A Petrographical Approach to Study Mineral Phases Paragenesis of Gold Bearing Rocks occurring around Hosur Village of Western Gadag Schist Belt, Karnataka, India

*Abrar Ahmed¹, Manjunatha M.C² and Basavarajappa H.T³

¹,³Department of Studies in Earth Science, Centre for Advanced Studies in Precambrian Geology, University of Mysore, Manasagangotri, Mysuru, India
²Department of Civil Engineering, Maharaja Institute of Technology, Thandavapura, Mysuru, India

India hosts several world class gold prospects like Kolar Gold Fields (KGF), Hutti Gold Fields (HGF) and Gadag Gold Fields (GGF). Karnataka is the prime state for gold production since all of these gold deposits are located within. Apart from these world class gold deposits, several other gold prospects in India were identified and exploration activities are under progress. The present study aims to characterize the mineral assemblage and paragenetic phases of gold bearing Precambrian rocks around Hosur village in Gadag Schist Belt through detailed examination by Ore Microscopy. Gadag Schist Belt (GSB) is known by its significance of gold deposits for centuries. Gold mineralization in GSB is associated with tholeiitic meta-andesite, quartz porphyries and argillite greywacke assemblage. The Gadag Gold Field (GGF) constitutes one of the most important auriferous zones of the Archaean Greenstone terrains in Southern India. All known mineralization is in the form of structurally controlled vein systems. The occurrence of the gold is intimately associated with arsenopyrite. Representative samples were studied under polarizing reflected-light microscope to identify and to characterize the mineral phases of gold occurrences and its textural relationships. It has been observed that there are five phases of mineralization only in the third phase gold has formed along with arsenopyrite. Surface morphology of gold and sulphide mineralization was examined under SEM; whereas the elemental analysis of selected sample was carried out using EDS. The present work reveals the clear perception of gold occurrence and mineral phases paragenesis using ore microscopic approach.

Keywords: Gold, Ore Microscopy, Ore Mineral phases, Hosur village, Gadag Schist Belt, Karnataka.

INTRODUCTION

The major Archaean lode gold deposits are situated in the late Archaean Cratons of Australia, Brazil, Canada, India, South Africa, Tanzania and Zimbabwe. They contribute about 18% to the world’s gold production. The gold content of these deposits ranges from less than one ton to more than 1500 tons with average grades vary from 2 to 50 g/t. The gold deposits are observed to be hosted by the volcanic and sedimentary rocks of Neoarchaean granite-greenstone belts and are seldom in the enclosing gneiss and intrusive granites. Most of the greenstone lithologies can serve as better hosts for gold mineralization. Likewise, a variety of rock types of volcano-sedimentary sequences of Kolar, Hutti, Ramagiri, Gadag and Mangalur greenstone belts within the granite greenstone metamorphic terrain of Dharwar Craton have hosted vein type of primary gold deposits (Ziauddin and Narayanaswami, 1974; Rao and Reddy, 1985; Ugarkar and Deshpande, 1999). There is clear coincidence between the distribution and linear composite structurally dilatants shear systems/ zones over the Craton. The major gold producing nations have similar geological settings like the Dharwar Craton in India, viz., Barberton mountain range in South Africa, Yilgarn and Pilbara provinces in Australia, Superior province in Canada. Gold occurs in narrow sub-parallel shear/mylonitic zones which consists of en-eclelon veins, lenses and stringers of quartz distributed within schistose
and foliated metabasic rocks in case of Kolar (Narayanswamy et al., 1960; Rajamani et al., 1985), Mangalur (Ugarkar and Tenginkai, 1988,1989) and Hutti (Roy, 1991; Raju and Sharma, 1991) while in Gadag Gold Field, the auriferous zones occur both in metavolcanic (mafic to felsic) and metasedimentary rocks (Narayanswamy and Ahmed, 1963; Ugarkar and Deshpande, 1999).

