Special Publication of the Palaeontological Society of India, No.2, 2005, pp. 269-278

GEOCHEMICAL CHARACTERISTICS OF THE TATTAPANI COMPLEX, NW LESSER HIMALAYA, INDIA: CONSTRAINTS ON ITS TECTONIC SETTING

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ABSTRACT

Tattapani Complex, the oldest formation of Simla Group, occurs as dismembered thrust-bound packages of basaltic flows intercalated with low-grade metasediments exposed all along the Main Boundary Thrust in the Lesser Himalaya tectogen of Himachal Pradesh. Geochemical composition of the volcanic component of the complex constrains the tectonic setting of eruption. The apparent duality of geochemical signatures, displaying characteristics of both extensional and compressional tectonics, has been interpreted in terms of a back arc setting.

Distinct Pre-Himalayan orogenic regimes in the Himalayan belt are yet to be established. A reappraisal of the geochemical characteristics of Tattapani Complex constrains the tectonic setting in terms of a back arc regime — providing leads to a Precambrian orogeny in the north-western sector of Indian Himalayas.

With the recording of imprints of a Precambrian subduction system in the Shali Basin, and reporting of similar tectonic setting remnants in Pakistan and northwestern India, tectonic evolution of the northern margin of Indian Plate solicits re-interpretation in terms of two divergent – convergent plate interactions rather than the existing model of consecutive failed/partial rifting finally culminating in subduction induced Himalayan orogenesis.

Keywords: Shali Stratigraphy, Basalt Geochemistry, Plate Tectonics.

INTRODUCTION

Basaltic rocks, ranging in age from Proterozoic to Cretaceous, have been reported from different parts of the Himalayas. In light of their unique capability of unmasking the effects of the ongoing Himalayan orogeny (by virtue of geochemical freeze at the time of crystallisation), they offer one of the best insights into the pre-Himalayan geological history of the area.

One of the earliest reported occurrences of basaltic rock from the Himalaya, in its northwestern sector, is the volcanics of Tattapani Complex — first described by McMahon (1882). Being exposed as a more-or-less continuous, thin strip all along the pre-Tertiary parauthochthonous belt from river Ravi upto Sundernagar, it serves as a good basis for regional correlation.

Present day understanding of global tectonics, in terms of 'Supercontinent cycles', necessitates periodic plate reorganisation. The record of the postulated reorganisation in the Himalayas needs to be looked into. Distinct pre-

Himalayan orogenic regimes in the Himalayan belt are yet to be established despite being postulated by Valdiya (1964) and Bhargava (1980). With increased reporting of Precambrian subduction in the northwestern part of the Indian shield (Baig *et al.*, 1988; Sinha-Roy and Mohanty, 1988; Williams *et al.*, 1989; Gyani *et al.*, 2001; Pandit *et al.*, 2001), a reassessment of the pre-Himalayan geology could have possible implications on the Rodinia – Gondwana transition. In this communication, an attempt has been made to geochemically discriminate the tectonic setting of Tattapani Volcanics, based on published database (Chatterjee *et al.*, In press).

GEOLOGICAL SET-UP

The stratigraphy of the Shali Basin, following Chatterjee *et al.,* (in press), is as follows:

Though a brief description of points relevant to this discussion are given, readers are referred to excellent communications by several workers for further details on the geological setting, stratigraphy, petrographic and general geochemical characters of the various sequences exposed in the area (McMohan, 1882; Fuchs, 1968; Patwardhan *et al.*, 1970; Pareek, 1973; Patwardhan and Bhandari, 1974; Srikantia, 1977; Ahmad and Bhat, 1987; Srikantia and Bhargava, 1998).

