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The Warsak basic rocks: Initial-rift stage continental tholeiites of Permo-Triassic "Panjal" affinity

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ABSTRACT: *A suite of basic rocks, comprising microgabbros, dolerites, metabasalts and volcaniclastic sediments, occurs associated, both in space and time, with the alkaline granites at Warsak near Peshawar. Detailed geochemistry, mainly based on trace elements, suggests that the magmatism responsible for the Warsak basic rocks was tholeiitic in composition and was erupted/intruded in a within-plate continental setting. Furthermore, the Warsak basic rocks have geochemical composition closer to rift volcanics rather than the plateau basalts.*

The Warsak basic rocks, in this study, have been identified to be related with the suite of tholeiitic basalts commonly encountered as dykes and sills in the Lower Palaeozoic or older rocks of northern part of the Indian plate. The volcanic and volcaniclastic component in the Warsak area is directly correlatable with the Karapa greenschist in Ambela area, and the amphibolite marker horizon in the upper part of the Marghazar Formation of Lower Swat, which are in turn correlatable with the Permo-Triassic Panjal volcanics of Kaghan and Kashmir.

INTRODUCTION

The Warsak village (34° 10' N, 71° 23' W), located about 30 km WNW of Peshawar is famous for its two rock types, the marble and granite (Coulson, 1936), both of which have been exploited for commercial gains. An equally voluminous rock type in the area is a metamorphosed microgabbro or dolerite. It was first reported by Ahmad et al. (1969) in a detailed map of the Warsak area together with an elaborate description of their field features and petrography. Kempe (1978) described the Warsak basic rocks both in terms of petrography and geochemistry. Tazeem Tahirkheli (1990) and Tazeem Tahirkheli et al. (1990) presented a detailed trace-element geochemistry of the Warsak igneous complex.

The occurrence of the basic rocks is not unique to the Warsak area. More or less the entire northern margin of the Indian plate is characterised by a sporadic presence of basic igneous bodies of Late Palaeozoic age. Panjal basic volcanics are widespread in the Zanskar and Pir Panjal ranges of NW Himalayas (Wadia, 1931; Srikantia & Bharagava, 1978). Martin et al. (1962) reported the occurrence of a stratigraphically persistent amphibolite horizon in lower Swat, while Khan et al. (1990) and Pogue et al. (1992) recognised a greenschist metabasalt horizon in the Buner area. Numerous dolerite bodies have been reported in the Palaeozoic rocks of NWFP and Kashmir, including Attock-Cherat (Tahirkheli, 1970), Tarbela (Jan et al., 1981), Khyber Agency (Khan et al., 1970; Shah et al., 1980); Hazara (Shams & Ahmed, 1968; Calkins et al., 1975) and Kashmir (Wadia, 1931; Pascoe, 1949).

Whereas, a great majority of these basic rocks are continental tholeiitic basalts, some are alkali-olivine basalts (e.g., Tarbela; Jan et al., 1981), while others are typically peralkaline (e.g., meltiegite at Tarbela; Siddiqui, 1973; Ijolite at Koga; Mian, 1987). A suite of ultramafic and gabbroic rocks, emplaced as a tectonic klippe at Dargai represents a distinct igneous association of ophiolitic affinity.

This work re-evaluates the geochemistry of the Warsak basic rocks with particular emphasis on their tectonic significance. It has been demonstrated that they are compositionally identical to the continental tholeiites from Panjal volcanics, the dolerite dyke/sill suite of Peshawar Plain, Hazara and Kashmir, and lower Swat greenschist and amphibolite metabasalt horizons.

FIELD RELATIONS AND PETROGRAPHY

Field Distribution

Sheeted bodies of basic rocks concordant to the foliation in granites and bedding in the metasediments are common in the Warsak area, making about 30% by volume of the igneous complex. On the road leading to the Dam, the first outcrops near Ismail Kili are those of fine-grained dolerite. Alternating with the sheets of porphyritic granites, there are two major sheets of basic rocks, 600 and 400 m wide, respectively (Fig. 1). Further to the west there are dozens of sheeted masses ranging in width from a few metres to several tens of metres. The Warsak main granite at the dam site contains several basic sheets each few metres in width, apparently enclosed in the granite mass. Ahmad et al. (1969) have reported minor stock-like intrusions of basic rocks in the Warsak porphyritic granites to the north of the river.

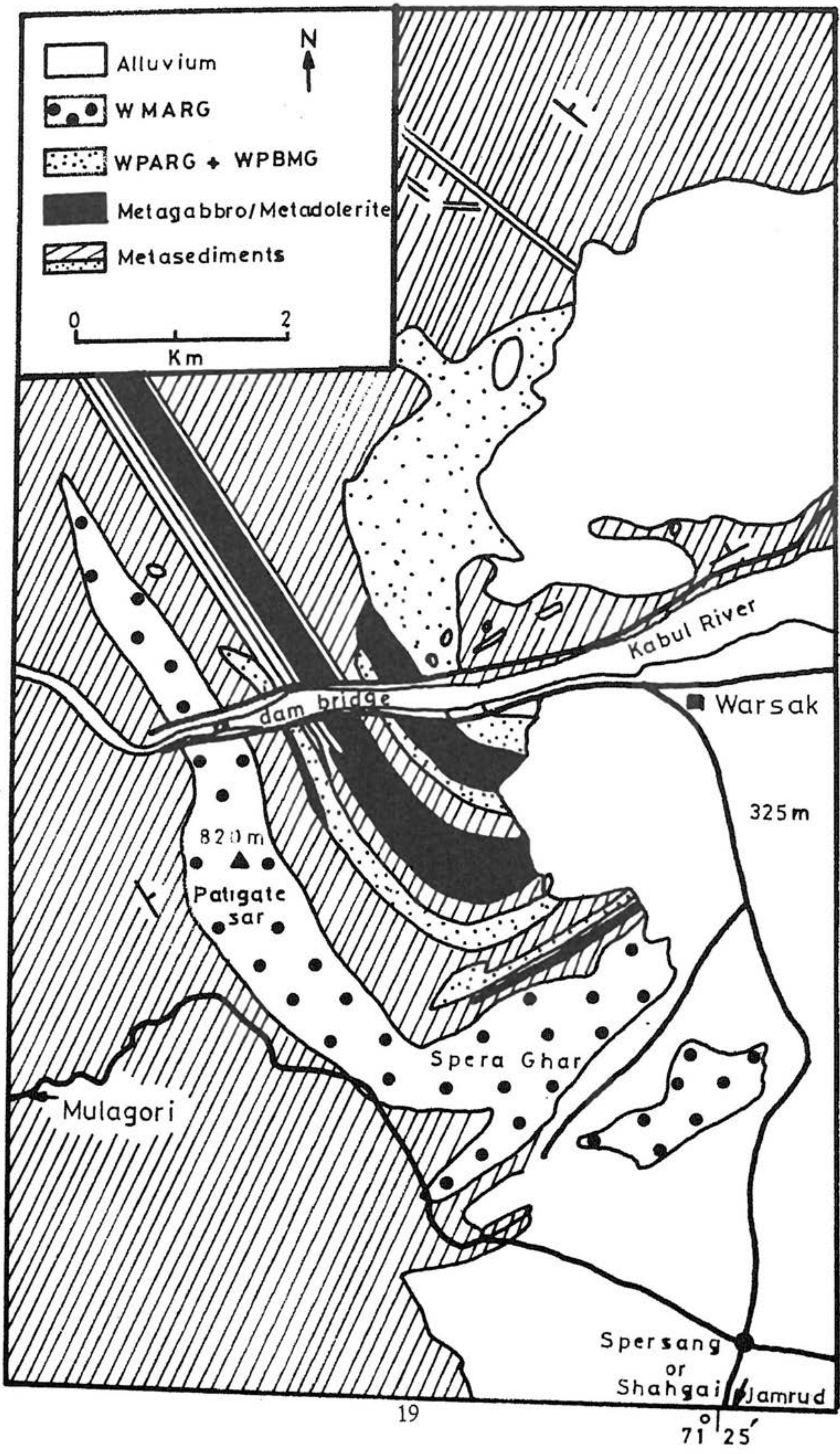
In addition to the basic rocks of an unambiguous hypobyssal igneous origin, there are sheeted masses of basic composition which are apparently volcaniclastic. These rocks which have been interpreted to be metamorphosed tuffs by Kempe (1978) and mapped as accicular hornblende schists by Ahmad et al. (1969) make about 10% of the basic rocks. The sheets of these rocks are generally less than 10 m in width occurring in alternation with the sheets of granites and metasediments in a fashion similar to the main basic sheets of dolerite/microgabbro composition.

