Volcanism in Gondwanas

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In India the Lower Permian event is marked by a major volcanic episode in the Himalayan belt and rift faulting in the Peninsula which gave rise to various Gondwana basins. The Lower Cretaceous major volcanic episode represented by the Rajmahal Trap represents the termination of Gondwana sedimentation. Lower Permian volcanism is represented by the Panjal Volcanics in Kashmir Basin and its equivalent, the Volcanics in Spiti-Zanskar Basin and Rotung Volcanics (Abor Volcanics) in Arunachal Pradesh. In Karakoram Basin of Ladakh, volcanism is associated with Changtash and Aqtash formations of Permian age.

The Agglomeratic Slates in Kashmir are supposed to have originated as explosive volcanism in the form of pyroclastics which was followed later by flows of the Panjal Volcanics represented by subaqueous and subaerial tholeiitic basalt with occasional basaltic, andesitic and rhyolitic volcanics. The Agglomeratic slates are divided into two divisions, the Lower Diamictite and the Upper Pyroclastic. At the base of the Pyroclastic division and at the top of the Diamictite division, we get Eurydesma-Deltopecten Fauna of Lower Permian age. It is thus established that volcanism in Kashmir, Spiti-Zanskar and Ladakh is restricted to Lower Permian only. The sills and dykes associated in the underlying sequence in Syringothyris Limestone and Fenestella Shale in Kashmir, in Lipak and Po formations in Spiti are related to this volcanism.

Key-words—Gondwana, Volcanism, Peninsular India.

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सारांश

गोंडवाना में ज्वालामुखीयता

सी० त्रिपाठी

भारत में अधरि परमी घटना हिमालयी पट्टी में प्रधान ज्वालामुखीय घटनाओं तथा प्रायद्वीप में रिफ्ट भ्रंशों से अभिलक्षणित है जिसके फलस्वरूप विभिन्न गोंडवाना द्रोणीयों का जन्म हुआ है। राजमहल ट्रैप से निरूपित अधरि क्रीटेशी कालीन प्रधान ज्वालामुखीय गोंडवाना घटना गोंडवाना अवसादन की समाप्ति इंगित करती है। अधरि परमी ज्वालामुखीयता काश्मीर द्रोणी में पंजाल ज्वालामुखी तथा इसके समतुल्य अरुणाचल प्रदेश में रोटंग ज्वालामुखी (अबोर) एवं स्पिती जन्सकार द्रोणी में ज्वालामुखीयों से निरूपित है। लद्दाख की कराकोरम द्रोणी में ज्वालामुखीयता परमी आयु की चाँगटाश एवं अकटाश शैल-समूहों से सम्बद्ध है। काश्मीर में संज्वालाश्म स्लेटें ज्वलखंडाश्मीयों के रूप में विस्फोटी ज्वालामुखीयता के कारण बनी हैं और इसके पश्चात् वहाँ पंजाल ज्वालामुखी का लावा बहा है। संज्वालाश्म स्लेटें अधरि डायामिक्टाइट तथा उपरि पायरोक्लास्टी नामक दो मंडलों में विभक्त की गई हैं। पायरोक्लास्टी मंडल के आधार पर तथा डायामिक्टाइट मंडल के ऊपर अधरि परमी आयु का **यूरीडेस्मा-डेल्टोपेक्टॅन** जीवजात मिलता है। इस प्रकार यह स्पष्ट हो गया है कि काश्मीर, स्पिती-जन्सकार एवं लद्दाख में ज्वालामुखीयता अधरि परमी कल्प तक ही सीमित है। स्पिती में लिपाक एवं पो शैल-समूहों तथा काश्मीर में साइरिंगोथाइरिस चूनाश्मों और फ़ेनेस्टॅल्ला शैलों में अधरिशायी अनुक्रम में सहयुक्त सिल एवं डाइक इसी ज्वालामुखीयता से सम्बद्ध हैं।

