CHAPTER: 5

GEOLOGICAL EVIDENCE
OF
NARMADA–SON RIFTING
This Chapter describes the Geological evidence of Narmada-Son rifting including the rift-related domal upwarping, volcanics, sedimentation and mineralizations.

5.1 RELATIONSHIP BETWEEN DOMAL UPWARPING AND RIFTING.

Studies on the continental rifts have indicated that the rifting process is intricately associated with large scale domal uparchings of the lithospheric crust. As back as 1926, Daly believed that continental rift and drift was caused by complex doming of a primitive continent (Pangaea) and its fragmentation along the axes of uplift.

Belousov (1962, 1969) illustrated rifting over broad low continental domes and called them epeirogenic uplifts or anticlises (Fig. 5.1).

Bailey (1964) suggested that upliftment of the continental crust is intimately associated with the formation of rifts. Tipnis and Srivastava (1968a) also suggested that vertical warping manifested by large scale crustal arcing is followed by the formation of grabens.
FIG. 5.1 RIFTING OVER BROAD LOW CONTINENTAL DOMES. 
THE FEATURES INDICATE THE SHAPE OF THE EPEIROGENIC 
STRUCTURE (APPEL, 1962).

FIG. 5.2 EXPERIMENTAL PRODUCTION OF A RIFT VALLEY 
BY SLOWLY ARCHING LAYERS OF MOIST CLAY. (REDRAWN 
FROM HOLMES, 1965; EXPERIMENTS BY HANS CLOOS.)
Menard (1973) elucidated the relationship between epeirogeny and plate tectonics and concluded that "One type of epeirogenic doming occurs over asthenospheric bumps which apparently are caused by rising plumes or limbs of mantle convection. It is possible that the initial disruption of lithospheric plates tends to occur over such domes and the tensitional rifts that spread out from them."

Thorpe and Smith (1975) proposed a genetic progression in the East African Rifts from unriifted domes through rifted domes to triple spreading ridge junction of Afar type. Rice (1977) illustrated present day crustal upwarps associated with the East African Rifts (Fig. 5.3). Burke and Whiteman (1977) described 16 uplifts, 29 rifts and 11 triple rift (rrr) junctions of Mesozoic to Tertiary age in Africa which reveal an evolutionary sequence from uplift to continental separation.

The domal upwarps associated with the Limagne, Bresse, Rhine and Hessen grabens (Logatchev 1978) as well as St. Lawrence rift system (Kumarapeli 1978) were also identified.

Several authors have proposed the mechanism of graben formation whereby crustal uparching due to rising asthenolith or upwelling magma plays a vital role in the initiation or propagation of continental rifts (Artemjev and Artyushkov 1971, Beaumont and Sweeney 1972, Logatchev 1978, Artyushkov 1981, and Bott 1981).
5.1 A EXPERIMENTAL VERIFICATIONS AND MODEL STUDIES.

In order to explain the genesis of East African Riffs, Cloos (1939) conducted an experiment and showed that excellent model of rift-valley morphology and tectonics result if, moist clay layers are arched or updomed from beneath (Fig. 5.2). The model revealed inward facing normal faults forming the boundary scarps and a rift-valley width approximating the thickness of the deformed layers, whereas no isostatic or mechanical inconsistencies developed. Cloos also demonstrated that cracks resembling the fracture pattern of a rift are produced by swelling a hot water bottle coated with clay. Later KumarPCI (1978) illustrated close similarity of fault patterns of the Rhinegraben, Eritrean graben and the St. Lawrence rift system with the fracture pattern of Cloos' hot water bottle experiment.

Cloos (1939) had considered the tension and the rifting to be a result of the gentle bending of the crust, much as tension develops in the convex region of a bent elastic plate. Ramberg (1974) modified Cloos' assumption slightly when he conducted a series of dynamic model experiments relating to a number of tectonic phenomena and found that tension in the model crust was not so much caused by the bending as it was created by the lateral spreading of the subcrustal body of abnormal mantle.

The tectonic effects of asthenospheric upwell and wedging of mantle-derived material on the elastic crustal plate and probable
patterns of development of ridge – rift valley structures in continental crust was analysed by theoretical and experimental studies (Bhattacharji and Koide 1975, 1978). The results showed that the origin of a ridge – rift structure is initiated first by wide domal uplift, antiform or ridge in an elastic crust prior to rift faulting.

Mathematical modelling by Withjack (quoted in Wood and Head, 1978) has shown that the crustal uplifts similar to those observed for the Kenya and Ethiopia rifts (~ 600 km wide, 3 km high) can be produced by mantle plumes 200 km wide and reaching up to the bottom of the crust. According to this model, wider and higher uplifts can result from broader plumes and/or greater crustal thicknesses. Rift-transsected crustal swells average ~750 km in diameter and 1 to 1.5 km in height (Wood and Head, 1978).

Neugebauer and Temme (1981) modelled the lithospheric deformation of the rift environment by applying finite element method. In the light of the stratigraphic records, K-Ar ages of the volcanic activity, paleotemperatures and the MOHO configuration of the Rhinegraben, they suggested that the initiation and propagation of crustal failure associated with continental rifting is a response of crustal uplift.

5.1 B PLACE OF UPWARPING IN TAPHROGENIC SEQUENCE

As described in preceding sub-sections, majority of scientists believe in a succession of events in which the graben formation is seen as a response of crustal domal uparching (Daly 1926, Cloos
Belousov (1969) suggested that the rift related Arabian - Ethiopian domal uplift, Rhine arched uplift and the Baikal arched uplift originated prior to rifting though intense uplift occurred simultaneously with the rift formation. Illies (1974 a) and Bhattacharji and Koide (1975) also believed in the succession from crustal doming to rifting but also emphasized on shoulder upliftment synchronous with the rift development.

Kent (1980) emphasized that the well established large scale rotation and tilting of marginal rift blocks contemporaneous with rifting and sedimentation, such as the one in Red Sea Rift, is incompatible with the concept of an initial phase of doming followed by the rift phase. During discussion on this paper, Gauss put forward that rifting occurred before uplift in case of the Red Sea where thickening crystalline basement was subsequently uplifted and suggested that "uplift and rifting are obviously not always consequent upon one another. None the less, there is an undeniable spatial and temporal correlation between uplift, rifting and volcanism ... The primary thermal energy made available can be expended on uplift and/or rifting and volcanism, there is no particular reason why one process should precede the other". Curra (1980) also suggested that rifting is sometimes preceded or accompanied by crustal doming though it may also take place in absence of doming.
5.2 **DOMAL UPWARPING ALONG NARMADA - SON RIFTS**

This section deals with the general geological evidence of crustal domal upwarping along the Narmada - Son Rifts while the geomorphological and geophysical evidence of domal upwarping are discussed in the respective chapters.