GEOCHEMICAL CHARACTERISTICS

Geochemical data of Tattapani Complex (Table-1), reported by Chatterjee *et al.* (in press), has been considered for geochemical evaluation of the volcanics. In light of their relative immobility during hydrothermal alteration and metamorphism (Smith and Smith, 1976; Hellman *et al.*, 1977; Myers and Breitkopf,

Table 1: Table showing stratigraphy of Tattapani Complex

AGE	GROUP	FORMATION
Holocene	Alluvium, Terraces, Soil	
Up. Pleistocene to Mid. Miocene	Siwalik Group	
Lr. Miocene to Up. Eocene	Sirmur Group	
Palaeocene		Kakara Formation
~~unconformity~~~~~~~~~~~~~~~~~~~~		
Terminal Proterozoic	Krol Group	
Neoproterozoic	Blaini Group	
	~~ unconformity~~~~~~~	
	Simla Group	Sanjauli
		Choassa
		Kunihar
		Basantpur
		Tattapani Complex
~~unconformity~~~~~~~~~~~~~~~~~~~		
Mesoproterozoic	Shali Group	Makri
		Parnali
		Tattapani
		Sorgharwari
		Khatpul
		Khaira
		Ropri
~~ ~~~unconformity~~~~~~~~~ ~~~~~~~~		
Palaeoproterozoic	Sundernagar Group*	
----------------------------------Base not exposed-		

* Sundernagar Group includes Mandi Complex.

