Journal of Mines, Metals and Fuels, *72(8): 783-791; 2024. DOI: 10.18311/jmmf/2024/44558*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Gold Mineralisation and their Lithological Controls at Nagavi Area, Gadag Schist Belt, in Karnataka, India

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Abstract

Dharwar craton is located in southern India is part of the Dharwar-Singhbhum proto-continent and is known for its complex tectonic and structural controls. It's made up of two distinct parts, Western Dharwar Craton (WDC) and the Eastern Dharwar Craton (EDC) house several schist belts. Many of these schist belts, such as the Kolar schist belt, Hutti schist belt, Chitradurga schist belt and the Gadag schist belt, are auriferous. In such schist belts, gold occurs in association with sulphides such as pyrite, pyrrhotite, arsenopyrite and chalcopyrite. Gold mineralization in these belts is found to occur in different lithologies. The Gadag schist belt is composed dominantly of metabasalt in its western half and meta sediments in the eastern half. Quartz-carbonate veins are observed to cut across these lithologies as well as the Banded Iron Formations (BIFs). This paper aimed to study the gold mineralization in different lithologies of the Gadag schist belt and found that metabasalts and BIFs are the dominant rocks hosting gold. It is also observed that mineralization is strata-bound. Most of the places' auriferous sheared zones were observed in the study area. In Nagavi area, BIF hosted gold mineralization is observed, and major gold concentration varies from <21 to <26 ppb (parts per billion). Pyrite occurs as characteristic cubic crystals and as clusters of small grains. In carbonated sheared anorthosite, the rock is fine to medium-grained and in-equigranular. It consists of simple to polysynthetically twinned subhedral (100-200 by 400-600 µm) laths (~40-45%) set in a groundmass of irregular anhedral grains of secondary carbonate (~35-40%), chlorite (~8-10%), opaque (~5-7%) and accessory epidote and quartz.

Keywords: *Gadag Schist Belt, Geological Structures, Gold Mineralization, Lithological control, Nagavi Area*

1.0 Introduction

In India, Dharwar Craton hosts many of the country's mineral resources, including the famous Hutti, Kolar, Gadag goldfields etc. The Dharwar Craton is divided into two blocks viz. Western Dharwar Craton (WDC) and Eastern Dharwar Craton (EDC) which are based on the abundance and nature of the greenstone belts and the age of the gneissic basement rocks (Hammond)[1]. These two Cratons are considered to have different evolutionary histories and metallogenic characteristics (Puranik)[2]. Gadag gold field is very well familiar in India and in rest of the world from ancient mining companies. In Nagavi, lithological controls of gold mineralization have gained more prominence (Ugarkar, *et al*)[3]. Geological Survey of India has done exploration work for Gold and associated mineral-bearing tracts and sulfide mineralization (Ram Mohan, *et al*)[4]. A detailed study has been conducted in Nagavi area especially on petrology and mineralogy and it is showing good results as it concerned with gold values of rock samples. At places auriferous sheared quartz veins were observed in Nagavi area.

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1.1 Location and Accessibility

The study area of Nagavi is located in the northern part of the Gadag gold field and about 5 to 6 km distance from Gadag city. Total study area is about 13 sq km and latitudes from 15^0 20' 25.14" to 15^0 24' 9.65" E and longitudes will be 75^0 35' 21.15" to 75^0 38' 13.20" and toposheet 48M/11 of 1:50,000 scale. The Nagavi area relates to railways and road connectivity (Figure 1).

2.0 Objectives

The following are the main objectives:

1. Detailed geological mapping of the study area,
2. To study the various lithounits through geochemistry to understand the gold mineralization,
3. To study the different geological structures to identify the auriferous shear zones, and
4. To study rock-chip samples through petrological microscope to understand gold mineralization

2.1 Scope

There is limited work that has been conducted particularly on gold mineralization in Nagavi area. Geochemistry and petrology play a vital role in identifying the auriferous sheared zones. Therefore, there is an urgent need for detailed research in the Nagavi area.

