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CONTINENTAL MAGMATISM RELATED TO LATE PALEOZOIC-EARLY MESOZOIC RIFTING IN NORTHERN PAKISTAN AND KASHMIR

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ABSTRACT

During the Late Paleozoic and very Early Mesozoic, three groups of igneous rocks originated in the present day northwestern part of the Indo-Pakistani subcontinental landmass: 1) The Peshawar plain alkaline igneous province (PAIP), 2) The Panjal volcanics and associated intrusive rocks of Kashmir and Kaghan, and 3) The dolerite dykes in Peshawar, Hazara and Kashmir regions. The PAIP comprises the Tarbela complex (gabbros, albitites, granites), the batholithic Ambela granitic complex (AGC: granites, syenites, carbonatite, dolerites), the Shewa-Shahbazgarhi and the Warsak granites (some alkaline), gabbros and dolerite, the Malakand granite, and the carbonatite complexes of Sillai Patti (Malakand) and Loe Shilman (Khyber). The Panjal volcanics consist of flows (basalt, andesite, rhyolite and alkaline types), agglomerates and tuffs, dolerites, gabbros and norites. The Panjal igneous activity spans from Carboniferous to Triassic, but it was most extensive and voluminous during Permian. Dolerite dykes of the Peshawar, Hazara and Kashmir regions are quartz-hypersthene normative in character and have a Permian stratigraphic age.

Reliable age data are lacking for most of the PAIP, but the Koga alkaline rocks within the AGC have Rb-Sr isochron ages of 297-315 Ma, the U-Pb systematics of zircon in the Malakand granite suggest a Carboniferous age, and the Shahbazgarhi porphyries have a Carboniferous stratigraphic age. The Panjal volcanics and the dolerite dykes have similar (essentially Permo-Carboniferous) stratigraphic ages. Based on the available geochemical data in combination with the ages of the three groups of rocks, it is suggested that the present day northwestern margin of the Indo-Pakistani landmass experienced a major episode of swelling and rifting, with associated magmatism which culminated during Late Carboniferous to Early Triassic.

INTRODUCTION

Based on the occurrence of alkaline rocks in Warsak, Shewa-Shahbazgarhi (Coulson, 1936), Koga (Siddiqui, 1965, 1967; Siddiqui et al., 1968) and Tarbela, Kempe & Jan (1970) suggested that an alkaline igneous province stretched across north Pakistan. Subsequent geochemical and petrographic data on granitic rocks of Ambela (Ahmad & Ahmed, 1974; Rafiq, 1987) and Malakand (Chaudhry et al., 1974), and the discovery of carbonatite complexes in Shilman (Jan et al., 1981) and Sillai Patti (Chaudhry & Ashraf, 1977) provided further support to the idea that the Peshawar plain alkaline igneous province (PAIP) extends for a distance of at least 150 km between the Indus river and Pak-Afghan border (Fig. 1). Field data summarised in Kempe & Jan (1980) indicate that the alkaline complexes are (1) generally emplaced along fault zones, and (2) restricted in occurrence to Paleozoic and Precambrian rocks. To date none has been reported in Mesozoic and Tertiary rocks.

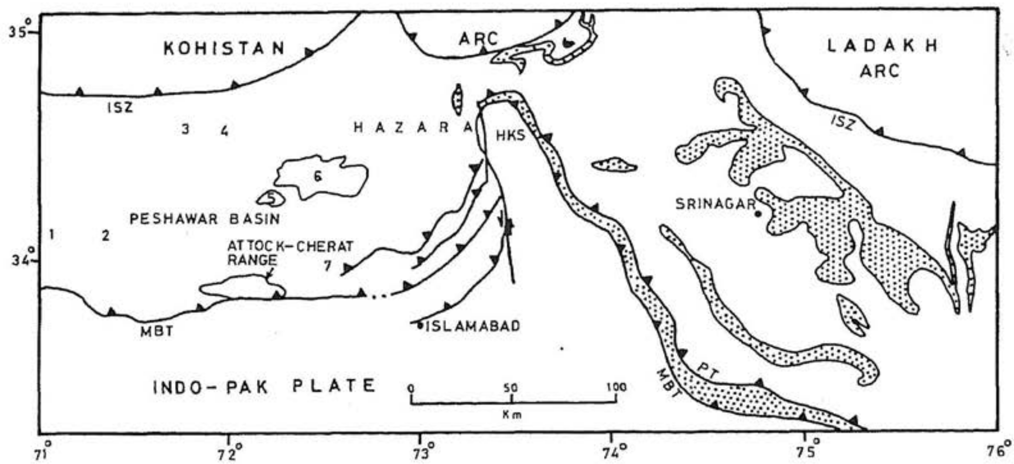


Fig. 1 Sketch map of part of north Pakistan, modified from Kazmi and Rana (1982), Kempe and Jan (1979), and Papritz and Rey (1989). Numbers refer to locations of the outcrops of the PAIP, discussed in text. The Panjal Volcanics are shown by dotts. Dolerite dykes occur in the area north of the MBT (Main Boundary Thrust). The ISZ (Indus Suture Zone) marks the boundary between the Indo-Pak. plate and the largely Cretaceous Kohistan-Laddakh island arc(s). PT: Panjal Thrust, HKS: Hazara Kashmir Syntaxis

Kempe (1973) and Kempe & Jan (1980) suggested that the rocks of the alkaline igneous province are associated with Tertiary rifting. Their conclusions, unfortunately, were based on only two K-Ar dates from Koga (50 Ma) and Warsak (41 Ma). Although additional Tertiary ages have also been reported for the Malakand granite (20-23 Ma fission track and Ar-Ar), Warsak granite (40 - 43.5 Ma Ar-Ar), Loe Shilman and Sillai Patti carbonatites (31 ± 2 Ma Ar-Ar), and Ambela syenite (47.5 ± 1.5 Ma Ar- Ar)

(Zeitler et al., 1982; Maluski & Matte, 1984; Le Bas et al., 1987), it is likely that these dates represent tectonometamorphic events rather than magmatism (see Table 1). The few reliable ages (Le Bas et al., 1987: Ambela; Zeitler, 1988: Malakand; Khan et al., 1990: Shewa-Shahbazgarhi) and the total absence of these rocks in the post Paleozoic sedimentary sequence favour a Late Paleozoic age for the PAIP.

The later part of the Paleozoic and beginning of the Mesozoic appears to have been a fertile time for magma generation in this part of the subcontinent. In addition to the PAIP, numerous dolerite dykes were emplaced in the thick sequences of slates and associated metasediments presently occurring between the Indus suture and the MBT. Then there was the volcanic activity of the Panjal cycle in Kashmir and adjoining areas. This rather extensive continental magmatism, spanning Carboniferous to Triassic period and ranging from granite to carbonatite on the one hand and mafic to rhyolitic on the other, is regarded by us to be connected to a major episode of continental swelling and rifting.

In this paper we present an integrated summary of the three groups of rocks to elucidate their petrography, emplacement ages, and tectonic setting based mostly on published data.

PETROGRAPHY AND GENERAL ASPECTS

The Peshawar plain alkaline igneous province (PAIP)

Of the three groups of rocks discussed in this paper, the PAIP is the most diversified in petrography. Kempe & Jan (1980) and Kempe (1983) considered ten occurrences that comprise the province. In the following we describe seven of these, ignoring those of eastern Afghanistan and Mohmand for want of authentic data and that of Mansehra for its dubious status.

1. *Loe Shilman, Khyber Agency.* Sill-form bodies of carbonatite are emplaced along an E-W-trending and N-dipping fault zone in pre-Mesozoic rocks of Khyber Agency. The main intrusion, reaching 170 m in width, extends for 2.5 km, passing westward into Afghanistan. Isolated sheets of carbonatite occur further east. The carbonatite comprises amphibole sovite which is intruded by biotite sovite and amphibole ankeritic carbonatite. There is a zone of fenitization up to 100 m broad (Mian & Le Bas, 1987). Syenites, lamprophyric rocks and Fe-rich hydrothermal veins are reportedly associated with the carbonatites (Jan et al., 1981), and Butt (1990) has described K-rich rocks from the complex.

Gabbro and dolerite sills, generally not more than a few meters thick, occur to the east and north of the carbonatite complex. These are amphibolitized and resemble

TABLE 1. RADIOMETRIC AGES FROM THE ALKALINE IGNEOUS PROVINCE

LOCALITY	ROCK	SYSTEM	AGE (Ma)	REFERENCE
1) Loe Shilman				
	Carbonatite	K-Ar (Bio)	31±2	Le Bas et al. (1987)
2) Warsak				
	a) Granite	K-Ar (Amp)	41	Kempe (1973)
	b)	Ar-Ar (Amp)	43.5 ± 5	
	c)	Ar-Ar		
		(Amp)	40 ± 5	Maluski & Matte
		(Bio)	42 ± 4	(1984)
	d) Hbl schist	K-Ar (Hbl)	184 ± 17	Kempe (1986)
3) Malakand				
	a) Granite	F.T (Ap-Zir)	20	Zeitler (1982)
	b)	Ar-Ar (Mus)	22.8 ± 2.2	Maluski & Matte (1984)
	c)	U-Pb (Zir)	Carbonif.	Zeitler (1988)
4) Silai Patti				
	a) Carbonatite	K-Ar (Bio)	31 ± 2	Le Bas et al. (1987)
	b)	F.T		
		(Zir)	32.3 ± 1.4	
		(Ap)	21.8 ± 0.4	Qureshi et al. (1990)
5) Ambela				
	a) Syenite	K-Ar (W.Rock)	50	Kempe (1973)
	b)	Ar-Ar (Bio)	47.5 ± 1.5	Maluski & Matte (1984)
	c) Syenite & ijolite	Rb-Sr (W.Rock)	315 ± 15 297 ± 4	Le Bas et al. (1987)
	d) Syenite	U-Pb (Zir)	Carbonif.	Zeitler (1988)
6) Tarbela				
	Albitite	K-Ar (Hbl)	350 ± 15	Kempe (1986)

those of the Warsak area, 35 km to the east. Jan (1969) has described gabbroic bodies in the intervening area which also contains isolated outcrops of granitic rocks like those of Warsak. The relationship between the gabbros and carbonatite is not known, but Jan et al. (1981) speculated that the two may be genetically related. A K/Ar date of 31$\pm$ 2 Ma on biotite was considered by Le Bas et al. (1987) to be the age of formation of the carbonatite .