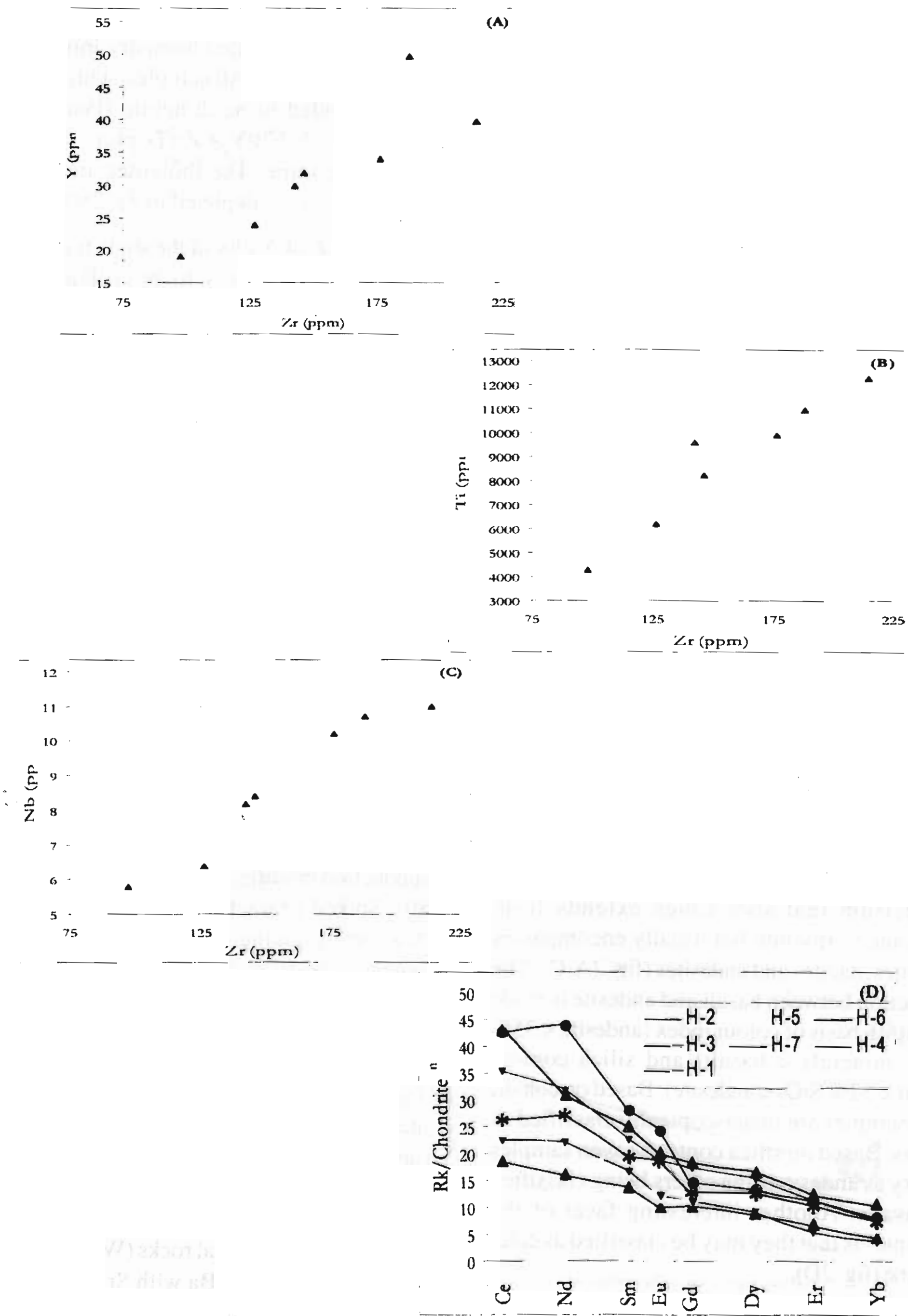

Fig. 1. Comagmatic nature of Tattapani volcanics

1989), the elements Nb, Ce, P, Zr, Ti and Y have been preferred while drawing petrogenetic inferences.

Good correlatibility on Y-Zr , Ti-Zr and Nb-Zr plots (fig. 1 A-C) suggests this suite of rocks to be comagmatic. Considerable scatter of data, despite suggestions of an overall magmatic trend, for the less mobile elements is indicative of the existence of some sort of chemical heterogeneity (subgrouping) within larger chemical groupings and may be partly due to alteration effects. Chondrite-normalized REE pattern (fig.- 1D) is regular and consistent with magmatic processes, implying that the rare earths and their ratios appear to reflect near primary magma characteristics (Arndt and Jenner, 1986). Hence, it may reasonably be concluded that the spectrum of geochemical data being considered, representing the volcanics exposed in the study area, belongs to a common parentage.

Of the sixteen samples analysed in a basaltic matrix, normative mineralogy reveals eight samples have normative quartz in CIPW norms (Table-2).

Chemical classification of megascopic basalts reveals a wide variety of rock suites in most schemes of geochemical classification — a spectrum that sometimes extends from phonolite to rhyolite but usually encompasses tholeiites, dacites and andesites (fig. 2A-C). The distinction between basalt and andesite is made mainly on basis of colour index (andesite < 35% mafic minerals < basalt) and silica content (basalt < 52% SiO_2 < andesite). Based on colour, most samples are megascopically classified as basalts. Based on silica content, seven samples qualify as andesites, the others being classified as basalts. Another interesting facet of the volcanics is that they may be classified as calc-alkaline (fig. 2D).

Y/Nb ratio has been used, instead of normative mineralogy or conventional total Alkali - Silica plots, to identify tholeiitic and alkalic members to rule out the possibilities of changes in major oxide chemistry introduced by sample alteration. All samples, with Y/Nb > 2, are concluded to be tholeiitic (Pearce and Cann, 1973). A Nb/Y - Zr/Ti plot (fig.-2B), reiterates the same. The tholeiites are low Ti tholeiites (2.5 wt%) depleted in Zr (250 ppm).

A 2Nb-Zr/4-Y plot of the study traps (fig.-3A) suggests the traps to be volcanic arc basalts. Though the 'volcanic arc basalt' pigeon-hole is partially shared by 'within plate tholeiite' in Meschede's tectono-magmatic discrimination diagram, keeping in light the fact that the Shali basin has never been conceptualised to have been in an intra-plate setting, the plots may be interpreted to suggest an volcanic arc setting. A Ti/100–Zr–Y.3 diagram (fig.- 3B), suggests the traps to be calc-alkaline basalts.