GONDWANA of the Indian Peninsula comprises a thick sequence of continental sediments laid down in glacial, fluvial and locally, lacustrine environments. They occur in several isolated linear belts or grabens roughly in consonance with the present day river valleys. We have thus, Gondwana basins in Damodar Graben, Son-Mahanadi Graben and the Godavari Graben. The orientation of the

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different grabens is such that they converge towards a main line, the Son-Narbada Lineament. The Damodar Graben is aligned almost to east-west, Godavari Graben to NNW-SSE while the Mahanadi Graben has an intermediate alignment from NW-SE. Thus their linearity, convergence of their trend to a common line, the Son-Narbada Lineament and the trend of the peripheral basins across the coastal trend are some of the features that link their sedimentation to pre-existing structures. Their east-west linearity is ridge trend. The linearity of the Godavari Gondwana basins is due to the sedimentation having taken place along a north-westerly drainage accentuated by subsequent faulting along the northern margin. This convergence of the trend of Gondwana basins might be ascribed to the great horst-like Maikala ranges in conjunction with the Satpura ranges and the Netarhat-Mainpat Plateau acting as a broad watershed. It is of interest to mention here the "Great Bhandara Triangle" of Late Durga Shankar Bhattacharji (1932) of the Geological Survey of India is located not far from this region whence all the great trends of the Indian Shield, the Dharwarian trend (N-S), the Eastern Ghat trend (NE-SW), the Mahanadi trend (NW-SE) and the Satpura trend ENE-WSW meet to form a triangle.

The structural framework of the peninsular Gondwana is, thus, reflected by boundary and marginal cross-faults which owe their origin to the reactivation of the pre-existing fault zones within the Precambrian basement. The intrabasinal cross-faults are mostly antithetic in nature and came into existence to cope up with the tensile stress of the sediments. Two such trends are most common, the NW-SE trend and the NE-SW or E-W trend. In the Godavari Graben, NW-SE trend dominates. In the Pench-Kanhan Basin also, the same trend continues. In the Son-Mahanadi Graben, the southern part that is the Talchir and Sohagpur Basin shows a NW-SE trend whereas the Singrauli Basin, the northernmost one as expected, being in the vicinity of the Satpura Range, E-W trending faults coupled with N-S trending faults dominate over the NW-SE trending ones. In the Damodar Graben, the westernmost Karanpura Basin, the E-W trending faults dominate over the N-S trending ones but the NW-SE trending faults occur in significant amount. In Bokaro Basin, NW-SE, NE-SW to NS trending faults occur almost evenly. In Jharia Basin NW-SE trending faults dominate over others whereas in the Raniganj Basin, NE-SW trending faults dominate over others. In the distant Rajmahal Basin, N-S trending faults occur predominantly. In Garo Hills, the Singrimari Basin shows the predominance of NNW-SSE to NW-SE trending faults over the NE-SE trending ones. These faults occur as simple linear structures or as a zone. The analysis of these fractures in different basins points out to a very interesting fact, that is this main NW-SW fault trend is roughly parallel to the main structural elements of the Indian Plate and one would to be tempted to draw this conclusion that this broad similarity is the result of identical events that pervaded the shield as well as the adjoining ocean (De, 1977). It is in fact a complex set of *en echelon*, NE-SE trending spreading zones and NW-SW to EW fracture zones. The Gondwana grabens on the Indian Craton and the inferred deep zones of extension along the synthetic as well as antithetic fault pattern have probably been formed due to the extension of the crustal slab as a result of tensional forces that operated perpendicular to the graben axis. Similar phenomena were most probably responsible in the formation of the structure of the Indian Ocean floor. The extension of the crustal slab in both areas might have taken place during the time of drifting of the Indian Plate in an anticlockwise rotation with probable centre of location around the Pamir Knot (De, 1977). As the Gondwana tectonism started at least in the Late Sakmarian, it is reasonable to believe that the spreading zones as well as compensatory fracture zone of the Indian ocean are also of the same age. It is interesting to note that these fracture zones get reactivated intermittently, once in Jurassic, then in Tertiary. Some of the faults in the Damodar Basin have been ascribed to Tertiary by Auden. The marine transgression in Permian on the Indian Shield indicates a Permian fragmentation of the Indian Plate. The linearity of these occurrences on the Indian Shield might also point out to fracturing along well-pronounced zones. The creation of the Indian Ocean also began at this time with the downwarping between India and East Africa that approached Malagasy, then not far south as now.