2. *Warsak*. A series of sill-form alkaline granites, microgranites, gabbros and dolerites occurs in a 5 x 8 km N-plunging syncline at Warsak (Coulson, 1936; Ahmad et al., 1969; Kempe, 1973, 1983). The granitic rocks, some of which are foliated and sheared, contain aegirine, riebeckite, astrophyllite and/or biotite $\pm$ garnet. The entire area has been matamophosed in upper greenschist facies, and mafic rocks contain abundant amphibole and relics of pyroxene. There are mafic tuffs, agglomerates and pillow lavas, raising the possibility that some of the acidic rocks may also be volcanic (Kempe, 1978). Small bodies of similar gabbroic and granitic rocks occur not only in Shilman to the west, but also 10 km to the south (Khan et al., 1970) and perhaps to the north.

The age relationship of the granitic and gabbroic rocks is not clear but the volcanic members seem to have preceded the intrusive phase. The Warsak area may well be a good example of contemporaneous bimodal magmatism. On the basis of limited data, Kempe (1978) suggested that the whole may constitute a differentiated series. Recent geochemical investigation (Khan, 1991) shows that the gabbros and granites have the characteristics of continental rift magmatism. A K/Ar amphibole date of 41 Ma was considered by Kempe (1973, 1983) as age of emplacement. This age, however, is at odds with the 187 $\pm$ 17 Ma K/Ar hornblende on a metamorphosed mafic tuff (Kempe, 1986). Maluski and Matte, (1984) thought that their 40 to 43 Ma Ar/Ar ages on amphiboles and biotite from Warsak were indicative of tectonometamorphic activity. The Warsak rocks are, however, strikingly similar in petrography and geochemistry to those of Shewa-Shahbazgarhi (Coulson, 1936; Kempe, 1973, 1983), which have a Carboniferous stratigraphic age (Khan et al., 1990).

3. *Sillai Patti.* Asharaf and Chaudhry (1977) reported a carbonatite occurrence about 20 km west of Malakand. Le Bas et al. (1987) suggested that the carbonatite was emplaced along a thrust in the form of a 12 km long and 20 m thick sheet. Butt (1989) presented geochemical data for the carbonatite and also noted that the carbonatite is made up of dyke-like bodies emplaced either within the metasediments or at their contact with granitic rocks.

The carbonatite, consisting of biotite-apatite sovite, amphibole-apatite sovite and alkaline pyroxenites, has fenitized the country rocks, especially the granitic gneisses. The latter appear to be an extension of Swat granitic gneisses which have been equated by Jan et al. (1981) with those of Mansehra (516 $\pm$ 16 Ma Rb/Sr whole-rock isochron age: Le Fort et al., 1980). K/Ar dating on an undeformed biotite in the carbonatite has yielded 31±2 Ma (Le Bas et al., 1987). An identical fission-track zircon age (32.3 ± 1.4 Ma) has been determined by Qureshi (1990). These authors have argued that the carbonatite, like that of Shilman, formed during Oligocene. Butt (1989), however, thinks that this may be the age of metamorphic overprinting and that the carbonatite may be late Paleozoic. We also prefer this possibility.

Before closing this section, we would like to mention that carbonatite (with biotite, pyroxene, amphibole) and associated fenites also occur in Jambil area of Swat. These are currently under our investigation. It is likely that further search would reveal additional bodies of carbonatite in the region.

4. *Malakand*. In the Malakand Pass area, granitic rocks intrude into the nosal part of an ESE-plunging anticline made up of gneisses and schists (Shams, 1983). Khan (1965), Chaudhry et al. (1974, 1976) and Hamidullah et al. (1986) have presented petrographic details and geochemistry of the rocks. The granite contains albite, microcline, quartz, muscovite, epidote, biotite, calcite, garnet, etc. Allanite and sphene are common in samples from Benton hydroelectric tunnel (Kempe & Jan, 1980). Pegmatites (some carrying tourmaline and fluorite) and aplites are commonly associated with the granites. The gneisses have more or less similar modes and have been chemically divided into siliceous, silica-rich granitic and normal granitic types by Hamidullah et al. (1986). These authors and Chaudhry et al. (1976) suggested that the granites were related to (at least some) granitic gneisses.

The Malakand granite has a 20 Ma fission-track apatite and zircon age (Zeitler, 1982) and an Ar-Ar muscovite age of 22.8 ± 2.2 Ma (Maluski and Matte, 1984). Thus, and in the light of chemical data of Chaudhry et al. (1976) who thought it to be "basically a soda granite" , Kempe and Jan (1980) considered that the Malakand granite may belong to the PAIP. Hamidullah et al. (1986) found the granite to be peraluminous and calc-alkaline, and not related genetically to the PAIP. Recent work on U- Pb zircon systematics shows that the Malakand granite is Carboniferous in age (Zeitler, 1988). We regard that 1) the Malakand granitic gneisses are an extension of the Swat granitic gneisses of early Paleozoic age, and 2) The Malakand granite is a product of the magmatic episodes of late Paleozoic and probably related to the PAIP.

5. *Shewa-Shahbazgarhi.* Acidic porphyries/microgranites with basic intrusions cover a 35 km^2 triangular area near Shahbazgarhi. Isolated outcrops of such rocks occur 15 km to the south (Martin et al., 1962) and further north near Rustam (Rafiq, 1987), suggesting that these sheared volcanic/subvolcanic rocks may once have covered a much larger area. On the basis of petrography and geochemistry, these rock have been considered to be consanguineous with those of Warsak (Coulson, 1936; Kempe, 1973; Kempe & Jan, 1970). The acidic rocks consist of an earlier garnetiferous group containing biotite and lacking alkaline ferromagnesian minerals, and later alkaline microgranites with aegirine, riebeckite and biotite (Kempe, 1983). Different petrographic and

geochemical divisions have, however, been suggested by Chaudhry and Shams (1983) and Ahmad et al. (1990). The mafic intrusions, like those of Warsak, are amphbolite facies(?) metamorphosed gabbros and dolerites containing hornblende (hastingsite) and epidote.

Chaudhry & Shams (1983) presented major element geochemistry of the acidic rocks and concluded that they are the product of anatectic melts of deep crustal origin, emplaced during alternate periods of tension and compression related to subduction of the Indian plate during late Cretaceos-early Tertiary. Ahmad et al. (1990) noted that the basic rocks share the characteristics of continental flood basalts and were (along with the alkaline and peralkaline acidic rocks) emplaced during continental rifting.

According to Khan et al. (1990), the "Shewa porphyritic microgranites" occur in cyclic intercalations with Early Carboniferous sediments (conodonts age). This discovery is important because, 1) the Shewa-Shahbazgarhi porphyries may at least partly be volcanic (? tuffs and flows), 2) this is the first stratigraphic age on any rock in the PAIP. This age is in conformity with those determined radiometrically for Malakand, Tarbela and parts of Ambela, and 3) the close similarity of these rocks with those of Warsak leads to speculate that the latter may also be Carboniferous.

6. *Ambela Granitic Complex (AGC)*. Covering about 900 km^2, the AGC is by far the largest body of the PAIP. Following the initial brief description (Martin et al., 1962), Siddiqui et al. (1968) presented the petrology of the alkaline rocks from the western part of the AGC in Koga area. Since then much more work has been done on this complex, of which that by Chaudhry et al. (1981), Rafiq (1987) and Mian (1987) is particularly important. Rafiq & Jan (1988, 1989) presented details of petrography and geochemistry, and classified the complex into three major groups of rocks. Group I, the product of the first magmatic episode, consists of granites and alkali granites which occupy ~ 70 % of the batholith. Group II, following the granites sequentially, comprises quartz syenites, syenites, feldspathoidal syenites, ijolite and carbonatite. Considerable metasomatism accompanied the successive phases of intrusions in this group. Finally, the complex was invaded by dolerite and lamprophyre dykes which occupy 5 % area and constitute the group III. As elsewhere, the dolerites display alteration/metamorphism and contain considerable amounts of hornblende and epidote. These have continental tholeiitic affinity (Rafiq & Jan, 1990)

The granitic rocks range from dominantly peraluminous through metaluminous to mildly alkaline, derived from melts by anatexis due to crustal thinning and rifting. Different degrees of partial melting and fractional crystallization led to variation in the composition of these rocks. With deepening of the zone of magma generation in the crust, the underlying mantle was activated, resulting in influx of volatiles and alkalies. This led to the generation of magma batches which were succesively more SiO_2-undersaturated and alkaline, resulting in production of group II rocks (Rafiq & Jan, 1989).

