www.gondwanags.org.in

JGSR
Journal of Geosciences Research
Vol. 6, No.2, July, 2021
pp. 136-145

Cobalt Mineralization Associated With Copper from Kalyadi Area, Western Dharwar Craton, South India

Mahantesha P.[1*], K.N. Prakash Narasimha[2], M. Shareef[3], G. Gopala Krishna[4] and T.K.A. Rahim[5]

[1]Geological Survey of India, SU: K and G, Bengaluru - 560111(KN), India
[2]DOS in Earth Science, University of Mysore, Manasagangotri, Mysore - 570006(KN), India
[3]Geological Survey of India, FTC, Chitradurga -577502(KN), India
[4]Geological Survey of India, NCEGR, Bengaluru -560111(KN), India
[5]Hutti Gold Mines Ltd., Raichur -584115 (KN), India
(*Corresponding author, E-mail: mantugeo11@gmail.com)

Abstract

Kalyadi Schist Belt (KSB) of the Western Dharwar Craton (WDC) is well known for Kalyadi ploymetallic copper deposit of Meso Archean (3.0Ga) age. The Kalyadi Supracrustal dominantly made-up of quartzite, ultramafic to mafic schist inter-bedded with chemogenic cherts. The copper mineralization in Kalyadi schist belt occurs as 1) disseminations and patches in quartzite, 2) stringers and veinlets in meta-volcanics and 3) rich concentrations along fractures. The mineralisation is lithologically and structurally controlled by narrow brittle-ductile shear zone as evidenced by the development of numerous fractures, joints, faults, veins, stringers and foliations in KSB. Magnetite, chalcopyrite, pyrite pyrrhotite and arsenopyrite are some of the common sulphide minerals observed in the area. Apart from Cu, Cobalt (Co) association is also known from Kalyadi schist belt. There is no separate Co mineral phases present in the area and the Co is ubiquitously associated with pyrite. Petrographic studies reveal that the chalcopyrite replaced the early pyrite and pyrrhotite. Chemical analyses of the samples from the mineralized zones by AAS have yielded Co values up to 1200 ppm and Cu up to 2.3 %. Negative correlation between Co and Cu is noticed.

Keywords: Copper- Cobalt Mineralisation, Kalyadi Schist Belt, Western Dharwar Craton

Introduction

Dharwar Craton offers unique opportunity to study important metallic and non-metallic mineral deposits. The Kalyadi schist belt of western Dharwar Craton hosts important polymetallic deposits. The KSB is well known for its Copper mineralisation. Probe into the past literature has shown that several scientists have worked on different aspects of kalyadi copper belt, but not much attention has been paid for the study of Cobalt associated with copper. In this study an attempt has been made to understand the mineralisation of Cobalt associated with Copper through field examination, coupled with petrography and geochemistry.

Worldwide Cobalt is typically mined as a by-product of copper and nickel. The major cobalt producing countries are Congo, Cuba, Russia, China and USA. Among these, Congo contributes more than 50% of primary cobalt production. The vast majority of these resources are in sediment-hosted stratiform copper deposits in Congo and Zambia; nickel-bearing laterite deposits in Australia; and magmatic nickel-copper sulphide deposits hosted in mafic and ultramafic rocks in Australia, Canada, Russia and the United States. More than 120 million tons of cobalt resources have been identified in manganese nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans. Apart from these, the Neo-proterozoic sediment hosted stratiform copper-cobalt deposits are reported from the Central African Copper Belt (Cailteux *et al.*, 2005).

The major cobalt producing states in India are Singhbhum district, Jharkhand; Kendujhar and Jajpur districts of odisha; and Tuensang in Nagaland. Singhbhum copper belt is constituent of Ni-Co-As-S mineralisation contributed by volcanic-sedimentary pile (Sarkar, 1982). The Khetri Copper Belt, a part of the Proterozoic Delhi–Aravalli Fold Belt in western India, hosts several Cu deposits, which are known to contain considerable amount of Au, Ag, Co and Ni (Pal *et al.*,

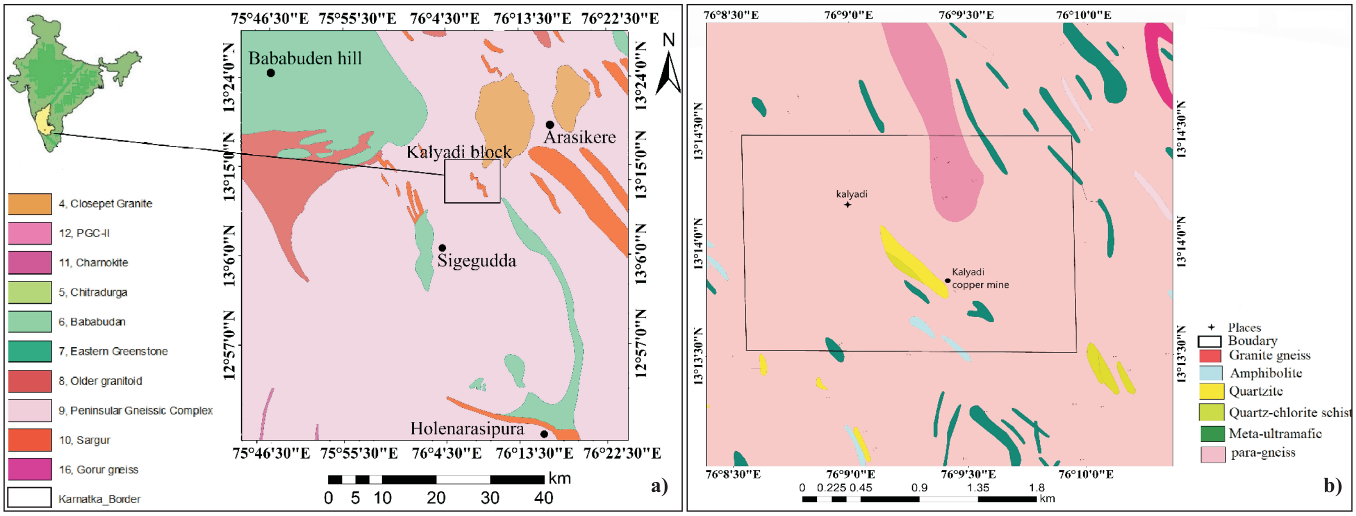

Fig.1a. Broad Geological Framework of Western Dharwar craton (*after* Ravindra *et al*. 1990) with inset map showing location of the study area **b.** Regional Geological Map of the study area showing different lithounits and location of the Kalyadi Copper Mine

