Preliminary Fluid Inclusion Study from Chigargunta Gold Deposit at South Kolar Greenstone Belt, Eastern Dharwar Craton, India

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Introduction: Archean lode gold deposits occur within the stable cratonic terranes that are regionally metamorphosed granite-greenstone assemblages such as the Yilgarn Craton in Australia, Superior Province in Canada, Kaapvaal Craton in Southern Africa and Dharwar Craton in India. The Archean lode gold deposit class is generally defined as structurally controlled wall rock and/or vein-hosted mineralization that occur in all types of rocks in the Archean granite-greenstone terranes. These deposits are considered to be epigenetic with respect to host-rock formation (Groves et al. 1998). This class of deposits is broadly formed from uniform hydrothermal fluids transporting gold and several other metals. Based on the range of structural, hydrothermal alteration and ore fluid characteristics, these deposits are interpreted to have formed over a range of paleo-crustal levels from shallow (<5 km) to deep (20 km) as a result of focused fluid flow late during active deformation and metamorphism in volcano-plutonic terrenes (Hagemann and Cassidy 2000).

These terranes host number of gold deposits ranging from Super giant (>2500 t Au) to world class (>100 t Au) to small deposits (few tonnes of Au). Some of the examples include Golden Mile deposit (>2000 t Au) near Kalgoorlie Australia and Hollinger-McIntyre deposit (>1000 t Au) near Timmins, Canada. Similarly, in Dharwar Craton, India few world class deposits and many small deposits occur. The world class deposits include the world famous Kolar and Hutti deposits in the Kolar and Hutti-Muski greenstone belts respectively. While Hutti is still in production with a proven reserve of >120 t Au, with an average grade of 4.42 g/t Au, Kolar mine was closed in the year 2000 after producing more than 800 t of Au, when gold content went below the cut-off grade. However, there are several small promising prospects/deposits occur in northern, southern and eastern extension of Kolar greenstone belt. One of them is the Chigargunta deposit in the south Kolar greenstone belt.

Regional Geology: Close to the southern boundary of eastern Dharwar Craton, Kolar greenstone belt extends for about 80 km length in N-S direction. It has a maximum width of 6 km in the middle part. The greenstones are mainly represented by amphibolite and Champian gneiss in which the amphibolite (mafic-volcanics) is surrounded by peninsular gneiss in the eastern and younger granite gneiss in the western side. Champion gneiss is the felsic-volcanic unit of the greenstones. Other rocks comprising greenstones are few occurrences of vocano-clastic sedimentary units represented by meta-greywackes to arkosic rocks with interbedded polymictic conglomerates and minor BIFs. The general trend of foliation in the belt varies from N-S to NNE-SSW that dipping steep towards west as well as east. The rocks are folded into doubly plunging synform and metamorphosed to middle amphibolite facies conditions (Rajamani et al. 1981; Mishra and Panigrahi 1999).

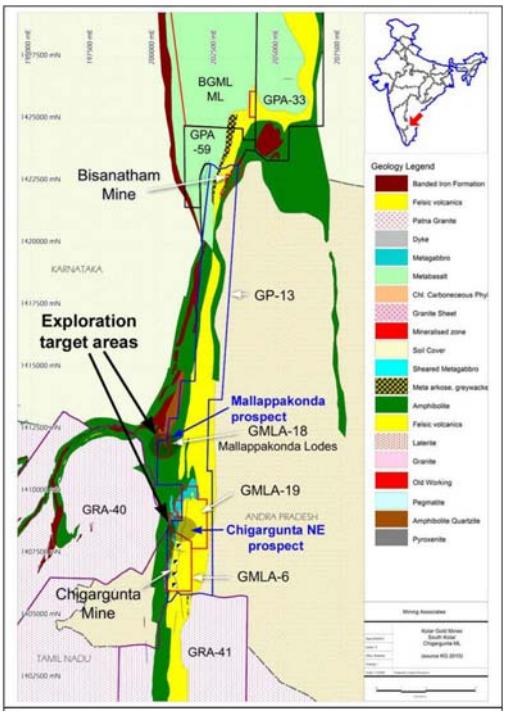

Figure 1: *Geological map of South Kolar greenstone belt showing Chigargunta Gold deposit along with other prospects. (Reproduced from CPR, KGL, December 2010).*

