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An overview of copper ore mineralization in the Nepal Himalaya

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ABSTRACT

Exploration of copper ore in the Nepal Himalayas has been carried out by different researchers at different times. The author conducted detailed geological studies and mineral exploration in some of the copper and polymetallic prospects and also reviewed the literature related to copper prospects in Nepal. The present research is able to delineate two distinct copper ore mineralization belts extending from west to east and identify the promising sites for copper ore and polymetallic mineralization that could be feasible for mining. The northern mineralization belt lies close to the Main Central Thrust where the mineralization occurs mostly in metamorphic rocks of garnet amphibolite facies in Darchula, Bajhang, Gorkha, Dolakha, Solukhumbu and Ilam districts. The southern mineralization belt in the Lesser Himalaya occurs in low-grade metamorphic rocks of greenschist facies in Dadeldhura, Rukum, Baglung, Myagdi, Tanahun, Dhadhing, Makwanpur, Dolakha, Udaypur, Bhojpur and Ilam districts. Most of these prospects were locally exploited on a small scale by traditional mining before 1951.

Almost all mineralization in both belts is related to hydrothermal dissemination, irregular multiple vein type, replacement and cavity fillings and only a few polymetallic mineralizations at the exo-contact zone of granite bodies. The ore minerals were concentrated during the processes of regional metamorphism at the time of Himalayan upheaval. In general, the copper content in the northern belt appears to be higher in grade and tonnage as compared to the southern belt. The frequent association of tungsten, molybdenum, bismuth, nickel, tin, lead, zinc ores and traces of gold suggests the urgent need for further detailed exploration and evaluation of selected prospects which could be economic deposits and feasible for mining.

Keywords: Copper ores, polymetallic prospect, northern and southern mineralization belts, Himalaya

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INTRODUCTION

The present research work was focused on the author's own field observations, laboratory investigations and review of published literature and reports on geology and mineral resources of Nepal by previous national and foreign researchers, and the Department of Mines and Geology (DMG, 2004). From the existing information and the author's own research it is quite clear that the geology of Nepal Himalaya is very complex due to the non-availability of fossil remains (except in some low-grade meta-sediments) in metamorphic rocks, continued geodynamic activities therein and geological structures like major thrusts, faults, folds, nappes, klippen, inverse metamorphism etc. The literature published by DMG show that Nepal is fairly rich in nonmetallic industrial minerals like limestone, dolomite, magnesite, quartzite, and decorative/ dimension stones like marble, granite, quartzite, schist etc. They are among the larger deposits, whereas metallic mineral deposits are scattered and comparatively smaller in tonnage (except a few iron ore deposits) and low in grade. So far, DMG has given priority only to iron, copper, lead, zinc, cobalt, nickel, tin, tungsten, uranium, gold, limestone, and magnesite exploration. However, precious metals (Au, Pt, Ag), battery metals (Li, Ni, Co, Mn), and other important minerals like Cr, V, Se, Sr, Hg etc., rare earth elements (Nd, Y, La, Ce, Eu, Sc, Tb, Pr, Dy, Sm, Gd, Lu, Yb, Er, Tm, Ho, Pm) and precious stones are still neglected. With the advancement of technology in electronics, engineering and medical science, the demand for trace and rare metals is increasing tremendously worldwide. Therefore, the government of Nepal and the private sectors should also give high priority to exploring and mining such minerals in addition to the base and precious metals. Previous exploration works conducted by DMG, UNDP/ MEDB and other researchers have concentrated mostly in the southern and central parts of the Lesser Himalaya in central Nepal and very few in the northern part in the vicinity of MCT. In addition to that, the priority was given mainly to base metals (Cu, Pb, Zn), and not to multi-element analysis of the ore samples besides only a few checkup analyses for gold and silver. Since almost all the past exploration works were not able to delineate mineable economic ore deposits, still there are higher chances to find promising copper/ polymetallic deposits, which could be feasible for mining were overlooked.

The main objective of this research was to compile and review the previous works, expose the weaknesses and partial fulfilment of this gap, delineate two distinct copper and polymetallic mineralization belts in the Nepal Himalayas and correlate them with similar prospects/ deposits in the eastern Himalayas in Sikkim and Darjeeling in India. Major findings and conclusions drawn from this work could be able to guide young researchers, exploration geologists, mining engineers as well as investors on where to look and give priority to finding mineable copper and polymetallic mineral deposits in Nepal.

GEOLOGICAL CONTROL OF COPPER ORE MINERALIZATION

Copper is one of the important base metals, which is used by human beings since the prehistoric time. Traditionally, it is one of the principal metals that was mined locally in different parts of Nepal. Copper metal was extracted from its ores with the help of charcoal for burning as a heating source and red clay as a flux in the hearth. The remnants of a number of old mines, mine waste dumps and slags in the smelting sites offer clear evidence of mining activities in the past. In those old days (before 1951) Nepal used to export iron and copper to Tibet. But at present, not a single copper mine is in operation despite more than 107 known copper occurrences/ prospects/ deposits (DMG, 2004) located in two distinct east-west extending copper ore mineralization belts, mostly in the Lesser Himalaya and a few others close to the main central thrust (MCT). A preliminary investigation was conducted only at a few places, and the rest still remained unexplored.

The present study attempts to identify the promising sites for copper ore and polymetallic mineralization/ deposits based on the author's own field studies and laboratory investigations of the ore samples, host rocks and the nature/ type of mineralization as well as a review of the existing literature of the previous works. All these studies confirmed that there exist two distinct copper/ polymetallic mineralization belts, presently identified as (A) northern copper ore (±gold) mineralization belt and (B) southern copper ore mineralization belt. Field studies and laboratory investigations of the ore samples conducted by different geologists (including the author) from Department of Mines and Geology (DMG) and Mineral Exploration Development Board (UN/ MEDB) in the past have clearly shown that copper ore mineralization in southern belt in the Lesser Himalaya are mostly found in low-grade metamorphic rocks like silicified chlorite mica schist and sericitic quartzite of greenschist facies, whereas the copper ore mineralization in northern belts close to MCT are mostly found in coarse-grained garnet mica schist of garnet amphibolite facies. In the southern belt, generally, mineralized bodies are irregular and scattered in distribution, small in size and low in grade; however, in the northern belt, although the mineralization is irregular and scattered, the size of the deposits is comparatively larger and the grade are also higher. In both belts, mostly the mineralization is structurally controlled (thrust, fault, joints and folds) and hydrothermally characterized by strongly shared and crushed zone (Kaphle, 1997; Shah and Paudyal, 2019) in the form of sulfide ore-bearing quartz veins, stringers, lenses, pods, and crosscut veins. In many cases, mineralization is concentrated in the foliation/ schistosity plane of the host rock as stratiform deposits and few others are related to intrusive rock bodies/ as skarn-type mineralization in the exo-contact zone (Kaphle, 1997; Shah and Paudyal, 2019; Shrestha, 1991). The available records indicate that there are four types of mineralization patterns in Nepal: (1) massive sulfide veins and stringers (2) reticulated patches and replacement along fractures and foliation planes (3) irregular disseminated veins and (4) hydrothermal cavity fillings and replacement. Original cavities in the rocks like pore spaces, crystal lattices, vesicles, cooling cracks and along bedding/ foliation planes and induced cavities like fissures, joints, shear zones, rock alteration openings and replacement of wall rocks filled with hydrothermal solutions where mineralization took place.

The layered nature of the mineralization in both belts indicates that the primary bedding/ foliation of the host rock, and later on the host rock as well as the ores had undergone a metamorphic process and recrystallized. At the same time, ore minerals had mobilized and concentrated along with hydrothermal quartz veins/ stringers/ lenses and confined to particular bands/ horizons of the host rock (stratiform deposit). This supports a syngeneic origin of the mineralization. Some of the important copper prospects/ deposits known from both the northern and the southern mineralization belts are briefly described below and their locations are shown in Figure 1.