2016). Stratiform quartz sulphides lodes in Ingaldhal occur in a typical greenstone belt of the Western Dharwar Craton, comprising metabasalt, tuff, chert and cherty iron sulphide formations having high cobalt contents of metavolcanics and of sulphide minerals (Mookherjee and Philip, 1979). The exploration work which was carried out by Geological Survey of India (Unpublished report of FS, 2019-20) in Banasandra area of the Western Dharwar Craton, has reported the occurrence of cobalt in associated with Ni in the Komatiite hosted ultramafic complex with values ranging from 150 ppm to 710 ppm. The KCB is one such example for copper –cobalt deposit, the cobalt resources was estimated as reserves of about 5.8 Mt with 650ppm cut of grade (Parameswaraiah, 1996; Krishna Rao, 1998). The demand for cobalt is expected to rise significantly over the coming years in India.

Regional Geology

The Kalyadi copper-cobalt deposit area is situated 21km west of Arasikere town in Hassan district, in the Western Dharwar Craton. The area represents remnants of older volcanic and sedimentary sequences fragmented and engulfed by later gneisses. Rao and Venkataraman (1982) considered as the Kalyadi suite as a part of the Nuggihalli Greenstone Belt. Ravindra *et al.* (1990) have considered the Kalyadi Area as an eastern limb of the Holenarasipur Greenstone Belt (Fig. 1). It is believed that the Paleo-Meso Archaean supracrustal belts throughout the world are devoid of economically workable syngenetic/stratiform copper sulphide deposits (Vasudev, 1983; Radhakrishna, 1984 and Sarkar, 1988). However, the stratiform copper deposit in the Kalyadi Schist Belt is an exception. Unlike the most massive sulphide deposits in Archaean greenstone belts which show a close spatial relationship with volcanic rocks, the Kalyadi Copper Deposit is sediment-hosted, similar to some rare deposits like the Sullivan in Canada. These deposits are commonly referred to as the ``SEDEX" (sedimentary ex-halative) deposits.

Geological Setting and Mineralization in Study Area

The mineralisation in the KSB is dominantly confined to the volcano sedimentary sequence. The copper ore, mainly chalcopyrite is confined to the meta-sedimentary quartzite bed, which extends for about 600m along in N15^{o} to 40^{o}W strike direction with an average width of 30m and shows sinistral type drag folding (Narasimhan and Viswanatha, 1970). This bed constitutes an ideal stratigraphic and lithological guide. The copper- cobalt metal enrichment was also observed in the meta-volcanics, which extends for about 300m along the eastern margin of the quartzite with an average width of 15m. The copper and cobalt content is almost uniform throughout this host rock and thus the meta-volcanic host rocks constitute an important lithological guide for exploration of copper and cobalt. Pink porphyritic granite (also known as Desani granite) extends southward into the Kalyadi Region (Fig. 2). An early phase of the granitic activity in the area is expressed as quartz porphyritic dykes (Viswanatha, 1972). The granitic activity in this area is succeeded by, intrusion in the form of pegmatite and quartz veins.

These rocks are clearly exposed in the underground copper mines and are characterised by admixtures of siliceous and mafic components interpreted as representing cyclic sedimentation (Subba Rao, 1991). As the rock units of the Kalyadi Region are involved in complex (at least three phase) deformation, only a tentative succession for Kalyadi is given (Fig. 3).

The study area has undergone three distinct phases of deformation. The early deformation represent by tight isoclinal folds were involved in second generation of coaxial

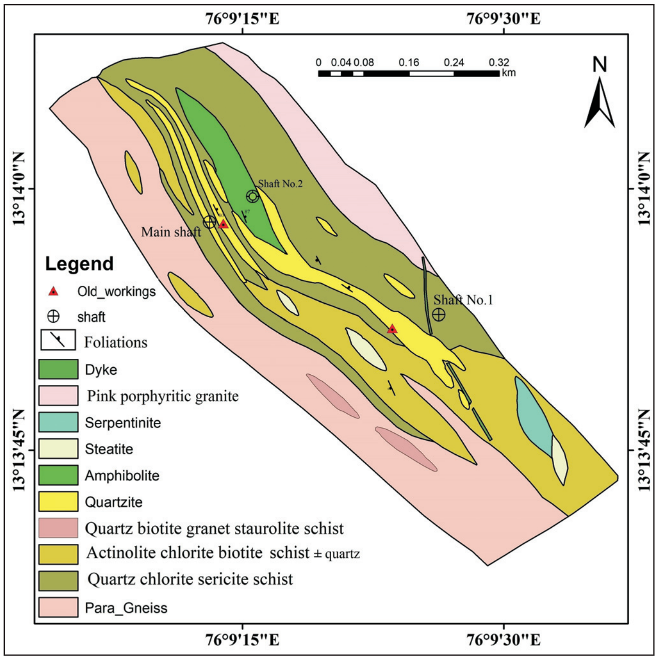

Fig. 2. Detailed Geological Map of Kalyadi Copper Deposit (*Modified after* Ravindra *et al.* 1990)

open folds which represents the D_2 deformations and D_3 deformation represents by warps. The mineralisation is mainly confined to the S_0 depositional planes in quartzite which are related to the volcanic exhalative source. Further, the hydrothermal fluids responsible for the mineralisation owe to the Desani granitic activity which resulted in D_2 deformation. During this granitic activity (Naik, 1984), fractures were developed and these fractures are found filled with mineralised quartz-calcite veins (Fig. 7c).