Field Features

The Warsak basic rocks are mainly fine grained and homogeneous. In one outcrop pillow-like structures are observed which are obliterated by shearing. At several places the fine-grained basic rocks grade into medium grained gabbros, apparently without any break. The larger bodies are commonly cut across by shear zones, whereas the smaller sheets are entirely sheared, furnishing a distinct planar fabric to the rocks.

The basic rocks generally lack any xenoliths. Their contact relations with the adjacent granite sheets are highly variable, either being knife-edge sharp or sheared. Apophyses of the basic rocks extending into the granites or vice versa are rare. As mentioned earlier, at the dam site, sheets of basic rocks are seen enclosed in the granites. Reverse relations have been mapped by Ahmad et al. (1969), whereby basic bodies of circular shape are seen intrusive into the microgranite. Thus it appears that the Warsak Igneous Complex represents a bimodal magmatism generated and emplaced either simultaneously or within a short time interval.

Fig. 1. Geological map of the Warsak area, Khyber Agency (simplified after Ahmad et al., 1969). WMARG = Warsak Main Aegirine-riebeckite Granite; WPARG = Warsak Porphyritic Aegirine-riebeckite Granite, WPBMG = Warsak Porphyritic Biotite-Muscovite Granite.


Alluvium
WMARG
WPARG + WPBMG
Metagabbro/Metadolerite
Metasediments
N
0
2
Km
Kabul River
34'
10
Warsak
dam bridge
325m
820m
Patigate
sar
Spera Ghar
Mulagori
Spersang
or
Shahgai
Jamrud
71°
25'

Petrography

The Warsak microgabbros, now metamorphosed to amphibolites, are generally black to dark green in colour and black to greyish yellow on the weathered surface. As mentioned earlier some are highly sheared and thus are schistose in appearance. Others range from foliated to massive, depending upon the degree of shearing. Amphibolitization is also controlled by the degree of deformation; the sheared rocks are generally more metamorphosed than the homogeneous ones.

The Warsak basic rocks are composed essentially of amphibole, plagioclase, epidote, quartz, biotite, sphene, ilmenite and rarely garnet. This mineralogy is typically found in the basic rocks now metamorphosed to amphibolites. Amphibole in these rocks occurs as short prismatic grains, with a matrix comprising of plagioclase commonly altered to epidote either partially or wholly. In the sheared rocks all the amphibole prismatic grains are aligned together defining shear fabric. In such rocks quartz epidote and relict plagioclase are concentrated into bands alternating with amphibole-rich bands. In some rocks, two textural varieties of amphibole are observed; one short prismatic to tabular and the other in the form of thin prismatic grains of substantial lengths (up to 6 mm) oriented parallel to the foliation. Plagioclase, when relict, occurs as untwined crystals containing abundant tiny epidote grains as alteration product. In the sheared rocks plagioclase is generally recrystallized as smaller grains accompanied by abundant alteration to epidote. Quartz typically occurs in small amoeboidal grains with undulatory extinction.

At several places, the gabbroic rocks have escaped shearing and metamorphism and thus retain the original igneous textures. Certain rocks, approaching ultramafic composition, are typically cumulate. In them there are large (4 x 4 mm in diameter) randomly oriented tabular crystals of clinopyroxene forming mosaics in which the interstices between the pyroxene crystals are occupied by post-cumulus plagioclase. In the gabbroic rocks both clinopyroxene and plagioclase are cumulus minerals, and it is only the magnetite and ilmenite and minor quartz which form post cumulus minerals. Unfortunately the proportions of the unmetamorphosed basic rocks, with original igneous mineralogy and textures intact, are very small in the Warsak Igneous Complex. On the basis of limited number of fresh samples, it has been concluded that the earliest crystallising mineral in the Warsak basic rocks was clinopyroxene, followed by plagioclase, iron-titanium oxides, and quartz. This sequence of crystallisation of minerals is typical of tholeiitic basic suites.

GEOCHEMISTRY, TECTONIC SETTING AND PETROGENESIS

Geochemical studies, based on a limited number of samples have previously been carried out by Kempe (1978). He classified the Warsak basic rocks as calc-alkaline, and suggested comparison and correlation with the calc-alkaline basic rocks of Kohistan (e.g., Chilas Complex; Jan et al., 1984; Khan et al., 1989). This is, however, at variance with the position of the Warsak area at the northern margin of the Indian plate rather than being the part of the Kohistan island arc terrane. If there is any possibility of correlation, it would be either with the basic rift-related tholeiite to alkaline basic rocks of the Indian plate (e.g., Tarbela, Koga, Lower Swat and Kaghan-Kashmir) or with the ophiolitic ultramafic and mafic rocks (e.g., Dargai). Here we use whole-rock geochemistry to define the nature of the Warsak basic rocks, particularly in terms of their tectonic setting of origin and relationship with the varieties of basic rocks found around Peshawar.

Twenty seven samples are listed in Table 1 of which 17 are analysed for both major and trace

TABLE 1. WHOLE-ROCK XRF ANALYSES OF THE WARSAK BASIC ROCKS.

