Journal of Asian Earth Sciences 78 (2013) 83–99

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Arc magmatism in the Delhi Fold Belt: SHRIMP U–Pb zircon ages of granitoids and implications for Neoproterozoic convergent margin tectonics in NW India

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ARTICLE INFO

Article history:
Available online 11 October 2012

Keywords:
Sirohi terrane
Aravalli Mobile Belt
South Delhi Terrane
Granites
Zircon U–Pb SHRIMP geochronology
Neoproterozoic

ABSTRACT

The northwestern region of Peninsular India preserves important records of Precambrian plate tectonics and the role of Indian continent within Proterozoic supercontinents. In this study, we report precise SHRIMP zircon U–Pb ages from granitoids from the Sirohi terrane located along the western fringe of the Delhi Fold Belt in Rajasthan, NW India. The data reveal a range of Neoproterozoic ages from plagiogranite of Peshua, foliated granite of Devala, and porphyritic granite of Sai with zircon crystallization from magmas at 1015 ± 4.4 Ma, 966.5 ± 3.5 and 808 ± 3.1 respectively. The plagiogranite shows high SiO_2, Na_2O and extremely low K_2O, Rb, Ba, comparable with typical oceanic plagiogranites. These rocks possess low LREE and HREE concentrations and a relatively flat LREE–HREE slope, a well-developed negative Eu-anomaly and conspicuous Nb and Ti anomalies. Compared to the plagiogranite, the foliated Devala granite shows higher SiO_2 and moderate Na_2O, together with high K_2O and comparatively higher Rb, Ba, Sr and REE, with steep REE profiles and a weak positive Eu anomaly. In contrast to the plagiogranite and foliated granite, the porphrytic Sai granite has comparatively lower SiO_2 moderately higher Na_2O, extremely high Y, Zr, Nb and elevated REE. The geochemical features of the granitoids [HFSE depletion and LILE enrichment, Nb- and Ta-negative anomalies], and their plots in the fields of Volcanic Arc Granites and those from active continental margins in tectonic discrimination diagrams suggest widespread Neoproterozoic arc magmatism with changing magma chemistry in a protracted subduction realm. Our results offer important insights into a long-lived active continental margin in NW India during early and mid Neoproterozoic, consistent with recent similar observations on Cryogenian magmatic arcs widely distributed along the margins of the East African Orogen, and challenge some of the alternate models which link the magmatism to extensional tectonics associated with Rodinia supercontinent breakup.

1. Introduction

The Neoproterozoic Era witnessed one of the most dynamic periods in Earth's history with the closure of ocean basins and subduction of oceanic lithosphere along a number of convergent margins associated with the assembly of at least two major supercontinents – Rodinia and Gondwana (Collins et al., 2007; Santosh et al., 2009a,b; Boger, 2011; Johnson et al., 2011). However, continental fits as well as the timing of formation and dispersal remain uncertain due to scarcity of geochronological and palaeomagnetic data for many of its constituent terranes (Torsvik et al., 2001a,b).

The NW Indian terrane is a key component in the paleogeographic reconstruction of Late Precambrian Rodinia accretion, break-up and its subsequent dispersal (Dalziel, 1991; Santosh, 2012). Geochronological and tectonic information from this region are therefore critical in evaluating the role and position of the Indian continental fragment with respect to supercontinental framework. Granitoid intrusions are ubiquitous components of the major orogenic belts in southwestern Rajasthan in NW India, and their geochemical and geochronological constraints provide useful criteria to identify geodynamic settings. Of particular interest in evaluating the Neoproterozoic history is the widespread felsic magmatism in the Sirohi region in South Delhi Fold Belt of Rajasthan.