The surface indications of copper mineralisation along the old workings like encrustation of Malachite and Azurite (Fig. 4a-b) as well as occurrence of visible sulphides in the form of stringers of chalcopyrite and pyrite are observed. The individual lenses of host quartzite have been dissected by three sets of pronounced joints (N40°E / 85°) resulting in rhombohedral blocks especially in the northern section of Kalyadi Ridge (Fig. 4e). The mineralisation occurs in the form of patches, stringers veinlets and disseminated sulphide ores, which comprises mainly of chalcopyrite, pyrite and pyrrhotite. The mineralised zones are bordered by a wide envelope of pervasive alteration zones, manifested by chloritisation, sericitization and saussuritization (Fig. 4d). Incidentally all associated quartzite and quartz-chlorite schists are in the form of short lensoidal beds (Fig. 2), suggestive of volcanogenic origin. Quartzite and quartz chlorite schist shows well developed laminations by chlorite foliations. The width of the mineralised zone varies from 5m to 35m, on the foot wall side. The copper-cobalt hosted quartzite and quartz-chlorite-sericite schist overly garnet staurolite biotite ± quartz schists and quartzo-feldspathic gneisses on the footwall side. On the hanging wall side, the ore formation underlies actinolite-chlorite-biotite ± quartz schists, which have been marginally affected by feldspathisation associated with the Desani-Banavar-Arasikere granitic intrusives.

Available borehole data in Kalyadi Area was used to prepare the borehole cross section (Fig. 5). The rock types recognised in the subsurface consist of mineralised quartzite, grey Quartzite, feldspathised quartzite, quartz-chlorite schist, actinolite-biotite-chlorite-quartz schist, chlorite-sericite-quartz schist,actinolite-biotite-chlorite -calc quartz schist and Gneiss.

The quartzite and basic metavolcanics are the main host rocks for copper and cobalt mineralisations, which were intruded by later thin veins of calcite-quartz and white quartz, near parallel to the strike of the host rocks. Some quartz-calcite veins (Fig. 7c) (with chalcopyrite) are mineralised and others are barren (without chalcopyrite). Sulphides occur in the form of patches, concentrations, stringers and disseminations. The wall rock alteration is not wide spread in the host rocks of the mineralised zones. The

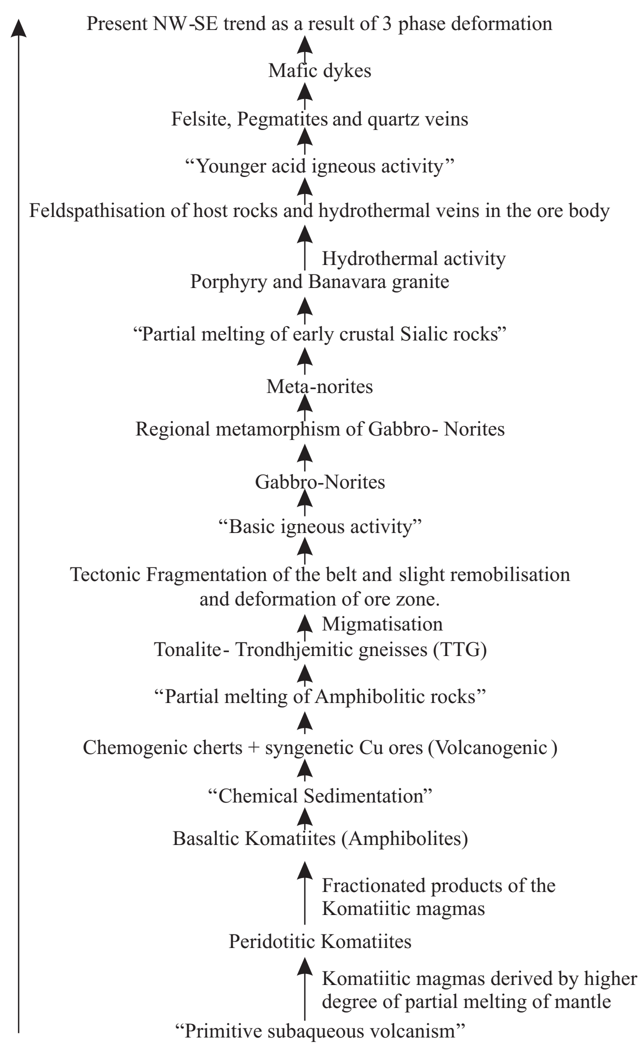

Fig. 3. Stratigraphic succession of Kalyadi area (*After* Naqvi and Rogers 1987)

