Geochemistry of the Ganesh Himal zinc-lead deposits, central Nepal Himalaya

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ABSTRACT

A dolomite hosted strata-bound high-grade (19–25%) zinc-lead sulphide deposit occurs, between 4,000 m and 5,100 m over an area of 5 km² in the ~7 km wide MCT zone of the Ganesh Himal area of central Nepal. The host crystalline milky white sugary dolomite occurs in a repeated sequence of garnet-mica schist, quartzite, calc-schist and concordant amphibolite of older Lesser Himalayan sequence (Upper Nawakot Group), all showing ductile deformation. The rocks along with the ore have undergone at least three phases of deformation. A series of overturned, steep northerly dipping and NE to ENE plunging anticlines and synclines form the dominating structure, characterised by disharmonic shape of the dolomite host rock because of apparent squeezing out from limbs into the axial regions. Compared to their strike lengths, the ore bodies and the host rock bodies have long extension along the plunge direction. The ore has a very simple composition of sphalerite-galena-pyrite with a little pyrrhotite, magnetite and chalcopyrite. Chemically, it consists mainly of zinc along with iron, lead, silver, and very low silica, silicates and alumina. Concentrations of trace and rare elements are very low. Ore body types vary from dissemination and bands to massive sulphide lenses, arranged en echelon, parallel to the schistosity/ bedding. The rocks of the area were subjected to almandine-amphibolite facies of metamorphism, to 750±150 MPa pressure and 500 °C to 750 °C temperature conditions. The latest thermal event was as young as ~12 Ma. The lead isotope data are interpreted to establish an age of 875 to 785 Ma for the Ganesh Himal deposits, while sulphur isotope data imply an age greater than 650 Ma. The Ganesh Himal deposit appears to be Vindhyan equivalent in the Himalaya, showing highest metal values as on date. Only two out of six occurrences in the area have been explored so far. The ore reserve estimates stand at 2.4 million tonnes with 14.66% zinc, 3.01 % lead, and 23.5 g/t silver. Taking into account all the occurrences, the Ganesh Himal basin might have had 861,000 tonnes zinc and 182,000 tonnes lead at the minimum. The lithologic sequence represents a shallow marine facies of deposition. The δ^{34}S values for Ganesh Himal sulphides indicate that the sulphur was probably produced by biogenic reduction of contemporaneous seawater sulphate. The lead isotope ratios of Ganesh Himal deposit fall on a single-stage growth curve, on which also fall many big deposits of the world, indicating that the Ganesh Himal zinc-lead deposit has high potential. The primary control of the mineralisation is stratigraphic, the present ore body configuration being controlled by south vergent folding related with the metamorphism and thrusting along the MCT. Pyrite framboids and geochemical characters of ore indicate that the mineralisation is syngenetic sedimentary, and it may have been deposited in association with a bioherm or reef in an anoxic environment. The source of metal ions is not clear yet, but the contemporaneous basic rock bodies providing the metal ions could be a possibility.

INTRODUCTION

The high-grade zinc-lead deposits in the Ganesh Himal region occur at six isolated locations within an area of about 5 km². The zinc-lead mineralisation occurs around the Lari valley, defined by 28°13'52.5" N latitude and 85°11'4.7" E longitude and about 58 km (aerial distance) N13°W of Kathmandu, between 4,000 m and 5,100 m altitudes. The deposits can be reached by 175 km drive from Kathmandu, followed by a few hours of trekking.

GEOLOGICAL SETTING

The mineralisation, at all the six places, occurs in an identical sequence of rocks consisting of garnet-staurolite-kyanite schist, calc-schist, dolomite, quartzite and amphibolite, the host rock being invariably milky white crystalline dolomite with a characteristic sugary texture (Fig. 1, and Table 1). The rocks are tightly folded (Fig. 2), with individual rock units varying widely in thickness (Chakrabarti 1982, Ghimire et al. 1996, Chakrabarti and Ghosh 1996). Staurolite-garnet-kyanite schist dominates the upper sequence of rocks, while thick calcareous units and quartzites dominate the lower sequence. A thin but persistent horizon of highly puckered calc-schist occurs above the crystalline dolomite followed upwards by light coloured coarse-grained garnet-mica schist containing occasional bands of greyish brown quartzite. The dolomite is generally a monomineralic rock, locally containing sphalerite, pyrite, phlogopite, actinolite, tremolite, magnetite, galena, chalcopyrite, quartz, garnet, kyanite, plagioclase, fuchsite, diopside, sphene, and epidote. Near the upper contact with calc-schist, the dolomite
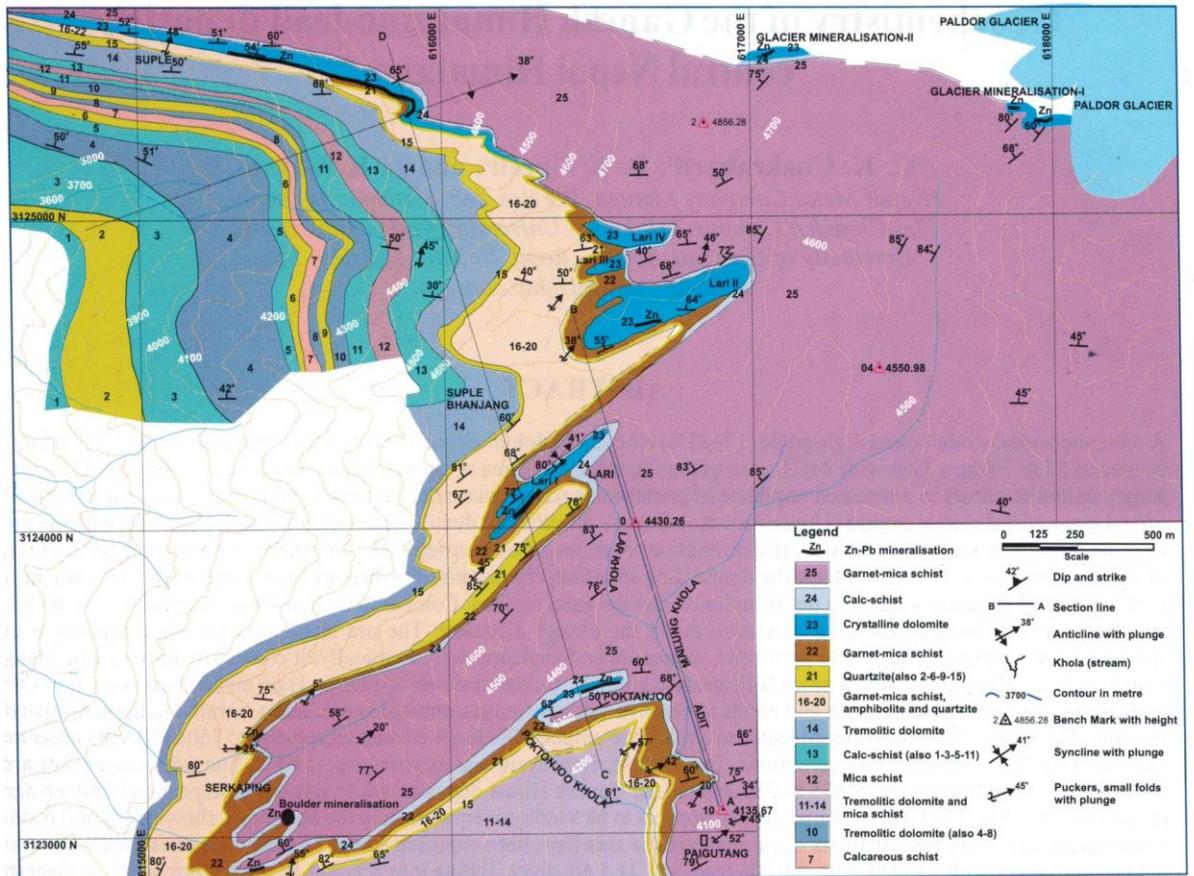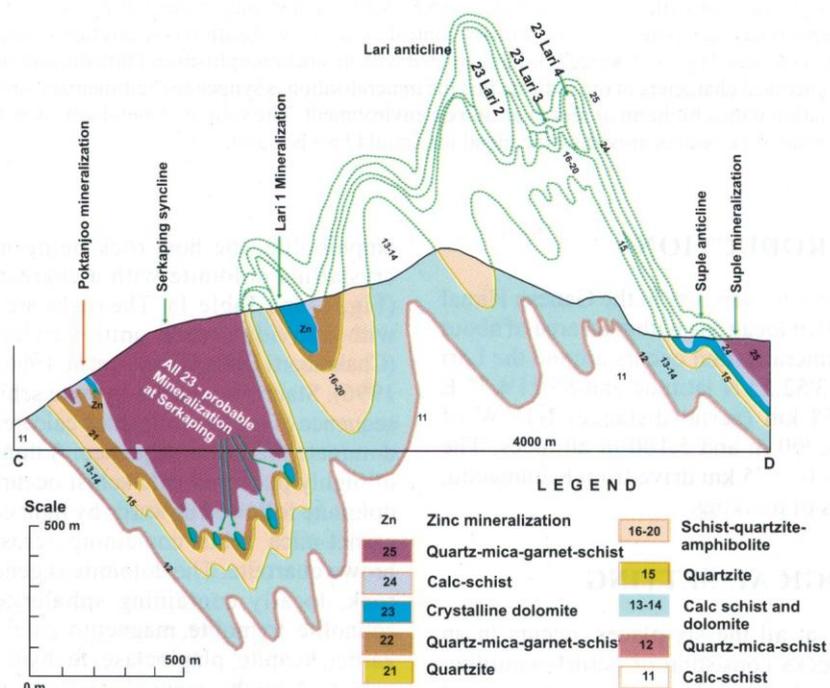
Fig. 1: Geological map of Ganesh Himal zinc-lead deposits

Fig. 2: Geological cross-section along C–D (Fig. 1) through Suple, Lari, and Poktanjoo

Table 1: Lithologic sequence in the Ganesh Himal ore deposit area

Unit No.	Lithology	Thickness (m)
25	Garnet-mica schist with quartzite bands	?
24	Calc-schist	0-6
23c	Coarse grained milky white crystalline dolomite, mineralised	0-29
23b	Medium to fine grained grey dolomite	0-1
23a	Dark grey crystalline dolomite/limestone	0-7
22b	Graphitic schist	0-2
22a	Garnet-mica schist	0.5-17
21	Quartzite	0.5-2
20	Garnet-mica schist	1-30
19	Garnetiferous amphibolite	0.5-20
18	Garnet-mica schist	0.5-7
17	Quartzite	0.5-13
16	Garnet-mica schist with amphibolite	0.5-30
15	Quartzite	0.5-7
14	Tremolitic crystalline dolomite	30-80
13	Calcareous schist	6
12	Quartz-mica schist	5
11	Calc-schist	6-30
10	Tremolitic crystalline limestone/dolomite	6-25
9	Quartzite	3-30
8	Tremolitic crystalline limestone/dolomite	5-15
7	Calcareous schist	5-15
6	Quartzite	3-25
5	Calc-schist	5-25
4	Tremolitic crystalline limestone/dolomite	15-60
3	Calc-schist	30-100
2	Quartzite	15-45
1	Calc-schist	?

occasionally contains tiny red crystals, locally known as "ruby", identified by Uhlir et al. (1998) as 'red and violet gahnites', which plot within the isomorphous series of spinel ($MgAl_2O_4$) and gahnite ($ZnAl_2O_4$).