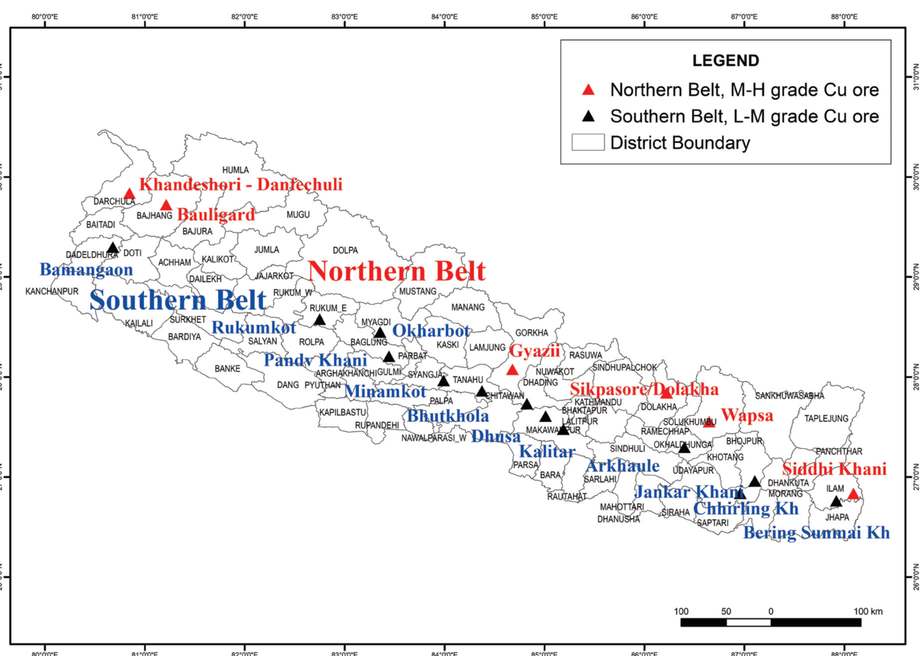

Fig. 1: Locations of major copper prospects/deposits in the Nepal Himalaya (source: DMG, 2004).

Northern copper ore mineralization belt

The northern mineralization belt lies close to MCT, where the copper/ polymetallic mineralization is confined and controlled by lithology and concentrated to the comparatively higher grade metamorphic host rocks, mostly in strongly silicified garnet mica schist and chlorite garnet mica schist of garnet amphibolite facies. In most cases, the chief copper ore mineral is chalcopyrite with minor assemblages of covellite, chalcocite, and secondary malachite and azurite in association with pyrite, arsenopyrite, pyrrhotite and traces of gold. Ore minerals in this belt are comparatively rich in copper content (>0.5 up to 14% Cu) with traces of gold (Kaphle, 2017). The copper ore deposits/ prospects located in this belt are medium to high in grade and medium in tonnage (5–12 million metric tons or more). This belt appears promising for copper and associated minor gold deposits. Most of these deposits were mined at Khandeshwari, the upper reaches of Bauligad, Gyazi, Sikpashor and Siddhi Khani. The local miners followed only the rich ore shoots/ veins (Kaphle, 2013, 2020) and traditionally mined on a very small scale, and obtained 10 to 22 metric tons of copper metal annually in the past, mostly before 1951. Only Wapsa and Gyazi mines were in operation till 1993. Detailed exploration and evaluation of some of these potential prospects are warranted to confirm the actual tonnage and grade of the ore for future mining. Some of the known major prospects/ deposits in the northern belt are briefly described below and their locations are shown in Figure 1 and the status is presented in Table 1.

Khandeshwari–Danfechuli copper prospect, Marma, Darchula

Khandeshwari copper prospect lies in the remote northeastern part of Darchula district at Marma. A number of scattered mineralization exist in this area where lots of old working mines were operated (Fig. 2) by local people before 1951. In those old days, it was famous for the name of Marma copper mine. Copper ore minerals mainly, chalcopyrite few covellite, chalcocite with secondary malachite and azurite are associated with some pyrite, pyrrhotite, traces of gold and concentrated in hydrothermal irregular quartz veins, lenses and pods in calc. chloritic garnet mica schist, talcosic schist, and feldspathic schist (host rocks). Copper content in low-grade ore is 0.39–1%, and higher in high-grade ore >1–14% (Kaphle and Khan, 1993). Similarly, the Danfechuli mineralization appears to be a north-west extension of the Khandeshwari mineralization and the ore consists of >0.3% to 2.6% Cu. The geology, nature of mineralization and the grade of ore indicate that Khandeshwari – Danfechuli mineralization could be an economic copper deposit. Detailed exploration and evaluation of this prospect are warranted to confirm economic viability.

Bauligad upper reaches copper prospect, Bajhang

Preliminary investigation of Bauligad copper mineralization towards the upper reaches of Bauligad (>8000 to 10,000 ft) indicated that there exists a very high-grade copper mineralization. Scattered ore floats samples consist of up to 11% Cu (Avg. >2%), and <1–8 ppm gold (Khan, 1997). Ore minerals are chiefly chalcopyrite, a few chalcocite and covellite along with pyrite, arsenopyrite, pyrrhotite, secondary malachite and azurite. Free gold is not visible to the naked eye since it is associated with chalcopyrite, arsenopyrite/ pyrite possibly in the crystal lattice. However, the panning of crushed ore samples (5–8 kg each) and microscopic study of a few selected polished sections of some of the ore was able to detect very few fine gold particles/ flakes in them. Because of high altitude, rugged topography, difficult terrain, harsh climatic condition, and lack of road approach detailed investigation has not been done yet, however, it is one of the most promising sites for detailed exploration and evaluation with a view to future mining.

Gyazi copper prospect, Gorkha

Gyazi copper mineralization in Gorkha District occurs in north dipping silicified biotite garnet mica schist with minor epidote. Ore minerals are mainly chalcopyrite, bornite minor covellite associated with pyrite, arsenopyrite, and secondary malachite and azurite (UN/ESCAP and DMG, 1993). In this prospect, copper ore mineralization is irregular and occurs in disconnected multiple quartz veins/ lenses/ stringers which can be traced at a distance of 5 km. The copper content in the massive sulphide ore is reported up to 16%. A lot of old working mines were operated by the local people following the rich ore shoots/ veins containing >3% Cu by applying traditional mining methods till 1993. Detailed investigation and evaluation of this prospect have not been done by DMG or any other private companies although the mineralization appears to be the potential to operate a mine applying advanced mining technology.

Sikpashore copper prospect, Dolakha

Sikpashore copper prospect is located at Marbu in Dolakha District, central Nepal. The area is represented by medium to high-grade metamorphic rocks like quartz-biotite schist, garnet mica schist, quartzite and gneiss. The chief copper ore mineral is chalcopyrite (Fig. 3) generally associated with pyrite and minor amounts of pyrrhotite, arsenopyrite, rarely galena, sphalerite, pentlandite and traces of gold. In this prospect, the mineralization is disseminated, and ore distribution is scattered and mostly confined along the foliation of quartz biotite schist, garnet mica schist and quartzite with numerous hydrothermal quartz and sulphide veins, stringers, patches and lenses. The copper content in the ore varies considerably from 0.5% to 8.6% (Thapa, 1978; Kaphle, 2011a). Copper concentration in the ore might have enriched and localized during the process of silicification and recrystallization of the host rock during metamorphism. It looks like a polymetallic deposit with a higher percentage of copper and a minor amount of nickel and traces of gold in the ore. Therefore, further detailed investigation is warranted to determine it as a medium to high grade, medium tonnage, copper/ polymetallic deposit. Very small-scale indigenous mines were operated by the local people before 1951.

