# Neoproterozoic tectonomagmatic evolution of the NW Indian craton: implications for paleogeographic reconstruction

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## Abstract
*Neoproterozoic has been heralded as an eventful period of global tectonics due to rapid movement of crustal blocks that amalgamated to form the sunpercontinent Rodinia during early Neoproterozoic. This supercontinent subsequently fragmented during later part of Neoproterozoic. It was also a period of changes in global climatic conditions and the end the Neoproterozoic is marked by the explosion of life during Cambrian. It is, therefore essential to evaluate various events in crustal blocks of Rodinia to model its assembly and break-up history. The northwestern Indian craton offers an suitable conditions to investigate the Neoproterozic events present as a well-preserved record from 1 Ga to the Precambrian – Cambrian transition. The Precambrians of this region include an Archean basement (3.3 to 2.5 ga) over which two supracrustal sequences, Aravalli (Paleoproterozoic) and Delhi (Mesoproterozic) supergroups were deposited. Both these belts are complexly deformed and variably metamorphosed. The 1 Ga Grenvillian event in this region is represented by Delhi Orogeny marked as the collision between Aravalli craton in the east and an unknown one in the west, the latter also known as Marwar craton. The 1 Ga event is marked by calk-alkaline granites and diorites and development of ophiolites in a linear zone along the western margin of the Delhi Fold Belt. At ~870 – 830 Ma vast acid magmatism has been witnessed in the region which is called as Erinpura Granite, which at places shows migmatitic characters. This is followed by a vast acid magmatic event called the Malani magmatism which has been described as the third largest acid magmatic province in the world. It has now been precisely dated at 770 – 750 Ma. This also forms the basement for the shallow tidal sedimentary sequence of Marwar Supergroup which is essentially arenacesous in the lower part, calcaresou in the middle and argillaceous – arenaceous in the upper part. C-isotopic characteristics of the carbonate facies suggest Precambrian – Cambrian transition which has further been supported by the recent report of trilobites from the uppermost part. In the conventional paleogeographic reconstructions, India – Australia – Antarctic have been shown as coherent tectonic trio even during pre-Rodinia times. Recent paleomagnetic studies undertaken in this region have shown a latitudinal difference of 45 degrees between Indian and Australia during Neoproterozoic, suggesting that they were amalgamated only during pan African Gondwana assembly.*

**Key words:** *Neoproterozic, NW India, Gondwana, Paleomagnetism, Rodinia.*

## Introduction
The Neoproterozoic can be called as one of the most dynamic periods in the history of the Earth in many ways. It was a period of large-scale perturbations in the atmospheric oxygen, rapid movement of continental blocks resulting in amalgamation and subsequent break-up of supercontinent Rodinia, and temperature fluctuations that ultimately led to the explosion of life in the Early Cambrian. Extreme climatic conditions and 'Snowball Earth' have also been associated with this period and Neoproterozoic glacial deposits have been recorded from

many parts of the world, even from close to equatorial regions, implying severe cold climatic conditions (Kirschvink, 1992; Evans, 2000, Hoffman and Schrag, 2002).

In the Indian context Neoproterozoic record from 1 Ga to the end Proterozoic is well-documented in NW part of Indian peninsula, also known as the Aravalli Craton. A well-preserved geological record offers a unique opportunity to study these rocks and moreover, this terrane is also known as one of the key crustal blocks in the plaeogeographic reconstruction of supercontinent Rodinia. Arid claimaitc conditions have ensured that the rock-types are fresh and well-preserved, and generally free from alteration. The Neoproterozoic events in the Aravalli craton are described in this paper and their implications on the global paleogeographic reconstructions are discussed.

## Regional Geological Setting

Precambrian geological history of the Aravalli craton in the northwestern territory of Indian shield has centered along an Archean basement ( called as Banded Gneiss Complex – Heron, 1953; Bhilwara Supergroup – Gupta et al., 1980) over which two major accretionary fold belts, Aravalli and Delhi fold belts, were developed (Fig. 1). The basement rocks have been reliably dated at 3.3 to 2.5 Ga using U – Pb zircon methods (Wiedenbeck et al., 1996; Roy and Kröner, 1996), however, there are no direct ages available for the fold belts on account of non-availability of suitable rocks for dating. Indirect evidences suggest Paleoproterozic and Mesoproterozoic ages for these fold belts, respectively. The Delhi Fold Belt, forming the most prominent geomorphic feature of this terrain as the Aravalli Mountain chain, extends across Rajasthan and northern Gujarat along a NNE-SSW trend. The Delhi Supergroup as envisaged by Heron (1953) is deposited in northern and southern domains, separated from each other by the Sambhar – Dausa lineament (Bakaliwal and Ramasamy, 1987). The acid magmatism with two distinct age clusters (1700 – 1500 Ma in northern domain) and (=800 Ma in southern domain) has led to the suggestion of diachronous evolutionary history for the Delhi Fold Belt. The diachronous sedimentation history has, however, been contested by some later workers (Roy and Jakhar, 2002). Temporal distinction between granitoid emplacement events between northern and southern domains is not very clear (Sinha Roy et al., 1998).