Chigargunta Geology: Chigargunta gold deposit is located near Kuppam district Andhra Pradesh close to the border area of Andhra Pradesh, Karnataka and Tamil Nadu (Fig. 1). Gold mineralization at Chigargunta is associated with several lode formations composed of quartz-calcite veins within silicified sulfide rich host rock (Fig. 2a) in a folded sequence made up of a meta-mafic and –ultramafic sequence (amphibolite) in the west and felsic sequence (Champion gneiss) in the east (Fig. 1). The assemblage has formed tight isoclinal fold with axial surface trending N-S direction and steeply dip towards both east and west. The mean principle orientation is 177/87W. The deposit consists of two main lode systems separated by a gap of approximately 150m. The lodes have a strike length of 3 km and widths of 140 m to 300 m up to a depth of 300 m. Total reserve of the deposit includes 12 t of Au with an average grade of 5.66 g/t. (Competent Person's Report (CPR) Kolar Gold Limited (KGL), December 2010).

The Champion gneiss is typically coarse grained, inequigranular and strongly foliated rock containing large polycrystalline granoblastic plagioclase and K-feldspar. Large quartz-feldspar aggregates are set in a fine grained mosaic of similar quartzo-feldspathic composition. Other minerals that occur in the rock are biotite, muscovite, chlorite and epidote. Quartz-feldspar myrmekitic and K-feldspar-plagioclase perthitic textures are common. Amphibolite, on the other hand, consist of mainly of actinolite, hornblende and plagioclase.

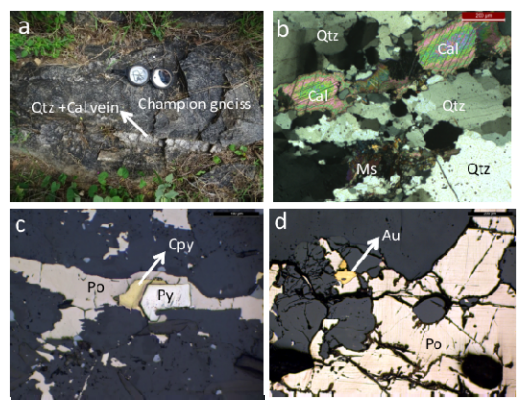

Figure 2: *(a) Field photograph showing quartz (qtz)-calcite(Cal) veins within the Champion gneiss; (b) Transmitted light photomicrograph, in cross polar, showing quartz microstructures, calcite and muscovite (Ms); (c) Reflected light photomicrograph shows* the *f*(S_2)-buffered *ore mineral assemblage of pyrite (Py), pyrrhotite (Po) and chalcopyrite (Cpy); (d) occurrence of gold with pyrrhotite. (c) and (d) are taken in plain polarized light.*

Quartz-carbonate veins contain drawn out quartz grains that show evidence of dynamic recrystallization, (Fig. 2b) implying deformation post-dating shearing or later reactivation of the same shear. In the mineralized zone the

common ore minerals are the $f(S_2)$-buffered assemblage of pyrite + pyrrhotite ± chalcopyrite (Fig. 2c). Gold occurs in association with sulfides such as pyrrhotite±pyrite±chalcopyrite (Fig. 2c). Other minerals in the ore zone are ilmenite and rutile.

Fluid Inclusion Studies: After initial petrography, three samples of champion gneiss from the mineralized lodes with auriferous quartz veins were selected for microthermometry. The inclusions are small in size (2 – 12 µm). They occur as clusters/isolated and along intra-granular trails (IGT) that are condidered as primary and pseudo-secondary respectively. These inclusions are grouped into two types both on the basis of their phase contents and disposition. These are: type-I monophase carbonic inclusions that occur as clusters or isolated inclusions and homogenize into liquid state; and type-II low salinity aqueous biphase inclusions that frequently occur as a part of the same cluster comprising type-I inclusions and also occur as IGT . Type-I inclusions furnished the following microthermometric data: dry ice (CO_2) melting temperature ($T_{m,CO2}$) = –56.0°C to –59.0°C, with a cluster between –57.0° and – 56.6°C (Fig. 2a), implying presence of gases other than CO_2.The temperature of CO_2 homogenization ($T_{h,CO2}$) varied from –22.1°C to 18.1°C, with two distinct cluster around –10°C to –20°C and 5°C to 10°C (Fig. 2b). For the type-II inclusions, temperature of last ice melting (T_m) varied from –19.5°C to –1.3°C; again with two clusters between – 12°C to –16°C and –2°C to –6°C (Fig. 2c). The observed range in liquid-vapor homogenization (T_h) is between 140°C and 226°C, with a significant clustering around 140°C to 160°C and 200°C to 220°C (Fig. 2d). Raman spectra, acquired on selected type-I inclusions, show presence of small amount of CH_4 along with the CO_2. Isochore were plotted for pairs of cogenetic and coeval inclusions i.e. assumed as synchronously trapped, an example shown in Figure 2e. The method of isochores intersection (cf. Roedder and Bodnar 1980) was adopted for estimation of inclusion entrapment P-T conditions. Three isochore intersection points (IIS) such as IIS1: 2.3kbar/362°C, IIS2: 1.3kbar/243°C and IIS3: 0.9kbar/185°C, pertaining to the ore fluid P-T conditions (Fig. 2f), were obtained.