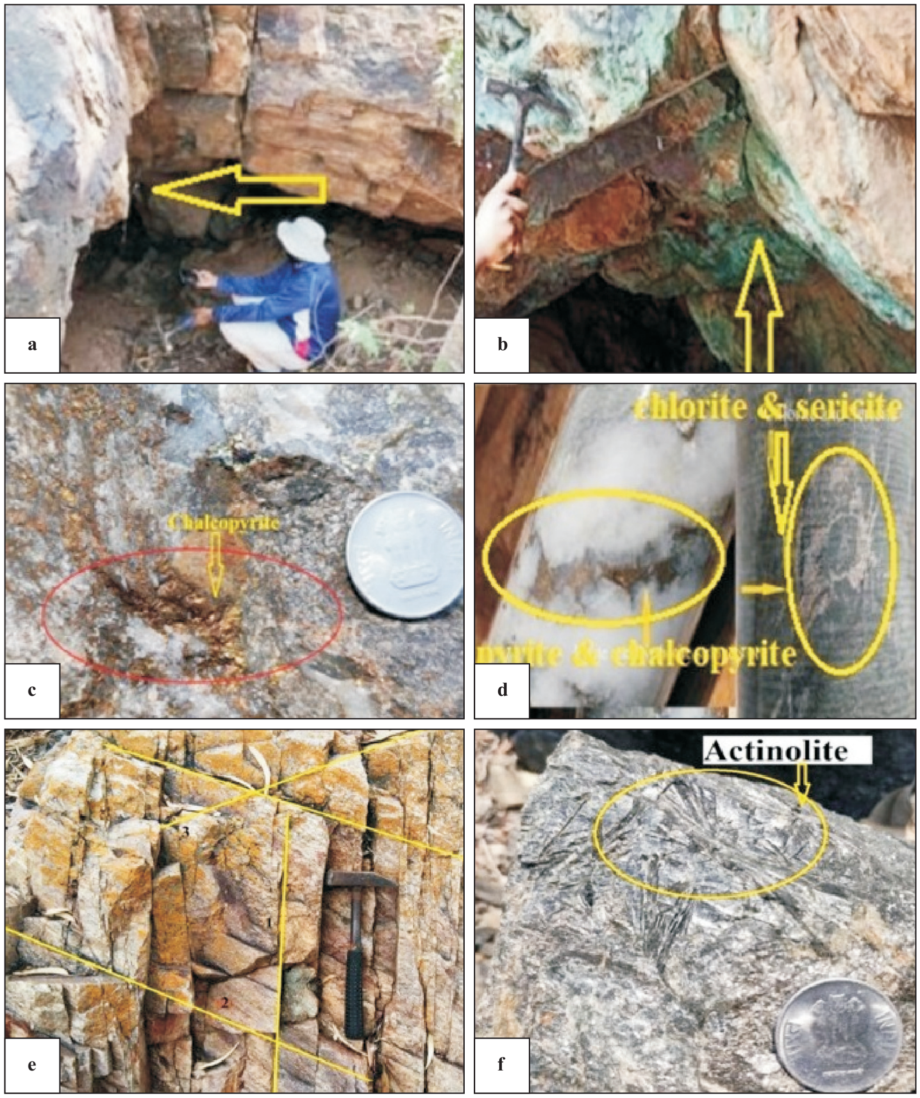

Fig. 4. (a) Old working evidences within the mineralised quartzite bands; (b) Malachite stains in mineralised quartzite bands; (c) Stringers of chalcopyrite in host rock; (d) Drill core shows sulphides (Pyrite and Chalcopyrite) in stringers form and also chlorite and sericite alterations; (e) Quartzite shows three sets of joints; (f) Actinolite-chlorite-quartz schist

quartz-feldspathic veins traversing Quartzite and quartz-chlorite schist (meta-volcanics) are showing sericitic and saussuritic alterations. Chlorite is the common mineral in the zone of alteration (1-3m width); biotite is getting chloritized in the mineralised host rocks (Fig. 7b).

Sub-surface Behaviour of Copper- Cobalt Mineralisation Based on Borehole Cross Sections

In the first two levels (30m, 60m) of underground mine, the dolerite dyke (Fig. 6) is observed along the hanging wall contact of the mineralised quartzite. In the third level (110m), this dyke cuts across the host rock due to steep and shallow dip of the mineralised quartzite from hanging wall to footwall of the quartzite. The mineralisation in quartz- chlorite sericite schist picks up in the middle part of the third level and show almost uniform copper - cobalt concentration. Further, mineralised Quartzite (NNW-SSE trending) decreases in width towards north. The feldspar rich greyish pink coarse grained granite is intersected 30m below the second level in the shaft no.1. It carries occasional clusters of chalcopyrite and specks of pyrite.

Cross sections prepared based on the available borehole core data are presented in Fig. 5, the boreholes have intersected the zone of sulphide mineralisation in host rocks in different depth intervals. The assay values indicate persistence of copper-cobalt mineralisation up to a depth of 200m. The copper-cobalt mineralisation in metavolcanics is almost uniform throughout the ore body, both along the strike and dip directions, where as in the quartzite, the copper content slightly decreases along the dip direction but with increase of cobalt content. Rahim and Nijagunappa (1998, 2001) have attributed copper mineralization to the lithostratigraphic and structural control.

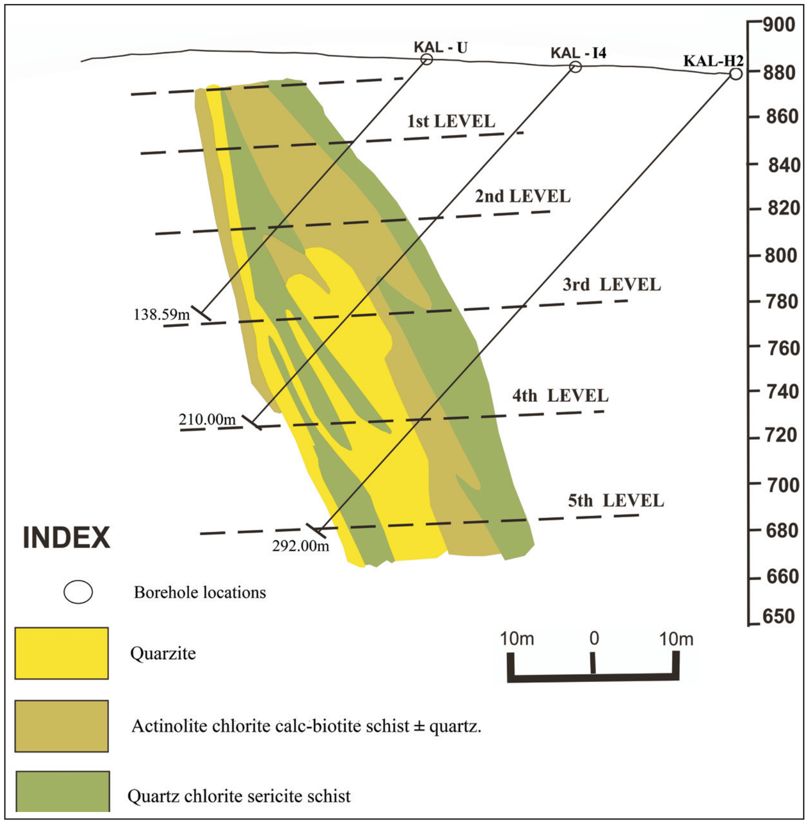

Fig.5. Borehole cross section showing intersections of mineralized host rocks in different levels (*Modified after* Rahim and Nijagunappa, 1998)

Methodology

Rock samples were collected from the surface outcrops of quartzite, quartz-chlorite- actinolite schist and granite. Subsurface samples were collected (Fig. 6) from drill cores and mine dump. Thin sections and polished sections were prepared and petrographic study was carried out using research grade polarising optical microscopes. Twenty four samples (Quartzite, Quartz- chlorite- sericite schist and chlorite actinolite schist) were subjected for Atomic Absorption Spectrometry (AAS), Spectra 220-FS available at Chemical Division, GSI, Bangalore for determination of concentrations of Cu, Co, Ni, Pb and Zn. Precision and accuracy of analysis determination were based on repeated analyses of national and international standards (http://www.gsiportal.gov.in, GSI, SOP- 2010).