5.2 A **GENERAL GEOLOGICAL EVIDENCE**

The undermentioned paragraph is an ingenious quotation from Auden (1949 a) who first proposed a domal upwarp related to the Narmada Zone: "The Narmada zone is related in the west to an upwarp of asthenospheric shell into superficial crust and here it also coincides with the Satpura range (between long. 74° and 76°) running between Narmada and Tapti valleys. The major upwarp west of Bombay runs under the Arabian sea and hits the coast of India in the low lying gulf of Cambay". Auden also indicated that the upwarp at Sial - Sima interface near Bombay and along the Narmada Valley could have been the focus of extrusion of Deccan Basalts.

The present elevation of 457 m of the Talchir Beds and the Permian Marine Beds of Umaria, which were presumably deposited near the sea level indicates an upliftment (Auden 1949 b) which should be of still higher magnitude because it now lies on the down-faulted segment of the rift valley.

Referring to the alkaline - carbonatite occurrences in the Kathiawar, West Coast and Narmada Valley regions, it was suggested that the alkaline magmatism involving rapid transfer of the product of partial melting from deeper part of the upper mantle is tectonically
favoured by crustal uparching and block faulting (Bose 1967, cited in Bose 1973). Tipnis and Srivastava (1968 a) studied volcanic, petrological and tectogenetic aspects of the Deccan province and suggested that "Narmada trough and North Konkan regions are tectonically akin to one another and are probably an outcome of linear crustal uplifts in the E-W and N-S directions respectively". They considered the Narmada trough and the North Konkan complex as belonging to two major rift systems, the Satpura Rift and the West Coast Rift, and suggested that the fracture patterns parallel to these linear uplifts generally conforming to the orientation of dyke swarms possibly represent initial tension cracks during the arching of crust. They proposed that the exposure of carbonatites from the central parts or cores of the volcanic necks by erosion of the superincumbent material, caused by upheaval of the region furnishes the evidence of uplift associated with continental rifts. The area between Narmada and Tapti was called Satpura uplift in view of the structural control exerted by the Satpura orogenic trend, upwarping of which perhaps led to the rift formation (op. cit.)

Choubey (1970) suggested that the Deccan Trap volcanism took place during a period of tension caused by rift-faulting and upwarping.

On the basis of geological mapping in different selected sectors across the Narmada Valley, Ghosh (1976) demonstrated absence of any rifting or faulting of commensurate scale either in the part of Narmada River Valley still covered by Deccan Trap
or that in which Precambrian Vindhyan, Bijawars and Archaean are exposed. He, however, suggested that "Narmada - Son Lineament represents an erosional post - Deccan Trap Narmada Valley formed at the crest of a domal upwarp with tension fractures and probably shallow depressions along the crest". Present author is astonished at such an accurate diagnosis and description of the rifting phenomenon by Ghosh without having named it a rift. Ghosh (op. cit.) conceived of an elongated upwarping at least in the upper part of the lithosphere with tholeiitic magma filling up the core and extruding through the tensional creatal fractures so that the parallel and oblique tension fractures on the wide crested region acted as vents through which the lava erupted. The large width of the area more than 40 km on each side of Narmada River over which dolerite and basaltic dykes are seen, indicate very low and wide cretal region (op. cit.).

Bedi (1976) studied the geomorphic set-up of Deccan Trap area or Rajpippa Hills with the help of LANDSAT and aerial photointerpretation and suggested that the observed block faulting (taphrogenesis was a consequence of large scale cymatogenic movements which resulted in the formation of Narmada and Tapti Rift Valleys since Deccan Trap period.

Murthy (1979) presented a synthesis of Late Mesozoic - Early Tertiary magmatic activity in the Deccan Trap area of the Indian Shield and attributed the magma tectonics to the cymatogeny. He suggested that prominent ENE-WSW, NE-SW and rarely E-W and N-S trending ancient basement lineaments south of 23° latitude were
reactivated possibly by the arching of the Indian Shield as a consequence of the Deccan Basalt magmatic activity. Supplementing this observations with the planation surface data, he suggested a cymatogenic arch across the southern Peninsular India in the Middle or Late Jurassic times. This led to the development of fractures in its hinge zone; the fractures lay along the West Coast of India and were later filled by the intrusive dykes. The abundance of basaltic dykes in the Narmada area (cutting through the Deccan Trap flows) is analogous to that of the West Coast and suggests that the fractures were evolved along the ENE-WSW trending hinge of a cymatogenic arch which were later filled by basaltic magma to form dykes (op. cit.).

5.2 B PLATE TECTONIC STUDIES

Stressing the plate tectonic implications of Deccan Volcanism in the Indian Plate, Bose (1973), referred to the Narmada-Son Rift Valleys and suggested that "This roughly east-west trending fracture zone within the Deccan province has great volcano-tectonic significance and should more aptly be described as 'Narmada swell and rift' resulting from the tendency of the infratrappean crust to buckling". Regarding the origin of this feature he assumed that when the Indian Plate approached the Tethyan subduction zone, some part of the continental front arrived the subduction zone before adjacent areas. Such plate margin would have locally restricted further subduction but continued forces resulted in the warping of the rigid continental plate and movement along the old fracture zone,
Considering the Deccan volcanism in this scheme of Indian Plate motion, Bose (op. cit.) concluded that "A regional uparching of the crust across the direction of body force, development of tensional zone and down faulting would account for the volcano-tectonics of the Narmada belt". Whereas Bose's model can be credited for the recognition of the crustal uparching, it suffers from sophistry on account of the mechanism and timing of the uparching and rifting events which are a corollary of the process of continental break-up and nowhere related to the Tethys subduction and continental collision.

Thorpe and Smith (1975) supported the relationship between mid-plate Cenozoic alkaline volcanism, domal uplift and rifting, and suggested that the Deccan Traps of India were related in space or time to continental separation. Thompson (1976, cited in Biswas 1982) suggested that the melting of lithosphere during basalt formation and consequent arching might have contributed to the widespread uplift, faulting and Deccan Volcanism during Cretaceous to Palaeocene time when the western margin of India crossed the hot-spot.