It is believed that faulting or subsidence along the margins or within the basins did not start before the deposition of the Karharbari Formation. Krishnan (1982) assigned a general Lower to Upper Triassic age to the major faults in the Godwana basins. Major faulting was followed by ultrabasic intrusions which in turn were followed by the emplacement of dolerite dykes. The dolorite dykes have displaced the mica-peridotite dykes proving conclusively that the former are older than the latter. The alignment of basic dykes of the Deccan Trap along definite fault planes indicates that faulting preceded the outpouring of the Rajmahal/Deccan lavas. The mica-peridotite dykes are actually a lamprophyre or phlogopite rich ultrabasic rock comprising olivine, calcite, phlogopite, leucite and apatite. It has no great thickness (1-2 m at the most) but whenever it has penetrated through the coal-seams, it has burnt them to *Jhama*, because of its high fluidity and high temperature. It occurs both as sills and dykes. They have a preference for the coal-seams and invade them at their interface with sandstones. They occur in Damodar Valley and the Lower Gondwana of the Eastern Himalaya. They are younger than the basal Panchet and invade strata older than the *Lystrosaurus*-bearing red and crimson shales. In the Eastern Himalaya, they occur below the *Estheria*-bearing shales. Hence, in all probability, they mark the Permian-Triassic boundary, in any case occurring not later than Triassic.

The Rajmahal Traps were emplaced around 100 million years ago. The type area of this phase of stupendous volcanic activity is the Rajmahal Hills located at the head of the Ganga delta near the border of Bihar and Bengal. The traps comprise 450-600 m of basaltic lava flows with intercalated carbonaceous shales and clays and porcellanites. Some of the flows resemble pitchstone in composition. The intertrappean sediments between the lower four or five flows contain plant remains, fossil wood and Unionids. *Thinnfeldia, Ptilophyllum, Williamsonia* and *Nipanioxylon* are some of the principal plant forms. They are Lower Cretaceous in age, coeval with the Cimmerian orogeny.

The Deccan basalts, even after 65 million years of weathering, occupy an area of 32,000 sq km in Maharashtra, Gujarat, Madhya Pradesh and parts of Deccan. Northwards they extend up to Orai in Jalaun, Belgaum in south, Rajmahendri in SE and Kutch or Sind in NW. Eastwards, they extend up to Ranchi Plateau. They are product of fissure eruption that is they erupted through long narrow fissures or cracks in the earth's crust. They are mostly horizontal except some flows on the west coast which show dips seawards. They are punctuated with many layers of intertrappeans throughout their thickness. They have been divided into following groups :

Upper Traps—Bombay and Kathiawar with numerous intertrappean beds and dykes

Middle Traps—Central India, Malwa with numerous ash beds and almost devoid of intertrappeans in upper part with profusion of dykes

Lower Traps—Madhya Pradesh and east of it up to Ranchi Plateau, with intertrappeans and ash beds.

Compositionally, they are plateau basalts comprising dolerite and basalt but in Girnar and Osham Hills, lamprophyre, limburgite, monchiquite, olivine gabbro, porphyrite, andesite, monzonite, nepheline syenite, granophyre, rhyolite, obsidian, pitchstone, etc. are also found. The carbonatite of Jhabua District, Madhya Pradesh needs a special mention in this context. The Deccan Volcanics roughly coincide with the rapid spreading of the ninety-east ridge of the Indian Ocean (66-62 million years). It has now been found that flows of Deccan volcanic episode occur associated with the Jurassic-Cretaceous rocks in Kathiawar region, which make them coeval with the Rajmahal Volcanics. The author has recently located volcanic rocks in the basal part of the Niniyur Stage of Tiruchirapalli Cretaceous. It is therefore certain that Deccan volcanic activity is as old as Jurassic-Cretaceous and may span well into Tertiary. This would indicate a protracted process of extrusion-intrusion in the Indian Craton. The Sylhet Traps and Abor Traps (Rotung Volcanics) and the Khasi Hill carbonatite occurrences and the eastern ophiolite belts of Mishmi-Naga-Patkai ranges are all coeval. The same holds good for the Indus Suture ophiolite zone of the Western Himalaya.