A continental crustal signature is indicated by geochemical parameters such as Ce/Pb (3.0-4.1) and Nb/U (2.5-7.1) ratios, which are distinctly lower than those of oceanic basalts (Miller *et al.*, 2001). As observed on an A.I. (Alkali Index) versus Al_2O_3 plot (fig.- 4A), more K_2O rich primitive basalts also have high alumina characteristics — perhaps suggestive of subduction modified mantle sources (Wilson, 1989). Spiked character of Ba, Rb, Th and K, with a corresponding trough at Nb, in a multi-element spiderdiagrams (fig.- 4B-C) is often inferred to reflect crustal composition (Thompson *et al.*, 1984; Lightfoot *et al.*, 1993). The relative enrichment of K, Rb, Ba etc. seen in fig.- 4C too is suggestive of some crustal contamination. The group of elements Ba, Rb, Th and K show very different patterns for upper and lower crustal contamination, as a consequence of the relative depletion of Rb and Th in the lower crustal rocks (Wilson, 1989). Variation of K, Rb and Ba with Sr (fig.- 4D) is not suggestive of any high-level crustal contamination by low Sr materials such as granite partial melts (Miller *et al.*, 2001).

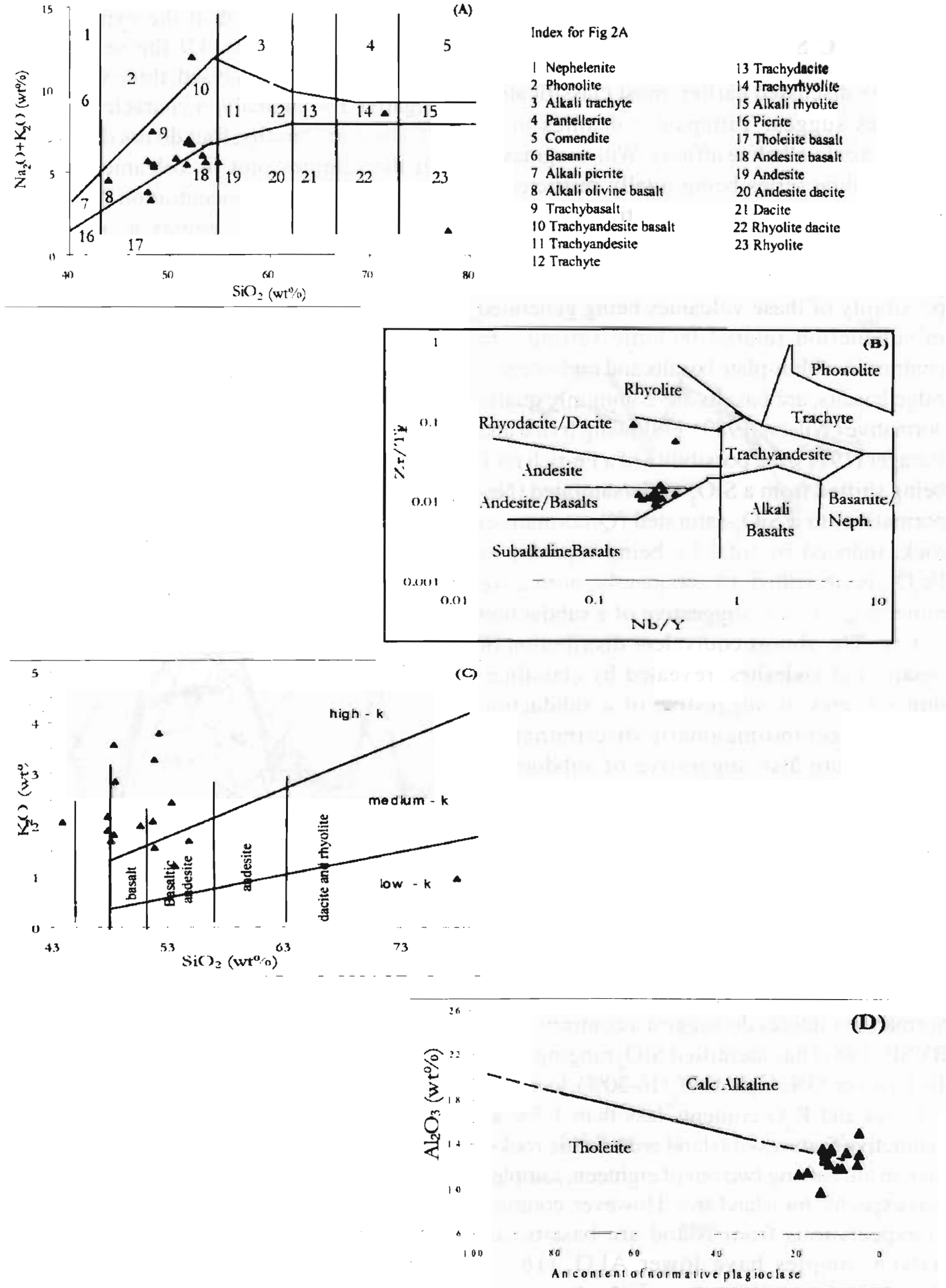

Fig. 2. Geochemical classifications of Tattapani volcanics after (A) Middlemost, 1985; (B) Winchester and Floyd, 1977; (C) LeMaitre, 1989 and (D) Irvine and Baragar, 1971.

DISCUSSION : THE CONSTRAINTS ON TECTONIC SETTING

As discussed earlier, most classification schemes suggest Tattapani volcanics to be having a calc-alkaline affinity. With magmas of calc-alkaline series being totally restricted to subduction related tectonic settings in present times (Wilson, 1989; Winter, 2001), geochemical classification of the study volcanics raises the possibility of these volcanics being generated in subduction related tectonic settings. In contrast to within-plate basalts and mid-oceanic ridge basalts, arc basalts are commonly quartz normative (Wilson, 