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Review

Precambrian geodynamics and metallogeny of the Indian shield

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ABSTRACT

In this overview, the Precambrian metallogeny in the Indian shield has been summarized in the backdrop of the evolution of different crustal domains and their linkages to the geodynamic history of the shield. The northern cratonic block (NCB) of the Indian shield is constituted by the Bundelkhand massif (BM), Aravalli–Delhi orogenic belt (ADOB), Shillong plateau and the Himalayan Proterozoic belts and is separated from the larger southern cratonic block (SCB) comprising the Singhbhum craton (SC), Bastar craton (BC), Dharwar craton (DC, including WDC, EDC as well as the Southern Granulite Terrain (SGT)) and the Eastern Ghat mobile belt (EGMB) by the ENE–WSW-trending Central Indian Tectonic Zone (CITZ). These two cratonic blocks are constituted by a few distinct crustal domains: the Archean cratonic nuclei and the Gneissic complexes with the granulitic or granite–greenstone terranes and the Proterozoic mobile belts and intra-cratonic basins, along with the anorogenic volcano-plutonic complexes and mafic dyke swarms. Within the various litho-tectonic domains of the Indian shield are concentrated vast resources of iron, manganese and aluminum and notable resources of chromium, copper, lead, zinc and uranium. There are also significant reserves of gold and tungsten as well as rare concentration of tin and platinoid metals. Titanium along with thorium and other REE are now largely concentrated in coastal placer deposits. Out of these, the Al and REE (including Th and Ti) resources, although derived from Precambrian rocks, are the products of metallogenic processes in the Mesozoic and Cenozoic eras, and have been left out of the discussion.

Metallogeny in the Indian shield spanned over a long period of 2.9 Gyr (~3.6 to 0.7 Ga) during five specific epochs. The earliest mineralization (+3.5 Ga) is recorded from a BIF in SC. Paleo- to Mesoarchean (~3.3 to 3.1 Ga) saw the formation of Ti–V–Fe, Cr + PGM, Au, Cu and Fe (BIF) in WDC and SC respectively. Intense and economically important metallogeny took place in Neoarchean (2.7 to 2.5 Ga) in SC, BC and DC represented by Fe, Mn, Cu–Mo, Sn, and Au and in Paleo- to Mesoproterozoic (2.2 to 1.5 Ga) in the mobile belts of SC, CITZ, ADOB and the Himalaya (Au, Cu–U, P–Fe, Mn, Zn–Pb–Cu, Pb–Zn deposits) and in intra-cratonic basins (Mn, Pb–Zn, U). In Neoproterozoic (1.0–0.75 Ga), the western fringe of ADOB saw VMS-type Zn–Pb–Cu and Zn–Cu mineralization as well as granite-related Sn–W deposits. Three of these metallogenic epochs coincide closely with Precambrian Supercontinent assembly of Kenorland (~2.7 Ga), Columbia (~1.8) and Rodinia (~1.0 Ga) respectively, as well as with the peaks of juvenile crustal growth in Neoarchean and Paleoproterozoic.

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1. Introduction

Ore deposits represent anomalous metal concentration in the earth's crust produced by various endogenous and/or exogenous ore-forming processes triggered by a variety of geological phenomena in the lithosphere. Since ore-forming (ore genetic) and rock-forming (petrogenetic) processes are now understood to be broadly similar, metallogeny is widely accepted to be part and parcel of crustal evolution through geological time (Barley and Groves, 1992; Groves and Bierlein, 2007; Windley, 1995). A major objective of all metallogenic studies is to develop detailed deposit-specific information from different ore districts and in a larger scale, from different metallotects (Routhier, 1963) and then integrate the data with the broader geological framework of a province. This exercise can shed light on some fundamental issues of ore genesis, viz., how, when, where, and why ore deposits are formed through an understanding of their spatial, temporal and chemical–lithological characteristics (Mookherjee, 1999). In a wider perspective, knowledge of these critical aspects of metallogeny generates a comprehensive insight into the geodynamic evolution of a metal-endowed segment of the continental crust, that is, of a metallogenic province and also that of the underlying sub-continental lithospheric mantle (SCLM).

