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Inaugural Address

Concepts, limits and extension of the Indian Gondwana

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DR VENKATACHALA, Dr Maheshwari, Dr Tiwari, Prof. R. C. Misra, Prof. Ahmad, Shri Tripathi, distinguished professors, geoscientists, ladies and gentlemen, I feel honoured to have been asked by the Organisers to inaugurate the Workshop on *Concepts, limits and extension of the Indian Gondwana* this morning in the beautiful and inspiring premises of Birbal Sahni Institute of Palaeobotany, on the occasion of the birth anniversary of the great man Professor Birbal Sahni, the founder of this leading Institute. A scientist of international repute, a perfect human being, a selfless nationalist, a visionary, soaked in work culture and highest intectualism and an inimitable Guru, as Professor Birbal Sahni was, his name and fundamental contributions in Botany, Palaeobotany and Geology, continue to inspire a large scientific community in the country and abroad. Professor Sahni and Professor Seward, his teacher, remain as immortal as the discipline of Palaeobotany.

It was unique experience for me to have been taught by this great man for 9 hours in three days in my B.Sc. Class. I am conscious that many of the distinguished scientists present here had the privilege of long and close association with Professor Sahni in various pursuits. I certainly envy them. The story of little *Azolla* and the palm, the romance of Saline Series, his infallible contributions to Palaeobotany and Geology of Gondwanaland and scores of other topics constantly impart strength, courage and vision to this Institute to enable it stand up to the founder's and his followers expectations. But then he was not meant to belong to only a few or to be confined. He has always been as inspiring and revered to us in the Geological Survey of India as to this Institute. I am indeed grateful to Dr B. S. Venkatachala, Director, B.S.I.P., and his associates for providing me and my Organisation this opportunity to humbly reiterate our faith and respect for the cause and pursuits for which Professor Birbal Sahni devoted all that he had.

The Indian Gondwana sedimentary basins occupying about 50,000 sq km provide crucial data to the geological and geodynamic history of the Indian Shield. Gondwana geology holds key to coal resources, evolution of plant life and vertebrate fossil fauna in India. Conceptual interests are developing in the possible oil and gas resources in some of these basins. Various organisations, institutes and geoscientists have been generating voluminous interesting data on Gondwana geology, Gondwanaland, continental drift, plate-tectonics, coal resources, etc. Geological Survey of India has been deeply engrossed in Gondwana geology and coal exploration.

A number of interesting researches and ideas have been made in recent years adding to or refining the classical ideas about the Indian Gondwana in peninsular, extra-peninsular part and in marine shelf areas of Indian sub-continent. I would, however, like to touch upon a few salient points of general interest.

DEFINITION OF GONDWANA

Gondwana geology, which had its birth in the Upper Palaeozoic-Mesozoic sedimentary basins of the peninsular Indian Shelf, blossomed into a distinct entity of earth-science with its ramifications of sedimentary, biotic, tectonic, magmatic and

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magnetic records in Southern Hemisphere. Evidently, in its wide usage, the term Gondwana often carried different connotations to stratigraphers, palaeontologists or workers in geotectonics and this has made its definition somewhat flexible. The Gondwana in its classical and stratigraphic sense includes a pile of typical essentially terrestrial rocks with closely associated paralic or shallow marine sediments which exhibit a distinct floral and faunal identity with the homotaxial rocks of southern continents implying similar climatic, geomorphic setting and proximal geographic location and bondage. It has both litho- and bio-stratigraphic attributes and in Indian sub-continent ranges in age from Late Carboniferous to Early Cretaceous.

CONCEPTS AND LIMITS AT GLOBAL LEVEL

The concept of Gondwanaland, invoked to explain the continuities of terrestrial conditions across the southern continents, also sharpened the broad palaeogeographic concepts of the Northern Continent (Laurasia); characterised by distinctive, geological, tectonic, faunal, floral and palaeoclimatic features. The concept of Tethys or inter-continental sea and the Pacific assumed greater necessity to accommodate the global fits. Concurrently, the theory of continental drift and all its attributes became compulsive to explain the Cretaceous-Tertiary seafloor spreading and present redistribution of continental and ocean areas. The Indian sub-continental crustal block thus defined in palaeogeographic terms attained distinctive limits and geotectonic identity in the then existing global frame. The revolutionary impact of expositions on marine geology and geophysical data transformed the theories of global rifts and drifts and the mechanisms into the comprehensive concept of plate tectonics. The Indian Plate is the new attribute, encompassing the Indian Gondwana continental block with its marine and other continental crustal adjuncts, bounded by the mid-oceanic ridges of the Indian Ocean and by the Tethyan sutures on the north and extending in south-east Asia up to East Pacific. The Indian peninsular crustal block is normally considered as a rigid mass put into motion on a smooth conveyor belt activated by the convection cell of the mantle. However, the rigidity concept of the peninsular shield in time and space is viewed with ample sceptism.

