Chapter 3

PETROGRAPHY AND MINERALOGY
3.1 Introduction

The Gadag schist belt establishes a remnant of Archean metavolcanics and meta-sediments such as aranite and argillite similar geological setup which are the gold producing mines in India (Hutti & Kolar). Mineralisation is also generally similar and auriferous quartz veins occurrences at numerous places throughout the schistose rocks in Gadag schist belt along with BIF formation and subsequent regional tectonic events have also played a major role in the formation of auriferous material by creating fissures through which the migrated ore bearing fluids.

Iron-bearing units are not restricted exclusively to the Precambrian geologic record. Younger rocks superficially representing BIFs, commonly termed ‘ironstones’, are distinctly more \( \text{Al}_2\text{O}_3 \)- \( \text{P}_2\text{O}_5 \)- and \( \text{Fe}_2\text{O}_3 \)-rich and usually have an oolitic or pisolithic texture (Schopf, 1983). Unequivocal BIFs appear to be absent from the Phanerozoic record. BIFs are found at the very beginning of the rock record, amongst the oldest rocks on Earth. Contrary to earlier belief (Cloud, 1973), there exists a considerable age-spread among Precambrian BIFs. 90% of all iron-formation was deposited between geological time of 3.8 Ga and 1.6 Ga, prior to the Paleoproterozoic-Mesoproterozoic boundary (Lowe and Knauth, 1977; Reimer, 1990; Groves et al., 1987).

The geological time of BIFs and their associated volcanic rocks are often statistically indistinguishable (Isley and Abbott, 1999). The petrology of these diverse volcanics ranges from ultramafic through felsic, while chemical affinities to ocean island basalts (OIBs), enriched mid-ocean ridge basalts (MORBs) and normal MORBs (NMORBs) have been reported (Hoffman, 1988). Units from the Barberton contain massive sulphides and collapsed chimney deposits, indicating proximal high-temperature hydrothermal activity.

In the context of early earth evolution, it is the possible link to an evolving biosphere that makes BIFs particularly interesting. Iron is used as a metabolic agent by numerous microorganisms. Some of these, including specific species of oxygenic- and anoxyogenic- photoautotrophs and chemoferrrotophhs, lend credit to the theory of BIF-deposition being, at least in part, a microbially mediated process. Direct evidence for a microbial role in Archaean BIF deposition remains elusive.
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Petrography and Mineralogy

The oxide facies of BIF typically appearances alternate bands of magnetite / haematite and quartz. Secondary hydroxides of iron such as goethite and martite are also observed in the BIF formation of the study area. Polished specimens of mineralised quartz veins show pyrrhotite, pyrite, arsenopyrite, chalcopyrite and sphalerite as ore minerals. These ore minerals show disseminated, mutual boundary, replacement, inclusion and exclusion textures. Gold occurs as fine occluded grains within arsenopyrite. Thus, the occurrence of sulfides associated with the quartz veins which are emplaced into shear zones suggests epigenetic style of mineralisation rather than syngenetetic style. It is more so due to sulphidation of BIF type of mineralisation in which the available iron in the BIF and HS$_2$ from the fluids have interacted to form sulfides.

The carbonates facies BIF revealed alternate layers of dark brown iron carbonate and cherty quartz. A few grains of fine grained haematite are also seen in the iron carbonate laminae. The absence of lithic fragments suggests chemical precipitation. The thin sections of the oxide facies BIF exhibits fine laminations made up of alternate layers of iron oxides and cherty quartz. The iron oxides comprise of hematite and magnetite and their size varies from 1m to 5m. Iron oxide grains also show the fused margins and continuity suggesting their formation by chemical precipitation. Fine, dusty particles of iron oxides are also seen mixed up with cherty quartz layers. In some sections, the grain margins of iron oxides and also cherty quartz are partially fused which may be due to early diagenesis. The interval of fracturing in the iron oxide layers is approximately equal to the thickness of these layers and apparently the strike of the fracture planes was parallel to the strike of the bedding and thus produced uniform long ‘boudin’ like segments. The deformation might have taken place during later stage in the diagenesis and compaction of the rock (Chakraborty, K.L, 1992).

