

## Limits of Greater Indian Plate during Gondwana time

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Limits of the Greater Indian Gondwana continent varied with its break-up and collisional episodes. Late Palaeozoic basal Gondwana type glaciogene and associated sediments containing cold-water marine fauna, with or without *Glossopteris*, Cathaysian floral remains or admixtures, occur in and across the Himalaya, in south Pamir, Tibet and in Shan-Tenasserim-Malaysian area, i.e., across the Late Mesozoic peri-Indian ophiolite belts. Cathaysian Flora with or without *Glossopteris* intercalations also occurs in western Iraq and New Guinea, both representing parts of the Gondwanic shield. Thus during Late Palaeozoic the Gondwana continents also hosted Cathaysian flora, especially in low palaeolatitudinal positions. The Himalaya, parts of Middle-East, Tibet, Shan-Tenasserim and Malaysian continental blocks therefore possibly formed parts of the Greater Indian Gondwanic continent.

The Late Cretaceous and Eocene olistostromal flysch belts tectonically flooring the ophiolite melange of the Indus-Tsangpo and Naga-Chin Hills-Andaman belts respectively delineate the northern and eastern continental margins of the Indian Plate. The present subduction zone beneath the Andaman island arc represents a westerly relayed Neogene margin of the Indian Plate.

**Key-words**—Gondwana, Greater Indian Plate, Palaeogeography, Plate Tectonics, Continental Drift.

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### सारांश

#### गोंडवाना काल में बृहत् भारतीय प्लेट की सीमायें

एस० के० आचार्य

बृहत् भारतीय गोंडवाना महाद्वीप की सीमायें संघट्टनों एवं टूटने के कारण भिन्नता प्रदर्शित करती हैं। अनंतिम पुराजीवी आधारी गोंडवाना के हिमजनित एवं शीतल जलीय समुद्री जीवजात, ग्लोसोप्टेरिस, कैथेसीय वनस्पतिजातीय अवशेष या सम्मिश्रण से सहयुक्त अथवा इनसे विहीन सहयुक्त अवसाद हिमालय, दक्षिण पामीर, तिब्बत तथा शान-टॅनॅसेरिम-मलेशिया क्षेत्र में पाये जाते हैं। ग्लोसोप्टेरिस से युक्त अथवा इसके बिना कैथेसीय वनस्पतिजात पश्चिमी इराक एवं न्यू गिनी में भी पाया जाता है। ये दोनों देश गोंडवाना प्लेट के ही भाग हैं। अतएव अनंतिम पुराजीवी कल्प में गोंडवाना, महाद्वीपों में विशेषतया निम्न पुराअक्षांसी स्थितियों, में विद्यमान था। इस प्रकार हिमालय, मध्य-पूर्व के भाग, तिब्बत, शान-टॅनॅसेरिम एवं मलेशिया ने मिलकर सम्भवतः बृहत् भारतीय गोंडवाना महाद्वीप के भागों का निर्माण किया है। अनंतिम क्रीटेशी एवं आदिनूतन कालीन ऑलिस्ट्रोमी फ़िलश पट्टियाँ भारतीय प्लेट की उत्तरी एवं पश्चिमी सीमाओं का चित्रण करती हैं। अण्डमान द्वीप-चाप के नीचे स्थित वर्तमान प्रत्यावर्तित मंडल भारतीय प्लेट की पश्चिमी क्रम-व्यवस्थित पश्च-तृतीयक सीमा का निरूपण करता है।

THE Gondwanic Indian continent is now separated from its continental neighbours by wide oceans. The Gondwana elements, like glaciogene or coal-bearing facies in its lower sediments, floral and faunal

elements are controlled by physiography and mainly palaeolatitudinal and climatic setting of the continent. It is possible to identify the extent of epicontinental shelf flanking the positive Indian

landmass. Presence of 'northern' palaeogeographic elements in extra-peninsular area may indicate palaeoclimatic variation within a large continent.

The situation is more complex for the Indian continent because of its fragmentation from the Gondwanaland and later accretion with the Laurasia to form the present Eurasia and thus create the Himalaya. Evidence in support of a wide Tethys separating the Gondwanaland and Laurasia is largely wanting. An older palaeo-Tethys possibly separated the Laurasia from the long narrow "Cimmerian" continent (Sengor, 1985) or chain of continents located close to the northern peripheral parts of the Gondwanaland. These were possibly fragmented earlier from the Gondwanaland and a younger Neo-Tethys was thus created. Closing of the Palaeo-Tethys by Cimmeria-Laurasia continental collision was in phase with opening of the Neo-Tethys (Stocklin, 1983; Sengor, 1985). This was followed by main break-up of the Gondwanaland, creating the Atlantic and Indian oceans and leading to closure of the Neo-Tethys by the collision of Cimmeria with Indian and African continents. Remnants of these palaeo-oceans occur as ophiolite remnants along collision sutures. Several such suture zones and continental fragments forms a complex mosaic along the peri-Indian mobile belt (Text-fig. 1). Deciphering the spatial extent of Gondwanic India within such a crustal mosaic of "displaced terrains" is by no means an easy task.

#### GONDWANA SEDIMENTS FROM INDIAN SHIELD AND HIMALAYA

Typical Gondwana sediments occur in broadly linear intra-cratonic basin belts in the peninsular Indian shield. The distribution is different for the Upper Gondwana (?Jurassic-Early Cretaceous) sediments, especially for their paralic facies equivalents which usually occur as basal sediments in the peri-cratonic Cretaceous—Tertiary basins and shelves. Contemporaneously widespread flood basalts erupted which also occur in other Gondwana continents. These appear to be related to main break-up of the Gondwanaland.