Results

Petrography

The area has undergone greenschists facies of metamorphism is accompanied by the development of schistosity (S_1) in quartz- chlorite schist (Fig. 7b). The quartzite shows fine grained nature and exhibits granoblastic texture at places (Fig. 7a). Laminations and bedding were also observed. Meta-volcanic rocks contain quartz-chlorite-biotite, plagioclase association with well-developed schistosity defined by mafic minerals.The petrographic studies of the ore samples indicate the presence of magnetite, chalcopyrite, pyrite, arsenopyrite, pyrrhotite and sphalerite. Disseminations, stringers and fracture filling sulphides are prominent in both the rocks. Sulphides are also associated with calcite-quartz veins as late fracture filling. Textural relationship between ore to ore and gangue minerals in the host rock indicates multistage mineralization in the area (Fig. 8). Magnetite is the earliest phase present, showing typical idiomorphic texture. The magnetite is being replaced by later sulphides such as both chalcopyrite and pyrite (Fig. 7f).

There are at least two generations of the chalcopyrite, in which the first generation chalcopyrite is being replaced by pyrite, which in turn is replaced by the (Fig. 7d) second generation chalcopyrite. The second generation chalcopyrite is seen associated with pyrrhotite and both show mutual or common boundary texture, (Fig. 7e) indicating their coeval nature. Euhedral pyrites shows fractures filled with secondary chalcopyrite. The fractured pyrites generally show resorbed margins due to laterchalcopyrite replacement (Fig.7d). Arsenopyrite is generally euhedral to subhedral being replaced by chalcopyrite at places (Fig.7h). Arsenopyrite and pyrite are not seen associated together, but may be derived from the same event owing to their replacement texture with late chalcopyrite.

Earlier studies have shown the presence of Co in association with pyrite (Krishna Rao, 1998), which is seen in

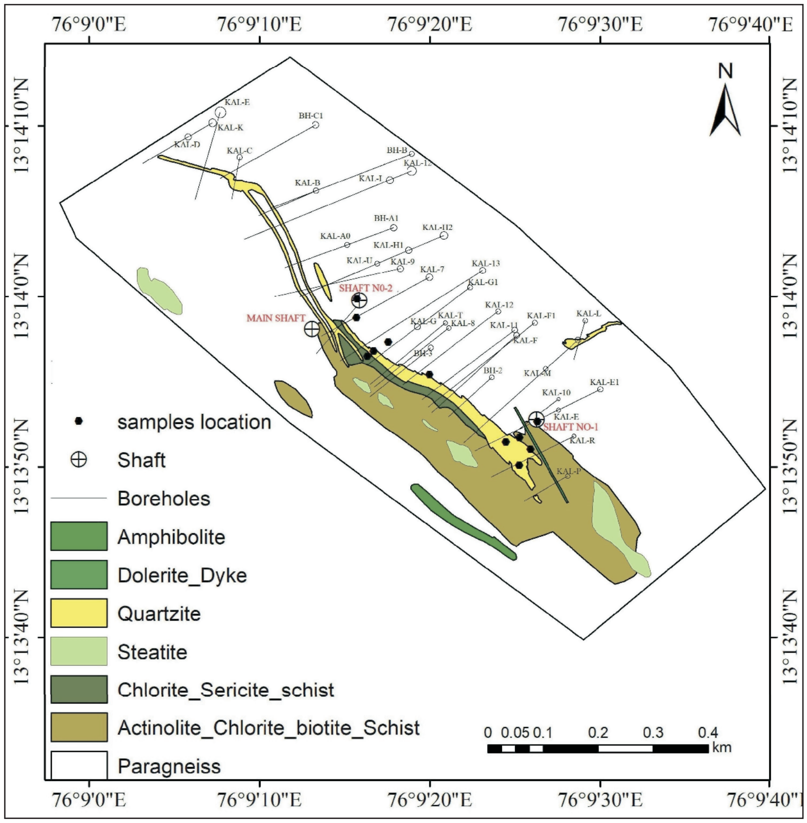

Fig. 6. Map showing sub surface disposition of mineralized host rocks in Kalyadi miner as inferred from the borehole data and samples location were also shown on Map (*Modified after* Rahim and Nijagunappa, 1998)

the both phases of mineralization. Stringers of chalcopyrite are present in the calcite-quartz veins and they represent the second phase. The chalcopyrite at places replaces pyrite. The Cobalt concentration is also associated with them. There are no separate cobalt phases observed.

Geochemistry

The results of the chemical analyses are presented in Table 1 and 2. In order to study the chemical changes in the ore body and its wall rock and for petro-genetic interpretations, representative samples were collected from the different levels of the underground mine and analysed for major and trace element.The trace element geochemistry of the quartzite indicates siliceous chemical precipitates derived from a volcanogenic source (Subba Rao and Naqvi, 1997).The quartzites are inter layered with ultramafic-mafic schists, which contains significant amount of Cu, Ni and Co. Except for the alkalies, the chemistry of the ultra- mafic schists and amphibolites has not been significantly changed due to post-magmatic alteration, deformation and metamorphism.