Wapsa copper deposit, Solukhumbu

It lies between Rue Khola and Gue Khola on the left bank of the Dudhkoshi River in Solukhumbu District. About 25–30 m thick host rock is represented by a strongly silicified zone of chloritic garnet mica schist, garnet mica schist and quartzite. Remnants of numerous scattered old working and trial mines exist in this area (Kaphle, 2011b). Miners mined only the rich ore shoots (>3% Cu) and extracted about 10–22 metric tons of copper metal annually by applying traditional methods.

Table 1: Major copper prospects/deposits in the northern mineralization belt.

Location/prospect/ deposits	District	Ore-type/ host rock	Exploration status	Findings/recommendation
Khandeshwari – Danfechulai (Marma) Copper Prospect	Darchula	Numerous hydrothermal quartz sulphide veins/ lenses with Cp, Py, Asp, Mal, Az, $\pm$Au in silicified garnet mica schist and quartzite.	So far less explored. Mineralization bands are partly traced by Geol. mapping. There exist scattered old working mines and mine waste dumps.	Avg. Cu >1%, rich ore up to 14% Cu, minor amounts of $\pm$ Au. Grade and Tonnage NK, detail exploration is recommended to evaluate the prospect.
Bauli Gad (upper reaches/ parts) Copper Prospect	Bajhang	Mainly Cp with Cc, Py, Po, Asp & minor Mal, Az. with hydrothermal quartz veins in coarse-grained garnetiferous mica schist and quartzite	Not well explored. Few extinct old working mines exist. It is a difficult site to work at high altitudes in the winter season.	Ore with 2–11% Cu, appears as MG - HG grade & and MG tonnage (?) Cu ore deposit with traces of gold. Detail exploration is recommended to evaluate the prospect.
Gyazi Copper Prospect	Gorkha	Cp, Cov, Bo, Py, in Qtz. veins and lenses in silicified garnet mica schist as host rock.	Partly explored. OW mine and mine waste exist. A well-known Cu mine run by the local people applying indigenous technology continued till 1993.	Avg. Cu content > 1%, in ore shoot up to 16% Cu. MG-HG grade, S-M tonnage deposit. Detail exploration is recommended to evaluate the prospect of future mining.
Sikpashore Copper Prospect	Dolakha	Cp, Cc, Asp, Po, Mal. Az, Mgt., in quartz biotite schist, garnet mica schist and gneiss as host rock	Less explored, scattered old working mines and mine dumps exist. Well-known mine run by the local people applying indigenous technology, till 1951.	Ores with numerous hydrothermal quartz veins and lenses, enriched during recrystallization. Rich ore up to 9%, avg. >1% Cu. Detailed exploration is recommended.
Wapsa Copper Deposit	Solukhumbu	Mainly Cp with Cc, Cov, Ml, Az, Py, Po, associated with many Qtz. veins and stringers in intense silicified chloritic garnet mica schist.	Well-explored, scattered old working mines and mine dumps exist. Mostly collapsed and covered. Well-known mines run by the local people by applying indigenous technology continued till 1997.	Cu content varies from <0.5- 6%. Reserve 2.53Mt ore. Rich ore shoots estimated 1.75Mt with 0.88% Cu. Geologically a complex copper deposit.
Siddhi Khani Copper Prospect	Ilam	Mainly Cp with Cc, Py, Mgt, Ml. Az in qtz veins disseminated in Biotite schist.	Less explored, remnants of OW still exist. Mine was destroyed by a landslide. Reserve not known.	Fairly rich Cu ore up to 8.8%. Mostly <0.25–0.86% Cu. Avg.>0.5% Cu. Detailed exploration is recommended.

Note: OW = old working, LG = low grade, MG = medium grade, HG = high grade, ST = small tonnage, MT = medium tonnage, LT = large tonnage, Mt = million metric ton, mt = metric ton, Cp = chalcopyrite, Cc = chalcocite, Bo = bornite, Py = pyrite, Po = pyrrhotite, Ml = malachite, Az = azurite, Gl = galena, Sph = sphalerite, Asp = arsenopyrite, Au = gold, Ag = silver, Mgt = magnetite, Bt = biotite, Gt = garnet, Qtz = quartz, Chl = chlorite, Mc = mica, expl. = exploration, NK = not known.

Fig. 2: Locations of major copper prospects/deposits in the Nepal Himalaya (source: DMG, 2004).

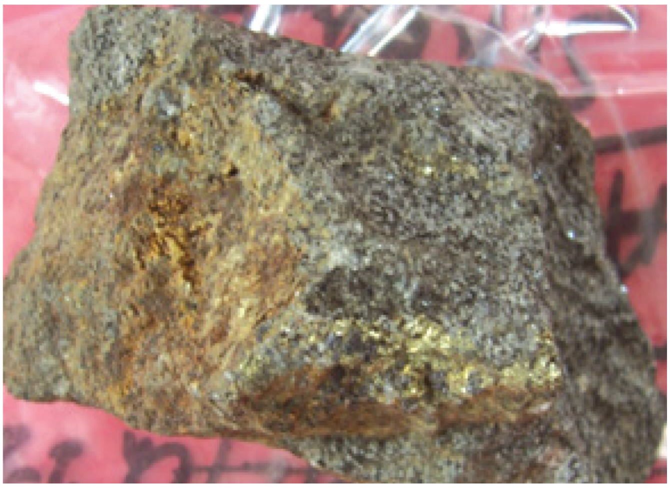

Fig. 3: Ore sample from Sikpashore copper prospect, Dolakha.

Indigenous mining work continued till 1993. The chief ore mineral is chalcopyrite with few covellite, and bornite accompanied by pyrite, pyrrhotite, magnetite, sphalerite and galena. Mineralization occurs in lenses, pods, and stringers along with quartz veins and the ores disseminated along foliation and partly cross-cutting veins. This prospect was well explored by geological mapping, a geochemical survey, followed a geophysical survey and drilling 6 drill holes (Fig. 4). Analytical data of all types of ore samples confirmed that the copper content in the ore varies considerably from 0.1 to 3.24% and rarely up to 6% in rich ore shoots. The estimated reserve is about 1.74 million metric tons with 0.88% Cu, 0.53 million metric tons with 1.54% Cu and 0.24 million metric tons with 3.24% Cu (Bhandary, 1978; Shrestha, 1980). The total combined ore reserve is roughly calculated as 2.53 million metric tons (UNDP/MEDB, 1981).

Siddhi Khani copper prospect, Ilam

Widespread disseminated copper ore mineralization is known from Siddhikhani in Ilam District for more than six decades. Remnants of quite a few old working mines can be found in this area which is mostly covered due to landslides. This prospect was partly explored by the Nepal Bureau of Mines (now the Department of Mines and Geology). The main load consists of copper ore like chalcopyrite, chalcocite, cuprite and secondary malachite, azurite along with pyrite and magnetite associated with hydrothermal quartz veins, stringers disseminated in garnet mica schist as host rock and calc-chlorite schist, sericitic quartzite and few minor amphibolites. About 30 m thick ore bearing highly silicified band represented by garnet mica schist is the host rock which comes in contact with garnet - kyanite gneiss of Higher Himalaya crystalline zone. Therefore, the mineralization band lies just below the contact (south of MCT). The reported copper content in the main lode is up to 8.86% (Malla, 1966; Sharma et al., 1968), and up to 4% (Kaphle, 2009a), while other scattered thin mineralized veins contain <0.02 to 0.86% Cu. Detailed exploration has not yet been completed and as a result, the total reserve and average grade of the ore is unknown.

