# CHAPTER - VI

# TECTONIC SETTING

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A huge batholithic body like that of Bundelkhand massif in the heart of peninsular India is very significant with regard to its evolution from tectonic point of view. The Son-Narmada lineament which lies in close proximity of the massif (Fig. 2 ) may have some important bearing on the evolution of the massif. There has not been any significant study on the tectonic evolution of the massif. In this chapter, an attempt has been made to elucidate the tectonic environment of emplacement of the granitoids employing geochemical signatures.

Several attempts have been made to discriminate granitoids of different tectonic setting based mainly on some critical trace elements since major element concentrations of granitoids from different tectonic environments exhibit gross similarities. Besides, the major elements being very mobile, any inference on the mode of emplacement of magma based on their concentrations may not be reliable. Majority of tectonic discriminant diagrams are drawn empirically from the study of the geochemical characteristics of rocks of known tectonic setting and later these diagrams are extrapolated to understand the geodynamic environment of other rocks (Pearce *et al.*, 1984; Harris *et al.* , 1986).

Pearce *et al.* (1984) have empirically drawn tectonic discrimination boundaries using some trace elements and then correlated them with geochemical modelling to have a theoretical relevance. Four main groups have been identified by Pearce *et al.* (1984): (i) ocean ridge granite (ORG), associated with ophiolite or belongs to oceanic crust (ii) volcanic arc granite (VAG)-fromed from subduction of oceanic crust (iii) within -plate granite (WPG)-anorogenic granite and (iv) collision granite (COLG)-evolved as a consequence of continent-continent, arc-continent or arc-arc collision. Samples of different types of granitoid were plotted on a number of tectonic discrimination diagrams (Fig. 51 ) of Pearce *et al.* (1984) based on Rb vs. Y+Nb, Yb+Ta and Nb vs. Y. Majority of the samples plot in the volcanic arc granite (VAG) field on these diagrams. On $SiO_2$ vs. Rb diagram (Fig. 52 ), the granitoids plot in the fields of volcanic arc granite (VAG) and syn-collision granite (syn- COLG). The hornblende granitoids are confined to VAG field, whereas the biotite granitoids and the leucogranitoids occupy both the fields of VAG and syn- COLG.

Harris *et al.* (1986), based on the systematic geochemical study of intermediate and acid intrusives, have recognised four groups of tectonic environment: (i) pre-collision volcanic arc granitoids (VAG), termed Group I intrusions, mostly derived from mantle, modified by subduction (ii) syn-collision peraluminous intrusions, referred to as Group II intrusions (iii) late or post-collision calc-alkaline intrusions, termed Group III intrusions and (iv) post-collision within- plate intrusions or Group IV intrusions. Group II granites which are syn-collision peraluminous granites contain restricted high range of $SiO_2$ and are generally enriched in Rb and depleted in HREE, Y, Zr and Hf. On $SiO_2$ vs. Rb/Zr diagram (Fig. 52 ), which is an effective discriminant diagram separating volcanic arc granite and Group III granite from Group II granite, the Bundelkhand granitoids plot in the combined field of VAG + Group III granites.

Multi-element normalised diagrams are very useful to discriminate granitoids of different tectonic setting. Such diagrams have been

