Jour. Geol. Soc. India* **11**:217-231.

SHARMA, N.L. – 1953 – Problems in the correlation of the pre-Vindyan igneous rocks of Rajasthan. Presidential address. 40th Indian Sci. Congr. Luchnow, 28 pp.

SMITH, A.W. – 1964 – Remobilisation of sulfide orebodies. *Econ. Geol.* **59**:930-935.

STACEY, J.S. and KRAMERS, J.D. – 1975 – Approximation of terrestrial lead isotope evolution by a two stage model. *Earth & Planet. Sci. Lett.* **26**:207-221.

STANTON, R.L. – 1972 – Ore petrology. McGraw-Hill. New York, 713 pp.

STRACZEK, J.A. and SRIKANTAN, B. – 1967 – The geology of Zawar zinc-lead area, Rajasthan, India. *Mem. Geol. Surv. India* **92**:85 pp.

VENKATASUBRAMANIAN, V.S., RADHAKRISHNA, B.P. and JAYARAN, S. – 1977 – Model galena ages from Karnataka and surrounding areas. *Jour. Geol. Soc. India* **18**(2):49-52.

VENKATASUBRAMANIAN, V.S., JAYARAM, S. and SUBRAMANIAN, V. – 1982 – Lead age measurements on galenas from peninsular India. *Jour. Geol. Soc. India* **23**(5):219-225.

VINOGRADOV, A., TUGARINOV, A., ZHYKOV, C., STAPNIKOVA, N., BIBIKOVA, E. and KHORRE, K. – 1964 – Geochronology of India Precambrian. 22nd Internat. Geol. Congr. Pt. X. Archaean and Precambrian Geology:553-567.

WINDLEY, B.F. – 1977 – The evolving continents. Wiley. London, 385 pp.

Recebido em 31 de julho de 1982