Southern copper ore mineralization belt

Lesser Himalaya is mainly represented by metasedimentary rocks of the Pre-Cambrian to Paleozoic age with few irregular mostly elongated granite bodies of the Cambro-Ordovician age (Einfalt et al., 1993; Bekinsley and Mitchel, 1981). Among them, dolomite, limestone, quartzite, phyllite/ slate, and mica schists are the predominant rock types, and rarely very few small bodies of amphibolite are there. Gneisses/ gneissic granites are found either in the periphery of granite bodies or as localized small isolated elongated mostly lenticular bodies. In the Southern Mineralization Belt, almost all copper/ polymetallic mineralization is lithologically confined to the host rocks represented by silicified chlorite mica schist, quartzitic phyllite, sericitic quartzite and rarely calc-mica schist of low-

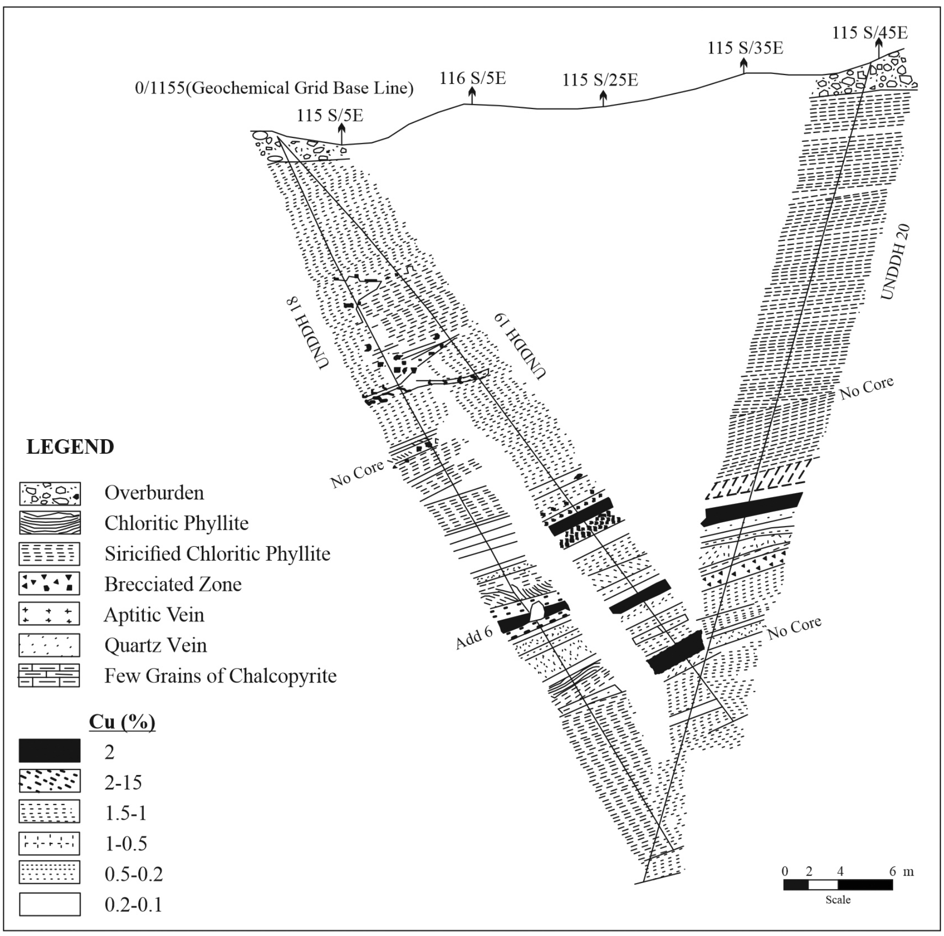

Fig. 4: Drill hole log in Wapsa Khani, Solukhumbu (MEDB, 1981).

grade greenschist facies. The mineralization is well traced from west to east at Bamangaon polymetallic mineralization in Dadeldhura; copper mineralization at Manakot/ Tallakot in Bajura, Rukumkot in Rukum; Pandav Khani in Baglung; Okharbot (Baise khani) in Myagdi; Minamkot in Syangja/ Tanahun, Bhutkhola in Tanahun; Dhusa in Dhadhing; Kalitar, Ipa-Baraghare in Makwanpur; Janterekhani in Okhaldhunga; Kurule in Udaypur; Chhirling Khola in Bhojpur; and pyrite rich polymetallic sulphide mineralization band exposed at Bering Khola – Sunmai Khola – Sukininda Khola in Ilam districts (Fig. 1, Table 2). All of them are fairly well explored by DMG (during 1967–1998) and UNDP/ DMG (than Nepal Geological Survey) cooperation projects (Talalov, 1972), and Mineral Exploration Development Board (1975–1980). Some of the rich ore shoots in these prospects were mined by the local people applying traditional mining methods before 1951 and only the Okharbot copper mine was in operation till 1993.

In almost all these prospects, chalcopyrite occurs as a chief copper ore mineral with a minor amount of chalcocite, covellite, bornite, cuprite, secondary malachite and azurite and associated predominantly with pyrite and few arsenopyrite, pyrrhotite, rarely magnetite. In polymetallic mineralization, copper ores are associated with some scheelite, molybdenite, bismuthinite, rarely magnetite, galena, sphalerite and traces of gold. All these mineralization are related to hydrothermal, disseminated irregular vein type and concentrated during the processes of regional metamorphism, possibly at the time of Himalayan upheaval. The source of polymetallic mineralization in the exo-contact zone like at Bamangaon, Sikri Khola and Kurule is granite (Kaphle, 1997; Shah and Paudyal, 2019; Madhikarmi, 1980). The average copper content in them is <0.5% except in some very small localized ore bodies and generally small in tonnage (mostly <5 million metric tons rarely up to 11 million metric tons). However, frequent association of W, Mo, Bi, rarely Ni, Co, Au, Ag, Pb and Zn still suggest that there is an immediate need for further evaluation of some of the selected potential prospects which could be economic deposits and feasible for mining at least two to three metals. Since the mineralization in the Southern Belt is generally low in grade and small in tonnage, it is not feasible to solely extract only copper. However, polymetallic prospects could be feasible if one could extract more than two metals from the same ore body as in Bamangaon polymetallic prospect to mine for copper, tungsten, molybdenum, bismuth and traces of gold. Multi elements analysis of stream sediments and mineral deposit modelling of central Nepal by Shrestha (1991) concluded that the structural features are the primary control and skarn type mineralization in the exo-contact zone for several types of mineral deposits. Some of the major prospects are briefly described and their status is given in Table 2 and locations are shown in Figure 1.

Bamangaon polymetallic prospect, Dadeldhura

Sulphide rich quartz veins, lenses, pods and stringers in the silicified phyllite and sericitic quartzite beds (host rock) are the favourable sites for chalcopyrite, pyrite, arsenopyrite, pyrrhotite, bismuthinite, scheelite, molybdenite and gold mineralization (Kaphle and Adhikari, 1980; Kaphle, 1997). Maximum metal content in the ore samples is 1.72% Cu, 0.22% W, 200 ppm Mo, 900 ppm Bi, 550 ppm Ni, 40 ppm Sn, 48 ppm Ag, and up to 1 ppm Au (one sample up to 14 ppm?) and up to 2.4% arsenic. Additional exploration and reevaluation of Bamangaon polymetallic mineralization (Cu, W, Mo, Bi, Ni with minor Ag, Au), based on the results obtained from the surface geological mapping, trenching, pitting (Figs. 5, 6), geochemical survey as well as geophysical survey (IP and SP, Magnetic) and three drill holes (334 m) data the geological ore reserve is calculated as 3.91 million metric ton ore with an average 0.25% Cu along with minor amount of W, Mo, Bi and traces of Ag and Au. Therefore, the Bamangaon prospect is a small tonnage, sub-economic polymetallic deposit. In addition to copper, other 2 or 3 associated minerals like W, Mo, Bi, and Au/ Ag must be extracted to make this prospect/ deposit feasible for mining.

