Geol. Bull. Univ. Peshawar, Vol. 36, pp. 49-63, 2003

Petrology and geochemistry of trondhjemites from the Waziristan Ophiolite, NW Pakistan

SAID RAHIM KHAN[1], M. QASIM JAN[2] & M. ASIF KHAN[3]
[1] National Geoscience Research Centre, Geological Survey of Pakistan, Shahzad Town, Islamabad, Pakistan
[2] Department of Geology, University of Peshawar, Pakistan
[3] National Centre of Excellence in Geology, University of Peshawar, Pakistan

ABSTRACT: *This paper presents the field relationships, petrography and geochemistry of the trondhjemites from Waziristan Ophiolite. The ophiolite occurs in the suture zone between the Indian plate to the east and Afghan block to the west. From east to west, the Waziristan Ophiolite is divisible into three thrust sheets or nappes: the Vezhda Sar nappe, entirely comprised of pillow basalts; the Boya nappe, made up of ophiolitic melange with an intact ophiolite section in the basal part; and the Datta Khel nappe, consisting of sheeted dykes with variable proportions of ultramafic, gabbroic and volcanic rocks. Trondhjemites have so far been recorded in the later two nappes only, where they form lensoid bodies, mostly intruding the ultramafic and rarely gabbroic rocks.*

Petrographic studies reveal that the trondhjemites are metamorphosed in greenschist facies. They show high Na_2O, low TiO_2, Rb, Nb, Y and very low K_2O contents. The various parameters used in specifying the tectonic setting of granitic rocks suggest that most of the rocks have subduction related/ induced chemical characteristics, but a few show normal ocean-ridge granite affinity. None of the tectonomagmatic discriminants suggests a within-plate or syn-collisional setting for these rocks. The transitional chemistry of these rocks between volcanic-arc granite, subduction-related ocean-ridge granite and normal ocean-ridge granite suggests a supra-subduction zone (back-arc basin) origin, as proposed also for the mafic members of the ophiolite.

INTRODUCTION

A small amount of leucocratic rocks is associated with most ophiolite suites. The rocks are composed of quartz, plagioclase and accessory ferromagnesian minerals, and have often been called oceanic plagiogranites or trondhjemites (Coleman & Peterman 1975). The plagiogranites occur mostly in the upper part of the gabbroic unit. Their association with ultramafic rocks is somewhat unusual. However, tectonic inclusions of such leucocratic rocks may occur within serpentinite mélanges derived from dismembered ophiolites or in well preferred ophiolites (Himmelberg et al., 1986; Peters & Kamber, 1994; Gnos & Nicolas, 1996).

The bulk chemical composition of plagiogranites is broadly similar to granites and rhyolites, but there is a significant chemical distinction, i. e., K_2O is usually less than 1 wt. % in plagiogranites, whereas normal granites and continental granophyres contain higher amounts. It is also to note that normal granites have higher iron and alumina and lower soda contents than plagiogranites.

The close association of the plagiogranite with gabbroic unit of ophiolites and compositional gradation from tonalites to albite granites suggest that these rocks are either the end products of differentiation of basaltic magma of the ophiolite suites or partial melts of altered basaltic rocks (Coleman & Donato, 1979; Pederson & Malpas, 1984).

In Waziristan Ophiolite, the trondhjemites are associated mostly with the ultramaifc and rarely with gabbroic rocks. The purpose of this research is to present the petrographic and geochemical data for the first time and to find out the origin of the trondhjemites.

REGIONAL GEOLOGICAL SETTING

Ophiolites in Pakistan can be divided into those occurring along the Indus Suture Zone and those along the western margin of the Indian plate. The later (Waziristan, Zhob, Muslim Bagh, and Bela ophiolites in Pakistan and the Khost Ophiolite in eastern Afghanistan) are grouped into the western ophiolite belt. Ophiolites and mafic-ultramafic complexes exposed along the Indus Suture Zone (Malakand, Shangla, Jijal, Sapat, Chilas and Dras ophiolites/igneous complexes) have been grouped into the northern ophiolite belt (Gnos et al., 1997; Khan et al., 1998a, 1998b; Khan, 2000).

