# Indian Gondwana Plate margin and its evolutionary history

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The outline of the Indian Plate in the Gondwanaland Plate mosaic has been reconstructed. The basic premise for the reconstruction lies in the identification of the suture zone along Indus-Yarlung tectonic zone and Indo-Burman range, both of which are wreathed with ophiolite complexes. The north-eastern margin of the Indian part of the Gondwana Plate, which was ill-defined in many earlier reconstructions, is now more precisely delineated with the find of slide-generated olistostrom bodies representing plate marginal trench setting around Ukhrul-Paoyi-Kiphire area of the ophiolite belt of Manipur-Nagaland. The recent report of continental Gondwanas close to this suture zone lends credence to this palaeogeographic reconstruction. On the north, the continental sediments having distinct Gondwana entity rarely extend to the Tethyan basin and as such the Indus-Yarlung Suture truly delimits the Gondwana Plate domain. The Himalayan front is regarded as a Tethys-facing margin of the Gondwana continent. Along the eastern margin of Indian Plate, rifting as a sequel to ocean floor spreading led to the evolution of coastal troughs of Cauvery, Palar, Godavari-Krishna and Athgarh which bear records of marine transgressions during Aptian-Albian time from a juvenile Indian Ocean. These oceanward tilted troughs may represent the rifted arm of a triple junction formed during the continental fragmentation. The discovery of such troughs in the Upper Assam and Bengal Basin suggests that the separation of India from Eastern Gondwanaland occurred in a NE-SW direction. The Cambay and the Kutch basins document similar evolutionary history along the western margin of Indian Plate. As a consequence of crustal tension accompanying the fragmentation, outpour of tholeiitic basalt took place in Rajmahal, Khasi-Garo-Mikir Hills and Upper Assam at 100-105 million years along the west coast. The earliest manifestation of volcanism has been recorded in Saurashtra which is considered to be contemporaneous with Rajmahal volcanicity. It is suggested that both the eastern and western margins of the Indian Gondwana Plate bear closely related records of fragmentation in Early Cretaceous time.

**Key-words**—Indus Suture, Indian Plate, Palaeogeography, Continental Drift, Plate Tectonics.

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## साराँश

**भारतीय गोंडवाना प्लेट की सीमा एवं इसका वैकासिक इतिहास**

एँन० डी० मित्रा

गोंडवाना प्लेट में भारतीय प्लेट की पुनर्रचना इन्डो-बर्मा श्रेणी एवं सिंधु-यारलुंग विवर्तनिक मंडल के संग-संग स्थित सूचर मंडल के अभिनिर्धारण के आधार पर की गई है। ये दोनों ही ऑफ़ियोलाइट-सम्मिश्र के साथ संलग्न हैं। गोंडवाना प्लेट के भारतीय भाग की उत्तर-पूर्व सीमा, जो कि अभी तक पूर्व पुनर्रचनाओं में सुस्पष्ट नहीं की गई थी, को सूक्ष्म रूप से परिसीमित किया गया है। इस सूचर मंडल के निकट अलवणीजल गोंडवाना की हाल की प्रस्तुत रिपोर्ट पुराभौगोलिक पुनर्रचना की पुष्टी करती है। उत्तर में गोंडवाना मूल से भिन्न अलवणीजल अवसादों का विस्तार टॅथीय द्रोणी तक बहुत ही कम है और इसी प्रकार गोंडवाना प्लेट सिंधु-यारलुँग सूचर से परिसीमित है। हिमालय का अग्र भाग गोंडवाना अवसादों की टॅथीय की ओर की सीमा के रूप में माना गया है। भारतीय प्लेट की पूर्वी सीमा के संग-संग समुद्र तल में हुई रिफ्ट के कारण ही कॉवेरी, पलार, कृष्णा-गोदावरी एवं अथगढ़ तटीय द्रोणीयों का निर्माण हुआ है जिनसे ऍप्शियन-ऍल्बियन काल में समुद्री अवनमन के प्रमाण मिलते हैं। उपरि असम एवं बंगाल द्रोणियों में ऐसी द्रोणिकाओं की उपस्थिति इंगित करती है कि

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पूर्वी गोंडवानाभूमि से भारत का सम्बन्ध विच्छेद उत्तर पूर्व-दक्षिण पश्चिम दिशा की ओर हुआ है। कैम्बे एवं कच्छ द्रोणियों से भी भारतीय प्लेट की पश्चिमी सीमा के संग-संग हुए वैकासिक परिवर्तनों के प्रमाण मिलते हैं। भूस्तरिक तनाव एवं विखंडन के फलस्वरूप राजमहल, खासी-गारो-मिकिर पहाड़ियों एवं उपरि असम में पश्चिम तट के संग-संग थोलाइटी बासाल्ट का निर्माण हुआ है। सौराष्ट्र में प्राचीनतम् ज्वालामुखीयता का प्रमाण मिला है जो कि राजमहल के समकालीन माना गया है। यह प्रस्तावित किया गया है कि भारतीय गोंडवाना प्लेट की पूर्वी एवं पश्चिमी दोनों ही सीमाओं पर प्रारम्भिक क्रीटेशी काल में हुए विखण्डन से घनिष्ठ सम्बद्ध चिन्ह अभिलिखित हैं।

THE precise outline of Indian Gondwana Plate and the inter-relation between India, Antarctica and Australia have long been a topic of lively discussion. Of the various fits, the one proposed by Smith and Hallam (1970) has received wide acceptance. In this fit the eastern edge of the Indian Plate lies in Assam and is separated from Australia by an oceanic gulf 'Sinus Australia'. Later it was postulated that Sinus Australia was occupied by a continental block which continues into the Indian crustal plate in an entity called Greater India (Veevars *et al.*, 1975; Sonson *et al.*, 1976). But the fact remains that in all these reconstructions the outline of the northeastern margin of Indian Gondwana Plate remains ill-defined. Recent geological studies in Assam, Mismi Hills, Nagaland and Manipur have yielded certain basic data which permit precise delineation of northeastern boundary of Indian Gondwana Plate.