Rukumkot copper prospect, Rukum

It lies in the Rukum district in western Nepal. Copper was mined locally by the local people before 1951. Lots of small old working mines and mine waste dumps exist at the site. In this prospect copper mineralization mainly occurs in association with multiple quartz veins and veinlets and as disseminated specks of chalcopyrite and chalcocite with few secondary malachite and azurite; pyrite and pyrrhotite also occur as associated minerals. Ore shoots are associated with intense silicification of limestone, as well as quartzite and slate. A mineralization zone of 1 m to 10 m wide with less than

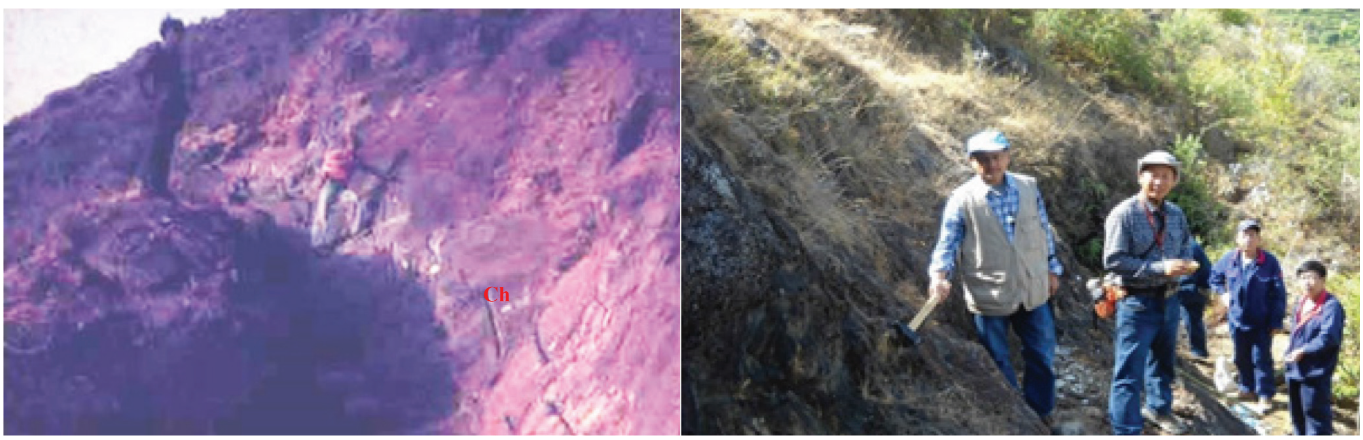

Fig. 5: 71 m long master trench No. 3 at Bamangaon polymetallic prospect from which channel samples (Ch) were collected and analyzed for Cu, W, Mo, Bi and selected for Au, Ag, Sn, As, Ni.

Table 2: Major copper prospects/ deposits in the southern mineralization belt.

Location prospect/ deposit	District	Ore-type/ host rock	Exploration status	Findings/ recommendation
Bamangaon Polymetallic (Cu, W, Mo, Bi ±Au) Prospect/ deposit	Dadeldhura	Cp, Py, Po, Asp, Sch, Mo, ± Bis, Nic, Cs, Au, in sericitic phyllite and quartzite	Fairly well explored, mineralization bands traced by geol. mapping, geochemical and geophysical survey, >40 trenches, 3 pits & 3 drill holes.	Geological reserve 3.9 Mt ore with an average 0.25% Cu, and minor amounts of Mo, W, Bi, ± Au. Additional drilling is recommended.
Rukumkot Copper Prospect	Rukum	Mainly Cp with Py, PO and minor Mal, Az.	Not well explored, Lots of old working mines and mine waste dumps exist.	Tonnage and grade not calculated but looks L to M grade and ST (?)
Okharbot/ Baise Khani Copper Prospect	Myagdi	Mainly Cp with Py, PO minor Mal, Az. ore shoots associated with intense silicification.	Less explored, lots of OW adits up to 150m long, 22 mines developed, operated till 1993. It is a famous OW mine.	Low to med. locally HG, MT (?), old working mine followed only rich ore.
Pandav Khani Copper Prospect	Baglung	Mainly Cp, Py, and a few Mal, Az.	Few OW, partly explored, by trenching and 3 drill holes.	L to M grade and ST. An uneconomic deposit.
Minamkot Copper prospect	Syangja/ Tanahu	Mainly Cp is associated with numerous quartz veins and Mal. & Az. can be seen in quartzitic slaty phyllite as host rocks.	OW adits are across the dip of the host rock. Partly explored but not in detail to confirm the deposit.	Exists about 43 old workings. Only 3 samples were assayed and Cu content varies from 0.22 – 1.4%.
Bhut Khola/ Nadra Copper Prospect/ deposit	Tanahun	Mainly Cp with Py, PO and lots of Mal, Az in qtz lenses & veins in sericitic quartzite and silicified phyllite as host rock.	Fairly well explored. Minn. bands traced by geological mapping, geochemical survey and a few trenches, pits, and 4 drill holes. Few OW/ mines exist.	Geol. reserve 2.6 Mt ore with 0.24% Cu, and traces of Au, L to M grade and ST, sub-economic deposit.
Dhusa Copper Prospect/ deposit	Dhadhing	Cp, Py, Mal, Az, in qtz veins and lenses in calc. phyllite and quartzite as host rock.	Fairly well explored, mineralization bands traced by geol. mapping, geochemical survey, and few trenches & pits, 3 drill holes, few OW/ mines recorded	Cu up to 1.4%, mostly 0.21 –0.91% and avg. <0.5%. It is MT, L-M grade sub-economic deposit. Recommended for reevaluation.
Kalitar East and West Copper Prospect	Makwanpur	The chief ore is Cp with Cc, Mgt, and minor Mal, Az in micaceous quartzite and Chloritic mica schist as host rock.	Fairly well explored, 10-12m thick mineralization band traced by Geol. mapping, geochem. survey and a few trenches, 7 drill holes. Few OW/ mines recorded.	Cu content 0.1–0.91% Avg. <0.5% Cu, 2.29Mt. Sub-economic, L to M grade, ST deposit.
Ipa Copper Prospect	Makwanpur	Chief ore is Cp with minor Mal, Az.	Partly explored, 30 m thick, 2 mineralization bands traced to 200m, 2–3 small OW.	LG and ST, an uneconomic deposit, are not feasible for mining.
Baraghare Polymetallic Prospect	Makwanpur	Ores of Cu, Pb, Zn, Bi, Sb As, Ag; chief Cu ore is Cp, minor Mal, Az, Py, and some Gln. and Sph.	Partly explored, 0.76%Pb and traces of Zn, Bi, Sb, Ag. Polymetals (Cu, Pb, Zn, Bi ± Ag) could be extracted.	LG and ST look not economic only for Cu or Pb. Follow up detail exploration for poly-metals is highly recommended
Jantare Khani Copper Prospect	Okhaldhunga	Cp in quartz, segregation in silicified phyllite and quartzite as host rock	Three famous old working/ mines were recorded, mine was in operation before 2051.	Low grade 0.1 to 0.9% Cu, ST, not feasible for mining
Chhirling Khola Copper Prospect	Bhojpur	The chief ore is Cp with Py and Mgt	Partly explored, two mineralization bodies were traced.	ST, LG, Avg. Cu <0.5%. An uneconomic deposit.
Bering Khola – Sunmai Khola - Sukininda Khola Polymetallic Prospect	Illam	Polymetallic, mostly Py, with few Cp, Asp, Mlc, Az at places Sph & Gln ± Au	Partly explored, 2 min. bands (total 3-5m thick) traced by Geological mapping, trenching, channel, chip, bulk sampling, and 2 drill holes.	Py rich (locally up to 30% sulfide) with Cp, Po, Avg. Cu<0.21%, Pb<1%, Zn<1%, and Au<0.25 ppm. Reserve roughly 11.7 Mt ore, sub-economic deposit.
Other copper prospects/ occurrences in >70 locations	In different districts of Nepal	Mostly related to hydrothermal quartz sulphide veins in silicified phyllite, sericitic quartzite, mica schist and calc. schist.	At places old workings/ mines were reported, some of them partly explored and others not explored at all.	Almost all of them are low in grade and small in tonnage. Not feasible for mining.