The mineralisation generally occurs near the lower contact of the crystalline dolomite. Near the bottom of the crystalline dolomite and below the mineralised zone, the dolomite becomes grey owing to the specks of black carbonaceous material gradually grading to highly crenulated graphitic schist, followed downwards by garnet-mica schist, carbonaceous at the top. The garnet is pre- to syn-kinematic, highly deformed and shows spiral inclusions. A very fine-grained quartzite occurring below garnet-mica schist is a prominent rock unit owing to its milky white colour. The band has been followed consistently almost all through the area. Below the quartzite occurs a garnet-mica schist horizon in association with amphibolite. The apparently concordant amphibolites, generally pock-marked caused by red garnets, appear ortho-amphibolite derived from basalt (based on MgO-CaO-Fe_2O_3 diagram of Walker et al. 1960), and generated in a continental setting, probably in a rifting environment (based on Zr, Ti and Y diagram of Pearce and

Cann 1973). No amphibolite occurs above the mineralised horizon, and it appears that the amphibolite is either approximately coeval to or slightly older than the Zn-Pb mineralisation. No granitic or any other magmatic bodies are seen to occur in the vicinity.

There is no unanimity about the location of the deposits with respect to the MCT. The Geological Map of Nepal prepared by DMG (1994) and UNESCAP (1993) show the Ganesh Himal zinc-lead deposits on the north of MCT probably owing to high-grade metamorphism, plastic folding and almost absence of brittle deformation. But the total absence of Higher Himalayan gneisses, abundance of carbonates, occurrence of carbonaceous rock and kyanite-garnet-mica schist in the region strongly suggest that the area is on the south side of and tectonically below the MCT, and belongs to the Upper Nuwakot Group (Stöcklin 1980) or upper part of the Older Lesser Himalayan Sequence (Upreti 1999). Kumar (1980), on the other hand, considered the rocks of the prospect as equivalent to the upper part of the Chail Nappe. The present authors place the zinc-lead deposits of Ganesh Himal in the MCT zone (Arita et al. 1973) occurring in the footwall of the MCT.

The quartzite beds show a surprising continuity in spite of intricate and tight folding, and have helped in deciphering the structure of the area (Fig. 1). This ductile deformation is exhibited throughout the area. The dolomite has apparently squeezed out from limbs and moved into the axial regions of synclines. A section from Poktanjoo to Suple (Fig. 2) provides the structural disposition of the rock units in the study area. The major structures of the area are the NE to ENE plunging Suple antiform, Lari antiform, Serkaping synform, and Wangpoo antiform (Figs. 1 and 2). The average strike of the foliations in the Lari–Paigutang area is N57°E-S57°W with 66° dip due N33°W. At Suple, the foliation strikes N85°E–S85°W with a dip of 53° due N5°W.

In many rocks in the area studied, bedding is well defined because of compositional difference. However, no other primary sedimentary structure is discernible. Kumar (1980) observed that the ore minerals have undergone three phases of deformation and isofacial metamorphism along with the host rock.

The area under study exhibits lower amphibolite facies metamorphism and also demonstrates inverted metamorphism. Formation of chlorite along fractures in garnet indicates retrogressive metamorphism. From the microprobe data, Rai et al. (1998) determined that the rocks were subjected to a temperature of 566 ± 136 °C and a pressure of 750 ± 150 Mpa during metamorphism. The cooling age by $^{40}Ar/^{39}Ar$ of a phlogopite sample from the Suple, about 20 m above the mineralisation, has been estimated at 11.98 ± 0.38 Ma (Dr. Giuliani of CRPG/CNRS, personal communication). Thus the temperature in this region of the MCT zone was above the blocking temperature of phlogopite till ~12 Ma.

Besides the pre-Tertiary metamorphism of the Lesser Himalaya, the prospect has undergone at least two more phases of metamorphism, the earlier one was associated with the MCT and should be about 20–22 Ma, and the later one ending around 12 Ma.

MINERALISATION AND ORE BODIES

At Ganesh Himal, six localities of mineralisation viz., Lari I, Lari II, Serkaping, Suple, Poktanjoo, and Glacier, have so far been identified within an area of 5 km² (Fig. 1), out of which only two, Lari I and Suple, have been explored in detail. The occurrence of two marker beds namely, the quartzite (unit No. 21) below and the calc-schist (unit No. 24) just above the mineralised dolomite (unit No. 23c), confirms that all the zinc-lead mineralisations are confined to the same stratigraphic horizon.

The dolomite host rock (unit No. 23c) has been intensely deformed and thereby squeezed into four apparently detached bodies with unequal concentration of mineralisation at Lari (Fig. 1). Of the four bodies, Lari I is the most mineralised one and Lari II contains some mineralisation. The Lari II is also an oval-shaped dolomite body, about 560 m long and 130 m across at its widest, and tapers at both ends. The Lari

I ore body was found to contain mineralisation in three zones, named A, B, and C zones. The mineralisation is parallel to bedding and schistosity ($S_o = S_1$), except at two places where the veins cut across the schistosity, probably caused by subsequent remobilisation. A big mass of black carbonate rock (predominantly dolomite) marks the termination of the A, B, and C zones at around the 4,130 m level (Fig. 3). The black carbonate rock, probably representing a reef, is rich in graphitic matter. The mineralisation reappears as P and R zones further northeast (Fig. 3).

Serkaping, occurring at 1,370 m S25°W of the Lari valley, was known for the occurrence of a big boulder of massive sulphide ore lying on a mound of talus. The mineralisation is associated with sugary white dolomite and black carbonaceous schist. The sulphides appear to occur almost in the schist, the dolomite being very thin. In situ mineralisation has also been recorded at many places at Serkaping.

Suple is at a distance of about 1,830 m N33°W of Lari (Fig. 1), where massive sphalerite occurs with abundant pyrite near the lower contact of dolomite with carbonaceous schist. The dolomite is about 29 m thick but pinches out completely 490 m to the west. The mineralisation occurs in an anticline plunging 38° N70.5°E, which is mostly covered by till in the east. Geophysical study indicates extension of the ore body further east.

The Poktanjoo mineralisation occurs about 700 m south of Lari on a steep slope. The host rock, dolomite, becomes very thin (1.5 m) and occurs in an alternating sequence of calc-schist and garnet-mica schist, all dipping steeply due northwest, most of the rock units pinching out towards the east. The ore is also massive and occurs like a thin continuous band parallel to bedding/schistosity.

A little above 5,000 m altitude, two areas of sulphide mineralisation were located by stream sediment geochemistry. The main mineralisation known as Glacier I is partially covered by an approximately 20 m thick glacial ice. The mineralisation is confined to the medium-grained sugary dolomite cores of steep east-north-easterly plunging tight isoclinal folds. Dissemination and bands of sphalerite with abundant pyrite form the ore body, occurring parallel to the bedding plane schistosity. The Glacier II mineralisation is insignificant economically, but at this place the sequence of rocks seems inverted, as the calc-schist occurs below the dolomite.

At all the places, the ore occurs with very sharp contacts with the host rock without any wall rock alteration whatsoever.

The Ganesh Himal ore represents a simple assemblage of a few sulphide minerals, characterised by coarse-grained sphalerite and a lesser quantity of moderate to coarse-grained galena, abundant pyrite, locally predominant, pyrrhotite, graphite and magnetite, with minor chalcopyrite and marcasite (Figs. 4 and 5). The gangue is dominated by dolomite with minor to trace amounts of actinolite, muscovite, quartz, magnetite, and calcite. An X-ray powder diffraction
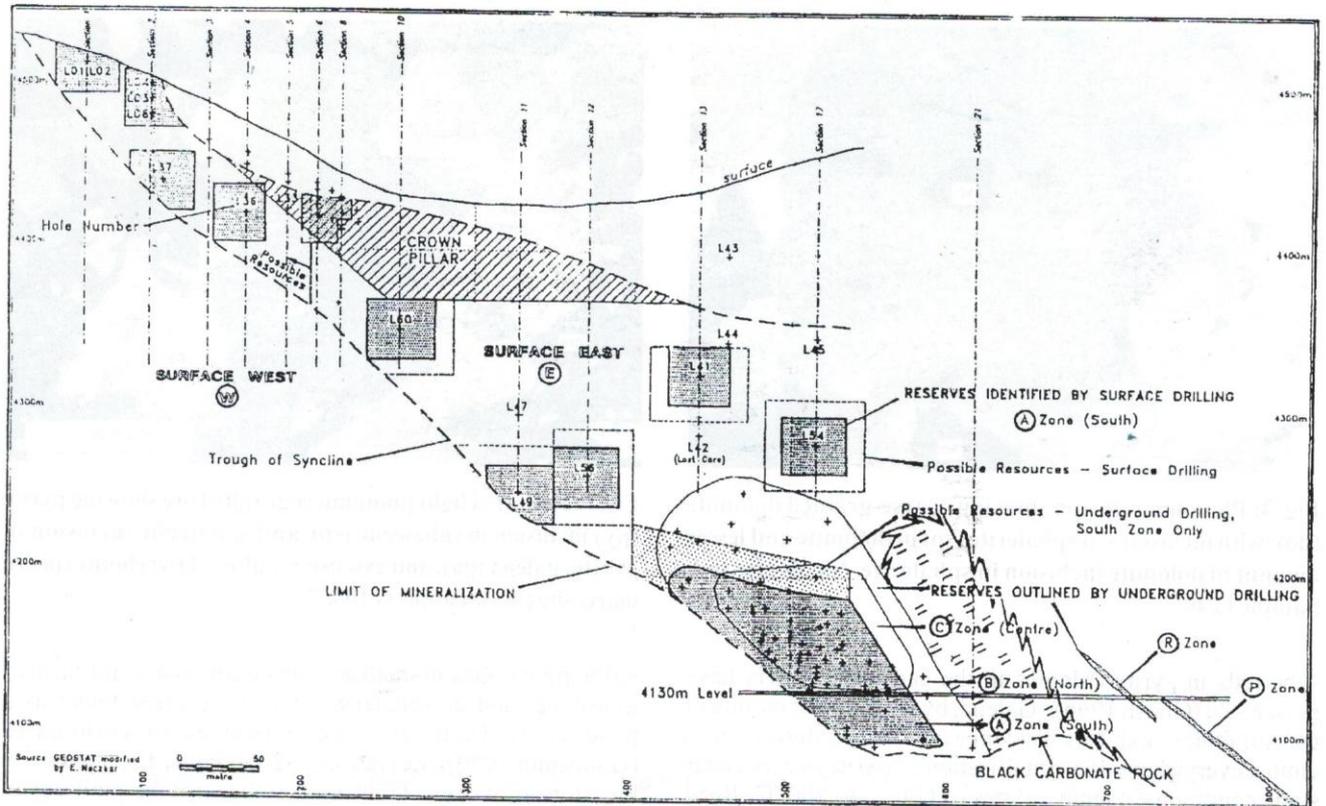
Fig. 3: Vertical projection of Lari I mineralisation, approximately on the axial plane of the Lari I syncline. The mineralisations (A, B, and C zones) abruptly terminate against a black carbonate body, and reappear again as P and R zones. Areas between possible resources are exploration gaps (after unpublished UNDP Report 1993).