Sample	W14	W17	W18	W19	W20	W26	W29	W30	W34	W36	W5	W54	T30	T31	T34	T35	T38	T39	T43	T44	T50	T52
SiO_2	49.00	46.00	44.00	48.00	47.00	48.00	49.00	48.00	48.00	48.00	49.00	50.00	—	—	—	—	—	—	—	—	—	—
TiO_2	1.54	2.02	5.22	3.56	1.46	3.30	2.80	3.70	1.59	1.50	1.90	2.90	—	—	—	—	—	—	—	—	—	—
Al_2O_3	13.00	9.00	10.00	16.00	11.10	10.00	13.00	11.00	12.00	12.00	11.00	11.90	—	—	—	—	—	—	—	—	—	—
Fe_2O_3	14.00	11.00	17.00	13.00	14.00	15.00	12.00	15.00	12.00	12.00	16.00	14.50	—	—	—	—	—	—	—	—	—	—
MnO	0.24	0.10	0.20	0.80	0.22	0.20	0.20	0.20	0.20	0.20	0.20	0.20	—	—	—	—	—	—	—	—	—	—
MgO	7.00	6.00	7.00	6.00	6.50	8.00	7.00	5.00	7.00	7.00	6.00	5.10	—	—	—	—	—	—	—	—	—	—
CaO	11.00	19.00	12.00	4.00	12.80	10.00	9.00	8.00	11.00	10.00	11.00	8.20	—	—	—	—	—	—	—	—	—	—
Na_2O	3.00	2.00	1.40	5.00	2.20	2.00	2.00	2.00	3.00	2.00	2.40	2.50	—	—	—	—	—	—	—	—	—	—
K_2O	0.51	0.45	1.13	0.92	0.20	0.40	0.50	1.00	0.30	1.00	0.50	1.50	—	—	—	—	—	—	—	—	—	—
P_2O_5	0.17	0.24	0.66	0.21	0.18	0.20	0.20	0.60	0.19	0.20	0.20	0.40	—	—	—	—	—	—	—	—	—	—
Total	99.46	95.81	98.61	95.81	95.7	97.2	95.8	94.5	95.3	93.9	98.2	97.0	—	—	—	—	—	—	—	—	—	—
Nb	7.0	23.6	46.5	37.0	4.1	14.3	10.4	25.6	10.6	8.9	6.9	28.5	6.3	—	—	6.8	—	—	—	—	24.0	—
Zr	98.4	220.6	236.7	405.8	93.9	143.7	121.6	308.5	133.4	116.8	127.7	339.4	69.9	—	18.0	115.4	8.6	27.7	9.6	10.7	198.8	22.1
Y	24.0	36.3	33.2	65.5	27.8	27.2	17.3	40.0	26.5	25.9	37.5	51.9	21.5	32.8	203.2	33.7	134.1	386.4	130.0	129.4	39.1	263.0
Sr	261.0	829.0	823.0	587.0	688.0	331.0	375.0	339.0	300.0	275.0	186.0	320.0	453.0	703.0	25.0	308.0	20.0	46.0	28.0	27.0	317.0	42.0
Rb	12.2	13.7	36.3	29.7	2.1	12.5	17.1	45.8	5.4	25.4	10.7	44.6	14.8	2.0	—	1.7	—	—	—	—	10.4	—
Th	3.5	11.5	5.0	12.5	1.0	4.5	4.0	5.5	4.5	3.5	4.0	8.5	1.0	—	31.8	0.9	14.0	49.9	21.5	11.2	1.7	65.8
Pb	4.0	12.5	10.0	9.5	11.0	6.5	4.0	9.5	8.5	5.5	6.0	4.0	—	—	2.1	—	0.8	4.1	2.4	1.6	—	5.1
Ga	19.0	25.0	25.0	34.0	19.0	21.0	23.0	24.0	22.0	20.0	21.0	23.0	20.0	19.0	—	19.0	—	—	—	—	25.0	—
Zn	86.0	70.0	140.0	84.0	83.0	120.0	91.0	147.0	82.0	82.0	108.0	125.0	89.0	82.0	24.0	112.0	23.0	26.0	19.0	19.0	111.0	26.0
Ni	57.0	77.0	44.0	135.0	56.0	96.0	26.0	17.0	99.0	98.0	53.0	50.0	62.0	57.0	102.0	53.0	92.0	146.0	80.0	80.0	26.0	121.0
Cr	70.0	381.0	20.0	366.0	46.0	121.0	42.0	17.0	248.0	245.0	53.0	51.0	38.0	49.0	27.0	38.0	29.0	21.0	93.0	107.0	12.0	11.0
V	350.0	216.0	474.0	355.0	363.0	587.0	344.0	418.0	313.0	306.0	439.0	367.0	474.0	374.0	33.0	376.0	40.0	17.0	254.0	260.0	520.0	14.0
La	6.9	32.3	34.3	52.6	5.9	13.2	8.9	24.1	9.7	8.2	6.7	28.2	—	10.0	397.8	—	327.9	389.5	314.2	316.4	18.7	358.6
Ce	18.4	75.8	77.2	113.0	16.7	30.1	20.2	54.5	25.3	18.8	19.6	68.3	23.1	26.9	13.5	18.0	12.3	27.1	9.2	10.0	51.7	23.4
Nd	10.5	37.4	44.5	63.2	11.5	17.1	12.6	31.0	14.5	13.1	14.1	38.1	11.0	16.2	32.3	13.0	27.8	67.8	20.9	22.2	30.0	62.9
Ba	131.0	242.0	399.0	197.0	54.0	323.0	214.0	345.0	72.0	179.0	128.0	381.0	232.0	87.0	19.0	61.0	17.0	40.0	14.0	14.0	84.0	34.0

elements and the rest only for trace elements. All the analyses were carried out on a Philips spectrometer using pressed powder pellets. Five analyses previously published by Kempe (1978) are used in subsequent plots.

Classification

Since the Warsak basic rocks are generally metamorphosed, their modal mineralogy classifying them as amphibolites does not yield much information about their original igneous nomenclature. La Roche et al. (1980) and Cox et al. (1979) have proposed classification schemes which are based on major elements and are thus particularly useful for rocks which are either fine grained or altered to the extent that original mineralogy is no more intact. Most of the Warsak basic rocks plot as a coherent group in the fields of various types of gabbros (including olivine gabbro, gabbronorite, and gabbrodiorite) in the classification diagram of La Roche et al. (1980) (Fig. 2a). Two samples plot in the field of ultramafic rocks; W20 near the position of dunite and W17 in the field of pyroxenites. Three samples are relatively feldspathic and plot in the field of syenodiorite, monzonite and monzodiorite. These samples are suspected to have been hybridised by reaction with closely associated and contemporaneous granitic fluids at the time of emplacement. In the classification scheme of Cox et al. (1979) (Fig. 2b), majority of the Warsak basic rocks plot in the field of basalts, with the exception of WS17 and WS20, which plot in the field of picrites.

MAJOR ELEMENT GEOCHEMISTRY AND C. I. P. W. NORMS

The Warsak basic rocks are characterised by a vast variation in the degree of silica saturation. Most of the rocks are quartz normative accompanied by hypersthene in the norms. Others are hypersthene and olivine normative, whereas one sample contains nepheline in the norms. These variations are reflected in the scatter of data on Figure 2a.

Variations in major element contents, monitored by plotting them against fractionation indices like SiO_2, MgO etc. show that TiO_2, Fe_2O_3, CaO and MgO decrease with increasing fractionation, whereas Al_2O_3 and alkalis increase (Tazeem Tahirkheli, 1990). These variations suggest a relatively greater role of crystallisation of ferromagnesian minerals (mainly clinopyroxene) than plagioclase during differentiation.

On the AFM plot (Fig. 3a), the Warsak basic rocks are typically enriched in iron relative to alkalis; a character found in tholeiitic basalts rather than calc alkaline. It is interesting that the data from Kempe (1978) also plot in the tholeiitic field. This, together with a greater number of samples used in this study, unambiguously classify the Warsak basic rocks as tholeiites (Fig. 3a, 3b). Since the basic rocks of possible alkaline nature are previously reported from the Peshawar plain, e.g. from Tarbela (Siddiqui, 1973; Jan et al., 1981) and Koga (Siddiqui et al., 1968; Mian, 1987), it was felt important to explore the alkaline character of the studied rocks. In Figure 3c total alkalis are plotted against SiO_2. Except for one sample, all the basic rocks from the Warsak area plot in the field of subalkaline rather than alkaline rocks, omitting the possibility of a similarity with alkaline basic complexes of the Peshawar plain.

TRACE-ELEMENT GEOCHEMISTRY AND TECTONIC SETTING OF MAGMA GENERATION

A stated earlier, determination of tectonic setting of magma generation for the basic rocks of the Warsak area is important in the context of changing palaeo-environments at the northern margin of the Indian plate. Alkaline ultrabasic and basic rocks have been already reported from the surroundings of the Peshawar plain (e.g.,