Note: LG = low grade, MG = medium grade, HG = high grade, ST = small tonnage, MT = medium tonnage, LT = large tonnage, Cp = chalcopyrite, Py = pyrite, Po = pyrrhotite, Ml = malachite, Az = azurite, Mgt= magnetite, Sch = scheelite, Bi = bismuthinite, Mo = molybdenite, Nic = niccolite, Gl = galena, Sph = sphalerite, Asp = arsenopyrite, Au = gold, Ag = silver, Cs = cassiterite, Cip = chip sample, Ch = channel sample, Blk = bulk sample, Mt = million metric ton, mt= metric ton.

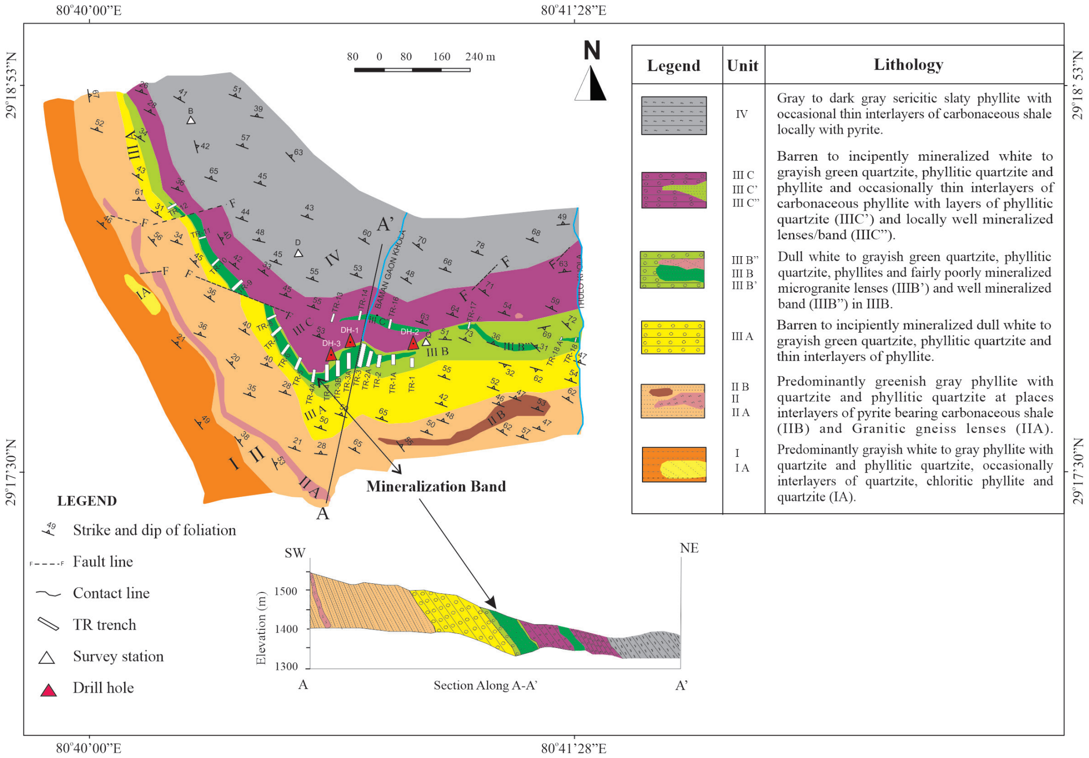

Fig. 6: Generalized geological map of Bamangaon polymetallic prospect (cross section along A–A').

100m strike length was traced. The copper content in the ore varies considerably from <0.1 to 0.5% (UN/ ESCAP, DMG report, 1993). Because of the very small size of the prospect and poor grade and tonnage, further work was suspended.

Okharbot copper prospect (Baise Khani), Myagdi

It was one of the very active traditional copper mines and is famous by the name of Baise Khani (22 mines) operated by the local people at a very small scale (extracted about 10–22 metric tons of copper metal/ year) for about 40 years till 1993. During mining, narrow adits were excavated up to 150 m following the rich ore shoots, veins associated with intense silicification (Joshi, 1972). The chief ore is chalcopyrite with few chalcocite, covellite, pyrite, malachite and azurite. The average grade of the ore is <0.5% Cu. Copper mineralization is associated with quartz veins and lenses of variable sizes (a few cm to 1 m width and 1m to a few 10s m long) hosted in silicified chloritic sericitic phyllite, sericitic quartzite and slaty phyllite. Most of the rich ore shoots (>3% Cu) were mined and whatever is left has to be evaluated for further possible mining in the future. Detailed exploration and evaluation of this deposit is warranted to confirm its economic status.

Bhutkhola copper prospect, Tanahun

In this prospect, mineralization is hosted by silicified phyllite, sericitic quartzite and often with silicious dolomite. Copper ore is mainly represented by chalcopyrite and associated with pyrite, covellite, chalcocite, malachite and azurite in quartz veins and lenses. Several old workings (Fig. 7) follow copper ore-rich quartz veins, and lenses in silicified phyllite and quartzite (Kaphle, 2014). Mineralized quartz veins are irregular, exhibiting swelling and pinching nature. A maximum swelling portion is up to 12 m thick and extended to ≈100 m

Fig. 7: Bhutkhola copper prospect (a) old working, (b) mineralized band, (c) ore floats, (d) drill core.

in strike length. Nine such mineralized quartz bodies in 5 km strike length were traced by trenching and selected drilling (5 drill holes). All these data revealed that the average grade of the ore is 0.45% Cu. A probable reserve is estimated to be 2.6 million metric tons with an average grade of 0.24% Cu. Only in Nadra block ≈0.21 metric ton of copper ore with 0.87% Cu is proved (Jnawali, 1975; Manandhar, 1985; UN/ESCAP/DMG, 1993). It is a low-grade, small tonnage sub-economic deposit.

Dhusa copper prospect, Dhadhing

Several old workings exist at Dhusa, containing ores mainly chalcopyrite with some pyrite, malachite, azurite (as secondary minerals, Fig. 8) and rarely bornite. Geological mapping, geochemical survey, trenching/ pitting, channel sampling and drill core samples were analyzed for copper content. The grade

Fig. 8: Dhusa copper prospect (surface exposures and ore samples).

of copper in the drill hole samples is less than 1% Cu except in a 19 cm thick layer (1.4% Cu) in dolomite and in 18 cm thick contact zone between breccia and graphitic schist (1.3% Cu, Tamrakar, 1978; Kaphle, 2009b). From the available information, it is roughly estimated to be 9 million metric tons possible reserve with low average grade (<0.5% Cu) which is not feasible for mining copper ore. Since the technology to extract metals from the ore is well developed and the current price of copper in the international market is increasing, it can offer Dhusa copper prospect as feasible for mining. Therefore, reevaluation of the deposit is recommended.