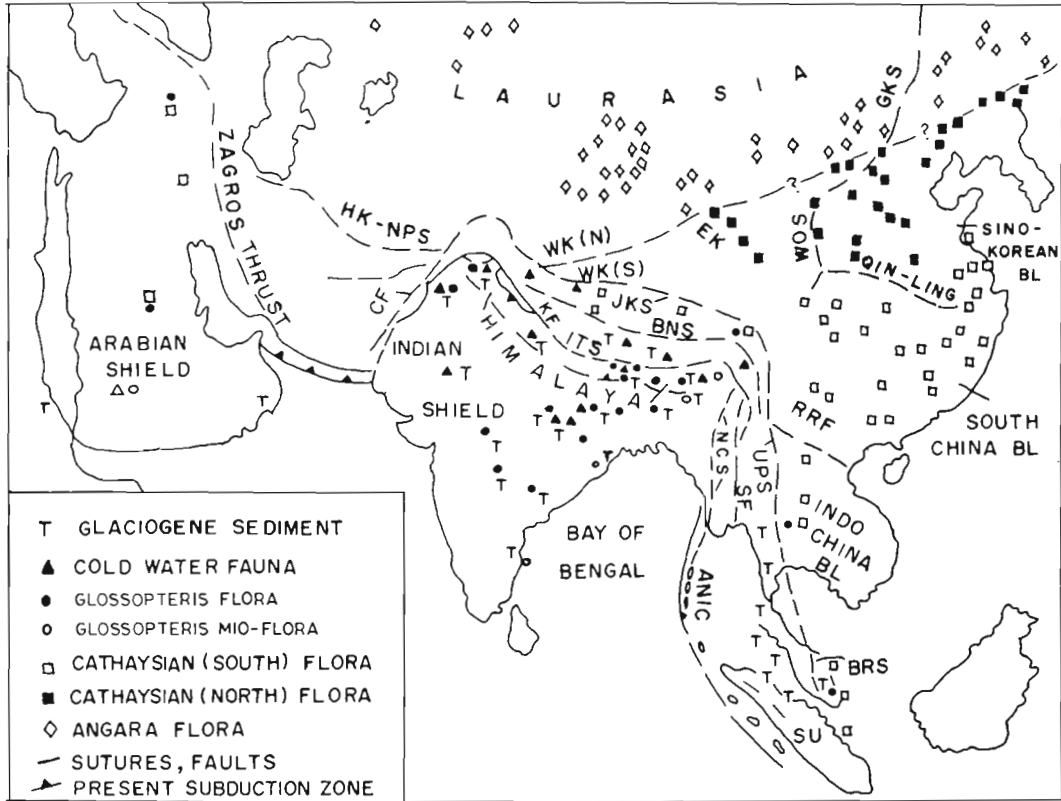
Gondwana type sediments containing characteristic floral/faunal elements also occur in the Himalaya. Late Palaeozoic Lower Gondwana sediments are much better represented. Phanerozoic sediments in the Himalaya occur as two belts on either side of the Central Crystalline Axis made up of reactivated Proterozoic continental basement. The Phanerozoic shelf with minor breaks, mainly represented by shallow marine facies, is more complete, and thicker in the Tethyan Himalayan belt. In the Lesser Himalaya, the Palaeozoic and Mesozoic

succession is truncated and thinner, the latter being more accentuated by tectonism. Best developed tract of Late Palaeozoic Gondwana in the Lesser Himalaya is from eastern Nepal to western Arunachal Pradesh (Acharyya *et al.*, 1979; Bashyal, 1980; Tripathy & Roy Chowdhury, 1983; Banerjee & Dasgupta, 1983). It occurs as a continuous linear belt over 600 km in length where fluvial and paralic Damuda type coaly facies contain well-preserved Glossopteris Flora (Early and Late Permian). A significant find from Kameng area, was stems of lycopods of Cathaysian affinity occurring in association of *Glossopteris* (Anon, 1984). In eastern Arunachal Pradesh, equivalent beds are mainly shallow marine nodular-black slate in facies with local association of coaly beds having Lower Gondwana spores, linoproductid dominant *Stepanoviella-Cyrtella*-bearing Sakmarian fauna and occasionally preserved Late Permian marine fauna (Acharyya *et al.*, 1979). The basal Gondwana diamictite-bearing unit, locally containing *Eurydesma* (Asselian) and/or linoproductid dominant (Sakmarian) or other fauna has wider extent and nearly cover the entire Himalaya. Equivalent beds occur even beyond as would be discussed later.

The Gondwana and associated sediments from the Lesser Himalaya are usually highly disturbed. These have narrow linear open-ended distribution, without any evidence of basin closure, basement relation, etc. The diamictite and associated sediments are often closely associated with contemporaneous volcanics and volcanoclastics (Acharyya, 1973; Acharyya *et al.*, 1979; Bashyal, 1980). Clasts in the diamictites as well as from the associated immature sediments are derived from adjacently exposed older rocks and contemporaneous volcanics. All these indicate rift tectonic setting for the Late Palaeozoic rocks from the Eastern Himalaya which is corroborated by the geochemical signatures of the associated volcanics (Acharyya, 1985).

Base of these Late Palaeozoic sediments is invariably unexposed, but from their nature, age and rarely preserved contact with the older rocks, these appear to generally disconformably overlie the Lesser Himalayan Proterozoic sediments with a pronounced time gap. A major break in sedimentation also occurs above the Permian sediments in the Lesser Himalaya.

In eastern Siang District, Arunachal Pradesh, the Abor Volcanics are widespread and extensive, but possibly include suites of more than one age. Volcanics having intercalation of black shales with Permian Gondwana spores, interbedded nature with older quartzite-limestone sequence and close



**Text-figure 1**—Distribution of Late Palaeozoic flora, coldwater fauna and glaciogene sediment in Eurasia (modified after Sengor, 1985).

**ITS**—Indus-Tsangpo Suture, **BNS**—Bangong-Nujiang Suture, **JKS**—Jinsha-Jiang-Kokoxiil Suture, **HK-NPS**—Hindu Kush North Pamir Suture, **WK**—western Kunlun (North & South belt shown), **EK**—eastern Kunlun, **NCS**—Naga and Chin Hills Suture, **SF**—Shan Fault, **UPS**—Uttaradit-Paklay Suture, **BRS**—Bentong-Raub Suture, **RRF**—Red River Fault, **WOS**—West Ordos Suture, **GKS**—Great Khingan Suture.

association with volcanoclastics containing Eocene plant fossils substantiate such contention.

