REVIEW

Formation of intracratonic Gondwana basins: Prelude of Gondwana fragmentation?

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The disposition of the Indian Gondwana basins along some linear zones coinciding with the boundaries of the Precambrian protocontinental components of the peninsular shield mosaic primarily indicates a major tectonic control on intracratonic rifting. These rift systems along with the late Paleozoic fault systems developed within the reconstructed Gondwanaland define broad concentric patterns with some radial strike-slip varieties about ‘centers’ tentatively located along the south-eastern margin of Africa. The reconstructed directions of ice movement of the late Paleozoic ice-sheet also define broad radial patterns about ‘centers’ located roughly between Madagascar and India, and western part of Antarctica. The radial pattern of ice movement and development of concentric fault zones can be attributed to some regional domal uplift, due to penetration of plume heads into the upper mantle. These ‘centers’ were located very close to the linear zone along which a rift system developed during Sakmarian (~ 280 Ma) and the Gondwana fragmentation was initiated with the separation of East and West Gondwana at around 170 Ma. The geochemical signatures indicate that this plume was possibly responsible for the earlier phases of emplacement of the potassium-rich lamproites within the Gondwana basin-fill succession and was finally led to the emplacement of Panjal volcanics. Therefore, it appears that the process of Gondwanaland break-up was initiated with the formation of the Gondwana rift system in India and its equivalents in the rest of the supercontinent. Acquisition of systematic geochemical and geochronological data from the intrusive bodies from the Gondwana basins can help in tracing back the complete history.

Keywords: Gondwana fragmentation, Late Paleozoic glaciation, Ultrapotassic lamproites, Gondwana rift system, LIP, LLSVP

INTRODUCTION

The term ‘Gondwana’ was coined in the year 1872 by Medlicott to describe the ‘deposits of conglomerate, sandstone, shale and coal measures of fluvio-lacustrine origin’ after the Gōndi (commonly referred to as Gond) tribe of central India. Identification of similar deposits in other parts of the globe led Suess (1892; page 767) to conclude that ‘*Versucht man ähnliche Vergleichen auf die vereinigte Masse von Asien, Afrika und Europa anzuwenden, so zeigt sich sofort, das shier verschiedene Gebiete zu einem grossen Continente aneinander geschweisst sind*’ [If one tries to apply similar comparisons to the combined mass of Asia, Africa, and Europe, it immediately becomes clear that various regions were welded together into a large continent], and he proposed

that (Suess, 1892; page 768) ‘*Wir nennen es Gondwána-Land nach der gemeinsamen alten Gondwána-Flora*’ [We call it Gondwana Land after the common ancient Gondwana flora]. Thus, the concept of the supercontinent Gondwanaland developed. In India, the major Gondwana basins are distributed along some conspicuous linear belts converging towards the Indian heartland. The disposition of the Gondwana basins along these linear belts, broadly coinciding with the boundary zones of Precambrian protocontinental components of the peninsular shield mosaic, primarily indicates a major tectonic control on intracratonic rifting. However, in view of the global extent of the Gondwana repositories, this intracratonic rifting seems to be the result of a global tectonic event, which bears a special significance in the Paleozoic history of the globe. In the present study, an attempt has been made to analyze certain evidence from the basin-fill records to elucidate the nature of such tectonic event. Certain issues, like the conspicuous concentric patterns of the

late Paleozoic fault systems and the radial dispersal pattern of the late Paleozoic ice sheets on the reconstructed Gondwanaland identified during this course of study, have to be resolved for a better understanding of the late Paleozoic history of the globe.

DISTRIBUTION OF THE INDIAN GONDWANA RIFT SYSTEMS: THE GLOBAL PERSPECTIVE

As mentioned earlier, the Gondwana basins of India occur along some linear zones coinciding with the boundaries of the Precambrian protocontinental components (Naqvi et al., 1974) of the peninsular shield mosaic. These include east-west aligned Koel-Damodar Valley basins along the central axis of the Chhotonagpur Gneissic Complex, northwest-southeast trending Son-Mahana-