Kalitar east and west copper prospect, Makwanpur

In this prospect, a 10–12 m wide copper mineralization zone occurs in micaceous quartzite and schist of the Kulekhani Formation. There are very few old workings/ mines operated by the local people applying traditional method (Fig. 9a). Chalcopyrite, pyrite, chalcocite, magnetite, veins or pods, lenses, stringers of massive ore up to 1 m long are disseminated in the host rock. On the surface, the average copper content in the ore is 0.1 to 0.3% and with an upper limit of 1.5%. The total strike length of the mineralized band is about 1300 m (east and west Kalitar prospect combined). 7 drill holes data revealed minor mineralization only in a 2 m thick zone, consisting of 1–1.5% Cu indicating high grade confined only in lenticular veins/ pods. Ore reserve was estimated as 1.39 Million metric tons with an average. <0.5% Cu and 90,000 metric tons with 1.5% Cu, and a total estimated deposit of about 2.29 Million metric tons (Karmacharya, 1978) indicate a smaller deposit and not feasible for economic mining (Fig. 9b).

Bering Khola-Sunmai–Sukininda Khola polymetallic mineralization, Ilam

Two mineralization bands of variable thickness extend at about 9 km and are traced from Goyang Khola in the west to Bering Khola – Sunmai Khola – Sukininda Khola in the east in Ilam District. Chalcopyrite, pyrite, pyrrhotite, associated with minor arsenopyrite, magnetite, locally galena, sphalerite are present in sericitic quartzite as the host rock. Ore distribution is not uniform throughout, however, in places, the concentration of combined sulphide (mainly pyrite) mineralization varies from 5–30% in massive sulphide ore (Thapa, 1967; Kaphle and Khan, 2007). Mineral association, grain size, and texture in the ore indicate remobilization and re-concentration of the ore minerals during the metamorphic process. A tentative estimated geological reserve is about 11.72 Million metric tons of sulphide ore with average grades of Cu = 0.21%, Pb <1%, Zn <1%, Au <0.1 ppm and Ag traces to 150 ppm (Kaphle and Khan, 2007) (Figs. 10a,b). It is a medium-sized low-grade polymetallic deposit which could be economic if more than two metals (Cu, Au, and Ag) are extracted. Pyrite can be used to extract sulphur, which is the raw material to manufacture sulfuric acid.

Chhirling Khola copper prospect, Bhojpur

The prospect area is represented by calcareous phyllite, sericitic quartzite, carbonaceous phyllite and impure dolomite. Two mineralization bands occur in association with quartz lenses and veins within impure dolomite and calcareous phyllite. Ore minerals like pyrite, magnetite and chalcopyrite with minor pyrrhotite and secondary iron oxide, malachite and azurite are widespread in quartz lenses showing hydrothermal nature of mineralization (Kaphle, 1976). The maximum combined thickness of the mineralized bodies is 21–30 m and the strike length is around 200 m. The average copper content in the ore is <0.5%, but some of the individual lenses and veins consist of up to 7% Cu (Kaphle, 1976; Tuladhar and Tater, 1978; Kansakar, 1978). It is a very small size low-grade copper ore deposit which is not feasible for further work unless precious or rare metals are detected.

Other mineralization

There is quite a few other copper ore mineralization in the southern belt like Jantare khani in Dhankuta, Devrali, Sanotar, Baraghare copper prospects in Makwanpur, Kurule in Udaypur, Pandav Khani in Baglung, Bhirkhu Khola section in Bajhang, Manakot – Tallakot in Bajura and at different parts of Taplejung, Bhojpur, Okhaldhunga, Ramechhap, Dolakha, Makwanpur, Chitwan, Dhadhing, Tanahun, Syangja, Myagdi, Baglung, Rolpa, Bajhang, Baitadi, and Darchula districts (DMG, 2004; UN/ESCAP cooperation with DMG, 1993; Kaphle, 2020). Almost all of these prospects except a few polymetallic prospect appear to be not significant for further exploration and not feasible for mining.

COPPER MINERALIZATION IN NEPAL AND INDIAN HIMALAYAS

Two copper/ polymetallic mineralization belts in the Nepal Himalayas namely the northern copper/ polymetallic mineralization belt in the north and the southern copper/ polymetallic mineralization belt in the south are identified (Fig. 1). It is likely that both belts are extended further to the east in Sikkim and Darjeeling in the Indian Himalayas. On the basis of geology, host rocks and nature of mineralization, the northern copper/ polymetallic mineralization belt can be correlated with the copper/ polymetallic mineralization at Bothang, Rangpo in Sikkim and the southern copper/ polymetallic mineralization belt with polymetallic mineralization in Gorubathan area in Darjeeling, India.

Correlation between the Bothang/Rangpo copper/ polymetallic mineralization in Sikkim, India and northern copper/ polymetallic mineralization belt in Nepal

The copper mineralization at Bothang in Rangpo, Sikkim is a stratiform polymetallic mineralization where hydrothermal solutions are responsible for ore concentration. The massive ore

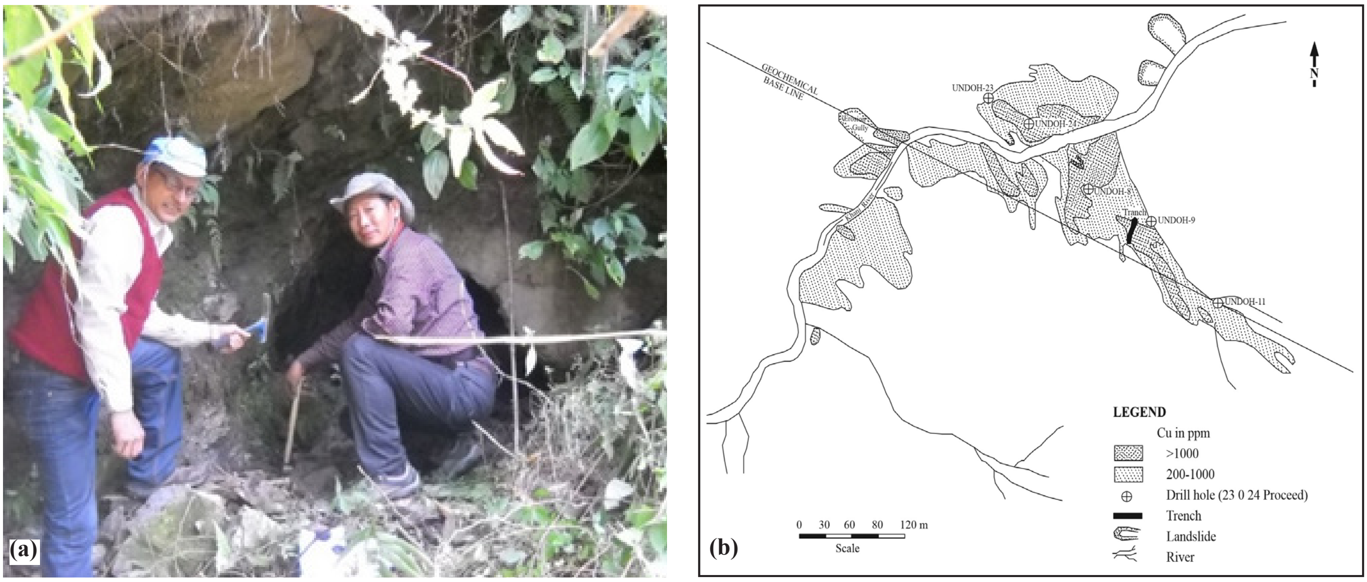

Fig. 9: (a) Old working adit, (b) geochemical soil copper anomaly map of Kalitar copper prospect (Karmacharya, 1978).