In the Tethyan Himalayan belt, the Gondwana affinity is best reflected from the Kashmir Valley and Mount Everest area. The Gondwana plant beds in the former area occur at two stratigraphic levels. The tuffaceous Nishatbagh plant bed overlies the Agglomeratic Slate and a lower volcanic flow, whereas, the other plant and vertebrate beds overlie the Panjal Volcanics but underlie the Zewan beds. The upper plant beds contain *Glossopteris* together with cones and stems of Cathaysian flora (Kapoor, 1979; Gopal Singh, Pers. comm., 1986). Further, the *Archaeosaurus-Actinodon* labyrinthodont fauna is closely similar to Early Permian European fauna (Acharyya *et al.*, 1977; Chatterjee, 1984; J. Schneider, Pers. comm., 1987). Diamictites, a lower *Eurydesma* dominant Asselian fauna and a linoproductid dominant Sakmarian fauna occur within the 'Agglomeratic Slate' (Acharyya & Shah, 1975). A homotaxial sequence of diamictites with associated cold-water marine fauna and *Glossopteris* floral remains have been recorded from Mount Everest

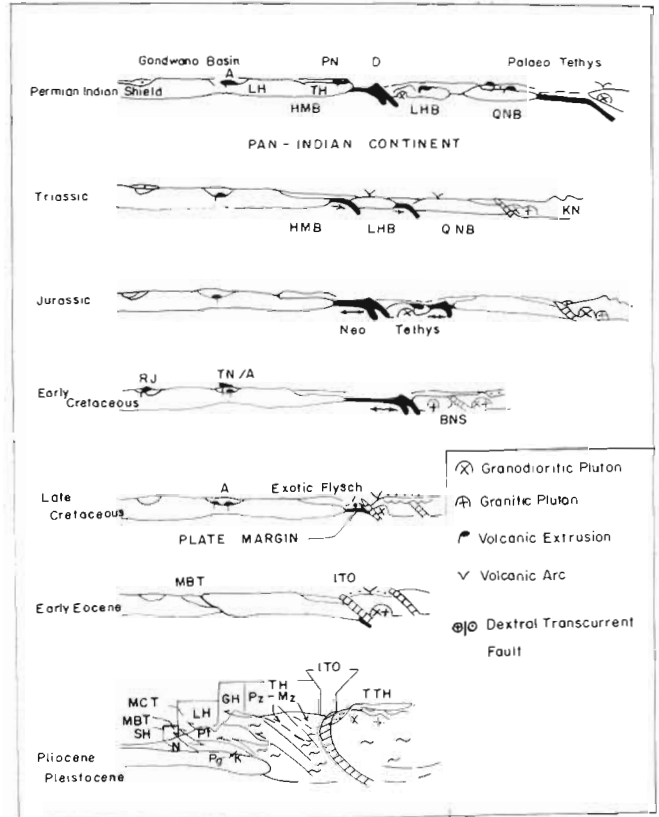
area, South Tibet (Chang & Pan, 1984). Diamictites and associated sediments with plant fragments or Gondwanic spores have been recorded from the Lachi Formation, northern Sikkim and Lingshi Basin, Bhutan.

The Late Palaeozoic diamictite and associated sediments from other parts of the Tethyan Himalaya are also often associated with similar cold-water marine fauna and usually have a minor time break at their base. These are also associated with contemporaneous volcanics like the Panjal, Phe, volcanics from central Nepal, etc. of which the Panjal is most extensive. These volcanics, their equivalents from the Lesser Himalaya and the Abor Volcanics are dominantly tholeiitic to alkaline basaltic in nature with minor percentage of acid volcanics and volcanoclastics. Trace element geochemical signature mainly based on contents and relative proportions of Ti, P, Zr, Y, Nb, Sr and B from Panjal, Abor Volcanics and those from Sikkim and east Nepal Lesser Himalaya suggest within-plate rift tectonic setting (Bashyal, 1980; Sinha Roy & Furnes, 1978; Honegger *et al.*, 1982; Bhat, 1984; Acharyya, 1985).

It should be mentioned that there is uncertainty about the glaciogene origin and age of some of the Himalayan diamictites, e.g., Blaini Formation which were earlier correlated with the basal Gondwana diamictites to which they are lithologically very similar. But these occur in association with Late Precambrian sediments. These are closely associated with virtually unfossiliferous limestones. Earlier reports of Gondwanic spores from some of these could not be confirmed. Ill-preserved acritarchs of Upper Precambrian affinity were recorded from macerated samples (matrix and stones) of the Blaini diamictite from Luxmanjhula area, Garhwal. Thus chance of reworking cannot be ruled out. Biota recorded by thin section and SEM study from the shale associated with the Blaini from Sivipuri area is not age conclusive but indirectly supports Upper Precambrian age (Dhoundiyal & Moitra, 1987). These possibly represent Late Precambrian rift related or glaciomarine sediments. These diamictites are, however, not closely associated with volcanics as the Gondwana diamictites.

Paralic to land facies with *Ptilophyllum* floral intercalations resembling the Upper Gondwana sediments occur sporadically at a few locations only in the Himalaya. The Triassic shallow marine sediments from the Kumaon Tethyan Himalaya of Malla Johar area have yielded spores of Gondwana affinity. Spore assemblage is richer in the underlying Permian sediments (Tiwari *et al.*, 1980). In Tansen area, Nepal Lesser Himalaya, the Fenestellid-bearing Late Palaeozoic diamictites are unconformably overlain by fluvial volcanoclastic conglomerates and then by basaltic flows. Lower parts of the sediments contain plant beds with rich *Ptilophyllum* Flora (Sakai, 1983). The succession closely resembles the Rajmahal Volcanics and associated plant beds. The Tansen Volcanics are unconformably followed by Late Cretaceous-Eocene marine sediments (Sakai, 1983).