spectrum indicates a possibility of pyrargyrite (Ag_3SbS_3) and peaks close to argentite (Ag_2S).

Sphalerite shows distinct colour variations from almost black through various shades of brown to olive green, greenish yellow, light sulphur yellow to honey yellow associated with variable proportions of pyrite and galena. The sulphide minerals occur as massive lenses and bands, semi-continuous or en echelon, parallel to the schistosity/ bedding, and as dissemination.

The Lari I ore bodies (A, B, and C zones) were prospected in detail and traced along the plunge of the fold towards the northeast for 900 m. The dolomite body continues further along the plunge. After a gap of 100 m, the ore body reappears further northeast at 4,130 m level with reduced concentration (Fig. 3) and continues further down the plunge. The Suple ore body has also been traced by diamond drilling for about 300 m along strike in spite of limitations posed by the presence of thick talus.

At the end of the 2002 exploration season, the mineable ore, at 5% cut-off, is estimated in the Lari I ore body at 1.3 million tonnes averaging 13.32% zinc, 2.13% lead and 27 g/t silver, and that in the Suple ore body at 1.1 million tonnes containing 16.25% zinc, 4.05% lead and 19.43 g/t silver (NMCL 2004). Combining Lari I and Suple, a total run-of-

mine (ore) of 2.4 million tonnes with average grade of 14.66% zinc, 3.01% lead and 23.5 g/t silver is demonstrated in the Ganesh Himal area, out of which 1.3 million tonnes of ore can be taken as proved. If all the mineralisations are considered, the geological ore reserve of the Ganesh Himal deposits is greater than 3 million tonnes.

The ore petrography shows that the ore is coarse-grained and recrystallised. Sphalerite shows yellow to reddish brown internal reflections and foam texture to granoblastic polygonal texture with triple-point junctions indicating metamorphic recrystallisation. Sphalerite contains some irregularly distributed chalcopyrite blebs. The olive variety of sphalerite, often containing inclusions of reddish brown sphalerite, does not display clear internal reflections and triple-point junctions, and has flowed along fractures within galena. Therefore, it appears that the olive sphalerite is paragenetically younger than the brown and darker varieties. A few electron probe analyses of sphalerite show some iron within the crystal lattice ranging between 3.5 % and 6.0 %. Aggregates of granoblastic pyrite with 120° triple-point junctions also occur abundantly. Pyrite ranges in size from 100 micron to as much as 1.5 cm across. Syn-deformational overgrowth of pyrite has often produced flattened grains. In spite of the high-grade metamorphism, the presence of a few relics of framboidal pyrite, and some disseminated tiny
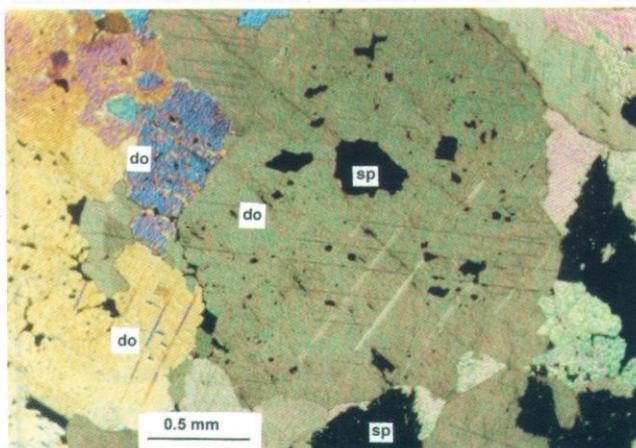
Fig. 4: Photomicrograph showing coarse-grained dolomite (do), with inclusions of sphalerite (sp) in dolomite and lesser amount of dolomite inclusion in sphalerite. Nicols crossed; Sample G 40
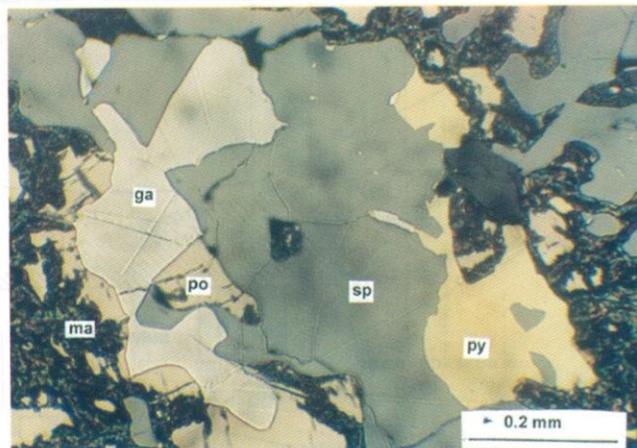

Fig. 5: Reflected light photomicrograph of ore showing pyrite (py) inclusion in sphalerite (sp), and sphalerite inclusion in pyrite, galena (ga), and extensively altered pyrrhotite (po) to marcasite (ma), sample G 108.

spheroids in pyrite colonies in the carbonate matrix have been noted (Ghosh 1996). Galena, by far the most mobile of the sulphides, exhibits evidence of ductile deformation almost everywhere. Recrystallisation of pyrite occurs under static conditions at temperatures of 600 °C to 800 °C (Read 1968), and at temperatures above 550 °C under dynamic conditions (Cox et al. 1981). The textural features of the Ganesh Himal ore indicate that the ore was possibly metamorphosed to a minimum temperature condition of 600 °C.

GEOCHEMISTRY OF THE ZINC-LEAD DEPOSITS

Most of the carbonate-hosted syngenetic zinc-lead deposits are in dolomites. Monseur and Pel (1972) established a close relationship between reefs, the process of dolomitisation and stratiform ore deposits. For some deposits, such as Pine Point in Canada, the dolomitisation of carbonate probably provided porosity that allowed the movement of solutions (Jensen and Bateman 1981). The host rock, crystalline dolomite of the Ganesh Himal ore, contains 30.66 % CaO and 23.27 % MgO in average. The ore is very low in silica, alumina, barium, manganese, and Na_2O, while K_2O and P_2O_5 were not detected. Both TiO_2 and Cr_2O_3 are also low, while FeO has been recorded to range between 1.126% and 4.091%.

Seawater cannot generally be considered to be the reservoir of lead and zinc, and marine carbonates are poor in Pb and Zn in most cases. Mason (1958) and Krauskopf and Bird (1995) estimated the concentrations of zinc in seawater at 0.014 ppm and 0.0003 ppm, and lead at 0.005 ppm, and 0.000003 ppm, respectively. The average content of zinc is about 40 ppm in clays, but its content increases considerably in sulphide-bearing marine sediments (like Permian Copper Shale of Mansfeld, Germany, containing as much as

9,000 ppm). Zinc in small amounts is a normal constituent of limestone, and as sphalerite, it is quite often found as a product of diagenetic reconstitution of carbonates (Goldsmith 1970). Levinson (1980) recorded 25 ppm Zn in limestone in average. Goldsmith opined that the similarity in radii between divalent zinc and the metals of the magnesium-iron group, especially between zinc and iron, determine the geochemistry of zinc. This similarity is clearly evidenced by the mutual replacement of zinc, cobalt, ferrous iron, and manganese in both oxygen compounds and sulphides. In sulphides, replacement of zinc by cadmium, mercury, indium, tin, germanium, and gallium is possible.

Goldsmith (1970) observed about 20 ppm Pb in arenaceous shales and 5–10 ppm Pb in limestones in average. Levinson (1980) recorded 8 ppm Pb in limestone. In black muds, the concentration of lead is much higher, in Permian Copper Shale of Mansfeld, Germany; Pb content is of the order of 5,000 ppm.

The geochemistry of lead in the minerals and rocks of the upper lithosphere is dominated by its properties both as a chalcophile and as a lithophile element. As a chalcophile element, it is found mostly as the sulphide, galena (PbS), and in related compounds with selenium and tellurium, as well as in a great number of sulphosalts, where it acts as a cation. As a lithophile element, it occurs in a large number of rock-forming minerals. Its ionic radius (Pb_2+ 1.32 Å) makes it possible for lead to replace strontium (1.27 Å), barium (1.43 Å), potassium (1.33 Å), and in certain cases even calcium (1.06 Å). Galena is an important 'host' mineral for quite a number of rare chalcophile elements viz., Ag, Se, Te, As, Sb, Bi, Th, Sn, and rarely Cd and Mo (Goldsmith 1970).