Mineral deposit types commonly have a distinctive temporal distribution with peaks at some specific periods of the earth's history (Meyer, 1985; Veizer et al., 1989) leading to the concept of metallogenic epochs. Thus, some ore deposits may be considered to be products of processes which characterize time-specific types of geologic environment. On the other hand, there are other deposits which are episodic in nature and are restricted to specific geological time and environment. The temporal distribution of mineral deposit types also reflect formational and preservational potential which were coupled in the Archean or Paleoproterozoic but were decoupled in the Neoproterozoic due to the evolution of a thinner, increasingly dense SCLM. The heterogeneous temporal distribution of mineral deposit type is clearly linked to earth's progressive cooling with time and its geodynamic evolution (Groves and Bierlein, 2007) from deep-seated plume-induced and oceanic platelet tectonics in the Hadean–Archean (4.4 to 2.7 Ga) through stagnant-lid convection in the mantle involving large, buoyant lithospheric plates in the Proterozoic (2.7 to 1.0 Ga) (Brown, 2007; Ernst, 2009; Kerrich and Polat, 2006) to modern-day type of plate tectonics in the Phanerozoic.

The purpose of the present article is to provide an overview of the Precambrian metallogeny of India, considered in the framework of the geological and geodynamic evolution of the Indian sub-continent. However, it needs to be mentioned at the outset that in this contribution geodynamic evolution has been traced using geochronology and geological processes such as magmatism, deformation, metamorphism and metallogeny and does not include the geophysical components of the solid earth and neither involves any physico-chemical and mathematical modeling to understand mantle convection and plate tectonics, formation of mobile belts and intra-cratonic basins, etc.

2. Physiography & geology

The total landmass of India (~3.3 million km^2) geographically comprises three major physiographic provinces: (i) the peninsular region fringed by the narrow coastal plains along the seaboards, bounded northward by (ii) the Indus–Ganga–Brahmaputra alluvial plains and the Thar desert to the west and (iii) the extra-peninsular region comprising the girdle of lofty Himalayan range and the Naga–Lushai hills in the north-east (cf. Vaidyanadhan, 2002) (Fig. 1).

The Indian shield represented by the peninsular region extends up to the southern edge of the Himalaya, underneath the alluvial deposits of northern India and comprises predominantly Precambrian rocks in two cratonic blocks with a few notable exceptions. These are the large patch (covering about 0.5 million km^2) of Upper Cretaceous Deccan traps in west-central India, the terrigenous coal-bearing Gondwana rocks, mainly in eastern and central India (Son–Narmada–Damodar basin, Satpura–Wainganga basin, Mahanadi basin and Pranhita–Godavari basin), Jurassic rocks of the Kutch region, Cretaceous marine sediments along the eastern coast in Tamil Nadu and the Cretaceous–Tertiary sediments of the Krishna–Godavari rift basins, and a roughly triangular zone of Tertiary rocks in Assam, east of Bangladesh (Fig. 1). Volcano-sedimentary units as well as magmatic intrusives of Precambrian age occur in patches along the lesser (lower) Himalaya and appear connected to the peninsular shield through three fault-controlled ridges under the 3000–7000 m thick sand and clay cover of the Indus–Ganga–Brahmaputra plains, which forms a foreland basin to the young fold mountain, the Himalaya. These are (from west to east): (i) Delhi–Hardwar ridge, a continuation of the NNE-trending Aravalli hills; (ii) Faizabad ridge, a NE-extension of the Bundelkhand massif and (iii) the Mungher–Saharsa ridge, a northward extension of the Satpura belt (cf. Valdiya, 2010) (Fig. 2).

3. Crustal architecture & crustal domains of the Indian shield

The crustal architecture of the Indian shield is defined by two large scale crustal blocks separated by a prominent ENE–WSW-trending Proterozoic mobile belt. The northern cratonic block (NCB) comprises the Bundelkhand massif (BM) in north-central India and the Aravalli–Delhi orogenic belt (ADOB) enclosing two tectonic blocks of the Banded Gneissic Complex (BGC) basement in north-west India, along with the outlying segment of Shillong Plateau in the north-east and the Himalayan Proterozoic belts in the north. The larger southern cratonic block (SCB) comprises the Singhbhum or Eastern Indian craton (SC), Bastar or Central Indian craton (BC), Dharwar or South Indian craton (DC, comprising the western, WDC and eastern, EDC segments) as well as the Southern Granulite Terrain (SGT), and the Eastern Ghat mobile belt (EGMB). The Central Indian Tectonic Zone (CITZ) of Proterozoic age separates the two cratonic blocks (Fig. 2) and forms a composite zone comprising the Mahakoshal belt in the north followed southwards by the Betul belt, Sausar and Sakoli belts and the Kotri belt. The CITZ is ca. 100 km wide and is marked by an aborted rift and intense shearing that got reactivated from time to time since Proterozoic (Acharyya and Roy, 2000) and now hosts two important west-flowing rivers,