di Valley between Bastar/Bhandara Craton and Singhbhum Craton, northwest-southeast trending Pranhita-Godavari Valley basins between Dharwar Craton and Bastar/Bhandara Craton, east-west trending Satpura basins between Bastar/Bhandara Craton and Aravalli and Bundelkhand Cratons, and north-south trending Rajmahal group of basins along the eastern margin of the Chhotonagpur Gneissic complex (Fig. 1). The contemporary major fault zones in different continents belonging to the Gondwanaland, as reconstructed by Guiraud et al. (2000; Fig. 5) after Rogers et al. (1995), are also found to have been developed along the margin of the Archean and Paleoproterozoic cratons. Disposition of these fault systems defines broad concentric patterns. Therefore, it is not unjust to apprehend that the rift systems throughout the Gondwanaland might have been developed in consequence of a single tectonic event.

Figure 1. Map showing distribution of Gondwana basins in Peninsular India. The Precambrian protocontinental components are marked as DC, Dharwar Craton; BC, Bastar/Bhandara Craton; SC, Singhbhum Craton; AC, Aravalli Craton; BKC, Bundelkhand Craton; CNGC, Chhotonagpur Gneissic Complex.

LATE PALEOZOIC GLACIATION

Understanding of the late Paleozoic glaciation has a strong bearing on the reconstruction of the initial phase of Gondwana sedimentation. Contrasting views were put forward to explain the causes of initiation and ending of the late Paleozoic glaciation. According to Eyles (1993), the drop in atmospheric CO₂ through the early Carboniferous could be attributed to carbon sequestration by expanding wetland forests, and accelerated rates of continental (silicate) weathering was considered as the likely driver for the late Paleozoic ice age. A similar idea was advocated by Cleal and Thomas (2005), who were of the opinion that the sea-level drawdown by initial ice sheets under falling atmospheric CO₂ levels might have promoted the expansion of lowland forests, which in turn amplified CO₂ drawdown and the expansion of continental ice. Montañez and Poulsen (2013) also opined that CO₂ was the fundamental driver for the build-up and breakdown of glaciers. The multi-proxy reconstruction of deep time atmospheric CO₂ for the late Paleozoic led Montañez et al. (2016) to infer that the dynamic carbon sequestration history of the repeated restructured Euramerican tropical forests had a major role for terrestrial vegetation-CO₂ feedbacks in driving eccentricity-scale climate cycles of the late Paleozoic icehouse. Goddérís et al. (2017), however, raised an objection to these models of atmospheric CO₂ depletion due to carbon sequestration by expanding forests as the cause of late Paleozoic glaciation, and argued that 'the plant expansion and carbon uptake substantially predate glaciation'. According to them, the uplift of equatorial Hercynian Mountains during the Late Carboniferous promoted silicate weathering through the removal of thick soil cover to the extent to cause atmospheric CO₂ concentrations to fall below the levels required for initiation of glaciation. It was further postulated that during the Permian, the lowering of the mountains led to the restoration of thick soil cover, which in turn, significantly restrained silicate weathering and the consequent rise in atmospheric CO₂ concentrations led to the termination of the glacial event. Therefore, the actual causes of initiation and termination of the late Paleozoic ice age are still not very clearly understood. Certain features preserved during the initial phase of Gondwana sedimentation in the Indian subcontinent, however, indicate a distinct relation between the development of the rift setting and the event of late Paleozoic glaciation. These signatures, in conjunction with some evidence from the other parts of the Gondwanaland, may elucidate the plausible cause of the termination of the late Paleozoic glaciation.

In India, the initiation of Gondwana sedimentation during lower Permian marked the end of a long phase