Describing the evolution of the Indian sub-continent in terms of the new global tectonics, Desikachar (1977) identified "Cymatogeni- warping and formation of troughs due to tension before the break up of the Gondwana continent and in the course of the rafting movement of the Indian plate".
Bose (1980) discussed the Deccan alkaline magmatism from plate tectonics point of view and suggested a model where the Deccan Trap magmatism is nourished by mechanisms such as continental splitting (incipient Indo-Madagascarian Rift), crustal warping and fracturing induced by plate motion and plume activity.

5.2 C GEOMORPHOLOGICAL AND GEOPHYSICAL STUDIES

Other evidence indicating the crustal domal upwarp including the peculiarities of regional drainage pattern and the rise of peneplanation surfaces have been discussed separately in the Chapter 7 on geomorphological studies.

Upliftment of the Conrad and Moho discontinuities as reflected in the Deep Seismic Sounding (DSS) Studies, Gravity signatures associated with the domal upwarping, and the palaeomagnetic imprints of upwarping are elaborated in the Sections 8.1, 8.2, and 6.3 C respectively of the Chapters on geophysical & structural studies.

5.3 RIFT-RELATED SEDIMENTATION AND PALAEOGEOGRAPHY

Gee (1932) suggested that the Gondwana basins of Peninsular India had a more widespread deposition and the present day distribution is nothing but erosional remnants of more widespread deposits, and that the faulting responsible for preservation of the Gondwanas was mainly of Jurassic age. Other proponents of such a belief include Jowett (1925) who placed the main phase of faulting in Middle Triassic, and Auden (1954) who advocated Tertiary age of the fault-tectonics. Ahmad (1966) also argued that major phase of
faulting associated with the Gondwana is entirely post-depositional spanning over a time from Cretaceous to Tertiary.

Pek (1934) on the other hand, believed that the Gondwana basins were laid down in the rift valleys and the present day faulted boundary delineates the original limit of the rift shoulders. Ghosh and Bandopadhyay (1967) and Ghosh and Mitra (1970) cited evidence in its support, suggesting the Gondwana sedimentation concomitant with faulting. Sen and Bhattacharya (1974) studied the geology of Bhopal - Itarsi area by the photogeological interpretation and suggested that the lithological association of the Gondwana rocks indicate a rapid upliftment and erosion of the surface areas and rapid deposition in the trough faulted inland basins.

A multidisciplinary study and analysis of the coal forming environments of different Gondwana basins of the southern hemisphere indicated that the Gondwana coals of the Peninsular India were deposited in the intracratonic graben-type basins (Laskar 1977). Gondwana sedimentation in the Peninsular India disposed in four main basin belts, viz. Damodar - Koel Valley, Son - Mahanadi Valley, Pranhita - Godavary Valley and Satpura areas, is probably a result of Plate interior tectonism which led to the evolution of Gondwana grabens in a tensional stress regime (op. cit.). Similarly, on the basis of environmental interpretation of Gondwana coal measures Batta et al. (1977) suggested that the evolution of embryonic Gondwana grabens took place in Late Carboniferous - Early Permian period.
Besides this main phase of rift faulting and graben development, a younger phase effected the Indian craton during Late Jurassic - Early Cretaceous periods when the new grabens developed mainly along the East Coast of India and along the Narmada Lineament (op. cit).

The evolution of Jharia basin by faulting synchronous with the sedimentation has also been proposed by De (1977) and Mukhopadhyay (1984).

Discussing the tectonic framework of the Gondwana basins of Peninsular India, Ahmad and Ahmad (1977) questioned and called for a re-examination of the field observations made by Ghosh and Bandopadhyay (1967), and Ghosh and Mitra (1970) who cited evidence of faulting concomitant with the Gondwana sedimentation. Referring to their field observations, Ahmad and Ahmad (1977) remarked that "... these definitive statements, particularly from persons who had ample opportunities to examine the field areas, are, to say the least, surprising, particularly so after almost incontrovertible evidence had been presented on more than one occasion indicating that faulting was by and large post - depositional".

The presence of post - Gondwana faulting along the Narmada - Son Lineament can not be denied but it merely represents an extended phase of the rift - tectonics which has been taking place spasmodically from Late Carboniferous to Late Cretaceous, when the gradually deepening faults reached the upper mantle to trigger the Deccan Volcanic eruptions. The marine incursions of Permian and
Late Cretaceous periods along the Narmada Rift Valley, discussed in the subsequent sub-section, also furnish evidence in support of this presumption. As regards Tertiary, no major post-Trappian faulting of large magnitude, enabling the preservation of Gondwanas, has been reported along any of the Central Indian Gondwana Basins except the Cambay Graben area, though minor faulting related to the post-rift stage has been observed. Moreover, a continuous freshwater sequence of Gondwana sediments (Chanda 1968, Srinivasa Rao et al. 1977a, Mitra et al. 1977, Mukhopadhyay 1984, and Chakrabarti 1984) cannot be accounted except for gradually subsiding basins pari passu with sedimentation. The presence of Bagra conglomerate in the northern margin of the Satpura Gondwana Basin, with a land barrier to the north (Choubey 1971a), and occurrence of fanglomerates in the near vicinity of faults in Son-Mahanadi Gondwana basin (Choudhary 1977) furnish additional evidence in support of synsedimentary basin formation by faulting. Progressive northward shifting of depo-centres of the Satpura and South Rewa Gondwana Basins resulting in northerly, younging lithological layout (Datta et al. 1983) can also be seen as a response of rift-tectonics where unstable basin floor gradually tilted towards north due to greater displacement along the northern boundary fault over the northern flank of the domal upwarp.

5.3 A **PERMIAN MARINE INCURSIONS**

During the Permian times, two arms of epeiric seas entered
the Peninsular India giving rise to marine horizons of Badhaura, Umaria, Manendragarh and Rajhara (Fig. 5.4). Several versions of the alignments and connections of these arms have been proposed from time to time (Fox 1931, Ahmad 1964, Sastry and Shah 1964, Ghosh and Bandopadhyay 1967, Ghosh and Mitra 1970, Rao 1970, Shah and Sastry 1973, Choudhary 1977, and Ahmad 1971).