Mineral identification and textural characterization through ore microscopy examines the order of formation of associated minerals in time succession and the estimation of the conditions under which the minerals have formed or have re-equilibrated. The mineralogical literature contains many paragenetic studies undertaken in varying amounts of detail by Craig and Vaughan (1994). Although not all of the points considered are equally applicable to all ores; indeed, some ores, especially those that have been intensely metamorphosed are not so amenable to paragenetic studies. Either, because the original record is insufficiently distinctive or because it has been subsequently altered beyond recognition. The main aim of this paper was to find out the ore minerals paragenesis through Reflect light microscopy. This paper documents the mineralization characteristics for ore types occurring around Hosur gold deposits, focusing on mineral assemblages and paragenetic relationships. Sulphide minerals show its presence in at least 5 main paragenetic mineral assemblage stages that have been identified carefully by observations of available data.

Geology of the study area

The Gadag Schist Belt constitutes the northern extremity of the eastern arm of Chitradurga schist Belt and is located in Western Dharwar Craton. The Geological formation of Gadag Schist Belt consists chiefly of metavolcanics (rhyolite, rhyodacite to basaltic andesite) and metasedimentary (argillite-arenite-arkose-graywacke suite of rocks, limestone, chert, BIF and conglomerate) belonging to the Chitradurga Group of Dharwar Super Group. Besides there are abundant gabбро and dolerite intrusive phases. The peninsular gneiss and the granite envelope the Schist Belt, the former forming the basement to the Gadag. Three principal zones of mineralization are there, these zones are generally referred to in literature as: eastern lode system, central lode system, western lode system. The GGF is best known for its auriferous reefs since the beginning of the century and the earlier work was devoted to gold occurrences. The mineralization is mainly structure–controlled and the deposit is hydrothermal-epeigenetic lode (Chakrabarti et al., 2006) as it occurs in a zone of deformed rock associated with a large regional shear-zone structure. The study area is a part of Western Lode system of GSB best exposed near Hosur is hosted by pillow basalts and andesite consists of both free milling and sulphide hosted gold. Sheared metabasalt zone shows contact with narrow bands of quartz porphyry with occurrence of free gold in quartz. Auriferous quartz veins run roughly parallel to each other with average gold grade of 4.02 g/ton (Chakraborty et al., 1992, Ugarkar et al., 2016) in east of Hosur champion. Gold occurs here in Quartz-Carbonate Veins (QCVs) emplaced in metavolcanic rocks and metagraywacke-argillites (Chakraborty et al., 1992). The auriferous tract of the study area consists of metavolcanic, metasedimentary, younger basic intrusives and quartz veins. The auriferous quartz-carbonate veins contain a stringers and dissemination of sulphides like pyrite, pyrrhotite, arsenopyrite and chalcopyrite. The geological map of Gadag Schist Belt showing sample collection points in the study area is as shown in Fig.1 (a) and (b).

Table 1: Locations of rock samples collected during field visit

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Name of the Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Sample Number</th>
<th>Sample Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>East of Hosur village</td>
<td>15°17'52.9&quot;</td>
<td>75°35'24.9&quot;</td>
<td>HS-1</td>
<td>Andesite</td>
</tr>
<tr>
<td>2</td>
<td>East of Hosur village</td>
<td>15°17'52&quot;</td>
<td>75°35'23.1&quot;</td>
<td>HS-2</td>
<td>Ancherite</td>
</tr>
<tr>
<td>3</td>
<td>East of Hosur village</td>
<td>15°17'36.1&quot;</td>
<td>75°35'24.6&quot;</td>
<td>HS-3</td>
<td>Metabasalt</td>
</tr>
<tr>
<td>4</td>
<td>East of Hosur village</td>
<td>15°17'36.2&quot;</td>
<td>75°35'20&quot;</td>
<td>HS-4</td>
<td>Andesite</td>
</tr>
<tr>
<td>5</td>
<td>East of Hosur village</td>
<td>15°17'35.4&quot;</td>
<td>75°35'21.2&quot;</td>
<td>HS-5</td>
<td>Andesite</td>
</tr>
<tr>
<td>6</td>
<td>East of Hosur village</td>
<td>15°18'15.2&quot;</td>
<td>75°35'24.5&quot;</td>
<td>HS-6</td>
<td>Acid Volcanics</td>
</tr>
<tr>
<td>7</td>
<td>East of Hosur village</td>
<td>15°18'23&quot;</td>
<td>75°35'20.4&quot;</td>
<td>HS-7</td>
<td>Acid Volcanics</td>
</tr>
<tr>
<td>8</td>
<td>East of Hosur village</td>
<td>15°17'36.1&quot;</td>
<td>75°35'24.6&quot;</td>
<td>HS-8</td>
<td>Andesite</td>
</tr>
<tr>
<td>9</td>
<td>East of Hosur village</td>
<td>15°17'34.9&quot;</td>
<td>75°35'23.8&quot;</td>
<td>HS-9</td>
<td>Andesite</td>
</tr>
</tbody>
</table>
A Petrographical Approach to Study Mineral Phases Paragenesis of Gold Bearing Rocks occurring around Hosur Village of Western Gadag Schist Belt, Karnataka, India

