Deccan traps, mantle activity and extentional tectonics in the Pachmarhi

Dr. N.L. Dongre

Fissure eruption in Sendhwa (Narbada Valley)

ABSTRACT - Chemical characteristics of Deccan basalts, like other continental flood basalts, indicate them to be relatively evolved magmas. Recognition of Deccan basalt as a derivative magma has given rise to speculations regarding the nature of primary magma and its source. The present paper projects, picrite and as prospective primary magma types which might evolve to Deccan basalt composition. Some recent petro genetic models for Deccan basalt are constrained by extensive development of sub continental source. Although an apparent similarity of Deccan basalts has been suggested, the generation of unmodified primary Deccan magma with typical depleted trace element geochemistry and isotopic composition has not been documented within the volcanic province. Obviously, the models have to invoke unquantified modifying mechanisms to derive the relatively enriched Deccan basalt and alkaline magma types of the volcanic province. Derivation of moderately evolved Deccan basalt by extensive fractionation of olivine ($+pyroxene$) from primary picritic magma has also been proposed. The Deccan picrite being fertile could produce an enriched derivative closer to Deccan Basalt, thus minimizing the role of mixing processes. Significantly, the bulk of Satpura (Mahadeva) Deccan basalts (excluding the highly contaminated types) in terms of Nd-Sr isotopic Compos itions, are identical with most continental rift zone magmatism. Geochemical correspondence of average Deccan basalt to the whole spectrum of incompatible elements is remarkable. Extensive Dev elop pment of a sub continental lithospheric source affiliated mantle can develop a relatively simpler petro genetic model for the Deccan basalt. Geochemical variability of Deccan basalts can be ascribed to variable degree of source enrichment caused by asthenospheric plume activity. Sublithospheric-mantle upwelling was favoured by extensional tectonics related to lithospheric attenuation. The extensional tectonic history possibly also influenced the geochemical records in successive flows. The rising mantle plume was associated with active continental rifting which caused further chemical diversity of the Deccan magmas. Intensive quantitative geochemical studies must be extended to the interior continental areas to develop a unified model for Deccan basalt petrogenesis

In spite of their extensive spatial distribution and stupendous volume, the continental flood basalts ($CFBs$) maintain a more or less uniform composition over a span of last thousand million years. Like the alkalic magmatism, the flood basalt volcanism had to await global cratonisation and rigidation of the crust by mid-proterozoic. Growth of extensive continental crust was coupled with formation of a thick variably fertile sub continental lithosphere (SCL). This coupling does not necessarily imply that SCL has been the immediate source of $CFBs$ but the lithosphere possibly influenced the ultimate composition on the flood basalts. Although in details, particularly in terms of petrographic characters and trace element chemistry, the $CFBs$ in different volcanic provinces and within individual province may show slight variations, in bulk they may be designated as iron-rich relatively evolved tholeiitic basalts. Some of the CFB volcanism occurred prior to continental fragmentation, some closely accompanied drifting, like the Deccan volcanism, where as others are of post-drifting age.

Low Mg value, moderate iron-enrichment and trace element characteristics strongly indicate that Deccan basalts represent derivative rather than primary magma. Recognition of Deccan basalt and other $CFBs$ as derivative magmas obviously has given rise to speculations regarding the prospective primary magma and source material. Absence of xenoliths in the basalts constrains the speculation and at the same time reiterates that Deccan basalts (and other $CFBs$) are not primary in nature. One would also expect that during the long time span from pre-fragmentation to post-fragmentation of super continent as mentioned above, the sub continental lithosphere has increasingly become heterogenous (through repeated subduction and under plating), but the $CFBs$ maintained a uniformity at least in terms of major element and qualitative mineralogy. This would hint that sub continental lithosphere (SCL) was not the possible source of $CFBs$. The $CFBs$ are buffered by the continental crust from the underlying upper lithosphere which is likely to be variably depleted due to the separation of the crust itself. On the other hand the $CFBs$ are in general uniformly enriched in terms of incompatible trace elements. $CFBs$ show an apparent similarity with the oceanic tholeiites viz-ocean island basalt (OIB) and mid-oceanic ridge basalt (MORB) in terms of major element chemistry An alluring aspect of comparison has been the low potash contents of some less evolved $CFBs$ which rank as low K tholeiites comparable to MORB. Low Mg value ($Mg/Mg + Fe$) for $CFBs$ in general indicate that the source cannot be normal $MORB$. Distinction between $CFBs$ (including Deccan basalt) and normal $MORB$ is very clear from a comparison of their trace element contents. On the other hand $CFBs$ are closely similar to OIB in this respect. Not only the Deccan basalt but all other $CFBs$ are never so depleted as $N - MORB$ to which the CFBs have often been related as discussed later. On the other hand trace element data suggest that $CFBs$ are linked to P-MORB Indeed there may be some mineralogical similarity of $CFBs$ with $MORB$ both having olivine on the liquidus surface but $Sr - Nd$ isotopic composition of $CFBs$, and Deccan basalts in particular are remarkably different from that of $MORB$. Further, some CFB provinces as the Deccan volcanic province, record local manifestation of alkaline magmatism, which cannot readily be related to $MORB$.

Overlapping isotopic compositions for intimately associated tholeiite and alkali basalt in parts of the Deccan volcanic province suggest a closely similar or identical source for both and imply that magma diversification was not due to diversity in source materials (Mahoney *et al.* 1985). High $P_2O_5 - TiO_2(HPT)$ and low $P_2O_2 - TiO_5(LPT)$ basalts in individual flood basalt province have often been related to different mantle source composition (Wilson, 1989). Deccan basalts however do not reflect bimodality in P_2O_5 and TiO_2 distribution. When plotted against MgO, both TiO_2 and P_2O_5 show smooth variation, though high values correspond to alkaline magmas (Krishnamurthy and Udas, 1981). Variations of P_2O_5 and $Ti0_2$ are sympathetic with Al_2O_3,KiO and Na_2O relating them to progressive fractionation or partial melting. To account for relatively high $Ti0_2$ content of Deccan basalt (ranging from 1 to about 4 percent), OIB appears to be a suitable parent than $MORB$ as discussed later, there are several geochemical features to indicate OIB to be the primary magma for Deccan basalts. Therefore, the generation of Deccan basalt from $N - MORB$ modified by contamination and fractionation appears to be more hypothetical relative to a more convincing, simplistic all Fe as $Fe_2O_3 +$ All Fe as FeO model of OIB primary magma with limited contamination. This dominantly OIB type magma composition can be related by a binary mixing process in $MORB$ (Wilson, 1989). It is significant that in terms of (La/Sm) N value, average Deccan basalt and other available data on Deccan basalt lies on the mixing curve between $P - MORB$ and $N - MORB$ and is closer to the former. Thus Deccan basalt in general is genetically affiliated more to $P - MORB$ source rather than to depleted $N - MORB$.