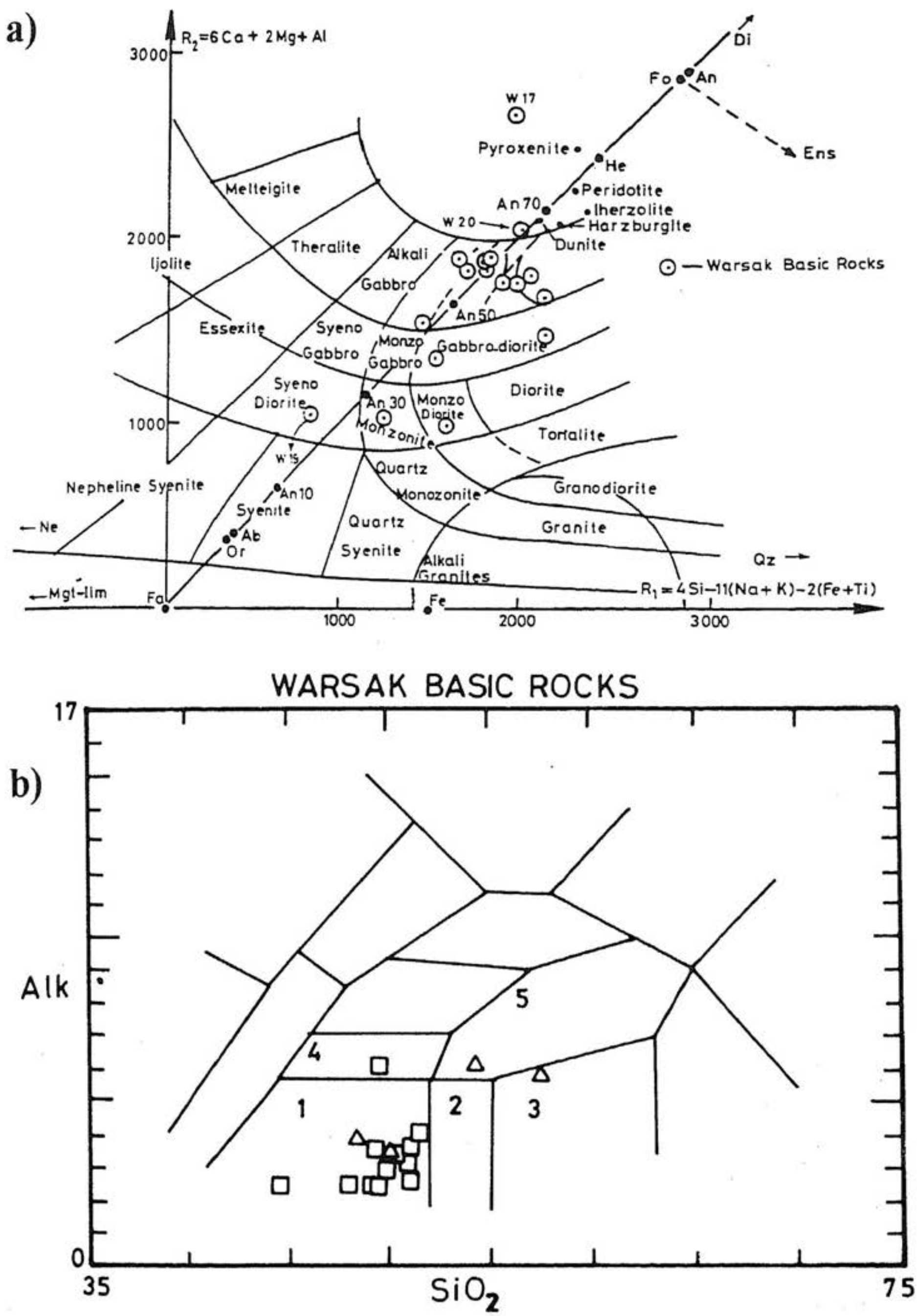


Fig. 2. Classification of the Warsak basic rocks using schemes of a) La Roche et al. (1980), b) Cox et al. (1979). Squares = samples analysed during this study, triangles = data from Kempe (1978). 1) Basalt, 2) Basaltic Andesite, 3) Andesite, 4) Hawiites, 5) Dacites.

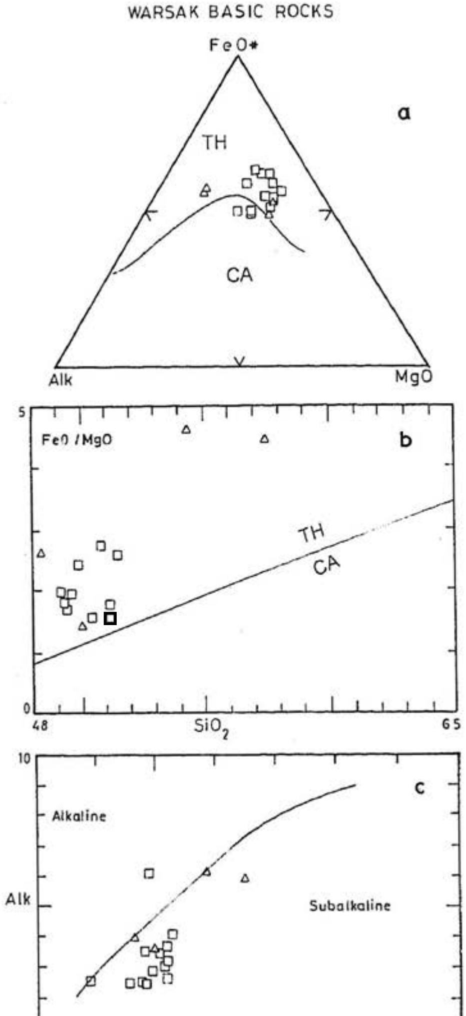


Fig. 3. a) AFM plot of the Warsak basic rocks. The line demarcating the division between calc-alkaline and tholeiite basalts is after Irvine and Baragar (1971). b) The FeO (total)/MgO vs SiO_2 plot of the Warsak basic rocks for the characterisation of their tholeiitic nature (after Miyashiro, 1974). c) The characterisation of tholeiitic vs alkaline character of the Warsak basic rocks (after Irvine & Baragar, 1971). TH = Tholeiite, CA = Calc-alkaline. Alk = Na_2O + K_2O.

Tarbela: Jan et al., 1981; Koga; Siddiqui et al., 1968; Mian, 1987), which together with the peralkaline granites (such as those of Warsak and Shewa Shahbazgarhi) and nepheline syenite of Koga area (Rafiq, 1987; Le Bas et al., 1987) suggest extensional environments (rifting) in the Indian plate sometime in Carboniferous (Le Bas et al., 1986). The tholeiitic nature of the Warsak basic rocks demonstrated above negates any direct comparison with the alkaline basic magmatism. However, detailed treatment of trace element data in terms of discrimination diagrams show that the Warsak basic rocks represent within-plate continental tholeiites with a strong component of initial-rift regimes.

Within-plate position of the Warsak Basic Magmatism

In the last two decades several discriminatory diagrams have been proposed to determine tectonic setting of magmatism. High-field strength elements (HFSE) such as Zr, Y, Ti, and Nb, which are least susceptible to alteration are found to be particularly useful in determining the tectonic setting of magma generation. Figure 4 shows incompatible trace element composition of tholeiite basalts from the three main settings of

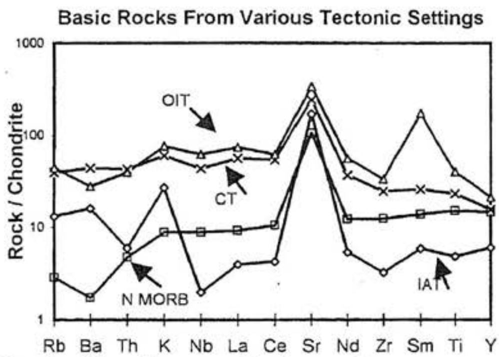


Fig. 4 Chondrite-normalised trace-elements patterns for the tholeiitic basalts from various tectonic settings. Mid-Oceanic Ridge Basalts (MORB), Oceanic Island Tholeiites (OIT), Island-Arc Tholeiites (IAT) and Within-Plate Continental Tholeiites (CT).

magma generation; island arc, mid-ocean ridge, and within plate (including within ocean island and within continent). The within-plate tholeiites are clearly enriched in all the incompatible trace elements (except for Sr) relative to the tholeiites of other two tectonic settings. Although, the lower or higher concentrations of incompatible trace elements may be due to the composition of the source material, their concentration is also influenced by the degree of fractional crystallisation. Inter-element ratios of incompatible trace elements are, however, indices which are not changed by processes such as fractional crystallisation or degree of partial melting, but reflect composition of the source material. There are several discriminatory diagrams which are based on concentrations of the trace elements, in particular, HFS elements and their inter-element ratios.

1) Pearce and Norry (1979) showed that the basalts from island arcs, mid-oceanic ridges and within-plate environments contain different levels of Zr contents, being lowest in the arc basalts and highest in the within-plate basalts. In the Warsak basic rocks there is a variable content of Zr with a minimum at 60 ppm, which is distinctly higher than what is commonly found in basic rocks of island arcs and oceanic ridges (Fig. 5a).