Sastry and Shah (1964), on the evidence of the restriction and manner of distribution of Productids and Eurydesma, suggested that the Umaria and Manendragarh Beds lying very close could only have formed under different marine and climatic environments in independent and unrelated sea-arms, bringing the Umaria sea arm along the Narmada Rift and connecting it with Badhaura occurrence of Rajasthan, while the Manendragarh sea arm came from the northeast.

Rao (1970) brought into light certain tectonic features of great structural significance which appear to have been responsible mainly in the close association of two different fauna of different climatic and environmental conditions so that Umaria (faunal assemblage indicating a warm water conditions), and Manendragarh (a cold water condition) Beds, though geographically only 150 km apart, not only belong to two different geological horizons but were also deposited in two different arms of the sea. That Umaria is a separate marine entity from Manendragarh and Rajhara has also been agreed to by several other authors (Ghosh and Bandopadhyay 1967, Lele and Chandra 1969, Waterhouse 1970 and de Lapparent 1971; later two papers cited in Ahmad 1971).
Shah and Sastry (1973) suggested that the Manendragarh and Rajhara Marine Beds occur in the lower and middle parts of the Talchir Formation representing the Asselian transgression, while those at Umaria and Badhaura were deposited in Sakamarian transgression at the base of the overlying Karharbari Formation. They proposed that the Asselian transgression probably came from east of Manendragarh and Rajhara as indicated by the faunal resemblance to those of Khemgaon - Wak in Sikkim while the Sakamarian transgression entered Umaria from the west along the Narmada Rift (Fig. 5.4). That these two marine transgressions coming from opposite directions were stopped at points about 150 km apart, was explained by the presence of a hidden basement high of metamorphics in Rewa - Sohagpur area (also indicated by the drilling results of G.S.I.) named 'Huges Ridge' by Shah and Sastry (op. cit.).

Ahmad (1964, 1977) conceived of an open sea southeast of Central India during Permo - Carboniferous time and suggested that the marine transgressions of Umaria and Manendragarh are attributable to successive phases of coastal inundations of this palaeo-sea. In either case, one would expect to find evidence of marine beds along the route which has not so far been found (Kumar 1985). Therefore, it is considered more probable that an arm of western sea transgressed for a short duration through the Narmada Rift zone up to Umaria, as also suggested by Choudhary (1977) and Krishnan (1982).
FIG. 5.4: EARLY PERMIAN MARINE TRANSgressions IN PENINSULAR INDIA (AFTER SHAH AND SAstry 1973)
5.3 B CRETACEOUS MARINE TRANSGRESSION

The marine rocks of Late Cretaceous age exposed as inliers in the Deccan Trap terrain along western part of the Narmada River, closely approximate the Narmada Rift zone (Fig. 5.5). Murthy (1979) surmised that the "Narmada became an area of sedimentation in Cretaceous times as indicated by the presence of the Bagh Beds far into the interior and is also suggestive of sinking of the area along what is now considered to be a graben". Discussing the rift structure of Narmada Valley, Murthy and Mishra (1981) suggested that during the later part of Permo-Carboniferous as well as during Cretaceous Period marine transgressions took place which found its way through the present day lower Narmada Valley which at these times was indeed a depression.

Mishra (1982) prepared a palaeoecological model for the sub-Trappaean sedimentation of Narmada Valley and suggested that an ENE trending 50 km wide graben established during Late Aptian (Ca. 110 Ma) probably on the Lineament of a Permo-Trias basin. He proposed that the Narmada basin was a seat of nearly continuous sedimentation from Late Aptian through Turonian when Nimar and Bagh sediments were deposited, including the marine incursions between Middle Albian to Turonian with the peak of transgression in Cenomanian. The post-Bagh/infra-Lameta Traps, the Lameta and the Deccan Traps were thought to be of Coniacian through Palaeocene age in this graben (op. cit.).
FIG. 5.5: DISTRIBUTION OF BAGH BEDS IN WESTERN INDIA (BASED ON JAIN, 1970).

FIG. 5.6: TURONIAN MARINE TRANSGRESSION ALONG THE NARMADA VALLEY (AFTER ROBINSON, 1967).
The Bagh beds exposed a few kilometers east of the type locality, in the Man River Section (Fig. 5.6) consists of about 30 m thick fresh water succession of unfossiliferous sandstone and conglomerates known as Nimar Sandstone overlain by fossiliferous Nodular Limestone and coralline Limestone of Bagh Beds (Kumar 1985). The Nirmar Sandstone has yielded plant fossils of Late to Early Cretaceous (Hauterivian) age (op. cit.) which can therefore be considered as the lower age limit of Cretaceous rift faulting and basin formation in which the Nimar Sandstone Beds were deposited. Biswas (1982) proposed that the Nimar Sandstone Beds were deposited by a river system flowing along the Narmada Lineament, while at the western margin of the basin where the river intersects the Cambay Graben, the deltaic facies of Nimmars were deposited. Thereafter, the Narmada Valley opened into a rift basin in Late Cretaceous time, and marine sediments were deposited in a progressively deepening environment until the end of Cretaceous when sedimentation ended abruptly as a result of regional uplift followed by Deccan Trap activity in Early Palaeocene time.

Upper part of the Nimar Sandstone with a rich assemblage of trails, tracks and burrows in fine grained sandstone and shale, named the Trace fossil Horizon is overlain by a thin shaly bed with Oyster casts and shark teeth which probably indicates the first marine incursion in the Cretaceous history of Narmada Valley (Chiplonkar 1982). The Oyster Bed marks the commencement of marine Bagh Bed deposition which continued through the Cenomanian
and Turonian ages (op. cit.). Rapid fluctuating conditions due to numerous transgressions and regressions during the deposition of Bagh Beds have been indicated on the basis of lithologic and faunal assemblages (op. cit.) which perhaps represents recurrent deepening of the basin in successive phases of rift-faulting and graben floor subsidence. On the basis of trace fossil distribution in Bagh Beds, the asymmetric nature of the Narmada basin, with the deepest part lying near the present course of Narmada River and the steeper southern flank has been suggested by Chiponkar, 1980 and Ghare and Badve, 1980 (both papers cited in Chiponkar 1982). It is interesting to note that such an asymmetry is also seen in the Mehmadabad—Silimora D.S.S. Profile (Fig. 8.6) where the southern fault of Jambusar—Broach Graben is steeper than the northern fault.