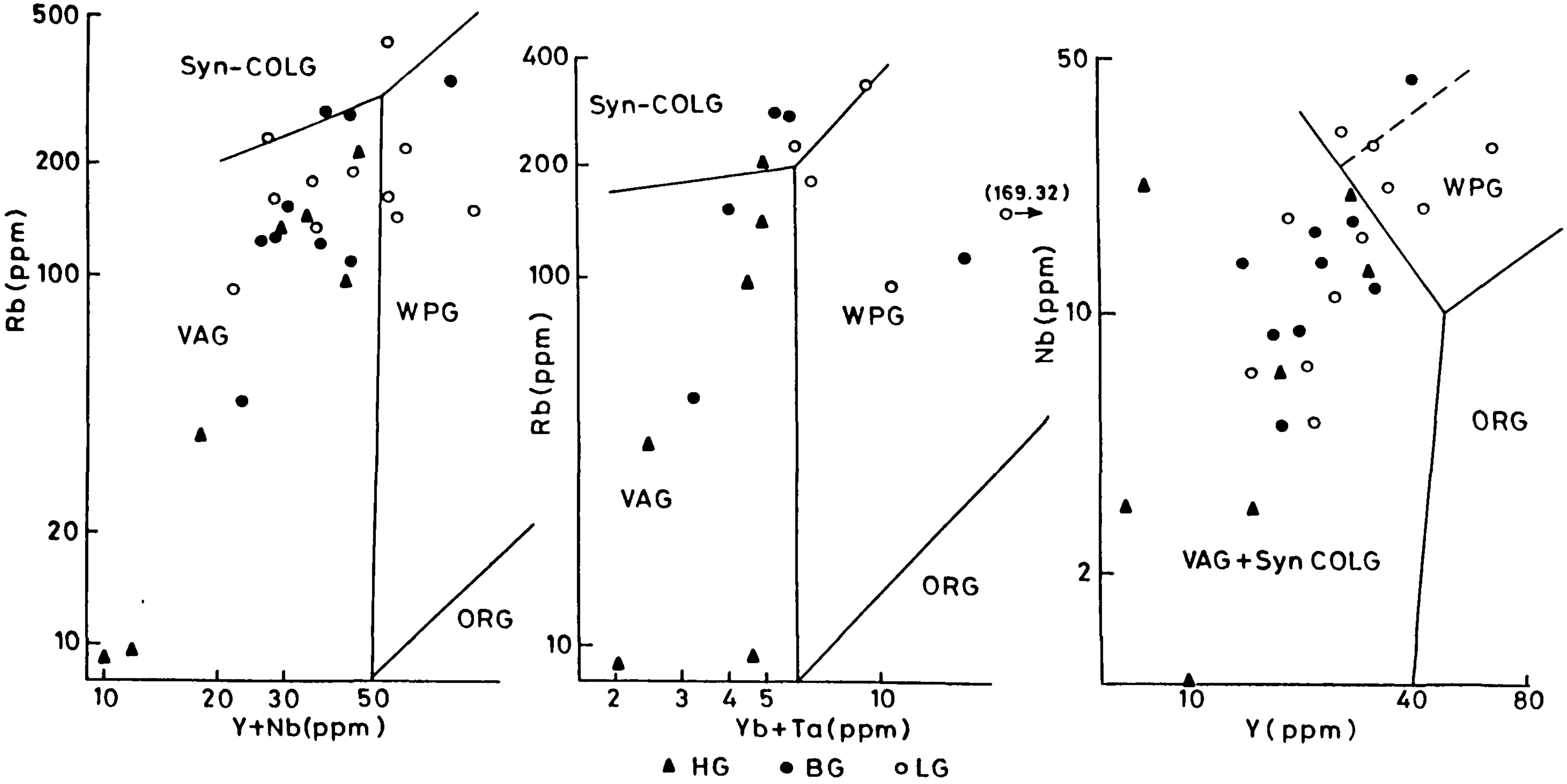


**Fig. 51 :** Rb vs. Y + Nb and Yb + Ta, and Nb vs. Y tectonic discriminant digram Fields. VAG volcanic arc granite, Syn-COLG syn-collision granite, WPG within-plate granite, ORG ocean ridge granite (after Pearce et al , 1984) Symbols : HG hornblende granitoid, BG biotite granitoid, LG leucogranitoid

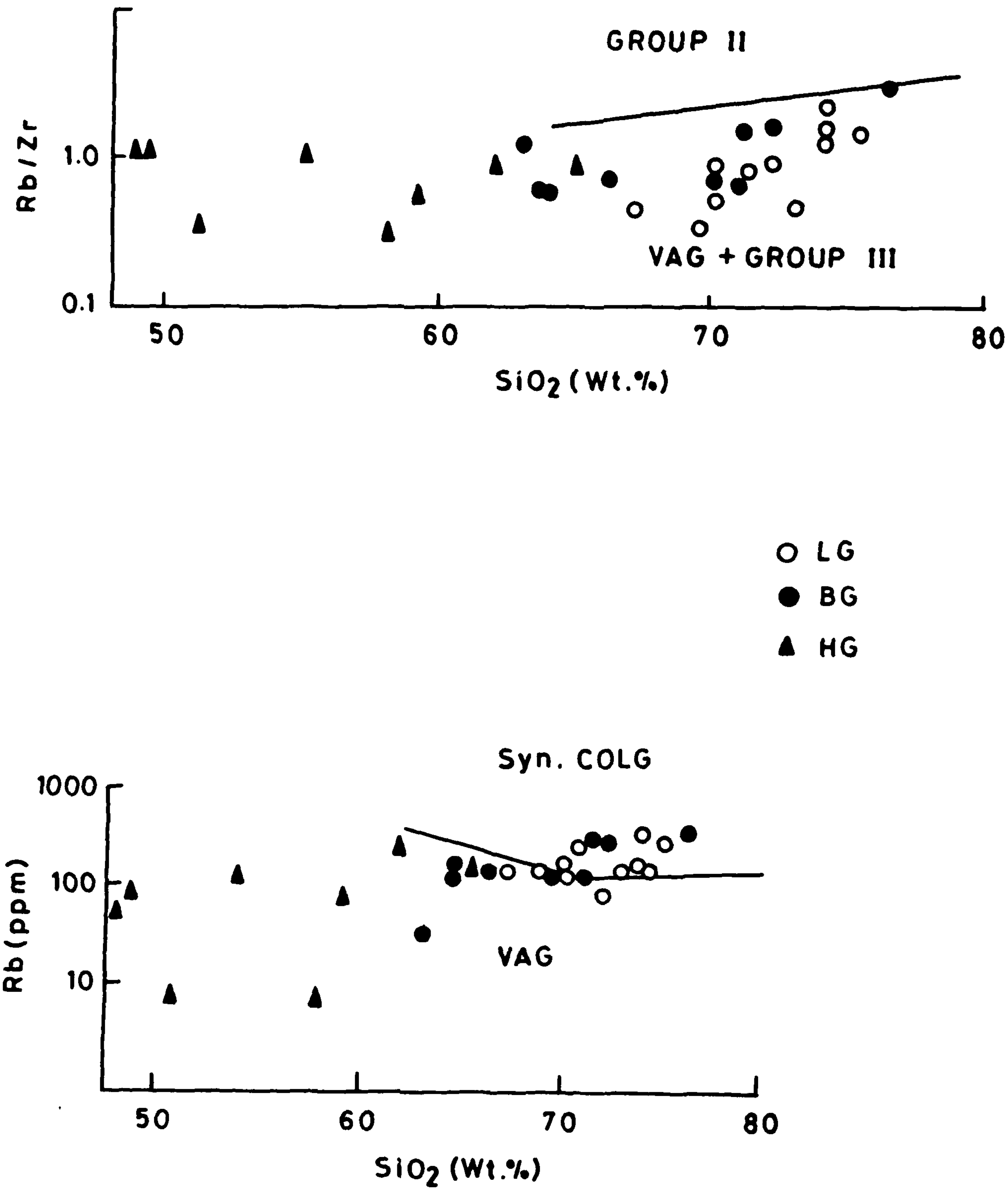


Fig. 52 : Rb/Zr vs. $SiO_2$ (Harris et al., 1986) and Rb vs. $SiO_2$ plots (Pearce et al., 1984) for Bundelkhand granitoids. Fields : VAG volcanic arc granite, Group II syn-orogenic granites, Group III post-tectonic granites, Syn-COLG syn-collision granite. Symbols : as in Fig. 51.