of non-deposition that had prevailed in the Indian subcontinent since the Late Proterozoic. Being the lowermost unit of the Gondwana succession, the Talchir Formation received special attention from the generations of workers. Identification of certain features as of glacial origin within some of these deposits led a number of workers (Ghosh, 1962; Niyogi and Sanyal, 1962; Banerjee, 1963; Smith, 1963a, 1963b, 1963c; Banerjee 1966; Chatterjee and Ghosh, 1967; Ghosh and Mitra, 1967, 1975; Ahmad, 1975; Sengupta et al., 1979; Das and Sen, 1980; Casshyap and Tewari, 1982; Casshyap and Srivastava, 1988; Bose et al., 1992) to postulate that the deposits assigned to the Talchir Formation were dominantly glaciogenic sediments. A critical review of these interpretations led to the conclusion that the pioneering contribution of Blanford et al. (1856) was, in common, cited in favor of the glacial origin of the lower part of Talchir succession (Sastri et al., 1977). However, the fact is that Blanford et al. (1856) made an attempt to explain the co-existence of boulder and fine mud within the 'basal boulder bed' and analyzed different possibilities (Blanford et al., 1856) for the simultaneous deposition of the materials of contrasting hydraulic properties. Finally, a probable situation very similar to the effects of the action of ground-ice that enabled boulders to be carried down by sluggish currents and produced an intermixture of large boulders and fine mud was postulated (Blanford et al., 1856). Simultaneously, the possibility of transport by true glaciers was strongly ruled out (Blanford et al., 1856). Hence, the idea of a pure glacial origin of the lower part of Talchir succession of Talchir basin and identification of the 'basal boulder bed' described by Blanford et al. (1856) as tillite do not have any strong foundation.

Detailed analysis of the Talchir succession of Talchir basin by Dasgupta and Sahoo (2007), however, revealed that the depositional imprints preserved in this part of the sedimentary succession indicated emplacement of successive subaqueous debris flows generated through remobilization of pre-existing unconsolidated sediments. Small pockets of fine-grained turbidites presumably deposited from the entrained turbidity currents associated with the debris flows suggested the composite character of the subaqueous debris flow deposits. Dasgupta and Sahoo (2007) further concluded that the idea of the probable situation resembling the effects of the action of the ground-ice that enabled boulders to be carried down by sluggish current producing an intermixture of large boulders and fine mud put forward by Blanford et al. (1856) can be regarded as one of the pioneering contributions in the concept of debris flow.

After studying the rocks of Talchir Formation in the Damodar Valley basins, Fox (1930) expressed serious

reservations regarding the identification of these sediments as purely glacial deposits. Fox (1930) analyzed the gravel composition of the Talchir conglomerates of Damodar Valley basins and correlated the major fraction with the Proterozoic Vindhyan 'quartzites' of Central India. This led him to conclude that although the general character of the gravel fraction indicates initial derivation by moving ice sheet from a distal source, the character of the present deposits lacked evidence for a primary glacial origin, and instead showed indications of reworking. Ganju and Srivastava (1959) and Niyogi (1961) also advocated the probable deposition of the Talchir sediments through reworking of glacial moraines.

Detailed facies analysis of the Talchir succession of the Jharia basin, India revealed that the sedimentary succession recorded two distinct depositional breaks (Dasgupta, 2006). Brecciation of the oldest sediments was attributed to hydraulic fracturing that possibly occurred as a consequence of unloading during the process of deglaciation (Dasgupta, 2006). The presence of in-situ breccia is not a unique feature of the Jharia basin. Bose et al. (1992) described a similar unit from the Talchir Formation of West Bokaro basin (Fig. 1). The fractured conglomerate had also been reported from the basal Talchirs of Mand-Raigarh coalfields (Fig. 1) of central India (Raja Rao, 1983). The evidence of similar brecciation was recorded from the basal part of Talchir succession of the Raniganj basin (Fig. 1), the easternmost basin of Damodar valley adjacent to the Jharia basin (Dasgupta, 2006). Although these occurrences indicate the regional extent of the event of brecciation, it is not evident in all Gondwana basins. The glaciogenic sediments might have originally accumulated within erosional depressions, and subsequently, the consolidated part suffered brecciation. This view was substantiated by the occurrence of Talchir deposits as outliers on the Archean basement, often quite dispersed from the regional distribution of the Gondwana sediments (Sastry et al., 1977). In some places, the intracratonic rift system passed through some of these sediment-filled depressions, and the brecciated conglomerate was buried under the new basin-fills. Some Gondwana basins possibly developed in areas without any such sediment-filled depressions, and the younger Talchir Formation lies there directly on the Precambrian basement. However, the products of resedimentation processes, constitute the major part of the Talchir Formation of most of the basins. These deposits are overlain by the fluviolacustrine sediments of the Barakar Formation. The broad character of these deposits in conjunction with the asymmetry of basin-fill suggests half-graben nature of the depository that commonly develops at the initial phase of extensional tectonics. These further indicate development

of the intracratonic extensional setting after deglaciation and the initiation of depositional processes through resedimentation of the pre-existing glacial debris.

