New explanation of the geological evolution of the Indian subcontinent

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A team of earth scientists from the Geological Survey of India and Birbal Sahni Institute of Palaeobotany, Lucknow, has advanced new views[1,2] about the paleaogeographic and geologic evolution of India from the time it was part of an early supercontinent existing during pre-Gondwanaland periods till its splitting from the latter and migrating to the present location. According to them, present day India is a composite of four independent blocks which got welded between 1600 and 500 m.y. ago before it broke away from Gondwanaland, where it lay sandwiched between Africa–South America on one side and Australia–Antarctica on the other, and traveled 7000 km northwards over a period of about 30 m.y. They say that their model answers earthquake enigmas in regions of India long considered quite stable.

Concepts about mobility in earth, though centuries old, have evolved to an acceptable form only in the last half a century after advances in geophysics, ocean floor surveys and earth science related space technology. Between 1908 and 1912, the noted geologist Alfred L. Wegner proposed that earth's continents moved slowly over geologic time, but fellow scientists of his times, who were wedded to an orthodox view of stable configuration of the continents, were skeptical. His ideas, therefore, remained neglected for years until the unfolding of plate tectonic theories during the 1950s and 1960s. The growing awareness, during this period, to the influence of earth's internal heat generation on some of the geological processes, breakthroughs in understanding of the evolution of ocean floors, earthquake mechanisms, mid-ocean ridges and volcanic island chains, all helped to refine the concepts about proposed global mosaic of crustal plates and their movements. The advent of palaeomagnetic techniques in the seventies offered excellent ways to derive the ancient orientation of lands and offered infallible proofs of their drifts, thereby putting an end to speculative palaeogeographic modelling. With the entrenchment of plate tectonic theories, geologists could explain discoveries of rocks and fossils of marine character deep inland and in mountain ranges, recognize ancient continental margins and oceans that must have existed, establish fragmentation of landmasses, their subsequent parting, drifting and re-assembly or collisions along mobile belts and mountain ranges and in fact, resolve many of the geological manifestations through time. Substantial data about these aspects have come mainly from evidences gathered from continental crust, as the ocean floors older than 200 m.y., which can provide information about plate boundaries and other palaeogeographic changes, are today lost to subduction processes. Nonetheless, increased palaeogeographic research during the post-1950s has resulted in a better picture of ancient distribution of lands and oceans.

Large continents were nonexistent during early Archaean times and the small ones that had formed, were short-lived as they were recycled back into the mantle. Surviving detrital minerals (zircons), dated around 4.2 billion years in Australia are evidences about these early crusts that had existed once[3–5]. Relatively stable configuration of lands could materialize only during the long Proterozoic period (between 2800 and 570 m.y. ago) when several of the early blocks (cratons) came together at collision zones to form a giant supercontinent towards the close of this period[6]. Pangea, that had stretched from pole to pole, was one such huge ancient landmass that had resulted from such an assembly. Some 180 m.y. ago, by the end of the Triassic period, this Pangean supercontinent parted into a southern Gondwanaland and northern Laurasia. Fresh inputs about the physics and chemistry of earth's interior link these crustal motions to the upwelling and downwelling mantle currents. This rifting and breakup of Pangea during Triassic–Jurassic periods was accompanied by massive volcanisms, events considered very much connected to mantle currents[7–9]. Their migrations are also believed to have been aided by earth's attempts to correct imbalances of mass (lands) resulting from periodic shifting of pole or the spin axis – the phenomenon of true polar wander (TPW). Such recurring shifts are also known to trigger sea level changes, like those that occurred during the 130–50 m.y. period, when the Indian subcontinent was evolving[10,11].

Fragmentation, within the Gondwanaland, by development of rifts, isolated India from a composite Africa–South America and Antarctica–Australia combine on its either sides (Figure 1).