constructed following the scheme of Pearce *et al.* (1984); the ordering of the elements in the diagram is broadly in accordance with their relative incompatibility during mid-oceanic-ridge basalt genesis. The samples have been normalised to a hypothetical ocean ridge granite (ORG) composition (Pearce *et al.*, 1984). The Bundelkhand granitoid series have similar patterns of volcanic arc granite marked by enrichment of $K_2O$, Rb, Ba, and Th relative to Ta, Nb, Hf, Zr with significant low values of Y and Yb (Fig. 53). The normalised patterns of the granitoids of Bundelkhand massif closely correspond to those produced by volcanic arc granitoids; however, some of the biotite granitoids and the younger leucogranitoids exhibit similarity with collision-related granitoids (Fig. 53, inset). A low value of Y and Yb compared to the normalising values is a significant feature of the patterns. These characteristics, coupled with the selective enrichment of Ce and Sm relative to Hf and Y, depletion of Y and Yb and pronounced high Nb and minor Hf and Zr troughs indicate a volcanic arc affinity of the Bundelkhand granitoids.The volcanic arc tectonic setting of the granitoids is also evident from the ORG normalised geochemical patterns ; the patterns correspond to those of a volcanic arc (Fig. 54, inset) as observed by Harris *et al.* (1986).

**Arc Maturity**

Studies of igneous rocks in modern continental margin orogenic belts have revealed a temporal as well as spatial geochemical zonation. If the Bundelkhand batholith represents a volcanic arc magmatism, the arc may exhibit maturity with respect to time and space in relation to subduction margin. With a view to understand and ascertain such trends, studies have been undertaken to determine the variation in the chemistry of the granitoids at intervals across the collision boundary.