Sporadic occurrences of small pockets of marine-fossil bearing sediments within Talchir succession of some of the Gondwana basins (Sinor, 1923; Gee, 1928; Reed, 1928; Ghosh, 1954; Bhatia and Singh, 1959; Dutta, 1965, 1971) added a new dimension to the Talchir problem. Although the marine indicators are present in less than 1% of the general Talchir succession (Chandra, 1996), these have led some workers to conclude that marine conditions might have been widespread in these rift basins during Talchir sedimentation. De (1996) proposed the entry of Tethyan water through inland seaways along the intracratonic graben zones, thus explaining the evidence for the marine environments in an otherwise continental framework. Under such condition, the marine sediments would have been distributed throughout the basin-floor below the younger succession. But in most of the basins, the younger succession partially overlies the rocks of Talchir Formation and mainly rests directly on the Archean basement over the major part of these basins (Ghosh and Mitra, 1975; Sastry et al., 1977; Das and Sen, 1980; Raja Rao, 1983; Ghosh and Mukhopadhyay, 1985). Hence, the idea of episodic marine influx along intracratonic graben zones does not hold true.

Although there is no convincing sedimentary succession of probable marine origin found within the Talchir Formation, the overall sedimentation history throws some light on the postulated event of marine incursion associated with Talchir sedimentation in some of the Gondwana basins. By analogy to the glacioisostatic condition prevailing in Fennoscandia (Scandinavia and Finland) (Sharma, 1984), it may be assumed that the continental block of peninsular India underwent a phase of subsidence during Permo-Carboniferous glaciation. Subsequent events of deglaciation caused a slow isostatic rebound of the lithosphere. During deglaciation, melting of ice caused a rise in sea level and this part of the globe possibly experienced a short spell of marine flooding until the isostatic equilibrium was restored. Sufficient crustal stretching, required for the development of rift systems, is also not expected before the completion of isostatic rebound. Hence, the marine incursion did not take place along the intracratonic rift system as conceived by some earlier workers, and the absence of marine sediments throughout the floor of the Gondwana basins thus finds an explanation. It may further be postulated that during marine flooding some marine fauna from the marginal part of Tethys were carried into the continental block and were partly trapped within topographic depressions. The sediments containing the organic remains were subsequently remobilized and deposited in small pockets

Figure 2. (A) Photograph showing the exposure of pebbly conglomerate containing marine bivalves, Hasdeo River section, Manendragarh, Sohagpur basin. (B) Close-up view of the encircled part of (A) showing bivalve-gravel association (coin diameter 25 mm.).

within some of the Gondwana basins. That is why the marine fossil-bearing sediments do not show any bathymetric control and stratigraphic preference in Talchir succession. Moreover, these units are of very limited spatio-temporal extension, the facies associations do not show any distinct marine signature, and the faunal populations are of remarkably small size – features that are inconsistent with the development of Gondwana basins in a marine setting. In Hasdeo River section (Lat. $23^{\circ}12'25.74''\text{N}$; Long. $82^{\circ}13'20.75''\text{E}$) near Manendragarh in Sohagpur basin, the occurrence of marine fossil (dominantly bivalves)-bearing pebbly conglomerate as small pockets within basement granite (Fig. 2) led to this inference.

PLAUSIBLE CAUSE OF DEGLACIATION AND DEVELOPMENT OF THE RIFT BASINS

The preceding discussion leads to the conclusion that the

Gondwana basins were possibly formed during the terminal phase of the late Paleozoic glaciation. In Peninsular India, the sense of movement of the ice sheets during the onset of the terminal phase of the late Paleozoic glaciation can be worked out from the geographic position of the provenance as determined by Fox (1930). This fits well within the inferred pattern of the Permian ice cap movement reconstructed by du Toit (1937) based on the evidence of ice movement in different constituent continents of the Gondwanaland. Careful examination of these ice movement directions reveals broad radial patterns with centers located approximately to the east of Madagascar and west of Antarctica (Figs. 3A and 3C). No explanation for these conspicuous radial patterns has so far been put forward. Simple topographic control does not seem to be a plausible factor for this global event.

