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Geochemical characteristics of gold bearing boninites and banded iron formations from Shimoga greenstone belt, India: Implications for gold genesis and hydrothermal processes in diverse tectonic settings

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ABSTRACT

This paper is the first documentation of boninites from the Kudrekonda Formation of Shimoga greenstone belt (SGB) in western Dharwar Craton (WDC), India and the occurrence of native gold in the associated quartz veins. We also investigate the gold mineralization hosted in the banded iron formations (BIFs) of Ganajur, Karajgi and Palavanahalli areas of the SBG. The Kudrekonda metavolcanic rocks are composed of clinopyroxene, orthopyroxene and plagioclase with secondary amphibole. The geochemical attributes of these rocks, based on MgO, TiO_2 Ni, Cr and Co contents, Al_2O_3/TiO_2, $(Gd/Yb)_N$ and $(La/Sm)_N$ ratios, classify them as boninites and their relative LILE-HFSE abundance suggests magma generation in an intraoceanic arc setting. The Gd/Yb and Dy/Yb ratios suggest parent magma origin through partial melting of a spinel lherzolite mantle source. Geochemical signatures of the boninites suggest high temperature, shallow level melting of refractory mantle wedge metasomatized by fluids derived through dehydration of oceanic slab during subduction initiation. Quartz veins present in the Kudrekonda boninites contain gold grains showing affinity towards quartz-carbonate vein type greenstone hosted occurrences. EPMA data record 88.5–90.3 wt.% Au content with 7.7–8.4 wt.% Fe, 0.05–2.1 wt.% S and negligible Ag. The Au is hosted in Fe-oxides. Bulk chemical analyses show 4.1–684.4 ppb Au and 139.4–2186.4 ppb Ag in the studied samples. The gold mineralization of Kudrekonda boninites is syngenetic, mesothermal, convergent margin orogenic type. Decarbonation, desulphidization and metamorphism of subducted oceanic lithosphere and devolatilization of metasomatized enriched mantle wedge in intraoceanic arc setting are the viable processes that contributed to gold genesis in the Kudrekonda boninites. Devolatilization during prograde metamorphism, hydrothermal fluid generation, syntectonic gold remobilization and migration of gold enriched fluids through shear zones account for Au transportation and precipitation in quartz veins emplaced within the boninites. The BIFs of Ganajur, Karajgi and Palavanahalli areas of Shimoga greenstone belt dominantly comprise alternating Si-rich layers of quartz and Fe-rich hematite and magnetite layers. Geochemical characteristics of the BIF samples including their depleted ΣREE, positive Eu anomalies, negative to negligible Ce anomalies, and superchondritic Y/Ho ratios suggest that the BIFs were (i) derived by chemical sedimentation from paleo-ocean enriched in dissolved iron and silica with marked contributions from hydrothermal fluids of volcanic origin, and (ii) deposited in an off-shelf marine environment proximal to a mid-oceanic spreading centre where hydrothermal activity induced release of Eu and Y enriched hydrothermal solutions under low oxygen fugacity conditions. Native gold occurs in banded strata-bound disseminated sulphide lenses compositionally characterized as pyrite, arsenopyrite, chalcopyrite and galena. Mineral chemical analyses reveal 73–100% Au content with variable concentrations of Ag (0.02–15.2 wt.%). Geochemical compositions of BIFs are characterized by pronounced enrichment in Au (706–15,831 ppb) and Ag (630–2435 ppb). Gold mineralization in Shimoga BIFs is epigenetic, epithermal type akin to Homestake type iron-formation hosted vein and disseminated lode gold deposit. Gold genesis in these BIFs is attributed to migration of oxygen depleted, reducing, sulphidic–auriferous fluids of hydrothermal origin to the site of BIF deposition that served as chemical traps for the auriferous fluids. The Kudrekonda boninites represent accretion and preservation of a slice of older oceanic crust onto a relatively younger, active continental margin through arc–continent collision during Neoarchean time.