Deccan volcanism and CFB magmatism in general, can be related to extensional tectonics which involve lithospheric stretching and deep mantle upwelling. Under extensional stress regime, the continental crust suffers brittle extension whereas the mantle suffers ductile stretching and thinning. Lithospheric attenuation perturbs the deeper part of the mantle viz. the asthenosphere, and triggers plume upwelling. The extensional stress with increasing intensity may progressively produce fissure swarms, crustal rifting and miniature spreading centre (as in a back-arc region) with increasing asthenospheric control on generated magma. CFB magmatism is usually considered to be limited to fissuring and brittle deformation of the crust but there is no rigid boundary between fissure development and continental rifting. In the Satpura deccan basalt area stress regime cause magmatism at least locally, transitional from fissure eruption-towards continental rift zone type magmatism with variable alkalinity. It is also suggested that Deccan lavas are central eruptions rather than fissure eruptions. The central edifice possibly developed over a mantle plume or hot spot (Beane *et al.* 1986 in Biswas, 1988).

Petro genetic modeling for the Satpura basalts is constrained by relative proportions of different litho components. Although these can be determined in the older eroded CFB provinces, in the Satpura, many variants like acid, felsic flows, and picrites might be concealed under thick lava pile on the flanks of the Satpura. But, acidic and alkalic rock besides picrites are particularly prevalent in the south and south eastern area of the Satpura. Again, recent works have shown the greater abundance of alkaline flows than previously known (Mahoney *et al.* 1985; De, 1988). In the absence of adequate information on the relative abundance of various litho components in the Satpura, any petrogenetic model is likely to be inconclusive.

Deccan basalt: an old controversy on primary magma

Washington (1922) first attempted to establish the uniformity in chemical character of the Deccan basalt. However, this observation on tholeiitic character of Deccan basalt in bulk was closely followed by the report of analcitised nepheline basalt from Kutch among the samples collected by Washington (Bowen 1927). Continued study also revealed local rock-diversity within an overall uniformity (Mathur *et at.* 1926; Chatteree, 1932 ; Crookshank 1936 ; West, 1958 ; Sukheswala and Poldervaart, 1958 ; Chatterjee. 1964). Many of these parallel investigations highlighted the occurrences of alkaline rocks nourished the idea of a parent alkali olivine basalt magma for at least a part of the Deccan volcanic province or of a primitive primary magma which fractionated to contrasting magma types (Chatterjee, 1961). Vemban (1946) and West (1958) conceived of a primitive (high magnesian?) basaltic magma which on fractionation produced contrasting types including picrites. In some of the later models on Deccan basalt petrogenesis, extensive fractionation of mafic phases from a picritic / high magnesian basalt has been invoked (Cox,1980; Sen, 1988). It has not been clarified, however, whether the parent primitive magma was inherently tholeiitic or alkali basaltic in composition. Some of the above picrites are nepheline normative (Bose, 1972) and may have followed an alkaline line of descent. Further, the picrite basalts described by Krishnamurthy and Cox 1977) are remarkably enriched in incompatible elements as is not (expected of truly primitive normal picrite. Debate on this "petrogenetic paradox" for Deccan basalts has raged for long. Recent studies have modified the dimensions of this problem and have emphasized more on source identification. There is a growing tendency among Deccan petrologists to relate magma types to similar / common source but they are less concerned about mechanism of magma genesis and physical separation of the different magma types viz. tholeiite, alkali basalt and picrite. These rocks often occur in intimate association.

Bose (1980 a, b) and Biswas (1988) drew attention to unique tectonic setting and related alkaline magmatism in this volcanic province and emphasized on the role of plume activity in this region. The genetic relation of Deccan basalts of the Satpura to plume activity is an acceptable hypothesis in view of the present coastal configuration, network of rift systems, and mantle up doming in the Pachmarhi (Figure 1) in association with high thermal anomaly (Crookshank, 1936). Study on mantle convection pattern under the Indian shield has amply confirmed the mantle upwelling model of Bose ($1980\ a, b$). Chemographic approach strongly indicate 'withinplate' magmatism, however, a weak affinity towards ocean island environment should not be overlooked (Bose,$1980\ b$). Intraplate volcanism, whether oceanic or continental is essentially controlled by deep mantle upwelling. It may be mentioned that the association of both tholeiite and alkali basalt (and their respective derivatives) as observed in the Deccan volcanic province, is a characteristic feature of plume controlled ocean island magmatism. Continental rift zone (CRZ) magmatism which is controlled by plume activity is also characterized by varying degrees of alkalinity. It is not unlikely therefore, that tholeiite alkali basalt and fertile picrite of Satpura are all deeply related to a plume source (Bose, $1980\ a$; Sen, 1994). Extensional tectonics, also prevailing in the continental interior very likely aided passive rise of the mantle (Bose, $1980\ b$) and favored fissure type to rift controlled type of volcanism.

The Deccan trap flows in the pachmarhi

At in the history of the Satpuras, the compression, which had continued from the early Triassic, died out, and an age characterised by tension in the earth's crust set in. As a result, faults and fissures parallel to the lines of least resistance became everywhere common. These were rapidly filled with dolerite intrusions, some, of which actually reached the surface, and poured out over the surrounding country side. The Gondwana basin seems to have been an area of special weakness, for the intrusions in it are far larger and more numerous than those in the neighbouring crystallines.