The disposition of the major fault zones of the Gondwana as reconstructed by Guiraud et al. (2000; Fig. 5) also displays broad concentric patterns with centers located along the south-eastern margin and south of Africa (at the tip of South America) and one far south-west of South America (Figs. 3A and 3B). Most (three out of four) of these points and the centers of dispersal of the ice sheet fall very close to the reconstructed position of the 'Owen Fault Zone' (between Africa, and India and Antarctica), where the Gondwana fragmentation was initiated from with the separation of East and West Gondwana at about 170 Ma (Svensen et al., 2018). Initially, a rift system developed during Sakmarian (~ 280 Ma) along this zone (Stampfli and Borel, 2002, Fig. 6). However, the development of the concentric fault zones points to an event of crustal stretching, and the directions of extension converge to a point. The radial strike-slip faults (Guiraud et al., 2000; Fig. 5) (Figs. 3A and 3B) were developed for adjustment of differential stretching. This type of crustal stretching can be attributed to the regional domal uplift due to penetration of a plume head into the upper mantle (Griffiths and Campbell, 1990; Segev, 2002; Nyblade and Sleep, 2003). Development of European late Hercynian intermontane troughs was also attributed to the regional extension caused due to the lateral spreading of mantle diapir (Lorenz and Nicholls, 1976). According to Segev (2002), in Carboniferous Variscan (Hercynian) orogen, 'the post-convergent extension is typified by crustal thinning, low viscosity of the lower crust, significant uplift, formation of numerous sedimentary basins (Lorenz and Nicholls, 1984; Ménard and Molnar, 1988) and widespread alkaline/subalkaline magmatism'. The anomalous elevation (~ 500 m) of the southern African Plateau has been attributed to Mesozoic plume events (Nyblade and Sleep, 2003). However, the subcrustal heating caused due to such penetration might have led

Figure 3. (A) Reconstructed Permian Gondwanaland after (Rogers et al., 1995) showing major fault zones (after Guiraud et al., 2000) of the Gondwana and the reconstructed flow directions of late Paleozoic ice sheet (after du Toit, 1937). (B) The concentric patterns of the Gondwana faults are apparent about the tentative centers (solid circles) located along the south-eastern margin of Africa, at the tip of South America and further south-west. (C) The broad radial pattern of the reconstructed paleoflow directions of the ice sheet (shown by arrows) about the centers (black solid circle) located tentatively between Madagascar and India, and in the western part of Antarctica are noteworthy. The position of the 'Owen Fault Zone' along which the east and west Gondwana were separated is shown by the broken line between India and Africa.

to the melting of the ice-sheet and its radial dispersion. The plausibility of such an event can only be probed through the evaluation of the record of magmatic activities in the constituent continents of the Gondwanaland.

The magmatic record

So far as the magmatic activities in the Gondwanaland are concerned, the major information has been made available on the LIPs (large igneous provinces). Based on geochronology of non-orogenic igneous provinces of the Levant and six igneous provinces of Gondwana (central and southern Atlantic Ocean, Indian Ocean, Karoo, Marie Byrd Land-Eastern Australia, and Balleny), Segev (2000) identified 17 synchronous global magmatic events attributed to upper mantle convection in the course of the last 205 Ma. The chronology of these events in Gondwana igneous provinces points to short-term magmatic cycles, consisting of magmatic events plus intermagmatic intervals, with an average duration of ~ 13 Ma, depicting events of periodic magmatism. With a view to understanding the evolution of upwelling mantle flows and their role in continental breakup processes Segev (2002) synthesized and interpreted the evidence from the Mesozoic-Cenozoic igneous provinces and the fragmentation of Gondwana. Accordingly, it was inferred that the Permo-Carboniferous European-northwest African, the Jurassic Karoo and Northwest Australia - and convergent environments (Variscan Orogen, the Pacific and the Tethyan subduction zones, respectively) were genetically associated. It was further concluded that the Indian path consisting of an exceptionally relatively short-lasting swarm of plumes: Rajmahal-Kerguelen (~ 20 Ma), Madagascar (~ 8 Ma) and Deccan (~ 7 Ma), whose migration significantly changed course from the main trend. The recurrent consequential breakup and formation of spreading centers along this path are indicative of migration below the upper mantle circulation. Therefore, it is not unjust to conceive that the tectonic events experienced by the Gondwanaland were parts of a continuous process in consequence of the phases of growth and demise of the mantle plumes.