The common major elements in lead-zinc deposits are Pb, Zn, Fe and S, and also Cu in certain cases. A definitive geochemical character of a lead-zinc deposit may possibly
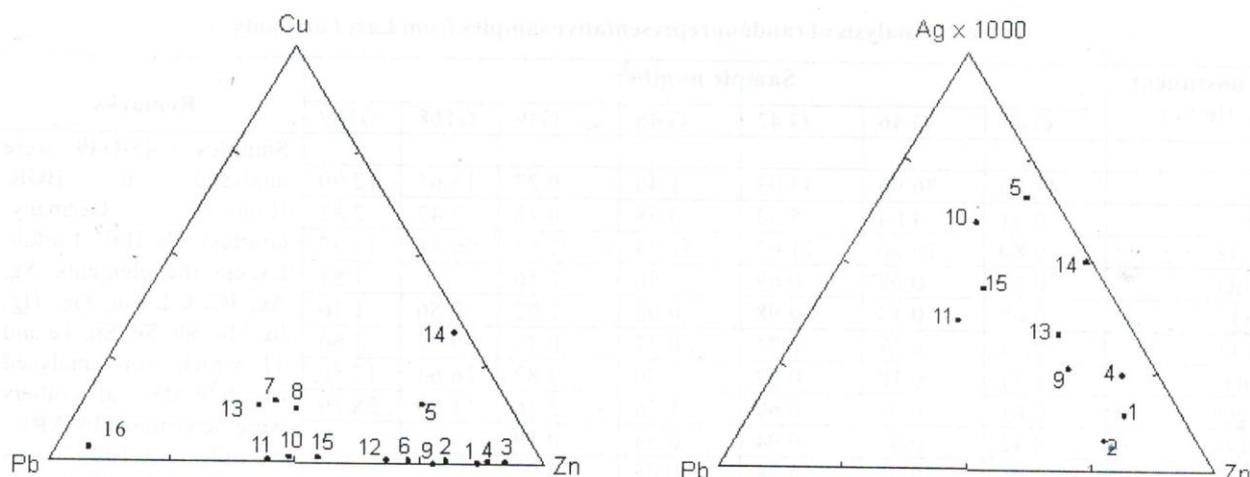
Fig. 6a: Cu-Pb-Zn ternary diagram showing plots of some important deposits of the world and also the Ganesh Himal deposit and Fig. 6b: Ag-Pb-Zn ternary diagram showing plots of some important deposits of the world and also the Ganesh Himal deposit, 1. Ganesh Himal (Lari), Nepal, 2. Ganesh Himal (Suple), Nepal, 3. Phakua, Eastern Nepal, 4. Rampura-Agucha, India, 5. Rajpura-Dariba, India 6. Zawar, India, 7.Ambaji, India 8. Deri, India 9. Red dog, Alaska, 10. Madem Lakkos, Greece 11. Broken Hill, Australia, 12. Pine Point, Canada 13. Saxberget, Sweden, 14. Abitibi, canada 15. Aguilar, Argentina, and 16. Sargipali, India

be expressed in terms of Pb–Zn–Cu ratio. A Pb–Zn–Cu ternary diagram (Fig. 6a) shows plots of some important sulphide deposits, including some deposits and occurrences of Nepal and India. Similarly, the Ganesh Himal and some other important sulphide deposits are shown in a Pb–Zn–Ag ternary diagram (Fig. 6b).

Kucha and Viaene (1993) suggested that sulphur compounds with mixed and intermediate sulphur valences are stable below 250–300 °C, and might have been widely involved in the formation of carbonate-hosted Zn-Pb deposits. It appears that the ore bodies in carbonate rocks are almost entirely devoid of copper, and show a strong tendency to be much richer in zinc than in lead. Copper-rich deposits in carbonate rocks are, therefore, less common. Xuenin (1984) concluded that highest Zn/Cd ratios (417–531) are recorded by volcano-sedimentary and some Alpine type deposits and lowest Zn/Cd ratios (104–214) by hydrothermal and skarn deposits, while Zn/Cd ratios of metamorphosed sedimentary deposits and carbonate hosted strata-bound and stratiform deposits are moderate (252–330). The igneous rocks and shale contain in average 0.2 ppm Cd while limestone contains 0.1 ppm Cd (Levinson 1980) indicating reduction of Cd in a limestone environment. Monseur (1967), Monseur and Pel (1972) and Guilbert and Park (1986) showed that Co/Ni ratios in pyrites of sedimentary origin are generally less than unity. Low Tl in pyrites also indicates a sedimentary origin (Monseur 1967). The abundance of U and V in chemical precipitates, shales and organic sediments have been recorded. Large S/Se ratios are typical of sedimentary values where sulphide S is derived from the basin or pore waters containing only minute amounts of Se (McGoldrick and Keays, 1990).

The average zinc, lead, and silver contents of the Lari I ore body have been estimated at 16.44 %, 2.55 %, and 32.3 g/t respectively, with a zinc-lead ratio of about 6.45 (UNDP 1993). Iron (as Fe_2O_3) contents of two representative ore samples (Table 2) were recorded at 11.97% (Fe 8.37%) and 16.41% (Fe 11.48 %) while the average iron content, obtained from 315 underground channel samples, is estimated at 4.66 %. The Ganesh Himal deposits are rich in zinc. The zinc-lead ratios determined on drill cores do not show good correlation. The ore is low in silica and alumina, high in iron and also contains graphitic carbon. Silver content of the ore is moderate, gold is absent, copper is very low, also arsenic, antimony, bismuth, mercury, nickel, cobalt, and barium are very low. Copper in selected ore samples ranges between 18 and 3,300 ppm, while copper in zinc concentrate goes up to 980 ppm and in lead concentrate up to 440 ppm (Table 3). Ganesh Himal sphalerites are low in Cd. Four sphalerite samples contained 655 ppm cadmium in average while six samples of zinc concentrate show an average of 1,080 ppm (Table 3). It is estimated from Cd/Zn plots that the ore body with 16.44% zinc should contain about 250 ppm cadmium, with Zn/Cd at 656. Trace element concentrations of Ga, Ge and In are very low. Two random samples, show S/Se ratio at 24000 and 4433 while a zinc concentrate sample shows S/Se ratio at >113666, a lead concentrate sample shows the ratio at 52,750. The Ganesh Himal ore is highly variable in both grade and thickness.

From a multimetal sulphide mineralisation at Rangpo in Sikkim, India, Ghosh (1975) recorded high concentrations of cobalt (155–9700 ppm), nickel (28–380 ppm) and mercury (1070–5000 ppm). The Ganesh Himal ore is deficient in all

Table 2: Analysis of random/representative samples from Lari I ore body

Constituent (in %)	Sample number							Remarks
	G 45	G 46	G 47	G 48	G49	G168	G169	
								Samples G45-G49 were analysed at BGR, Hannover, Germany, courtesy Dr H.C. Einfalt. Except the elements Ag, As, Bi, Cd, Ga, Ge, Hg, In, Mo, Sb, Se, Sn, Te and Tl, which were analysed by ICP/MS, all others were determined by XRF. Sample G168 was analysed chemically at National Metallurgical Laboratory, India. Sample G169 was analysed chemically at Hindustan Zinc Ltd, Udaipur, India.
Zn	47.40	36.96	43.03	1.40	0.27	13.63	12.90	
Pb	0.91	3.04	5.53	3.58	0.18	2.47	2.82	
Fe_2O_3	9.80	16.60	11.03	51.28	52.62	16.41	11.97	
MnO	0.81	0.08	0.69	1.56	2.56		1.81	
SiO_2	0.05	0.14	0.98	0.02	0.02	0.56	1.16	
Al_2O_3	0.13	0.53	0.71	0.37	0.21	0.97	1.60	
CaO	1.31	0.18	0.62	5.70	4.82	16.64	17.50	
MgO	0.81	0.08	0.69	1.56	2.56	11.89	28.19	
Na_2O	0.42	0.03	0.04	0.64	0.19			
K_2O	0.06	0.07	0.28	0.05	0.03			
P_2O_5	0.08	0.07	0.02	0.18	0.07			
SO_3	12.00	13.49	13.30	7.44	6.11	39.90	39.25	
C#							0.42	
Insoluble							1.76	
LoI	15.22	19.24	12.46	25.24	27.34	10.98	15.00	
(in ppm)								
Ag	50.00		88.00				Samples G168 and G169 are representative ores. Samples G45-G49 are grab samples. # Carbon is graphitic carbon.	
As	3.00		4.00					
Ba	320	<50.00	81.00	<50.00	<50.00			
Bi	0.20		0.70					
Cd	640		750.00					
Ce	<35.00	<35.00	<35.00	<35.00	<35.00			
Co	18.00	15.00	24.00	138.00	30.00			
Cr	<7.00	8.00	12.00	27.00	<7.00			
Cu	22.00	18.00	269.00	49.00	3300.00			
Ga	2.00		5.00					
Ge	1.70		7.00					
Hf	<18.00	<18.00	<18.00	<18.00	<18.00			
Hg	0.50		4.00					
In	0.03		0.03					
Mo	1.10		8.60					
Nb	<5.00	10.00	10.00	12.00	10.00			
Ni	9.00	35.00	8.00	92.00	<7.00			
Rb	16.00	16.00	25.00	18.00	7.00			
Sb	13.00		12.00					
Se	2.00		12.00					
Sn	2.00		12.00					
Sr	<5.00	11.00	<5.00	12.00	<5.00			
Ta	<10.00	<10.00	<10.00	13.00	<10.00			
Te	0.07		0.24					
Th	<10.00	<10.00	<10.00	<10.00	<10.00			
Tl	0.70		3.5.00					
U	12.00	29.00	<5.00	6.00	<5.00			
V	<10.00	19.00	14.00	<10.00	<10.00			
W	<10.00	<10.00	<10.00	<10.00	<10.00			
Y	<5.00	<5.00	<5.00	<5.00	<5.00			
Zr	13.00	51.00	53.00	284.00	67			