1989). Following Irvine and Barager (1971), the possibility of a Fe-rich rock being shifted from a SiO_2-undersaturated (Ne-normative) to a SiO_2-saturated (Q-normative) rock, induced by total Fe being reported as Fe_2O_3, is overruled. Consequently, normative mineralogy, too, is suggestive of a subduction setting. The almost equivalent distribution of basalts and andesites, revealed by classification schemes, is suggestive of a subduction regime. Tectono-magmatic discrimination diagrams are also suggestive of subduction regimes.

Thus, it may reasonably be concluded that the Tattapani tholeiites are subduction related. However, some geochemical indices are suggestive of a contrary tectonic setting. Though twelve samples are Q-normative, as expected in volcanic arc basalts, six Ol-normative samples do suggest a contrary view. BVSP (1981) has identified SiO_2 ranging from 48% to over 53%, high Al_2O_3 (16-20%), low TiO_2 (≤1.2%) and K_2O contents less than 1.5% as distinctive features of island arc basaltic rocks. SiO_2 in all, barring two out of eighteen, samples is as expected for island arcs. However, contrary to expectations from island arc basalts, all sixteen samples have lower Al_2O_3 (16%). Despite eight samples having TiO_2 as expected in case of island-arc basalts, eight samples have higher TiO_2. K_2O contents, appearing to be consistently higher than the expected values of island-arc basalts. Of the seven samples whose REE were analysed, three samples show negative Eu-anomaly, a characteristic feature of island-arc basalts; four do not do so. Though all the samples plot in volcanic arc 'pigeon hole', their REE concentration (20–40 times chondrite value) suggests a 'constructive margin' setting (Wilson, 1989).

The authors propose resolution of this apparent duality of geochemical constraints on the tectonic setting of Tattapani tholeiites by invoking a back-arc setting. Tattapani volcanics