The concentrations of Co, in quartzites band varies from 160 to 2000ppm. The cobalt mineralisation enrichment in quartzite, changes with respect to depth from surface *i.e.* first level (250ppm) to third level (680ppm). When plotted on Co/Cu diagram (Fig. 9a), there is negative correlation between cobalt and copper. The cobalt content in meta-vocanics shows variation from 110 to 1200ppm, when plotted on Co/Cu, Co/Ni and Co/Cr diagram (Fig. 9c-d), negative correlation is observed with Ni and Cr, whereas Cu shows positive correlation (Fig. 9b). The concentration of Cobalt in host rocks changes variably from shallow level (within 30m depth) cobalt content is about 200ppm whereas at 2^{nd} level (60m depth) it shows rich concentration about 1200ppm but slightly decrease in 3^{rd} level (110m depth) and shows about 420ppm. The cobalt concentrations in quartzo-feldspathic veins and granitic intrusionsvary from 110ppm to 500ppm.Shows negative correlations with Cu and Ni. Cobalt content increases with depth in intrusives from 1^{st} level 200ppm to the 3^{rd} level with 500ppm.

Discussion

In the Kalyadi Copper Belt, the host of the copper-cobalt mineralisation are meta-sedimentary and meta-volcanic suite of rocks. Field and petrographic evidences indicate remobilization of mineralization. The earliest phase of mineralization is derived as part of volcanogenic exhalative, which got mobilized due to later deformation and hydrothermal activity resulting in fracture filling sulphides in the host rock. The rock chemistry of the quartzite has indicated siliceous chemical precipitates derived from the volcanogenic

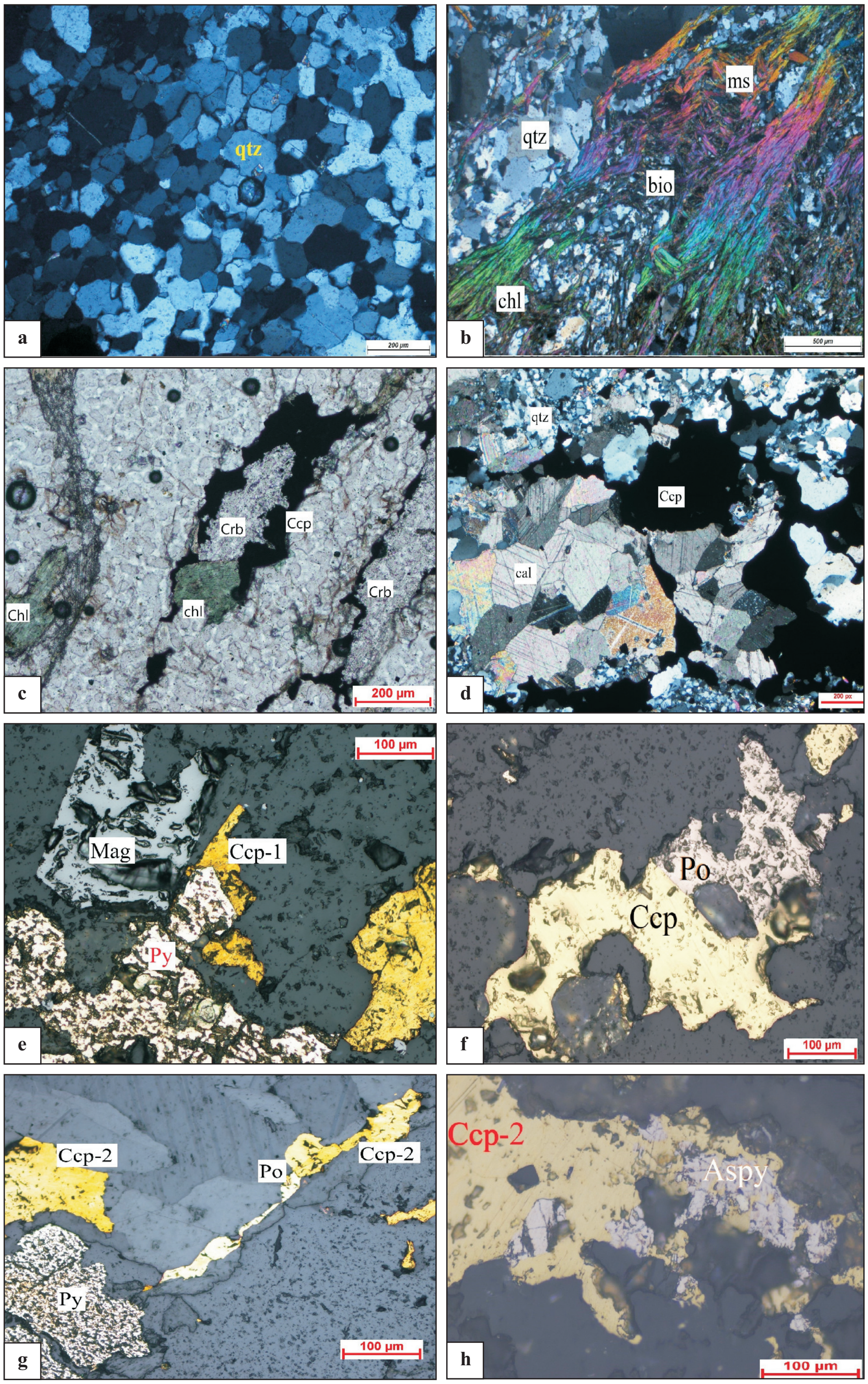

Fig. 7. Photomicrography of hosts rocks and ores (a) Quartzite showing granoblastic texture (b) Quartz-chlorite-biotite schist showing shearing evidences defined by S-C fabrics; (c) Carbonate veins carries sulphides; (d) Calc- quartz vein carries secondary chalcopyrite: (e) Magnetite replacing by chalcopyrite and chalcopyrite replacing by pyrite; (f) Chalcopyrite (Xenomorphic texture) and Pyrrhotite showing mutual boundary texture; (g) Pyrrhotite and chalcopyrite showing fracture filling nature; (h) Chalcopyrite and Arsenopyrite association

source further supporting the exhalative evidences for mineralization. Sarkar (1988) in his review of genesis and evolution of ore deposits of peninsular India suggested a volcanic origin for the copper mineralisation in the Kalyadi. Ravindra *et al.* (1990) considered a volcanic exhalative source for copper genesis.