Fig. 10: Mineralized bands exposed at (a) Bering Khola, (b) Sunmai Khola, Ilam.

occurs as veins, lenses, pockets etc. in the rich mineralization part. The dominant ore minerals are chalcopyrite, pyrrhotite, sphalerite, galena associated with a few pyrite, arsenopyrite, covellite, chalcocite, cobaltite, bornite, and malachite, azurite as secondary minerals and traces of silver and gold localized in garnetiferous chloritic mica schist and quartzite belonging to the garnet amphibolite facies of Daling Series/Group of Pre-Cambrian age (Ghosh, 1975; Dasgupta, 1967/68). In Bothang copper, lead, and zinc mineralization do not represent any systematic zonal arrangement (Ghosh, 1975), and the width of the ore body varies from 1.5 to 5 m, and the average total combined Cu-Pb-Zn content is 4.90% which was mined before (Mukherjee and Rao, 1974). The south-western part is rich in copper content and the north-eastern part is rich in lead-zinc (Mukherjee and Rao, 1974). Further northeast at Bungthing, Chengmari Taluk in Bhutan, there exists Pyrite and Polymetallic Prospect (Raghavan et al., 1976; Sinha, 1977) which could be an eastward extension of the northern belt.

Similarly, in Nepal Himalaya, the copper/ polymetallic mineralization in the northern belt from west to east like at Khandeshwari – Danfechuli in Darchula, upper reaches of Bauligad in Bajhang, Gyazi in Gorkha, Sikpashore in Dolakha, Wapsa Khani in Solukhumbu and Siddhi Khani in Ilam are also located in the similar geological environment. The nature of copper/ polymetallic ore mineralization also appears quite similar. The ore minerals are mainly chalcopyrite with some pyrite, pyrrhotite, galena, sphalerite and a minor amount of bornite, niccolite, cobaltite, bismuthinite and appreciable amount of silver and traces of gold are also associated with quartz veins in strongly silicified garnetiferous chloritic mica schist and quartzite (garnet amphibolite facies) as host rock of Pre-Cambrian age. Therefore, the northern copper mineralization belt in the Nepal Himalaya can be well correlated with Bhothang/Rangpo copper/polymetallic mineralization in Sikkim and the polymetallic prospect at Bungthing, in Bhutan. Further investigation and detailed exploration of some of these prospects in the northern belt could detect mineable, medium to high-grade economic copper ± gold/polymetallic deposits in Nepal.

Correlation between polymetallic mineralization zone in the Gorubathan area in Darjeeling in India and southern copper/ polymetallic mineralization belt in Nepal

The stratiform polymetallic mineralization zone (Fe-Pb-Zn-Cu) in the Gorubathan area in Darjeeling extends to 3.5 km, and it is associated with quartz–muscovite–chloritic schist and sericitic quartzite (greenschist facies) belonging to Gorubathan Subgroup of Daling Group of Pre-Cambrian age (Sharma and Nair, 1982). It can be well correlated with Bamangaon polymetallic mineralization (Cu, W, Mo, ± Au, Py, Asp, Po) in Dadeldhura, Baraghare polymetallic mineralization (Pb, Zn, Cu, Py, Asp) in Makwanpur, and Bering Khola – Sunmai - Sukininda Khola polymetallic sulphide mineralization (Cu, Pb, Zn, Py, Asp ± Au) in Ilam and few other copper mineralization belonging to the southern mineralization belt in Nepal Himalaya. Previous exploration works in most of the prospects as described above indicate that they are low in grade and small in reserve size. However, few polymetallic mineral deposits like Bamangaon polymetallic deposit from where extraction of more than two metals (Cu, W, Mo, Bi ± Au) from the same ore body could be possible and feasible for future mining. Therefore, further detailed exploration, and evaluation of these deposits is warranted.

In the case of the Nepal Himalaya, the host rock in the northern mineralization belt is represented by garnet amphibolite facies whereas the southern mineralization belt is represented by the host rocks of greenschist facies. Similarly, stratigraphically the copper mineralization section of Bhothang in Rangpo, Sikkim, and polymetallic mineralization in Gorubathan in the Darjeeling area belong to the upper and lower part of the Pre-Cambrian Daling Group (Sharma and Nair, 1982). Since the rocks of Gorubathan belongs to greenschist facies of metamorphism and further north at Rangpo in Sikkim, there is a gradual increase in the grade of metamorphism and reached garnet-amphibolite facies. As a result, at Rangpo, copper/ polymetallic sulphide mineralization (Cp-Po-Gln-Sph) is associated with garnetiferous chloritic mica schist and quartzite of Daling Series (Dasgupta, 1968; Ghosh, 1975; Sinha, 1977). It appears that there was a high degree of remobilization of sulphide ores of Rangpo as compared to that of Gorubathan mineralization as in the case of northern and southern copper/ polymetallic mineralization belts in Nepal.

Due to their similarities in the overall nature and type of mineralization, mineral assemblages, ore grade, genesis, as well as the grade of metamorphism of the host rocks, the northern copper/polymetallic mineralization belt can be well correlated with Rangpo Bothang copper mineralization in Sikkim and the southern copper/ polymetallic mineralization belt with the Gorubathan polymetallic mineralization in Darjeeling area, India in the east.

CONCLUSION

It is quite clear that there exist two distinct northern and southern copper/ polymetallic mineralization belts in the Nepal Himalaya. Among these two identified copper/ polymetallic mineralization belts, the host rocks of the northern mineralization belt is comparatively higher in metamorphic grade (belongs to garnet amphibolite facies) and also fairly rich in copper content (up to 3–14%) with traces of gold, and bigger in reserve (tonnage) than the southern mineralization belt in which the host rocks are of low grade (belongs to greenschist facies) and low in average grade of ore and small in tonnage. In both belts, chalcopyrite occurs as the chief copper ore mineral in association with a few other sulphide and oxide minerals of copper, iron etc. and traces of gold, and their hydrothermal nature of mineralization.

Strong silicification and sericitization of the host rocks, as well as hydrothermal fluids developed during the metamorphism of host rocks, appear to be responsible mainly for copper ore mineralization in the northern mineralization belt in the Nepal Himalaya. The copper ore mineralization genetically appears to be similar in nature to those of Bhothang, Rangpo copper mineralization in Sikkim, India. Similarly, the northern mineralization belt is fairly rich in copper content with gold and few other ore minerals. Southern copper/ polymetallic mineralization belt in the Lesser Himalaya in Nepal appears to be similar to the metamorphic grade of the host rock, nature of mineralization/ occurrence (hydrothermal, stratiform type of deposit), ore grade, tonnage, etc. It can be well correlated with Gorubathan polymetallic mineralization in the Darjeeling area in India. The study clearly shows that two distinct mineralization belts traced in Nepal are also likely to continue further eastward to the Indian Himalaya.

Inadequate mineral exploration works conducted in the past were concentrated mainly on the southern belt in the Lesser Himalaya in Nepal. Priority was given to base metals (copper, lead, and zinc) and only a few for iron, tin, tungsten, cobalt, and gold mineralization. In most of the cases, multi-element analysis was lacking rather neglected. Therefore, it is highly recommended to conduct detailed investigations for the major copper and polymetallic prospects mainly in the northern mineralization belt, where the chances of finding out mineable economic copper/ polymetallic mineral deposits appear fairly high. In addition to that further exploration is also recommended only in a few selected polymetallic mineral prospects/deposits in the southern mineralization belt.

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