There are also divergent views about the extent of northern margin of Gondwanic India. Debate persists whether the Indus Suture Zone defines the relic of a closed ocean that lay between Indian Gondwana Plate and Asia or the suture zone is intracontinental in origin. Further studies on Indus-Tsangbo Zone have thrown considerable light on the question of plate boundary. Similarly the data of offshore drilling and geophysical survey in coastal areas of India provide significant clues for outlining the Gondwana crustal plate along east and west coasts of India. A synthesis of all available information has been made for the reconstruction of Indian Gondwana Plate which is outlined in Text-figure 1.

## NORTHERN MARGIN OF INDIAN PLATE

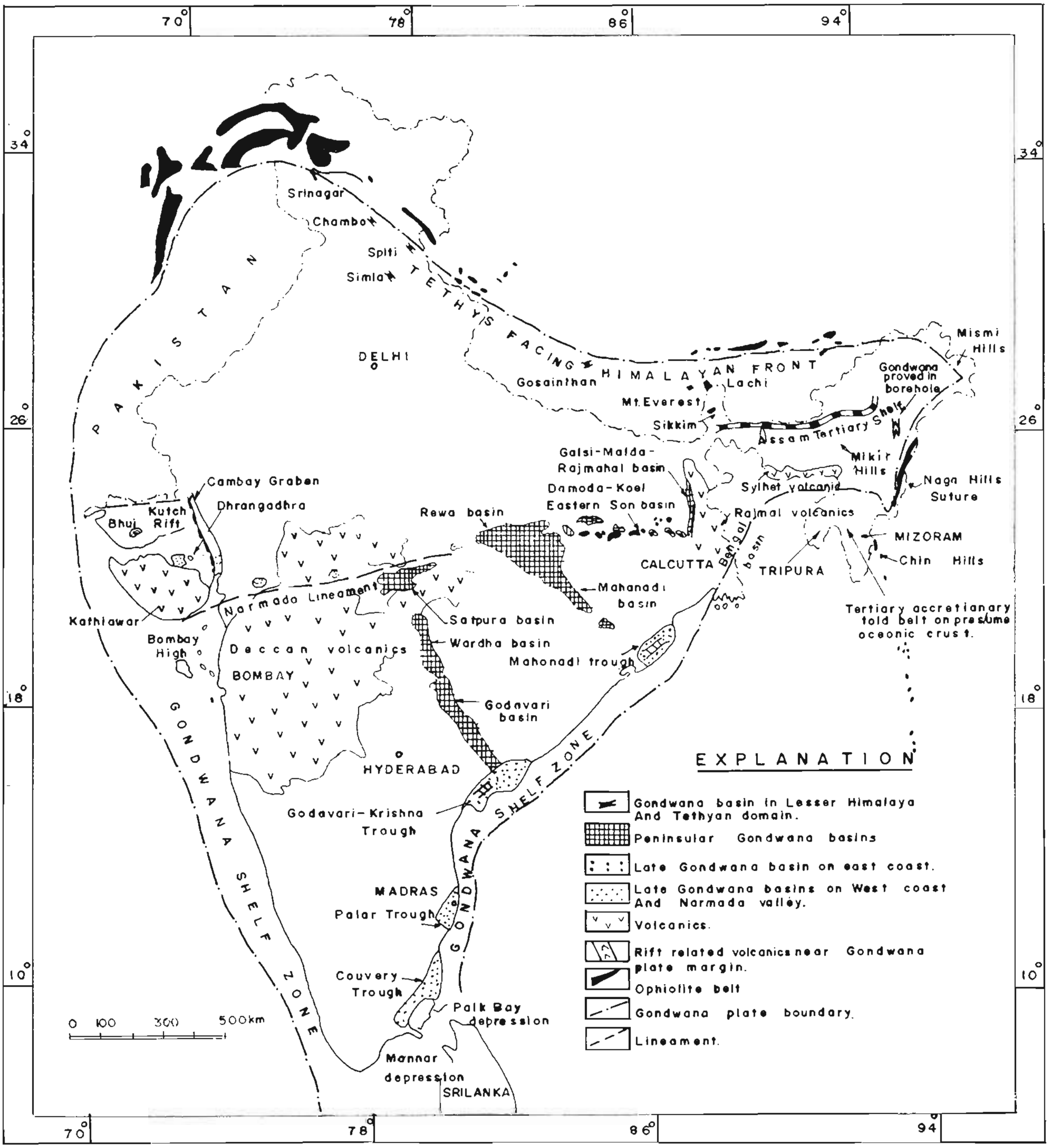
The northern and northeastern margins of Indian crustal plate are now occupied by two major geosutures exposing resurrected ophiolitic masses of ancient oceanic lithosphere. The Indus-Tsangbo suture of the north, however, can not be continuously traced around the northeastern tip of India into the ophiolite belt of Nagaland-Manipur. The physical continuity is disrupted in Miami Hills and it is a point of debate whether these two sutures are dislocated portion of the same belt, preserving the records of a single event of collision history or they represent two separate belts of different history. With the objective of reconstruction of Indian Gondwana Plate the critical information from these sectors are reviewed.