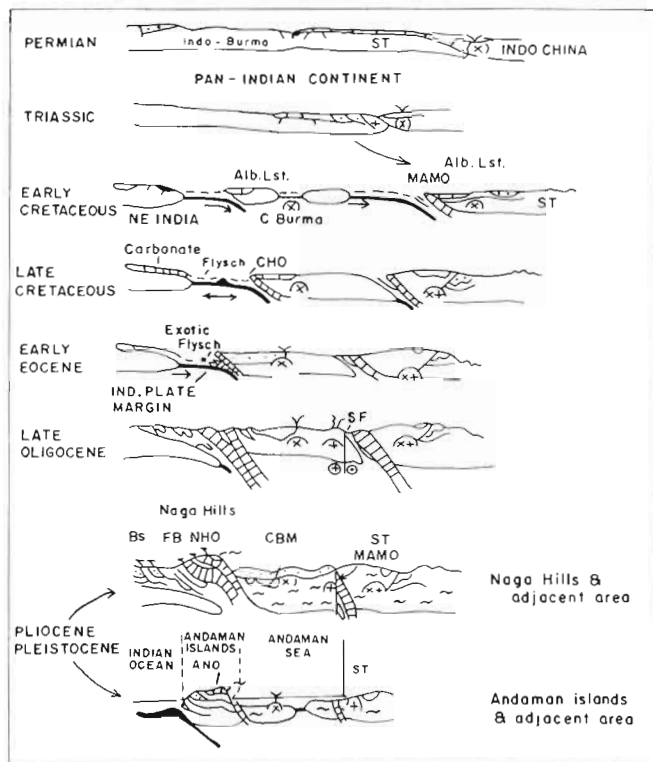
This singular occurrence of Upper Gondwana with subaerial Early Cretaceous basalts from Lesser Himalaya occur within its narrow Late Palaeozoic Gondwana belt. Presence of younger Eocene volcanics within the Abor Volcanics occurring further east along the same belt was mentioned earlier. The Abor Volcanics from the Siang River Section, where these are not in stratigraphic association with datable sediments, have yielded Cretaceous K-Ar whole-rock dates (90-140 Ma, Geochronology Division, GSI unpubl. report). The volcanism appears to be subaqueous having well-developed pillow structures in some of the dated sections (SKA, unpubl. data). It is worth noting that contemporaneous Early Cretaceous (110-121 Ma) mantle derived minette intrusives (Sarkar *et al.*,



**Text-figure 2**—Plate tectonic cartoons showing break up and collisional history of the Pan-Indian continent and shifting northern margin of Indian Plate with time. **A**—Abor Volc, **PN**—Panjal Volc, **D**—Dras Volc, **LH**—Lesser Himalaya, **TH**—Tethyan Himalaya, **KH**—Kunlun, **RJ**—Rajmahal Volcanics, **TN**—Volcanics of Tansen area, **ITO**—Indus Tsangpo Ophiolite, **MBT**—Main Boundary Thrust, **MCT**—Main Central Thrust, **SH**—Sub-Himalaya, **GH**—Great Himalaya, **TTH**—Tibetan Trans-Himalaya; Plio-Pleistocene cartoon enlarged view.

1980) also occur restricted to the same belt from Darjeeling foot-hills to Siang River Section (Acharyya *et al.*, 1979) and connect the occurrences of volcanics from Tansen and Abor (Acharyya, 1985). It thus appears that failed Late Palaeozoic rift activity along the Lesser Himalaya was reactivated during Early Cretaceous. Similar cases of reactivations have also been noted elsewhere within the Indo-Himalayan Block (Acharyya, 1986b).

In the Tethyan Himalayan belt, *Ptilophyllum* floral intercalations have been recorded from Thakkhola Basin, Nepal and Lingshi Basin, Bhutan, placed between the Spiti Shale and the Neocomian-Aptian marine beds (Barale *et al.*, 1978; Ganeshan & Bose, 1982). These successions resemble closely the Upper Gondwana from the coastal tracts of peninsular India.



**Text-figure 3**—Plate tectonic cartoons showing break up and collisional history of the Pan-Indian continent and shifting eastern margin of the Indian Plate with time. Plio-Pleistocene cartoons for Naga Hills and Andaman along with their adjacent areas shown separately. **CB**—Central Burma, **MAMO**—Myitkyna-Mandalay ophiolite, **NACHO**—Naga and Chin Hills ophiolite, **ST**—Shan-Tenasserim Block, **CBVL**—Central Burma volcanic line, **BS**—Belt of Schuppen, **FB**—Flysch belt Naga Hills, **NHO**—Naga Hills ophiolite, **CBM**—Central Burma molasse basin, **Ind-Oc**—Indian Ocean, **ANO**—Andaman ophiolite, **ANS**—Andaman Sea.

Thus the Gondwanic Indian shield did extend up to the northern margin of the Tethyan Himalaya. The Indus-Tsangpo Suture was generally regarded as the northern margin of the Indian Gondwana Plate to which some even now subscribe (Honegger *et al.*, 1982; Zhang *et al.*, 1984). Presence of Permian Cathaysian floral and European tetrapod remains from Kashmir Tethyan belt was believed to represent a land-bridge between the Indian and northern continent. But the facies, floral and marine faunal elements from the Late Palaeozoic rocks of Kashmir Valley and those from the Eastern Lesser Himalaya are closely similar. The Kashmir Valley sequence is also similar to those at Salt Range (Fatmi, 1973) which structurally corresponds to the Indian Shield. A similar sequence of Late Palaeozoic diamictite with

cold-water marine fauna and Late Mesozoic-Tertiary marine shelf facies is developed in Jaisalmer Basin, western India (Rao *et al.*, 1979).

### PALAEOGEOGRAPHIC AFFINITY OF PAMIR-AFGHANISTAN BLOCKS

Recent studies in Pamir and Afghanistan show that the earliest Permian foraminiferal complex from south Afghanistan, south Pamir; Early Permian bivalve and brachiopod from Basardara suite, SE Pamir; brachiopod fauna from Dacht-E-Nawer region, central Afghanistan are characterised by cold-water fauna. These beds are also often associated with glaciogene facies indicating Gondwanic affinity. The earliest Permian foraminifer from North Pamir and Permian fauna from North Afghanistan, juxtaposed against those of the south block by the North Pamir—Hindukush Suture, are of thermophilic type (Leven, Novikov & Montenant *et al.* in: Belov *et al.*, 1986; Lapparent *et al.*, 1970). The Early Palaeozoic sediments from Iran, Afghanistan and South Pamir also indicate Gondwanic affinity by the absence of thermophilic Ordovician corals which are also rare during Early Silurian (Belov *et al.*, 1986).

