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Evidence for the Neoproterozoic Phulad Suture Zone and Genesis of Malani magmatism in the NW India from deep seismic images: Implications for assembly and breakup of the Rodinia

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ABSTRACT

Deep seismic reflection images across the late Mesoproterozoic South Delhi Fold Belt (SDFB), NW India, provide evidence for crustal-scale tectonic imbrication and collisional tectonism. An Andean-type margin with eastward subduction of oceanic lithosphere and subsequent collision of volcanic arc with Mewar craton is responsible for the evolution of the SDFB. Contrasting geophysical (particularly the deep seismic and gravity models) and geological signatures found across the SDFB suggest this as a suture, the Phulad Suture Zone (PSZ) with its extension into the Himalaya. Post-collisional delamination and orogenic collapse are responsible for the equilibrated younger Moho and evolution of Malani magmatism in the region. The present study envisages an evolutionary model for the Malani volcanics, unambiguously identifying for the first time the SDFB rocks as their basement. This model successfully resolves the ambiguity by correlating the Marwar Terrain with the Rodinia assembly rather than later Pan-African orogeny located further west. Evolution of the SDFB and Malani magmatism are coeval with the Rodinia assembly and breakup. The South Delhi orogeny, located between the east- and the west-Gondwana fragments, plays an important role for reconstruction of the Gondwana.

1. Introduction

Convergence of two cratonic blocks (continents or island arcs) leads to subduction of the oceanic crust and its subsequent closing and finally a collision of these cratonic blocks with the formation of an orogenic belt between them. During the process of convergence, Alpine–Himalayan-type collisional orogens or the Pacific-type or Andean-type island arc accretionary orogens are evolved depending on the nature of the lithospheric plates. Convergence and collision of a large number of continental blocks carrying ancient cratons together with accreted terrains have created a single larg3e landmass termed as supercontinent (Rogers and Santosh, 2004). Collision and accretion of crustal blocks with formation of supercontinent and its subsequent breakup is a fundamental process of continental evolution and occupies a central position in terms of processes of Earth system. A number of supercontinents are believed to have existed since Paleoproterozoic/Archean.

A collisional boundary where the cratonic blocks of independent evolutionary history are stitched together represents the suture. A number of anomalous features exhibiting different physico-chemical and thermo-mechanical properties are developed at the suture zones during the orogenic process. Therefore, various geological/geochemical and geophysical methods are employed to identify the suture zones by mapping their diagnostic properties. Among various geophysical methods, seismic methods are the most effective as they provide high-resolution structural images of the deep crust. Study of the suture zones plays an important role in identifying the metallogenic provinces and seismicity, besides revealing the evolutionary history of a region.

The Indian shield consisting of five Archean cratonic blocks with 3.6 Ga age rocks represents one of the oldest parts of the Earth (Fig. 1a). The lithospheric evolution of the Indian shield is intimately related to a large number of orogenic episodes involving these cratonic blocks since the late Archean, and the associated suture zones are now located in the continental interior (Vijaya Rao, 2008). The late Mesoproterozoic orogenic belts and the associated suture zones of the Indian shield, related to the Rodinia assembly, are shown in Fig. 1a. The orogenic cycle is a two-stage process involving both evolution of collisional orogeny and its subsequent collapse due to extension (Dewey, 1988). Collisional suturing is thus usually followed by addition of various types of magma in the form of volcano-plutonic sequences. Thus, a model involving both collisional and post-collisional activities provides better constraints to understand the lithospheric evolution of a region. In this context, the present study examines both the collisional and post-collisional tectonic features of an orogenic cycle related to the crustal evolution of one of the orogenic belts of the Indian shield, namely the South Delhi Fold Belt (SDFB).

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Deep seismic reflection and limited refraction/wide-angle reflection data were acquired along a 400-km long Nagaur–Jhalawar transect covering the Paleoproterozoic Aravalli and Mesoproterozoic South Delhi fold belts (Fig. 1b). Structure and tectonics along this transect were discussed in earlier papers (Tewari et al., 1997; Vijaya Rao et al., 2000), especially the broad structural features of both these fold belts. They essentially discussed the reflectivity characteristics to distinguish various tectonic domains in the region as well as the crustal thickness in each of them. However no attempts were made there in, to recognize and investigate the suture zone with its characteristics, to study the genesis of the Malani magmatism, and to understand nature as well as significance of the Marwar Terrain. It is the purpose of the present study to resolve these issues, essentially by examining the characteristic geophysical and geological indicators that help to delineate the suture zone and to provide an insight into the genesis of the post-collisional Malani magmatism, also convincingly presenting the possible candidate basement of the Malani volcanics in the region. The basement of the Malanis in the region is little or ambiguously known as it is completely obscured by the later sediments/sands of the Thar desert. It is recognized that, delineating the basement of the Malani volcanics unambiguously, is an essential step forward in order to understand the paleo-environment and plausible tectonic scenario in which they were evolved.

Deep seismic reflection images are effectively utilized and examined towards realizing the above objectives. Further, in the present study, gravity modeling is carried out across the South Delhi orogenic belt along a segment, coincident with the seismic transect, in order to substantiate the crustal structure and the suture zone characteristics. This study presents a new analysis and interpretation of the seismic, gravity and other geophysical datasets as well as the geological signatures, leading to significant results that are reported here for the first time. It deals with the important details on accretion and dynamics related to both regional and global orogenic activity.