Fig. 1 (a) Geological Map of Gadag Schist Belt [GSI, Gold ores in India, 1994]; (b) Location map of the study area showing sample collection points

Fig. 2. (HS-1): Andesite shows fine grained greenish to grey colored volcanic minerals with sulphides mineralization; (HS-2): Ankerite contains reddish to brownish colored quartz minerals; (HS-3): Metabasalt Inclusions of medium grained pyrite within a sheared rock; (HS-4): Andesite shows the occurrences of both pyrite and arsenopyrite; (HS-5): Andesite shows the presence of sulphides in quartz carbonate veins; (HS-6): Green colored Acid volcanic are observed; (HS-7): Acid volcanic containing sulphides in quartz veins; (HS-8): Andesite shows the presence of sulphides in quartz carbonate veins; (HS-9): Andesite shows the presence of sulphides and quartz veins.
Nine field based rock samples were collected from the western lode system of Hosur Champion and carried carefully to the laboratory. Based on the availability of instruments detailed microscopic and EDX studies were carried out. Selected samples of sulphide bearing were examined by Reflected Light in polished section and the paragenesis of the ore minerals was determined based on their textures and assemblages. The composition of the minerals in selected samples was analyzed by Energy Dispersive X-ray Spectroscopy (EDS). The surface morphology of gold was observed using a Hitachi S-3400N Scanning Electron Microscope (SEM) with energy of 5.00 kV model EVO LS15 to detect the gold specks under 1 to 2 micron scale. The Research methodology adopted is as shown below in the form of flowchart:

**RESULTS AND ANALYSIS**

**Petrography**

**Reflected Light Microscopy**

Mineral identification and textural characterization through ore microscopy examines the order of formation of associated minerals in time succession and the estimation of the conditions under which the minerals have formed or have re-equilibrated. The mineralogical literature contains many paragenetic studies undertaken in varying amounts of detail by Craig and Vaughan (1994). In recent years, reflected light microscopy has become a useful technique in studying paragenetic studies of economic minerals. Totally, 4 polished rock samples were studied using reflected light microscope. Their description and Photomicrograph is as shown below:

**Sample number: 9(HS-9)**

Mainly in rock sample number 9(HS-9), as shown in figure 3(a),3(b),3(c),3(d), 3(e). Arsenopyrite is the dominant sulphide mineral present along with chalcopyrite, acanthite and gold in minor amounts. Arsenopyrite is subhedral to euhedral in nature showing strong anisotrophism. Chalcopyrite is seen as fracture filling within arsenopyrite. Gold is yellowish to bright orange in colour showing high reflectance present as interlocked grains within arsenopyrite.

**Fig.3 (a) Chalcopyrite and Acanthite as fracture filling within Arsenopyrite**

(b) Subhedral to Euhedral Arsenopyrite grains (c) and (d) Interlocked bright orange colored gold grain within Arsenopyrite (e) Interlocked gold grains within Arsenopyrite
Sample number: 4(HS-4)

Fig. 4: Chalcopyrite within Euhedral Arsenopyrite

Mainly in rock sample number 4 (HS-4), as shown in figures 4. It is observed that islands of chalcopyrite within euhedral arsenopyrite.