### PALAEOGEOGRAPHIC AFFINITY OF TIBETAN BLOCKS

The Tibetan Plateau may be subdivided into two continental blocks, e.g., Lhasa and Qantang bounded by the Indus-Tsangpo, Bangong-Nujiang and Jinsha Jiang-Kokoxili sutures (Text-fig. 1). The Kun Lun belt occurs to the north of the last named suture (Allegre *et al.*, 1984a; Chang *et al.*, 1986).

#### Setting of the continental blocks

Presence of Late Palaeozoic Gondwanic tilloid and *Gangamopteris* beds in Harpa-Tso Formation, eastern Karakorum (Norin, 1946) indicating extension of the Indian Gondwana continent beyond the Indus-Tsangpo Suture has been substantiated and supplemented by recent studies on Tibet. Glacio-marine tilloidic and ice-rafted sediments, locally associated with cold-water fauna containing *Eurydesma*, *Stepanoviella*, *Lytvolasma*, *Monodiexodina*, etc. have been recorded from extensive area, as far as to the north of Qantang Block in North Tibet and reaching south slope of Karakorum mountains (Chang & Pan, 1984; Tingdong *et al.*, 1986; Belov *et al.*, 1986). But such records from the Qantang Block are sparse and rare compared to those from the Lhasa Block. The record of Dammung-Linzhu diamictite and Permian Cathaysian flora from Lhasa Block was initially regarded anomalous and glacial origin for the former

was doubted because "the Cathaysian flora is traditionally interpreted as being typical of an equatorial climate" (Allegre *et al.*, 1984b). Later studies, however, corroborate glaciomarine nature of the former based on dropstone and other characters and association of cold-water Gondwanic marine fauna. Similar occurrences were also recorded from some additional locations from Lhasa Block. But no mention is made about the record of Permian Cathaysian flora from Lhasa Block (Chang & Pan, 1984; Chang *et al.*, 1986). This flora, however, is recorded from a few locations from the Qantang Block and from its eastern part Cathaysian and *Glossopteris* mixed flora is reported (Xiao & Gao, 1984; Chang & Pan, 1984; Chang *et al.*, 1986).

From the consideration of facies and marine faunal character, there is no palaeogeographic distinction or discontinuity up to Early Permian between the Himalayan and both the Tibetan blocks. The *Glossopteris* Flora is mainly restricted to the south of the Indus-Tsangpo Suture. On the other hand, Cathaysian Flora with typical elements like *Gigantopteris* is recorded from the Qantang block. A faunal distinction is noticed north of the Indus-Tsangpo Suture since early Late Permian. The cold Gondwanic fauna gets gradually replaced by thermophilic *Neoschwagerina* fusulinids and *Iranophyllum-Wentzelella* corals together with some lingering cold-water brachiopods (Chang & Pan, 1984).

The diamictites from Lhasa area contain clasts of feldspar-phyric felsite (Chang *et al.*, 1986). Basaltic flows occur within the overlying Early Permian limestone which underlie coal-bearing beds (Chang & Pan, 1984). North-west of Lhasa, basaltic flows unconformably underlie Late Triassic-Jurassic reef limestone and clastics. Occurrence of thick Triassic platform carbonates containing emersion surfaces and elsewhere limestone turbidites indicate platform break-up (Chang *et al.*, 1986). In the Qantang block, the oldest exposed rocks are transitional to alkaline basalts with minor agglomerates and acidic flows which underlie the Permian plant beds. Both subaerial and submarine flows are present. These Late Palaeozoic volcanics from Lhasa and Qantang blocks indicate rift setting (Chang & Pan, 1984; Chang *et al.*, 1986).

Allegre *et al.* (1984a) have highlighted on palynomorph assemblage from latest Triassic sediments from north of Lhasa which closely resembles those from equatorial European areas and lacks any Indian taxa; record of silicified wood *Protopodocarpoxyton* from the Early Cretaceous clastics exposed in and around Lhasa, the wood being widely represented from western Europe, northern Africa and South-East Asia but never from

India. Presence of growth rings in these fossil-woods suggesting a palaeolatitude not too close to equator during Early Cretaceous is in agreement with palaeomagnetic studies indicating low northern palaeolatitude (Allegre *et al.*, 1984a).

The Triassic clastic sediments in Lhasa area are associated with calc-alkaline volcanics. Argillaceous and carbonate sediments with basalt-andesite intercalations are widespread from east of Lhasa (Chang & Pan, 1984). In the Qantang block also, thick Triassic fluvial gravels derived from north are overlain by calc-alkaline arc-related volcanics. Preliminary palaeomagnetic results from these lavas show a northern hemispheric location. Thick Late Mesozoic molassic red-beds are derived from the uplifted Kunlun Range (Chang *et al.*, 1986).

Mention may be made also about the *Ptilophyllum*-bearing Fukche flora of Middle-Late Jurassic age, recorded from the Upper Indus Valley, north of the Ladakh Range and close to the Karakorum fault (Bose *et al.*, 1983). The floral assemblage with some new elements is different from the Upper Gondwana assemblages recorded from the Indian Shield and those few from the Himalaya. Instead it broadly resembles the Jurassic assemblage known from the Tethys-Karakorum belt. A *Cladophlebis*-bearing floral assemblage, possibly corresponding to same tectonic unit occurs about 5 km south of Fukche.

The Kunlun belt occurring to the north of Jinsha-Jiang-Kokoxiili Suture contain warm-water Carboniferous fauna with Laurasian coral, brachiopod and foraminifera (Chang & Pan, 1984; Chang *et al.*, 1986; Belov *et al.*, 1986). The Late Palaeozoic Angara Flora is well-developed north of Kunlun mountains. Northern Cathaysian Flora together with warm-water fauna are developed in east Kunlun belt (Xiao & Gao, 1984; Sengor, 1985).

The phytogeographic map of Eurasia for the end of Early Permian by Durante (in Belov *et al.*, 1986) shows conspicuous absence of mixed Angara-Cathaysian floristic complexes indicating that their respective domains were separated by the Palaeo-Tethyan ocean. However, during end of Late Permian there was mutual infiltration of plants, the Angara elements moving south and the Cathaysian elements north indicating considerable shrinkage of the oceanic barrier.