The ophiolite belt along Indus-Tsangbo Zone extends for 2,000 km along the upper reaches of the Indus-Yarlung-Tsangbo River. In this zone the dismembered suite of ophiolites is represented by tectonised harzburgite, layered gabbros, sheeted dykes and pillow lavas. A plutonic calc-alkaline belt known as Gangdise or Trans-Himalayan pluton follows the Indus Suture to the north over a distance of 2,000 km. The U-Pb ages substantiate that this magmatic activity lasted from 94 million years (Cenomanian) to 41 million years (Lutetian; Scharer *et al.*, 1984). South of the suture the Tethyan facies is characterised by a sedimentary sequence which formed in shelf environment on the Indian Shield. These comprise Palaeozoic-Mesozoic, richly fossiliferous shallow marine, largely neritic limestone with interbands of sandstone and shales. A characteristic facies of the Tethyan zone near the suture is a wild flysch horizon with exotic blocks ranging in age from Permian to Palaeocene as shown in Text-figure 2A. These exotic blocks are regarded to be olistoliths which have slid off the Tethyan carbonate shelf and have been tectonically incorporated within the sediments both during deposition and emplacement (Brookfield & Andrews, 1984).

There are three divergent opinions regarding the northward extent of the Gondwana continent vis-a-vis time of creation of the oceanic crust now represented in the Indus-Tsangbo Suture:

(i) The Tibetan Block is included as part of Gondwanaland (Stocklin, 1983) on the basis of occurrence of cold-water Permocarboniferous fauna and glossopterids in northern Tibet (Shang & Lee, 1974) in alleged glaciofluvial deposits. The common history ended in Late Palaeozoic when Tibet rifted away as a microcontinent, and got accreted to the Asian Plate which is indicated by the significant differences in sedimentary and tectonic history between Tibetan and Himalayan margin during Mesozoic.

(ii) The Indian Gondwana Plate extended up to the southern margin of Kunlun-Animaching mobile belt on the basis of geophysical data (Kaila & Narain, 1981).




**Text-figure 1**—Schematic outline of Indian Gondwana Plate showing plate margin along Indus-Tsangbo and Naga Hills suture zones. The plate boundary along coastal areas is drawn based on geophysical and offshore borehole data. **1**, Gondwana basins in Lesser Himalaya and Tethyan domain; **2**, Peninsular Gondwana basins; **3**, Late Gondwana basins on east coast; **4**, Late Gondwana basins on west coast and Narmada Valley; **5**, Volcanics; **6**, Rift related volcanics near Gondwana Plate margin; **7**, Ophiolite belt; **8**, Gondwana Plate boundary; **9**, Lineament.

(iii) The Indus-Tsangbo Suture is the northern limit of Gondwanaland and marks the location of closure of the tethys.

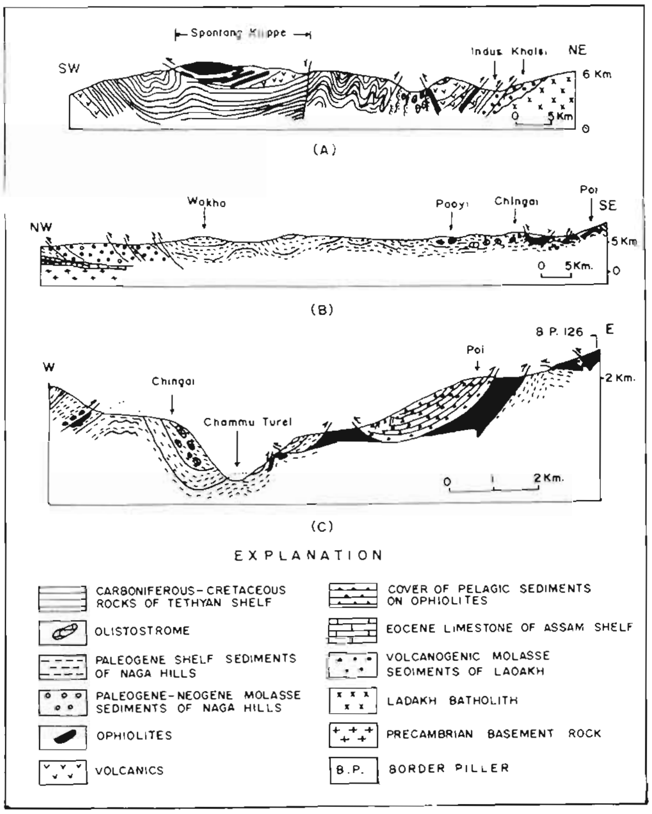
The first two opinions receive support from the doubts raised by workers about the existence of 6,000 km wide Tethyan ocean separating India from Palaeo-Asia (Stocklin, 1983). For delineation of Indian Gondwana Plate margin the evidences from this debated zone are re-examined. The find of Glossopteris Flora from northern Tibet has not been accepted by other Chinese geologists (Hsü, 1976). On the contrary Early Permian Cathaysian flora, discovered in the Lhasa Block, does not contain Gondwanic elements. The Rhaetian palynoflora from north of Lhasa shows close relation with the equatorial flora and lacks any Indian taxa (Allegre *et al.*, 1984). This find suggests that the Lhasa Block, which has been interpreted as part of 'Greater India', was actually situated near equator as early as Late Triassic.