The southern sector of the Delhi Fold Belt (DFB) is considered to represent a Grenville age (~1 Ga) arc terrane (e.g. Deb et al., 2001; Pandit et al., 2003), the formation of which coincides with the broad timing of amalgamation of crustal blocks within the Rodinia supercontinent. The western margin of the DFB along which the granitoids of present study are emplaced is regarded as a Proterozoic suture (Gupta et al., 1980). The ophiolite suite in Phulad and the ophiolite mélange in Basantgarh along the 300 km long and

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http://dx.doi.org/10.1016/j.jseaes.2012.09.007

20–50 km wide suture further supports this region to represent a major zone of ocean closure (Dharma Rao et al., 2012). Previous geochronological data including the 1024 ± 78 Ma age of Ranakpur diorites from the Phulad suite (Volpe and Macdougall, 1990) and the 987 Ma, and 968 Ma ages for rhyolites from this sector (Deb, 2001; 968.3 ± 1 Ma) are coeval with the arc magmatism in this terrain. Mafic rocks of the Phulad Suite are juxtaposed with shallow water sediments in the east followed by platformal and continental slope sediments further east indicating a gradual thickening of the crust from west to east and an eastward subduction polarity (Khan et al., 2005). Sandwiched between these is the high-grade metamorphic suite of the Sandmata Complex, thus representing a typical Pacific-type orogen where the high-grade metamorphic belt extruded during the final collision and slab break-off in a subduction regime (Santosh, 2012). The Sirohi terrane thus represents a critical link in understanding the processes and timing of the suturing as it lies close to Proterozoic suture and on the interface between the two well-established ophiolite suites.

In this contribution, we present new geochemical as well as precise SHRIMP U–Pb zircon ages of zircons from granitic rocks from the Sirohi terrane which reveal major pulses of Neoproterozoic arc-related magmatism in the Sirohi terrane. Our results have important implications in evaluating the Neoproterozoic subduction history along the NW Indian margin.

2. Geological framework

2.1. Geotectonic background

The Aravalli Craton in Rajasthan forming part of the NW Indian Shield preserves a complex geological history from the Early Achaean (ca. ~3.5 Ga) to Late Proterozoic (ca. ~0.75 Ma). The major thermo-tectonic events in this region are accompanied by widespread magmatism and metamorphism at ~3.0 Ga, ~1.8 Ga, ~1.1 Ga and 850–750 Ma (Deb and Sarkar, 1990; Bhushan, 1995; Sharma, 1999; Vijaya Rao et al., 2000; Dharma Rao et al., 2011b, 2012). This region therefore offers an important domain to investigate tectonic history and crustal evolution through time. The four major tectono-magmatic and metamorphic events in the region are represented by the Banded Gneissic Complex (BGC; ca. 3.0 Ga), the Aravalli Orogeny (ca. 1.8 Ga), the Delhi Orogeny (ca. 1.1 Ga) and the post-Delhi magmatic event (ca. 0.85–0.75 Ga). A major part of the Aravalli mountain range was constructed during Meso-Neoproterozoic (~1.8–0.85; Kaur et al., 2009, 2011, 2012), when extensive felsic magmatism is recorded (Sharma, 1999; Van Lente et al., 2009). A well established erosional unconformity that separates the Aravalli region with the BGC is widely considered as a tectonic suture that is the expression of a Proterozoic oceanic-basin closure (e.g. Sinha-Roy, 1988; Gupta et al., 1989; Sharma, 1999). Major granitoid magmatism occurred at ~1.7 Ga, ~1 Ga, ~900–800 Ma and ~750 Ma (Roy, 2001; Sharma, 2004), in association with subordinate mafic to ultramafic complexes and arc magmas including the Punagarh and Sindreth mafic units and meta-tuffs (Dharma Rao et al., 2012). Remnants of the accreted oceanic lithosphere have also been reported such as the Phulad Ophiolite Suite (Khan et al., 2005) and the Basantgarh ophiolite mélange (Sinha-Roy and Mohanty, 1988). The Grenville ages for magmatic units reported include the 987 ± 6.4 Ma for the rhyolites of the so-called 'Sendra–Ambaji–Ajmer arc terrane' (Deb et al., 2001) and the ~967 Ma calc-alkaline granitoids of Sendra (Tobisch et al., 1994; Pandit et al., 2003).