### Nature of the oceans

The Indus-Tsangpo Ophiolite (ITO) is regarded as an intra-Gondwanaland rift zone which created a narrow Permian-Jurassic ocean (Crawford, 1974; Chang & Pan, 1984), or it created an ocean by Mesozoic rifting (Honegger *et al.*, 1982; Xiao, 1984;

Allegre *et al.*, 1984a). Late Palaeozoic rifts active both in the Himalayan and Tibetan blocks possibly created some oceanic crust remnants of which could be recognised from the Tibetan suture zones and magmatic arcs (Acharyya, 1985). The Triassic arc-related volcanics in Lhasa block was inferred to have been produced by earlier subduction of the Indus-Tsangpo ocean (ITO) (Chang & Pan, 1984, p. 198). Contemporaneous arc-related volcanics also occur in the Qantang block located to the north of the Bangong-Nujiang suture. Further, the Dras Volcanics from the ITO, the Gaik and another granite body from the Ladakh and Gangdise batholiths have yielded closely consistent 235-265 Ma, Rb-Sr whole-rock isochron age and 0.703-0.708 Sr<sub>i</sub> (Honegger *et al.*, 1982; Trivedi *et al.*, 1982; Yu, 1982). The gneisses from Brakhor area, north of Shyok ophiolite belt has also yielded contemporaneous 260 Ma, <sup>39</sup>Ar/<sup>40</sup>Ar age (Reynolds *et al.*, 1983). Exotic blocks of Late Palaeozoic limestones, usually believed to represent sea-mount facies, are well known from the ITO belt and have also been recorded from the Shyok belt (Reynolds *et al.*, 1983). Permian radiolarites have been also recorded recently from the ITO and Bangong-Nujiang Ophiolites (Jingehuan, 1984). Thus narrow Permian oceans were possibly created between the Himalayan, Lhasa and Qantang blocks.

Excluding the possible Permian remnants, the oldest recorded age from the magmatic sections from the ITO from Xigaze area correspond to 120 Ma (Allegre *et al.*, 1984a) and from Kohistan arc-complex and Shyok Ophiolite corresponds to 130-150 Ma (Reynolds *et al.*, 1983). The lowermost chert or detritic sediments forming normal cover over the pillow volcanics from the south Tibetan ITO belt are also Middle Cretaceous in age (Bassoullet *et al.*, 1984). Similarly the Shyok Ophiolite containing Early Cretaceous microfauna are followed by Late Cretaceous flyschoid sediments (Srimal & Bhandari, 1985). Thus the oceanic domains of ITO from South Tibet to Kohistan arc, and that from Shyok are broadly contemporaneous and Late Mesozoic in age. The Indus-Tsangpo ocean separated the Karakorum-Lhasa and the Himalayan microcontinents. Initiation of Mesozoic rifting along the northern edge of the Himalayan microcontinent had commenced since Triassic as evidenced by occurrence of pockets of alkaline pillow volcanics associated with Early Triassic pelagic limestone within the Lamayuru exotic flysch (Honegger *et al.*, 1982; Chang & Pan, 1984) which tectonically underlies the ITO melange. Collapse of the Tethyan Himalayan shelf is also indicated by the thick pile of Mesozoic flysch sequence developed closer to the ITO belt.

In the Bangong-Nujiang suture zone, the pillow

basalts south of Amdo are succeeded by Late Jurassic deep-sea pelagic sediments, whereas west of Danquiao weathered ophiolites are transgressively covered by paralic patch-reefs of late Upper Jurassic age (Chang *et al.*, 1986). These broadly constrain the date of closing of this ocean, which must have had Mesozoic to Permian, continuous or discontinuous, development history.

The age and nature of the ocean represented by the Jingsha-Jiang suture is not clearly known. It is generally considered to represent the Palaeo-Tethyan ocean with Late Palaeozoic-Early Triassic oceanic remnants (Xiao & Gao, 1984; Belov *et al.*, 1986). According to others, the Bangong-Nujiang ocean represents the main Palaeo-Tethyan ocean whose northward subduction created a Late-Early Permian-Mesozoic back-arc basin along the Jinsha-Jiang belt (Tingdong *et al.*, 1986).

A convergence between the Indo-Himalayan and Lhasa-Karakorum blocks, corroborated by palaeomagnetic data, caused subduction of the Indus-Tsangpo oceanic crust beneath the northern block creating a magmatic arc of Middle Cretaceous to Middle Eocene (95-40 Ma) in age (Scharer *et al.*, 1984). This palaeo-subduction zone thus became the margin of the Gondwanic Indian Plate. The Indus-Tsangpo Ophiolite (ITO) appears to be accreted during Late Cretaceous as evidenced by 75-80 Ma, <sup>39</sup>Ar/<sup>40</sup>Ar age of phengite from blue schist at Shangla, Swat (Maluski & Matte, 1984) and contemporaneous K/Ar mineral dates from Kargil granodiorite and Dras Volcanics indicating rapid cooling (Sharma, 1987). This was possibly caused by initial collision between the Kohistan-Dras island arc with the Karakorum-Lhasa continent (Acharyya, 1985). The accreted ITO also resulted in formation of exotic flysch of latest Cretaceous age which tectonically floors the ITO (Text-fig. 2). The ITO was then thrust over the Tethyan Himalayan shelf sediments because of terminal Indo-Himalaya and Tibetan continent-continent collision during Middle Eocene. The tectonic zone represented by exotic flysch possibly representing oceanic trenchal or continental margin sediments, and the ITO melange in their palinspastic position represent the northern limit of the Gondwanic Indian Plate during end of Cretaceous.

#### **PALAEOGEOGRAPHIC SETTING OF INDO-BURMESE RANGE AND ANDAMAN-NICOBAR ISLAND ARC**

The Indo-Burmese Range is mainly constituted of a frontal Neogene molasse, and a Palaeogene shelf and flysch deposited on the Indian continent overridden by the Naga and Chin Hills ophiolite sequence of Cretaceous-Eocene age (Acharyya,

1986a). Towards east, the range is flanked by the Central Burma Basin mainly housing Tertiary sediments and a N-Q arc-related volcanic belt. The Andaman-Nicobar island arc geologically closely resembles inner parts of the Indo-Burmese Range and represents its southern extension. The Tertiary shelf sediments in north-east India flanking the Indo-Burmese Range contain significant fraction of reworked Permian Gondwanic spores. Recently an exploratory well in Barapathar area, in Mikir foot hills, Assam has intersected Gondwana sediments below the Upper Cretaceous-Tertiary shelf sequence. It is interesting to note that the truncated Gondwana sediments here are similar to those from Athgarh and Palar basins of the Indian east-coast belt occurring further south-west. The Upper Gondwana sediments with Late Mesozoic spores directly overlie the Tachir equivalent sediments which also contain shallow marine palynomorphs.