Based on a 50 Ma K/Ar syenite date, Kempe (1973) proposed that the complex formed during Eocene. Such an idea was further substantiated by a 50 Ma Ar/Ar biotite age from a syenite (Maluski & Matte, 1984). Hence Kempe & Jan (1980) equated these rocks with those of Warsak, Shewa and Tarbela, and placed them in the PAIP (see also Ahmad & Ahmed, 1974). Le Bas et al. (1987) reported that the alkaline rocks of Koga have Rb/Sr isochron age of 297 $\pm$ 4 to 315 $\pm$ 15 Ma. Zeitler (1988) also found a Carboniferous U-Pb zircon age for the syenite. The AGC is mainly intrusive into the sedimentary rocks of Siluro-Devonian age, however, late pegmatites and veins occur in Early Triassic rocks (S. R. Khan, pers. com.). The batholith contains xenoliths of (? cover) volcanics similar to those of Shewa-Shahbazgarhi (Rafiq et al., 1988). On these grounds it can be safely concluded that the AGC was emplaced mainly during Carboniferous between 300 and 350 m.y. ago.

7. *Tarbela*. The Tarbela " alkaline " complex comprises gabbroic rocks (oldest), dolerites, a variety of albitites, normal and sodic granites, albite-carbonate rock/breccia, and (?) carbonatites (youngest) (Jan et al., 1981). The rocks stretch for at least 4 km, but many outcrops have been removed or covered during the construction of the dam. The complex may have been intruded along a fault zone between the Tanawals and Salkhalas. Some of the gabbroic intrusions display insitu differentiation, with one intrusion grading from pyroxenitic outer margin to leucogabbroic/dioritic interior with a core of " intrusive " albitites. Considerable metasomatic activity accompanied the rocks with the development of scapolite, albite, carbonate, quartz and pyrite. some albitized country rocks resemble adinoles and it has been suggested that most albitites may be metasomatic (Le Bas, pers. com. 1985).

Amongst typical alkaline minerals, sodic amphiboles and pyroxenes are restricted to sodic granites, now removed. However, trace elements in albite-carbonate rocks and the high quantity of albite carbonate along with consistent presence of zircon, rutile and/or sphene in most albitites are suggestive of their alkaline affinity. The alkaline affinity of the gabbroic rocks is suggested by the abundance of amphibole (hornblende, kaersutite, hastingsite), low An content of plagioclase, clinopyroxene composition, the general absence of primary quartz, and the possibly high Ti content reflected in amphibole, sphene and ilmenite. Preliminary geochemistry supports this view. Kempe (1986) has reported a K/Ar date on hornblende from an albitite as 350 $\pm$ 15 Ma, which is close to the formation age of the nearby Ambela granitic complex.

The Panjal volcanics

Having a wide distribution and covering about 12000 km^2 area, the Panjal volcanics are a prominent feature of NW Himalaya. They occur in an up to 40 km broad belt of intermittent outcrops extending NW from Zanskar through Pir Panjal range, Neelum and Kaghan valleys, turning around the western Himalayan syntaxis to

Balakot. The volcanics are a succession (up to 2500 m thick) of thin (mostly a few cms to 3 m) basaltic flows with interbedded tuffs and limestone, underlain by agglomeratic slates, grits, pyroclastics, limestone/marble, graphitic schists, pelitic schists and metaconglomerate. Wadia (1961) also reported dykes and laccoliths of mafic composition in the volcanics. Included here are the volcanic rocks of Suru and those of Zanskar which consist of Late Carboniferous-Early Permian basaltic flows (Srikantia et al., 1978). It is not clear but some volcanic members of the PAIP may be the equivalent of Panjal.

The Panjal volcanics have been stratigraphically assigned to Late Carboniferous to Triassic, but much of the volcanic activity took place during the Permian (Pareek, 1982; Gupta et al., 1982). Ghazanfar et al. (1986) and Chaudhry et al. (1987) divided the rocks into Panjal formation (volcanics) of Permian age and Chushal formation (agglomeratic slate, etc.) of Late Carboniferous age. The volcanics are dominantly basaltic in composition, but andesite, rhyolite, trachyte, and subordinate nepheline basalt, ankeramite and limburgite also occur (Honegger et al., 1982). The basaltic members are mostly non-porphyritic but some have pyroxene/plagioclase phenocrysts in a fine-grained or glassy matrix. In Azad Kashmir and Kaghan the top of the succession contains a high proportion of tuffs and ashes (mostly intermediate to acidic), and the flows locally appear to have pillow structure (Chaudhry et al., 1986).

The volcanics have undergone varied degrees of alteration, metamorphism and deformation. Tight folding is common throughout and the rocks may display shearing, schistosity and flow banding. They are greenish and amygdaloidal, but locally "mottled" due to black and dark green amygdules in red and white mineral aggregates (Greco, 1986; Sinha, 1981). Epidote , calcite, chalcedony and jasper are widespread alteration products (Pascoe, 1949). Metamorphic grade has been reported to increase from south with zeolite and greenschist facies (Papritz & Rey, 1989) to green schist (Chaudhry et al., 1986) or even amphibolite facies in the north (Greco et al., 1989). Spencer et al. (this volume) report eclogites derived from the Panjal volcanics in the upper part of the Kaghan valley.

The Peshawar-Hazara-Kashmir dolerites

Between the Indus Suture and the Main Boundary Thrust (MBT), there are numerous dolerite bodies in the Precambrian to Paleozoic rocks of NWFP and Kashmir. Notable occurrences are those of Attock-Cherat Range (Wadia, 1957; Tahirkheli, 1970), Khyber Agency (Khan et al., 1970; Shah et al., 1980), Hazara (Shams et al., 1968; Calkins et al., 1975), and Kashmir (Wadia, 1961; Pascoe, 1949). The association of such rocks in the PAIP has already been discussed in a previous section.

The dolerites commonly occur as sills and dykes, but locally as stock-like bodies. They rarely exceed 10 m in thickness and a few hundred meters in length. Locally the dykes may occur in swarms. Available data on the orientation of dykes show E-W trends in Khyber Agency (Shah et al., 1980), Attock-Cherat (Karim & Sufyan, 1986) and Hazara (Calkin & Ahmad, 1968). In at least two places where associated with a central gabbroic plug, the dolerites occur in a radial pattern. The dykes were probably subjected to late thrusting events during Himalayan orogeny, which may have modified their regional trends, however, their parallelism is preserved.

Only limited mineralogical data have been presented for these rocks in Attock-Cherat (Karim & Sufyan, 1986) and Mansehra (Ahmed, 1985). Common minerals in these rocks consist mostly of plagioclase (An_{45-71}), augite, Fe-Ti oxide, biotite, pigeonite, hornblende, epidote, and chlorite. A few rocks contain olivine (Fo_{38-52}). Many can be classified as dolerites, but some are lamprophyres, norites and gabbros. Some of the latter in Kashmir have acted as feeder dykes, sills and bosses to the Panjal volcanics (Pascoe, 1949). The rocks have experienced low grade metamorphism and weathering: chlorite, epidote, secondary amphibole and sodic plagioclase are common. Some garnet amphibolites in the basement rocks of Kaghan valley have been considered the subsurface equivalent of the Panjal volcanics (Papritz & Rey, 1989).

The dolerites intrude Late Paleozoic rocks (upper Permian in Khyber Agency; Shah et al., 1980, and Carboniferous in Attock-Cherat Range), but they have not been reported from Mesozoic-Tertiary rocks including the Triassic of Kalachita (A. Hussain pers. Comm). Therefore, it can be concluded that many of the dolerites may be of Permian to Early Triassic age, but some may be older and related to the PAIP and early Panjal cycle.

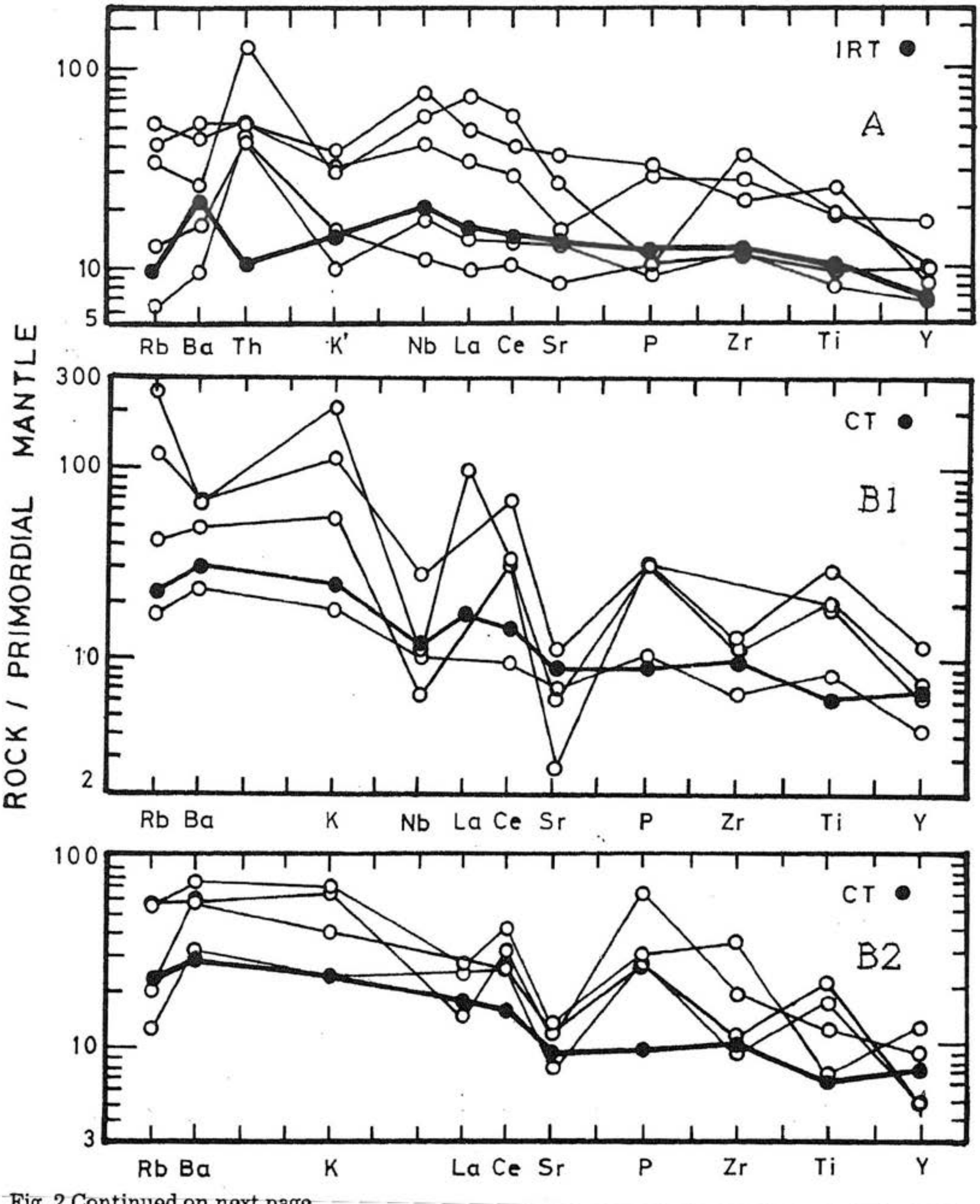
Sheet-like bodies of metabasites (amphibolites) of uncertain age occur in the Malakand-Swat area. Humayun (1986) reported their affinity with continental flood basalts associated with early rifting of the Paleotethys (Siluro-Devonian).