2) Pearce and Norry (1979) showed that although the Zr content is generally high in the within-plate basalts, it is the ratio of Zr/Y which is of a greater diagnostic value. They emphasised that whereas the content of Zr (or for that matter any incompatible element) may vary depending upon the degree of fractional crystallisation, ratios such as Zr/Y reflect the differences in the source mantle regions. They showed that the arc basalts have least, MORBs intermediate, and within-plate basalts highest, Zr/Y ratios (Fig. 5a). The differences in the Zr/Y ratio between MORB and within-plate basalts is attributed to differences in the source mantle; being depleted (N-type) in the case of MORB and enriched (E-type) in the case of the within-plate basalts. In the case of arc basalts the lowest Zr/Y ratio was attributed to relatively greater degree of partial melting from a depleted mantle source. Most of the basic rocks from Warsak have high contents of Zr and high Zr/Y ratios, comparable with within-plate basalts (Fig. 5a).

3) Pearce and Gale (1977) demonstrated that Nb is typically high in within-plate basalts compared to the arc volcanics and mid-oceanic ridge basalts. The Warsak tholeiites contain Nb in the range of 3-50 which is distinctly higher than arc and mid-oceanic ridge basalts and comparable with basalts from the within plate settings (Fig. 5b).

4) A discriminatory plot involving Zr, Nb, and Y was suggested to be most powerful in distinguishing various types of tholeiitic basalts by Meschede (1986). The Warsak basic rocks do not plot as a coherent group in this diagram, some of the samples plot in the field of volcanic arc basalts, a couple in the field of E-type MORB, and one in the field of within-plate alkali basalts. Most of the samples from Warsak, however, plot in the field of within-plate tholeiitic basalts (Fig. 5c).

5) High Ti content is another diagnostic characteristic of within-plate basalts. The Warsak basic rocks plot mostly in the field of within-plate tholeiites in diagrams involving Ti as discriminatory element (Fig. 6a,b,c).

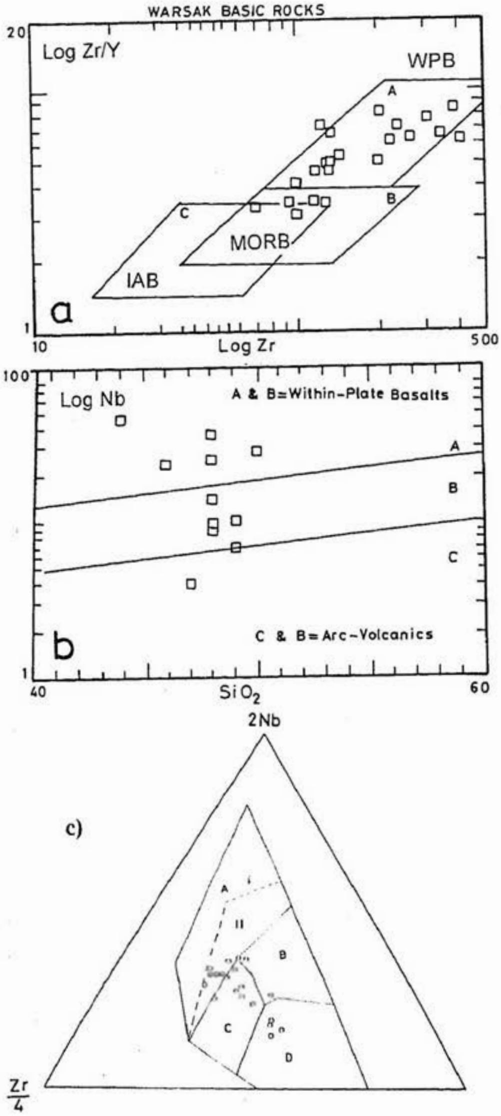


Fig. 5. Characterisation of the tectonic setting of origin of the Warsak basic rocks using a) Zr content and Zr/Y ratios (after Pearce & Norry, 1979). WPB = Within-plate basalts, MORB = Mid-ocean ridge basalts, IAB = Island arc basalts, b) Nb (Pearce & Gale, 1977), and c) Nb-Zr-Y (Meschede, 1986 A I & A II = Within-plate alkali basalts, A II & C = Within-plate tholeiites, B = P-MORB, D = N-MORB, C & D = volcanic arc basalts.

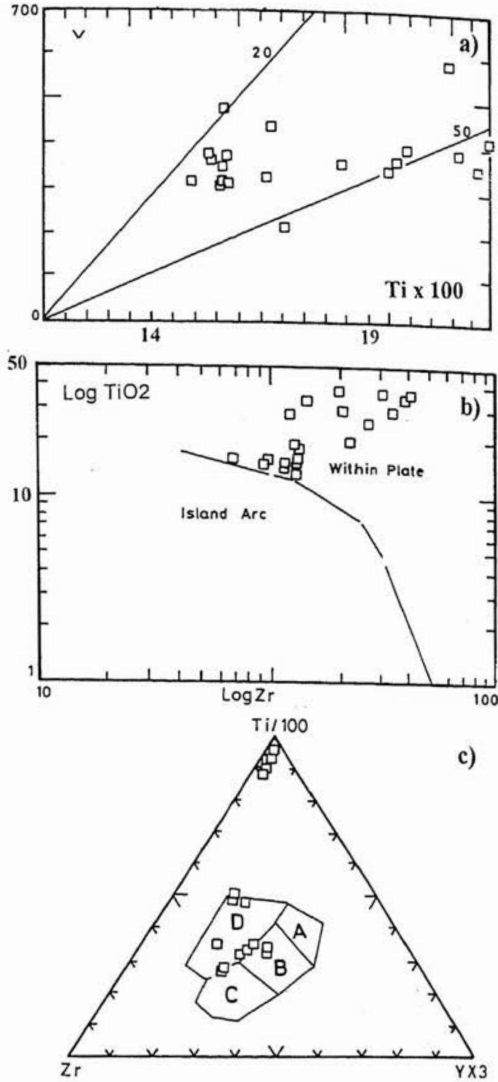


Fig. 6. Various discrimination diagrams involving Ti, for the characterisation of tectonic setting of magma generation for the Warsak basic rocks: a) Ti vs V plot (after Shervais, 1982). Flood basalts of within-plate origin (e.g., Columbia river) plot between the lines defining V/Ti ratios 20 and 50, as do those of the Warsak area; b) TiO_2 vs. Zr. c) Zr-Ti-Y (after Pearce & Cann, 1973) A = Arc basalts, B = Ocean-floor basalts, B & C = Calc-alkali basalts and D = Within-plate basalts.

6) Higher Zr and Ti contents relative to Y in within plate basalts have been used to discriminate them from basalts of other tectonic setting (Pearce & Cann, 1973). Some of the Warsak basic rocks have abnormally higher Ti and thus cluster near the Ti end in this diagram, however, rest of the samples plot in the field of within-plate basalts (Fig. 6c).

It is clear from the incompatible trace-element data of the Warsak basic rocks that they belong to a within-plate setting of magma generation. Within-plate tholeiites, however, can be either oceanic or continental.

The warsak basic rocks as continental tholeiites

It is generally difficult to distinguish continental basalts from the basalts erupted in oceanic islands from within-plate oceanic settings. Rocks from both these settings are considered to have derived from mantle sources enriched in incompatible trace elements. Moreover, the degree of partial melting is considered to be low, so that melting of major constituent mineral phases does not dilute the concentrations of the incompatible trace elements. Lo (1981) has devised diagrams involving ratios of Rb/Sr, Ca/Sr, K/Rb and K/Sr distinguishing continental tholeiites from the oceanic and island arc tholeiites. The Warsak basic rocks have high Rb contents, and low K/Rb and Ca/Sr ratios which clearly assign them a setting similar to that of the continental tholeiites (Fig. 7a,b,c).