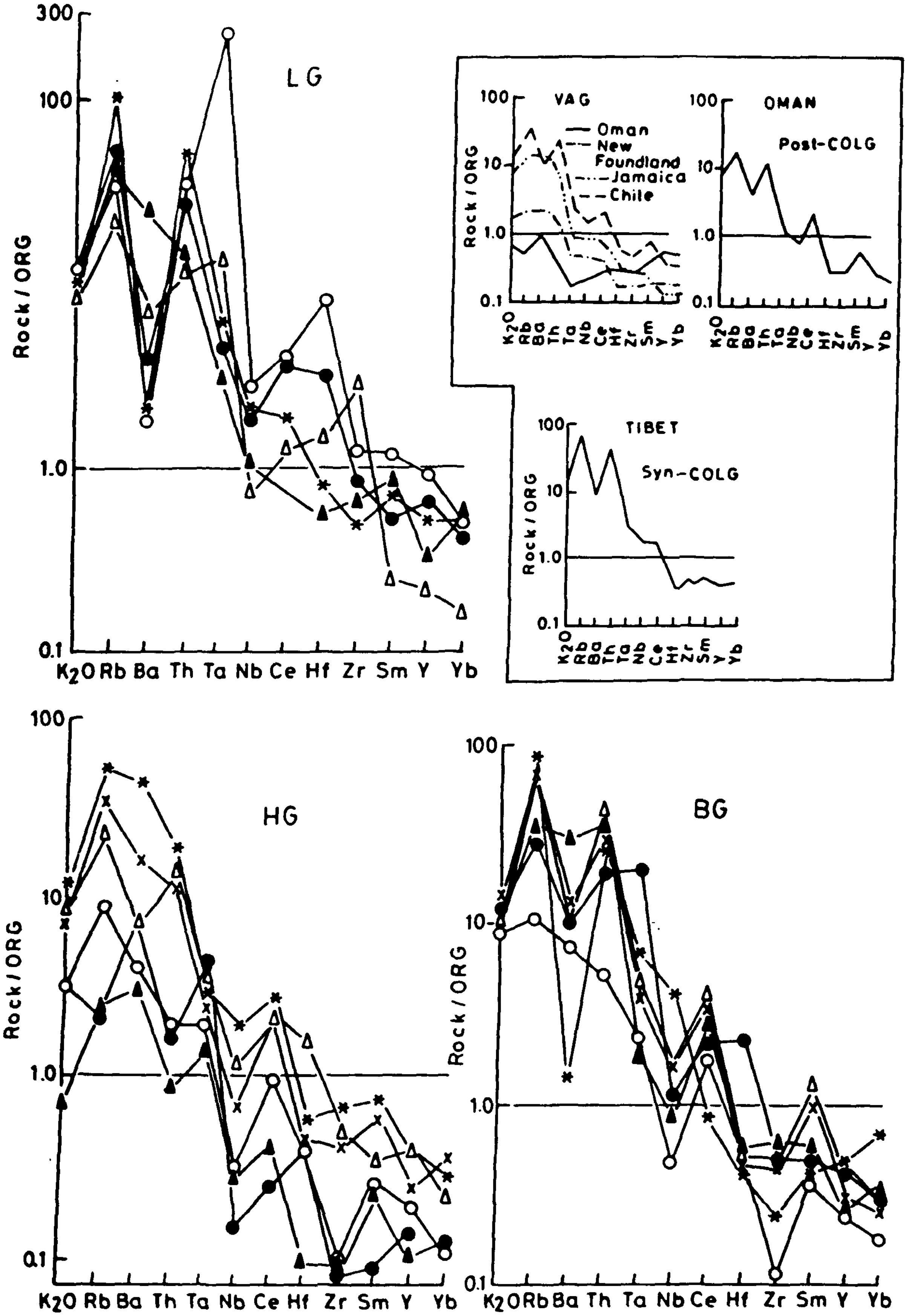


**Fig. 53** : Ocean ridge granite (ORG) normalised multi-elements spidergram for Bundelkhand granitoids. Inset from Pearce et al. (1984). Symbols : as in Fig. 51.

Brown *et al.* (1984) have made provisonal comparisons of different subduction-related suites and utilized some trace element abundances and ratios, which are less affected by fractionation, to distinguish plutonic rocks from different arc environments. They have distinguished three types of granitoid bearing arcs: (i) primitive island and continental arcs, mainly dominated by calcic metaluminous granitoids (ii) normal continental arcs with abundance of calc-alkaline metaluminous to peraluminous suites and (iii) mature continental arcs which are alkali-calcic and peraluminous, often associated with two-mica granitoids.

Several approaches have been undertaken to envisage the geochemical arc maturity trends. The calc-alkali index, defined by $CaO/(Na_2O+K_2O)$, is an useful parameter to discriminate calc-alkaline (compressional) field from alkali-calcic (extensional) field and has widely been used to identify tectonic environments (Christainsen and Lipman, 1972; Brown, 1979; Petro *et al.*, 1979). The granitoids of the Bundelkhand massif on calc-alkali ratio vs. $SiO_2$ diagram show a progressive change in composition from calc-alkaline to alkali-calcic from southern to northern part of the massif (Fig. 55). Rocks of southern region are predominantly calc-alkaline, whereas those of the northern region are dominantly alkali-calcic. This change in composition from calc-alkali to alkali-calcic is compatible with increase in arc maturity (Brown, 1982).

Brown *et al.* (1984) have proposed a primordial mantle (PM) normalised (Wood, 1979) trace element spidergram to illustrate the trends with increasing arc maturity. The major trends with increasing arc maturity for a number of elements have been shown by arrows at the