The reported occurrence of *Lystrosaurus hedini* and *L. youngyi* from north of Tienshan in Tarim-Sino Korean Block is rather enigmatic. These remains of Lystrosauridae are comparable to those of India, South Africa, Antarctica and Laos (Zhang *et al.*, 1984). It is, however, quite striking that there exists a similarity between the Triassic vertebrates of South Africa and those of USSR for which migration via a circuitous route has been envisaged. On the same line it may be argued that the Triassic reptiles in China migrated from Russian segment of Angaraland. In other words, *Lystrosaurus* may be regarded as Pangean vertebrate. It is also to be examined whether the Lystrosaurus Fauna from different places of Northern Hemisphere document a history of parallel evolution (Dutta & Mitra, 1982). Upper Gondwana floral elements including *Elatocladus plana* and *Ptilophyllum* are reported from the area north of Indus Suture (Sharma *et al.*, 1980). These plants are, however, not strictly restricted to Gondwana Sequence as in Upper Jurassic-Lower Cretaceous Period the provincialism of flora is not clearly manifest.

The Cretaceous pole derived from Albian-Aptian red beds of southern Tibet placed the margin near Lhasa at a palaeolatitude of 11.5 ± 3 °N (Phillippa & Achache, 1984). On the other hand, Eocene limestone sample from south of Indus Suture on northern margin of Indian Plate gives a palaeolatitude of 6°S. Based on palaeomagnetic studies it is visualised that northern margin of India collided with Ladakh island arc nearly 54 million years ago.

Seismic exploration of deep structures in Lhasa Block and bordering sutures shows that in the area to the north of Himalayas 70 km deep Moho can be traced at approximately that depth until it is abruptly terminated in the region of Yarlung-Tsangbo. Here 20 km change in Moho depth is recorded (Hirn *et al.*, 1984). This abrupt change in crustal thickness is consistent with the model of plate junctions and post suture strike slip movement. High heat flow values recorded from southern tibet are also in conformity with the data in old continental collision zones (Francheteau *et al.*, 1984).

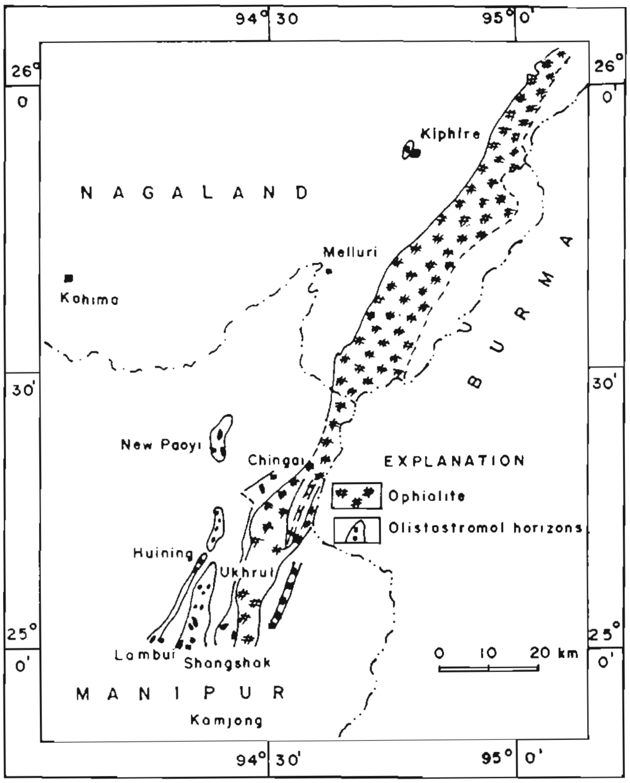
The above evidences document that rocks with Gondwanic affinity *sensu stricto* never extended beyond the Indus Suture Zone. On the other hand, tectonic signature along the Indus Suture clearly points out that this zone marks the site of a collision. The calc-alkaline magmatism of Gangdise belt is therefore, a product of subduction of Tethyan oceanic lithosphere beneath continental margin of Asia. Evidently, Gondwanic India with its sedimentological and palaeontological entity extended northwards up to Indus-Tsangbo suture and the Himalayan front was the Tethys facing margin of Indian Gondwana Plate.




**Text-figure 2**—Geological sections across Indus Tectonic Zone and Naga Hills suture showing the disposition of olistostrome horizons and ophiolite bodies. **1**, Section across Indus Tectonic Zone, Ladakh; **2**, Section across Naga Hills; **3**, Section across the ;suture zone in Manipur, Naga Hills; **4**, Palaeogene-Neogene molasse sediments of Naga Hills; **5**, Ophiolites; **6**, Volcanics; **7**, Cover of pelagic sediments on ophiolites; **8**, Eocene limestone of Assam shelf; **9**, Volcanogenic molasse sediments of Ladakh; **10**, Ladakh batholith; **11**, Precambrian basement rock.

## NORTH-EASTERN MARGIN OF INDIAN PLATE

In the northeast the only reported occurrence of Gondwana rocks of Talchir and Barakar formations is from Singrimari in the western tip of Meghalaya craton. However, the predominance of Lower Gondwana miospores from the younger Tertiary sediments of Upper Assam has indicated that




**Text-figure 3**—Map showing the distribution of olistostromal horizons in Manipur-Nagaland ophiolite belt. **1**, Ophiolite; **2**, Olistostromal horizons.