The extruded magma no doubt mounted through fissures extending down into some deep-seated and wide-spread reservoir. Such channels have not always connected directly with the surface, for I have seen at least two instances in which the immediate source of the extrusive rocks has been a large sill-like intrusion. In one of these cases the basal flow in the country around Belkheri is the result, and in the other a higher flow. The lower flows are separated by quite considerable intervals of time, for rocks are sometimes found on their surface in which plant and animal remains are entombed. This could not have occurred if there had not been quiescent intervals after flows, during which a flora and fauna could become established. The comparative rarity of these fossilliferous beds among the basalts in the Satpura region is perhaps an indication that the flows in this tract followed one another more rapidly than they did elsewhere. This would be comprehensible if, as I think likely, the Gondwana valleys were the main channels through which the Mahadeva basalts have flowed; for it is clear that, where a number of flows are extruded, each of which spreads a varying distance from its source, an area remote from that source will tend to receive fewer flows than one which is near it, and consequently there will be shorter Intertrappean intervals in tracts such as the Satpura region, which are believed to be adjacent to the main source of the flows. (Medlicott H B , 1873 , Crookshank H. 1936)

The tensile stress must have continued right up to the end of the Deccan trap period of the Central Indian for the faulting then became very pronounced. Probably at this time the Narbada rift valley was formed, and the various scarps which are now the chief topographical features on the southern flanks of the Satpura with the disappearance of the tensile stress, igneous activity waned rapidly. Aqueous emanations from the crystallising magmas may have continued a little longer, for chalcedony and zeolites characteristic of the Trap flows have been found along faults of late Deccan trap age. After the Deccan trap era, compression probably reappeared and possibly continued to the present day. As a result the rocks in the vicinity of the Narbada rift valley have been crushed, and a hill range has arisen along its border sufficiently high to divert some of the

Largei Rivers arising in the Mahadeva range from their original courses. This compression has had little effect on the main mass of the Gondwana sediments further to the south. Since the last of the Trap flows the Satpura rocks have been exposed continuously to denudation. As a result, a thickness of at least $500\ meter$ of rock has been planned off the surrounding country, and carried off to the sea, or deposited in the Narbada rift valley.

The flows with their associated intertrappean beds (Figure 1) occur in three main areas: (1) the high rising southern scarpment (2) the Trap flows covered by Tawa and Sonbhadra river region including the southern part and Chandkia-Golandoh fault : (3) in many places along the boundary of Pachmarhi.

There are also a number of minor basalt outliers, (Figure 2), (Figure 3), (Figure 4) which owe their preservation either to faulting, or to their superior hardness.These outliers generally though always occur on the tops of the higher hills throughout the Pachmarhi. The preservation of the Trap on the high plateaus of this part of India is due to its tough nature in comparison with the underlying rocks and to its being the youngest of the great rock formations of this region. It's unexpected occurrence in the lowland is probably due to post-trappean faulting. The mountains were under trap flow and trap formation found over the top (Figure 5).

Extention of trap flow

In the region south of the Pachmarhi gradual rises and falls in the level of the base of the flows amounting in some cases to $100\ meter$ in a kilometer were repeatedly observed. These do not seem to have been due to faults, which are scarce in this region, nor to folds, of which there is no definite evidence either in the Traps themselves or in the underlying rocks. They are supposed, therefore, to reflect the pre-trappean topography of this area.

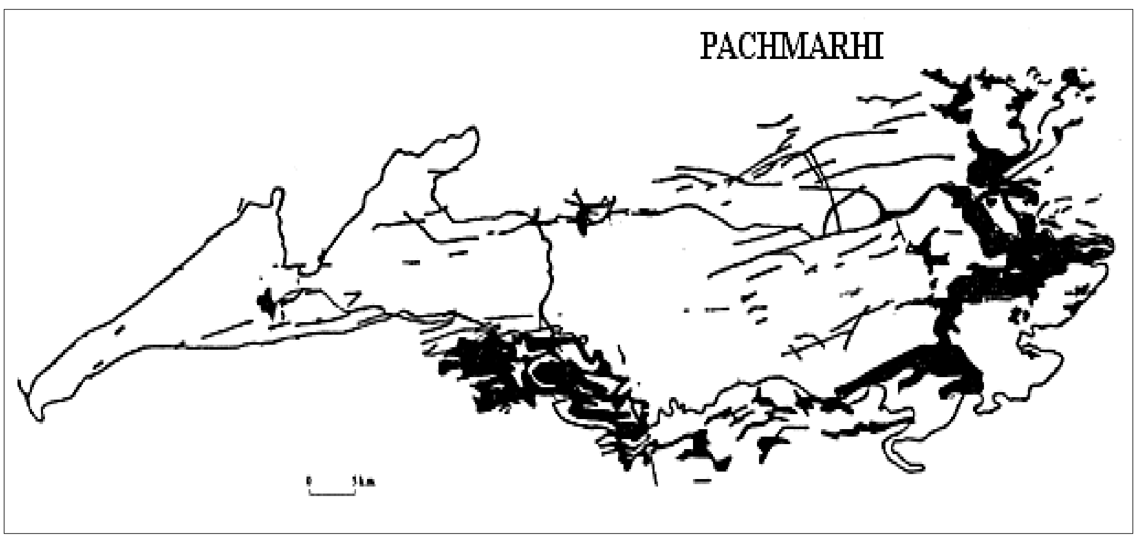

Figure 1. Deccan Trap Flows in the Pachmarhi,

Figure 2. The outlier, on the top of the Pachmarhi hills.