GEOCHEMISTRY

For the different groups of rocks discussed here, considerable geochemical data have been presented, especially over the past 20 years. In the following we use these data to arrive at conclusions regarding the tectonic environments prevailing during the development of these rocks. Our work is mostly based on literature data except for new XRF analyses for Mansehra and Attock-Cherat dolerites, and Tarbela gabbros along with microprobe data for the latter. It may be mentioned that the time relation of the dolerites and mafic members of the complexes of the PAIP are not clear to us. Despite the possibility that they may be contemporaneous and related, we have treated them separately in the following.

The Peshawar plain alkaline igneous province

Figure 2 shows the mantle-normalized abundances of some trace elements for the mafic rocks from Warsak (A), Shewa-Shahbazgarhi (B1,B2), and Tarbela (C). They all display enrichment of large ion lithophile elements (LIL) relative to high field



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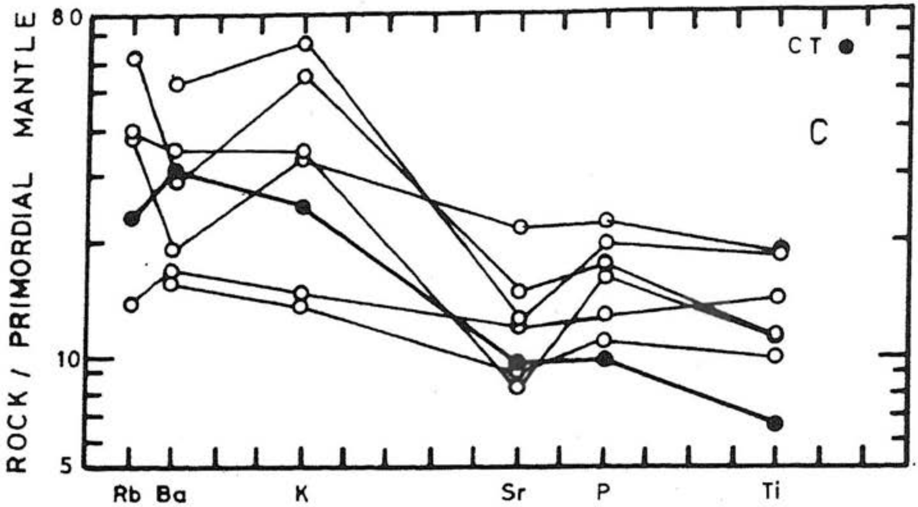
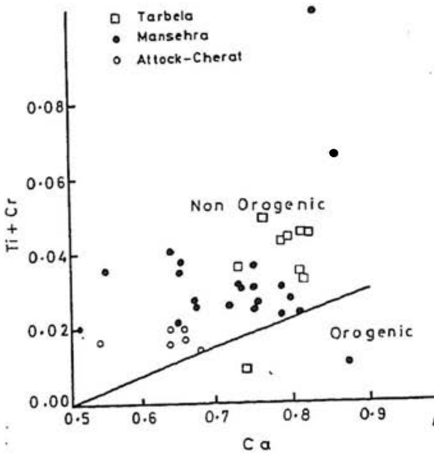


Fig. 2. Mantle-normalized spidergrams for the mafic rocks of the PAIP. Normalizing values after Wood (1979). The Warsak rocks (A) show analogy with initial rift tholeiites (IRT) of Holm (1985). The Shewa Shahbazgarhi dolerites (B1) and gabbros (B2) have trace element patterns characteristic of continental tholeiites, especially the right tilting slope and negative Nb anomaly of the dolerites. (CT) is the average composition of continental tholeiitic basalts (Holm, 1985). The patterns depart from the average trend at the Sr, P and Ti points, indicating mineralogical control. The Tarbela mafic rocks (C) follow the pattern of average continental tholeiites. Source of data for Shewa Shahbazgarhi: Ahmad et al. (This Vol.); Warsak: Khan (Un pub. M. Phil. data).

strength elements (HFS), and their spidergrams broadly resemble average continental flood basalts. The Warsak rocks show component of initial rifting in their genesis (Khan 1991), and can be related to an event of continental splitting. Chemically they are distinct from the rest of the mafic rocks of the PAIP. The pyroxene composition from Tarbela gabbroic rocks (Fig.3) support their affinity with non-orogenic suite. The mafic rocks from the four complexes plot in the field of tholeiites on MFA diagram (Fig. 4), however, some alkaline characters are obvious. The Tarbela gabbroic rocks (nine analyses), for example, contain 2 to 6 % TiO_2, 0.1 to 0.5 % P_2O_5, and 1.5 to 4.5 % $Na_2O + K_2O$.

Considerable amount of data have been presented for the granitic and alkaline rocks of the PAIP. Chemically the silicic rocks are predominantly granitic but some classify as adamellite, granodiorite and monzonite, and range from peraluminous to alkaline and peralkaline in character (cf. Rafiq & Jan, 1989). The continental affinities of these rocks can be pointed out from their chemistry and their paleogeographic location during their emplacement in the Late Paleozoic. Figure (5) shows a plot of $CaO/(Na_2O + K_2O)$ against SiO_2 with fields for type extensional and compressional suites. It can be seen that the PAIP rocks fall along the extensional suites.



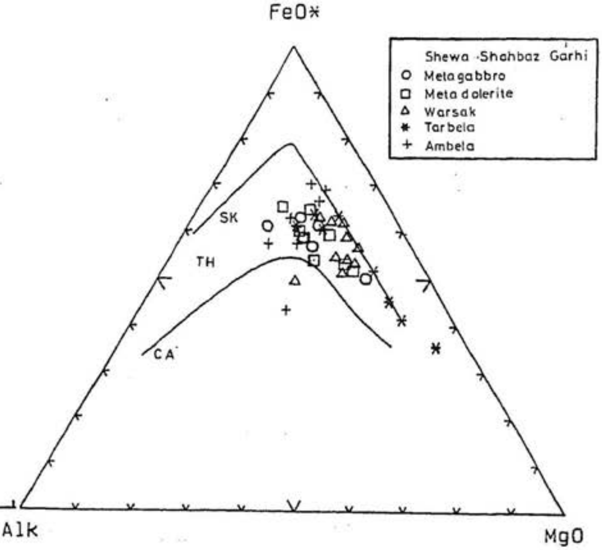


Fig. 3 (Left). Tectonic discrimination diagram, based on the composition of clinopyroxenes in the mafic rocks of the PAIP. Fields for orogenic and non orogenic basalts are after Leterrier et al. (1982). Source of data for Mansehra: Ahmad, (1985); Attock-Cherat: Karim and Sufyan (Un pub. M. Sc. data).

Fig. 4 (Right). MFA diagram for the mafic rocks of the PAIP. CA is the boundary between calc-alkaline and tholeiitic series, after Irvine and Baragar (1971). SK is the trend of Skaergaard liquid. All iron expressed as FeO*. Rocks containing excess alkalies fall off the trend of Skaergaard liquid, but occupy the tholeiitic field. Source of data for Shewa Shahbaz Garhi: Ahmad et al. (This Volume); Ambela: Rafiq, (Un pub. Ph.D. data); others as in Fig. 2 & 3.

Pearce et al. (1984) used trace elements to distinguish within plate, volcanic arc, collision and orogenic granites. The Rb vs SiO_2, Rb vs Y + Nb and Nb vs Y diagrams unequivocally classify the PAIP granitic rocks to have originated in within-plate environments (Fig. 6). It is then obvious that both the mafic and granitic members of the PAIP have apparently originated in continental tectonic regime.