3.2 Petrographic studies

3.2.1 Banded magnetite / hematite chert / quartzite

The study area consists of Banded iron formation (BIF), metabasalt, schist, sheared quartz veins, shale and carbonated sheared anorthosite. The compositional layer is usually expressed on several scales at any given outcrop, from fine sub-millimeter
scale - like laminae to meter-scale bands. Even on a microscopic scale, the boundary between the ferruginous and siliceous layers is distinctly abrupt. The BIF exposure with alternating shear quartz veins were observed on reef and these BIF outcrops are trending NW-SE direction and dipping 45° NE directions. Table 3.1 represents the description of rock samples.

Table 3.1 Different rock samples collected from Nagavi study area

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Sample No.</th>
<th>Rock type</th>
<th>Sample location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NNB -1</td>
<td>Banded magnetite/hematite chert/quartzite</td>
<td>near Nagavi village on top of hill and about 4km from Gadag city towards SW</td>
</tr>
<tr>
<td>2</td>
<td>NNB -10</td>
<td>Carbonated Sheared Anorthosite (Pyrite grains)</td>
<td>Near Mallasamudra village and 3km from Gadag city.</td>
</tr>
<tr>
<td>3</td>
<td>NNB -11</td>
<td>Banded magnetite/hematite chert/quartzite</td>
<td>Near Nagavi village about 4.5km from Gadag city towards SW on top of hill.</td>
</tr>
<tr>
<td>4</td>
<td>NNB -13</td>
<td>Sheared carbonated Metabasalt</td>
<td>Near Mallasamudra village and about 2.3km from Gadag city towards SW at on top of hill</td>
</tr>
<tr>
<td>5</td>
<td>NNB -18</td>
<td>banded magnetite/hematite chert/quartzite</td>
<td>North of Nagavi village and about 2.7 km from Gadag city towards SW.</td>
</tr>
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</table>

The sheared quartz veins thickness ranges from about 1m to 2m and it is also dipping parallel to BIF bedding (45° NE). The alternate bands of hematite, magnetite and chert are identified. The banded magnetite/hematite chert/quartzite exposure (sample no. NNB 1) is composed of alternate bands of quartz rich and opaque rich bands and under in megascopic examination it is compact and greyish brown color and the quartz rich bands consists of highly recrystallized equigranular (~100 μm) quartz grains with triple-point junctions and subordinate amount of opaque. Opaque rich bands are up to 4 mm thick and consist of euhedral to subhedral, square to rectangular shaped opaque. Opaque are rimmed by goethite indicating that most of the opaque are iron-oxides. Few needles of goethite and opaque are also present. Few parallel to sub-parallel quartz veins cutting the banding at approximately 45° angle is also present. Quartz in these veins is also recrystallized with the development of triple-point junctions (Plate 3.1).
There are sets of quartz veins; first one is massive milky white variety, smoky quartz and rose quartz. The highly fractured, sheared, silicified, ferruginous with contains sulphides within and boundary of quartz vein. This quartz vein is intruded within BIF formation and it appears grey in color with indication of the Au mineralization (Plate 3.2).

Another set of formation is banded magnetite/hematite chert/quartzite exposure (Sample No- NNB 11) were observed on reef near Gadag. Megascopic studies of the rock have been done and rock units composed of dark to greyish brown colored magnetite and alternate bands of quartz-rich were observed. The quartz-rich bands are recrystallized equigranular (~40-50 μm) quartz grains with triple-point junctions and subordinate amount of opaque minerals. These bands are 0.4-1.5 mm in thick and contains up to 10% ~ 10 μm sized opaque. Few quartz grains are elongated parallel to the banding. Opaque-rich bands are up to 50 -500 μm thick and consist of euhedral to subhedral and square to rectangular shaped opaque in nature. Opaque are rimmed by goethite indicating that most of the opaque are iron-oxides. These bands are mostly boudinaged and one band shows intrafolial folds (Plate 3.3 and 3.4).

The pattern of the fold can be observed in the photomicrograph as well as field out crop (Plate 3.4). The contacts between chert bands and quartz veins as well as chilled thin quartz veins across chert bands were observed. The continuity of the Nagavi banded magnetite / hematite chert / quartzite exposure were observed between Gadag – Haveri main road. The rock formation consists of compact, fine grained, greyish brown colored and equigranular in nature. It consists mainly of opaque with rare quartz rich bands. The quartz rich bands consist of highly recrystallized equigranular (~40-50 μm) quartz grains with triple-point junctions and subordinate amount of opaque. Quartz also occurs as small enclaves within the opaque-rich portion. Few quartz grains are elongated parallel to the banding. Randomly distributed and oriented needles of apatite occur as accessory within quartz-rich portion. Opaque-rich portion consists mainly of iron-oxide. Opaque are rimmed by goethite indicating that most of the opaque are iron-oxides. The rock is sheared with the development of asymmetrical tails in originally rectangular opaque grains. Many of the opaque grains
are surrounded by a thin rim of quartz and form asymmetrical tails indicating shearing (Plates 3.5 to 3.7).