Based on age of oceanic pelagic sediments recorded from the ophiolites of Naga Hills and Andaman islands, K-Ar date of a pegmatite intruding the Chin Hills Ophiolite, Burma, broad geological setting of the Naga-Chin Hills-Andaman Ophiolite (NACHAO) and geo-chemical signatures mainly recognised within the ophiolite volcanics from Naga Hills and Andaman island, it has been inferred that the NACHAO belt represents an once connected narrow ocean which was possibly created by Late Mesozoic break-up of India and Burmese continents (Acharyya, 1986a; Acharyya *et al.*, in press; Ray *et al.*, in press). India and Burma converged and collided in stages, during Middle Eocene and Late Oligocene causing accretion and emplacement of this ophiolite over the downgoing Indian continent (Text-fig. 3) (Acharyya, 1986a, b; Acharyya *et al.*, in press). An extensive and broadly contemporaneous olistostromal Eocene flysch sediments tectonically underlying the Naga-Chin Hills-Andaman Ophiolite possibly represent eastern margin of the Indian continent during Eocene when accretion of the ophiolites was in progress. The present subduction zone of the Indian Ocean crust below the accretionary wedge of the Andaman island-arc possibly represents a post-collisional westerly relayed Neogene plate margin. This subduction has resulted in creation of back-arc Andaman sea and arc-related volcanism in Andaman and central Burma basin (Text-fig. 3).

#### **PALAEOGEOGRAPHIC AFFINITY OF SHAN-TENESSERIM-SUMATRA BELT**

Broadly N-S trending Shan-Tenasserim-Sumatra belt occurs to the east of the Indo-Burmese Range and the Andaman Nicobar Island Arc. Further east

occurs the Indochina block (Text-fig. 1) major part of which is covered by Late Mesozoic continental sediments overlying mainly Precambrian metamorphic basement or folded Silurian-Early Carboniferous sediments occurring mostly along the periphery of the Precambrian craton. Upper Carboniferous, Permian and Triassic marine sedimentation also occurred around the enlarged craton and were later subjected to Triassic-Jurassic Indosinian folding (Workman, 1975).

Though traditionally excluded, the Shan-Tenasserim-Sumatra block is now believed to be a fragment of the Gondwanaland during Late Palaeozoic (Acharyya, 1979; Stauffer, 1983; Bunopas & Vella, 1984). A nearly continuous and extensive (< 2000 km) belt of "Pebbly mudstone", diamictite with local intercalations of volcanic rocks from this belt was compared and correlated with those from Late Palaeozoic basal Gondwana diamictites from Tibet and Himalaya by Acharyya (1979). Presence of drop-stones exotic blocks and other glacio-marine features and often close association of Carboniferous to basal Permian cold-water peri-Gondwana fauna has been corroborated subsequently (Stauffer, 1983; Bunopas & Vella, 1984). A review is thus necessary of the extensive shelf carbonates closely associated with and overlying the pebbly-mudstones which were earlier believed to indicate warm-water facies (Gobbett & Hutchison, 1973). Fusuline species reported from the Ratburi Limestone in Thailand and equivalent beds from Malayasia have been analysed from palaeogeographic point of view by Toriyama *et al.* (1978). The Middle Carboniferous to early Late Carboniferous fauna indicates good connection with the Arctic and Tethyan realms. During late Early Carboniferous and early Early Permian the Tethyan sea maintained some connection with the Arctic realm. A remarkable palaeogeographic change occurred after early Early Permian when the fauna developed eastern Tethyan character with no Arctic elements. Based on petrological studies also it was inferred that the Chuping Limestone has been formed in cool climate, whereas the overlying Triassic Koding Limestone from West Malaya has been formed in warm tropical climate (Rao, in Gatinsky *et al.*, 1984). A close similarity of the Palaeozoic fauna from the Shan-Tenasserim block and Tibet with those from Australia record by Archbold *et al.* (1982), Burret and Stait (1985) also corroborates their Gondwana affinity. Palaeomagnetic studies on Late Palaeozoic diamictites from Thailand also corroborate southern hemispheric location and same appears to be valid also for the Malayan peninsula contrary to earlier belief (Bunopas & Vella, 1984).

The extensive belt of pebbly-mudstone facies



from this block possibly also represents rift-related sediments associated with glacio-marine setting (Stauffer, 1983; Bunopas & Vella, 1984; Gatinsky *et al.*, 1984). Further east of these pebbly facies in Malaya and south Thailand, contemporaneous sediments are of normal shallow marine facies (Stauffer, 1984, p. 1076).

Placed between the western Thai-Malaysian and Indo-China-East Malayan blocks, the belt of mafic-ultramafic rocks along the Uttaradit-Pak Lay belt in northern Thailand and those along the Bentong-Raub line in Malaya are regarded to represent a Palaeo-Tethyan suture. Their ophiolite nature, age and in between continuity is still in doubt (Thanasuthipitak, 1978; Stauffer, 1983; Helmecke, 1985). Closely parallel and east of this so-called suture in Thailand occurs the Loei-Phetchabun fold belt whose eastern and western limits are concealed below the Late Mesozoic strata. A strong unconformity occurs over the folded Silurian-Lower Carboniferous rocks overlain by the Permian limestone and flysch. Permian section in Loei and Phetchabun areas have also yielded Cathaysian Gigantopteris Flora with *Glossopteris* elements present in the latter place. Though earlier explained as a stray migrant or a case of parallel evolution, the Phetchabun Flora requires re-examination in view of Gondwana affinity now recognised for Thailand till basal Permian.

Existence of Permian-Triassic calc-alkaline volcanics, Triassic granites with high Sr<sub>1</sub> ratio, and a later phase of lower-middle Triassic folding along this belt is consistent with convergence, easterly subduction and collision of the Shan-Tenasserim and Indo-China blocks (Workman, 1975; Stauffer, 1983) and true oceanic crust may or may not have separated them wide apart (Text-fig. 3).