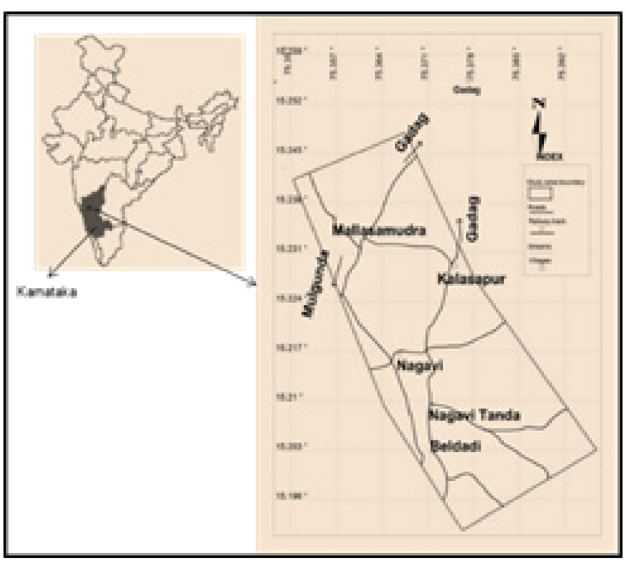

Figure 1. Location map of Nagavi area.

2.1.1 Geology of Nagavi Area

The gold and other associated mineralisation is observed on top of the hill (reef). BIF is dominantly associated with gold mineralization at the top of the hilly area. The gold mineralization is localized in the reef at the top of the hill of Nagavi area, which is well defined by the BIFs prominently forming the ridges (Agasnalli, *et al*)[5] (Figure 2). The alternating silica and iron-rich layers in Banded Iron Formations (Agasnalli *et al*[6], and Agasnalli *et al*)[7]. These different layers are observed in the field from millimeter scale to meter scale bands. The Gadag schist belt consists of a 2000 m thick pile of meta-volcanic and meta-sediments (Chakrabarti *et al* and Chakrabarti *et al*)[8,9] and a banded iron formation (Radhakrishna *et al*[10]). The structural disposition of the belt is the result of an overall E-W compressional regime with uplift and diaperism of the sialic basement within which the N-S trending Archaean shear systems have caused buckling and refolding of earlier fold belts, making all the linear elements parallel to the direction of shear (Figure 3).

In addition to that the craton contains several Archean greenstone belts, including the well-known Kolar Schist Belt, Hungund-Kushtagi schist belt, Sandur schist belt, Gadag Schist Belt, Chitradurga schist belt and Dharwar-Shimoga schist belt. The development of Gadag schist belt in the 1990s has assisted in greater understanding

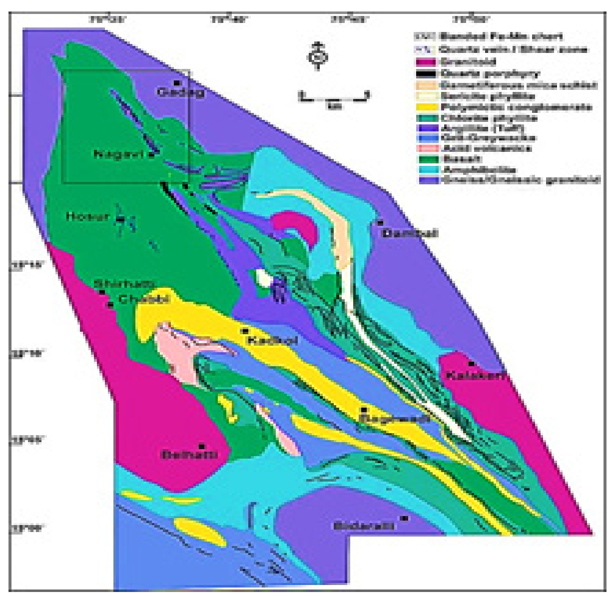

Figure 2. Geological map of Gadag Schist Belt (Source: GSI, Gold ores in India, 1994).