Plate 3.1 Photomicrograph exhibiting Iron oxide as opaque, quartz and Iron rich bands

Plate 3.2 Photograph showing banded magnetite / hematite chert / quartzite (photo orientation NW direction)
Plate 3.3  Photomicrograph exhibiting Banded magnetite/hematite chert/quartzite exhibiting intrafolial fold

Plate 3.4  Photograph showing out crop of folded banded magnetite/hematite chert/quartzite
Plate 3.5 Photomicrograph exhibiting banded magnetite/hematite chert/quartzite

Plate 3.6 Photomicrograph exhibiting banded magnetite/hematite chert/quartzite lenses
The massive banded hematite quartzite with intrusion of fractured quartz veins were indicating the solid solution entering into BIF with mineralization. There are numerous small barren quartz veins intruded within the BIF (Plate-3.2h). Also metabasalt and schist at various angles and it consists of disconnected lenticular patches of quartz. The bluish grey variety, at several places, quartz “blows” varying in width and strikes. These blows are largely un-mineralized and the massive character is indicative of poor gold content which is also indicated by the absence of ancient workings of any significant size on outcrops of this nature.

3.2.2 Metabasalt

The metabasalt one of the major lithounit in the study area and exposed few kilometers along both the hanging wall and foot wall side of the hill. These metabasalt exposures are trending NW-SE direction N 50°-55° W to S 50°-55°E and dipping towards NE direction (45° to 50°) and at some places fine grained quartz veins are cutting across the metabasalt. The appearance of chlorite in the metabasalts and sericite in the greywackes / argillites implies the indication of regional grade of metamorphism or the green schist facies metamorphism. Its effect is seen in the
argillites which resulted in the reconstitution of the argillaceous minerals into sericite. BIFs do not show any changes, wherever intense shearing accompanied by the emplacement of auriferous hydrothermal quartz veins is seen, and wall rock alteration such as chloritisation, silicification, sericitisation, and carbonatisation. Chloritisation due to wall rock alteration and chlorite alteration from augite in metabasalts due to greenschist facies metamorphism are to be viewed separately.

Under microscope, the metabasalt show fine to medium grained glassy texture. Pyroxene and plagioclase are the main constituent minerals with magnetite and pyrite in the accessory phase. Most of the pyroxenes are altered to epidote and chlorite. Unaltered, relict pyroxenes are identified as augites.

Devitrified glass masses comprising fine crypto crystalline silica, calcite and submica (sericite) are seen. Minor silicification is also observed. Augite crystals are partially carbonatised. Skeletal plagioclase (quenched) is also seen alongwith saussuritised plagioclase (clouded) grains. The opaque minerals are made up of magnetite and pyrite. Altered basalts show thin silica and calcite veinlet as results of silicification and carbonatisation. All the thin sections studied showed an alteration assemblage which is due to the regional grade greenschist facies of metamorphism / pervasive alteration due to basalt sea water interaction.

The sheared carbonated metabasalt rock exposure (sample no. NNB 13) near Mallasamudra has been examined under megascopic. It is compact, weathered, greenish grey coloured, fine to medium grained and inequigranular. Under microscope it consists of medium sized subhedral grains of twinned to un-twinned plagioclase (~40%), anhedral carbonate (~40%), and actinolite mostly altered to chlorite (~20%) 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. The rock is sheared with the development of feldspar porphyroclasts and recrystallized feldspar and quartz (Plates 3.8 to 3.18).
Plate 3.8 Photomicrograph showing feldspar porphyroclasts and recrystallized feldspar and quartz

Plate 3.9 Photomicrograph showing feldspar porphyroclasts, chlorite and pyroxene
Plate 3.10 Photomicrograph showing feldspar and recrystallized feldspar

Plate 3.11 Photomicrograph showing pyroxene and plagioclase
Plate 3.12 Photomicrograph showing feldspar porphyroclasts and recrystallized feldspar and quartz.