Figure 3. Basalt outlier which owe its preservation to their superior hardness

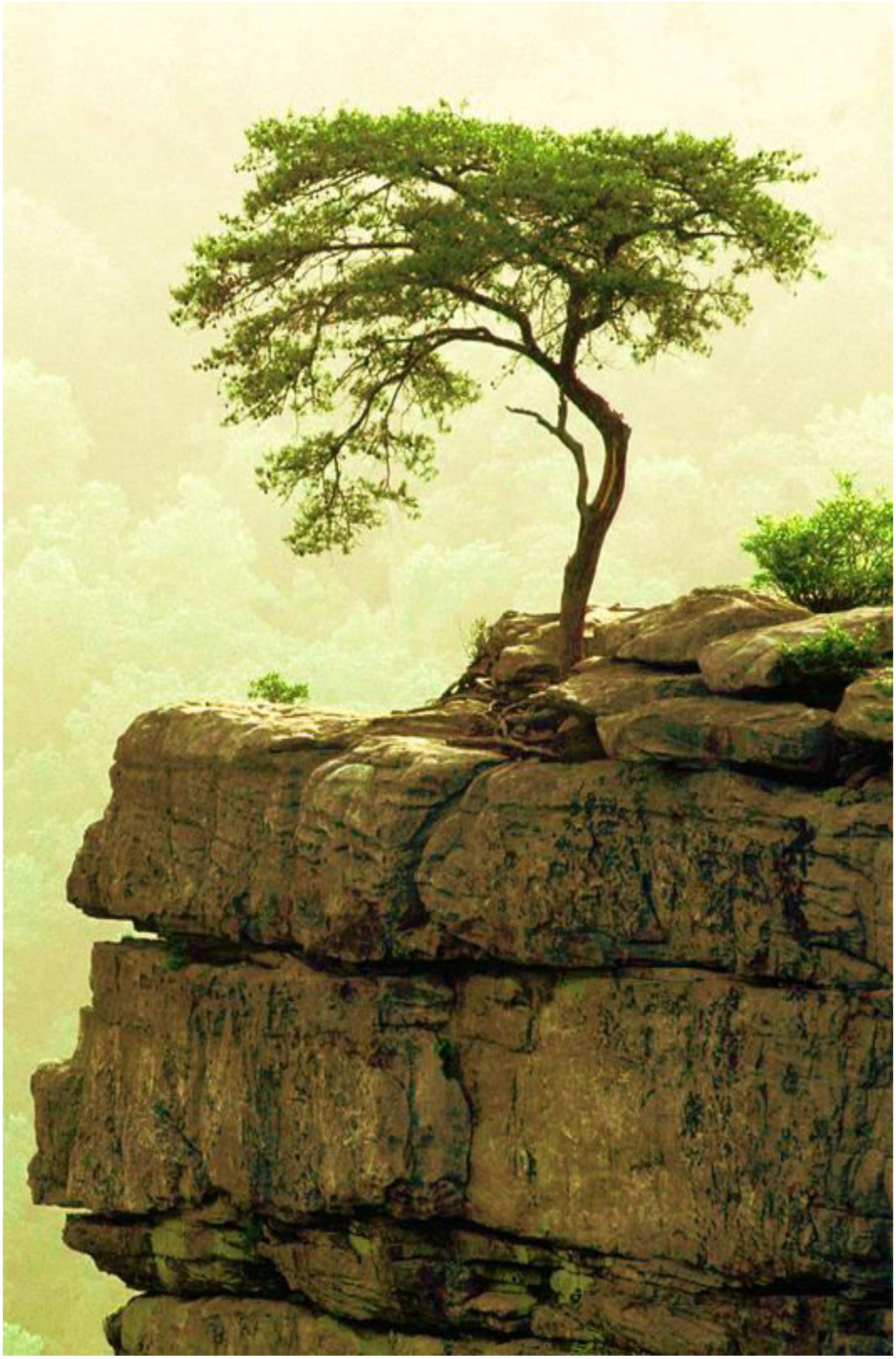

Figure 4. The Trap outliers on the top of the Tamia Mountain

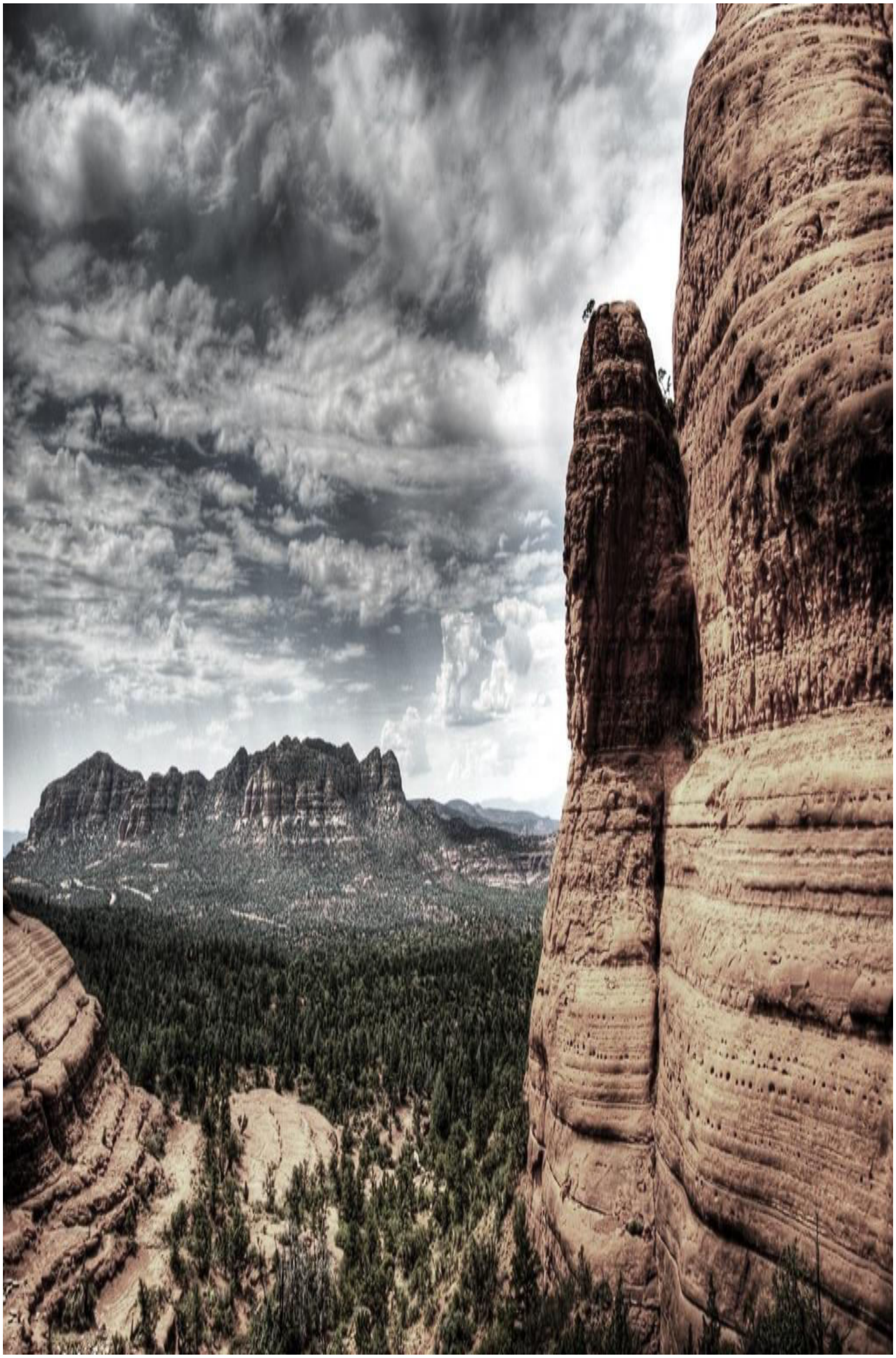

Figure 5. Trap Occurrence in the lowland due to post trappen faulting

Elsewhere the boundary of the Trap flows is a sinuous line roughly following the contours of the hills (Figure 6) If this be followed carefully and far enough, it will be found that there are in certain places sudden changes of level, which may be anything up to $50\ meter$.In most cases these are due to faults.