Greater frequency of the occurrence of Oyster Beds in the upper part of the Nimar Sandstone in the western outcrops of the Bagh Beds suggests that the marine transgression came from the west (Kumar 1985). Shallow marine condition during the deposition of Nodular Limestone and the lower parts of Coralline Limestone followed by open sea characters, with abundant ostracods and planktonic foraminifers, during the deposition of upper beds of Coralline Limestone (Jain 1971) clearly reflects the deepening of basin by rift faulting.

Chanda (1968) studied the Jurassic—Cretaceous stratigraphy
of Jabalpur area and suggested that "While the Jabalpur's were mainly deposited in flood plains, an environment with clear shallow marine tendency corresponding to the Cretaceous transgression set - in during the Lameta sedimentation ". That the Lametas were deposited in the inner neritic marine waters of a shallow epicontinented sea is evidenced by i) the occurrence of autochthonous glauconite and algal limestones with coralline algae and (?) ostracodes, ii) low plasticity, and iii) lack of autochthonous fossils indicating terrestrial non-marine origin, as against the underlying Jabalpur's (op. cit.). Chanda (op. cit.) further suggested that the "Westward stratigraphic thickening and increasing intercalations with typical marine formations down the Narmada Valley in Dhar District integrated with the above data indicate the existence of an open oblong, intracratonic basin, plunging towards west ... The configuration of the basin appears to coincide with the so-called 'Narmada - Trough' of Krishnan (1964)". Similarly Kumar and Tandon (1979) studied the environment of deposition of the sedimentary succession of Jabalpur and suggested that the Jabalpur Formation of the upper Gondwana and Green Sandstone Member of the lower Lameta Formation are of fluvial origin but the succeeding Lameta rocks are of supratidal to coastal sand complex origin.

Singh et al. (1983) also suggested that Lametas were deposited on a peneplained uniform westerly sloping basin in estuarine channel with marine tidal influence as indicated by the bipolar nature of
palaeocurrent and presence of glauconite and thalassinoioids type of burrows in the basal sandstone. Lateral as well as vertical facies association of Green Sandstone with bioturbated carbonates and marls also support this fact.

Kumar (1985) also suggested the extension of Cretaceous marine transgression along Narmada Valley upto Jabalpur on the basis of marine intercalations known from the lower parts of Lameta Beds of fluviatile to estuarine origin.

5.4 RIFT RELATED VOLCANISM.

The spatial relationship between volcanism and rifting was first proposed by Cloos (1939). In a study of the volcanism and seismic activity associated with the World Rift System, Tipnis and Srivastava (1968 b) observed that the tholeiitic basalts and the alkaline igneous eruptive centres are generally confined to the continental rifts. The relationship between volcanism and rifting with special reference to the Narmada Rift is given in this Section.

5.4 A RELATIONSHIP BETWEEN BASALT VOLCANISM AND RIFTING.

The tholeiitic and / or alkali basalts are now considered to be a characteristic of continental rifts (Lippolt et al. 1972, Falvy 1974, Condie 1976, Burke and Whiteman 1977, Bridwell 1978, Illies 1981 a, and Artyushkov 1981 ). In the East African Rifts and the Rhinegraben area, volcanicity seems to be persistent and constant feature associated with the rift valleys, the loci of eruption being on the faults (Valdiya 1984).
Formation of basaltic magma, in the 'hot-spot' theory of Wilson, presumably results from increased temperatures caused by concentration of radioactive minerals in the deeper earth. But an alternative theory of its genesis from pressure reduction in the asthenosphere caused by areal-extension faulting (Thompson 1976) in conjunction with the former appears to be a better mechanism. Such hot-spot or plume reservoirs are considered to be the source of alkali basalts, nephelinites, melilitites, basanites, kimberlites and continental tholeiites which it provides by varying degree of partial melting (Anderson 1981). Thorpe and Smith (1975) also ascribed the petrogenesis of magmas varying from nepheline–alkali basalt to oversaturated tholeiite, to the partial melting or fractional crystallization of the upper mantle.

5.4 B BASALT VOLCANISM ASSOCIATED WITH NARMADA RIPT.

The Deccan basalts constituting the most extensive tholeiitic eruptions of Cretaceous - Eocene age in the world occupy 500,000 sq.km area in the western and central parts of the peninsular India with probable original extent of over 1.5 million sq.km (Raja Rao et al. 1978). Earlier, the generally accepted view was that the Deccan Trap flows constitute a typical tholeiitic province (Sukheswala and Poldervaart 1958, cited in Kailasam 1979). However, Ghose (1976) compiled the geochemical data and suggested that the average composition of Deccan basalts is intermediate between oceanic tholeiites and the alkali basalts from the islands of the Indian
Ocean. Bose (1978) and Konda (1984) also surmised that the available data for Deccan basalts show a spread from tholeiite to alkali basalt fields.

Discussing the problem of genesis of Deccan Trap, West (1967 a) related it with the Narmada Valley and described: "... tranquil outpouring of lavas accompanied by faulting over the greater part of the area, and explosive activity and foundering of the crust accompanied by faulting on the western side of India and in the Narmada Valley". Based on the association of tholeiitic basalts and alkali igneous intrusive centres and other tectonic observations, Tipnis and Srivastava (1968 a) suggested the presence of the Satpura Rift, with Narmada trough at its western end.

Discussing the mode of eruption of Deccan Traps, Biswas and Deshpande (1973) drew analogy between the East African rifts and the Rhinegraben with those of the Narmada - Son and Cambay grabens and suggested that these grabens and the faulted West Coast were the main sites of volcanic activity during the Deccan Magmatism.

Adyalkar (1975) suggested the eruption of basaltic lava through the fractures of the Narmada - Tapti and Purna rift valleys.

Condie (1976) mentioned that "... the Deccan Traps in India appear to be related to extensive tensional faulting".

A.K.Ray (1978) indicated that the Narmada - Tapti - Son Lineament is an incipient continental rift sitting over a mantle
cushion from which Deccan Trap volcanism appear to have taken place. Based on the plate tectonic interpretation of basaltic and alkaline volcanism related to the Deccan Traps, Bose (1980) also proposed the presence of Warmada and Rajasthan - Gujarat rifts (i.e. the Cambay graben).