Delhi Supergroup shows a complex evolutionary history involving polyphase deformation and up to amphibolite facies metamorphism. Delhi orogeny coincides with the globally recorded Grenvillian events at ~ 1 Ga, manifested in collision of Marwar Craton in the west and Aravalli Craton in the east.

## Calc-alkaline magmatism (~1 Ga)

The Neoproterozoic geological history in this region began with the intrusion of 1Ga continental collision manifested in 1000 Ma diorites and gabbro in Ranakpur (Tobisch et al., 1994) and 967 Ma old calc-alkaline granitoids in Sendra area (Pandit et al., 2003). Sendra and related granitoids occur linearly along the western flank of the Delhi Fold Belt in the southern domain. Geochemical and mineralogical characteristics of Sendra Granite suggest an I-type source and subduction setting (Pandit et al. 2003). The western margin of the Delhi Fold Belt is marked by linear exposures of mafic – ultrmafic rocks called Phulad Ophioloite Suite which also corresponds with the Western Margin Fault. The rocks of Phulad Ophiolite suite are interesting in the sense that they represent fragments of Ancient Ocean. The WMF also marks a shear zone called Phulad Shear Zone.

**Erinpura Granites (870 – 830 Ma)**

A vast granitoid terrance to the west of southern domain of Delhi Fold Belt is popularly known as Erinpura granite. First described by Heron (1953), the Erinpura granite occurs along the western flank of southern Delhi Fold Belt further continuing beyond Ajmer in the northeast. The Erinpura granite is extremely variable in texture, ranging from porphyroblastic to gneissic and even migmatitic (with granophyric and myrmekitic intergrowth of quartz and feldspar). Mineralogical and textural variations in Erinpura granites allows their classification as granite gneiss, true granite to granodiorite and suggest more than one pulse of magmatism. Chief mineral phases are quartz, plagioclase, K-feldspar and biotite with minor amounts of muscovite, epidote, sphene, zircon and Fe-Ti oxides (Chattopadhyaya et al., 1982). Overlapping I- and S-type characteristics of Erinpura granite have led to contradictory source composition models envisaging an igneous protolith (Bhushan, 1995) to a meta-sdimentary parent material (Gangopadhyay and Lahiri, 1984). Keeping in view the large areal distribution of the 'Erinpura'granite, no generalized model of magmatism is possible and the Erinpura granite are a result of complex petrogenetic history involving variable sources and processes. Paucity of the geochemical information has further rendered such interpretations merely subjective and valid for a restricted part only. 'Erinpura Granite' is used as a basket term, however, the rocks are best exposed in the type area around Sirohi and Sumerpur. For a considerable time Erinpura Granite has been described as 830 Ma in age on the basis of limited whole rock Rb – Sr ages (Choudhary et al., 1984). Some of the more recent studies based on structurally controlled monazite dating have shown a much wider range of magmatism (870 – 830 Ma) in Erinpura rocks (Jana et al., 2010). At least one phase of Erinpura Granite can be considered as mineralized with occurrence of tungsten mineralization in a NE-trending linear belt. Some of the known deposits include Balda near Sirohi in the south, Degana in central part and Tosham in the north. In between the Erinpura Granite terrane and the soutern part of the Delhi Fold Belt occurs the Mt. Abu batholith which stands approx 1200 m above the ground level. Mt. Abu is a fault bounded NE elongated composite granitoid body which comprises a granite gneiss rim and a relatively undeformed granitoids in the middle. The latter granitoids, also described as 'pink granite' (Gupta et al., 1997) include a range of textural variants. Available ages indicate 800 – 780 Ma for Mt. Abu granitoids. For a considerable time the Mt. Abu granitoids have been described as late orogenic with respect to Delhi Orogeny and separate from the undeformed granites and felsic volcanics of the Malani Igneous Suite. On the basis of magnetic fabric, de Wall and Pandit (2007) have shown that the deformation in these rocks is syn-intrusional and not related to the Delhi orogeny.