Initial-rift component in the genesis of the Warsak basic rocks

Myers and Breitkopf (1989) have rightly pointed out that the tectonic settings of magma generation are not static but evolve continuously. The implication is that basalt compositions are as transitional as the tectonic processes. Although it has been demonstrated that the Warsak basic rocks are within-plate continental tholeiites, there are certain trace-element characteristics which suggest their transitional composition between plateau-type continental flood basalts and basalts erupted in initial rifting of a continental plate.

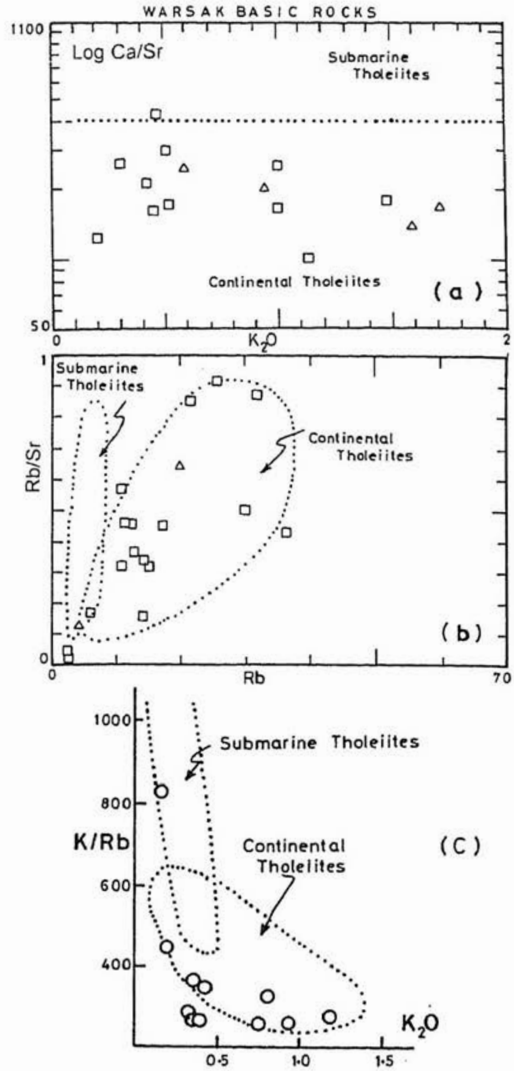


Fig. 7 (a, b, c). Distinction of continental and oceanic tholeiites (after Lo, 1981).

1) Pearce et al. (1975) devised a diagram based on incompatible elements K, Ti, and P to separate basalts of oceanic and

continental tholeiites (Fig. 8a). Holm (1985) has introduced a diagram based on elements Nb, Ti, and Th, with a similar objective (Fig. 8b). Whereas the Warsak basic rocks have yielded signatures of truly within-plate, continental tholeiites on several diagrams, their plots in Figures (8 a,b) yield scatters between the continental and oceanic tholeiites. As reviewed by both Holm (1985) and Myers and Breitkopf (1989), there are several basaltic suites from apparently within-plate continental settings (including e.g., Tertiary basalts of Scoresby Sund area of East Greenland; basalts of west Greenland and Baffin Island; basalts of the Deccan plateau) which, like the Warsak basic rocks, straddle the fields of oceanic and continental-tholeiite in the discriminatory diagrams of Pearce et al. (1975) and Holm (1985). Although it can be argued that factors like alteration, contamination and fractional crystallization may be responsible for the scatter of the data in these diagrams, more likely it is the transitional nature of the basalts from these suites which accounts for their combined continental and oceanic characters. In theory, a thinned continental crust with eruption of plateau basalts is likely to ultimately develop into an actinic basin with MORB like basalts, if extensional environments prevail for a considerable geological time. Pearce et al. (1975) interpreted the transitional nature of the basalts from East Greenland, West Greenland and Baffin island and Deccan plateau as indicating "initial rifting of the continent and generation of sea floor" of the Atlantic ocean, Labrador Sea, and Indian ocean, respectively. The transitional characteristics of the Warsak basic rocks can similarly be interpreted as related to tholeiites erupted in the initial stages of a rift. The initial rifting component in the Warsak basic rocks is also indicated in Figure 8c, based on TiO_2 vs K_2O/Alkalis devised by Chandrasekharam and

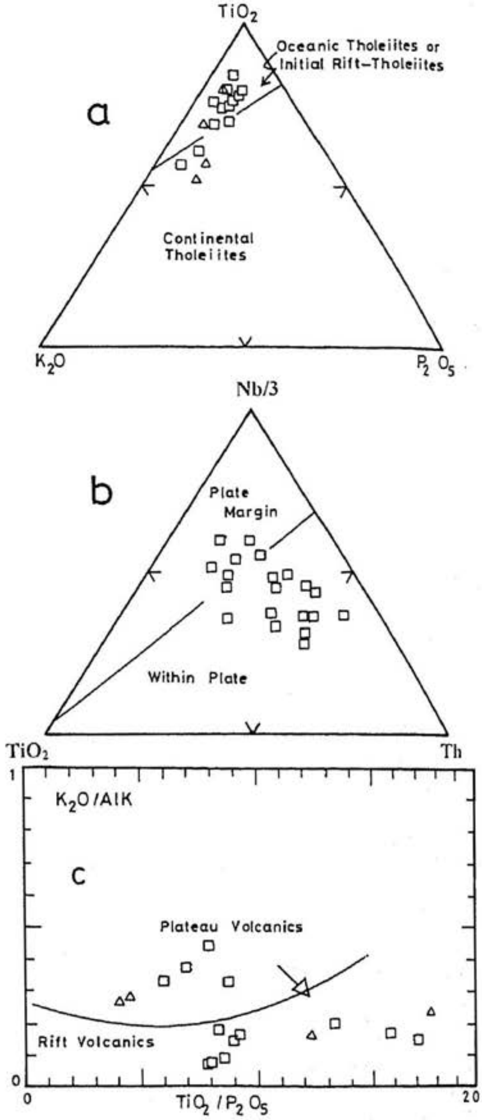


Fig. 8. Various diagrams used to determine the initial-rift component in the Warsak basic rocks: a) TiO_2-P_2O_5-K_2O (after Pearce et al., 1975); b) The TiO_2-Nb/3-Th (after Holm, 1985) and c) K_2O/Alkalis vs TiO_2/P_2O_5 (Chandrasekharam & Parthasarty, 1978).

Parthasarty (1978) for distinguishing plateau basalts from rift volcanics.

2) Affiliation of the Warsak basic rocks to initial rifting is also indicated by mantle-normalised multi-element patterns such as those shown in Figure 9. According to Holm (1985), the mantle-normalised trace-element patterns of continental flood/plateau basalts are characterised by a general negative slope (sloping towards left), with a negative Nb anomaly. The initial-rifting tholeiites, in comparison are characterised by an asymmetrical inverted U, positive Nb anomaly, and a high Ti/Y ratio, reflected in a negative slope for the segment Ti-Y (Fig. 9a). Representative samples from the basic rocks from Warsak are shown in Figure (9b, c). It is noticeable that except for some differences in the segment Rb-K, which comprises relatively mobile trace elements, the pattern of Warsak basic rocks is comparable with initial-rifting tholeiites particularly in terms of a positive Nb anomaly and a high Ti/Y ratio.