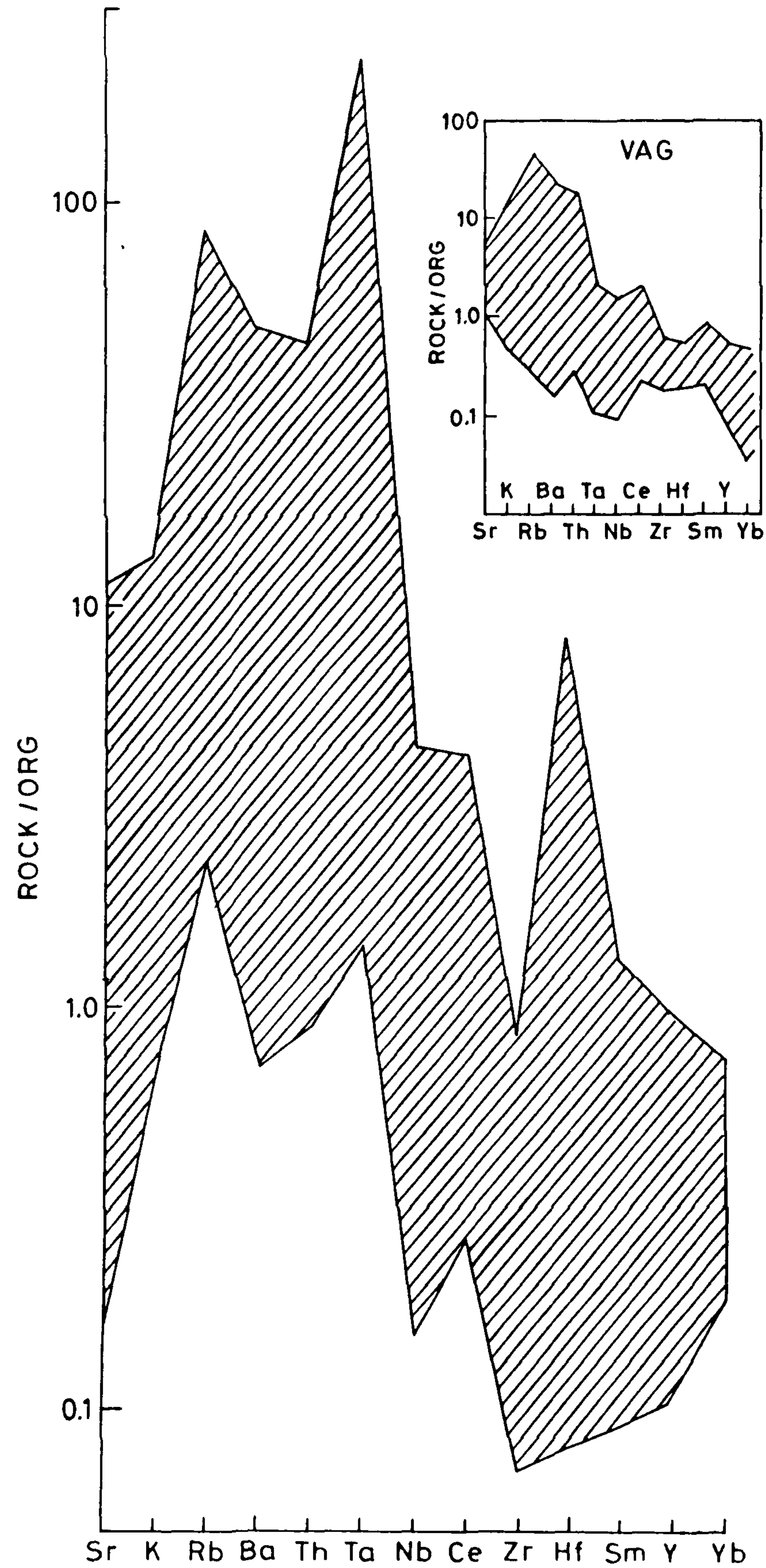


**Fig. 54** : Ocean ridge granite (ORG) normalised multi-elements patterns of Bundelkhand granitoids. Inset showing the patterns of volcanic arc granitoids (VAG) is from Harris et al. (1986).

top in Fig. 56 B. Granitoid samples from different parts of the massif have been plotted on this diagram (Fig. 56 A) to determine possible arc maturity trends. Increasing maturity trends from southern part to northern part of the massif can be deciphered from the diagram.

It is observed that the granitoids from northern region which are predominantly alkali-calcic show marked depletion in Ba, Sr, P and Ti compared with those from southern region which are predominantly calc-alkaline in nature (Fig. 56). Such trends are compatible with increasing arc maturity (Brown *et al.*, 1984). The depletion in Ba, Sr, P and Ti in the mature arc may arise from greater degree of fractionation of plagioclase, alkali-feldspar and Fe-Ti oxide, whereas the general increase in incompatible elements, like Rb, Th, U and Nb in mature arc may be due to increasing assimilation-fractional crystallization (AFC), since the magma, as the arc matures, traverse through increasingly thick crustal rocks (Brown *et al.*, 1984). Rb, Th, and U which are strongly lithophile elements show an enrichment trend from southern region to northern part of the Bundelkhand massif (Fig. 56). Such enrichment trends, for a subduction related environment, have been ascribed to addition from subduction zone component and sometimes to continental crustal components (Saunders *et al.*, 1980; Saunders and Tarney, 1982).

On Rb/Zr vs. Nb and Y diagram (Fig. 57), the granitoids follow the trend of increasing arc maturity. The increase in Nb at a given Rb/Zr may be due to contribution from within-plate mantle sources (Brown *et al.*, 1984). They opine that as the arc matures and magma generation migrates from active subduction zone to rear regions of subduction, the influence of a within-plate mantle source becomes evident. Subduction related source variation trends are depicted from Th vs. Ta diagram