**Malani Igneous Suite (MIS)**

Spread over an area of >51, 000 km$^2$ in the state of Rajasthan (NW India), the MIS is considered to be the third largest felsic volcanic province of the world. However, the magmatism is polyphase in nature with predominant felsic volcanics (at places with minor basic flows at the base) with granites and a wide array of dyke rocks (rhyolite, trachyte, dolerite/gabbroic) that intrude the earlier lithologies. For a long time the available ages were based on whole rock Rb –Sr data with contradictory results which included 100 milion years span of magmatism (780 – 690 Ma) to a single event at ~725 Ma. More robust U – Pb zircon geochronologic results (Gregory et al., 2009; van Lente et al., 2009) have shown a 770 – 750 Ms duration for Malani magmatism. These results olace the MIS rocks in the coeval time window of the Seychelles and northern Madagascar. MIS felsic rocks (volcanics and granites) can be discriminated into peraluminous and peralkaline types, both the varieties defining a systematic spatial relationship with each other, however, the former is the predominant one. Geochemical features such as high abundances of silica, alkalis, LREE, HFSE, LILE and a high Fe/Mg ratio, with extreme enrichment of such elements in the peralkaline rocks have been considered as a basis to call them anorogenic or A-type. The other model includes an Andean type setting on the basis of decoupling of LIL and HFS elements and lack of evidence of continental interior setting. The geochemical features do indicate derivation from high temperature melting of a lower-crustal amphibolitic source with addition of some juvenile material (Ashwal et al., 2002).

**Marwar Supergroup (Precambrian – Cambrian transition)**

The MIS rocks form the basement for a shallow sag basin which developed during the later part of Neoproteroszoic. This shallow basin, called as Marwar basin extends E – W and shows sedimentation under subtidal conditions indicated by predominant arenaceous faceis Jodhpur Group (gritty at the base). This was followed by platform deposition of a calcareous facies rocks of Bilara Group in the middle while the youngest unit is Nagaur Group which comprises argillaceous and arenaceous facies sedimentation. These rocks are generally undeformed and sub horizontally disposed, however, minor tilts are observed at places. Age of the Marwar supergroup has remined contentious and in the classical sense it has been correlated with Upper Vindhyan and even assigned Cambrian age on the basis of presence of evaporates. However, such contentions could not be substantiated due to absence of body fossils. Pandit et al. (2001) carried out systematic C- and O-isotopic studies of the Bilara Limestiones (the middle unit of Marwar Supergroup) and reported Precambrian – Cambrian transition on the basis of extreme fluctuations in the C-isotopic record. Some of the more recent paleontological studies have reported fossil trilobites from the Nagaur Group (upper most unit). However, such claims should await substantiation.

**Implications for Paleogeographic reconstructions**

The final assembly of superconitnent Gondwana has been estimated at ~550 Ma and paleogeography within Gondwana is reasonably well established. However, individual continental paleolocations prior to final Gondwana suturing are often poorly constrained. It is generally accepted that the components of western Gondwana were not a coherent group while east Gondwans formed a coherent assembly of India – Antarctic – Australia even prior to Gondwana assembly. An alternative model suggests assembly in a more complex manner in the late Proterozoic with the suturing of Gondwana. New paleomagnetic and geochronologic data from the Malani Igneous Suite (MIS), Rajasthan, Central India, improve the paleogeographic reconstruction of the Indian subcontinent between dispersal of the supercontinent Rodinia and Neoproterozoic assembly of Gondwana (Torsvik et al., 2001; Gregory et al., 2009). A virtual geomagnetic pole from 4 mafic dikes has a declination=358.8°

and inclination=63.5° (with k=91.2 and Î±95=9.7). This normal polarity direction includes a fine-grained mafic dikelet that showed a reversed direction with declination=195.3° and inclination=-59.7° (k=234.8 and Î±95=8.1) and also records an overprint of normal polarity from the larger dikes. Synthesizing the paleomagnetic data on rhyolitic flows and mafic dykes a mean paleomagnetic pole of 67.8°N, 72.5°E (A95=8.8) is obtained for the MIS. A comparison of 755 ±3 Ma Mundine Well dykes in Australia and MIS, and equivalent Seychelles at 750 Â±3 Ma indicates a latitudinal separation of nearly 45° between the reconstructed Indian plate (plus the Seychelles) and its location in a traditional Gondwana fit. This suggests that East Gondwana was not amalgamated at c. 750 Ma and therefore that these two cratons were assembled later into the Gondwana supercontinent, possibly during the Pan-African c. 550 Ma Kuunga Orogeny.

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