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Archean turbidite hosted orogenic gold mineralization in the Gadag greenstone belt, Western Dharwar Craton, Peninsular India

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ABSTRACT

Turbidite hosted orogenic gold mineralization in the Archean Gadag greenstone belt of the Western Dharwar Craton, forms a major auriferous zone (Central Auriferous Zone) extending over a strike length of about 12 km in the Gadag duplex. The turbidite sequence comprises thick inter-bedded, medium to coarse grained lithic graywacke and thin laminated layers of fine grained carbonaceous phyllite. Gold bearing quartz veins impregnate preferentially along the en-echelon shear planes, fractures and schistosity planes. Auriferous quartz veins are enveloped by the altered wall rocks.

Mineralogy of the auriferous zone is dominated by gangue minerals like quartz, ankerite, chlorite, sericite and carbonaceous matter, with subordinate plagioclase. Monazite and xenotime are the important accessory minerals. Arsenopyrite and pyrite are the major sulfide minerals, but pyrrhotite, chalcopyrite, sphalerite, galena and scheelite are also present. Gold in native state occurs within quartz, silicates and arsenopyrite.

Notable distinctions in mineral assemblage, texture and in chemical compositions of altered wall rocks compared to the precursor host rock in the study area implies that the metasomatism and wall rock alterations are the results of pervasive infiltration and intense interaction between hydrothermal fluids and the surrounding host rocks over a prolonged period.

Sulfides, carbonates, carbonaceous matter, K_2O, MgO, CaO, Cr, Ni, Cu, Pb, Zn, As and higher values of gold (0.98–4.72 ppm) are added into the altered wall rocks, immediately enveloping the auriferous quartz vein bodies. The chondrite normalized REE pattern of altered wall rocks exhibits enriched LREE (La_N/Yb_N = av. 9.54), with prominent negative Eu anomaly. The observed variation in geochemical characteristics and mineral assemblages in the alteration zones indicates differential response of the host rock and intensity of alteration depending on the composition of host rocks and hydrothermal fluids.

The auriferous hydrothermal fluids were of low salinity (2.0 to 6.6 wt.% NaCl), dominated by CO_2–H_2O (about 30 mol% CO_2) with moderate densities (0.7 to 1.04 g/cm^3), and gold deposition occurred over a wide temperature range between 175 °C and 325 °C. Gold deposition was influenced by fluid mixing, phase separation and redox reactions. Mixing between CO_2–H_2O fluids and more reduced fluids, which evolved during fluid reaction with adjacent carbonaceous wall rocks, was the key factor causing gold deposition.

The formation of the Gadag duplex, deformation, folds and reverse strike slip faults (discontinuities) was caused by the compression associated with subduction related tectonic processes. During the initial period of intrusive magmatism (2,555 ± 6 Ma), regional metamorphism occurred in the entire greenstone belt, while during later period, hydrothermal fluids responsible for gold mineralization probably were derived from metamorphic processes as well as from intrusive granites. Such fluids channeled through the thrust in host turbidite sequence carrying dissolved gold, associated metals and sulfur, ultimately were precipitated in a reducing environment in the splays to the thrust in the Gadag duplex at about 2,522 ± 6 Ma, resulting in retrograde alteration assemblages.

1. Introduction

An improved understanding of gold deposits in metamorphic terrains, especially in the last three decades (Groves et al., 1998; Kerrich et al., 2000; Goldfarb et al., 2005; Large et al., 2011; Xue et al., 2013; Tomkins, 2014), has witnessed the comprehensive communication of the distribution of epigenetic gold deposits in China as well as in Russia and in Asian countries (e.g. Kerrich, 1993; Ugarkar et al., 2000; Zhou et al, 2002; Mishra and Pal, 2008; Yakubchuk et al., 2002; Tomilenko et al., 2010; Sarma et al., 2011, and references there in). Thus, the distribution of gold in metamorphic terrains over geologic time has become fairly well established, as summarized by Kerrich et al. (2000), Goldfarb et al. (2005) and Groves et al. (2003). In recent years, systematic approach has been made in studying gold deposits, particularly to classify and in understanding their genetic aspects. As a result, three main classes of

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deposits are defined, each having a range of specific deposit types with common mineralogical, lithological, genetic and geodynamic settings, namely the orogenic (ORG), reduced intrusion-related (RIR) and oxidized intrusion-related (OIR) ones (Groves et al., 1998; Sillitoe and Thompson, 1998; Poulsen et al., 2000; Goldfarb et al., 2005; Robert et al., 2007). However, other types of globally important gold deposits include Carlin, Au-rich VMS and Witwatersrand type deposits (Sillitoe and Bonham, 1990; Huston, 2000; Hofstra and Cline, 2000; Law and Phillips, 2005).