Thus the emerging concept of plate tectonics gradually but firmly enlarged the concepts of limits and extent of Indian Gondwana in terms of the small or large crustal blocks, etc. within the definition of the Greater Indian Plate.

In such a mileau, besides taking due note of the terrestrial early Gondwana elements in Tibet, glacio-marine sediments in Burma, Thailand, the Precambrian affinities of Seychelles with west-coast Precambrians, etc. it is important to explore the possibilities of the likely Gondwana elements in the Naga Patkai-Arakan-Andaman-Nicobar belt.

GONDWANALAND FIT

A universally acceptable concept of the Gondwanaland fit vis-a-vis the Indian Segment still evades us. The notable contributions of Professor F. Ahmad in this regard have to be given due thought. The most controversial segment is the eastern Indian margin. According to many models (based on plate tectonic concepts), the eastern coast is juxtaposed against Antarctica, bringing in the East Indian Gondwana rifts in the proximity of Enderby Gondwana rift and radiating ice fields. Considering the coal geology, workers like N.D. Mitra and others have favoured such a fit. Against the view, the fit presented by O'Driscoll (1980) juxtaposes Australia to the East Coast margin, and Antarctica is not shown in the proximity of India. S. K. Acharyya and others have favoured such a fit, using plate tectonic concepts and broad geological and geodynamic considerations. Even though there may be different schools of thoughts, there is need to critically study these issues by way of producing optimal structural, isotopic and palaeomagnetic data on the Indian Gondwana and its Precambrian basement of the East Coast in conjunction with the off-shore deeper probes into the sea bed of Bay of Bengal.

LIMITS OF GONDWANA IN THE INDIAN PLATE

The Precambrian frame of the Indian Plate, as integral part of the Gondwanaland was ingrained in relation to the regional Palaeozoic tectonics of supercontinent. The late Precambrian tectonics is reflected by the upthrust Eastern Ghats against the marginal drying up Late Precambrian-Cambrian basins; and similarly the attenuated Vindhyan Basin shifted northwards away from the bounding up-thrust Aravalli-Satpura compression belt. The block in between the uplifted thrust blocks had engrained in itself a ENE-WSE trending compressional Narmada-Son mega lineament which also had strike slip movement; and orthogonal to it, the NW-SW rift systems abutting against the Eastern Ghats. Early Palaeozoic-Late Precambrian thermal and diastrophic activity is indicated in this block in terms of the younging Fission Track dates in Nellore mica-schist belt, K-Ar dates in crystallines of Tamil Nadu, Gauhati granites, etc. However, there is no established early Palaeozoic sedimentation record preserved in this block. The high palaeolatitudinal position of India in Early Permian synchronised with the initial sedimentation as glacio-marine deposits in the Palar Basin and other NW-SE rifts, etc. It is surmised that across the uplifted Eastern Ghats there must have been probably an epicontinental sea which invaded and intermixed with Permian glacial deposits, not only in Godavari-Palar basins but also in the Mahanadi, Bangladesh and Assam areas. A fit with Australia or Antarctica may constrain such a hypothesis. Perhaps detailed study of boulder of the Permian glacio-marine beds of Palar and other East-Coast basins may throw light on the provenance areas other than the Indian Shield.

The Early Permian of the Damodar Valley and other Gondwana basins perhaps received glacial deposits from the uplifted Aravalli-Satpura-Chhattisgarh-Vindhyan domain. The uplift of blocks adjacent to undulating low lands might have been due to late Palaeozoic tectonics in the Gondwanaland. It is a moot question whether the westward or north westward master slope and drainage of the basins or low land in the Barakar and subsequent times had any linkage with the Rajasthan Permian shelf and its southward extension. More light will be thrown on this issue after the possibility of hidden Gondwana basins below the Deccan Trap is fully explored and appreciated. Interpretation of a DSS Profile across Nepanagar-Ujjain has already indicated presence of a hidden Gondwana Basin in Narmada Valley.

Thick Talchir (total 380 m) sediments underlying the Asselian marine beds in Daltonganj Basin need detailed palynological and microbiotic studies to explore the possibilities of Late Carboniferous sedimentation in this and some other basins.