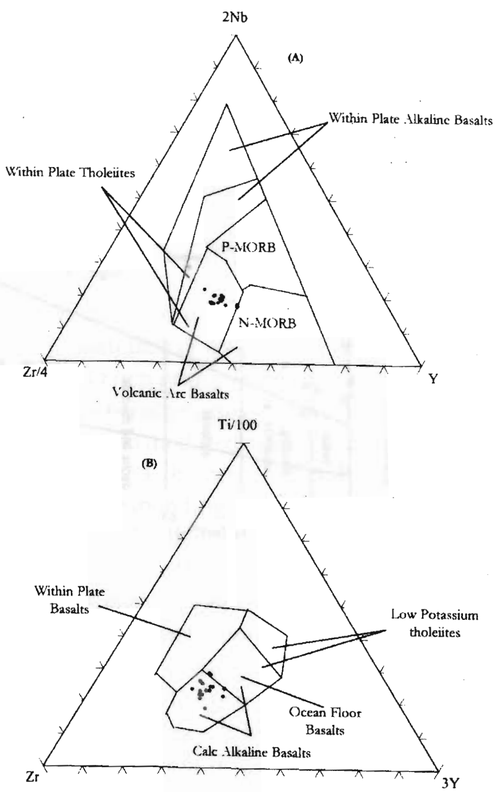

Fig. 3. Tectono-magmatic discrimination of Tattapani volcanics (A) 2Nb-Zr/4-Y plot after Meschede, 1986 and (B) Ti/100-Zr-3. Y after Pearce and Cann, 1973.