The Panjal Volcanics

The Panjal volcanics show a variable degree of alteration rendering major element chemistry unreliable for inferring magmatic affinities (Humayun et al., 1987). Hundreds of major element analyses, many of which accompany trace elements, have been published, but few REE data have been presented on these rocks. The Panjal volcanics show compositions of rhyolite, andesite, basalt and trachyte (Pareek, 1982) and are tholeiitic to mildly alkaline in character (Honegger et al., 1982; Gupta, 1982).

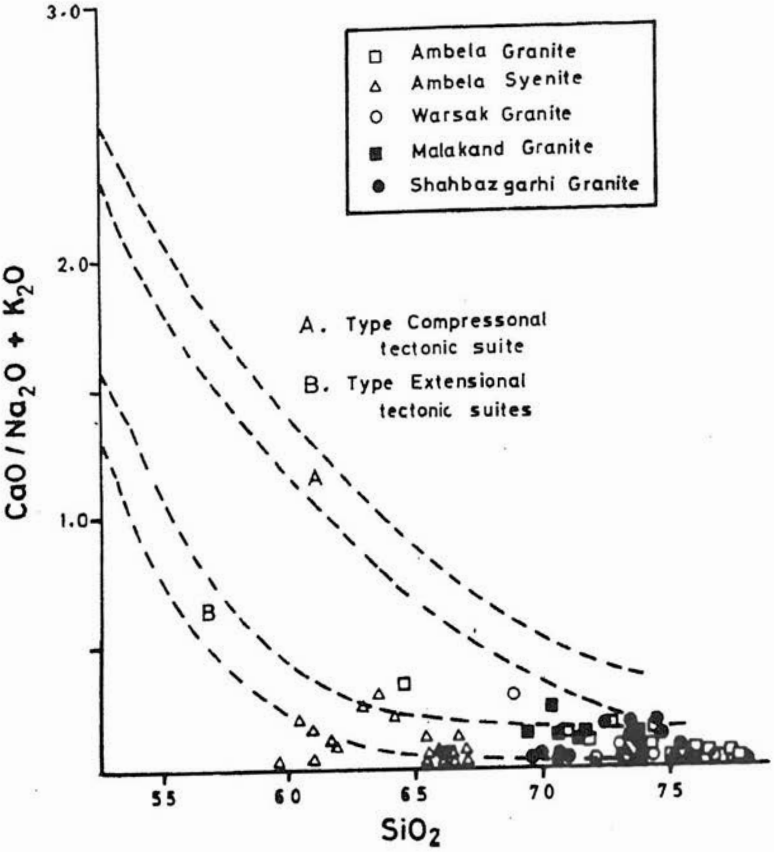


Fig. 5. $CaO/(Na_2O+K_2O)$ vs SiO_2 plot for distinguishing type compressional suite from type extensional tectonic suites. Fields extrapolated from data compiled by Petro et al. (1980). The silicic rocks of the PAIP follow the trend of type extensional tectonic suites. Source of Data: Chaudhry & Shams (1983); Chaudhry et al. (1984), (1976); Hamidullah et al. (1986); Kempe (1973); Rafiq & Jan (1989).

Honegger et al. (1982) noted that the Zr and Rb abundances in Panjal basalts are very high for MORB, the light REE are enriched by a factor of 4-5 relative to MORB and are similar to plateau basalts. Papritz & Rey (1989) used trace element data from western syntaxis area for inferring paleotectonic environments during eruption of the Panjal volcanics, and compared their results with Honeggear et al. (1982) for Suru area. There is a strong suggestion that these rocks originated in within-plate environments. Fig. (7) shows the mantle-normalized trace element spidergrams for the Panjal basalts. The patterns compare well with continental tholeiites.

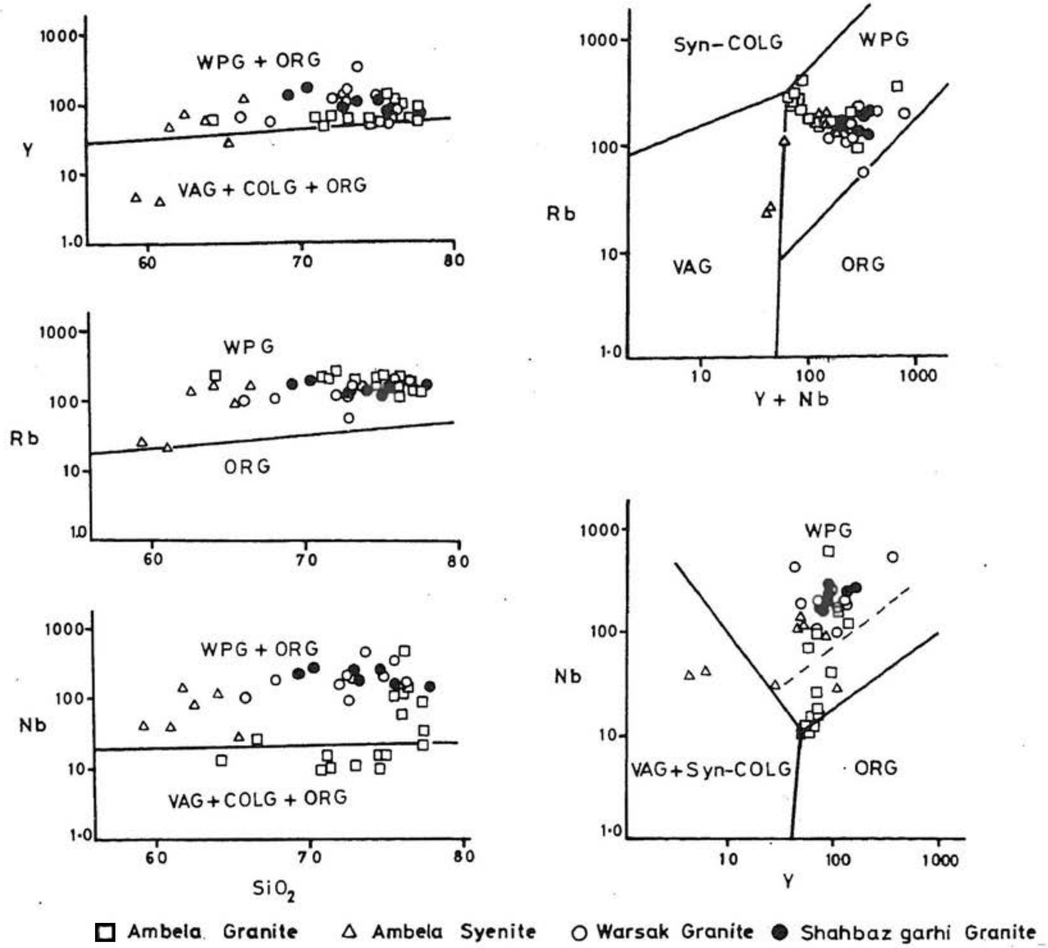


Fig. 6. Tectonic discrimination diagrams for silicic rocks. The PAIP rocks are characterized as within-plate on these plots. Field boundaries after Pearce et al. (1984). Source of data as in Fig. 5.

The Peshawar-Hazara-Kashmir Dolerites

Despite a widespread occurrence, little geochemical work has been performed on the dolerites. Ignoring the mafic rocks associated with the PAIP, the only geochemical data available on these rocks can be found in Karim & Sufyan (1986) and one analysis in Le Fort et al. (1980). Since 1986, we have performed XRF analyses on ten samples for trace elements to arrive at some conclusion regarding their origin.

The dolerite dykes are mostly quartz-hypersthene normative, and classify as basalt and andesite. Fig. (8) shows the mantle normalized abundance patterns for some of the trace elements from Attock-Cherat Range (A) and Mansehra (B). The patterns for Mansehra show semblance with average continental tholeiites. The Attock-Cherat dolerites show enrichment in LIL elements relative to HFS elements (Rb/Y values 2.4-9.7). The negative slope, Nb trough and shapes of the spidergrams are comparable with those for average continental tholeiites. Generalised pattern for REEs is apparent from La/Y ratios (values range from 2.1 to 6.1) and indicates LREEs enrichment relative to HREEs, which supports their affinities with continental basalts. Their within-plate character is further supported by the Nb-Ti-Th plot of Holm (1985) in which all the samples consistently plot in the within-plate field (Fig. 9). Clinopyroxene compositions of dolerite dykes in the Attock-Cherat Range and Mansehra occupy the field of non-orogenic suites on Ti+Cr vs Ca discrimination diagram (Fig. 3).

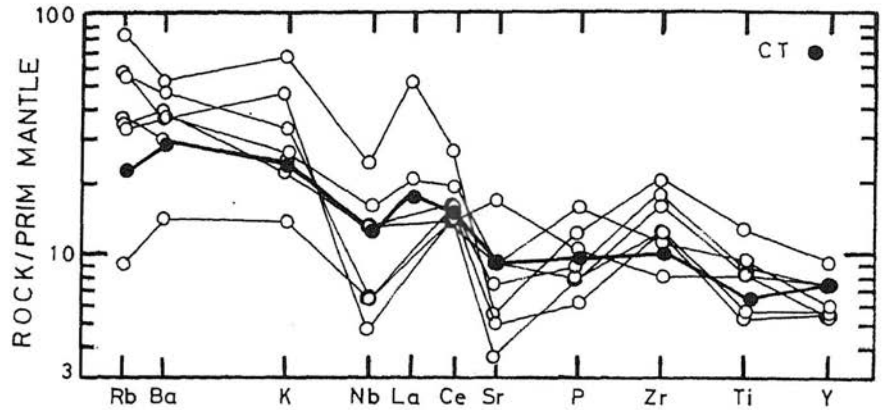


Fig. 7. Mantle-normalized spidergrams for the Panjal basalts. Normalizing values after Wood (1979). These share features such as negative slope, Nb trough and shape of the spidergram with that of the average continental tholeiite (CT) of Holm (1985). La values below detection are taken as zero. Source of data Honegger et al. (1982).