Wherever the base of the flows can be seen for a considerable distance, its aspect is markedly regular. This is very striking in the cliffs of The Sonbhadra gorge (Figure 7) and Pathalkot gorge, (Figure 8) and further west towards Tamia. (Figure 9) Here the Trap flows form a 'cliff on the top of soft Mahadeva sand stone sand the junction can be seen for kilometer by an observer standing on the edge of the gorge. Except for a few small faults, and a complete break in the cliffs at one place, the junction seems to be absolutely horizontal.

Instances in which the base of the flows depart notably from the horizontal, were observed near Sua Am ($22°18'$: $78°30'$) and near Morghat. In the former region there is a sudden dip in the base of the Trap about $350\ meter$ in depth, which is probably an infilling of a pre-trappean valley in the underlying Bijori rocks. A similar thing on a small scale was observed near Morghat, where the flows have worn very thin, and the resulting boundary with the Gondwanas is very complex. This is due to the fact that the surface of the underlying rocks was not in this area a smooth plain, when it was first covered by the Trap, but jutted up in a series of small parallel strike ridges (Figure 10). These are now exposed, while the hollows between are filled with basalt

Figure 6. The boundary of the Trap flows is a sinuous line roughly following the contours of the hills.

Figure 7. The Trap flows at the Sonbhadra River bed

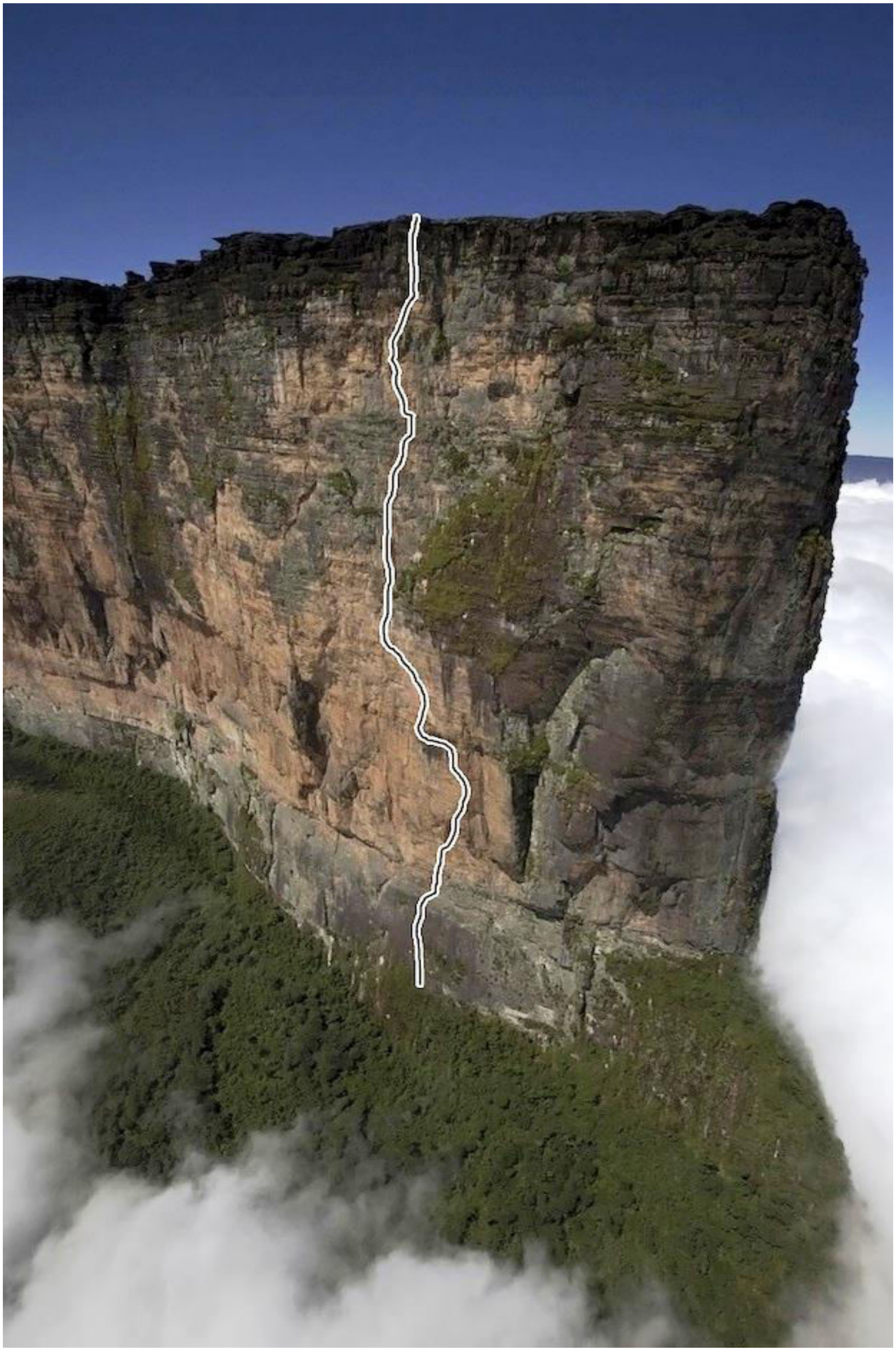

Figure 8. Very striking gorge of Patalkot and Trap Flow on the Top.

Figure 9. North of Tamia, the trap flows form a Chandimai cliff on the top of soft Mahadeva sandstone

Figure 10. Here it is seen that a flow is not uniform in vertical section, but underlying rocks were series of parallel stricke fidges and valleys.

Variations in single basalt flow.

Over most of the region covered by the flows, no very clear idea of the individual units of which the basalt plateaus are composed variations can be obtained on account of the weathered basalt flow state of their surfaces. To get a clear idea of an unweathered flow, it is necessary to go to any of the areas where cliffs of basalt cover the Gondwana rocks. Here it will be seen that a flow is not uniform in vertical section.

Figure 11. Columnar jointing at Dolerite-Basalt junction.

The base consists of a thin porous layer of earthy basalt. This passes rapidly into the main body of the flow, consisting of a great thickness of hard basalt. In typical cases this part shows vertical columnar jointing (Figure 11) but this may not be very conspicuous and is often not noticeable. Above the main mass is a thick layer of tough basalt characterized by its conchoidal fracture (Figure 12). The upper part of this is normally increasingly porous, and passes with little or no break into the porous base of the next flow. The relative thickness of the various parts varies greatly, but the upper part is always thicker than the basal part, and thinner than the central.

After this, the next most frequent type of flow is a medium-grained massive black basalt in which olivine can sometimes be distinguished this sort weathers into much larger boulders, and may be distinguished from the preceding variety by the absence of the glomero-porphyritic aggregates of augite.