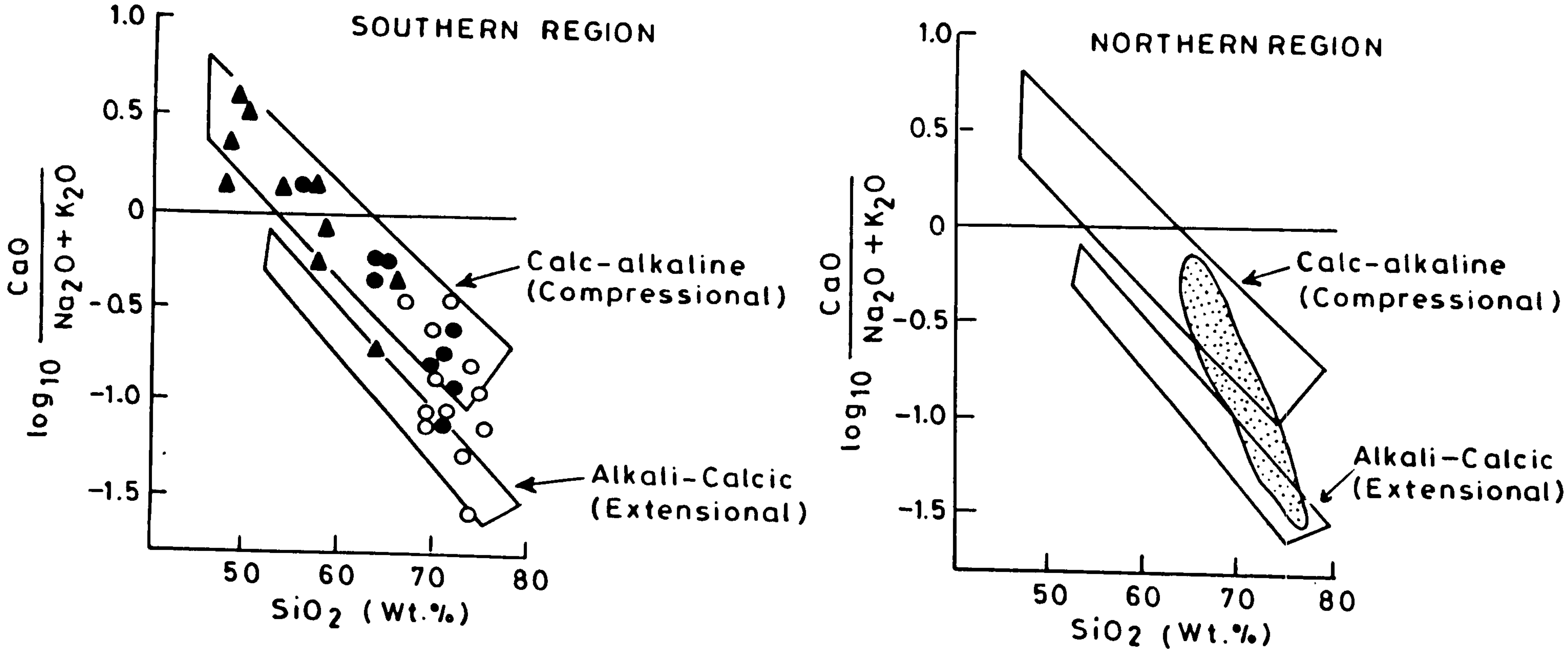


**Fig. 55 :** Calc-alkali ratio vs. $SiO_2$ plots of Brown (1982). Symbols : as in Fig. 51, steppled area is the field of granitoid samples from northern area.

(Fig. 57). Both these elements are enriched in within-plate magma and maintains a roughly equal proportion. Subduction process selectively enriches Th, and not Ta, whereas assimilation-fractional crystallization (AFC) enriches both Ta and Th and depending on the rate of assimilation/ crystallization, a trend in between the within-plate source variation and subduction-related source variation is formed (Brown *et al.*, 1984). The Bundelkhand granitoids show a selective enrichment of Th in comparison to Ta and follow the trend of subduction related source variation (trend 2) in Fig. 57.

**Discussion**

The Ben Ghnema batholith which is calc-alkaline in nature has been inferred to be subduction related (Rogers, et al. 1978). Similarly, the predominantly calc-alkaline nature of the Bundelkhand granitoids may indicate its subduction related environment. On the bases of field and geochemical features akin to volcanic arc granitoids, it is proposed that the granitoids of Bundelkhand massif represent an arc-related tectonic setting associated with subduction of an oceanic plate under a continental plate (Fig. 58). The continental crust thickened in the northward portion of the massif where the basement gneisses are exposed, whereas in the southern portion of the massif, predominantly oceanic environment existed. The gravity high along the southern margin of the massif (Verma and Banerjee, 1992) which possibly indicates obduction of ophiolite (Sharma and Rahman, 1993) and the mafic-ultramafic suites in the southern margin of the massif further support the existence of an ocean and consequent subduction of the ocean from the soùthern portion of the massif.

It is observed that the massif exhibits temporal as well as spatial maturity trends. Rocks far away from the southern margin of the massif