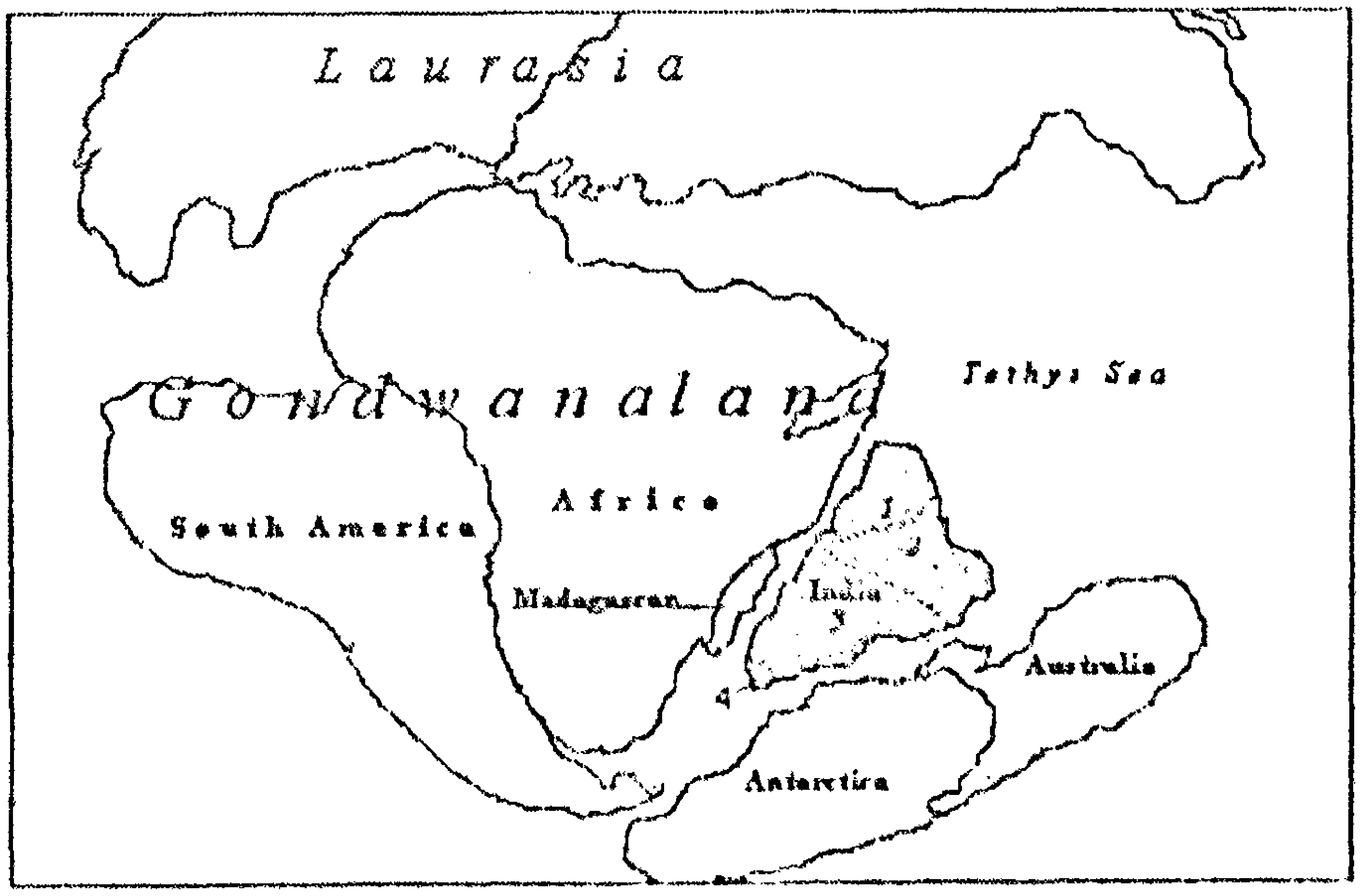

Figure 1. Breakup of Gondwanaland and separation of India (shaded portion) from Africa–South America and Australia–Antarctica. Numbers 1–4 represent the following four terranes sutured together along the dotted lines: 1, Trans-Aravalli Block; 2, Bundelkhand Block; 3, Dharwar Block; 4, South Indian–Sri Lankan Granulite Block.