The SDFB is located on the western margin of the Indian shield, which in turn was located on the western margin of Rodinia supercontinent during the late Mesoproterozoic period (Hoffman, 1991). It is a major component of a system of Mesoproterozoic orogenic belts of the Indian shield and plays an important role in the Rodinia assembly. Further, the Malani igneous activity (750 Ma) plays an important role in reconstruction of the Gondwana, and thereby the Rodinia supercontinent. The significance of both the important events in the region, viz., the South Delhi orogeny and Malani magmatism, are discussed in the context of assembly and breakup of the early Neoproterozoic Rodinia supercontinent.

2. Geological framework

The NW India is regarded as one of the most important Precambrian terrains of the Indian shield, as it has a geological history from the Mesoarchean to Recent. This region consists of a number of fold belts, shear zones, metallogenic provinces, paleo-sutures and undeformed Vindhyan and Marwar basins (Fig. 1b). It exhibits polyphase metamorphism. The Mewar craton, in NW India is one of the oldest cratonic blocks of the Indian shield. It has a cratonic nucleus around Udaipur with 3.3 Ga old rocks, presently represented by the Banded Gneissic Complex (Gopalan et al., 1990; Roy and Kroner, 1996). The Paleoproterozoic Aravalli and Mesoproterozoic Delhi sediments were deposited successively over this Archean basement (Roy, 1988). The Untala and Gingala granites were emplaced during 3.1–2.9 Ga. The Berach granite (2.5 Ga) represents the late Archean cratonization in the region.

During the Proterozoic, the region experienced operation of Wilson cycle events — rifting of rigid Archean continent, opening of an ocean, contraction of that ocean by subduction and finally collision and suturing of continental fragments with the evolution of orogeny between them. The Archean Bundelkhand and Mewar cratons collided with each other with formation of the Aravalli fold belt during the late Paleoproterozoic (~1800 Ma). This fold belt was a part of the Paleoproterozoic Columbia supercontinent (Vijaya Rao and Reddy, 2002). During the Mesoproterozoic geological evolution, the Mewar craton collided with the Marwar terrain with formation of the Delhi fold belt (1100–1000 Ma). Crustal evolution of this region is explained by various models in the plate tectonic framework (Deb and Sarkar, 1990; Sinha-Roy, 1988; Vijaya Rao et al., 2000).

The Aravalli–Delhi fold belt (ADFB) is 30–200 km wide and extends to a distance of 700 km in the NE–SW direction from Delhi through Rajasthan to Gujarat (Fig. 1b). This region contains many important base metal sulfide deposits and provides substantial part of copper production in India. In addition, the region has occurrences of tungsten, tin, uranium, manganese and vast resources of sedimentary phosphorites. The Delhi fold belt (DFB) is divided into two parts, viz., the North and South Delhi Fold Belts (NDFB and SDFB) located to the north and south of Ajmer respectively (Fig. 1b). Based on the lithofacies association and available age data Sinha-Roy et al. (1995) suggest that the DFB is diachronous and the evolutionary histories of the NDFB and SDFB are different. On the other hand, many researchers consider these two parts of the DFB as stratigraphically homologous and tectonically contiguous.

The western part of the DFB, referred as Marwar Terrain, is least studied and less understood because of its hostile environment. More than 95% of the area is covered either with sands of the Thar desert or later sediments, making the region of earlier events inaccessible for the geological studies. The region exhibits only Neoproterozoic–Phanerozoic geological history and there is no reliable evidence for rocks older than 1100 Ma. The region experienced younger tectonothermal events in the form of Erinpura and Malani plutonic-volcanic suites during 850 Ma and 750 Ma respectively. The undeformed and unmetamorphosed Marwar basin consisting of flat clay evaporate sequences, sandstones and siltstones, is formed in the Marwar Terrain during the late Neoproterozoic–Eocambrian. A number of Mesozoic basins were formed over the western-most part of the Marwar Terrain (Fig. 1b). Table 1 shows the chronological order of geological/tectonic events in the NW India.

3. Previous work

3.1. Deep crustal seismic study

The present study revisits the seismic images from Nagaur to Masuda segment of the 400-km long Nagaur–Jhalawar transect covering the Neoproterozoic Marwar Terrain and the Mesoproterozoic DFB (Fig. 1). It deals with the collisional suturing of the two crustal blocks of the Indian shield during the late Mesoproterozoic period and their characteristics, along with the post-collisional tectonics responsible for genesis of the Malani magmatism.

Seismic reflection data revealed detailed images of the crust, which are very diagnostic for understanding the crustal dynamics and evolution of the region. The study clearly distinguishes crustal structures formed in different tectonic environments. Individual terranes are recognized by differences in their reflectivity characteristics: amplitudes, orientation and spatial distribution of reflectivity, which are interpreted in terms of lithological variations and structure. Major changes in either lithology or structural style often indicate a seismically distinct unit, known as a seismic terrane.

The important structural feature (Fig. 2a, b and c) observed in the region are:

- SE-dipping reflection band
- NW-dipping reflection band
- Subhorizontal reflection fabric around 12.5 s twt (two way time).

A line drawing of the seismic stack sections is shown in Fig. 3.

Deep seismic reflection images along the Nagaur–Masuda segment indicate strong and continuous SE-dipping reflection bands extending from the upper to lower crust covering a distance of ~80 km in the Marwar Terrain (Fig. 2a and b). The extension of these reflections further west is