Table 3: Composition of Ganesh Himal zinc concentrate and lead concentrate

Constituents (in %)	Zinc - concentrate						Lead - concentrate		
	Sample number								
	G170	G171	G172	G173	G174	G175	G176	G177	G178
Pb	1.49	0.56	0.30	1.80	2.08	0.51	79.00	59.00	68.90
Zn	58.70	59.2	63.45	51.50	55.60	55.97	4.0	16.4	4.50
S	33.50	34.10		29.80	30.10	32.55	16.40	21.10	
Fe	4.46	5.65		8.60	7.00	6.28	0.45	3.25	
CaO	0.18	0.25	1.30	0.31	1.65		0.05	0.19	
MgO	0.22	0.15	0.82	0.63	2.45		0.02	0.19	
SiO_2	0.14	0.13		0.70	0.27	0.20			
Al_2O_3		<0.10		3.55	2.35			<0.10	
BeO		<0.01						<0.01	
F		0.01						0.01	
Insoluble				1.04	0.35				
(in ppm)									
Ag	36.00	19.00				Trace	810	674.00	394.97
Au	0.09	0.03.00					0.11	0.40	Trace
Cu	530.00	470.00	140.00	700.00	980.00	Trace	91.00	440.00	
Sn		<10.00						<10.00	
As	3.50	<20.00	N.D.	56.00	27.00		7.20	50.00	N.D.
Sb	<5.00	<20.00	N.D.	98.00	50.00		65.00	140.00	N.D.
Cd	1000.00	1000.00	1100.00	1860.00	1220.00	300.00	50.00	280.00	
Bi	<5.00	<20.00		25.00	30.00		<5.00	50.00	
Hg	22.00	21.00		50.00	50.00		1.40	5.30	
Se		<3.00						4.00	
Te		<5.00						<5.00	
Cl		42.00	N.D.					51.00	
Br			N.D.						
I			N.D.						
Cr		<30.00	Trace					<30.00	
Ge		<10.00		<5.00	<5.00			<10.00	
Mn				3250.00	270.00	Trace			
Ni		<20.00	10.00	43.00	37.00			<20.00	
Cobalt		<20.00	10.00	16.00	10.00	10.00		<20.00	
Chloride				350.00	350				
Remarks	#1	#2	#3	#4	#4	#5	#1	#2	#3

Note: N.D.-Not detected, Blanks not assayed, Analysed at : #1-CRM, Canada, #2-Lakefield Research, Canada, #3-Ontario Research, Canada, #4-HZL, India, #5-NML, India

Table 4: Average element contents of the Lari I ore

Element	Concentration (%)	Element	Concentration (ppm)
Zn	16.44	C	4200
Pb	2.55	Ga	1.04
Fe	4.66	Ge	1.29
		In	0.01
(ppm)		Sn	2.07
Ag	32.37	Tl	0.62
Cu	160.00	Hg	0.66
Cd	250.00	U	3.08
Ba	135.00	Th	0.13

Table 5: Comparison of Ganesh Himal and Phaluwa ores (random samples)

Constituent	Ganesh Himal Ore #	Phakuwa Ore @	Analysis type
(In percent)			
SiO_2	1.45	63.15	XRF
Al_2O_3	0.39	1.17	XRF
Fe_2O_3	28.27	2.51	XRF
Zn	25.81	8.26	XRF
Pb	2.65	0.58	XRF
(In ppm)			
Ag	69.00	7.00	ICP/MS
As	3.50	35.00	ICP/MS
Bi	0.45	2.80	ICP/MS
Cd	507.50	160.00	ICP/MS
Ga	3.50	6.00	ICP/MS
Ge	4.35	3.40	ICP/MS
Hg	2.25	25.00	ICP/MS
In	0.03	0.15	ICP/MS
Mo	4.85	13.00	ICP/MS
Sb	12.50	28.00	ICP/MS
Se	7.00	1.00	ICP/MS
Sn	7.00	33.00	ICP/MS
Te	0.16	<0.05	ICP/MS
Tl	2.10	0.60	ICP/MS

Average of 5 random samples @ 1 random sample, Analysed at BGR. Hannover. Courtesy Dr. H.C. Einfalt.

these elements. Co/Ni ratios of five random samples (Table 2) show that for only one sample the ratio is less than unity. However, Co/Ni ratio of the three zinc concentrate samples (Table 3) lies between 1 and 0.27. Tl content of the ore is also very low (Table 2).

Five random samples of the Ganesh Himal ore recorded <5 to 29 ppm U and <10 ppm Th. The concentrations of U in the eastern Indian Himalayan deposits of Gorubathan and Dikchu were estimated by Ghosh and Kunzendorf (1988) between 0.85 and 3.58 ppm.

Although the sample population is too small for a concrete conclusion, it appears that compared to the Gorubathan and Dikchu ore, the Ganesh Himal ore is slightly more enriched in uranium.

The low Tl and large S/Se ratios of sulphides of Ganesh Himal ore may indicate their sedimentary genesis. The average element contents of the Lari I ore are shown in Table 4.

As geochemical data for the deposits in Nepal other than Phakuwa are not available, a comparison of geochemical features of all deposits is not possible at this stage. However, the massive to disseminated strata-bound zinc–lead mineralisation in the metamorphosed Phakuwa Group of the Kathmandu Complex in eastern Nepal, about 235 km S71°E from the Ganesh Himal mineralisation (Tuladhar 1991) is (i) carbonate hosted, (ii) strata-bound and stratiform, (iii) structurally controlled by the first phase deformation, (iv) having a high zinc:lead ratio, and (v) have a low silver content, but is (i) high in quartz content, and (ii) high in sulphosalts as compared to the Ganesh Himal ore. Einfalt, H.C. (1991–93, per. communications) found the following differences in the Phakuwa mineralisation of eastern Nepal from that of Ganesh Himal: (1) the gangue is dominantly silicate, and (2) concentrations of Hg, As, Mo, Sb, Sn, Ga, Ge, and In are greater in the Phakuwa mineralisation (Table 5) indicating an environment of formation different from that of Ganesh Himal. Phakuwa mineralisation is also characterised by a lower concentration of pyrite in the ore.

There are many base metal occurrences in the Himalayas, but only a few have been studied in detail. Roy Chowdhury et al. (1960) recorded occurrences of dolomite–hosted low-temperature galena–sphalerite–chalcopyrite mineralisation in the region, between Jammu and Almora in the western Himalaya where intrusive igneous rocks are absent. Biyani (1997) reported lead-zinc mineralisation in quartz veins between quartz schist and biotite schist in the upper Yamuna valley. Valdiya (1980) opined that Chail units in Ramgarh and Pokhri Nagnath show promising occurrences of sulphides, and noted the Cu–Pb–Zn mineralisation in chlorite schist at Askot, and that dolomites and magnesites contain dissemination of Cu and Pb at many places. Tewari (2002) recorded occurrences of uranium, tungsten, iron, copper, etc. in Almora–Askot–Berinag areas of Uttaranchal Lesser Himalaya. In the eastern Himalaya, the only working Zn–Pb–Cu mine exists at Rangpo (Sikkim). The Pb–Zn deposit of Gorubathan (West Bengal) and Cu–Zn deposit of Dikchu (Sikkim) also occur in this part of the Himalaya (Ghosh 1975, Ghosh 1996, Ghosh and Biswas 1986, Ghose et al. 1989). The carbonate hosted Genekha Pb–Zn deposit of Bhutan strongly resembles the Ganesh Himal deposit (UNESCAP 1995).

Ghose et al. (1989) suggested that sulphide occurrences of some significance in the 'Main Himalayan Belt' are largely strata-bound and associated with meta-argillites and

Table 6: Lead isotope analyses of galena from Ganesh Himal

SN	Sample	^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb
1	TQ 97-5	17.63	15.69	37.62
2	TQ 97-5 duplicate	17.63	15.69	37.64
3	TQ 97-8	17.67	15.67	37.60
4	TQ 97-10	17.64	15.69	37.64
5	TQ 97-10 duplicate	17.66	15.69	37.62
6	TQ 90-62	17.65	15.69	37.63
7	Moore, 1990	17.6257	15.6610	37.4980

Note: The first five samples were collected by the author. The sixth sample (No.90-62) was previously thought from Phakuwa, subsequently found to be from Ganesh Himal. The seventh sample (Moore, 1990) was collected by the author and analysed by Dr. Allen Moore, Australia. Others were analysed by Dr. R. I. Thorpe in Canada.

Table 7: δ^{34}S content in Ganesh Himal sulphides

Sample	Mineral	δ^{34}S
TQ-97-5	Galena	+10.1
TQ-97-5	Honey sphalerite	+11.2
TQ-97-6	Galena	+1.5
TQ-97-7	Galena	-0.8
TQ-97-8	Galena	-0.4
TQ-97-8	Light brown sphalerite	+0.3
TQ-97-9	Galena	+3.3
TQ-97-10	Galena	+3.9
TQ-97-10	Brown sphalerite	+11.8
TQ-97-11	Brown sphalerite	+1.7
TQ-97-12	Galena	+0.7
TQ-97-12	Brown sphalerite	+1.4
TQ-97-12	Pyrite	+2.0

associated volcanogenic sediments, and all are related to pre-Himalayan tectonism, although the study did not include the Ganesh Himal and Genekha deposits.

The exposed host dolomite of the Ganesh Himal ore at Lari contains 938–3,992 ppm zinc and 133–392 ppm lead in average. While dolomite from one drill-core recorded 6,440 ppm zinc, another hole recorded 1,307 ppm zinc in average. It is to be verified whether this sphalerite-galena in dolomite is the result of metamorphic diffusion or not. It has been estimated that the entire 10 km long host basin has had approximately 861,038 tonnes zinc and 182,653 tonnes lead.

Lead isotope analysis of galena from Ganesh Himal ore are shown in Table 6. The Pb isotope compositions of ores, particularly those with Late Proterozoic and Palaeozoic ages that are hosted by sedimentary sequences, do not yield precise ages. This is largely because of the multitude of possible lead sources, each of which may have had very different evolution histories. The model by Stacey and Kramers (1975) is a useful general guide, but is based on a limited number of deposits of different types that were not well constrained in age at the time the model was formulated. The same is true for other models. Nevertheless, as illustrated in Fig. 7, a general age range for the Ganesh Himal deposit can be deduced from a consideration of the Pb isotopic compositions of other deposits whose approximate ages are known.