Copper and Cobalt mineralization is closely associated with each other in the study area. Pyrite and the second generation chalcopyrite provide the bulk of Co. The subsurface chemical studies have indicated the decrease of copper content with increase of cobalt with depth.Cobalt is invariably associated with pyrite, which are conspicuous in the

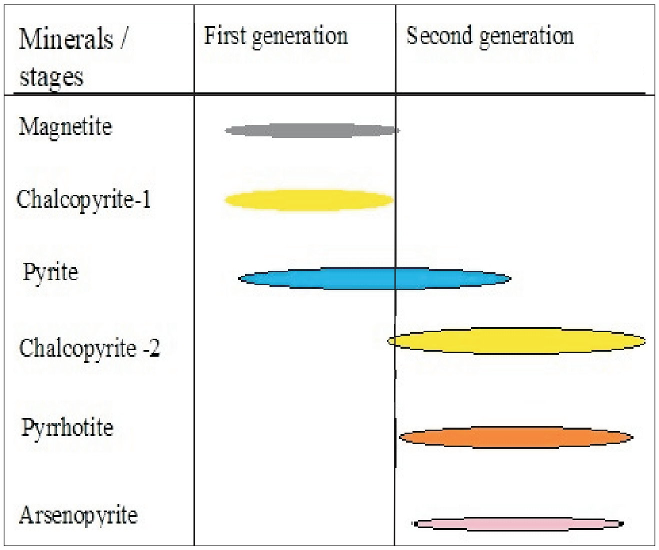

Fig.8. Ore mineral Paragenesis sequences

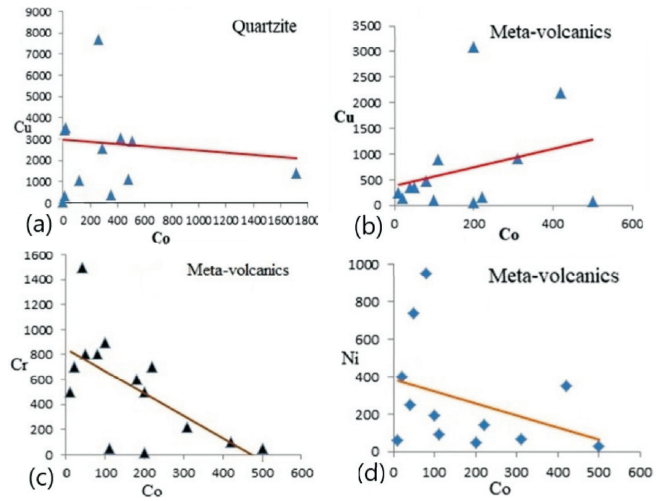

Fig.9. Correlation plots for Trace elements from host rocks of Kalyadi Copper mines area. (a & b). Cu vs. Co in quartzite; (b). Cu vs. Co (c) Cr vs. Co; and (d). Ni vs. Co in Meta-volcanics

Table1: Chemical analysis of representative samples of Quartzite from Kalyadi Copper Mine (in different mining levels) (Trace elements in ppm).

Level	1st level				2nd level			3rd Level			
Sample No.	KL-12	KL-15	KL-16	KL-18	KL- 4	KL-05	KL-09	KL- 24	KL- 25	KL- 26	KL- 28
Type	Quartzite										
Cu	3100	435	5700	1700	3600	300	1500	1800	210	1010	370
Pb	10	10	30	10	20	10	10	20	20	40	20
Zn	20	15	15	15	300	300	300	115	20	20	15
Ni	60	60	100	60	30	20	80	80	160	120	110
Co	90	110	280	260	140	300	400	160	2000	220	50
Cr	40	20	60	40	160	400	250	120	400	600	10
Mo	5	5	5	5	5	10	10	5	15	5	10
Sn	10	10	10	10	10	10	10	10	15	10	10
W	30	30	30	30	30	30	30	30	30	30	30
Zr	50	30	30	30	60	50	30	30	30	30	230
Ag	1	1	2	2	1	1	1	1	1	1	1

Table 2: Chemical analysis of representative samples of Meta-volcanics and intrusives from Kalyadi Copper Mine (Trace elements in ppm)

Level	1st level				2nd level			3rd level		1st	2nd	3rd
Sample No.	KL- 11	KL- 13	KL- 17	KL- 19	KL- 07	KL- 10	KL-21	KL-23	KL-27	KL-30	KL-14	KL-8	KL-29
Type	Greenschists										Intrusives		
Cu	3100	2100	475	1000	60	800	355	100	170	2200	910	80	900
Pb	40	10	20	20	10	10	20	20	20	60	10	10	30
Zn	80	40	25	15	300	300	20	15	20	40	15	300	25
Ni	370	60	190	180	50	20	250	190	140	350	70	30	90
Co	200	10	400	100	220	580	40	100	220	420	310	500	110
Cr	500	20	600	500	1500	220	800	700	50	800	30	60	30
Mo	5	5	5	5	5	40	5	5	5	10	5	5	5
Sn	10	10	10	10	10	10	10	10	10	10	10	10	10
W	30	30	30	30	30	30	30	30	30	30	30	30	30
Zr	30	600	30	30	80	30	30	30	100	30	50	60	80
Ag	2	1	1	1	1	1	1	1	1	2	1	1	1

host rocks and formed as disseminations by filling of pores. The other forms like patches and stringers have been formed by deformational events, local remobilisation, migration and enrichment might have been taken place due to the heat source by igneous activity from Desani granites.

Conclusions

Copper –cobalt mineralisation in the Archean Greenstone Belts is essentially a result of geological changes and mineral transformations which occur during the geological events like tectonic activity, metamorphism, igneous activity and hydrothermal processes. Based on field and laboratory studies, it can be concluded that the copper associated cobalt mineralizationin the study area is controlled by structurally weak zones and lithology. Further, the hydrothermal fluids responsible for the mineralisation owe to the Desani granitic activity which resulted in D2 deformation.