5.4 C RELATIONSHIP BETWEEN ALKALINE - CARBONATITE MAGMATISM AND RIFTING.

Describing the process of continental rifting, Bailey (1954) suggested the generation of alkaline magma by partial melting of the upper mantle and the lower crust material in response to a release of loading at the sight of rifts. It is now generally believed that these acid to intermediate eruptives associated with rifts are the differentiates of basalts of upper mantle provenance, and not the products of sialic remelting or sialic assimilation.
McCall and Hornung 1972). The magmatic origin of carbonatites is also a proven fact (Sukheswala 1976). Whatever the origin, the world-wide distribution of alkaline rocks and carbonatites show that they occur in stable continental platforms along the rift zones (Sethna 1974, Sukheswala 1976). McConnel (1972) illustrated a close spatial relationship between the carbonatites and the rift faults of the East African Rifts (Fig. 5.7).

Petersen (1978) described the composite plutonic ring complexes (for such is a general mode of occurrence of these rocks), as a structural characteristic of rift zone plutonism and noted that "They occur in distinct structural belts which, according to global tectonic models, define major continental rupture lineament associated with former triple junctions. Their origin, therefore seems to be related to process of continental rifting." Lazarenko (1984) also suggested that the alkaline suites and sodic type show a distinct tendency to be related to the earth's rift system.

Valdiya (1984) surmised that the aborted rifts are characterized by alkaline volcanism of phonolites, trachytes, carbonatites and pyroclastics, representing central type of eruption, and their plutonic equivalents such as nepheline-leucite-syenites, and alkali gabbro (ijolite).

In a study of the chemical composition and volumes of Kenya Rift volcanics, Williams (1972) suggested that the rift valley is

characterized by widespread alkaline magmatism. Ralph (1976) observed the association of continental rifts and lineaments with 45 major fluorspar districts (evidently with carbonatites and alkaline rocks which form important host rocks of fluorspar) in Alaska, U.S.A. and Mexico, and also suggested relationship of fluorspar occurrences with the Rhinegraben, Baikal rift zone and Afro - Arabian rift zone.

The volcanic rocks associated with rift and uplifted areas in Africa has been extensively studied and it was found that alkali basalts predominate these areas, but many other alkaline and peralkaline rocks also occur (Burke and Whiteman 1977).

5.4 D ALKALINE - CARBONATITE COMPLEXES ALONG NARMADA RIFT

Krishnan (1953) observed that several eruptive centres have been recognized roughly aligned in ENE - WSW direction in the Saurashtra and Narmada Valley regions but Sukheswala and Udas (1964) first suggested the relationship between Narmada Rift zone and alkaline magmatic activity.

Yellur (1967) reported Netrang, Ambadongar and Barwaha carbonatite complexes which are circular or oval volcanic plugs of 5 to 25 sq. km area. He suggested a relationship between Narmada Rift Valley and the occurrence of these carbonatites which were thought to be emplaced along faults associated with the Narmada Rift. Later, Yellur (1968) concluded that the overall
structural set-up of the Rift Valley shows that this region was in a state of great tension immediately antecedent to the compression of the Himalayan movement which acted along much the same direction and the deep crustal fractures accentuated volcanic activity in the form of plugs and dykes emplaced during the end phase of eruptive cycle.

Tipnis and Srivastava (1968 a) observed linear disposition of volcanic cones of acid and alkaline differentiates of magma along the Narmada Rift system, while Sukheswala and Avasia (1971) considered the present Narmada tract as "a major fault zone - a rift with ENE trend ", based on the structural and geological characteristics of carbonatite - alkaline complexes of the Panwad - Kawant area of Gujarat.

Bose (1973) suggested the Narmada - Son fracture zone within the Deccan province to have great volcano - tectonic significance, and corroborated its tectonics with the alkaline magmatism along this belt.

Based on the geological mapping of Amba Dongar area by the research students of St. Xavier's College, Bombay Sethna (1974) reported four ENE - WSW trending major faults with southerly downthrows north of Satpura along which the carbonatite and alkaline plugs were intruded, and it was suggested that if there is a rift it should be north of Narmada River. Sethna (op. cit.) envisaged the following sequence of events to explain the evolution
of Narmada - Tapti Rifts with intervening Satpura horst:

(i) After the initial doming a major rift developed along the present Satpura Range, followed by extensive volcanic activity that mainly filled up the rift depressions (Fig. 5.8 A).

(ii) While rifting continued, the surrounding domed up flanks started subsiding. Thus the Cretaceous Bagh sediments north of Satpura developed a southerly tilt. Parts of the lavas then started overflowing on to the flanks of the rift. Towards the late stage of the eruptive activity the Amba Dongar carbonatite erupted just north of the rift (Fig. 5.8 B).

(iii) The end of eruptive phase was probably due to the rifting of the Indian subcontinent which carried the Satpura zone away from the hot mantle. The rift then became isostatically unstable over the cold dense mantle and started rising with the development of essentially vertical faults (Fig. 5.8 C).

Based on fluor spar and alkaline rock association, Ralph (1976) inferred the Narmada Rift structure and wrote: "At Amba Dongar, Gujarat, India, very large fluor spar deposits associated with carbonatite, syenite, and other potassium feldspar rocks in a ring complex have been found about 5 km north of a major Tertiary rift dissecting the Deccan Plateau (Deans and others, 1972). Other
FIG. 5.8 A. Uploming and rifting of Satpura zone with Deccan trap effusives filling the rift depressions.

B. Subsidence of the dome and overflowing of the effusives onto the flanks of the rift followed by the carbonatite activity at Amba Dongar.

C. Uplift of the Satpura horst accompanied by sympathetic step faulting. (After Sethna 1974).
fluorspar deposits are near this rift along the Narmada Valley, 80 km west and 200 km east of Amba Dongar deposits”.

Discussing the composition and origin of Deccan Volcanic Province, Ghose (1976) mentioned that the undersaturated basalts, nephelinites, carbonatites, intermediate and acid differentiates have also been encountered in parts of Western India which are broadly aligned in two major rift zones viz., the Narmada Son and Cambay Grabens, and the faulted West Coast. Besides the Amba Dongar carbonatite with alkaline gabbro and syenite, and carbonatite of Netrang and Barwaha, the Narmada graben is marked by andesite, rhyolite, pitchstone, trachyte and mugearite flows seen between Taleja and Una, and a few dykes of carbonatite and dolerite (Tiwari 1977, cited in Valdiya 1984). In the same line are plugs of Kimberlite at Hinota and Jungel (op. cit.).