The age range is calculated using this comparison method. A comparison of the Ganesh Himal analyses with those from deposits of Amjhor (Balasubramanyan and Chandy 1976), Ambaji–Sendra and Tosham (Deb et al. 2001), Carmina (Velasco et al. 1996), Waldassen (Höhndorf and Dill 1986) and Rauschwitz (Bielicki and Tischendorf 1991) gives 875 to 785 Ma age for the Ganesh Himal ore. Ages by the Stacey and Kramers (1975) model are a little higher. It may be noted, however, that these ages are quite similar to the K–Ar hornblende (in amphibolite) age of 819± 80 Ma determined by Krummenacher (1966) in the MCT zone, from a cross-section along the Kali Gandaki River, about 120 km WNW of the Ganesh Himal deposits.

In spite of the small sample population, the data clearly show that the Ganesh Himal lead has very homogenous isotopic composition indicating derivation of lead from an isotopically homogenous source.

The δ^{34}S values of some Ganesh Himal sulphides are shown in the Table 7. From the previously established patterns of sulphur isotope data for seawater and for certain types of ore deposits presented by Claypool et al. (1980), Strauss (1993) and Ross et al. (1995) which show a shift of δ^{34}S values of seawater to more positive values subsequent to 650 Ma, it is unlikely that the Ganesh Himal deposits are younger than 650 Ma, and that its sulphur was produced by biogenic reduction of contemporaneous seawater sulphate.

The apparent equilibration temperatures based on the fractionation between various sulphide pairs as estimated from the experimentally determined fractionation curves (Friedman and O'Neil 1977), clearly establish a high equilibration temperature (Table 8), a fact that is consistent with the amphibolite facies metamorphism to which the deposit has been subjected. Five of the six sulphide pairs suggest that the equilibration temperature may have been as high as 600 °C, and three of these indicate that a temperature as high as 750 °C would be permissible. A minimum equilibration temperature of about 500 °C seems to be indicated by the data. The explanation for the very low apparent galena-sphalerite equilibration temperature for sample TQ 97-10 is not known. Possibly this sample represents sulphides that were remobilised under low temperature conditions. An alternative explanation might be that, for some unknown reason, equilibrium was not attained.

The Ganesh Himal deposits are Vindhyan equivalent. The Pb isotope compositions for the Amjhor deposit (Balasubramanyan and Chandy 1976) are similar to those of the Ganesh Himal deposits. To further investigate this possible equivalence, more Pb isotope analyses are required for the Amjhor deposit. Nair and Ray (1977) found characteristic syndepositional
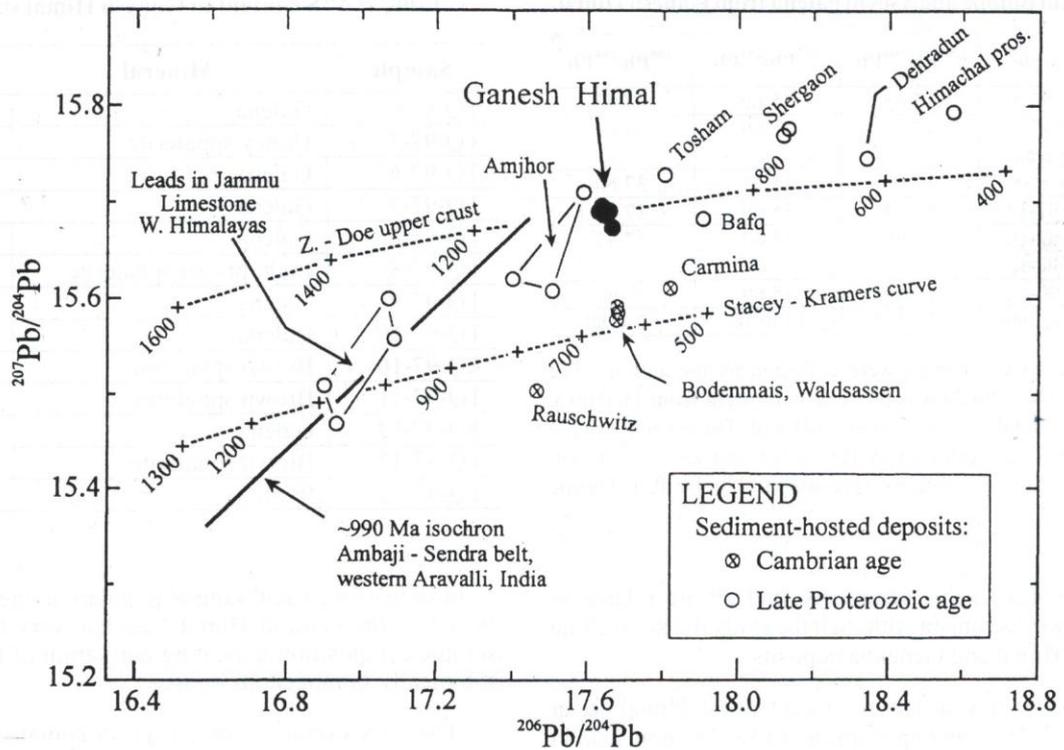
Fig. 7: Ganesh Himal Pb isotope data (^{206}Pb/^{204}Pb–^{207}Pb/^{204}Pb) shown in relation to the general isotopic evolution curve of Stacey and Kramers (1975) and the upper crust curve (Model I) of Zartman and Doe (1981) and comparison deposits (Ghosh et al. 2005).

Table 8: Approximate fractionation temperatures of different mineral pairs

Sample	Mineral pair	$\Delta^{\delta 34S}$	Approximate fractionation temperature
TQ-97-5	Galena-sphalerite	1.1	425 °C – 625 °C
TQ-97-8	Galena-sphalerite	0.7	500 °C – 750 °C
TQ-97-12	Galena-sphalerite	0.7	500 °C – 750 °C
TQ-97-12	Sphalerite-pyrite	0.6	325 °C – 600 °C (?)
TQ-97-12	Galena-pyrite	1.3	600 °C – 750 °C
TQ-97-10	Galena-sphalerite	7.9	25 °C – 50 °C

features in the sedimentary Amjhor pyrite, deposited in a shallow water reducing stable marine shelf environment changing to unstable shelf conditions. Sulphur isotopes of Amjhor pyrite (Pandalal et al. 1991) indicate bacterial sulphate reduction in an environment closed with respect to SO_4^{-2} and open with respect to H_2S. Nair and Ray (1977) also determined very low carbon–sulphur ratios for Amjhor pyrite, characteristic of late Proterozoic to early Palaeozoic rocks from other areas.

Lead isotope data from two zinc-lead deposits of Nepal are available. Seven analyses of Ganesh Himal lead (Table 6)

and two analyses from Phakuwa (Table 9) show that they are isotopically different and belong to two different ages.

The lead isotope data for disseminated galena from the Jammu limestone (Raha et al. 1978) would appear to suggest an age of about 1,000 Ma (Fig. 7). This major carbonate unit and its equivalents are widely distributed within the Lesser Himalaya. The Jammu Limestone has been grouped with the Shali Formation (Raha and Das 1989; Tewari 1993, 1996; Kumar and Srivastava 1995), for which a preliminary Re-Os black shale age of 839 ± 138 Ma has been obtained (Singh et al. 1999). This suggests that the Ganesh Himal deposits, with their interpreted age of 875 to 785 Ma, could possibly be equivalent in age to that of galena from the Jammu Limestone.

Therefore, between Bhutan in the east and Jammu (India) in the west, through Ganesh Himal (Nepal), there lies the possibility of the existence of a zone of Neoproterozoic base-metal mineralisation. As discussed above, the Amjhor pyrite also appears coeval with the Ganesh Himal deposit. In that case, there had been a huge region where the sea was shallow and sulphate reducing bacteria generated sulphur, assuming that both the Genekha and Jammu Limestone sulphides were also formed by bacterial action. Where the base metal ions were available, zinc and lead deposits formed. A shallow

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Table 9: Lead isotope analyses of galena from other Himalayan occurrences

Location	Sample No.	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Phakuwa, Nepal	TQ 98-5	16.180	15.480	35.881
Phakuwa, Nepal	TQ 98-6	16.188	15.487	35.919
Genekha, Bhutan	TQ 97-17	17.708	15.712	37.771
Genekha, Bhutan	TQ 97-18	17.687	15.695	37.773
Genekha, Bhutan	TQ 97-19	17.705	15.710	37.774
Shergaon, India	TQ 91-24A	18.132	15.776	38.076
Shergaon, India	TQ 91-24B	18.118	15.770	38.040
Himachal, India	TQ 94-4	18.788	15.817	39.244
Himachal, India	TQ 94-5	18.568	15.793	38.817
Dehradun, India	TQ 85-31	18.336	15.743	38.134
Bageswar, India	B6-1	16.240	15.551	35.956
Bageswar, India	B6-2	16.424	15.555	36.051
Bageswar, India	B6-3	16.236	15.541	35.941
Dickchu, India	TQ 98-2	15.583	15.397	35.495
Rangpo, India	NAFW/2/R/8	15.818	15.400	35.439
Rangpo, India	MAHW/17/B/7	15.822	15.410	35.489
Rangpo, India	MAHW/17/R/6	15.876	15.457	35.250
Rangpo, India	NAB-3/P/5	15.805	15.386	35.402
Gorubathan, India	D$_2$/6/4	15.948	15.511	35.606
Gorubathan, India	K5/6/4	15.858	15.428	35.502
Gorubathan, India	S/31/6/3	15.830	15.420	35.509

tidal (epicontinental) sea existed from the Mesoproterozoic to Cambrian period in the Garhwal–Kumaon region (Tewari 2002). One should, therefore, expect more deposits of zinc and lead in the Himalaya. However, the mineralisations could be nearly isochronous, but not necessarily cogenetic. Further research on this subject should be carried out to determine the possible source of base metal ions.

When all the reported lead isotopic ages of mineral deposits in the Himalaya (Sarkar et al. 2000), are considered (Tables 6 and 9), there appears to be broadly four generations of mineralisation in the Lesser Himalaya as follows:

(i) The oldest group– Gorubathan, Rangpo and Dickchu: 1830-1889 Ma, could be related to ~ 1800 Ma Rampura–Agucha deposit of the Bhilwara sequence of the Aravalli–Delhi orogenic belt.

(ii) The middle group– Phakuwa and Bageswar: 1608–1732 Ma, could be related to the ~ 1700 Ma Zawar group of

deposits of the Aravalli sequence of the Aravalli–Delhi orogenic belt.