CONCLUSION AND DISCUSSION

In the preceding pages we summarised pertinent data on field, petrographic and geochemical aspects of the PAIP, the Panjal volcanics and the Peshawar-Hazara-Kashmir dolerites. Some important conclusions can be readily reached.

1) All the three groups of rocks have originated within a restricted range of time. The magmatism started in Early Carboniferous and terminated in (? Early) Triassic, with its peak during Pennsylvanian to Permian. There is a possibility that the PAIP is a little older than the Panjal volcanics. If true, it would mean that the magmatism became younger to the east. Although in a few areas the doleritic rocks are the

subsurface manifestation of the Panjal volcanics, the time and genetic relationship of the three groups of rocks are not clear. More field and age data are required.

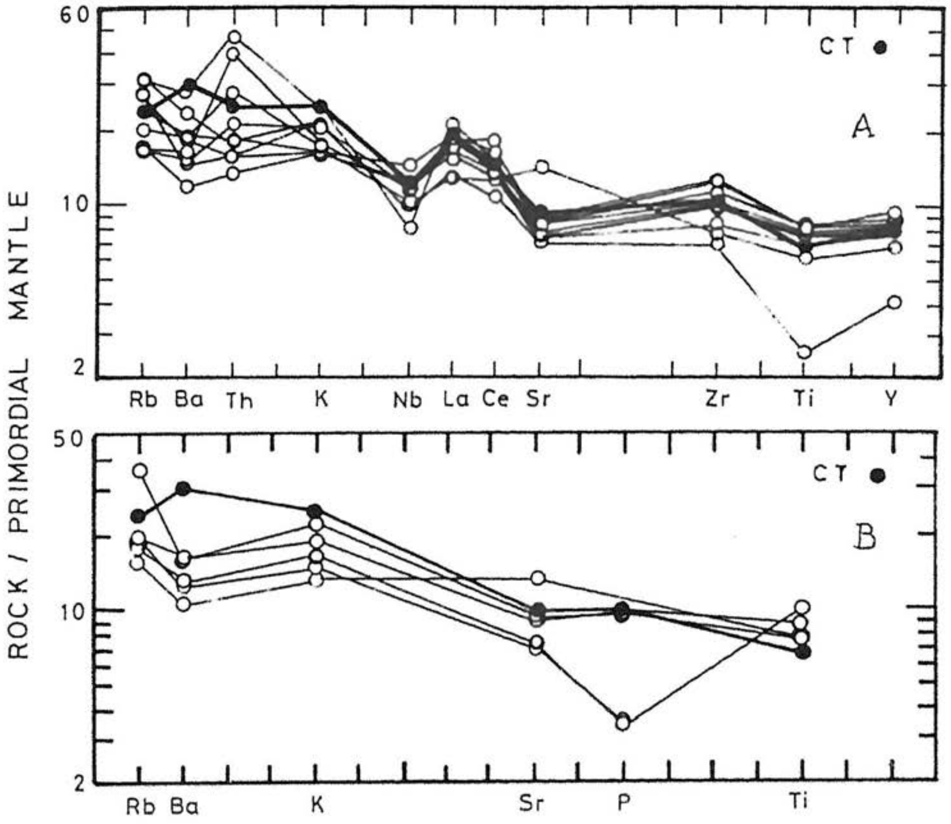


Fig. 8. Mantle-normalized spidergrams for the dolerite dykes in the Attock-Cherat Range (A) and Mansehra (B). Normalizing values after Wood (1979). Their patterns closely match average continental tholeiitic basalt (CT) of Holm (1985), except for the segment Rb-Ba, a consequence of mobility of these elements to alteration. Source of data for Attock-Cherat: Karim and Sufyan (Un pub. M.Sc. data).

2) Despite petrographic diversity from mafic to silicic and alkaline composition, all three groups of rocks appear to have originated in similar tectonic environments. Several of the PAIP complexes are bimodal, the granitic rocks sharing the affinities of those from continental extensional regimes. The mafic rocks are mostly tholeiitic with traits of continental flood basalts. Geochemistry and paleogeography, then, clearly suggest that the rocks originated within a continental plate during an extensional regime.

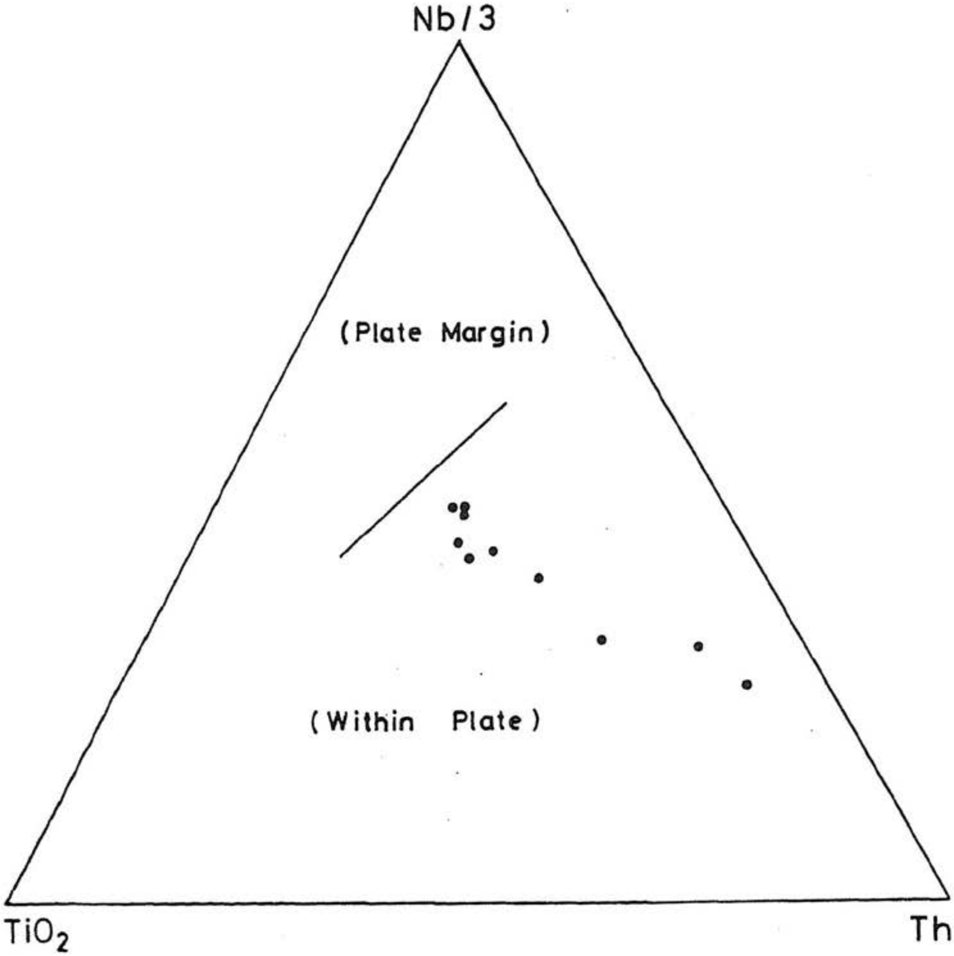


Fig. 9. Tectonic discrimination plot for the Attock-Cherat dolerites. Fields of plate margins and within-plate after Holm (1985). Source of data as in Fig. 8.

3) The three groups of rocks occur in a 500 km x 150 km zone along the northwestern edge of the Indian plate between the Indus Suture and the MBT. The dolerites occur in much of the area, whereas the PAIP and the Panjal volcanics occur, respectively, to the west and east of the Hazara-Kashmir syntaxis. Whether this means that the area to the west of the syntaxis is eroded to a deeper level or the volcanics did not extend that far cannot be ascertained at this stage. Again additional work is required.

To sum it up, then, in the northwestern margin of the present day subcontinent there was an extensive Permo-Carboniferous magmatism with chemical characteristics typical of continental extensional environments. This conforms to the previously held views about the three groups of rocks.

Kempe & Jan (1980) suggested that the PAIP was associated with rifting in the Peshawar valley. The rifting was assumed to be related to relief tension, following compression release initiated by collision between the Kohistan arc and the Indian plate. Kempe (1983), and Rafiq & Jan (1989) also favoured doming and rifting mechanism for these rocks. Le Bas et al. (1987) regarded that the PAIP was not related to the Himalayan collision, that there were two alkaline magmatic episodes (Carboniferous and Oligocene), and that there is no evidence of rifting at least in the case of Oligocene carbonatite complexes. We agree with them in assigning the PAIP to Permo-Carboniferous but regard the Oligocene K/Ar and FT dates to record thermotectonic events.

Nakazawa et al. (1975) and Honegger et al. (1982) suggested that the environmental conditions during the eruption of the Panjal volcanics were coastal subaqueous to subaerial and terrigenous as indicated by the associated rocks. Much earlier on, Pascoe (1968) opined that the volcanics were erupted on an old coastal land surface subjected to occasional transgressional sea or a submarine shelf. Acharyya (1973) proposed that the Permo-Carboniferous Panjal volcanics and clastic sediments accumulated in tectonically active basins. Andrews-Speed & Brookfield (1982) thought that these rocks indicate rifting on a previously stable continental shelf. Many others have also favoured a rift-related origin for the Panjal traps (Honegger et al., 1982; Pareek, 1982; Humayun et al., 1987; Papritz & Rey, 1989).