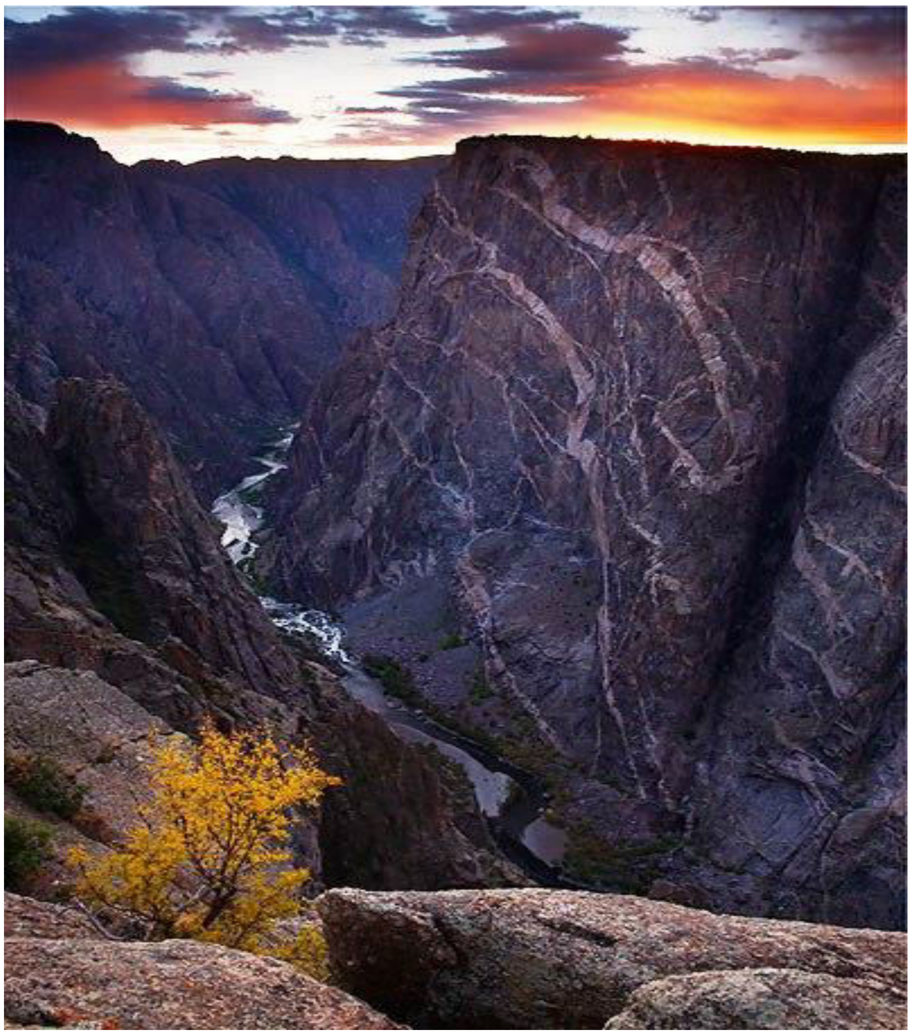

Figure 12. Above the main mass, it is a thick layer of tough basalt characterized by its conchoidal fracture

Number of the flows

The number of flows noted in the area north of the Tamia-Harrai main road does not exceed seven. South of this the Trap hills rise to a great height, and I have no idea how many flows are there represented. In the west, the Trap is thinner than in the east, and three or four flows at most are present. Extrapolating the experimental observations by Presnall *et al.* (1979) and Takahasi and Kushiro (1983).Sen (1988) inferred that primary Deccan tholeiite was generated at $10 - 15\,kb$ from a heterogenous but $N - MORB$ type mantle source. Sen (1988) has also considered the possibility of generation of Deccan basalt magma through fractionation of olivine and aluminous pyroxene from more primitive high magnesian basalt. This high magnesian basalt ($MgO > 10$ percent, the immediate parent to the Deccan basalt, could be generated by mantle melting at high pressure (Sen, 1988).

The models for Deccan basalt petro genesis as given in Sen (1988) are based on major element compositions of the source, and its partial melt products which are again involved in fractionation contamination. However, no data are presented on the nature of trace element partition during the two-stage processes or during direct derivation of the basalt magma from $N - MORB$ mantle (Sen, 1989). On the other hand the very existence of extensive $N - MORB$ type sub continental mantle has been questioned (Thompson *et al.* 1984). There is considerable mineralogical difference between MORB and the Deccan basalt. Deccan basalts frequently carry pigeonite and occasionally orthopyroxene as opposed to their complete absence.