Sample number: 5(HS-5)

Fig. 5 (a) Arsenopyrite replacing pyrite and both replaced by chalcopyrite
(b) Replacement texture exhibited by Pyrite-Arsenopyrite
(c) and (d) Replacement texture exhibited by Pyrite-Arsenopyrite-Chalcopyrite
(e) Replacement texture exhibited by Pyrite-Arsenopyrite

Mainly in rock sample number 5 (HS-5) as shown in figures 5(a), 5(b), 5(c), 5(d), 5(e). Sulphides are mainly pyrite, arsenopyrite, chalcopyrite, in decreasing abundance. Replacement texture is very prominent and the paragenesis sequence observed is as follows Pyrite-Arsenopyrite-Chalcopyrite.
A Petrographical Approach to Study Mineral Phases Paragenesis of Gold Bearing Rocks occurring around Hosur Village of Western Gadag Schist Belt, Karnataka, India

Ahmed et al. 332

Sample number- 8 (HS-8)

Mainly in Sample number 8 (HS-8) as shown in figure 6(a), 6(b), 6(c), 6(d), 6(e), 6(f). Pyrite, chalcopyrite, acanthite, arsenopyrite, pyrrhotite are seen. Chalcopyrite and acanthite are showing mutual boundary and exsolution texture indicating their coeval nature. Pyrrhotite is also present in minor amount and are probably represent earliest sulphide phase. subhedral to euhedral pyrite is dominant. Goethite along grain margins of silicate/gangue minerals showing colloform banding.

Based on the ore textures observed under reflected light, possible paragenetic stages can be recognized. There is no standard method for carrying out paragenetic studies; because each deposit is unique. However, as the goal of all such studies is to decipher the sequence of mineral formation. From all the above samples studied 5 phases of ore minerals paragenesis has occurred and it has been given below in Table 2.

Table 2: ore minerals paragenesis in western part of Gadag Schist Belt

<table>
<thead>
<tr>
<th>Ore minerals</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalcopyrite</td>
<td>Present</td>
<td></td>
<td></td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>Present</td>
<td></td>
<td></td>
<td>Present</td>
<td></td>
</tr>
<tr>
<td>Pyrite</td>
<td>Present</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenopyrite</td>
<td>Present</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>Present</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acanthite</td>
<td>Present</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Covellite</td>
<td></td>
<td></td>
<td></td>
<td>Present</td>
<td></td>
</tr>
</tbody>
</table>

Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy (SEM-EDX)

This combined technique is referred to as SEM-EDS or SEM-EDX Analysis (PinakiSengupta et al., 2008). The most reliable way to identify minerals through the SEM is to compare their characteristic morphologies with the elemental compositions determined by the EDX. After the above observations only 1 polished rock sample with gold content(HS-9) was studied using scanning electron microscope (SEM) for high magnification. Their description and photomicrograph is as shown below in figure 7 (a), 7(b), 7(c), 7(d).
Fig.7 (a) and (b) Gold mineralization inside the Arsenopyrite in 2 microns; (c) and (d) Gold mineralization inside the Arsenopyrite in 1 micron size.

Elemental analysis of a sample is obtained by collecting the characteristic X-rays generated as the electron beam scans the sample. In general, the EDX is used to obtain rapid analysis of elements. One sample was tested; the sample number (HS-9) and the results are as follows in figure 8.

Table -3: Quantitative Results

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Element Line</th>
<th>Weight %</th>
<th>Weight Error %</th>
<th>Atom %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>C-K</td>
<td>11.58</td>
<td>+0.57</td>
<td>34.50</td>
</tr>
<tr>
<td>2.</td>
<td>O-K</td>
<td>5.33</td>
<td>+0.31</td>
<td>11.92</td>
</tr>
<tr>
<td>3.</td>
<td>Si-K</td>
<td>0.62</td>
<td>+0.07</td>
<td>0.79</td>
</tr>
<tr>
<td>4.</td>
<td>Si-L</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5.</td>
<td>S-K</td>
<td>16.08</td>
<td>+0.22</td>
<td>17.94</td>
</tr>
<tr>
<td>6.</td>
<td>S-L</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>7.</td>
<td>Fe-K</td>
<td>19.18</td>
<td>+0.48</td>
<td>12.28</td>
</tr>
<tr>
<td>8.</td>
<td>Fe-L</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>9.</td>
<td>Ga-K</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10.</td>
<td>Ga-L</td>
<td>0.51</td>
<td>+0.31</td>
<td>0.26</td>
</tr>
<tr>
<td>11.</td>
<td>As-K</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>12.</td>
<td>As-L</td>
<td>46.69</td>
<td>+0.51</td>
<td>22.29</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100.00</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

From the above observations atomic percents of Fe, Ga, S, C, O, Si and As were determined. Presence of arsenic is comparably more which gives evidence indirectly the presence of gold because arsenic is the indicator element for gold which is found by using EDS / EDX studies.