Gradual widening of the rifts further separated it from Africa–South America landmass (leading to the birth of Indian Ocean, about 140 m.y. ago) and later, by early Cretaceous, freed it from Australia–Antarctica, to set it on its northward migration as a subcontinent. This initial lithospheric connection with Australia was the reason to refer this Indian plate movement as the Indo-Australian plate movement, though recent studies have brought out that this plate had since split and both India and Australia had started moving in different directions[12,13]. After complete separation from Gondwanaland, India moved away rapidly (at 195–180 mm/year)[14] and collided against the Asian continental plate (continent–continent collision) more than 50 m.y. ago marking the beginning of the Himalayan orogeny. This collision warped up the colliding faces and pushed the crust deep down, thus thickening the crust and producing other features quite unique to this place. According to some, the Indian plate is thought to subduct beneath the Asian plate, but to others, this is not possible as the lower density of the lithospheric crust should prevent its sinking below the asthenospheric zone (70–250 km depth)[15–18]. Volcanism (seen as ophilolites and basic igneous rocks in the Himalayas), which form part of such geological processes is, accordingly, considered by some as due to partial melting of the plunging lithosphere, while to others it is a normal event in any trench zone created by the subduction of oceanic crust.

Geological evolution of India is thus closely linked to that of Gondwanaland from which it had fragmented, but the various tectonic, magmatic and orogenic events and associated sea-level fluctuations, prior to this breakup, have not received adequate attention in earlier reconstructions. Now a team of geologists has proposed a stage by stage evolutionary model for pre- and post-Gondwanaland India, up to the rise of Himalayas during the Cenozoic period[1,2]. In this task, they have chronicled the various tectonothermal events, sea-level fluctuations and associated impacts on climate and marine life during this period and identified imprints of these events in the Indian subcontinent. According to the authors, India is an integration of four distinct blocks, and each of them had separate evolutionary history. Their assembly took place between Palaeoproterozoic and early Palaeozoic times, before parting from Gondwanaland. This new view of India as a mosaic of four blocks is a major departure from existing views, which always considered the country as a single rigid block. Secondly, in their view, Tethys Sea that once lay to the north of India, came into existence much earlier than the generally assumed period towards the end of Precambrian. Thirdly, the authors differ also from the current usage of the term Gondwana, synonymous with the sediments confined to the narrow period between Carboniferous and Mesozoic, ignoring its much wider temporal connections. In tracing the subcontinent's evolutionary stages, they have recognized, with isotopic age data support, as many as eight distinct tectonothermal episodes between mid-Precambrian (2400 m.y.) and mid-Palaeozoic (450 m.y.), each culminating in an orogeny and changes to the life of the times.

The four terranes or blocks (Figure 1), *identified by the team as mosaics forming* the Indian subcontinent are apparently a few of the several independent Archaean fragments (cratons) that had fused to form the supercontinent of pre-Proterozoic period (> 2400 m.y. period). The Indian mosaics or blocks are (Figure 2) (a) Bundelkhand block (BB), an early Proterozoic magmatic terrane of granitic and gnessic rocks enclosing remnants of 3.0–3.5 billion years old Archaean crusts and extending beyond Himalaya northwards; (b) Dharwar block (DB), with Archaean cratons – Karnataka, Bastar, and Singhbhum; (c) Trans Aravalli Block (TAB), with remnants of palaeoproterozoic granulitic and charnockitic rocks and younger age granitic events; (d) South Indian–Sri Lankan Granulite Block (SI-SLGB), showing > 2.5 billion year old Archaean crusts. The orogenic belts that suture these blocks are: (i) the Satpura Mobile Belt (SMB), a remobilized tectonically emplaced Archaean basement, between DB in southern India and BB in the north; (ii) the Aravalli–Delhi Mobile Belt (ADMB) suturing the BB and TAB made up of *volcano-sedimentary sequences* of 2.6–0.95 billion year period; (iii) the Palghat–Cauveri Shear Zone (PCSZ)