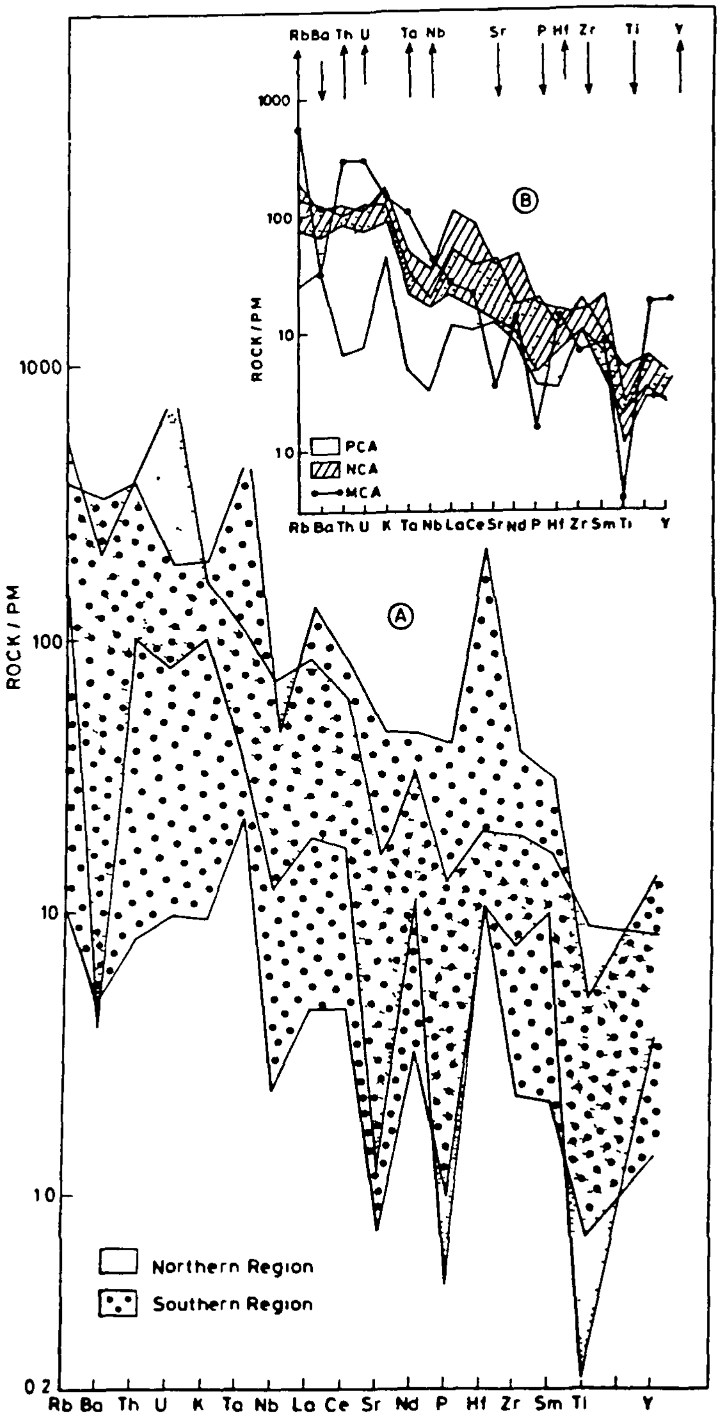


Fig. 56 (A) Primordial mantle (PM) normalised multi-element patterns for Bundelkhand granitoids from southern and northern region (B) Inset from Brown et al (1984) Arrows indicate major arc maturity trends PCA primitive island and continental arc, NCA normal continental arc, MCA mature continental arc

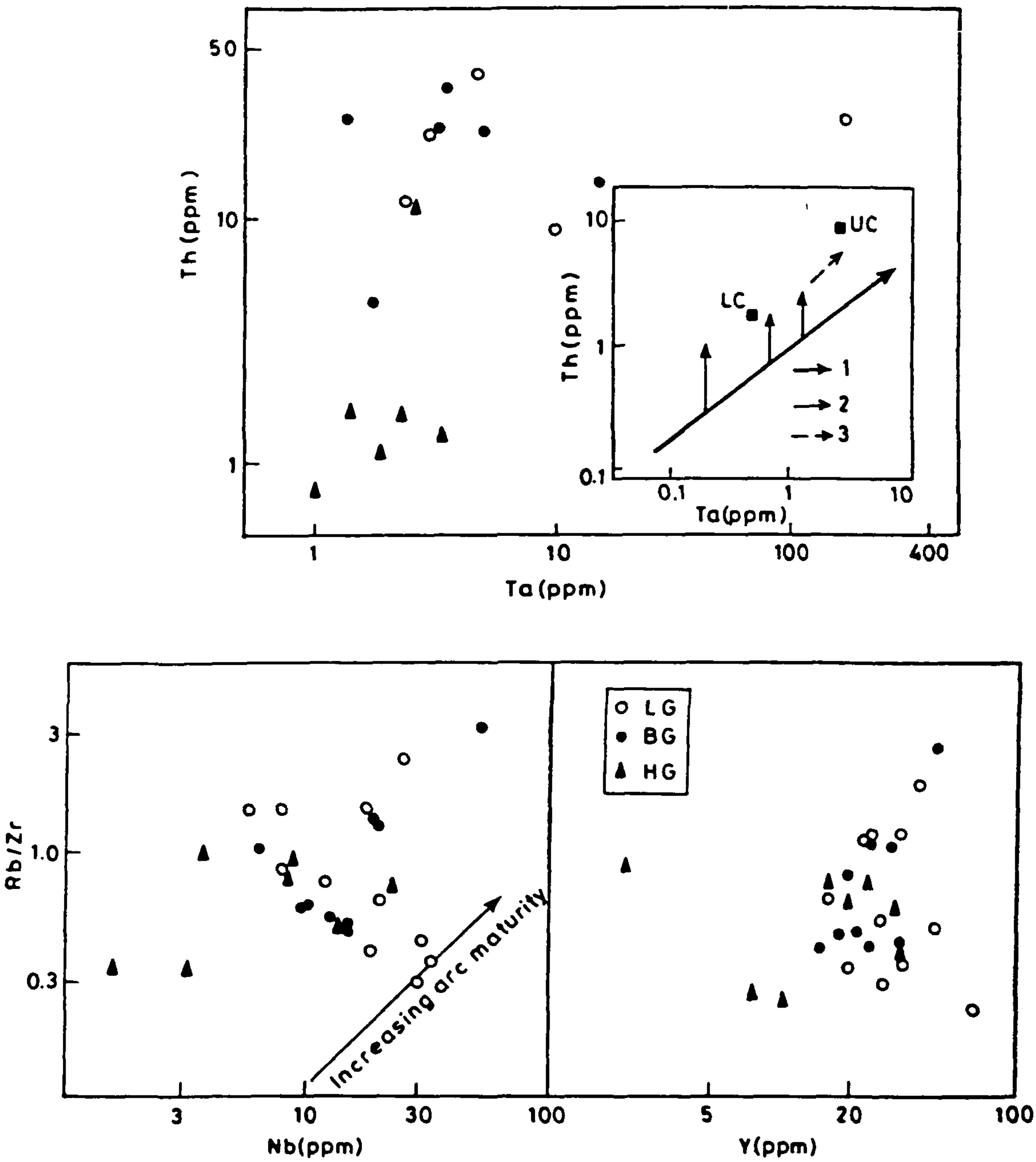


Fig. 57 : Plots of Rb/Zr vs. Nb and Y and Ta vs. Th for Bundelkhand granitoids. Increasing arc maturity trends from Brown et al. (1984). Trends: 1 within-plate source variation. 2 subduction related source variation. 3 assimilation-fractional crystallization (Thorpe et al., 1984). Lower crust (LC) and upper crust (UC) data from Taylor and Mc Lennan (1981). Symbols . as in Fig. 51.

are more silicic than their counterparts in the southern region. A change in composition from calc-alkaline to alkali-calcic with the increasing distance from the southern margin of the massif can be deciphered from the calc-alkali ratio vs. $SiO_2$ diagram. Such trends can be observed from the Rb/Zr vs. Nb and Y diagrams. Primordial mantle normalised spidergram also corroborates the maturity trends. Many orogenic belts exhibit close association, in terms of space and time, of calc-alkaline and alkaline magmas (Bonin, 1990).