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1. Introduction

The Neoarchean period (2.7 Ga), marked by a peak in crustal growth, development of volcano-sedimentary greenstone sequences, komatiite-basalt volcanism, large scale deposition of banded iron formations (BIFs), cratonization, regional deformation and metamorphism, development of shear zone systems, generation of deep-seated hydrothermal fluids, remobilization and mineralization of precious metals, represents an important timeframe in the geological evolution of Archean shield areas (Isley and Abbott, 1999). The Archean cratons and late Neoproterozoic–Phanerozoic fold belts around the world are characterized by a variety of mafic and felsic igneous rocks and sediments including BIFs that host mesothermal orogenic gold deposits (Zhai and Santosh, 2013, Goldfarb and Santosh, 2014). The geological and geodynamic settings, nature of host rocks, structural control, depth of formation, ore–fluid oxidation state are the key parameters that control gold mineralization (Robert et al., 1997; Groves et al., 1998; 2005). On the basis of their geodynamic setting, gold deposits over the globe have been classified as convergent margin orogenic, continental margin to intracratonic Carlin type, arc related epithermal gold–silver deposits, oceanic arc to continental arc copper–gold porphyry deposits, orogenic to late orogenic iron oxide copper gold deposits and gold rich submarine volcanic hosted massive sulphide (VMS) to sedimentary exhalative (SEDEX) deposits (Kerrich et al., 2000; Li and Santosh, 2013; Guo et al., 2013; Groves and Santosh, 2015).

The concentration of orogenic gold deposits at 2.8–2.55 Ga, 2.1–1.75 Ga and 750–735 Ma corresponds to well defined periods of lithospheric growth at continental margins. This contention is consistent with the fact that gold mineralization is associated with addition of new oceanic lithosphere onto older cratonic margins through mantle plume activity and subduction accretion events (Condie, 2000; Kerrich et al., 2000; Groves et al., 2005). The metallogenesis of orogenic gold mineralization associated with Archean granite–greenstone terranes is primarily controlled by structural style, tectonic setting, metamorphism of host and associated rocks, timing of mineralization with respect to metamorphism and intrusive activity, alteration geochemistry, shear zone activity, hydrothermal system involving physico-chemical processes and flow of hydrothermal fluids for mobilization, transportation and deposition of gold (Goldfarb et al., 2001; Groves et al., 2003). Gold deposits hosted in metasedimentary rocks have spatial and temporal association with collisional orogens and are referred to as synorogenic gold deposits. The widespread distribution of these deposits throughout the accreted terranes of western North America suggests a direct association between continental growth and ore genesis (Barley et al., 1989; Kerrich and Wyman, 1990). Gold ores have formed both in interior orogens developed between large land masses during continent–continent collision (Appalachian–Caledonian, Hercynian, Uralian) and in peripheral orogens built during subduction of oceanic crust along continental margins (Cordilleran, Tasman). Collisional tectonic activities trigger crustal heating that is critical for devolatilization reactions and ore fluid formation (Powell et al., 1991; Phillips, 1991; Goldfarb et al., 1993). Transform movements along major crustal fault zones, contemporaneous or subsequent to heating also play a vital role for ore-forming process leading to relaxation of regional compressive forces and enhanced crustal-scale permeabilities. In many Phanerozoic belts, however, subordinate mafic volcanic rocks are interbedded with slates and graywackes which reflect contemporaneous sedimentation and oceanic arc or ridge volcanism prior to collision. Synorogenic mesothermal gold deposits are predominantly hosted by oceanic sedimentary rocks and despite a wide range in *P*–*T* of ore formation, these are widely-distributed in accreted terranes.