Plate 3.13 Photomicrograph exhibiting feldspar, Chlorite, recrystallized feldspar and quartz
Plate 3.14 Photomicrograph exhibiting Plagioclase feldspar, opaque minerals and Quartz

Plate 3.15 Photomicrograph exhibiting carbonate, feldspar and chlorite
Plate 3.16 Photomicrograph exhibiting feldspar and Chlorite

Plate 3.17 Photograph showing contact of Metabasalt, BIF, Schist exposure (Mallasamudra old workings)
3.2.3 Carbonated sheared anorthosite

Microscopic study of the polished specimens of sulphides-bearing carbonated sheared anorthosite samples shows sulfide assemblages of Pyrite and arsenopyrite. They show mutual boundary, replacement, inclusion, panidiomorphic and exsolution textures. Some grains show dotted appearance due to exsolved blebs of chalcopyrite. Chalcopyrite shows brass yellow colour and occurs as blebs in sphalerite and as growth crystals in arsenopyrite and as replacement in pyrrhotite.

The carbonated sheared anorthosite rock exposure near Mallasamudra and the rock sample (sample number NNB - 10) has been examined under megascopic and it shows compact and light greenish grey in colour. The rock is very fine to medium grained and inequigranular. 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. Plagioclase is slightly saussuritized carbonate appears to be after plagioclase. Carbonate also occupies fracture in plagioclase and rarely forms bands parallel to tectonic foliation. Opaque mostly occurs as euhedral to subhedral, square to rhomb shaped 100 by 100 to 150 by 250 μm sized randomly
distributed discrete grains. Small sized aggregates of opaque occurring parallel to the tectonic foliations in association with chlorite are also noticed. Opaque are mostly magnetite and rarely pyrite. Tectonic foliation is defined by presence of recrystallized feldspar, bent plagioclase lamellae and tapering deformation twins in plagioclase (Plate 3.19 to 3.23).

Pyrite is the dominant mineral. It occurs as individual or aggregates of subhedral to all otiformic grains. It is fine to medium grained and creamy to whitish yellow coloured. It also occurs as inclusions in the pyrite grains. It shows strong yellowish to greyish anisotropism and brownish cream to reddish brown bi-reflectance. Pyrite occurs as perfect cubes (panidiomorphic) with slightly corroded margins and as aggregates. It shows yellowish white reflectance. It also occurs as fine to coarse grained, euhedral to subhedral crystals and as fracture fillings along with pyrrhotite and arsenopyrite. Thus, pyrrhotite (FeS) is the first sulfide to appear from which other sulfides-pyrite (FeS2) and arsenopyrite (AsFeS) are formed.

Plate 3.19 Photomicrograph exhibiting Plagioclase with Pyrites
Plate 3.20 Photomicrograph exhibiting secondary carbonates with Pyrites

Plate 3.21 Photomicrograph showing chlorite and opaque pyrite crystals
Plate 3.22 Photomicrograph showing plagioclase and pyroxene

Plate 3.23 Photograph showing Banded Iron Formation (BIF) with fracture quartz veins intrusion
Large crystals of disseminated pyrite contain small inclusion of arsenopyrite observed in the metabasalt and also show mutual boundary texture with arsenopyrite which suggests simultaneous growth of these minerals (Plate 3.24). Pyrite occurs as characteristics cubic crystals and as clusters of small grains. Coarse grains are also reported by Rao et al., (1996) and Jyothikumari (1998). If pure gold particles are present they show bright yellow colour and typical greenish tint under crossed nicols. Au rich arsenopyrite crystallizes at 200 to 250\degree C and Au poor arsenopyrite crystallizes between 250\degree C and 500\degree C (Cathelineau et al, 1988). The earliest ore mineral to form is pyrrhotite which is a simple sulfide to iron (FeS). This is modified to pyrite (FeS) which forms with the addition of sulfur to pyrrhotite, arsenopyrite (FeAs S), chalcopyrite (Cu2 Fe2 S4), Galena (PbS) and sphalerite (ZnS) with the influx of arsenic, copper, lead and zinc respectively. Thus, the paragenetic sequence would be pyrrhotite-pyrite-arsenopyrite-chalcopyrite-sphalerite-galena. Gold in its minute form (Particle size) gets occluded within arsenopyrite.