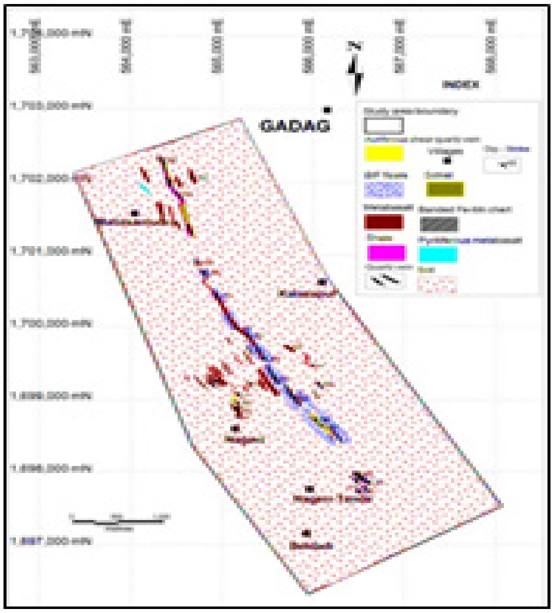

Figure 3. . Geological map of Nagavi study area (Chandrashekharappa Agasnalli, 2014).

of the Geology and gold mineralisation. It is composed dominantly metabasalt in western half of the belt and sediments in Easter half (Chadwick *et al*)[11].

3.0 Methodology

3.1 Field Techniques

Detailed geological mapping has been conducted in different traversing intervals across the regional strike of the area. The general trend of litho-units in the study area is NW to SE and dipping towards NE. Geological mapping of the area has been carried out by traversing (200 m interval) in field across regional strike of the area along with a Global Positioning System (GPS) (GPS its Garmin made map 62S model with 3 to 4m accuracy and compass). Noted down all the litho-units and rock exposure, the litho-contacts, rock exposure, sampling rock exposure trends (dip and strike), sheared quartz zones and the sulfide zones and descriptions are recorded during the geological traverses.

During field visits the secondary structures are observed like folds, faults, sheared zones and thrust zones which are induced by directional stresses. The bedding represents the presence of beds well separated from their adjacent litho-units on either side. The auriferous lodes occur mainly in the vicinity of stratigraphic contacts of schistose and sheared fault zones (Agasnalli, *et al*)[12]. It clearly indicates that the fold and faults are formed due to high pressure and supports for fluid movement. The ripple marks are wave shaped structures formed by fluid movement over sediments and are non-deformational modifications.

3.2 Rock Chip Sampling

During the field visit rock outcrop samples of auriferous quartz vein were collected from different locations. It is sealed and packed properly and sent to GSI Lab Bangalore for petrographic studies.

3.3 Quality Control During Sampling and in Laboratory

In the field we collected samples at fresh face of rocky area to avoid contamination for sampling. During geological traversing in the field, we carefully observed the litho-contacts and noted down it systematically. Systematic samples preparation has been done in the laboratory to avoid contamination.

3.4 Rock-Chip Sample Analysis for Gold Mineralization

The rock samples tests are performed in GSI Lab Bangalore under the Carl Zeiss/Nikon binocular petrological microscope. The rock chip samples have been collected from sheared quartz veins, trial pits and analysed with Graphite Tube Atomizer (GTA) and Atomic Absorption Spectroscopy (AAS) method.

4.0 Petrography and Mineralogy

4.1 Banded Magnetite/Hematite Chert/Quartzite

Nagavi study area consists of banded iron formations, meta basalt, schist, auriferous shear quartz veins, shale and carbonated sheared anorthosite. The boundary between the ferruginous and siliceous layers is very thin and even on a microscopic scale. The alternate bands of hematite, magnetite, and chert are identified. The banded magnetite/hematite chert/quartzite exposure (Sample No. NNB 1) (Figure 4). Under megascopic examination,

Figure 4. Metabasalt associated with BHQ bands and quartz veins.

Figure 5. Quartz vein within BIF

it is compact and greyish brown color. The quartz-rich bands are highly recrystallized, equigranularity (~100 **µm**) with triple-point junctions (Figure 4). This quartz vein is intruded within BIF formation and appears grey, indicating the Au mineralization (Agasnalli *et al*)[12] as shown in Figure 5.