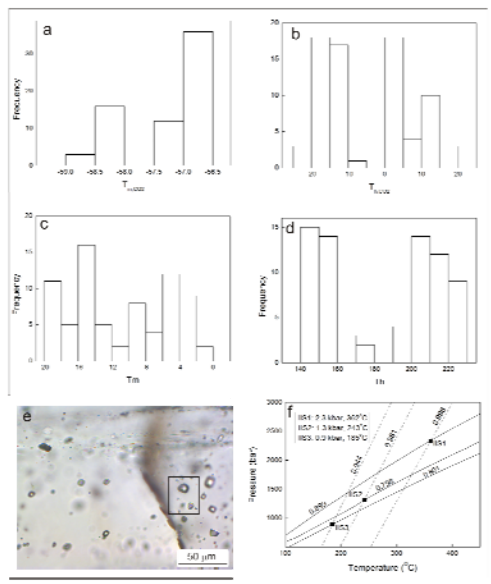

Figure 3: *Histogram plots for fluid inclusions showing temperatures of (a) CO_2 ice melting, and (b) CO_2 homogenization of type-I inclusions; (c) Last ice melting and (d) liquid vapor homogenization of type-II inclusions. Photomicrograph showing coexisting type-I and type-II inclusions within the solid square (e); P–T estimation by the intersecting isochores of type-I (solid lines) and type-II (dashed lines) in the auriferous quartz-calcite veins (f).ISS= Isochore inter section.*

Conclusions: Gold mineralization at Chigargunta is concentrated in the quartz-calcite veins as well as in the altered host rock-Champion gneiss that is strongly sheared, mylonitized and showing strong

N-S trending steeply dipping axial planar fabric. At proximity to mineralized lodes the Champion gneiss is intensely altered and depicts significant changes in the grain size and texture. Alterations in the rock include: silicification, biotitization carbonatation and sericitization. Gold occurs in the main ore zone in association with sulfides as a consequence of mineral-fluid interaction, sulfidation of oxides/silicates in the host rock (Mikucki 1998; Pal and Mishra, 2002), thereby reducing the ore fluid ΣS and precipitating Au and sulfides (Fig. 2d). The auriferous veins contain low to moderate salinity aqueous biphase H_2O-NaCl and CO_2 (± CH4) gaseous fluid inclusions that occur in the same Fluid Inclusion Plane (FIP) (Fig. 2e) indicating a regime of fluid immiscibility of the two fluids types that are characteristic of lode-type gold deposits. Precipitation of quartz-calcite and gold took place in the P-T range of 0.9 to 2.3 kbar at 185°−362°C. Although these P-T values are in accordance with the broad P-T regime of gold precipitation in the Dharwar Craton (Mishra and Panigrahi 1999; Pal and Mishra 2002, 2003; Pandalai et al. 2003; Mishra et al. 2005; Saravanan et al. 2009) there is wide variation in pressure and also in temperature. Fluid inclusion petrography and microthermometry, from both the inclusion types, clearly indicates that there are two groups of inclusions from each type. Relatively high dense (high P-T; IIS1 in Fig. 3f) inclusions occur as isolated/clustered and the low dense (low P-T; IIS3 in Fig.3f) inclusions occur along intra granular trails indicating a possible fluid evolution during gold mineralization. However, this is to be verified by more rigorous and detailed fluid inclusion study from this study area.

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