The record of magmatic activities within the Gondwana basin-fill successions of India is represented by the dykes and sills of lamproites and younger doleritic dykes. According to Rock et al. (1992), the Cretaceous (~ 110 Ma) lamprophyric sills in the Gondwana coalfields of India show a comagmatic continuum from olivine-lamproites to lamproites and minettes. According to them, the radiogenic isotopes ($\epsilon_{\text{Sr}} +7$ to $+21$ and $\epsilon_{\text{Nd}} -1.5$ to -3.1) of four sills in the Jharia basin imply derivation from a metasomatized lithosphere mantle source with time-integrated Rb/Sr and Sm/Nd slightly higher than

bulk Earth. Jia et al. (2003) described a comagmatic suite of lamproites, ultramafic lamprophyres, and minettes, which intruded at ~ 100 Ma the basin-fill successions of Gondwana basins of eastern India. The ^{15}N -enriched lamproites were interpreted to have formed from partial melting of enriched harzburgitic mantle lithosphere by decompressional melting accompanying extension. Despite considerable textural diversity and variable mineralogy, according to Chalapathi Rao et al. (2014), the ultrapotassic rocks (claimed to be from previously unstudied localities) from Jharia and Raniganj Gondwana basins in Damodar Valley, eastern India, display broadly similar geochemistry highlighting their co-genetic nature. It was further concluded that the ultrapotassic rocks of this study represented small degree-partial melts derived from a depleted garnet-bearing harzburgitic source which had experienced metasomatism by carbonate- and rutile-rich fluids/melts via Kerguelen plume. Olierook et al. (2017) were, however, of the opinion that the Sr-Nd-Pb isotopic characteristics of the majority of the ~ 140 – 117 Ma circum-eastern Gondwana magmatic provinces displayed only source contributions from the depleted asthenosphere and lithosphere with negligible contribution from the Kerguelen mantle plume. Therefore, the derivation of the ultrapotassic melts is not beyond controversy. Whatsoever, Chalapathi Rao et al. (2014) also emphasized that the depleted mantle (T_{DM}) model ages (0.95–1.4 Ga) of the Damodar Valley ultrapotassic rocks are strikingly similar to those of the Deccan-age orangeites from the Bastar craton, central India, and the emplacement ages (1.1–1.4 Ga) of kimberlites and lamproites from the eastern Dharwar craton, southern India.

Besides discrepancies in the reconstruction of the derivation of the ultrapotassic melts, the proposed age may imply that the ultrapotassic melts were emplaced almost at the terminal phase of the basin history. However, the field evidence does not attest to this view. In the Jharia basin of eastern India, it is evident that the lamproites intruded the basin-fill sediments at phases starting at least from the early Permian. In the lower part of the Barakar Formation (early Permian) thin tar layers, extracted during the coking of coal (Fig. 4) due to the emplacement of ultrapotassic melts, were found as interlayers within argillaceous sandstone succession. The tar layers bear a distinct signature of deposition of the overlying argillaceous sand layer after the cooling of the tar, as is evident from the profusely developed shrinkage cracks within the thin tar layers (Fig. 5) (Jamunia River section, Lat. $23^{\circ}45'38.23''\text{N}$; Long. $86^{\circ}10'55.1''\text{E}$). Svensen et al. (2018) also admitted that the detailed evolution and melt-flux estimates for the Gondwana-related Large Igneous Provinces (LIPs) are poorly constrained, as they

Figure 4. Photograph showing pillow-shaped lamproite intrusions within coked coal, Jamunia River section, Jharia basin.

Figure 5. Photograph showing shrinkage cracks developed within the layer of coal tar, which was released during coking of the coal due to lamproite intrusion before deposition of the overlying fine-grained argillaceous sandstone, Jamunia River section, Jharia basin.

are not yet sufficiently explored with high-precision U-Pb geochronology.