The strategic importance of cobalt minerals and its impact in nation development and the progress has encouraged the country to embark on several ambitious projects to identify and develop the copper cobalt deposits. Search for cobalt is never ending process and it is widely used metal because of its highly industrial usage. India has been facing shortage of cobalt; this led to intensive efforts in exploration activities to find new deposits.

Authors' Contributions

Mahantesha P: Investigation, Conceptualization, Methodology, Software, Writing - Original Draft. K. N. Prakash Narasimha: Supervision, Editing. Md. Shareef: Visualization, Writing - Reviewing and Editing. G. Gopala Krishna: Formal Analysis. T.K.A. Rahim: Reviewing and Editing.

Acknowledgments

Authors expresses sincere gratitude to Prof. P. Madesh, chairman of the Department of Earth Science and Prof. K. G. Ashamanjari, Chairman, Board of Studies in Earth Science, University of Mysore, Mysore for the constant support and encouragement during the studies. Authors profusely thank to the Deputy Director General, and officers of Chemical Division, GSI, Bangalore for providing analytical facilities. Authors also express sincere thanks to the anonymous reviewers and the Editor of the JGSR.

References

Cailteux, J. L. H., Kampunzu, A. B., Lerouge, C., Kaputo, A. K. and Milesi, J.P. (2005). Genesis of sediment-hostedstratiform copper-cobalt deposits, central African copper belt: in Jour. Afric. Earth Sci., v. 42, pp. 134-158.

Krishna Rao, N. (1998). Strategy for the benefeciation of ores of some strategic metals in India. Metal. Mater. Process., v.10(1), pp. 21-40.

Mookherjee, A. and Philip, R. (1979). Distribution of copper, cobalt and nickel in ores and host rocks, Ingaldhal, Karnataka, India. Miner. Deposit., v. 14, pp. 33-55.

Naik, M. S. (1984). Granite magmatism and copper mineralisation at Kalyadi, Hassan district, Karnataka. Proc. Sym. Metallog. Precamb., IGCP Prog. 91. Geol. Surv. India, v. 22, pp. 153-166.

Naqvi, S.M. and Rogers, J.J.W. (1987). Precambrian Geology of India. Oxford Univ Press, Oxford.

Narasimhan, M. and Viswanatha, M.N. (1970). Detailed investigation for copper ore in Kalyadi area, Hassan district, Mysore state. Geol. Surv. India. Unpublished report, pp. 9-12.

Pal, D.C., Abu Saeed Baidya and Sen, Atlanta (2016). Textures and compositions of cobalt pentlandite and cobaltianmackinawite from the Madan-Kudan copper deposit, Khetri Copper Belt, Rajasthan, India. Jour. Earth Syst. Sci., v. 127, pp. 56

Paremeswaraiah, K.S. (1996). Cobalt- a new economic metal in the mineral map of India. Proc. All India Sem. 'Minerals in the Economy of India", the Institution of Engineers (India), Karnataka State Center, Mining Engineering Division, Bangalore.

Radhakrishnan, B.P. (1984). Crustal evolution and metallogeny: evidence from the Indian Shield, a review. Jour. Geol. Soc. India, v. 25, pp. 617-640.

Rahim, T.K.A. and Nijagunappa, R. (1998). Geochemistry and Genesis of Copper Mineralisation at Kalyadi, Arsikere Taluk, Hassan District, Karnataka State, India. Mineral. Deposit., v. 42, 230p.

Rahim, T.K.A. and Nijagunappa, R. (2001). Mineragraphy of sulphide mineralisation in kalyadi copper mine~ Hassan district, Karnataka. Mineral. Deposit., v. 32, 220p.

Rao, B. and Venkataraman, S. (1982). Geochemistry and genesis of Archean meta-volcanic rocks from a part of the Nuggihalli schist belt, Hassan district, Karnataka, India. Brasil. Geosci., v. 12(1-3), pp. 375-379.

Ravindra, B.M., Krishna Rao, B.,Vasudev, V.N. (1990). Ore-petrological aspects of copper mineralisation near Kalyadi, Hassan district, Karnataka. Jour. Geol. Soc. India, v. 35, pp.159-172.

Sarkar, S.C. (1982). Uranium (-Nickel-cobalt-Molybdenum) Mineralisation along the Singhbhum Copper belt, india, and the problem of Ore Genesis. Miner. Deposit., v. 17, pp. 257-278.

Sarkar, S.C. (1988). Genesis and evolution of the ore deposits in the early Precambrian greenstone belts and adjacent high grade metamorphic terrains of peninsular India ± a study in similarity and contrast. Precamb. Res., v. 39, pp. 107-130.

Subba Rao, D.V. (1991). Geology and geochemistry of the Kalyadi schist belt with special reference to basemetal mineralisation in Hassan

(Dt), Karnataka, India. [PhD thesis] Osmania University, Hyderabad.

Subba Rao, D. V. and Naqvi, S.M. (1997). Geological setting, mineralogy, geochemistry and genesis of the Middle Archaean Kalyadi copper deposit, western Dharwar Craton, southern India. Mineral. Deposit., v. 32, pp. 230-242.

Unpublished Report of FS (2019-2020). Preliminary exploration for Komatiite- hosted Ni-PGE-Au mineralisation in the mafic-ultramafic rocks around Banasandra, Tumkur district, Karnataka, FS 2019-20, GSI, SU: Karnataka and Goa, Bangalore.

Vasudev, V.N. (1983). Geological evolution of Archaean and early Proterozoic sulphide deposits of the Dharwar Craton, India. In: Precambrian of South India, Naqvi, S.M. and Rogers, J.J.W. (Eds.). Geol. Soc. India Mem. 4, Bangalore.

Viswanatha, M.N. (1972). Corundum-pegmatite and Corundum-sillimanite-pegmatite from kalyadi area, Hassan district, Mysore state. Indian Miner., v. 26, pp. 20-23.

(Received: 30 March 2021; Revised Form Accepted: 12 June 2021)