Some of the important features observed in the study area are:

- A large number of ancient workings have been seen, small shafts of about 60cm × 60cm and of about 90 meters maximum depth, the remaining being pits and trenches open to surface. Some of the ancient pits are shown in fig.9 (a), 9(b), 9(c). Along with many old shafts there are many old poundings were also seen. Old poundings are as shown in figure 10.
A Petrographical Approach to Study Mineral Phases Paragenesis of Gold Bearing Rocks occurring around Hosur Village of Western Gadag Schist Belt, Karnataka, India

Ahmed et al.

Fig.9 (a) closed old Gold working Shaft (it’s a vertical Shaft up to 100 feet down) (b) 150 feet old open Gold shaft of Britishers time; c) Inclined shaft during Britishers time

Fig.10 An ancient pounding on Andesite Rock from where Gold was powdered and panning was done

DISCUSSION

The ore zones are mainly distributed in the western part of the Gadag greenstone belt trending in NNW-SSE to NW-SE direction. In part of western Gadag schist belt (study area) it has been observed that Gold Mineralization has occurred only in core regions of Arsenopyrite mineral. In addition to gold, ore minerals occurring in the study area include considerable amounts of arsenopyrite, pyrite and pyrrhotite and minor constituents of chalcopyrite, acanthite and covellite. 5 phases of ore minerals paragenesis has occurred and recorded. Sulphides are noticed mainly as pyrite, arsenopyrite, chalcopyrite, acanthite in decreasing abundance. Replacement texture is very prominent and the paragenesis sequence observed as pyrite-arsenopyrite-chalcopyrite-acanthite. Goethite occurs along the grain margins of silicate/gangue minerals showing colloform banding. The indicator element for Gold i.e., Arsenic presence is comparably higher which indirectly representing the gold deposits using EDS studies.

CONCLUSION

Gadag Schist Belt (GSB) is known by its significance of gold deposits for centuries. The Gadag schist belt known area comes under Archeans of Western Dharwar craton. Three principal zones of mineralization are there, these zones are generally referred to in literature as: Eastern lode system, Central lode system, Western lode system as each ore deposits are unique, the goal of this paper is to decipher the Phases of ore minerals paragenesis through ore petrography. Several old workings inclined shaft, vertical shaft along with many old poundings were observed in this area. In part of western Gadag schist belt around Hosure village (study area). From all the above rock samples studied 5 phases of ore minerals paragenesis has occurred. first phase - chalcopyrite+pyrrhotite, second phase- pyrite, third phase- arsenopyrite+gold, fourth phase- chalcopyrite+acanthite, fifth phase- chalcopyrite+acanthite and only in the third phase gold has formed along with arsenopyrite. Sulphides are mainly Pyrite, Arsenopyrite, Chalcopyrite, Acanthite in decreasing abundance. Replacement texture is very prominent and the Paragenesis sequence observed is as follows Pyrite-Arsenopyrite-Chalcopyrite+Acanthit. Goethite along grain margins of Silicate/Gangue minerals showing Colloform banding. From EDS study presence of Arsenic is comparably more which gives evidence indirectly the presence of Gold because Arsenic is the indicator element for Gold. So around Hosure area in the Andesite rock that too in the core regions of Arsenopyrite mineral invisible Goldgrains mineralization has occurred.
ACKNOWLEDGEMENT
The authors are indepthly acknowledged to Prof. P.Madesh, Chairman, Department of Studies in Earth Science, Centre for Advanced Studies in Precambrian Geology, University of Mysore, Manasagangotri, Mysuru; I would like to express my special thank of gratitude to Dr. Ashok Rao, General Manager (Exploration) and Mr. Dhyaneshwar Gaonkar, geologist at Baldota Group for their valuable guidance in the field. Iconvey my sincere gratitude to Dr. VS Hegde (Professor) SDM Engineering College Dharward, fortheir kind help and sharing their valuable experiences. I would like to thank Mohammed Shareef, Geologist at (GSI) Geological Survey of India for helping me and giving valuable guidance to enrich my knowledge. I would also like to thanks Institute of Excellence, Vijnana Bhavan, Manasagangotri, Mysore for helping in doing sample analysis.

REFERENCES
isotopic and geochronological constraints with example from the Dharwar craton, southern India. Ore Geology Reviews 107, pp. 754-779.