Kailasam (1979) suggested that "The prominent WSW - ENE trending Narmada - Son Lineament to the north of the Deccan Plateau comprises the Narmada - Son Rift, which is characterized by basic alkaline rocks and carbonatite occurrences in its western extremity and - kimberlite pipes over its eastern parts ". Bose (1980) outlined the development of alkaline rock assemblages in plug like bodies and hypabyssal minor intrusions and noted the alignment of magmatic activities along four volcanotectonic belts meeting near the Gulf of Cambay. He suggested that the mantle plume activity and associated crestal rifts are responsible for characteristic alkaline carbonatite magmatism along these volcanotectonic belts.
three of them penetrating the Indian Shield and one trending along its western border. Singh and Rao (1981) reported alkaline magmatism of carbonatites associated with the East Son graben of the Narmada - Son Rift System in Sidhi district of Madhya Pradesh. Gupta and Gaur (1984) suggested that the alkaline magmatic activity continued up to Oligocene near the junction of the three prominent features - the West Coast fault, the Narmada - Son - Tapti Lineament, and the Cambay Graben.

The locations of reported alkaline - Carbonatite complexes of Western India have been shown in Fig. 5.9. It is concluded that their alignment along the Narmada Valley furnishes ample evidence to testify its rift Valley structure. In addition to this spatial association, the radioactive age data further brackets the alkaline magmatism with the rifting and basalt volcanism in time.

K - Ar age determinations of Ambadongar alkaline complex (Deans and Powell 1968) revealed an age of 37.5 ± 2.5 Ma. Pavagarh rhyolite was dated at 43 ± 2 Ma (Rama 1968, as cited in Mishra 1979), while Pavagarh alkaline complex gave an age of 63 - 61 Ma (Wellman and McElhenny 1970). Two samples of feldspars from Ambadongar were dated at 61 ± 2 Ma and 76 ± 2 Ma (Deans et al. 1973, as cited in Nagpal et al. 1974). These age determinations clearly establish the alkaline volcanic activity to be of syn - to post - Deccan Volcanic phase. Such a relationship in space and time is in accordance with McCall and Hornung (1972) who suggested that the acid and intermediate eruptives associated with rifts are the differentiates of basalts of upper mantle provenance.
LEGEND

POSITIVE GRAVITY ANOMALY ZONE.

* VOLCANIC PLUGS AND CONES.

INDEX

1. BARWAHA
2. MANDLESHWAR
3. BAGH
4. BARWANI
5. AMBA DONGAR
6. PANWAD
7. PHENAI MATA
8. RAJPILLA
9. RODHAN
10. PAVAGAD
11. NETRANG
12. KADI
13. MUNDWARA
14. CHAMARDI CHOGAT
15. GIRNAR
16. OSHAM
17. ALECH
18. BARDAR
19. SILVASSA
20. JAWAHAR
21. HASSEIN
22. SALSETTE
23. TROMBAY

FIG. 5.9; MAP SHOWING IMPORTANT LOCALITIES OF ACID AND ALKALINE INTRUSIVE ROCKS IN THE DECCAN VOLCANIC PROVINCE (BASED ON YELLUR 1967, 1968; GHOSE 1976, BOSE 1980 AND MURTHY AND MISHRA, 1981)
5.5 **RIFT - RELATED MINERALIZATION.**

Rift related mineral deposits can conveniently be divided into those within or related to magmatic rocks, stratabound deposits in sedimentary successions, and vein type deposits formed by hydrothermal activity (Mitchell and Garson 1981).

Magmatic activity associated with rifts largely comprises undersaturated alkaline and peralkaline rocks including carbonatites with apatite, pyrochlore, rare earths, strontianite, copper, uranium, and baddeleyite mineralization; diamondiferous kimberlites; and probably ultrabasic – basic intrusions at depth along the rift axis with Cr–Ni–Pt–Cu ores (op. cit.).

Depending on the latitude or climatic zone, the failed rifts may become repositories of evaporites containing Na–K salts, magnesite and phosphates, or of clastic sediments containing bedded coal and bituminous deposits. The oil and gas may also be formed and trapped under suitable conditions. The presence of thick Gondwana coal seams and the alkaline and peralkaline magmatic bodies along the Narmada Rift has already been described in Sections 5.3 and 5.4 respectively. However, the sediments deposited in the developing rifts become host rocks to stratabound epigenetic or diagenetic sulphides. These include major copper and copper–cobalt deposits and some Ag–Pb–Zn ore bodies, while some rift successions may include vein-type lead–zinc and fluorite mineralizations (op. cit.). Association of such minerals with the Narmada–Son Rifts has been illustrated in this Section.
Rao et al. (1968) first called the Narmada - Son Lineament as a base metal province, occurring in the river valley where base metal mineralization is found in the Archaean, Bijawars and upper Vindhyan.

Remnants of old prospecting for copper and lead in the form of pits, trenches and shafts near Sleemanabad railway station were reported, which was carried out by P.C. Dutt of Jabalpur along with Mersrs Burn and Co. in 1904 - 1908 (Pandey, 1972).

Ghosh (1976) described various lead and copper mineralizations in the Narmada - Son Valleys: "Study of the ancient workings for galena near Joga Kalan (22°25' : 76°46' ) on the east bank of south - flowing Narmada west of Harda show that the mineralization is most likely to be of patchy nature and is controlled by en echelon low - intensity discontinuous fracture zones trending NE-SW and dipping at 70° - 80° towards west within Bijawar dolomite with bedding dip upto about 10° towards east and north. About 6 km north-east of Joga, and on the north bank of Narmada river at Tamakhan ancient copper working in the form of two trenches arranged in sinistral en echelon pattern is seen trending NNW-SSE and located within Archaean granitoid terrain. At Kua, near Jabalpur (23°35' : 79°52' ) Copper and lead mineralization is found along shear zone trending N-S in Bhandar Limestone quite away from Narmada Valley".

He also reported copper occurrence in Imalia - Amgaon copper-lead mineralized belt near Sleemanabad located within the area where mineralization follows shear fracture zones with N-S to NNW-SSE
trend and westerly dip in dolomite forming part of the Archaean. He also documented copper mineralizations in Dhandu Kuia and Karhi in Son Valley along NE-SW and ENE-WSW shears of limited extent within Archaean phyllitic rocks.