The orogenic type of deposits constitutes a distinctive class of epigenetic precious metal deposits that are generated at mid-crustal levels (5–15 km) proximal to terrain boundaries, in transpressional subduction–accretion complexes of Cordilleran-style orogenic belts (Groves et al., 1998; Kerrich et al., 2000). Generation and transportation of hydrothermal fluids and deposition of gold from such fluids are attributed to these fundamental geological and tectonic processes. The specific deposits in this clan include the turbidite-hosted and greenstone (metavolcanic) hosted vein deposits, as well as the banded iron formation-hosted veins and sulfidic replacement deposits (Kerrich et al., 2000; Robert et al., 2007). As there remains some ambiguity in the distinction between ORG and RIR deposits, Goldfarb et al. (2005) and Robert et al. (2007) restrict the ORG to deposits composed of quartz–carbonate veins and associated wall rock replacements and their equivalents hosted in metamorphosed terrains associated with compressional or transpressional geological structures such as reverse faults and folds formed at mid-crustal levels. The auriferous zones are located on regional structures where there are large scale discontinuities with strike-slip duplexes (Sibson, 1990; McCuaig and Kerrich, 1998; Kerrich et al., 2000). So far, more than hundred gold deposits of this nature have been reported from different parts of the world (Goldfarb et al., 2005). Further, in orogenic deposits, three main types are distinguished based on their host-rock environment: greenstone-hosted (e.g. Dome; Norseman, Groves et al., 2003; Goldfarb et al., 2005), turbidite-hosted (e.g. Bendigo, Stawell, Victoria; Hodgson, 1993; Bierlein et al., 2000; Robert et al., 2005) and BIF-hosted (e.g. Homestake, Lupin; Caddey et al., 1991; Kerswill, 1996). Gold deposits hosted by turbidites have wide distribution throughout the world, occurring in rocks ranging in age from Archean to Tertiary; their abundance is less compared to greenstone hosted gold deposits. However, turbidite hosted terrains have been important sources of gold, particularly in Victoria of Australia, Nova Scotia, Canada, SE Guighou, China (Kontak et al., 1990; Cox et al., 1995; Lu et al., 2005).

Three main types of orogenic gold deposits are present in various Neoarchean greenstone belts of Dharwar Craton of southern Peninsular India. They are metavolcanic-hosted deposits in Kolar, Hutti, Ramagiri and Mangalur belts, turbidite-hosted deposit of Gadag belt and BIF-hosted deposits of Kolar, Chitradurga and Gadag belts (Narayanaswamy and Ahmed, 1963; Rao and Reddy, 1985; Ugarkar and Tenginkai, 1988; Sawkar et al., 1995; Ugarkar and Deshpande, 1999). The Archean Gadag greenstone belt (Fig. 1) hosting gold mineralization in all the three types of host rocks, which is the subject of present paper, forms the most deserving example of orogenic type of gold mineralization. This is the only greenstone belt in the Dharwar Craton, where gold mineralization occurs in turbidite sequence, apart from metavolcanics and banded iron formations in a duplex structure (Gadag duplex). A complete study of characteristics of mineralization and geological anatomy of such a gold deposit is of fundamental importance for better understanding of the evolution of the greenstone belt and gold mineralization event. The present paper deals with the field, petrographic, mineralogical, geochemical and ore fluid characteristics of turbidite hosted Central Auriferous Zone and host rocks in understanding gold mineralization and prevailing geodynamics in the Gadag greenstone belt.