Similarly sharp difference in sedimentary-magmatic and tectonic setting of Palaeozoic and Triassic rocks across the Bentong-Raub line in Malaya, character of the Main Range Granite can be explained suitably assuming the Bentong Raub line as the site of a closed ocean. Upper Carboniferous clastic facies with volcanic intercalations from Central and East Malaya had occasionally yielded *Lepidodendron*-bearing Cathaysian floral elements (Gobbett & Hutchison, 1973). A significant recent floral find from eastern Malaya contains *Gangamopteris* occurring in association with tilloidic beds (Azher, in Stauffer, 1983). The situation thus is comparable to that inferred from Thailand. In eastern Sumatra, the Djambi nappe comprising Late Palaeozoic clastics, limestone, volcanics and volcanoclastics has yielded thin coal and rootlet beds with well-preserved Gigantopteris Flora overlying a *Pseudoschwagerina*-bearing limestone.

Late Triassic-Jurassic *Sagenopteris*-bearing plant assemblage from the Tembelling Formation, Central Malaya is similar to European-Central Asian flora. *Ptilophyllum* occurs with this as well as, younger Mesozoic formations of Malaya (Gobbett & Hutchison, 1973). *Glossopteris* in association with *Dictyophyllum*, *Taeniopteris*, etc. is recorded within the Upper Triassic red-beds of Central Yunnan (Coggin Brown, 1922).

## CONCLUSION

1. Late Palaeozoic to Early Cretaceous Gondwana facies and biotic elements occur both in the Lesser and Tethyan Himalayas where they are associated with shallow marine sediments and rarely contain Cathaysian floral remains.

2. Based on presence of cold-water marine fauna and association of glacio-marine facies during major parts of Late Palaeozoic, the South and Central Afghanistan-South Pamir block, Tibetan blocks, Shan-Tenasserim-Sumatra block bear Gondwana affinity and they possibly constituted the Pan-Indian continent. Contemporaneously North Afghanistan-North Pamir block, Kunlun block north of Jinshajiang suture housed thermophilic marine fauna. Cathaysian Flora of northern affinity occur in eastern Kunlun belt. The Angara Flora occurs further north of the Kunlun belt. These two palaeogeographically distinct continental domains were possibly separated by the Palaeo-Tethys.

3. Permian Cathaysian Flora of southern affinity with rare *Glossopteris* floral intercalations occurs in the Qantang block, Tibet. Similar relation is also recorded from the Lhasa block and the Gondwanic Arabian Shield (McClure, 1980; Stauffer, 1983). Similarly the Indo-China-East Malayan block with dominant Late Palaeozoic Cathaysian floral character has some *Glossopteris* floral intercalations close to their converging margin flanking the Shan-Tenasserim-West Malayan block.

4. Thus during Late Palaeozoic, the *Glossopteris* and Cathaysian floras appear to be more closely related and their distribution might have been climatically controlled. On the other hand, no such intermingling occurs between the contemporaneous Cathaysian and Angaran flora till end of Late Permian.

The polarwander paths from the South China and Sino-Korean block also corroborate that these blocks were also parts of the Gondwanaland assembly at least during Early Palaeozoic (Lin *et al.*, 1985).

5. Late Palaeozoic Gondwanic rocks from the Himalaya and Tibet (both belts) are closely associated with rift-related volcanism.

Contemporaneously narrow oceans possibly perforated and separated the two Tibetan blocks at places and remnants of these are recognisable within the Indus-Tsangpo, Shyok and Bangong-Nujiang suture zones. Triassic arc-related volcanism in Lhasa and Qantang blocks may have been produced by closing of these narrow oceans. Late Palaeozoic diamictites from Shan-Tenesserim belt are also associated with rift-related sedimentation.

6. During Late Triassic and Early Cretaceous the floral records from Lhasa block are distinctly different from the Gondwana and have northern (Cathaysian/Angaran) affinity. In the Shan-Tenesserim belt arctic faunal elements disappeared after early-Early Permian when the fauna also assumed eastern Tethyan affinity. The Triassic Kodiang Limestone from western Malaya were deposited in warm tropical climate. The Triassic-Jurassic flora from Central Malaya has European and Central Asian affinity, whereas, the Upper Triassic red-beds from Central Yunnan still contain *Glossopteris*.

7. The peri-Indian ophiolites, like the Indus-Tsangpo, Shyok, Bangong-Nujiang occurring to the north of the Himalaya and the Naga-Chin Hills-Andaman and parallel but less extensive belts occurring in central part of Central Burma, western flank of East Burma, central belt of Sumatra, represent remnants of Neo-Tethys which were mainly created by Late Mesozoic rifting and fragmentation of the peripheral parts of the Pan-Indian continent. Some of these Mesozoic rifts were controlled by and superposed over earlier Late Palaeozoic structures.

The Pan Indian Plate so created contained the Gondwanic continental fragments and narrow Neo-Tethyan Ocean.

8. The northward movement of the Indian continent, as revealed by palaeomagnetic data, was not as an island-continent, as generally believed, but along with its crustal neighbours (Acharyya, 1986a, b). This explains closer similarity of Early Permian to Late Cretaceous Tetrapod fauna from Indo-Himalaya with those from Europe and China in addition to Gondwanic South Africa and South America (Chatterjee, 1984). The Pan-Indian Plate possibly developed space constraints during its protracted northward journey causing convergence of its continental fragments. Thus new active plate margins were developed along the northern margin of the Himalayan microcontinent and eastern margin of the extension of the Indian continent flooring the Indo-Burmese Range and its possible extension southward to the Andaman Island arc (Text-figs 2, 3).

9. The belt of exotic flysch possibly

representing trenchal sediments bordering the subduction zone or continental margin sediments, and the over-riding Indus-Tsangpo or Naga-Chin Hills-Andaman ophiolite melange in their palinspastic position would represent the northern and eastern active margins of the Indian Plate during latest Cretaceous and Eocene respectively. The present eastern active margin of the Indian Plate below the Andaman Island arc possibly represents a westerly relayed Neogene subduction zone which caused opening up of the Andaman Sea and N-Q arc-related volcanism in Central Burma and in Andaman Sea.

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