Ralph (1976) suggested that major fluor spar districts are localized chiefly along and near continental rift zones/lineaments and noted that at Amba Dongar, Gujarat, very large fluor spar deposits in alkaline rocks have been found about 5 km north of a major Tertiary rift dissecting the Deccan Plateau, and that other fluor spar deposits are near this rift along the Narmada Valley, 80 km west and 200 km east of Amba Dongar.

Balasundaram (1977, cited in Atchuta Rao et al. 1980) showed the presence of a belt of basemetal mineralization exactly coinciding with the Narmada - Son Lineament (Fig. 5.10).

Babu Rao et al. (1980) suggested that the NNE-SSW trending aeromagnetic lineaments passing through Katangi appear to correlate well with a shear zone with copper mineralization. Atchuta Rao et al. (1980) also suggested close association of Cu - Pb - Zn mineralization with the ENE - trending aeromagnetic lineaments in the eastern part of the Narmada Valley.

Soni (1981) reported base metal mineralization in the rocks of Semri Group, Vindhyan Supergroup in parts of Damoh and Chhatarpur districts of M.P. Mineralization of galena, sphalerite, chalcopyrite and pyrite in dolomite is reported at Imlichowk. Soni (op. cit.) noted that the mineralization, in the form of disseminated grains
FIG. 5.10: COPPER-LEAD-ZINC MINERALSATIONS ALONG NARMADA SON RIFT ZONE [AFTER ATCHUTA RAO et al. 1980]
and patches, is confined to the upper portions of the dolomite near its contact with overlying chert breccia. In one case the galena has been found along the fracture planes. In the same area the mineralization of pyrite and galena is found in upper portions of dolomite. Chauraiya is the second locality where galena crystals occur in the loose calcareous soil and also in chert breccia. In chert breccia complete crystals of galena have been found as disseminations in the middle part of the 2 to 3 cm thick chert bed. Though Soni (op. cit.) believed in syngenetic nature of mineralization, a possibility of replacement and hydrothermal deposition can not be ruled out based on the report of galena along fracture planes and the confinement of disseminated ore in upper part of carbonate host rock dolomite with overlying chert breccia acting as a barrier.

Occurrence of native sulphur and limonite in the silicified and gossanized horizons in the lower part of Semri Group, south of Kohari area have been reported (Khan et al., 1981). Kohari is about 80 km NNW of Satna. Interest has been further accentuated because of distinct dispersions of the copper, lead and zinc in the host rocks of limestone and breccia. Khan et al. considered that the sulphur and base-metal mineralization is either genetically related to the volcanic activity within Semri Group of rocks or the base metal sulphides might have originated through later hydrothermal action.

The geographic locations of over 30 base metal mineralizations reported along the Narmada - Son Lineament have been documented
here which, in addition to other rift-related minerals such as diamondiferous kimberlites, Fluorite bearing carbonatites and coal beds provide ample support for the Narmada - Son rifting:

- Lead and Silver mineralization at Gokula Kua, Dewas Distt., M.P.
- Basemetal mineralization at Jobat (22°24'50" : 74°33'45"), Jhabua district, M.P.
- Copper mineralization at Tamakhan - Mirzapur (22°27' : 76°50' ), Dewas Distt., M.P.
- Galena silver mineralization at Joga (22°26' : 76°48' ), Hoshangabad distt., M.P.
- Copper mineralization at Barman - Kalan (22°2' : 79°1' ), Hoshangabad distt., M.P.
- Lead mineralization at Piparia (22°38'30" : 78°23'30" ), Hoshangabad distt., M.P.
- Galena mineralization near Joga Kalan (22°25' : 76°46' ), Hoshangabad distt., M.P.
- Lead - Zinc mineralization at Deepa (23°01' : 79°01' ), Narsinghpur distt. M.P.
- Lead - Zinc mineralization at Jhiria (22°57'30" : 78°38'40" ), Narsinghpur distt., M.P.
- Copper mineralization at Barman Khurd (23°1'25" : 79°1'5" ), Narsinghpur distt., M.P.
- Copper and lead mineralization at Imalia (23°37' : 80°16' ), Jabalpur distt., M.P.
- Lead - Zinc mineralization at Sleemanabad - Imalia - Bhula
  (23°36' : 80°16'), Jabalpur distt., M.P.

- Lead zinc and silver mineralization at Selarpur - Nawalia
  (23°39' : 80°28'), Jabalpur distt., M.P.

- Copper mineralization at Amgaon (23°40' : 80°29'),
  Jabalpur distt., M.P.

- Base metal mineralization at Karua Kap (23°49' : 80°39'),
  Jabalpur distt., M.P.

- Copper mineralization at Sunhera - Sunheri - Mohania
  (23°41'30" : 80°27'20"), Jabalpur distt., M.P.

- Lead zinc mineralization at Chauraia (24°25'10" : 79°34'30"),
  Damoh distt., M.P.

- Base metal mineralization at Kua (23°33'45" : 79°51'5"),
  Damoh distt., M.P.

- Cu - Pb - Zn mineralization at Imlichowk (24°31' : 79°40'),
  Chhattarpur distt., M.P.

- Pb - Zn mineralization at Charka (24°4'55" : 81°17'58"),
  Shahdol distt., M.P.

- Cu mineralization at Panwara (24°22'45" : 81°50'20"),
  Sidhi distt., M.P.

- Cu mineralization at Bohera - Satnara (24°21' : 80°56'),
  Sidhi distt., M.P.

- Cu mineralization at Byrialah - Boheratola (24°20' : 81°52'),
  Sidhi distt., M.P.
• Cu mineralization at Dhankhori (24°22'30": 81°46'50") Sidhi distt., M.P.

• Cu mineralization at Jhala, Sidhi distt., M.P.

• Pb mineralization at Suagath (24°24': 81°34') Sidhi distt., M.P.

• Pb mineralization at Chitrangi (24°29'30": 82°23'0") Sidhi distt., M.P.

• Cu mineralization at Dhandu Kuia (24°03': 81°16') Sidhi distt., M.P.

• Cu mineralization at Karhi (24°06': 81°19'), Sidhi Distt., M.P.

• Basemetal mineralization at Kohari (24°51'30": 80°29'30") Satna distt., M.P.