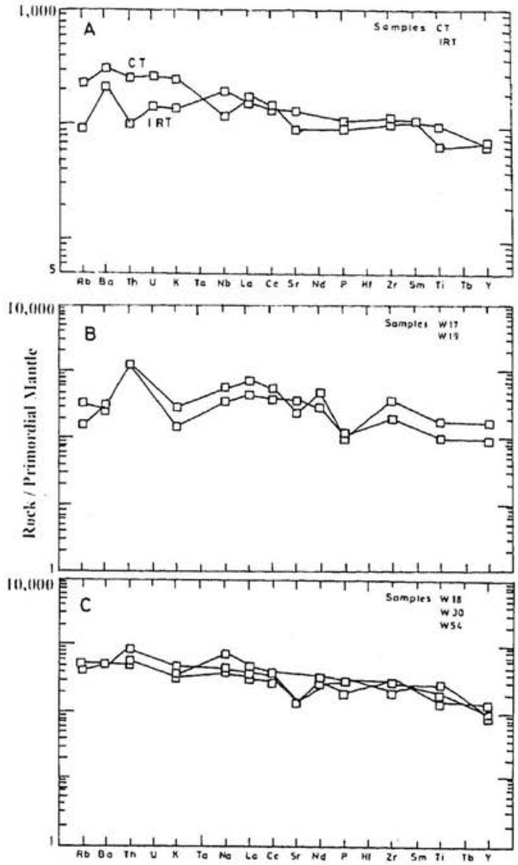


Fig. 9. A) Mantle-normalised trace-element patterns of the continental tholeiitic basalts (CT) compared with tholeiites with components of initial rifting (IRT) (after Holm, 1985); B, C) Mantle normalised patterns of the Warsak basic rocks showing an initial-rifting component reflected in a positive Nb anomaly and a high Ti/Y ratio.

REGIONAL CORRELATION

The existence of an alkaline province in the surroundings of Peshawar is recognised since long (Kempe & Jan, 1970, 1980; Kempe, 1973; Butt et al., 1980; Le Bas et al., 1987). However, the basic rocks, found commonly associated with alkaline granites were not considered part of the province. For instance, Kempe (1978) correlated the Warsak basic rocks with high-aluminium basalts of subduction-related origin from Kohistan. The suggestions that the alkaline rocks of the Peshawar Plain may be related with the associated basic rocks came from the work of Jan et al. (1981) from the Tarbela area, where the basic rocks were found to be ranging from alkaline to tholeiitic in composition and closely associated with the peralkaline granites. Most recently, Khan et al. (1990) and Pogue et al. (1992) have recognised a metabasalt horizon in the Jafar Kandao Formation of Permian age from south of Daggar, lower Swat. Recent mapping in the Khyber area (Ashraf Khan & Aslam Khan, unpublished work) has resulted in the recognition of an intact stratigraphy between Siluro-Devonian Gundai Sar reef at Jamrud and metamorphosed argillaceous rocks at Warsak. The strata at Warsak is commonly considered to be of Palaeozoic age

(Ahmad at al., 1969; Kempe, 1978). Our field observations around Warsak suggest a close resemblance between the Warsak metasediments and those of the Jafar Kandao Formation of Khan et al. (1990). Both are predominantly argillaceous, contain sporadic pebbly horizons and include stratigraphic horizons comprising metabasalts and microporphyries. It is notable, that Tazeem Tahirkheli et al. (1990) suggested that porphyritic granites in the Warsak area are probably older than the main alkaline granite of Warsak. In the light of work by Khan et al. (1990) and Tazeem Tahirkheli (1990) it appears that Peshawar Plain granite porphyries (including those of Shahbazgarhi; Kempe & Jan, 1980; Ahmed et al., 1990 and Warsak; Ahmad et al., 1969; Tazeem Tahirkheli, 1990) are metamorphosed rhyolites and associated tuffs emplaced as an extrusive horizon during the deposition of the Jafar Kandao Formation. The metabasalts at Warsak and Karapa (Khan et al., 1990; Pogue et al., 1992) extruded more or less simultaneously with the granite porphyry and occupied a specific horizon in the upper part of the Permian Jafar Kandao Formation.

The findings regarding extrusive equivalents of the gabbroic and dolerite rocks around Peshawar Plain occur as stratigraphic horizons in the Jafar Kandao Formation at Karapa (lower Swat) and Warsak have important bearings on the regional stratigraphic correlation at the northern margin of the Indian plate. The existence of Panjal volcanics as a major volcanic event in the late Palaeozoic at the northern margin of the Indian plate is a common knowledge. It is wide spread in the Panjal Range of Kashmir and the extension has been recognised at least up to the Kaghan valley in the east. A suite of basic dykes in Kashmir and Kaghan intruding the rocks older than the Late Palaeozoic is considered to be plutonic equivalent of these rocks (Papritz & Rey, 1989; Spencer et al., 1990). The Peshawar-Plain basic rocks resemble closely with the Panjal volcanics in terms of the time of emplacement (i.e., late Carboniferous-Early Triassic), existence of a suite of gabbroic and doleritic rocks intruding strata older than Late Palaeozoic (Pogue et al., 1992) and a predominantly tholeiitic to mildly alkaline basaltic composition. Thus several lines of evidence support a close correlation between the Warsak basic rocks and the Panjal volcanics, as noted previously by Tazeem Tahirkheli et al. (1990) and Jan and Karim (1990).

DISCUSSIONS

The Warsak igneous complex is a bimodal suite of igneous rocks comprising peralkaline to peraluminous granites, on the one hand, and basic rocks of basaltic (gabbroic) composition on the other. These diverse igneous lithologies are in a close field association, in the form of alternating sheeted masses which are concordant both mutually and with the metasedimentary country rocks. The field relations do not yield unambiguous relative age relations between the two rock types; Ahmed (1951) considered the granites to be older than the basic rocks, whereas Ahmad et al. (1969) suggested the basic rocks to be older. During this work the large-scale field relations such as occurrences of the basic rocks as large xenoliths in the granites were used to show that the basic rocks are probably older or synchronous with the granites. Rocks of intermediate composition between the gabbros and granites are rare and restricted to the marginal portions of the sheets, Such rocks have originated probably as a consequence of mutual contamination of the diverse lithologies.

The within-plate (alkaline) magmatism around the Peshawar plain is known since 1936, when Coulson (1936) first reported occurrence of alkaline granites from Warsak and Shahbazgarhi areas. By 1970, alkaline granites and carbonatites were reported from several other places from Loe

Shilman, Sillai Patti, Ambela, Koga, Malakand, and Tarbela, which led to suggestion by Kempe & Jan, 1970 (see also Kempe & Jan, 1980; Kempe, 1983; Butt et al., 1980) that there was an alkaline province in the vicinity of Peshawar plain, formed around mid Tertiary (based on K/Ar age data by Kempe, 1973). In the recent years various occurrences of carbonatites and other alkaline rocks have been studied in considerable details (Jan et al., 1981; Rafiq, 1987; Mian, 1987). Le Bas et al. (1987) has produced new age data based on Rb/Sr whole-rock isochron for the alkaline rocks from the Koga-Ambela area, suggesting a Carboniferous age for the Peshawar plain alkaline province. The Warsak granites were considered by Kempe (1973) to be Tertiary in age on the basis of K/Ar data on separated minerals. Maluski & Matt (1984) obtained similar ages from the Warsak granites which they interpreted as age of a tectonometamorphic event and not the age of primary emplacement. The age of the Warsak granites is probably same as that of the Ambela-Koga alkaline rocks; i.e., Carboniferous rather than Tertiary, but this has to be confirmed by dating of the Warsak granites with a dating system with higher blocking temperatures than the Ar^{40}/Ar^{39}.

The basic rocks are not that abundant, but are commonly found in association with alkaline rocks in the Peshawar plain alkaline province, including Tarbela, Shewa-Shahbazgarhi, Ambela, Koga, and Sillai Patti (Kempe & Jan, 1980). At places the basic rocks are older than the associated alkaline granites and other alkaline rocks, such as Warsak, Tarbela, and Sillai Patti, whereas in Ambela and Shewa Shahbazgarhi, the basic rocks are relatively younger than the alkaline granites. The composition of the basic rocks is also not consistent; in the Warsak area they are tholeiitic, in Tarbela they are alkali olivine basalts, whereas in Koga, they are strongly alkaline with ijolitic compositions (Mian, 1987). Interestingly, the whole spectrum of the basic rocks in the Peshawar plain alkaline province ranging from tholeiites to ijolites indicate a tectonic setting in which an episode of intra-cratonic rifting is ongoing; a setting which is indicated also by the A-type alkaline granites. Tazeem Tahirkheli et al. (1990) suggested that the rift-related magmatism in the Peshawar plain initiated with tholeiitic plateau-type basalts, now represented by the Warsak basic rocks and common tholeiite dykes found intruding the Precambrian slates and Palaeozoic strata in N. Pakistan (Karim & Qazi, 1989). The rift-related magmatism in the Peshawar plain probably continued for a considerable time during the late Palaeozoic while India was in the process of separation from the Gondwana, the supercontinent. The various compositions of basic rocks were intruded during this rifting event ranging from tholeiitic, through alkali olivine basaltic to strongly alkaline basic rocks. The thinning of the continental crust and the emplacement and passage of these basic rocks resulted in the partial melting of lower continental crust, yielding the A-type granite magmatism ranging from peralkaline to peraluminous compositions.