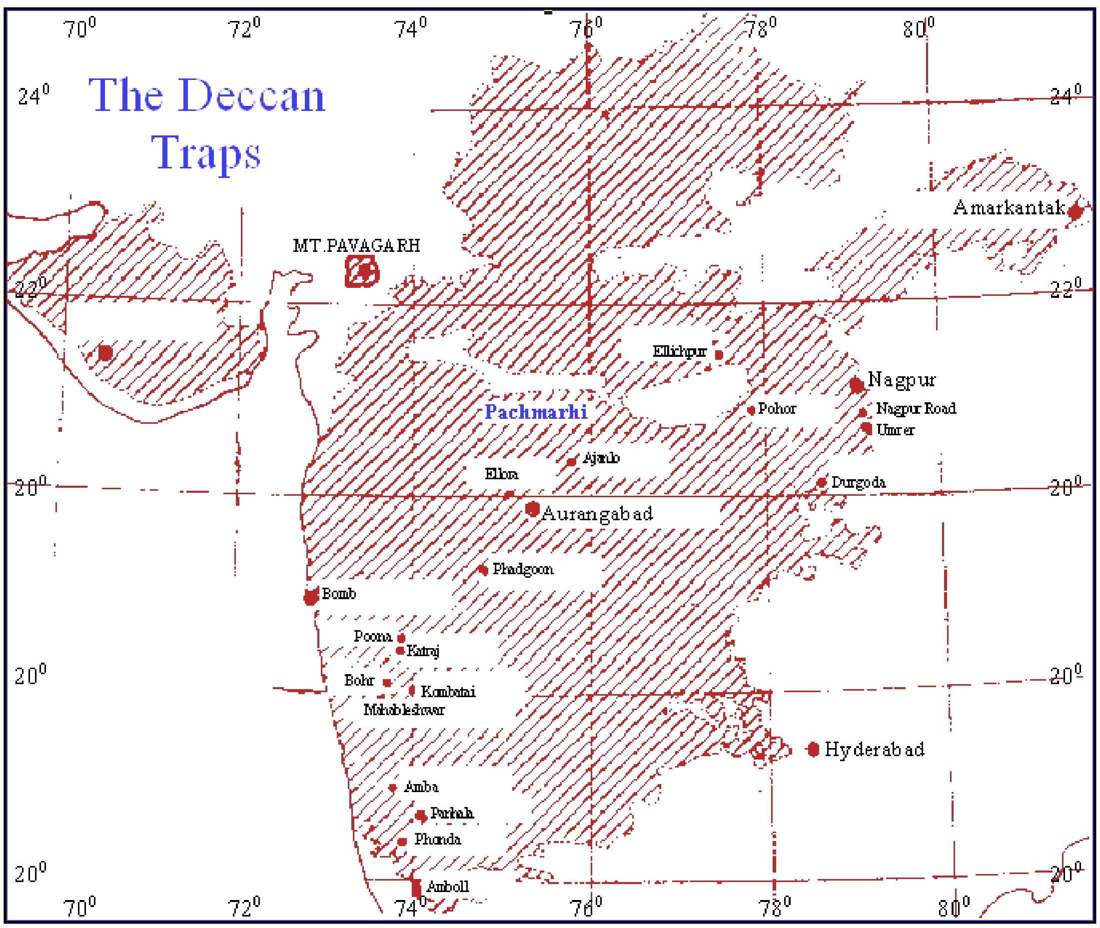

Figure 13 . The areas covered by the Deccan basalt

Oib primary magma and mantle activity

Diapiric upwelling of asthenospheric plume and its passage through lithosphere also initiates partial melting. Mixing of the partial melts (both from the plume and lithosphere) produces a compositional array as constrained by several workers. However, mixing may be influenced by several factors including rate of ascent, nature of flow, and thirming of the lithosphere itself as controlled by prevailing extensional stress regime. The role of lithospheric contamination in developing alkali magma is uncertain. Indeed the alkalic and tholeiitic rocks occurring in close association studied by Mahoney *et al.* (1985) have $Sr-Nd$ isotopic composition overlapping with that of lithosphere and their ultimate chemical evolution may be related to varying depths of fractionation. But lithospheric alkali enrichment cannot produce ultrapotassic magma for which phlogopite bearing mantle source has to be invoked (Mahoney *et al.* 1985). Such an atypical mantle composition again has to be related to mantle metasomatism associated with initiation of rifting (Bailey, 1985). Therefore the Deccan volcanic province is not wholly fissure controlled flood basalt province but bears signature of continental rift zone magmatism.

Deccan volcanism and extensional tectonics

Deccan volcanism is considered to be a manifestation of extensional tectonic regime (Figure 13) developed within the continental lithospheric plate (Bose, 1980 a, b; Chandrasekharam, 1985). Stress condition initiated formation of fissure swarms and with increasing intensity, developed miniature continental rifting. Nair and Talwani (1982) noted continental rupturing along the Narbada valley followed by dyke injection and volcanic outpourings. At the initial stage of extensional tectonics, passive rifting could have triggered mantle perturbation. Lithospheric attenuation was then confined to rift zones only. Gradual asthenospheric upwelling extended the region of uplift and lithospheric thinning beyond the rift. Thus doming, rifting and magmatism occurred in a much wider scale. Picritic lavas and alkaline magmatism in the Northera Satpura areas are possible signatures of crustal thinning and rifting, developed in various magnitudes.

In the prevalent classification of modern rifts as active and passive (Wilson, 1989), the former is related directly to asthenospheric upwelling (plume) which breaks through the lithosphere and is reflected in the tectonic sequence: doming-volcanism-rifting. Passive rifting is primarily related to lithospheric stretching and thinning which triggers asthenospheric diapirism and develops the sequence: rifting fissuring doming - volcanism (Wilson, 1989). Increasing data from different volcanic fields indicate that the two classes of rifting may be interrelated so that one may grade to the other (Wilson, 1989). Lithospheric stretching related to the migration of the Indian plate (Bose, 1973) might have played a dominant role in the initial stage to develop fissure swarms. Within-plate, hot spot track also might have weakened the lithosphere favouring subsequent rift formation (Morgan, 1983).

In consequence to lithospheric stretching and decompression asthenospheric upwelling could be induced. In case of intense extensional stress, a sequence of brittle extension of the continental crust, ductile stretching of lithosphere and asthenospheric upwelling has been documented during Proterozoic volcanism in Satpura (Bose, 1994). Extensive stretching viz oceanisation of continent can cause the generation of $MORB$ type magma (Mckenzie and Bickle, 1988; Bose, 1994) but this situation was not developed for the major part of the Deccan volcanic province but .

. However, continental rifting and lithospheric stretching along the Narbada valley margin of Satpura volcanic province could have generated high magnesian lavas akin to $MORB$ (Bose, 1980 b). Again this $MORB$ type magma on the flank of the spreading ridge and manifested along the southern coast may be modified $MORB$ which could follow an alkaline line of descent, offering clues to some alkaline and sub alkaline rock association in the Satpura

In the Satpura Deccan volcanic province particularly in continental interior, the interrelation between doming, rifting and volcanism has not been clearly established. Crustal extension, domal uplift and volcanism were roughly synchronous in Satpuran region (Sen, 1994). In the northwestern part of the province, doming, rifting and alkaline magmatism have been related to plume activity (Bose, 1980 a, b). Plug like subvolcanic bodies appear to cluster around the mantle plume and they do not occur well within the continental extension of the province (Biswas,1988). The Satpura region characterized by gravity highs and heat flow anomaly (Biswas,1988) possibly represents mantle upwelling resulting in updoming, volcanism and rifting (Figure 13). The passive mantle up rise in subdued scale might have been the dominant controlling mechanism for magma genesis in the continental interior. It is conjectured that there possibly developed a number of two dimensional mantle upwelling (mantle ball stars) which developed incipient rifts on their crests. (Bose.1980 b).

Crustal thinning is inherent in some models of Deccan basalt petrogenesis. In the model proposed by Cox (1980), dense picritic magmas pond near the base of the crust and they can reach the surface in regions of crustal thinning through brittle extension. The geochemical behaviour of flow succession in the Pachmari can be interpreted in terms of crustal extension. At the early stage of volcanism through extensional tectonism, the magma has greater chance of crustal contamination as it makes way to the surface. This signature of crustal contamination is recorded in basal flows in lava sequence as observed in the Chandkia Golandoh flows of western Pachmarhi. As the fissures are widened, magmas ascend rapidly in great volume and as the channel walls are protected by magma coating, less contaminated magma can come up to the surface. Crustal thinning further reduces the chance of contamination. Thus uncontaminated or least contaminated flows closer to primary composition well up as represented by Satpura flows. Subsequent magma ascending to the surface possibly suffers both contamination and fractionation and is thus more evolved than the uncontaminated near primary magma. This model of course is an alternative to an intermagma mixing model (Cox and Hawke worth,1985).