From west to east, the region comprises of the Afghan–Kabul blocks, the Katawaz Basin, the ophiolite belt, and the Indian plate (comprising Mesozoic shelf-slope sediments of the Axial belt, Sulaiman and Kirthar ranges, Sofed Koh fold belt, and the mollase deposits in the fore deeps of the Kirthar and Sulaiman ranges), respectively (Tapponnier et al., 1981; Treloar & Izatt, 1993; Khan, 2000). The continental blocks (Afghanistan-Kabul-India) are presently welded to each other by a network of sutures, which are defined by the ophiolite outcrops. The Waziristan Ophiolite (WO) is located near the western termination of the Himalayan orogen, and is presently sandwiched between the Afghan-Kabul blocks to the west and the Indian plate to the east. The WO is strongly dismembered, but contains all the segments of an ideal ophiolite suite. However, an intact ophiolite section occurs at Mami Rogha, where ultramafic rocks are overlain by isotropic gabbros and pillow basalts capped by pelagic sediments (Khan, 2000). The ophiolite and the Indian plate sediments, are intensively deformed by folding, faulting and, in places fractured and brecciated.

The WO is thrust eastwards onto the Indian plate sediments, rather than beneath them, as suggested by Robinson et al. (2000). Regionally the Main Waziristan Thrust (MWT) trends north to south and dips towards west. This clearly indicates overthrusting of the ophiolite onto the shelf-slope sediments of the Indian plate. Local changes in the trend of the MWT (from N–S to E–W), and dip (from west to north) or overlying of the shelf-slope sediments on the ophiolite occur north of Boya-Mohammad Khel. These changes have been produced by the later east-west trending faults. Thus, these are not to be taken as evidence of over thrusting of the Indian plate sediments onto ophiolite. The field evidences, for example the intact ophiolite section (base towards east and top towards west), the westward dip of the MWT, and deposition of Tertiary sediments on top of the ophiolite to the west, clearly support overthrusting of the ophiolite onto the Indian plate sediments towards east. The study area can be divided into two main tectonic blocks: i) the Waziristan Ophiolite to the west, and ii) the shelf-slope sediments to the east (Fig. 1). The shelf-slope sediments, comprising of limestone, shale, sandstone and siltstone of lower Middle Triassic to Late Cretaceous age, are thrust under the ophiolite.