4.2 Meta-basalt

These metabasalt exposures are trending NW-SE direction N 50^0-55^0 W to S 50^0-55^0E and dipping towards NE direction (N45^0 to 50^0 E). At some places, fine-grained quartz veins are cutting across the meta-basalt (Naqvi *et al*)[13]. The appearance of chlorite in the meta-

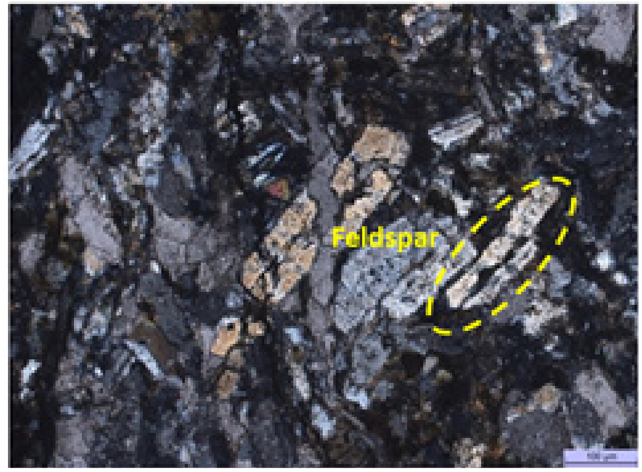

Figure 6. Photomicrograph showing feldspar porphyroblasts and recrystallized feldspar and quartz (under plane polarized).

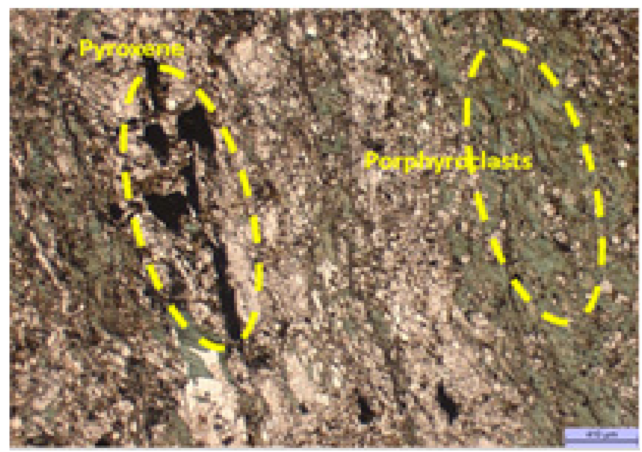

Figure 7. Photomicrograph showing feldspar porphyroblasts, chlorite, and pyroxene (under plane polarized).

basalts and sericite in the greywackes/argillites implies the regional grade of metamorphism or the greenschist facies metamorphism. The sheared carbonated meta basalt rock exposure (Sample No. NNB 13) near Mallasamudra has been examined under megascopic study and it is compact, weathered, greenish-grey colored, fine to medium-grained, and equigranular. Under the microscope, it consists of medium-sized subhedral grains twinned to un-twinned plagioclase (~40%), anhedral carbonate (~40%), and actinolite mainly altered to chlorite (~17%) with minor opaque (~3-5 %). Carbonate appears to be after pyroxene. Carbonate also occupies fracture in plagioclase and rarely forms bands parallel to tectonic foliation (Groves)[14]. The rock is sheared with the development of feldspar porphyroblasts and recrystallized feldspar and quartz as shown in Figure 6 and Figure 7.

4.3 Carbonated Sheared Anorthosite

In Microscopic study of the rock samples especially in polished thin section, quartz veins samples show sheared anorthosite and sulfides assembles of pyrite and arsenopyrite (Figure 8 and Figure 9) and thin showing mutual boundary.

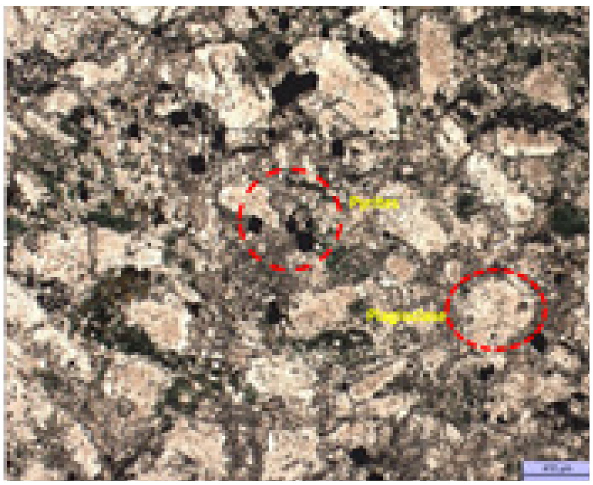

Figure 8. Photomicrograph exhibiting Plagioclase with Pyrites (under plane polarized)