2. Regional geology

The Dharwar Craton, which includes several Archean greenstone belts, is one of the ideal terrains for understanding the nature of the Archean crustal evolution and metallogeny. The craton has been divided into two distinct blocks, the Western Dharwar Craton (WDC) and the Eastern Dharwar Craton (EDC) based on the nature and abundance of greenstones, crustal thickness, grade of regional metamorphism and degree of melting (Swami Nath et al., 1976; Rollinson et al., 1981; Jayananda et al., 2006; Chardon et al., 2011). The steep mylonitic zone, a major thrust-fault contact (Chitradurga Thrust Fault) along the eastern margin of the Chitradurga greenstone belt, extending over a length of 400 km from Gadag in the north to Mandya in the south is considered as the boundary between the two blocks (Kaila et al., 1979; Chadwick et al., 2000; Sengupta and Roy, 2012). The volcano-sedimentary association present in the greenstone terrains of the WDC and EDC displays distinct geodynamic settings, as deciphered by recent petrological and geochemical studies (Balakrishnan et al., 1999; Manikyamba et al., 2008, 2014; Manikyamba and Kerrich, 2011; Jayananda et al., 2013, 2014; Ugarkar and Nyamati, 2002; Ugarkar et al., 2000, 2013). Based on combined U–Pb zircon ages and Nd isotope data, the craton has been divided into three provinces western (3.4 to 3.2 Ga), eastern (3.4 to 3.2 Ga) and central with mixed old and younger crust (3.4 to 3.2 Ga and 2.56 to 2.52 Ga) and eastern with mainly younger (2.56 to 2.52 Ga) crust (Peucat et al., 2013; Jayananda et al., 2013). However, the western and eastern greenstone terrains record different geological, geophysical and structural characteristics (Manikyamba et al., 2014; Borah et al., 2014). The WDC is dominated by old basement (>3.2 Ga TTG with interlayered Sargur Group greenstone belts) which is unconformably overlain by 2.9 to 2.7 Ga Dharwar Supergroup volcano-sedimentary greenstone belts (Swami Nath and Ramakrishnan, 1981; Nutman et al., 1996; Peucat et al., 1993; Jayananda et al., 2008, 2012; Sarma et al., 2011). The Dharwar Supergroup is divided into a lower Bababudan Group and an upper Chitradurga Group (Swami Nath and Ramakrishnan, 1981). The EDC comprises younger (2.7 to 2.6 Ga) gray tonalitic gneisses with large remnants of 3.0 to 3.32 Ga TTG (Krogstad et al., 1991; Peucat et al., 1993; Balakrishnan et al., 1999; Jayananda et al., 2000; Chardon et al., 2002), thin elongated 2.7 to 2.56 Ga volcanic dominated gold bearing greenstone belts of Kolar Group and diamondiferous kimberlites (Swami Nath et al., 1976; Balakrishnan et al., 1990, 1999; Jayananda et al., 2012). The whole Archean crust in the Dharwar Craton was affected by at least four major tectonothermal events at 3.24 Ga, 3.1–3.0 Ga, 2.62 Ga and 2.51–2.45 Ga (Peucat et al., 1993, 2013; Jayananda et al., 2011, 2013; Chalapathi Rao et al., 2013). The craton corresponds a large tilted oblique section of the Archean continental crust, and from north to south in the craton, in general, there is a progressive increase in the grade of metamorphism from greenschist facies to granulite facies.

In the WDC, the Sargur Group greenstone sequences are dominated by 3.35 Ga komatiite–basalt metavolcanic sequences with interlayered sediments corresponding to shelf environment (Naqvi and Rogers, 1987; Jayananda et al., 2008). The lithounits comprise banded iron formations, fuchsite quartzite of detrital origin, metapelites, basaltic amphibolites, metaperidotites, and stratiform gabbro anorthosites (Radhakrishna and Vaidyanathan, 1997). Metamorphic grade in the Sargur is amphibolite facies grading into granulite facies (Swami Nath and Ramakrishnan, 1981). Chromite, barite, magnesite, titaniferous magnetite, nickel, platinum and copper mineralization occur in the Sargur Group (Radhakrishna and Vaidyanathan, 1997; Devaraju et al., 2009). The Bababudan Group comprises mafic–ultramafic volcanics, arenites, phyllites, polymict and oligomictic conglomerates and banded iron formations (Swami Nath and Ramakrishnan, 1981; Naqvi and Rogers, 1987). Thin lenses of carbonate rocks are, however, seen with iron formations. Manganese formation is conspicuously absent in this group. The metamorphism is mainly amphibolite facies at the borders of the belts with greenschist facies at the portions. The Chitradurga Group comprises mafic–ultramafic volcanic rocks, banded iron formations, arenites, phyllites, stromatolitic carbonates, carbonaceous phyllites, polymict and oligomict conglomerates, graywackes and felsic metavolcanics (Swami Nath and Ramakrishnan, 1981). The