2.2. Geological setting

The present study area is located at the southern end of the Aravalli Mountain Range in the Sirohi region (Figs. 1 and 2) which forms the southern extension of the Phulad tectonic zone. The Sirohi terrane occupies a key position in the South Delhi Fold Belt bounded on the northeast by Phulad ophiolite suite and southeast by the Basantgarh ophiolite mélange (Fig. 1C). A thick sequence of mafic–ultramafic rocks runs along a length of over 300 km from Basantgarh in the south to Phulad in the North (Sinha-Roy, 1988; Khan et al., 2005). Sinha-Roy and Mohanty (1988) considered the Phulad sequence of layered gabbros and serpentinized ultramafic rocks with pillow basalt and hyaloclastic material as an ophiolitic mélange of contrasting ensialic rift and arc–trench marginal basin tectonic domains. The trench metagreywacke contains relict blueschist assemblages that have been overprinted by regional greenschsit facies metamorphism. Rhyolites, andesites and basalts intercalated with chert and marble overlie this sequence. This succession represents a typical ocean plate stratigraphy, and the presence of ophiolite and blueschist clearly mark the signature of subduction tectonics (Santosh, 2012). The complex petrological association of chromite-bearing serpentinites, gabbro, amphibolite and chert, all intruded by granodiorites and granites along the western flank of the South Delhi Fold Belt, were collectively termed the Phulad ophiolite suite (Gupta et al., 1980; Khan et al., 2005).

The Sirohi terrane (Fig. 1C) sandwiched between these two ophiolite suites consists of low grade meta-sedimentary rocks exhibiting multiple phases of deformation (Roy and Sharma, 1999). The terrane is extensively intruded by the Erinpura granites (ca. 850–735 Ma, Crawford, 1975; Choudhary et al., 1984), the Malani igneous suite (ca. 793–818 Ma, Bhushan, 2000; Murao et al., 2000; 827.0 ± 8.8 Ma, Pradhan et al., 2010) and Sindreth volcanics (765.9 ± 1.6 Ma, M-15, Van Lente et al., 2009, 765–768 Ma; Dharma Rao et al., 2012).

The basement granites and gneisses define a tectonized contact with the Sirohi Group meta-sediments, while the Balda Granite shows an intrusive relationship (Sharma, 2004). The long narrow and linear Sirohi sialic basin in the Sirohi–Ras–Makarana region is considered to have opened at 1.0 Ga (Roy and Sharma, 1999), assuming coevality with the regional mafic magmatism (Volpe and Macdougall, 1990). Although the age of Sirohi sedimentation is not precisely constrained as yet, the rhyolitic flows from the overlying Sindreth Group have yielded a zircon U–Pb age of 761–765 Ma (Van Lente et al., 2009), equivalent to the 770–750 Ma Malani Igneous Suite (Torsvik et al., 2001a) and the Sindreth meta-tuffs 765–768 (Dharma Rao et al., 2011a). Sugden and Windley (1984) noted the arc nature of the rocks of this part of SDFB. Deb and Sarkar (1990) also interpreted these rocks as parts of an island arc sequence. According to them, the geochemistry of pillow and massive metavolcanics rocks, and the presence of an ophiolite assemblage, indicate subduction along the western part of the arc.

2.3. Sample description

In this study, we carried out geochemical and zircon SHRIMP U–Pb studies on the major granitoids from three different domains in the Sirohi terrane. Our samples include a plagiogranite from Peshua about 15 km southwest of Basantgarh from the ophiolite suite, foliated granite from Devala and porphyritic granite from Sai (Fig. 1C). Brief descriptions of these granites that outcrop in the area around Sirohi are summarized in the following section.

2.3.1. Plagiogranites

Plagiogranites are exposed near Peshua village (24.85N: 73.03E) in Pindwara Mandal of Sirohi District in Rajasthan State. This location (Fig. 1C) is close to, and to the west of, Basantgarh sequence considered as an ophiolitic mélange made up of pillowed metabasalts, pillow breccias, layered metagabbros, serpentinites, talc–chlorite schist, metagreywacke and plagiogranite (Sinha-Roy and Mohanty, 1988).