(iii) The Ganesh Himal–Genekha group: 780–870 Ma, related (?) to the ~990 Ma Ambaji–Deri deposits of the Delhi sequence of the Aravalli–Delhi orogenic belt. The Group appears to be Vindhyan equivalent.

(iv) The youngest group of Shergaon, Himachal and Dehradun: Age data scattered, slightly to significantly younger than the Ganesh Himal– Genekha group.

It is interesting to note that the oldest group and the middle group could be synchronous with the Ulleri granite gneiss of the Nepal Himalaya and its equivalents elsewhere.

It was observed by Guilbert and Park (1986) that major ore deposits tend to have single, uniform isotope ratios (Fig. 8). The Ganesh Himal deposit also falls almost on the stated single-stage growth curve, which may be an indication of the potential of the Ganesh Himal zinc-lead deposits.
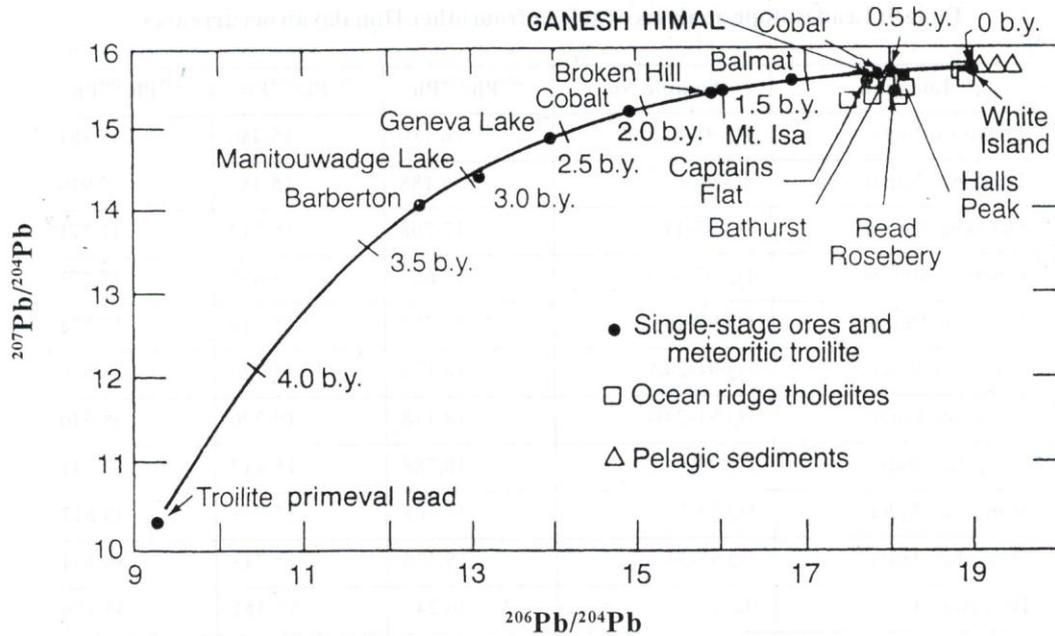
Fig. 8: Single-stage growth curve and lead isotope ratios from selected ores, ocean-ridge tholeites, and pelagic sediments reproduced from Guilbert and Park (1986), which highlights close plots of data of big deposits of the world on the growth curve μ=9.6, suggesting a general homogenous mantle source for the deposits. Ganesh Himal Lead also falls on the curve.

CONCLUSIONS

The Ganesh Himal deposits, which have been subjected to lower amphibolite-facies metamorphism, have the following geochemical attributes:

(i) It is a carbonate (dolomite) hosted strata-bound deposit.

(ii) The occurrence of a carbonaceous zone just below and also associated with the mineralisation confirms the existence of an anoxic environment, which favoured accumulation of metals.

(iii) The repetition of carbonates, argillaceous and arenaceous beds, and the graphitic bed indicates that the sequence represents a shallow marine facies of deposition.

(iv) A shallow tidal sea might have existed at the time of formation of the deposits.

(v) The ore is very low in silica, silicates, and alumina.

(vi) It has a very simple mineral composition of sphalerite-galena-pyrite, and element composition of Zn-Fe-Pb with some Ag and a little Cd, along with traces of other elements.

(vii) The mineralisation exposed at Lari I (4,535 m altitude) continues along plunge as far as 4,110 m level, and abuts against the black carbonate (Fig. 3), reappearing again at a slightly higher stratigraphic level. The black carbonate mass may represent a reef.

(viii) The low intensity magmatic activity in the Ganesh Himal basin represented by concordant amphibolite bodies, with slightly higher zinc and lead than in normal basalts, below the mineralisation indicates possibility of contribution towards zinc-lead budget of the deposit.

(ix) The isotopic composition of sulphur suggests biogenic reduction of sea water sulphate.

(x) Low Tl and large S/Se ratios of sulphides may indicate a sedimentary origin for the deposit. Low Cd and high Zn:Cd ratio may also indicate a sedimentary carbonate environment. Less than unity Co/Ni ratios may indicate a sedimentary genesis. While 5 random samples do not show any clear trend, the Co/Ni ratios of three zinc concentrate samples show a range between 1 and 0.27, indicating probably sedimentary genesis.

(xi) Based on comparisons with other deposits of known age, the Pb isotope data are interpreted to establish an age of 875 Ma to 785 Ma for the Ganesh Himal deposit. This age is quite similar to the Ar-Ar hornblende (in amphibolite) age of 819± 80 Ma determined by Krummenacher (1966) in the MCT zone, from a cross section along the Kali Gandaki river, about 120 km WNW of the Ganesh Himal deposits. S isotope data for the metamorphosed Ganesh Himal Zn-Pb deposit imply an age greater than 650 Ma.

(xii) A depositional age of 875 Ma to 785 Ma for the Ganesh Himal, and the Genekha (Bhutan) deposits falls within the age range for Vindhyan Supergroup strata, which supports the postulated wide distribution of Vindhyan sequences throughout the Himalayan chain.

(xiii) S isotope fractionation between sulphide pairs yields apparent temperatures of 500 °C to 702 °C. Ore

textures indicate that the ore was subjected to a minimum temperature of 600 °C. This is in accord with geothermometry results indicating about 550 °C to 660 °C for metasedimentary rocks in the area, so that sulphide equilibration must have occurred during one of the two metamorphic phases that have been reported for the area.

(xiv) Unlike most Mississippi Valley Type deposits, the Ganesh Himal deposit (1) does not contain Ba and F, (2) is very low in trace and minor elements, (3) is poor in Ni and Co, and (4) its lead isotopes are simple.

(xv) Unlike most VHMS deposits, the Ganesh Himal deposits (1) do not contain copper, (2) do not contain Ba and Mn, and (3) are associated with minor volcanics only.

(xvi) The studied 10 km portion of the Ganesh Himal basin must have contained at least 861,000 tonnes of zinc and 182,000 tonnes of lead.

(xvii) The mineralisation thus appears to be of syngenetic sedimentary type, and it may have been deposited in association with a bioherm or reef. Sulphur was probably supplied by biogenic reduction of seawater sulphates. The source of metals is not clear as yet, but approximately coeval basic bodies could have contributed the metal ions. The lead isotopes indicate a homogeneous source. The lead isotope ratios fall almost on the single-stage growth curve (Fig. 8), probably indicating a potential of the Ganesh Himal zinc-lead deposits.

REFERENCES

Arita, K., Ohta, Y., Akiba, C, and Maruo, Y., 1973, Kathmandu region, *In*: Hashimoto S., Ohta, Y., and Akiba, C. (eds.) *Geology of the Nepal Himalayas.* Saikon Publishing Co., Ltd., Tokyo, 286 p.

Balasubrahmanyan, M. N. and Chandy, K. C., 1976, Lead isotope studies of galena from some occurrences in India. Rec. Geol. Surv. India, v. 107(2), pp. 141–148.

Bielicki, K. H. and Tischendorf, G., 1991, Lead isotope and Pb-Pb model age determinations of ores from Central Europe and their metallogenic interpretation. Contrib. Mineral. Petrol., v. 106, pp. 440–461.

Biyani, A. K., 1997, A Preliminary Geological Investigation of Sisakhan Base Metal Occurrence of Higher Himalayan Yamuna Valley, U. P. Jour. Geol. Soc. of India, v. 49, pp. 723–726.

Chakrabarti, C. K. and Ghosh, A. K., 1996, Base-metal Mineralisation in the Ganesh Himal Region of Nepal Himalayas. Indian Minerals, v. 50, pp. 205–216.

Chakrabarti, C. K., 1982, Zinc-Lead Mineralisation in Ganesh Himal Region of Central Nepal. Jour. Nepal Geol. Soc., v. 2, pp. 38–45.

Claypool, G. E., Holser, W. T., Kaplan, I. R., Sakai, H., and Zack, I., 1980, The age curves of sulphur and oxygen isotopes in marine sulphate and their mutual interpretation. Chemical Geol., v. 28, pp. 199–260.

Cox, S. F., Etheridge, M. A., and Hobbs, B. E., 1981, The Experimental Ductile Deformation of Polycrystalline and single Crystal Pyrite. Econ. Geol., v. 78, pp. 2015–2117.

Deb, M., Thorpe, R. I., Krstic, D., Corfu, F., and Davis, D.W., 2001, Zircon U-Pb and Galena Pb isotope evidence for an approximate 1.0 Ga terrane along the western margin of the Aravalli–Delhi orogenic belt, northwestern India. Precamb. Res., v. 108, pp. 195–213.

Department of Mines and Geology, 1994, Geological Map of Nepal, Scale 1:1,000,000

Friedman, I. and O'Neil, J. R., 1977, Compilation of stable isotope fractionation factors of geochemical interest. US Geol. Surv. Professional Paper 440-KK.

Ghimire, J. R., Khandka, R. K., and Chakrabarti, C. K., 1996, Zinc-lead Mineralisation in the Ganesh Himal Region, Central Nepal. Jour. Nepal Geol. Soc., v. 14, pp. 65–77.

Ghose, A., Ray, K. K., and Kumar G., 1989, Metallogeny in the Himalaya. Geol. Surv. India Special Publication No. 26.

Ghosh A. K., Thorpe, R. I., and Chakrabarti, C. K., 2005, Interpretation of Pb and S isotope data for the Ganesh Himal metamorphosed stratiform Zn-Pb deposit, central Nepal Himalaya. Jour. Geol. Soc. India, v. 65 (6), 725–733 pp.