There seems to be a spatial change in tectonic style of the emplacement of the Bundelkhand granitoids. The granitoids from the southern region of the massif exhibit predominantly compressional environment, whereas those of the northern region show extensional environment. Extension in a convergent margin is generally associated with either intra-arc rifting or back-arc spreading. To account for the change in tectonic style from compressional (calc-alkaline) to extensional (alkali-calcic), a low angle of subduction can be postulated. It is proposed that an ocean existed in the southern portion of the massif where volcano-sedimentary rocks including banded iron formations were deposited. Subduction and consequent melting of this oceanic plate gave rise to the Bundelkhand complex. Initially the dip of the subduction slab is inferred to be shallow like the one in "ice-floe" tectonics as proposed for the Laramide orogeny (Rodgers, 1987). Later the dip of the subducting slab, as the subduction ceased, steepened and as a result extension took place far away from the southern margin of the massif resulting in the intrusion of alkali-calcic magma.

The apparent lack of features like typical ophiolite, blue schist facies metamorphism and continental margin sedimentary sequence which are generally assoicated with a compressional environment, can

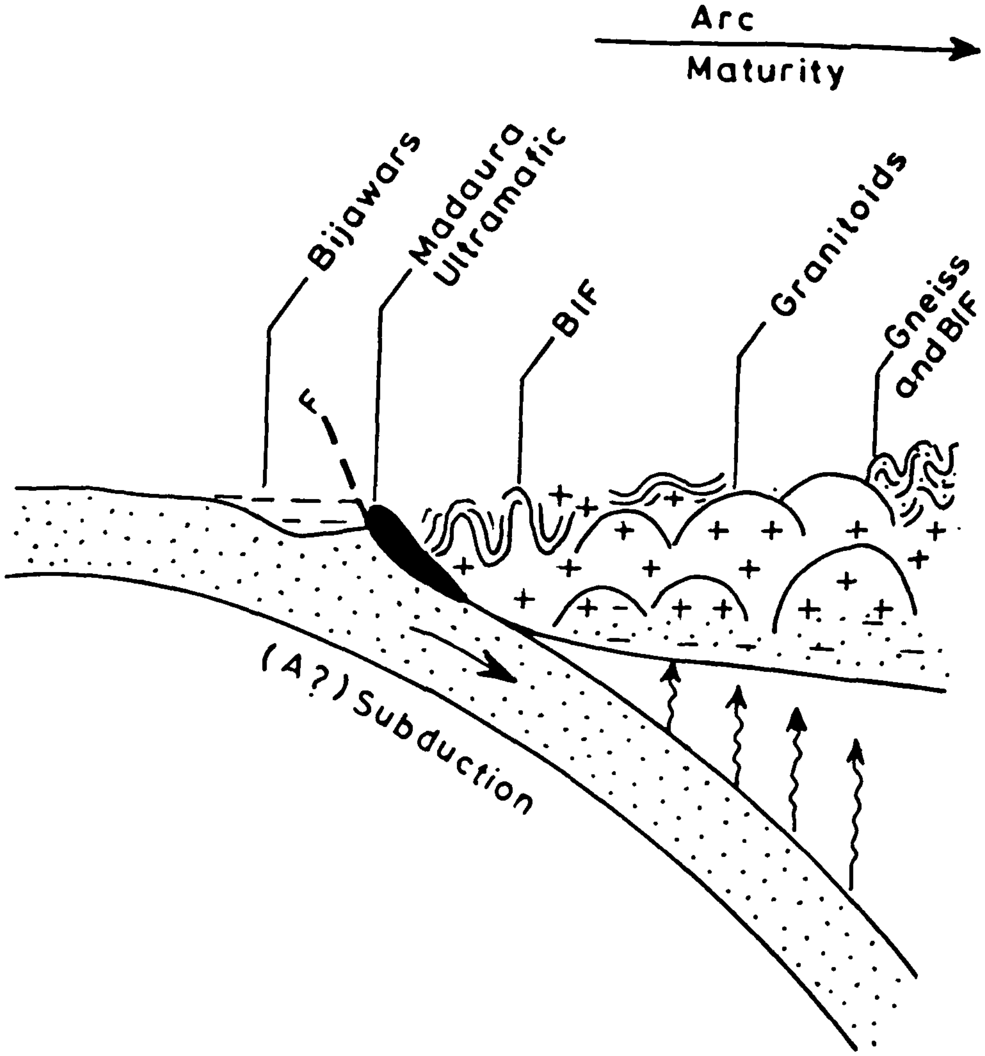


Fig. 58 Plate tectonic cartoon to show the evolution of Bundelkhand massif.

be accounted for by invoking "A-subduction" (Kroner, 1981) in which a subcontinental lithosphere sinks in an ensialic environment. The Proterozoic mafic dyke swarms have been linked with A-subduction where the source of the dykes is thought to be mafic material emplaced into a rheological weak zone in the lithosphere and later the mafic material transforms to eclogite and initiate A-subduction (Tarney, 1992). Such an environment has also been advocated to explain the abundance of dykes near subduction margin (Tarney, 1992). The apparent absence of typical ophiolite, blue schist metamorphic rock and abundance of mafic dykes in the southern margin of the Bundelkhand massif may point to possible A-subduction environment operating during Archean in the southern portion of the massif.