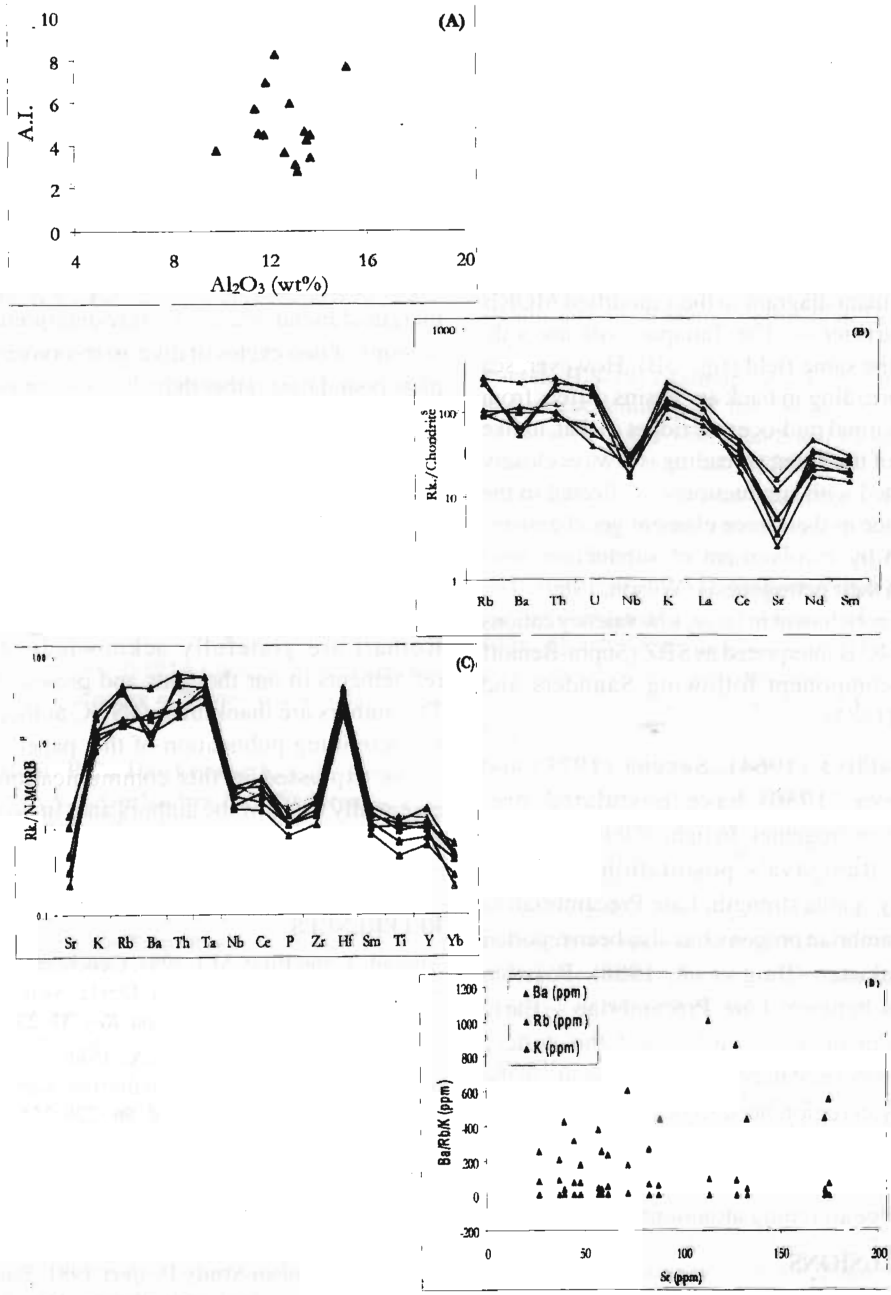

Fig. 4. Crustal contamination of Tattapani volcanics (A) A.I> Versus Al2O3 plot after Middlemost, 1975; (B) Chondrite normalised spiderdiagram after Sun, 1980; (C) N-MORB normalised spiderdiagram after Pearce, 1983 and (D) Variation diagram of K, Rb, Ba versus Sr.

display geochemical signatures of a rift setting concurrent to subduction setting signatures. Back arc volcanics, by virtue of their unique tectonic setting, may be expected to bear an intimate genetic relationship with magma genesis processes operative at both convergent and divergent plate margins. Bose (1997) has attributed plotting of back-arc basalts within (MORB + IAT) field of Ti/100-Zr-Y.3 discriminant diagram to their modified MORB like character — The Tattapani volcanics do plot in the same field (fig.- 3B). However, sea floor spreading in back arc basins differs from that at normal mid-oceanic ridges in that, unlike in case of the latter, spreading is always closely associated with subduction — reflected in the difference in their trace element geochemistry induced by involvement of subduction zone fluids in their petrogenesis (Wilson, 1989). The relative enrichment in large, low valency cations in Fig.- 4C is interpreted as SBZ (Supra-Benioff Zone) component following Saunders and Tarney (1984).

Valdiya (1964), Saxena (1971) and Bhargava (1980) have postulated pre-Himalayan orogenies. In light of this communication, Bahrgava's postulation of 'Shali Orogeny' gains strength. Late Precambrian to Early Cambrian orogeny has also been reported from Pakistan (Baig *et al.,* 1988). Possible linkages between Late Precambrian – Early Cambrian orogenic uplift and the widely observed lower Palaeozoic unconformity in the Himalayan region need to be worked out. The role of such an orogeny in the transition from Rodinia to Gondwana is another facet of knowledge soliciting attention.

CONCLUSIONS

Volcanics of the Tattapani Complex display geochemical signatures of both constructive and destructive plate margin volcanism. In consonance with the conclusions drawn by Saunders and Tarney (1979), the Tattapani volcanics are interpreted to be back-arc basalts.

With the recording of imprints of a Precambrian subduction system in the Shali Basin, and reporting of similar tectonic setting remnants in Pakistan (Baig *et. al.*, 1988; Williams *et al.*, 1989) and northwestern India (Sinha-Roy and Mohanty, 1988; Gyani *et al.*, 2001; Pandit *et al.*, 2001), tectonic evolution of the northern margin of Indian Plate solicits re-interpretation in terms of two cycles of divergent–convergent plate boundaries rather than the existing model of consecutive failed/partial rifting finally culminating in subduction induced Himalayan orogenesis.

ACKNOWLEDGEMENTS

Discussions with Dr. J. Sahoo, D. Dutta, M. Shukla, S. K. Biswal, Dr. G. C. Dutta, and V. Kothari are gratefully acknowledged for refinements in our thoughts and presentation. The authors are thankful to ONGC authorities for permitting publication of this paper. The views expressed in this communication are essentially those of the authors and, in no way, reflect the views of the organization/institution they represent.

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