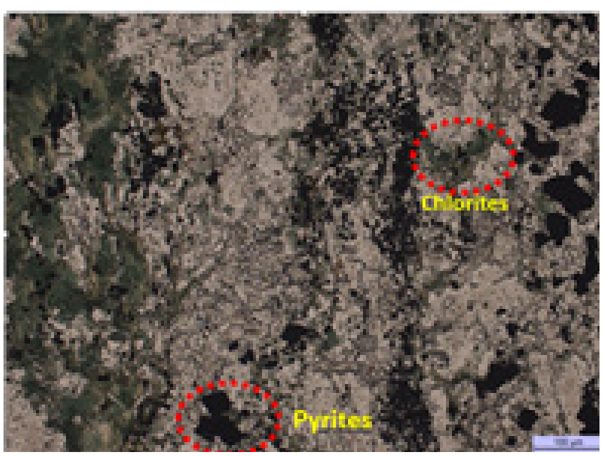

Figure 9. Photomicrograph showing chlorite and opaque pyrite crystals (under plane polarized)

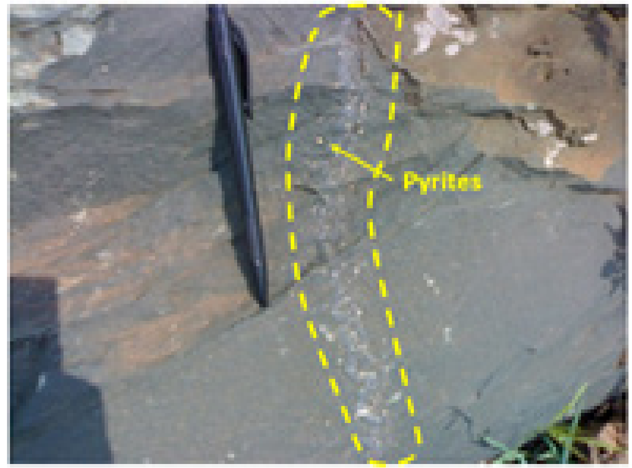

Figure 10. Photograph showing fine-grained meta basalt with disseminated pyrites.

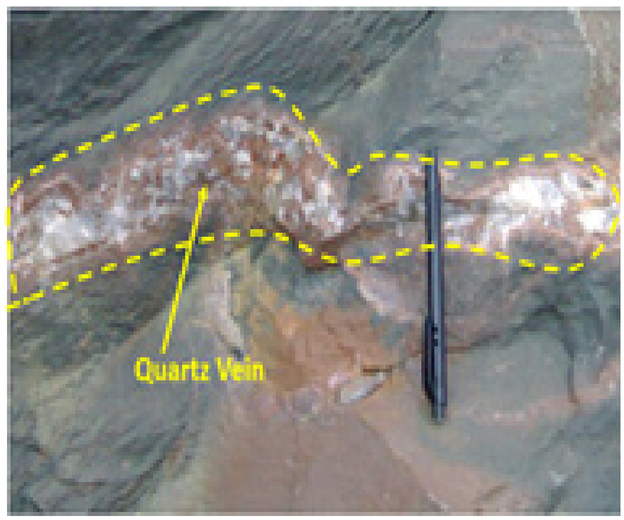

Figure 11. Photograph showing quartz vein within meta basalt (Photo facing East-West direction).

The carbonated sheared anorthosite rock exposure near Mallasamudra and the same rock sample (sample number NNB - 10) has been collected and studied properties. The rock is fine to medium-grained and in-equigranular. It consists of simple to polysynthetically twinned subhedral (100-200 by 400-600 μm) laths (~40-45 %) set in a groundmass of irregular anhedral grains of secondary carbonate (~35-40 %), chlorite (~8-10 %), opaque (~5-7 %) and accessory epidote and quartz. Opaque mainly occurs as euhedral to subhedral, square to rhombus shaped 100 by 100 to 150 by 250 μm randomly distributed discrete grains. Tectonic foliation is defined by the presence of recrystallized feldspar, bent plagioclase lamellae, and tapering deformation twins in plagioclase as shown in Figure 8 to Figure 11. Pyrite occurs as characteristic cubic crystals and as clusters of small grains. Coarse grains are also reported by Bhaskar Rao *et al*[15].