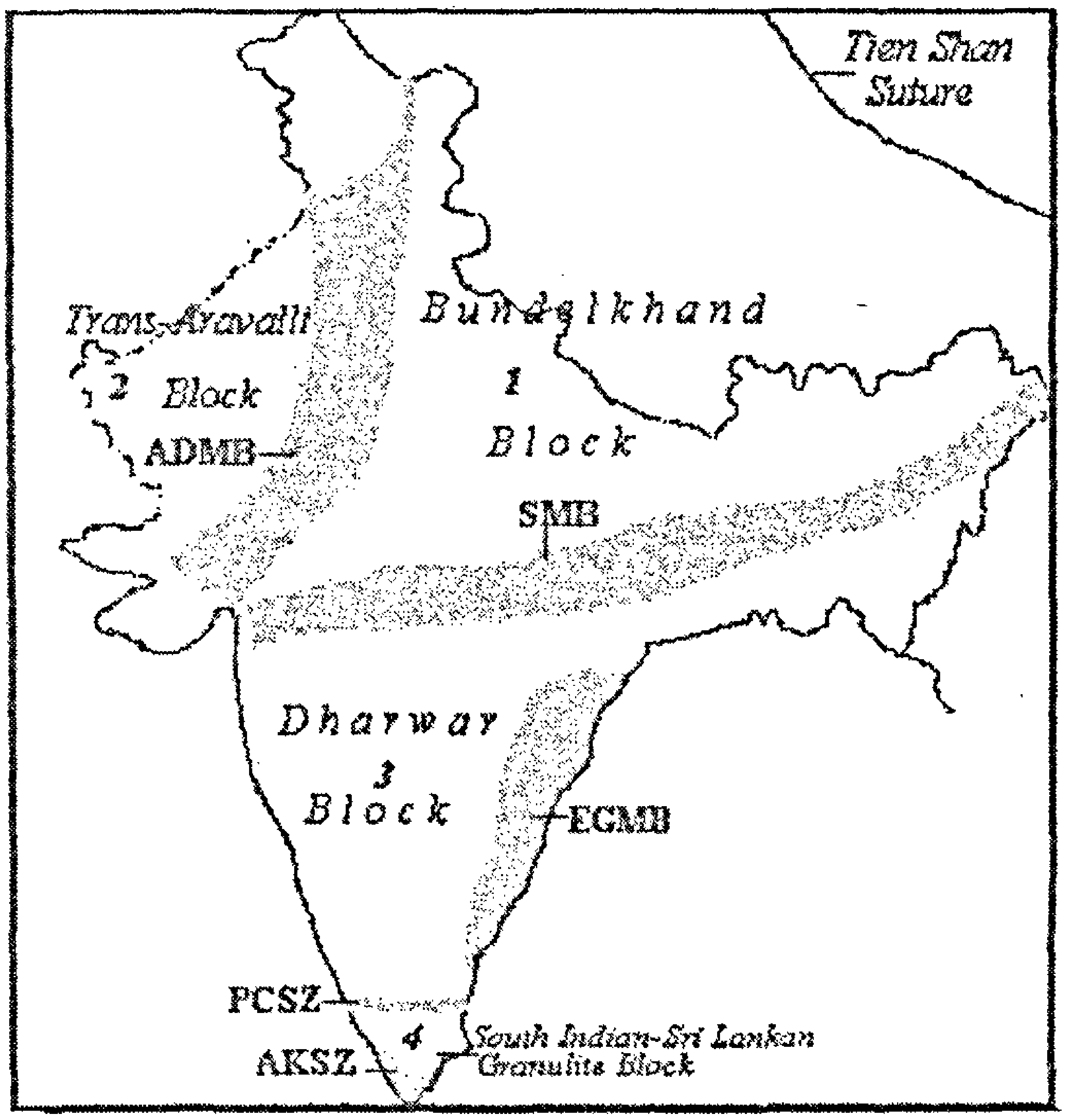

Figure 2. Mosaic of the four Archaean–Proterozoic Blocks that amalgamated to form the Indian subcontinent. Shaded portions represent the mobile belts (suture zones): ADMB, Aravalli–Delhi Mobile Belt; SMB, Satpura Mobile Belt; EGMB, Eastern Ghat Mobile Belt; PCSZ, Palghat–Cauveri Shear Zone; AKSZ, Achhan Kovil Shear Zone. (from Ravi Shankar *et al.*[2]).