Gondwana rocks had earlier a wider spread on the Assam Shelf. Recently Oil and Natural Gas Commission has proved near Borpathar close to the western periphery of the Naga Hills, the glaciogene Talchir Formation of Gondwana Sequence at depth beneath the cover of younger Tertiary rocks. This find suggests that the domain of Lower Gondwana sedimentation encompassed the large segment of Upper Assam Shelf.

As the terrestrial Gondwana rocks and their homotaxial marine facies have mostly been denuded by pre-Tertiary erosion in Upper Assam Shelf and the adjoining continental margin to the east, it poses serious limitations in defining the plate boundary. Further, the Tertiary fold belts which have been accreted on the northeastern margin have added to the complexity of the problem. However, the recent analysis of stratigraphy and structure of Cretaceous-Tertiary rocks of Nagaland-Manipur gives a better insight into the problem of Gondwana Plate boundary.

## MISMI HILLS SECTOR

Geological data from Mismi sector is rather scanty and it still remains an unknown gap in the jigsaw puzzle. On the basis of information collected during a couple of geological traverses in the area, attempts of palaeotectonic reconstruction have been made. The Indus-Tsangbo Suture gets lost eastwards in the complex structural set up of the Eastern Himalayan Syntaxis. Along Mismi Thrust, an accepted tectonic feature in the frontal belt, quartzites, and marbles override the Quaternary sediments. In Tidding Valley cutting across this Mismi pack of sediments, a highly folded limestone is flanked by a silver of sheared serpentinites. Further northeast, the metasediments are juxtaposed against a diorite granodiorite complex (Nandy, 1980; Chattopadhyay & Chakraborty, 1984). On the basis of this limited geological account contradictory tectonic models have been proposed. According to Acharyya (1981) the granite granodiorite complex possibly joins up with the Trans-Himalayan batholiths and the serpentinites correspond to the ophiolite belt of Mitkyina and Mandaley in Burma. Nandy (1980) postulates that the serpentinites represent ophiolite emplacement along palaeosutures and they have no linkage with Tsangbo Zone. Chattopadhyay and Chakraborty (1984), however, observed that the serpentinites are intrusive into the limestone, producing wollastonite. The diorite-granodiorite complex according to these authors shows intrusive relation with the Mismi metasediments. They have suggested a cryptic suture lying south of Tidding.

Correlation of the serpentinites with the ophiolites of Mogok belt of Burma appears unrealistic as the magmatic event in Mogok suite of Surma is characterised by rift related alkaline rocks (Goossen, 1978). The intrusive relationship shown by the serpentinites with the adjoining metasediments makes them unacceptable as an ophiolite association correlatable with any nearby ophiolitic rocks of the area. In the absence of any radiometric age for the diorite granodiorite complex, it is highly speculative to correlate the magmatic activity with Trans-Himalayan granitic events.

It is possible that these metasediments together with the serpentinite and the acid igneous rocks represent a cover transported along Mismi Thrust. As such, rocks of Gondwanic affinity if at all developed in the northeast periphery of the Indian Plate, are likely to be covered by this transported mass. The Gondwana Plate boundary, therefore, seems to be underneath the thrusted mass.

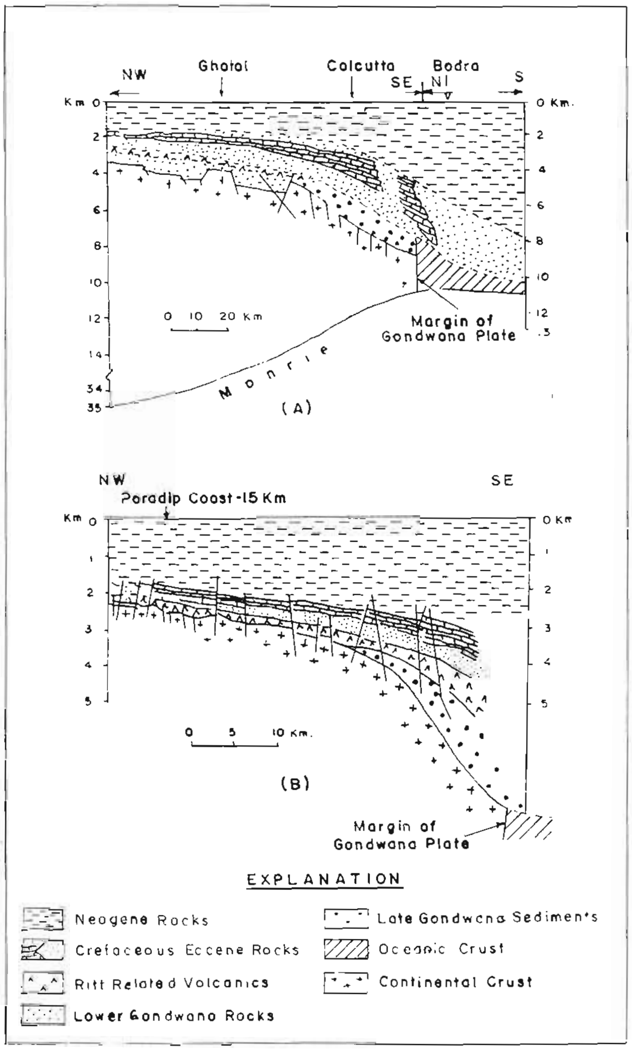
## NAGALAND-MANIPUR SECTOR

The continental Gondwanas have recently been proved close to the western periphery of the Naga Hills. The Gondwana crustal plate, however, extended to the east beyond the confines of continental Gondwana basins. Precise delineation of plate margin involves an integrated study of the ophiolite melanges in Naga Hills, olistostromal bodies of Manipur-Nagaland and the rift related volcanics near plate margin.