Structural evidence for extensional tectonics in NW Himalayas is inadequate. The Paleozoic stratigraphy of the southern Tibet (Lhasa block) is identical to that of Gondwanaland (Tapponnier et al., 1981) and it has been suggested that the Lhasa block may have been contiguous with India during Permo-Carboniferous. Occurrence of shallow water marine sediments of this age in southern Tibet and NW India, for example, suggests that the two were not separated by a large, open ocean. Andrew-Speed & Brookfield (1982) have summarised data which point to similar closeness between India and Karakoram plate (which also contains volcanics of the same age and petrography as the Panjal). The eruption of the Panjal volcanics was, however, followed by the evolution of a passive (Atlantic Type) continental margin in Triassic (Steckler and Watts, 1978; Papritz & Rey, 1989), during which time lateral differences in facies became evident. Bassoulet et al. (1978) noted that the extensional tectonic activity at the break of Permo-Triassic is documented by a distinct change in sedimentary environments from neritic to pelagic. With the development of this continental margin, the character of volcanism, which was tholeiitic to mildly alkaline during Permo-Carboniferous, changed to typical alkali-basalt series during the Triassic. Thus Late-Paleozoic rifting led to break up of microcontinents from Gondwana and opening up of an ocean during Triassic and Early Jurassic.

We conclude that despite a lack of structural evidence, the Permo-Carboniferous magmatism on the NW edge of the Indo-Pak subcontinent was the manifestation of doming, crustal thinning, and rifting (cf. Kent, 1991). Continental rifting is commonly associated with three types of igneous activity: intrusion of basic dykes and alkaline complexes, and extrusion of lavas (Windley, 1984). The PAIP-Panjal-dolerite trio in NW Himalaya represents a perfect analogy. Bimodal magmatism typify several known extensional settings and occurs in rift environments of all ages. The significance of bimodal magmatism in rifts has been noted by Barberi et al. (1982), Marsh, (1987) and Piccirillo et al. (1987). The lack of structural evidence for rifting may partly be due to insufficiently detailed studies. Besides, the Mesozoic-Tertiary deformation, geomorphological changes and sedimentation may have obscured such rift-related features. The rifting and magmatism may ultimately be tied up to a hot spot (cf. Gupta et al., 1982). In the present day configuration, the proposed rift system has a NW-SE trend in Kashmir and Zanskar, along which flows the Jhelum river (Pareek, 1982). West of the syntaxis in the Peshawar plain, it seems to have a north curving E-W trend, raising the possibility that the Peshawar plain may be a rifted graben.

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REFERENCES

Acharyya, S.K., 1973. Late Paleozoic glaciation vs.volcanic activity along the Himalayan chain with special reference the Eastern Himalaya. Himal. Geol. 3, 209-230.

Ahmad, I., Hamidullah, S. & Jehan, N., 1990. Petrology and petrochemistry of the Shewa Shahbaz Garhi complex, Mardan, North Pakistan. Abs. sec. Pak. Geol. Cong. 46.

Ahmad, M., Ali, K.S.S., Khan, B., Shah, M.A. & Ullah, I., 1969. The geology of the Warsak area, Peshawar, West Pakistan. Geol. Bull. Univ. Peshawar 4, 44-78.

Ahmad, S. & Ahmed, Z., 1974. Petrochemistry of the Ambela granites, southern Swat district, Pakistan. Pak. Jour. Sci. Res. 26, 63-69.

Ahmad, Z., 1985. Mineral microanalytical data on the doleritic dykes from Mansehra-Amb state area, Hazara division, Pakistan. Acta Mineral. Pak. 1, 98-115.

Andrews-Speed, C.P. & Brookfield, M.E., 1982. Middle Paleozoic to Cenozoic geology and tectonic evolution of the northwestern Himalaya. Tectonophysics 82, 253-275.

Ashraf, M. & Chaudhry, M.N., 1977. A discovery of carbonatite from Malakand. Geol. Bull. Punjab Univ. 14, 91-94.

Barberi, F., Santacroce, R. & Varet, J. 1982. Chemical aspects of rift magmatism. In: Continental and oceanic rifts. A.G.U. Geodynamic series, (G. Palmason ed.) 8, 223-258.

Bassoulet, J.P., Colchen, M., Guex, J., Lys, M., Marcoux, J. & Mascle, G., 1978. Permian terminal neritique scythien pelagique et volcanisme sous-marin, Indices de processus tectono-sedimentaires distensifs a la limite Permian-Trias dans un bloc exotique de la suture de L ' Indus (Himalaya du Ladakh). C. R. Acad. Sci., Paris serie D 287, 675-678.

Butt, K. A., 1989. Chemistry and petrography of the Sillai Patti carbonatite complex, North Pakistan. Geol. Bull. Univ. Peshawar 22, 197-215.

Butt, K.A., 1990. Ultrapotassic hypabyssal rocks from Khyber Agency. Abs. Sec. Pak. Geol. Cong. 23.

Calkins, J.A., Offield, T.W., Abdullah, S.K.M. & Tayyab Ali, S., 1975. Geology of the Southern Himalaya in Hazara Pakistan and adjacent areas. U.S. Geol. Surv. Prof. Paper 716 C.

Chaudhry, M.N., Jafferi, S.A. & Saleemi, B.A., 1974. Geology and Petrology of the Malakand granite and its environs. Geol. Bull. Punjab Univ. 10, 43-58.

Chaudhry, M.N., Ashraf, M., Hussain, S.S. & Iqbal, M., 1976. Geology and Petrology of Malakand and a part of Dir (Toposheet 38 N/4). Geol. Bull. Punjab Univ. 10, 43-58.

Chaudhry, M.N., Ashraf, M., Hussain, S.S. & Iqbal, M, 1981. Petrology of the Koga nepheline syenites and pegmatites of Swat district. Geol. Bull. Punjab Univ. 16, 1-14.

Chaudhry, M.N. & Shams, F.A., 1983. Petrology of the Shewa porphyries of the Peshawar Plain Alkaline Igneous Province, NW Himalayas, Pakistan. In: Granites of Himalaya, Karakorum and Hindukush (F.A. Shams ed.). Inst. Geol. Punjab Univ., Lahore, Pakistan, 171-181.

Coulson, A.L., 1936 A soda-granite suite in the North-West Frontier Province. Proc. Nat. Int. Sci. Ind. 2, 103-111.

Ghazanfar, M., Chaudhry, M.N. & Latif, M.A., 1987. Three Stratigraphic Provinces of Hazara-Kashmir Boundary, Pakistan. Kashmir Jour. Geol. 5, 65-74.

Greco, A., 1986. Geological Investigations in the Rashian Area (Jhelum valley, State of Azad Jammu and Kashmir. Kashmir Jour. Geol. 4, 51-66.

Greco, A., Martinotti, G., Papritz, K., Ramsay, J.G & Rey, R., 1989. The Himalayan crystalline rocks of the Kaghan valley (NE-Pakistan). Ecologae geol. Helv. 82/2, 00.

Gupta, K.R., Gergan, J.T. & Kumar, S., 1982. Geochemistry of the volcanic rocks of North-Western Himalaya and its bearing on Tectonics - A review. In: Contemporary Geoscientific Researches in Himalaya, 2 (A.K. Sinha ed.). Singh, Dehra Dun, 9-17.

Hamidullah, S., Jabeen, N., Bilqees, R. & Jamil, K., 1986. Geology and Petrology of the Malakand Granite, Gneiss and Metasedimentary complex. Geol. Bull. Univ. Peshawar 19, 61-76.

Holm, P.E., 1985. The geochemical fingerprints of different tectonomagmatic environments using hygromagmatophile element abundances of tholeiitic basalts and basaltic andesites. Chem. Geol. 51, 303-323.

Honegger, K., Dietrich, V., Frank, W., Gansser, A., Thoni M. & Trommsdorf, V., 1982. Magmatism and metamorphism in the Ladakh Himalayas (the Indus-Tsangpo suture zone). Earth Planet. Sci. Lett. 60, 253-292.

Humayun, M., 1986. Petrology of the Swat amphibolites and the development of "Lesser Himalayan" basin. Geol. Bull. Univ. Peshawar 19, 83-100.

Humayun, M., Jan, M.Q. & Khan, M.J., 1987. A review of "Evidence of an incipient Paleozoic Ocean in Kashmir, Pakistan, K.A. Butt, M.N. Chaudhry & M. Ashraf". Kashmir Jour. Geol. 5, 121-126.

Irvine, T.N. & Baragar, W.R.A., 1981. A guide to the chemical classification of common volcanic rocks. Can. Jour. Earth Sci. 8, 523-548.

Jan, M.Q., 1969. Preliminary geology of Shilman area, Khyber Agency, with note on a copper bearing gabbro. Geol. Bull. Univ. Peshawar 4, 92-93.

Jan, M.Q., Asif, M. & Tahirkheli, T., 1981. The geology and petrography of the Tarbela "Alkaline" complex. Geol. Bull. Univ. Peshawar 14, 1-28.

Jan, M.Q., Asif, M., Tahirkheli, T. & Kamal, M., 1981 Tectonic subdivision of granitic rocks of north Pakistan. Geol. Bull. Univ. Peshawar 14, 159-182.

Jan, M.Q., Kamal, M. & Qureshi, A.A., 1981. Petrography of the Loe Shilman carbonatite complex, Khyber Agency. Geol. Bull. Univ. Peshawar 14, 29-40.