In India, gold mineralization has been documented from a wide variety of litho-assemblages such as i) lode gold occurring in quartz-carbonate veins of metamorphosed volcanic rocks of Archean greenstone belts, such as the gold mineralization in Kolar and Hutti, Ramagiri-Penakacherla, Gadag and Ajjanahalli greenstone belts of Dharwar Craton (Manikyamba, 2000; Manikyamba et al., 2004; Pal and Mishra, 2004); ii) gold and associated sulphides in Neoarchean BIFs, such as the gold mineralization in Shimoga, Chitradurga and Sandur greenstone belts of Dharwar Craton (Manikyamba et al., 1997; Naqvi et al., 1998; 1999), Sonadehi in Madhya Pradesh; iii) vein and stratiform type gold deposits in southern granulite terrain (SGT), as exemplified by the Wyanad region of Kerala; iv) disseminated gold occurring in extrusive and intrusive igneous rocks, as represented by the Malanjkhand in Madhya Pradesh; v) gold in association with base metals like copper, lead, zinc occurring in Proterozoic volcanogenic polymetallic sulphide deposits, as seen in Khetri in Rajasthan, Rakha in Bihar; vi) detrital gold occurring in quartz-pebble conglomerates and quartzites, e.g. Dhanjori in Bihar, Bababudan in Karnataka, Cuddapah in Andhra Pradesh, vii) gold occurring in greywacke or turbidites of Neoarchean sedimentary successions along with volcanic intercalations e.g. Gadag in Karnataka; viii) detrital gold occurring in river alluvium and placers; and ix) gold occurring in laterites, soil and weathering profiles e.g. Nilambur valley in Kerala (Santosh and Omana, 1991). Gold mineralization in metabasalts, felsic volcanic rocks and banded iron formation is known from various greenstone belts of Dharwar Craton.

In the present paper, we report for the first time gold mineralization in the boninites of Kudrekonda, and document their geochemical characteristics based on which we evaluate the genesis of gold. We also discuss the gold mineralization hosted in BIFs from Ganajur, Karajgi and Palavanahalli areas of Shimoga greenstone belt in western Dharwar Craton (WDC). This paper reports boninites for the first time from the Shimoga greenstone belt in WDC and present the mineral chemical and whole rock geochemical data of gold bearing lithologies from these regions to address their genesis and evaluate the role in crustal growth and tectonic evolution of Shimoga greenstone belt.

2. Geological setting

The granite greenstone associations and intrusive granitoids of Dharwar Craton in southern peninsular India comprise a vast section of Meso-Neoarchean continental crust and range in age from 3.4 to 2.5 Ga (Swami Nath and Ramakrishnan, 1981; Naqvi and Rogers, 1987; Naqvi, 2005; Ramakrishnan and Vaidyanadhan, 2010; Jayananda et al., 2006, 2013a,b; Yang et al., 2014). The broad lithological components of the Dharwar Craton are represented by 3.36–2.7 Ga tonalite–trondhjemite–granodiorite (TTG) Peninsular gneisses, two generations of volcano-sedimentary sequences of 3.3–3.1 Ga Sargur Group and 2.9–2.5 Ga Dharwar Supergroup greenstone belts and 2.6–2.51 Ga calc-alkaline to potassic granitoid plutons (Chadwick et al., 2000; Moyen et al., 2003; Jayananda et al., 2008; Chardon et al., 2011; Fig. 1A inset).

The volcano-sedimentary sequences of 2.9–2.6 Ga Dharwar Supergroup are exposed in Bababudan, Chitradurga and Shimoga greenstone belts (Fig. 1A). The Bababudan Group includes oligomictic conglomerate, quartzite, phyllite, mafic–felsic volcanic rocks, tuffs and thick sequence of BIFs. The mafic volcanic rocks of Bababudan Group have an Sm–Nd whole rock isochron age of 2.9–2.8 Ga (Kumar et al., 1996) and zircons from felsic volcanic tuffs yield 2.2 Ga age (Trendall et al., 1997a,b). The Chitradurga Group comprises polymictic conglomerates, greywackes, argillites and limestones with intercalations of mafic-felsic volcanic rocks and BIFs (Chadwick et al., 1991). In general, the greenstone belts of WDC consists of ultramafic–mafic sequences, basalt–andesite–dacite–rhyolite (BADR), banded iron and manganese Formations, cherts, conglomerates, quartzites, greywackes and phyllites (Fig. 1A). The Dharwar Supergroup greenstone belts also consist of subordinate komatiites and komatiitic basalts besides predominant mafic–felsic volcanic rocks (Chadwick et al., 1991, Naqvi, 2005; Manikyamba et al., 2013, 2014a,b). The Shimoga greenstone belt is divided into Jhandimatti, Joldhal, Medur and Ranibennur Formations (Harinadha Babu et al., 1981; Fig. 1B). Detailed studies by Chadwick et al. (1991) have divided the Dharwar Supergroup rocks occurring adjacent to the Honnali dome of the Shimoga greenstone belt into three stratigraphic units viz.