The eastward extension of the Raniganj Basin, the N-S trending Rajmahal-Purnea-Bangladesh-basinal configuration has some important attributes if viewed in terms of limits and extension. Across Bangladesh, but slightly northwards, the Garo-Hills Gondwana and the recently discovered coal basin of Hallydaygunj in Assam close to the western fringe of Garo Hills show a strong N-S linearity and structural grain, and perhaps thickening of sediments towards Bangladesh. Some of the Permian coal seams of this area have attained coking properties. Most part of Rajmahal-Bangladesh Basin is covered by Upper Gondwana, Rajmahal Traps and Tertiary sediments. These cover rocks, except Quaternary, are not well-developed in Garo Hills. Taking the total frame of Meghalaya-Assam basement and the configurations of Permian basin around Rajmahal, one is tempted to suggest that the Garo-Hallydaygunj basins may represent northward shifted part of the Rajmahal-Purnea-Bangladesh Permian Basin across a N-S trending fault system. It is likely that geothermal gradients in this region had started steepening in Permian times initially and the tectonism during the period may be the precursors of the much younger 90° E structure of the Bay of Bengal.

The northern margin of the Indian Plate and therefore the extent of Indian Gondwana is a subject of controversy. But recent studies in Tibet have shown that the glaciogene sediments and cold water marine fauna of Lower Gondwana affinity are associated with volcanics. Acharyya and some other workers believe that the Indian Gondwana margin extended up to southern margin of Kun Lun fold belt till late Palaeozoic times. The rifting mechanism responsible for the creation of Neo Tethys oceans and microcontinents from the extended and tectonised Indian Plate, also influenced intermixing the Early Permian Gondwana elements with marine sediments and association of alkaline basic and subordinate acidic volcanic compositions. These rock units overlie the Tethyan lower Palaeozoic sediments. Such events were perhaps related to the marine transgressions and accentuation of faulting in the terrestrial Gondwana basins in peninsular India. However, no late Palaeozoic volcanism has so far been noticed in the peninsular set up.

The paralic Gondwana of the Lesser Himalayan belt particularly of Eastern Himalaya shows marine and volcanic associations. Whether these are allochthonous bodies derived from the main Tethyan front or represent deposition in faulted basins in front of the late Palaeozoic uplifts in a southern domain is a subject of varied opinions. However, one has to recognise the revised stratigraphic position of the erstwhile late Palaeozoic-Mesozoic Blaini-Krol-Tal sequence now corresponding to Cambrian-Late Precambrian age. Search for any basal Gondwana sequence deposited over the Tal Formation would be worthwhile.

Could there be other locales of late Palaeozoic volcanism and associated Gondwana and marine sediments in the Indian sub-continent? Perhaps the crustal areas close to some of the Mesozoic rifting having higher heat flows, pulsating crustal features during late Palaeozoic could be considered as favourable locales and thus showing up as forerunner of the Mesozoic rifting.

The upper age limit of the Gondwana coincides with significant changes in basin configuration over a given time, active rifting and the separation of the Indian Plate having attained its independent north to north-eastward motion.

During the Early Cretaceous extensional regime, when the Indian Ocean was being created, the Indian Gondwana Plate possibly got separated from the Antarctica-Australian segment. Considerable geochemical diversity has been noted within the Rajmahal-Sylhet volcanics. Alkali basalts and olivine-theoliites initially occurred as surface materials. The former were produced by melting of enriched metasomatised mantle, whereas, the latter may represent large partial mellts of deeper source (Bakshi *et al.*, 1987). Mahoney *et al.* (1983) and Bakshi *et al.* (1987) postulate these flood-basalts as an effect of the Kerguelen Hotspot which possibly lay below the eastern Indian continent. This is more or less consistent with the reconstruction of Gondwanaland by Norton and Sclater (1979) but require India to be 10° further east.

Contemporaneous mantle derived alkaline-ultramafic intrusives are represented by mica-lamprophyres which occur restricted to Damodar Valley coal basins and also to late Palaeozoic belt from eastern Lesser Himalaya. Recently, lamprophyre-lamproite assemblage have been recorded from Damodar Valley area.

The pericratonic Gondwana basins and shelfs evolved in response to rifting episode occurring along the east and west coasts. Thus the Athgarh, Godavari-Krishna, Palar, Cauvery, Kutch and Saurashtra troughs were formed. Basaltic flow is underlain by Early Cretaceous terrestrial sediments in the eastern shelf off Mahanadi delta.