In the extra-peninsular or the Himalayan region, the Gondwana sediments occur as paralic facies where plant-bearing horizons containing Gondwanic floral elements are found intercalated with marine sedimentary sequence with contemporaneous volcanism. Here again, they are developed into two distinct tectonostratigraphic domains, namely, the Lesser Himalayan belt and the Tethyan Himalayan belt. In the Lesser Himalaya, Gondwana of Permian age shows more or less a continuous development from Arunachal Pradesh to central Nepal, tectonically emplaced between the Mio-Plio-Pleistocene Siwalik molasse and the Precambrian metasediments. Gondwana plant-bearing horizons of Jurassic-Cretaceous age are known from Tanşen area in central Nepal. Volcanics in some form or the other occur throughout, associated with the Permian rocks and later in Jurassic and or Cretaceous and even Tertiary.

In the Tethyan Himalaya, Permian Gondwana are developed intermittently from one end of the Himalaya to the other. In the west, they occur in Salt Range and Kashmir. In the east and northeast they occur in Sikkim and Bhutan. Jurassic-Cretaceous Gondwana are also known from Salt Range in Pakistan, Ladakh in India, Thakkhola in central Nepal and Lingshi in Bhutan.

In Arunachal Pradesh, the Abor Volcanics comprise a thick sequence of volcanic flows and sedimentary beds in Siang District. Similar volcanic rocks found in Ranga Valley, Subansiri District are considered equivalent. Besides, lamprophyre dykes of the minette type are also found included in marine Gondwana sediments of Ranga Valley. The Abor Volcanics were found to contain Tertiary plants in the Intertrappean beds associated with them. To accommodate this age span, it was split into two, the Rotung Volcanics and the Geku Volcanics. The former was assigned a Permian age while the latter, a Tertiary age. Later workers found that all these volcanics belong to Tertiary suite only. If that be so, and it is quite likely that it is so, the flows associated with the Gondwana sediments in various sectors of Arunachal Pradesh Himalaya, would belong to the Permian phase of extrusion. Quite distinct from these flows and dykes the occurrence of minette-like lamprophyre dykes associated with the Ranga Valley Gondwana point out to their similarity with those of the Darjeeling Hill area and the peninsular Gondwana. On the basis of their association with the Permian strata in Arunachal Pradesh I venture to date them as Late Permian or Early Triassic.

The Abor Traps of the type area in Siang District comprise predominantly pahoehoe and "a-a" type lavas, agglomerates and volcaniclastic breccia with possibly pillow lavas also. In Siang District, a consanguinous assemblage of basaltic to andesitic flows, silicic tuffs, lapillis, agglomerates, volcinistic sediments, basaltic sills and dykes occur. They are of Permian age. A thick succession of basaltic to andesitic flows occurs in the Ranga Valley in various Lower Gondwana horizons. In short, seven of the Abor Volcanics of the type area are included entirely in the Tertiary. There are volcanics in plentiful associated with the Permian strata. The serpentinite rocks associated with the Tidding Limestone in Mishmi Hills are the northern extension of the ophiolite belt of Naga-Patkai ranges.