Breaking up of Indian Plate from Gondwanaland plate mosaic in Lower Cretaceous period was accompanied by distension of the crust along the margin of the plate. This caused volcanism in the plate margin which is recorded in Koliajan and other places of Mikir Hills on Assam shelf. It is felt that the rift related volcanics in Mikir Hills are genetically linked with the Sylhet volcanics which have a large spread in the southern periphery of Meghalaya craton. The Sylhet Volcanics in turn join up across the Bangladesh subsurface with the Rajmahal volcanic suites of Bihar and Bengal Basin which is dated 100-105 Ma (McDougal & McElhinny, 1970). The Sylhet volcanics 250-600 m thick comprise predominantly tholeiitic basalt with subordinate alkali basalts, rhyolites and acid tuffs. Closely associated are alkali lamprophyre dykes in eastern Garo Hills.

The continental Gondwana and associated rift related volcanics of Mikir-Upper Assam Shelf are covered by a thick sequence of shelf sediments of Palaeogene age which are over-riden by tectonised and dismembered ophiolite suite of rocks in Nagaland Palaeogene age which are over-riden by tectonised and dismembered ophiolite suite of rocks in Nagaland and Manipur. The ophiolite suite includes tectonised peridotite, garnet Iherzolite, dunite, harzbargite, Iharzolite, ultramafic and mafic cumulates, plagiogranites, alkaline to tholeiitic volcanics with interbedded radiolarian cherts and pelagic limestone (Acharyya *et al.*, in press). The fossil assemblages of the radiolarian chert and limestones show mainly a Maestrichtian affinity though in Manipur the volcanics show Lower Eocene age based on the biota of interbedded limestones. Nevertheless, the thick sequence of volcanics, which are preserved in some segments of this belt, definitely point to an earlier age of the oceanic crust, may be Aptian-Albian. The ophiolites have a thick cover of oceanic pelagic sediments characterised by variegated shales and radiolarian cherts.

The Naga Hills ophiolite belt defines a prominent suture which is linked southward with Chin-Arakan-Andaman-Indonesian arc. This narrow tectonised belt is believed to represent the Palaeo-Tethys sea which was consumed during the collision of Indian Plate with the Eurasian Plate. In this suture zone the ophiolites are juxtaposed against rocks which show significant regional variation in their depositional environment. In Naga Hills, Eocene




**Text-figure 4**—Crustal sections across plate margin, **A**, Bengal basin; **B**, Mahanadi offshore area, Orissa. The cross sections show the limit of Gondwana crustal plate; **1**, Neogene rocks; **2**, Cretaceous-Eocene rocks; **3**, Rift related volcanics; **4**, Lower Gondwana rocks; **5**, Late Gondwana sediments; **6**, Oceanic crust; **7**, Continental crust.

shelf deposits have been imbricated with the ophiolites during the obduction of oceanic lithosphere. On the other hand, along this suture zone in southern Burma and Andaman, the ophiolites are juxtaposed against rocks which were not deposited on the shelf of Gondwana continent. Rather they rest over the oceanic basement which was formed after the breakup of Gondwanaland. Here the present day plate edge lies along Sunda-Andaman arc and this tectonic zone from western flank of Mentwai-Nias Ridge has been traced northward into the young fold belts of Chittagong and Tripura (Roy, 1983). The adjoining Mizoram fold belt has also evolved from similar arc trench related subduction and subsequent continental accretion. Thus the resurrected oceanic crust of Palaeo-Tethys is juxtaposed both against Gondwana crustal rocks as well as against young accreted fold belts along this arcuate Andaman-Nagaland. Suture. However, an orderly analysis of palaeoenvironment of the Early Tertiary sediments lying against the sutured edge of the ophiolite belt provides clues for the reconstruction of Gondwana Plate outline.

The most significant information for the reconstruction of palaeoplate margin in Nagaland-Manipur is provided by stratigraphically ordered olistostrome bodies which occur in a distinct belt flanking the outer edge of the suture from New Paoyi to Huining and from Chingai to Lambui in Manipur as shown in text-figures 2B, 2C and 3. To the north it extends up to Kiphire in Nagaland. This facies occurs in the upper part of Disang Formation (Eocene) which has a large spread as distal shelf facies on the northeastern periphery of Gondwana Plate. The majority of olistoliths are of limestone blocks which measure up to 150 m along the long axis. The blocks are composed of rocks of Maestrichtian (*Globotruncana*-bearing), Palaeocene and Middle Eocene (with Nummulites, *Discocyclina* biota) age. The olistostromal facies is usually formed in marginal trenches as a result of tectonic disruption of continental margin followed by a major phase of gravity sliding (Robertson, 1977). The age of this synorogenic rock is provided by youngest fossil record of the exotic blocks and as such a late Middle Eocene age for Naga Hill olistostromal deposits is suggested. Based on the distribution of olistostromal facies in autochthonous Early Tertiary deposits of Naga Hills it has been possible to define the palaeoplate boundary in northeastern India as these facies mark the site of ancient continental margin The occurrence of olistostromal bodies in identical tectonic level along the northern margin of Indian Plate close to Indus-Tsangbo Suture corroborates this approach of plate delineation.