5.0 Rock Samples Analysis Results

The various types of auriferous sheared gold mineralization are observed in the study area. There are 3 different genetic models namely Syngenetic, Epigenetic, and hybrid of both the epigenetic and syngenetic for its gold mineralization (Fripp, Phillips)[16,17].

Four samples were collected and analyzed from different locations in the study area for Au by GTA - AAS method (Table 1). NNB -1sample were collected from top of the hill where quartz vein intruded into the BIF and gold analytical results showing <22 ppb. Sample NNB 10 was collected near Mallasamudra village Carbonated Sheared Anorthosite (Pyrite grains) and gold analytical results showing <26 ppb. BIF hosted gold mineralization forms an integral part of many Archean greenstone belts in countries such as Australia (Vielreicher, *et al*)[18], Canada (Lhotkaand and Nebitt)[19], South Africa (Pretorius, *et al*)[20]. These results show positive signature for further exploration in the Nagavi area.

If pure gold particles are present, they show a bright yellow color and typical greenish tint under crossed Nicols. Au-rich arsenopyrite crystallizes at 200 to 2500 C, and Au-poor arsenopyrite crystallizes between 2500 C and 5000 C (Cathelineau, *et al*)[21]. The earliest ore mineral to form is pyrrhotite, a simple iron-sulfide (FeS) (Figure 10 and 11).

6.0 Nagavi Structures

Geological structures play a vital role for gold mineralization in the Nagavi area. The fold pattern can be observed in the photomicrograph and field outcrop. The contacts between chert bands and quartz veins and chilled thin quartz veins across chert bands are observed. The banded magnetite/hematite chert/quartzite exposure is observed between Gadag – Haveri main road (Saager, *et al*)[22]. The rock formation consists of compact, fine-grained, greyish-brown colored, and equigranular (Brown[23]). These bands are mostly bounding, and one band shows intra-folial folds and sheared/fractured milky quartz veins intruded within BIF Minor faults across and the strike of the formation (Figure 12 and Figure 15).

Table 1. Details of rock chip samples analysis.

S. No.	Sample No.	*Au by GTA – AAS (in ppb)	Rock type	Sample location
1.	NNB -1	<22	Banded magnetite / hematite quartzite	Near Nagavi village on top of the hill and about 4km from Gadag city towards SW)
2.	NNB - 10	<26	Carbonated Sheared Anorthosite (Pyrite grains)	Near Mallasamudra village and 3km from Gadag city.
3.	NNB - 11	<21	Banded magnetite/ hematite / quartzite	Near Nagavi village, about 4.5 km from Gadag city, towards SW on top of the hill.
4.	NNB - 13	<20	Sheared carbonated Metabasalt	Near Mallasamudra village and about 2.3km from Gadag city towards SW at on top of the hill

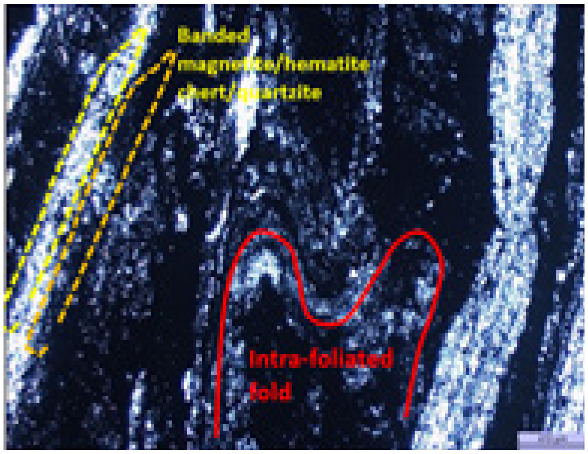

Figure 12. Photomicrograph exhibiting Banded magnetite/hematite chert/quartzite exhibiting intrafolial fold (under plane polarized).

