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Volcano-sedimentary and metallogenic records of the Dharwar greenstone terranes, India: Window to Archean plate tectonics, continent growth, and mineral endowment

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ABSTRACT

The Dharwar Craton in southern peninsular India incorporates well developed Meso-Neoarchean greenstone terranes where komatiite-tholeiite and picrite-boninite-Nb-enriched basalt-high Mg-andesite- and adakite are well-preserved. These lithological associations, their geochemical and geochronological features offer important insights on mantle plume and subduction zone processes in the early Earth. The juxtaposition of these lithounits in most of the greenstone belts of western (WDC) and eastern (EDC) sectors of the Dharwar Craton attests to plume-arc accretion, generation of continental lithosphere and related mineral deposits. The iron and manganese deposits of the greenstone belts of WDC endorse the oxygenated protooceans and biogeochemical processes that are evidenced through the stromatolitic carbonates/cherts. The larger greenstone terranes of WDC and their gradual transition into smaller and fragmented belts appear to reflect a gradual change from plume-arc to arc-continent collision and the Archean higher geothermal gradient. The smaller plates and large number of subduction zones provided ideal setting for the generation of major metallic mineral deposits of Cu, Pb, Zn and Au. The shallow to deeper shelf environment became suitable loci for the deposition of iron and manganese formations. Secular cooling of the mantle was accompanied by a transition from stagnant lid tectonics to rapid development of plate tectonics from 3.5–2.0 Ga with a peak of mantle plumes, crustal growth, BIF deposition and gold mineralization in the greenstone terranes of the Dharwar Craton. The transition from mantle plume activity to subduction zone tectonics recorded in the greenstone belt lithologies of WDC and EDC provide insights into the thermal and tectonic transition in our planet during Archean.

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1. Introduction

The geological features that have secluded our Earth from its close equivalents in the solar system include an atmosphere with appropriate ingredients to support life, large oceans of liquid water making up the hydrosphere and an active lithosphere comprising large tectonic plates that move apart, converge and dip beneath each other giving way to asthenopheric outpouring through volcanoes, triggering earthquakes, forming orogenic belts and continental landmasses. However, the concept of fragmentation of rigid lithosphere (oceanic and continental) into plates, their lateral movements over liquid asthenosphere and recycling at subduction zones, as propagated by the theory of modern plate tectonics, cannot be envisaged during the early stages of the earth's history considering the higher temperatures of Archean mantle with thick, dense and magnesium rich primordial crust of the Earth (Cawood et al., 2006; Stern, 2002, 2016). Since its inception as a hot, rounded mass of volatiles and planetesimals, a silicate planet like earth has been shaped and modified over time by early heating, accretion, differentiation, impacts, radioactivity subsequently followed by gradual cooling, thickening and formation of a dense and strong lithosphere. The temporal evolution of the earth has been affected by several magmatic styles and tectonic cycles, the most significant stages being represented by (i) stagnant lid tectonics (4.6–3.0 Ga) followed by plate tectonics (3.0 Ga onwards; Stern, 2016; Johnson et al., 2014; Tang et al., 2016). The earth just after its accretion had a shallow magma ocean stage that experienced differentiation, crystallization and stirring by mantle convection. The magma ocean lasted for several million years after the giant impact and crystallized to form primordial crust that enveloped the earth as a single, unstable lid (Hamano et al., 2013; Stern, 2016; Ichikawa et al., 2017). The primordial crust gradually cooled, thickened and was punctured by conduits of magma called heat pipes that allowed outpourings of asthenospheric melts. The magma accumulations and progressive thickening caused vertical descent of primordial crust called “drips” accompanied by upwelling of asthenosphric mantle material (Stern, 2016). Geodynamic modelling and computer simulations have suggested that the base of magmatically over-thickened primordial crust became gravitationally unstable at mantle temperatures >1550 °C and sank by a process called delamination that was again counterbalanced by asthenospheric upwelling and melting. At this stage, the unstable lid tectonics gradually progressed to subduction erosion and recycling of primordial crust into the mantle through subduction channels that marked the onset of plate tectonics on earth (Ichikawa et al., 2017; Azuma et al., 2016). Operation of plate tectonics during the early history of the Earth and the tripartite interactions between lithosphere, hydrosphere and atmosphere played a vital role for life forming processes and nurtured the Earth to a habitable state (Dohm and Maruyama, 2015; Santosh et al., 2016a).

The granite-greenstone belts preserved in ancient cratonic nuclei of continents provide significant geological evidences for the evolution of the earth, mantle dynamics, crust-mantle interactions, crustal growth and various metallogenic processes which operated during the Precambrian (De Wit and Ashwal, 1995; Kerrich et al., 1999a, 1999b; Smithies et al., 2003, 2009; Hegner et al., 2007; Polat, 2012).The greenstone belts of Archean cratons of the world composed of various lithological assemblages which preserve distinct geological and geochemical imprints of mantle evolution, varying conditions of magma generation, ancient subduction processes, plume-arc interactions, tectonic episodes of crustal accretion and continental growth, hydrothermal activity, remobilization and formation of major metallic ore deposits (Kerrich et al., 1998; Polat et al., 1998; Hollings and Kerrich, 2000; Polat and Kerrich, 2001; Manikyamba et al., 2004a, 2004b, 2005, 2008, 2009, 2012, 2014a, 2014b; Zhai and Santosh, 2011; Furnes et al., 2013). Archean greenstone belts are predominantly composed of variably metamorphosed and deformed ultramafic-mafic to felsic volcanic and siliciclastic sedimentary rocks (Condie, 2005; Condie and Kröner, 2013). There are also volumetrically minor banded iron formations (BIF), gabbros, anorthosites, serpentinites, cherts, and carbonates (locally stromatolitic) in some belts (Goodwin, 1977; Smithies et al., 2005). The genesis of Archean ultramafic-mafic rocks, as attributed either to extrusive magmatism of mantle origin or to the crystallization of layered intrusions of subvolcanic magma chambers, is one of the important aspects of mantle evolution. The ultramafic-mafic magmatism of Archean greenstone sequences are associated with a wide variety of tectonic settings ranging from intraoceanic (oceanic crust or oceanic plateau) to oceanic ridge, forearc basin, marginal back arc basin and active continental rift environments (Polat et al., 1998; Polat and Kerrich, 2006). The studies