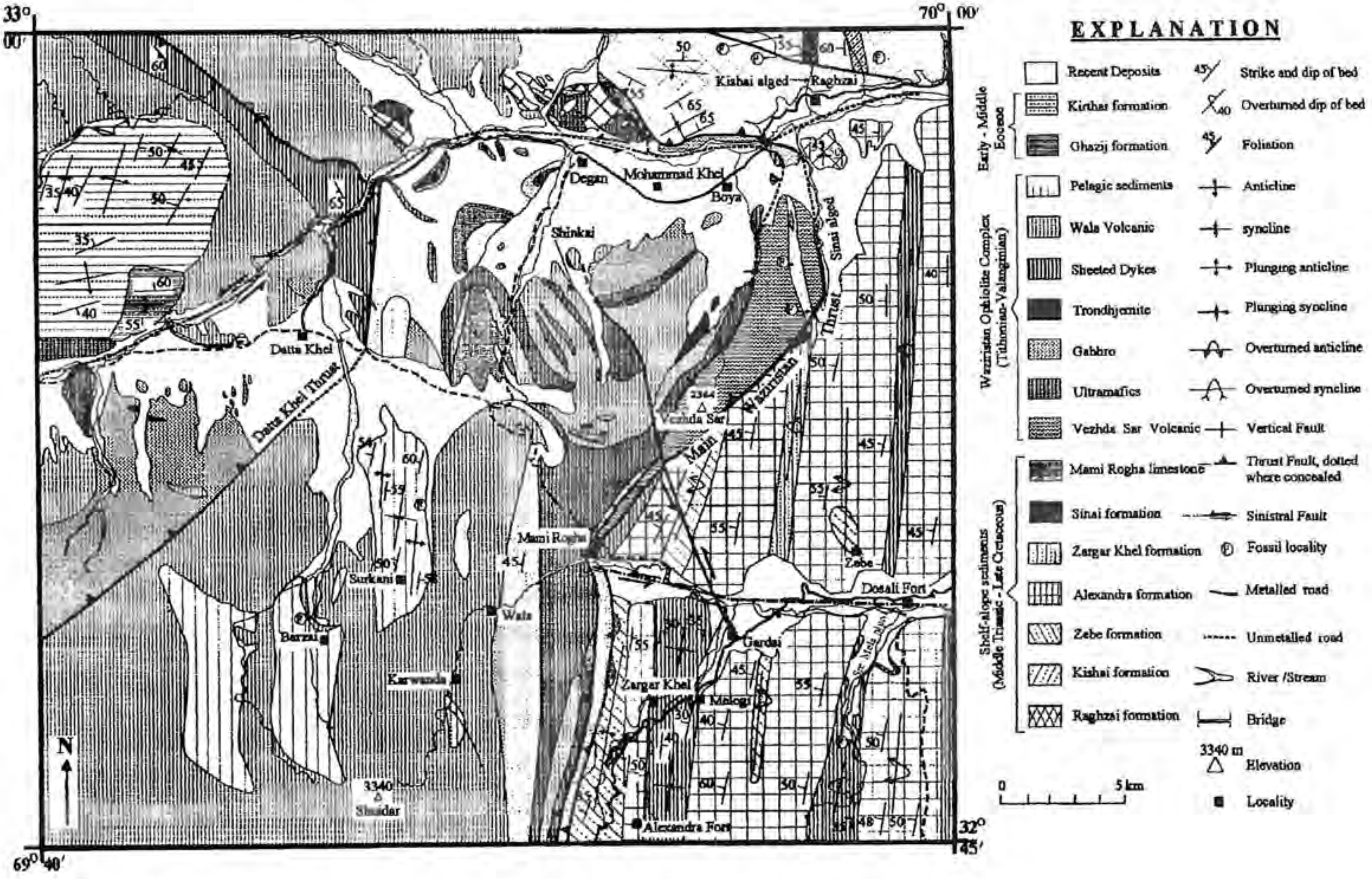


Fig. 1. Geological map of a part of the Waziristan Ophiolite, NW. Pakistan.

GEOLOGY OF WAZIRISTAN OPHIOLITE

The WO extends westward into eastern Afghanistan, where it is believed to represent a fragment of the same ophiolite and known as Khost Ophiolite (Cassaigneau, 1979). The WO contains all the members of an ideal ophiolite suite (Penrose Conference, 1972). It is dividable into three thrust sheets or nappes. From east to west or from base upwards, these are here named as: i) Vezhda Sar, ii) Boya, and iii) Datta Khel nappes. The Vezhda Sar nappe forming the eastern edge of the WO, is thrust over the shelf-slope sediments of the Indian plate. It consists exclusively of pillow basalts. Pelagic sediments and other ophiolitic components have not been located, however, exotic blocks of ultramafic rocks are found in the pillow basalts. Several tectonic blocks of the Indian plate sediments of variable sizes occur within the pillow basalts.

The Boya nappe forms the central part of the WO, which is strongly dismembered, giving the appearance of a typical melange (Khan, 2000). Here, the ultramafic and gabbroic rocks are irregularly distributed as fault - bounded blocks within a larger mass of the pillow basalt. However, an intact ophiolite section occurs in the southern part of this nappe at Mami Rogha. This section is composed of ultramafic rocks at the base, followed upwards by isotropic gabbros, and pillow basalts, capped by pelagic sediments. The pelagic sediments occur as isolated bodies, intercalated with, and overlying the pillow basalts. This section is devoid of layered gabbros and sheeted dyke complex. Trondhjemite intrusions occur as mall lensoid bodies and veins, mostly in the ultramafics and rarely in the gabbroic rocks.

The Datta Khel nappe forms the western most part of the WO. Its base, exposed WSW of Datta Khel, starts with a sequence of layered gabbroic rocks, but ENE of Datta Khel, the basal part of the nappe cuts up section, and exposes only a sheeted dyke section. Small tectonic blocks of ultramafic rocks, which are otherwise missing from the basal part of the nappe (probably due to a higher level of propagation of the Datta Khel Thrust), are exposed only along the Tochi River, west of Datta Khel. In this nappe, the pelagic sediments are missing and trondhjemite intrudes the gabbros. The nappe is unconformably overlain by sediments ranging in age from Early Eocene to Middle Eocene.

The pelagic sediments contain radiolarian fauna (Tithonian–Valanginian), suggesting Late Jurassic or older age for the formation of WO (Khan, 2000; Khan et al., 1998a, 1998b). The WO contains tectonic blocks of Mami Rogha limestone of Late Cretaceous (Campanian) age, and is thrust over Maastrichtian green shale (Beck et al., 1996), indicating post-Maastrichtian, most probably Paleocene emplacement of the ophiolite. A sequence of the unconformbly overlying Ghazij Formation of Early Eocene and Kirthar Formation of Early to Middle Eocene age, lends support to the Paleocene emplacement of the ophiolite (Jan et al., 1985; Khan et al., 1982; Khan, 2000; Khan et al., 2001a,b).