Ghosh, A. K. and Biswas, A., 1986, Petrochemical features of the Metabasics from the Lead-Zinc Ore Field of Gorubathan, Darjeeling Foothills, Eastern Himalaya. Quart. Jour. Geol. Min. Met. Soc. India, v. 58(1), pp. 35–41.

Ghosh, A. K. and Kunzendorf, H., 1988, Distribution of Uranium in two Sulphide Ore Environments from the Reversed Metamorphic Sequence of the Daling Rocks in the Darjeeling-Sikkim Himalaya, India. Uranium, v. 4, pp. 341–349.

Ghosh, A. K., 1975, Abundance of Co, Ni, Cd, Ag, and Hg in Polymetallic Sulphide Deposit of Rangpo, Sikkim. Jour. Geol. Soc. India, v. 16(1), pp. 99–102.

Ghosh, A. K., 1996, Deformational and Metamorphic Imprint upon Lesser Himalayan Sulphide Ores: Examples from Nepal-Sikkim Belt. Jour. Geol. Soc. India, v. 48, pp. 3–13.

Ghosh, S., 1998, Studies on the galena mineralisation at Sargipali, in the Proterozoic fold belt of Gangpur, Orissa. A Ph.D. Thesis submitted to Calcutta University, 129 p. (Unpublished)

Goldsmith, V. M., 1970, *Geochemistry.* Oxford University Press, London, 730 p.

Guilbert, J. M. and Park, C. F. Jr., 1986, *The Geology of Ore Deposits.* W. H. Freeman and Company, New York, 985 p.

Höhndorf, A. and Dill, H., 1986, Lead isotope studies of strata-bound, vein-type, and unconformity related Pb, Sb, and Bi ore mineralisations from the western edge of the Bohemian Massif (F. R. Germany), Mineral. Deposita, v. 21, pp. 329–336.

Jensen, M. L. and Bateman, A. M., 1981, *Economic Mineral Deposits*, Third Edition, John Wiley and Sons, 593 p.

Krauskopf, K. B. and Bird, D. K., 1995, *Introduction to Geochemistry.* International Edition, McGraw-Hill, Inc., 647 p.

Krummenacher, P. D., 1966, Népal Central: géochronométrie des séries de l'Himalaya, Bull. Suisse Minéral. Pétrogr., v. 46, pp. 43–54.

Kucha, H., and Viaene, W., 1993, Compounds with mixed and intermediate sulphur valences as precursors of banded sulphides in carbonate hosted Zn-Pb deposits in Belgium and Poland. Mineral. Deposita, v. 28(1), pp. 13–21.

Kumar, R., 1980, Structure of Lead-Zinc Prospect Area of Ganesh Himal in Central Nepal. Him. Geol., v. 10, pp. 326–337.

Kumar, S. and Srivastava, P., 1995, Microfossils from the Kheinjua Formation, Mesoproterozoic Semri group, Newari area, central India. Precamb. Res., v. 74, pp. 91–117.

Levinson, A. A., 1980, *Introduction to Exploration Geochemistry.* Applied Publishing Ltd., Illinois, 924 p.

Mason, B., 1958, *Principles of Geochemistry.* John Wiley and Sons, Inc., New York, 2nd edition, 310 p.

McGoldrick, P. J. and Keays, R. R., 1990, Mount Isa Copper and Lead-Zinc-Silver Ores: Coincidence or Cogenesis? Econ. Geol., v. 85, pp. 641–650.

Monseur, G. and Pel, J.,1972, Reef Facies, Dolomitization and Stratified Mineralization. Mineral. Deposita (Berl.), v. 7(1), pp. 89–99.

Monseur, G., 1967, Synthese Des Connaissances Actuelles sur le Gisement Stratiforme de Reocin (Province de Santander – Espagne). Econ. Geol., Monograph 3, pp. 278–293.

Nair, N. G. K. and Ray, A., 1977, Syndepositional and Diagenitic Features in the Pyrite Ores of Amjhor, Bihar, India. Mineral. Deposita, v. 12, pp. 151–154.

NMCL, 2004, 50 t/d Mining and Beneficiation Demonstration. Project Report of Nepal Metal Company Limited, Nepal (Unpublished).

Pandalal, H. S., Changkakoti, A., Krouse, H. R., and Gunalan, N., 1991, The Relationship between Carbon, Sulphur, and Pyritic Iron in the Amjhor Deposit, Bihar, India. Econ. Geol., v. 86 (4), pp. 862–869.

Pearce, J. A. and Cann, J. R., 1973, Tectonic setting of basic volcanic rocks determined using trace element analysis. Earth Planet Sci. Lett., v. 19, pp. 290–300.

Raha, P. K. and Das, D. P., 1989, Correlation of stromatolite bearing Upper Proterozoic basins of India and palaeogeographic significance. Him. Geol., v. 13, pp. 119–142.

Raha, P. K., Chandy, M. C., and Balasubrahmanyan, M. N., 1978, Geochronology of the Jammu Limestone, Udhampur District, Jammu and Kashmir State, India. Jour. Geol. Soc. Ind., v. 19, pp. 221–223.

Rai, S. M., 1998, Les nappes de Kathmandu et du Gosaikund, Himalaya du Nepal central (etude cartographique, structurale, metamorphique, geochimique at radiochronologique). Ph.D. Thesis submitted to Joseph Fourier University, Grenoble, France, 244 p. (Unpublished)

Rai, S. M., Guillot, S., Le Fort, P., and Upreti, B. N., 1998, Pressure-temperature evolution in the Kathmandu and Gosaikund regions, Central Nepal. Jour. Asian Earth Sci., v. 16(2–3), pp. 283–298.

Read, R. A., 1968, Deformation and metamorphism of the San Dionisio pyretic ore body, Rio Tinto, Spain. Ph.D. Thesis submitted to University of London (Unpublished). *In:* Nebel et al. 1991, Ecom. Geol. v. 86, pp. 81–105.

Ross, G. M., Block, J. D., and Krouse, H. R., 1995, Neoproterozoic strata of the southern Canadian Cordillera and the isotopic evolution of seawater sulphate. Precamb. Res., v. 73, pp. 71–99.

Roy Chowdhury, M. K., Subramaniam, M. R., and Banerjee, P. K., 1960, Source bed concept in some sulphide ore bodies from the western Himalaya. IGC Proceedings, Section 16, pp. 138–148.

Sarkar, S. C., Chernyshev, I. V., and Banerjee, H., 2000, Mid-Proterozoic Pb-Pb ages for some Himalayan base-metal deposits and comparison to deposits in Rajasthan, NE India. Precamb. Ress., v. l 99, pp. 171–178.

Singh, S. K., Trivedi, J. R., and Krishnaswami, S., 1999, Re-Os isotope systematics in black shales from the Lesser Himalaya: Their chronology and role in the 187Os/188Os evolution of seawater. Geochim. Et Cosmochim. Acta, v. 63, pp. 2381–2392.

Stacey, J. S. and Kramers, J. D., 1975, Approximation of terrestrial lead isotope evolution by a two stage model. Earth Planet Sci. Letters, v. 26, pp. 207–221.

Stöcklin, J., 1980, Geology of Nepal and its regional frame. Jour. Geol. Soc., London, v. 137, pp. 1–34.

Strauss, H., 1993, The sulphur isotope record of Precambrian sulphates, new data and a critical evaluation of the existing record. Precamb. Res., v. 63, pp. 225–246.

Tewari, V. C., 1993, Precambrian and Lower Cambrian stromatolites of the Lesser Himalaya, India. Geophytology, v. 23, pp. 19–39.

Tewari, V. C., 1996, Discovery of pre-Ediacaran acritarch Chuaria circularis (Walcott 1989 and Ford 1985) from the Deoban Mountains, Lesser Himalaya, India. Geosci. Jour., v. 17, pp. 25–39.

Tewari, V. C., 2002, Proterozoic-Cambrian and Sedimentation and Associated Natural Resources of the Uttaranchal, Proc.: National Seminer on: Natural Wealth of Uttaranchal, March 14-15, 2002 (Organised by Lucknow University Alumni Association, Dehradun, India).

Tuladhar, R. M., 1991, Stratabound Zinc-Lead Mineralisation at Phakuwa, Sankhuashabha District, Eastern Nepal. Jour. Nepal Geol. Soc., v. 7 (Sp. Issue), pp. 41–58

Uhlir, C. F., Haserberger, K., and Kirchner, E.C., 1998, Red and violet gahnite (spinel) occurrences in Ganesh Himal (central Nepal): their chemistry, inclusions and microthermometry. Jour. Nepal Geol. Soc., v. 17, pp 29–35.

UNDP, 1993, Ganesh-Himal Zinc-Lead Project Feasibility Report, Unpublished report prepared for United Nations Science, Technology, Energy, Environment and Natural Resources Division, Department of Economic and Social Development, New York.

UNESCAP, 1993, Geology and Mineral Resources of Nepal, Explanatory Brochure, Atlas of Mineral Resources of the ESCAP region. v. 9, 107 p.

UNESCAP, 1995, Mineral Resources Potential and Policy for Development in the Asian Least Developed Countries and Vietnam, Mineral Concentrations and Hydrocarbon Accumulations in the ESCAP region. v. 9, 271 p.

Upreti, B. N., 1999, An Overview of the stratigraphy and tectonics of the Nepal Himalaya. Jour. Asian Earth Sci., v. 17, Special Issue, pp. 577–606.

Valdiya, K. S., 1980, *Geology of Kumaun Lesser Himalaya.* Wadia Institute of Himalayan Geology, India, 291 p.

Velasco, F., Pesquera, A., and Herrero, J. M., 1996, Lead isotope study of Zn-Pb ore deposits associated with the Basque–Cantabrian basin and Paleozoic basement, northern Spain. Mineral. Deposita, v. 31, pp. 84–92.

Walker, K. R., Germaine, A. J., Lovering, J. S., and Green, R., 1960, Metamorphic and metasomatic convergence of basic igneous rocks and lime magnesia sediment of the Precambrian of northwestern Queensland. Jour. Geol. Soc. Australia, v. 6, pp. 149–177.

Xuenin, S., 1984, Minor Elements and Ore Genesis of the Fankou Lead-Zinc Deposit, China. Mineral. Deposita, v. 19(2), pp. 95–104.