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REFERENCES

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

Ahmed, I., Hamidullah, S. & Jehan, N., 1990. Petrology of the Shewa Shahbaz Garhi Complex, Mardan, North Pakistan. Geol. Bull. Univ. Peshawar, 23, 135-159.

Ahmed, M. I., 1951. Report on the Warsak hydro-electric project. Govt of Pakistan.

Butt, K. A., Chaudhry, M. N. & Ashraf, M., 1980. An interpretation of petrotectonic assemblage, west of N. W. Himalayan syntaxis in Dir district and adjoining areas, Northern Pakistan. Geol. Bull. Univ. Peshawar, 13, 79-86.

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., Professional Pap. 716C.

Chandrasekharam, D., & Parthasarthy, A., 1978. Geochemical and tectonic studies on the coastal and inland Deccan trap volcanics and a modal for the evolution of Deccan trap volcanism. Neues Jahrb. Mineral., Abh., 132, 214-229.

Coulson, A. L., 1936. A Soda granite suite in the North-West Frontier Province. Proc. Nat. Inst. Soci. Ind., 2, 103-111.

Cox, K. G., Bell, J. D. & Pankhurst, R. J., 1979. The interpretation of Igneous Rocks. George Allen & Unwin, London, 450p.

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.

Irvine, T, N. & Baragar, W. R. A., 1971. A guide to the chemical classification of the common volcanic rocks. Can. Jour. Earth. Sci. 8, 527-549.

Jan, M. Q. & Karim, A., 1990. Continental magmatism related to Late Palaeozoic-Early Mesozoic Rifting in Northern Pakistan and Kashmir. Geol. Bull. Univ. Peshawar, 23, 1-25.

Jan, M. Q., Asif, M., Tahirkheli, T., Kamal, M., 1981. Tectonic subdivision of granitic rocks of north Pakistan, Geol. Bull. Univ. Peshawar, 14, 1-28.

Jan, M. Q., Khattak, M. U. K., Parvez, M. K. & Windley, B. F., 1984. The Chilas stratiform complex: field and mineralogical aspects. Geol. Bull. Univ. Peshawar, 17, 163-69.

Karim, A. & Qazi, S., 1989. Geochemistry of dolerite dykes from the Attock-Cherat range. Unpubl. M. Sc. thesis, Univ. Peshawar.

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 igneoûs province, NW. Pakistan. Geol. Bull. Univ. Peshawar, 13, 71-77.

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

Kempe, D. R. C., 1978. Aciculate hornblende schists and associated metabasic rocks from north-west Pakistan. Mineral. Mag., 42, 405-406 & M33-36.

Kempe, D. R. C., 1983. Alkaline granites, syenites and associated rocks of the Peshawar Plain. In "Granites of Himalayas, Karakoram and Hindukush" (F. A. Shams Ed.) Inst. Geol. Punjab University.

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

Khan, M. A., Jan, M. Q. Windley, B. F. Tarney, J. & Thirlwal, M. F., 1989. The Chilas Complex: root of an island arc. Bull. Geol. Soc. Amer. (special volume). 232, 75-94.

Khan, S. R., Khan, M. A., Nawaz, R. & Karim, T., 1990. Stratigraphic control for the age of Peshawar-Plain magmatism, northern Pakistan. Geol. Bull. Univ. Peshawar, 23, 253-263.

La Roche, H. De., Leterrier, J., Grandclaude, P. & Marchal, M., 1980. A classification of volcanic and plutonic rocks using R1R2-diagram and major-element analyses-its relationships with current nomenclature. Chemical Geology, 29, 183-210.

Le Bas, M. J., Mian, I. & Rex, D. C., 1987. Age and nature of carbonatite emplacement in north Pakistan. Geol. Rundschau, 317-323.

Lo, H. H., 1981. Geochemical investigation of some volcanic rocks from the Philippines. Chem. Geol., 34, 243-257.

Maluski, H. & Matte, P., 1984. Ages of alpine tectonometamorphic events in the Northwestern Himalaya (Northern Pakistan) by Ar^{39}/Ar^{40} method. Tectonics, 3, 1-18.

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

Meschede, M., 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram. Chem. Geol., 56, 207-218.

Mian, I., 1987. The mineralogy and geochemistry of the carbonatites, syenites, and fenites of N.W.F.P. Pakistan. Unpub. Ph. D. thesis, Univ. Leicester, U.K.

Miyashiro, A., 1974. Volcanic rock series in island arc and active continental margins. Amer. Jour. Sci., 274, 321-355.

Myers, R. E. & Breitkopf, J. H., 1989. Basalt geochemistry and tectonic settings: A new approach to relate tectonic and magmatic processes. Lithos, 23, 53-62.

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

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

Pearce, J. A. & Cann, J. R., 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth & Planet. Sci. Lett., 19, 290-300.

Pearce, J. A. & Gale, G. H., 1977. Identification of ore-deposition environment from trace element geochemistry of associated igneous host rocks. In: Volcanic processes in ore genesis (M. J. Jones, ed.). Instit. Mining & Metallur., Geol. Soc. London. Spec. Publ. 7, 14-23.

Pearce, J. A. & Norry, M. J., 1979. Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks. Contrib. Mineral. Petrol., 69, 33-47.

Pearce, T. H,. Gorman, B. E. & Birkett, T. C., 1975. The TiO_2-K_2O-P_2O_5 diagram: A method of discriminating between oceanic and non-oceanic basalts. Earth Planet. Sci. Lett., 24, 419-426.

Pogue, K. R., DiPietro, J. A., Khan, S. R., Hughes, S. S., Dilles, J. H. & Lawrence, R. D., 1992. Late Palaeozoic rifting in northern Pakistan. Tectonics, 11, 4, 871-883.

Rafiq, M., 1987. Petrology and geochemistry of the Ambela granitic complex, NWFP, Pakistan. Unpub. Ph. D. thesis. Univ. Peshawar.

Shervais, J. W. 1982. Ti- V plots and petrogenesis of modern and ophiolitic lavas. Earth. Planet. Sci. Lett., 59, 101-118.

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

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, F. A., 1973. Alkaline rocks of ijolitic affinity from Tarbela Dam area (Hazara district). Geonews, 111, p17.

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

Spencer, D. A., Ramsay, J. G., Spencer-Cervato, C., Pognante, U., Chaudhry, M. N. & Ghazanfar, M., 1990. High pressure (eclogite facies) metamorphism in the Indian plate, NW Himalayas, Pakistan. Geol. Bull. Univ. Peshawar, 23, 87-100.

Srikantia, S. V. & Bhargava, O. N., 1978. The Indus tectonic belt of Ladakh Himalayas: its geological evolution and significance. Tect. Geol. of the Himalaya, p.43-62.

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

Tahirkheli, T., 1990. Geochemistry of the Warsak Igneous Complex, NWFP, N. Pakistan. Unpubl. M. Phil. Thesis, Univ. Peshawar.

Tahirkheli, T., Khan, M. A. & Mian, I., 1990. A-type granites of Warsak: rift-related acid magmatism in the Indian plate. Geol. Bull. Univ. Peshawar, 23, 187-202.

Wadia, D. N., 1931. Geology of India. Macmillan & Co. London.