Karim, A. & Sufyan, M., 1986. Mineralogy petrology and geochemistry of dolerite dykes in Attock-Cherat Range, N.W.F.P, Peshawar. Un Pub. M.Sc. thesis Univ. Peshawar.

Kazmi, A.H. & Rana, R.A., 1982. Tectonic Map of Pakistan. Geological Survey of Pakistan, Quetta. Scale 1:2000,000.

Kempe, D.R.C., 1973. The petrology of the Warsak alkaline granites, Pakistan, and their relationship to other alkaline rocks of the region. Geol. Mag. 110, 385-404.

Kempe, D.R.C., 1978. Accicular hornblende schists and associated metabasic rocks from North-West Pakistan. Mineral. Mag. 42, 405-406. M 33-36.

Kempe, D.R.C., 1983. Alkaline granites, syenites, and associated rocks of the Peshawar Plain Alkaline Igneous Province, NW Pakistan. In Granites of Himalaya, Karakoram, and Hindukush (F.A. Shams ed.). Inst. Geol. Punjab Univ. Lahore, Pakistan. 143-169.

Kempe, D.R.C., 1986. A note on the ages of the alkaline rock of the Peshawar plain alkaline igneous province, NW Pakistan. Geol. Bull. Univ. Peshawar 19, 113-119.

Kempe, D.R.C. & Jan, M.Q., 1970. An Alkaline Igneous province in the North-West Frontier Province, West Pakistan. Geol. Mag. 107, 395-398.

Kempe, D.R.C. & Jan, M.Q., 1980. The Peshawar Plain Alkaline Igneous Province, NW Pakistan. Geol. Bull. Univ. Peshawar 13, 71-77.

Kent, R., 1991. Lithospheric uplift in eastern Gondwana: Evidence for a long-lived mantle plume system ? Geology 19, 19-23.

Khan, A.B., Shah, Z.H. & Naeem, S.M., 1970. Geology of the Ghundai Sar and, vicinity, Jamrud, Khyber Agency.Geol. Bull. Univ. Peshawar 5, 115-130.

Khan, S.R., Khan, R.N. & Karim, T., 1990. Field relationship: stratigraphic and structural position of the Shewa-Shahbazgarhi "Porphyritic microgranite". Abs. Sec. Pak. Geol. Cong. 36-37.

Khan, T., 1991. Geochemistry of the Warsak Igneous Complex N. Pakistan. Un. Pub. M. Phil. Thesis Univ. Peshawar.

Khan, W.M., 1965. The main Malakand granite. Geol. Bull.Univ. Peshawar 2, 8-10.

Le Bas, M.J., Mian, I. & Rex, D.C., 1987. Age and nature of carbonatite emplacement in North Pakistan. Geol. Runnd. 76/2, 317-323.

Le Fort, P., Debon, F. & Sonet, J., 1980. The "Lesser Himalayan" corderite granite belt typology and age of the pluton of Mansehra (Pakistan). Geol. Bull. Univ. Peshawar 13, 51-61.

Letterrier, J., Maury, R.C., Thonon, P., Girard, D. & Marshal, M., 1982. Clinopyroxene composition as a method of identification of the magmatic affinities of paleo-volcanic series. Earth Planet. Sci. Lett. 59, 139-154.

Marsh, J.S., 1987. Basalt geochemistry and tectonic discrimination within continental flood basalt provinces. In: (S.D. Weaver & R.W. Johnson ed.) Tectonic Controls on Magma Chemistry. J. Volcanol. Geotherm. Res. 32, 35-49.

Maluski, H. & Matte, P., 1984. Ages of alpine tectono-metamorphic events in northwestern Himalaya (North Pakistan) by $^{39}Ar/^{40}Ar$ method. Tectonics 3, 1-18.

Martin, N.R., Siddiqui, S.F.A. & King, B.H., 1962. A geological reconnaissance of the region between the lower swat and Indus rivers of Pakistan. Geol. Bull. Punjab Univ. 2, 1-13.

Mian, I. & Le Bas, M.J., 1987. The biotite-phlogopite series in fenites from Loe Shilman carbonatite complex. NW Pakistan. Mineral. Mag. 51, 397-408.

Nakazawa, K., Kapoor, H.M., Ishii, K, Bando, Y., Okimura, Y. & Tukuoka, T., 1975. The Upper Permian and the Lower Triassic in Kashmir, India Mem. Fac. Sci. Kyoto Univ. Series Geol. Mineral. 42, 1-106.

Pascoe, E.H., 1949. A Manual of the Geology of India and Burma (2nd ed.). Govt. of India Press, Calcutta.

Papritz, K. & Rey, R., 1989. Evidence for the occurrence of Permian Panjal Trap Basalts in the Lesser- and Higher-Himalayas of the western syntaxis area, NE Pakistan. Eclogae Geol. Helv. 82/2, 603-627.

Pareek, H.S., 1982. The Himachal Panjal Traps - A geochemical appraisal In: Contemporary Geoscientific Researches in Himalaya. Dehra Dun, India (A.K. Sinha ed.) 2, 1-7.

Pearce, J.A.,Harris, N.B.W. & Tindle, A.G. 1984. Trace element discrimination diagrams for tectonic interpretation of granitic rocks. J. Petrol. 25, 956-983.

Petro, W.L., Vogel, T.A. & Willband, J.T., 1979. Major element chemistry of plutonic rock suites from compressional and extensional plate boundaries. Chem. Geol. 27, 217-235.

Piccirillo, E.M., Raposo, M.I.B., Melfi, A.J., Comin-Chiaramonti, P., Bellieni, G., Cordani, U.G. & Kawashita, K. 1987. Bimodal fissural volcanic suites from the Parana basin (Brazil): K-Ar age , Sr-isotopes and geochemistry. Geoch. Brasil. 1, 53-69.

Qureshi, A.A., Butt.K.A., & Khan. H.A., 1990. Fission track dating of carbonatite complexes of Pakistan. Abs. Sec. Pak. Geol. Cong. 44.

Rafiq, M., 1987. Petrology and geochemistry of the Ambela granitic complex, N.W.F.P. Pakistan. Un pub. Ph.D. thesis Univ. Peshawar.

Rafiq, M. & Jan, M.Q., 1988. Petrography of the Ambela granitic complex, NW Pakistan. Geol. Bull. Univ. Peshawar 21, 27-48.

Rafiq, M. & Jan, M.Q., 1989. Geochemistry and petrogenesis of the Ambela granitic complex, NW Pakistan. Geol. Bull. Univ. Peshawar 22, 159-179.

Rafiq, M. & Jan, M.Q., 1990. Petrogenesis of basic dykes from the Ambela granitic complex, NW Pakistan. Abs. Sec. Pak. Geol. Cong. 45.

Shah, S.M.I., Siddiqui, R.A. & Talent, J.A., 1980. Geology of the eastern Khyber Agency, North Western Frontier Province. Geol. Surv. Pakistan. Rec. 44.

Shams, F.A., 1983. Granites of N.W. Himalayas in Pakistan. In Granites of Himalayas, Karakoram and Hindukush (F.A. Shams ed.) Inst. Geol. Punjab Univ., 75-122.

Shams, F.A. & Ahmed, Z., 1968. Petrology of the basic minor intrusives of the Mansehra- Amb state area, northern west Pakistan. Part-1, The dolerites. Geol. Bull. Punjab Univ., 7, 45-56.

Siddiqui, S.F.A., Chaudhry, M.N. & Shakoor, A., 1968. Geology and petrology of the feldspathoidal syenites and pegmatites of the Koga area, Chamla valley, Swat, West Pakistan. Geol. Bull. Punjab Univ. 7, 1-30.

Sinha, A.K., 1981. Geology and tectonics of the Himalayan region of Ladakh, Himachal, Garhwal-Kumaun and Arunachal Pradesh (H. K. Gupta & F. M. Delani, eds.). AGU-GSA Geodynamics series 3, 122-148.

Spencer, D.A., Ramsay, J.G., Spencer-Cervato, C. Pognante, U. Chaudhry, M.N. & Ghazanfar, M., 1991. High pressure (Eclogite facies) metamorphism in the Indian plate, NW Himalaya, Pakistan.

Srikantia, S.V. & Bhargava, O.N., 1978. The Indus Tectonic Belt of Ladakh Himalaya; its geology, significance and evolution. Tect. Geol. of the Himalaya (P. S. Sakalani, ed.) 43-62.

Steckler, M.S. & Watts, A.B., 1978. Subsidence of Atlantic type continental margin off NewYork. Earth Planet. Sci. Lett. 41, 1-3.

Tahirkheli, R.A.K., 1970. The geology of the Attock-Cherat Range, west Pakistan. Geol. Bull. Univ. Peshawar 5, 1-26.

Tapponnier, P., Mattauer, M., Proust, F. & Cassaignau, C., 1981 Mesozoic ophiolites sutures and large scale tectonic movements in Afghanistan. Earth Plant. Sci. Lett. 52, 353-371.

Wadia, D.N., 1961. Geology of India. Macmillan and Co London.

Wood, D.A., 1979. A variably veined suboceanic upper mantle-Genetic significance for mid ocean ridge basalts from geochemical evidence. Geology 7, 499-503.

Zeitler, P.K., 1982. Uproofing history of a suture zone in the Himalaya of Pakistan by means of fission-track annealing ages. Earth planet. Sci. Lett. 57, 227-240.

Zeitler, P.K., 1988. Ion microprobe dating of zircon from the Malakand granite, NW Himalaya Pakistan. A constraint on the timing of Tertiary metamorphism in the region. Geol. Soc. Am Abs. Programs 20, 323.