## SUTURING HISTORY

There has been a developing opinion of physical continuity of the Indus-Tsangbo Suture through Mismi Hills to Myithyina in Burma. It is further postulated that this suture, after an offset along dextral Sagaing transform fault, reappears in Naga-Chin Hills (Mitchell, 1984). This outline of the suture, which closely follows the Gondwana Plate margin, is based on certain presumed tenets. The new data emerging from present surveys are not in harmony with such an oversimplified model. Goossens (1978) suggests that in north Burma, which is essentially a region of Precambrian rocks, the Indus-Tsangbo Suture Zone and Naga Hills ophiolite belt are transected by ESE faults. As such the sutured edge of Gondwana Plate is often found to be disrupted by younger tectonic movements and the concept of a continuous peri-Indian suture line merits reappraisal.

Along the continental margin south of Indus Suture and west of Naga-Chin Hills there are changing scenes in depositional history. The rocks against which the oceanic rocks come to rest are different in various segments due to complex tectonic setting as seen in Text-figure 2. The northern Tethyan facies, south of Indus Suture, comprise mainly Triassic-Cretaceous rocks along with wild flysch which yield youngest fossils of Maestrichtian to Palaeocene age. In Manipur-Nagaland the ophiolites are juxtaposed against Disang Formation (Eocene). Often the western edge of the ophiolite in Naga Hills is marked by olistostromal units of Disang Formation. The exotics have youngest fossils of Middle Eocene age. In the Chin Hills, on the other hand, the olistostromal bodies associated with ophiolite belt are of Senonian and Upper Campanian age. The different ages of the tectonically controlled olistostromal deposits document that the ophiolites in different segments of continental margin were emplaced in different times. In fact, in Chin Hills the ophiolite was subducted, detached, emplaced and buried beneath the unconformity by Upper Albian times (Mitchell, 1984).

Further, in the arcuate Andaman-Naga Hills ophiolite belt the subduction is oblique as the polarity of the movement of the plate is at an angle to the trend of the suture while in the Indus Suture the polarity is towards the north. It is quite likely that the dynamism in the eastern fringe of Gondwana Plate could start only after the northerly movement of Gondwana Plate was hindered. Thus the suturing along Indus-Tsangbo Zone in Palaeocene time facilitated the oblique subduction in the eastern margin. The ocean floor data also suggests that Palaeocene was the time of change in relative plate motion in the entire Indian Ocean with the slowing of the rate of sea floor spreading (Sclater & Fisher, 1974).

In short, the suturing of the Gondwana Plate along the Indus-Tsangbo Zone and the oblique subduction in Naga Hills are in a sequential order which is in harmony with the motion of Gondwana Plate. But the Chin Hills document a much earlier history of emplacement unrelated to Gondwana plate margin and this may be a manifestation of intra plate (Burmese Plate) suturing. The occurrence of another ophiolite belt to the west of Chin Hills in Haka probably corroborates this postulate The Late Tartiary tectonic history with accretion of fold belt to the continents imposed a broad linearity in the lay of ophiolite belt of Naga Hills and Chin Hills despite their independent evolutionary trends in different plates.

## PLATE MARGIN ALONG EAST AND WEST COASTS

The delineation of plate boundary along east and west coasts has been made after an orderly analysis of the rifting episode. The rifting history of Indian Gondwana Plate along coastal areas is documented by an evolutionary sequence of uplift, rifting and uplift generated triple junction formation leading to continental break up. The Godavari-Krishna coastal trough on the east coast for example, represents the rifted arm during the continental fragmentation while the main Godavari-Gondwana Basin behaved as failed arm (Dutta & Mitra, 1982). On the west coast the Gulf of Cambay is, likewise, considered to be a triple junction with Cambay Graben as a failed arm. The high geothermic gradient in this region and occurrences of extensive volcanic plugs testify to the mantle plume activity in triple junction formation (Biswas & Deshpande, 1983).

Along the east coast, Aptian-Albian period of basin formation corresponds to the fragmentation history of Gondwana Plate. This involved fundamental changes in basement mosaic. In Cauvery, Palar and Godavari-Krishna coastal basins, down to basement faults define a series of horsts and grabens which are aligned NE-SW paralleling the present configuration of the coast (Kumar, 1983). The separation of Indian continent from eastern Gondwanaland evidently occurred in a NE-SW direction.

The seismological data and other surface and subsurface information from Godavari-Krishna Basin reveal that Late Gondwana (Lower Cretaceous) and younger Mesozoic sediments fill all the fault bounded depressions. Their deposition was evidently in response to the periodic marine transgressions from the juvenile Indian Ocean. Succeeding the deposition of Lower Cretaceous Gondwana sediments and younger cover rocks, the basinal area witnessed volcanic episode (Rajamundri Volcanics) in Maestrichtian period.

The Cauvery coastal basin is likewise segmented into a series of NE-SW trending horsts and grabens. The Palk Bay depression and Mannar depression of Cauvery Basin separating India from Sri Lanka are such pericratonic rift basins which evolved in response to the distension in the crust accompanying the fragmentation of Indian Gondwana Plate. This rifting episode is also characterised by thinning of the crust to induce volcanism. The volcanic rocks have been proved beneath the Upper Cretaceous sediments in a bore hole drilled in Gulf of Mannar.