The likes of Abor Traps are found in the Kashmir area in the form of Panjal Traps, entirely Permian in age. They comprise massive or amygdaloidal, spilitic pillow lavas and tuff breccia. Nakazawa and Kapoor point out to the oceanic character of these lavas and the basement being continental, they must have been formed by rifting. They began as explosive type of volcanism in the form of Agglomeratic slates, which culminated into thick bedded flows of andesitic to basaltic composition. Acid varieties such as rhyolite, dacite and trachyte are also found in them. The dolerite dykes associated with older rocks in Spiti Zanskar (Lipak and Po group of rocks), Karakoram Basin of Ladakh (Changtash and Aqtash formations) are all of Permian age. Volcanism is extensive in the Permian and Jurassic Gondwana of the intervening area particularly Nepal. Thus, Permian and Jurassic are two important phases of volcanic episode in the Himalaya besides the Cretaceous-Tertiary volcanism.

To sum up, the igneous activity in the Gondwana of peninsular India is represented by dykes and sills of dolerite, lamprophyres and basalt as in the coalfields of Raniganj, Jharia, Giridih, Jainti, Bokaro and Karanpura. Although the age of these intrusives/ effusives is uncertain, they are considered to form spatial link between the traps of Rajmahal and the lavas of the Deccan. In most of the cases these dykes and sills are associated with marginal faults of the Gondwana basins. In contrast, volcanism in Upper Palaeozoic in the Himalayas is mostly synsedimentational.

The volcanism associated with the fragmentation of the Gondwanaland is thus, a consequence of distensional tectonics. This distension was genetically related to the movement of the Gondwanic continents towards the northern continent. Evidences for distensional tectonics in other Gondwanic continents are also common. The Parana Basin of Brazil shows marginal faults which are associated with basic volcanics. Extensive volcanic activity associated with Early Mesozoic sediments occurs in Argentina and Patagonia. The volcanic activity associated with the Karroo basins of Africa is considered to have initiated in the Triassic. In the central Transantarctic Mountains of Antarctica. Early to Late Permian volcanogenic sediments lie within the coal-measures. Permian Radok conglomerate of NE Antarctica is overlain by the Bainmedart Coal Measures and the entire sequence is intruded by lamprophyre and basic volcanics.

This distensional tectonics which was the immediate cause of impending break-up of the Gondwanaland was accompanied by voluminous eruption of tholeiitic flood basalts and emplacement of dolerite sills and dykes. In certain cases this igneous activity predates actual fragmentation and drifting of the Gondwanic continents. The Ferrar Supergroup tholeiites in the Transantarctic Mountains are considered to have been emplaced at about 179 ± 7 Ma. The Stormberg Volcanics in the Karroo Basin is a continental tholeiitic sequence of Jurassic flood basalts and dolerites. Radiometric age determinations indicate Early and Middle Jurassic age for these volcanics. In the Australian part of the Gondwanaland, Early to Late Triassic calcalkaline volcanics are restricted only to areas of tectonism along the borderlands of the New Zealand Geosyncline. In Late Triassic/Early Jurassic, the basic continental magmas began to increase relative to calcalkaline volcanism in eastern Australia. The basic magmatism reached a peak by Middle Jurassic in the Australian mainland. Main fragmentation and drifting of the continental parts in these areas which started in Late Cretaceous/Early Eocene was accompanied mainly by basic volcanism.

Thus the Ferrar Supergroup of tholeiites (in Transantarctic Mountains), Karroo magmatism (in Africa), calcalkaline and basic magmatism in the Australian region, the basic volcanism of Parana Basin (in South America), the Abor/Rajmahal, Sylhet and Deccan traps as well as the intrusives in coalfields of the peninsular India were the major volcanic activities associated with fragmentation of the Gondwanaland. It may, however, be pointed out that the Ferrar Supergroup and Karroo magmatism predate the Parana, Rajmahal/Sylhet/Deccan trap activity and are about 40 Ma older than the oldest known seafloor magnetic anomaly associated with spreading between Gondwana fragments. From the above, the following conclusions may be drawn:

1. That accompanied magmatism did not necessarily form the sites of subsequent continental separation.

2. Igneous activity that accompanied Gondwana rifting was independent of any plate boundary.

3. Rifting was controlled possibly by pre-existing zones of weakness.

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