EVOLVING CONCEPTS OF STRUCTURAL AND SEDIMENTATIONAL CHARACTERISTICS OF INDIVIDUAL BASINS

Isolated basin or a cluster of basins have also been under study especially in relation to the tectono-sedimentary analysis and locales of peat deposition and coalification processes. In general, the Permian sedimentation exhibits an accummulation of 2 km thick column in about 50 million years. This slow rate of sedimentation of less than a millimetre a year does not reflect a highly pulsating basinal condition or a general high relief and fast erosion. However, taking into consideration the erosional processes as reflected in sediment mega cycles it may appear that sedimentation is punctuated by diachronous breaks of unknown duration.

The concept of rift basins in Gondwana has so far not withstood the test of time in the absence of contemporaneous volcanics and intrusives in the basin. The dykes of dolerite and mica-lamprophyres are post-depositional intrusives. Deposition outside the faulted half-graben, graben or proto-rift, has been postulated and post-depositional faulting is supposed to have preserved the fault bound sedimentary column. The test of the concept lies in full understanding of the sedimentary basins which are covered under thick post Upper Gondwana deposits.

Recent basinal studies and synthesis of data have indicated that application of facies variation concept, based on various sediment characteristics, defines the depositional behaviour and locales of different kinds of coals in a rational way.

In recent studies, strike slip movements and compressional deformation of the sediments in the proximity of faults has been observed. Influence of faulting on the sediment facies close by and its thicknesses, has also been observed. Recently, reverse faulting has also been recognised in a central Indian basin.

It is rather difficult to precisely demarcate the time boundaries within the Gondwana Sequence on the basis of mega-flora. However, estheriids and vertebrates have been used to narrow down the range of time planes with some success. Marine intercalations with micro- or mega-fossils, though thin and sparse and not available in all the basins, have been used to refine the time planes. Marine beds in the Barren Measures, with algal remains, etc. have given rise to phosphatic beds.

In order to get a comprehensive tectono-sedimentary and stratigraphic idea of the Gondwana formations, it is desirable to have a concerted multi-disciplinary programme of integrated basin analysis studies. Multi-institutional efforts on palaeomagnetic, isotopic age dating and palynostratigraphic studies on drill core samples of full successions of some representative basins is also necessary.

Geochemical studies on coal basins have provided many clues to refine our understanding on the sedimentological and coalification processes. Conceptually, formation of hydrocarbons is being postulated in appropriate geothermal conditions affecting the vegetal organic matter in Gondwana basins. Detailed geochemical, thermal gradient and coal petrographic studies are likely to throw light on these concepts and limitations thereof.

Coal basins are also not immuned to neotectonic activity, particularly in basins with geothermal waters and well documented seismic records. It may be worthwhile to study this aspect in relation to mining and environmental considerations.

CONCLUDING REMARKS

Gondwana geology is in a way the soul of Indian geology. It provides one of the best documentation for global interaction in geological, geophysical and geodynamic modelling. It is the mainstay for our solid fossil energy resources. Better understanding of the concept, limits and extension of Indian Gondwana would depend upon the Indian geoscientists' efforts in key areas of Gondwana geology in conjunction with the evolution of its basement and events leading to the breakup of the Gondwanaland. Deep crustal geology has to be built up onland and off-shore to find the signatures of Late Precambrian, late Palaeozoic and Cretaceous—Early Tertiary crust-mantle interactions. Attributes of rifting and the kind of processes involved require greater attention.

Gondwana basins and the sedimentary packages pose formidable problems of correlation, precise delineation of time planes and on the whole the process of basin evolution. It is absolutely necessary to formulate achievable short and long range programmes to develop a conjunctive lithologic, palynostratigraphic, isotopic magneto-stratigraphic data base on the complete sedimentary column of representative basins.

Problems of coalification, geochemistry of coals and associated sedimentary and igneous constituents, and development of data on palaeogeothermics and present heat flow studies have to be appropriately appreciated and tackled.

The future role of the Birbal Sahni Institute in contributing to the furtherance of Gondwana geology and geodynamics cannot be over emphasised. Geological Survey of India has been looking forward to multi-disciplinary, bilateral or multi-institutional pragmatic achievable geoscientific programmes aimed at fundamental and applied aspects of Gondwana Geology.

Ladies and Gentlemen, this is the auspicious day when we rededicate ourselves to the ideals and pursuits of Jawaharlal Nehru the moulder of modern India and almost his contemporary Professor Birbal Sahni, a model for Indian scientific pursuits.

Before I close, I extend my best wishes to all the participants and to the Organisers for very useful and successful deliberations in the next few days. I have great pleasure in inaugurating the Workshop.

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