Torsvik and Cocks (2013) pointed out that there were only two LIPs in the Paleozoic (510 and 289 Ma) that directly affected the Gondwanan continental crust. According to them (Torsvik and Cocks, 2013, page 1026), ‘The African and Pacific Large Low Shear-wave Velocity Provinces (LLSVPs), the dominant source of deep plumes, have probably been stable for the entire Phanerozoic, and possibly much longer..... The LIP activity punctuated plate tectonics by creating and modifying plate boundaries: the Panjal Traps (289 Ma) probably assisted in the opening of the Neotethys; the opening of the Central Atlantic was preceded by the emplacement of Central Atlantic Magmatic Province (201 Ma), and Karoo (183 Ma) heralded the Jurassic breakup of Gondwana’.

The geochemical similarity and variability between the basalts from three spatially and temporally distinct Phanerozoic continental large igneous provinces (continental LIPs) of India, represented by Panjal (~ 289 Ma), Rajmahal (~ 117 Ma), and Deccan (~ 65 Ma) led Kumar et al. (2018) to conclude that the Panjal basalts with lower La/Nb, Th/Nb, and Th/Yb ratios and distinctly higher (in comparison with the other two LIPs) ϵ_{Nd} values (-3 to +8) were derived from the sublithospheric sources – possibly a mantle plume plus E-MORB patches within the asthenosphere. It is noteworthy that the ϵ_{Nd} values of the Gondwana lamproites as determined by Rock et al. (1992) fall well within the range of the Panjal basalts. So, at least the older lamproites (emplaced during the Permian) of the Jharia basin might have been comagmatic with the Panjal volcanics.

DISCUSSION

The disposition of the Indian Gondwana basins along some linear zones coinciding with the boundaries of the Precambrian protocontinental components of the peninsular shield mosaic primarily indicates a major tectonic control on intracratonic rifting. In the process of probing into the plausible tectonic control on the formation of these intracratonic half-graben basins with reference to the late Paleozoic global scenario, a few interesting points were identified.

1. The disposition of the late Paleozoic fault systems on the reconstructed Gondwanaland defines concentric pattern about the points located along the south-eastern margin and south of Africa (at the tip of South America) and one far south-west of South America (Fig. 3).
2. Since the fault system developed in consequence of crustal stretching, an event of domal uplift at the center of the concentric fault systems can be conceived.
3. The reconstructed directions of ice movement of the late Paleozoic ice sheet also display broad radial patterns about a point located between Madagascar and India, and another point located at the south-western part of Antarctica. Since this ice movement was the consequence of the melting process, some sub-crustal heat source might have played some role. The radial pattern of dispersion of ice further indicates a radial gradient, which also could be due to crustal upheaval. Hence, domal uplift due to penetration of plume heads into the upper mantle can be postulated.
4. The global extent of these events of development of the concentric fault systems and the radial dispersion of the ice sheets can be explained from the

present-day analogy of the global hot spot density function contours (Stefanick and Jurdy, 1984) and the corresponding geoid anomalies (Condie, 2005; Figs. 4 and 18).

With a view to assessing the plausibility of any such plume head penetration, the records of magmatic activities within Peninsular India and in other parts of the Gondwanaland were scrutinized. A periodicity in magmatic activity with origin and demise of mantle plumes is well documented from different parts of the Gondwanaland. In the Indian subcontinent, however, the picture is not that inspiring. The ultrapotassic lamproites reported from different Gondwana basins of India were interpreted to have been emplaced during ~ 110 Ma. However, the field evidence clearly indicates that the emplacement of the lamproite intrusives initiated at least during the early Permian time. However, the geochemical signatures, particularly the ϵ_{Nd} values of these lamproites match well with the Panjal basalt, which was emplaced during 289 Ma. Therefore, the lamproites of the Gondwana basins of India, in the first-hand approximation, appear to be comagmatic with the Panjal volcanics. However, systematic acquisition of geochemical and geochronological data from the lamproites from different stratigraphic levels can portray a more precise picture.

CONCLUSION

The centers of the concentric fault system and those of the radial ice movement are located very close to the lineament along which a rift system developed during the Sakmarian (~ 280 Ma), and the Panjal volcanics were emplaced along the northern extension of the same rift system. And finally, the fragmentation of the Gondwanaland was initiated along this linear zone with the separation of East and West Gondwana at around 170 Ma. Therefore, the formation of the Gondwana basins seems to be the prelude of the fragmentation of the Gondwanaland.

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