In Mahanadi Shelf area in Orissa, a series of highs and lows aligned in NE-SW direction along continental shelf edge has been detected by bouguer gravity survey. The gravity high trend is interpreted to be a reflection of crustal changes from continental to oceanic type (Jagannathan *et al.*, 1983). Evidently the Gondwana continental margin runs along the zone of crustal change as shown in Text-figure 4B. The shelf margin of Gondwana Plate appears to represent a pull apart type of basin paralleling the coast line based on seismic refraction data. Here Late Gondwana sediments are closely associated with volcanics. Thus basin formation after the rifting is closely linked with a synchronous volcanic episode.

In the onshore Bengal Basin, the seismic survey shows a distinct basin architecture for Late Gondwana sediments as indicated in Text-figure 4A. The strong reflectors beneath the trap constitute the Late Gondwana sediments preserved in NE-SW trending troughs (Roy Burman, 1983). Similar morphotectonic configuration of Late Gondwana basins is envisaged in respect of Upper Assam Shelf

This analysis charters a continuous spatial distribution of the Late Gondwana coastal troughs and rift related volcanic episode which permits a precise delineation of the boundary of Gondwana crustal plate.

The rifting history of Indian Gondwana Plate in Early Cretaceous left similar tectonic signature along the west coast of India. The entire western shelf is segmented by NW-SE to N-S faults into many horsts and graben structure. This style of faulting shaped the architecture of newly evolving basins of Late Gondwana sediments.

The earliest history of rifting in Jurassic period is documented in the Kutch Peninsula followed by creation of rifted Cambay and Barmer basins in Lower Cretaceous. The phase of crustal fracturing, basin formation and marine transgression in Kutch commenced in Bathonian-Oxfordian period (Biswas & Deshpande, 1983). During Lower Cretaceous (Aptian) the basin witnessed shallow deltaic environment of deposition favouring accumulation of Umia beds with Upper Gondwana floral elements.

The rifting along the west coast led to the evaluation of Cambay Graben in Lower Cretaceous period. This basin is differentiated into uplifts and depressions and has morphotectonic configuration comparable with that of east coast Late Gondwana basins. The basin formation in Saurashtra denotes a coeval event. Here the deltaic sedimentation on newly evolved shore line commenced in Early

Cretaceous period. This history of basin opening in Jurassic-Lower Cretaceous period in Kutch-Saurashtra is closely related with the volcanism, which evidently predates the main phase of Deccan Trap volcanicity. The earliest manifestation of Deccan volcanism in western India is recorded from Saurashtra which is dated as 101 ± 3 million years (Alexander, 1981). In a bore-hole near Dhandhuka in Saurashtra, several older basaltic layers were also recorded below the main Deccan Trap flows with intervening parting of sandstones (Biswas & Deshpande, 1983). In other words rifting history of Indian Plate along western margin is linked with a phase of pre-Deccan Trap volcanism. The ocean opening and basin formation on Kerala Coast shows a close temporal relation. Here the presence of infratrappean deltaic sequence of Early Cretaceous age testifies to synchronous rifting history.

Thus the palaeogeographic and structural changes along the east and west coasts in Early Cretaceous period were manifestation of the similar response of Indian Gondwana crustal plate to the rifting event.

## SYNTHESIS

On the basis of the geological evidences presented so far the following conclusions can be drawn:

(i) On the basis of newly acquired information the outline of the Indian Gondwana Plate in the north-eastern sector can be precisely drawn along the zone of olistostromal deposits which convincingly mark the margin. The northern margin of the Indian Plate is also drawn on the basis of identical reasoning.

(ii) The olistostromal deposits point out that the trenchal deposits along northern margin of India formed earlier than those along the northeastern margin. It is possible that closure of Tethyan Ocean in the northern margin starts an easterly journey of the Indian Plate when suturing along the northeastern margin takes place.

(iii) Along the eastern suture varying tectonic domains are juxtaposed and like the northern margin this zone does not mark the Indian Gondwana margin plate boundary all through its length. This is true for the Nagaland-Manipur sector but in Andaman it marks a subduction zone along which ocean floor created during and after Gondwana rifting is being destroyed. Here the margin of Indian Gondwana domain lies much to the west near the Indian coast line. The ophiolites of Chin Hills document a much earlier history of emplacement, unrelated to Gondwana Plate margin.

(iv) The geophysical and drill data show a unified history of rifting along the east coast. The offshore gravity high parallel to Indian coast marks the crustal change from continental to oceanic type. Lower Cretaceous volcanic rocks, which are possibly rift related, are often associated with the Late Gondwana sediments. The coastal basins are fault bounded and preserve Lower Cretaceous Gondwana sediments and younger covers. It is evident that during rifting of India from the Gondwana mosaic, its marginal parts suffered tension producing fault generated depression and contemporaneous volcanism. The proto-Indian ocean inundated these depressions forming the coastal basin. This together with the parallel gravity high precisely mark the outline of the Indian Gondwana Plate.

(v) The development of Kutch, Cambay and Barmer basins along the western margin of India indicates a history of rifting identical to that of the east coast. The Lower Cretaceous stratigraphy of Cambay and Saurashtra basins suggests that happenings along both east and west coasts are contemporaneous. The Jurassic record in the Kutch peninsula points out that rifting along the west coast of India might have started earlier in certain segments and the rift generated depression of Kutch was innundated by the proto-Arabian Sea during Jurassic period.

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