The above account highlights some gaps in our knowledge on Deccan basalt petrogenesis, which need intensive studies. Presently the leading problems are identification of source characteristics and role of mantle dynamics related to Deccan volcanism in different parts of the province. Solutions available for other CFB provinces may not be readily applicable for the Deccan volcanic province which has some unique characteristics. Model studies carried out for Northern Satpura must be extended to the interior continental areas as well, to have a comprehensive picture of Deccan volcanism.

Reference

Al'mukhamedov. A.I. and Zolotukhin, V.V. (1988). Geochemistry of lowpotassic basalts from Siberia and DeccanTraps. Mem. Geol. Soc. India. No. 10, pp. 341-351.

Baily, D.K. (1985). Fluids, melts, flowage and styles of eruption in alkaline ultramafic magmatism. Trans. Roy. Soc-South Africa, v. 88, pp. 449-457.

Beane. J.E. and Hooper. P.R. (1988). A note on the picrite oasalts of the Western Ghats. Deccan Traps. India. Mem.Geol. Soc. India. No. 10, pp. 135-144.

Biswas, S.K. (1988). Structure of the western continental margin of India and related igneous activity.

Mem. Geol. Soc. India. No. 10, pp. 371-390.
Bose, M.K. (1972). Deccanbasalts. Lithos, v. 5,pp. 177-147.
Bose, M.K. (1973a). Petrology and geochemistry of the igneous complex of Mount Girnar, Gujarat, India. Contrib. Min. Petr. v. 39, pp. 247-266.
Bose, M.K. (1973b). Deccan volcanism and the Indian plate. Sem. Geodyn. Him-Region, Hyderabad, pp. \ 173-181.
Bose, M.K. (1980a). Alkaline magmatism in the Deccan volcanic province. Jour. Geol. Soc. India, v. 21, pp. 317-329.
Bose. M.K. (1980b). Magmatically defined tectonic framework of the Deccan volcanic province. Neus. Jb. Minor. Mil. Hf. v. 8, pp. 373-384.
Bose. M.K. (1994). Sedimentation pattern and tectonic evolution of the Proterozoic Singhbhum basin in the eastern Indian shield. Tectonophysics, v. 231, pp. 325-346.
Bowen, N.L. (1927). Analcite rocks from Deccan Traps, India. Jour. Wash Acad. Sci, v. 17, pp. 57-59.
Chandrashekharam, D. (1985). Structure and evolution of the western continental margin of India deducedfrom gravity, seismic, geomagnetic and geochronological studies. Phys. Earth. Planetary Interiors, v. 41, pp. 186-198.
Chandrashekharam, D. (1964). Petrochemistry of the lavas of Pavagad hill, Gujarat. Advan. Front. Geol. Geoplys,pp. 385-397.
Chatterjee, S.K. (1932). Igneous rocks from west Gir forest. Kathiwrar. Jour. Geol, v. 40,pp. 154-163.
Cox, K.G. (1980). A model for flood basalt volcanism. Jour. Petrol, v. 21, pp. 629-650.
Cox, K.G. (1988). Inaugural address In: Subbarao, K.V.(cd) Deccan Flood Basalts. Mem. Geol. Soc. India. No. 10, pp. 15-22.
Cox, KG. and Hawkesworth, C.J. (1985). Geochemical stratigraphy of the Deccan Trap at Mahabaleshwar, Western Ghats, India, with implications for open systemmagma process. Jour. Petrol, v. 26, pp. 355-377.
Crawford. A.R. (1983). Mantle convection pattern under India: Relevance to Loner Crater. Girnar node and Peri-ndian volcanism. Jour. Geol. Soc. India, v. 24, pp. 97-100.
Crookshank, H. (1936). Geology of the northern slopes of Satpura between SherandMorandrivers. Mem. Geol. Surv. India, v. 66, pp. 173-381.
De, A. (1981), Late Mesozoic-Lower Tertiary magma types of Kutch and Saurashtra. Mem. Geol. Soc. India, v. 3, pp. 327-339.
De, A. (1994). Fractionation trends of the Deccan Trap magmas in parts of western Gujarat and Satpuras. \ In: Subbarao, KV. (ed.) Volcanism, Wilev Eastern Ltd. pp. 277-294.
Hooper, P.R. (1994). Sources of continental flood basalts :Lithospheric component. In: Subbarao, K.V. (ed.) Volcanism, Wiley Eastern Ltd, pp. 29-54.
Krishnamurthy, P. and Cox, KG. (1977). Picrite basalts and related lavas from the Deccan Traps of western India. Contrib. Min. Petr, v. 62, pp. 53-75.
Krishnamurthy, P., Pande, P.. Gopalan, K. and Macdougall, J.D. (1988). Upper mantle xenoliths in alkali basalts related to Deccan Trap volcanism. Geol. Soc. Ind. Mem. 10, pp. 53-68.
Mahoney, J., Machougall, J.D., Lugmair, G.E.W., Murali. A.V, Sankar Das, M. and Gopalan, K. (1982). Origin of Deccan Trap flows at Mahabaleswar, inferred from Nd and Sr isotopic and chemical evidence. Earth Planet. Sci. Lett, v. 60, pp. 47-60.
Mahoney, J.J., Macdougall, J.D., Lugmair, G.W., Gopalan, K. and Krishnamurthy, P. (1985). Origin of contemporaneous tholeiitic and K-rich alkalic lavas: a case study from northern Deccan Plateau, India. Earth Planet. Sci. Lett. v. 72, pp. 39-53.
Middlemost, E.A.K. (1985). Magmatism and magmatic rocks. Longman, 266 pp.
McKenzie, D. and Bickle, M.J. (1988). The volume and composition of melt generated by extension of lithosphere. Jour. Petrol, v. 29, pp. 625-679.
Miyashiro, A. (1978). Nature of alkalic volcanic rock series. Contrib. Miner, Petrol, v. 66,pp. 91-104.
Morgan, W.J. (1983). Hotspot tracks and early rifting of theAtlantic. Tectonophysics, v. 94,pp. 123-139.
Nairn, B.R. and Talwani, M. (1982). Structural framework and evolutionary history of the continental Margin.