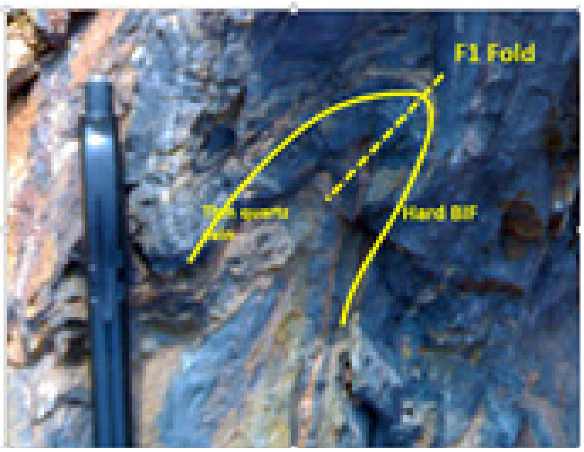

Figure 13. Photograph showing outcrop of folded banded magnetite/hematite chert/quartzite.

The greyish white quartz vein with an associated wall-rock of predominantly BIF and sericitic nature may indicate a somewhat more meso-thermal type of mineralisation than a deep-seated, high temperature, hypo-thermal type such as those of Kolar and Hutti (Beeraiah, *et al*)[24] and (Phillips, *et al*)[17] versus syngenetic origin (Fripp)[16].

7.0 Ore Localization in Nagavi Area

The auriferous shear zones especially ferruginous quartz with interpreted as Banded Iron Formations. In the study area the auriferous sheared zones and quartz veins crosscut

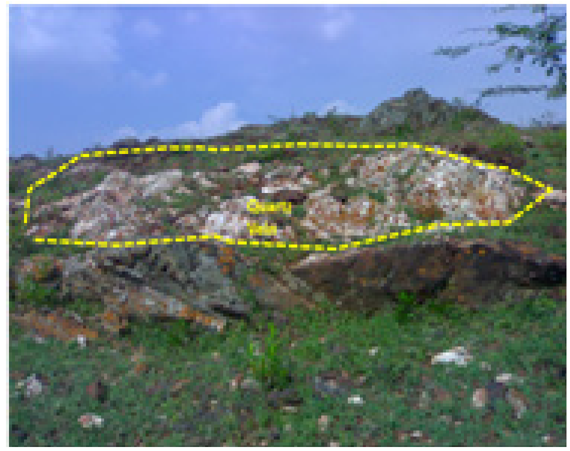

Figure 14. Sheared/fractured milky quartz veins intruded within BIF (photo facing NW direction).

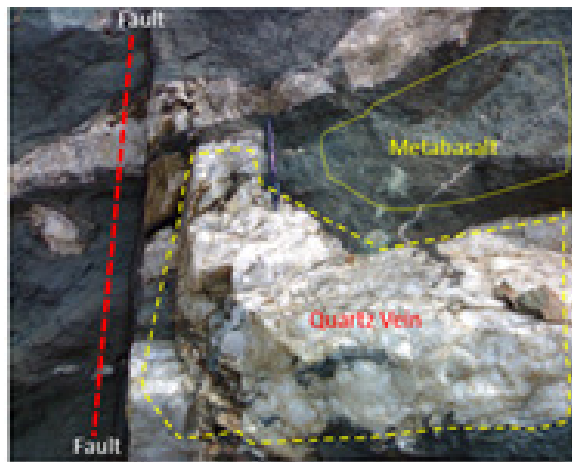

Figure 15. Minor faults across and along the strike in metabasalts (photo facing NW direction).

ferruginous quartzite which is interpreted as Banded Iron Formations (BIF). The banded iron formation which contains a major portion of world's iron ores and especially in Archean terrains, hosts gold mineralization (Gilligang and Foster, and Pretorius *et al*)[25,20].

8.0 Conclusions

In Nagavi study area the general geological and mineralization trend and massive, banded hematite quartzite with fractured veins intrusions indicate the solution entering the BIF with fluid. The BIF sample has been examined under the microscope, and it is composed of alternate bands of quartz-rich and ferrous rich bands.

The rock is compact and greyish brown in colour. In the microscopic examination, the quartz-rich bands consist of highly recrystallized equigranularity (~40-50 μm) quartz grains and subordinates' amount of opaque.

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