between the DB and the SI–SLGB, separating 2.0–3.0 billion year northern charnockitic zone from 0.5 billion year old southern charnockitic zone; and (iv) the Eastern Ghat Mobile Belt (EGMB), essentially granulitic and migmatitic rocks of 2.6–1.0 billion year period, along the eastern boundary of the DB; this block lay adjacent to East Antarctica during the pre-Gondwanaland times. According to the authors, the four blocks were welded together during two major tectonothermal events: (i) around 1600 m.y. ago that welded BB, DB and TAB and sutured them to western Australia and Antarctica to constitute east Gondwanaland; (ii) around 500 m.y ago, which sutured SI–SLGB with DB along the Palghat–Cauveri shear zone (PCSZ). With closure of these two events, the making of the Gondwanaland was completed. The Indian shield composed of several Archaean and younger Proterozoic terranes thus came into existence, the erosion of which developed sedimentary sequences of the younger Mesozoic to Phanerozoic periods, besides exposing in places the basement granitic and granulitic rocks[1,2].

Ravi Shankar *et al.* have identified as many as eight distinct orogenic events (tectonothermal and magmatic) progressively during the evolution of the Indian subcontinent. They are (1) the 2400 m.y., (2) the 2200 m.y. events traceable in the Archaean and Palaeoproterozoic blocks, (3) the 1900–1800 m.y. event traceable in BB, ADMB and certain Himalayan sequences, (4) the 1600–1500 m.y. event traceable in SMB and EGMB, (5) the 1000 m.y. event traceable in the EGMB, ADMB and some Himalayan sequences, (6) the 900–800 m.y. event traceable in TAB only, (7) the 750 m.y. event traceable in TAB and BB, and (8) the 450 m.y. event traceable in all the mobile belts and cover sediments.

The authors have traced the evolution of the Tethys Sea from its birth during Palaeoproterozoic to its demise during the Cenozoic. Through the Proterozoic and younger marine sedimentary sequences in the four terranes, including the region which later became the Himalayas, they have been able to distinguish two stages in the evolution of this sea – an earlier Prototethys and a later Palaeotethys[19]. The Prototethys offered a wide basin for meso- to neo-Proterozoic deposits collectively termed the Puranas (Cuddapah, Vindhyan, Chattisgarh, Kaladgi, Pranhita–Goadavari and Bhima basin sedimentaries), including the equivalents in the Himalayas stretching up to Kun Lun. All major tectonothermal events of this period resulted in sea level fluctuations affecting the coastline as well as climate and triggered glacial cooling, diversification of species and evolutionary changes to the biota[2]. Various forms of stromatolites and sponges were the main life forms. The most notable feature among these is the occurrence of Porifera with complex body organization in the Precambrian sediments (1350 m.y.), a find that strengthens the case for the dawn of metazoa much ahead of the long considered beginnings only during the Cambrian explosion of animal life[20,21]. The second stage in the evolution of the Tethys Sea is the Palaeotethys which resulted due to upliftment of Indian shield, pushing the existing sea northwards[2,19]. Sedimentation in Palaeotethys spanned 470–296 m.y. period, these sediments evolving in four stages in response to separate tectonothermal events, each resulting in characteristic supersequences and biota.

Ravi Shankar and his team's postulation of the paleogeographic evolution of India as an assembly of four independent terranes, welded along mobile belts before it parted from Gondwanaland are phases hitherto not highlighted in Indian stratigraphy. Assuming that the mosaic of four blocks had moved independently from different directions prior to their assembly[22], palaeomagnetic studies on available pre-Proterozoic (pre-assembly) magmatic rocks in these four blocks, should further strengthen their case. Their find of fossils of complex anatomy is of added interest, if these finds could meet the contentious criteria put forth by the participants in the current controversy on the emergence animals with complex body plan earlier than the accepted 570 m.y. datum line. Another of their important conclusions is that the suture zones, potential sites for accumulation of stresses for triggering shocks, explain the recurring earthquakes in Central India and Deccan plateau, long considered to be a single rigid block and hence unlikely places for earthquakes. Their views are bound to initiate a healthy debate, notwithstanding the fact that they fit well with post-Proterozoic scenario of continental development in this part of the earth.

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