FIELD RELATIONSHIP AND PETROGRAPHY OF THE TRONDHJEMITES

The trondhjemites in the study area are light-grey to white, and medium- to coarse-grained. These occur in the form of veins and small lensoid bodies, ranging from a few centimetres to three-meters in width and up to ten meters in length. The contacts of the trondhjemites with the host rocks (both ultramafics and gabbros) are sharp and intrusive, as evidenced by chilling on their margins. Associations of trondhjemites with ultramafic rocks have been documented in only a few other complexes, such as Kamray ophiolite, Norway and Oman ophiolite (Barker & Millard, 1979; Gnos et al., 1997).

Microscopic observation shows that the trondhjemites are inequigranular, medium- to fine-grained, and deformed. Mineralogically, they are characterized by virtual absence of potassium feldspar. They consist predominantly of quartz and plagioclase with only minor amounts (usually less than 10 vol. %) of biotite, muscovite, hornblende, and opaque minerals. The plagioclase, constituting up to 60 vol. % of the rocks, occurs as subhedral grains, commonly zoned with albitic margins and more calcic (upto calcic andesine) cores. It is decomposed and altered to epidote, chlorite, sericite and calcite, especially the cores of the zoned grains. Quartz is subhedral to anhedral, and locally granulated. Occasionally, vermicular quartz-plagioclase intergrowths, interpreted as a primary magmatic textural feature by Coleman and Donato (1979), are observed (Plate 1). Opaque minerals include magnetite and ilmenite. The biotite in one of the samples is strongly deformed, and shows alteration to prehnite and muscovite or chlorite. In this rock chlorite is also seen, and seems to be an alteration product of biotite and/or hornblende. A zircon, measuring 0.85 x 0.095 mm occurs as inclusion within a large plagioclase grain (Plate 2). The formation of a secondary mineral assemblage consisting of chlorite, muscovite, epidote, sericite and calcite indicates that these rocks have been metamorphosed under greenschist facies conditions.

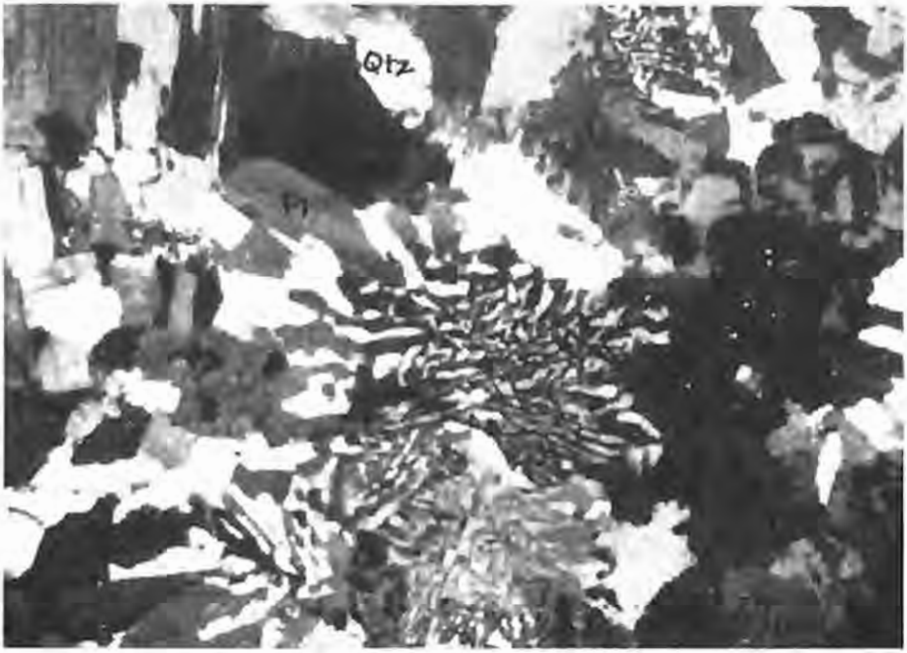


Plate 1. Photomicrograph of the Waziristan trondhjemite containing quartz, platioclase and biotite (brown). Graphic texture is also seen. Crossed polars.

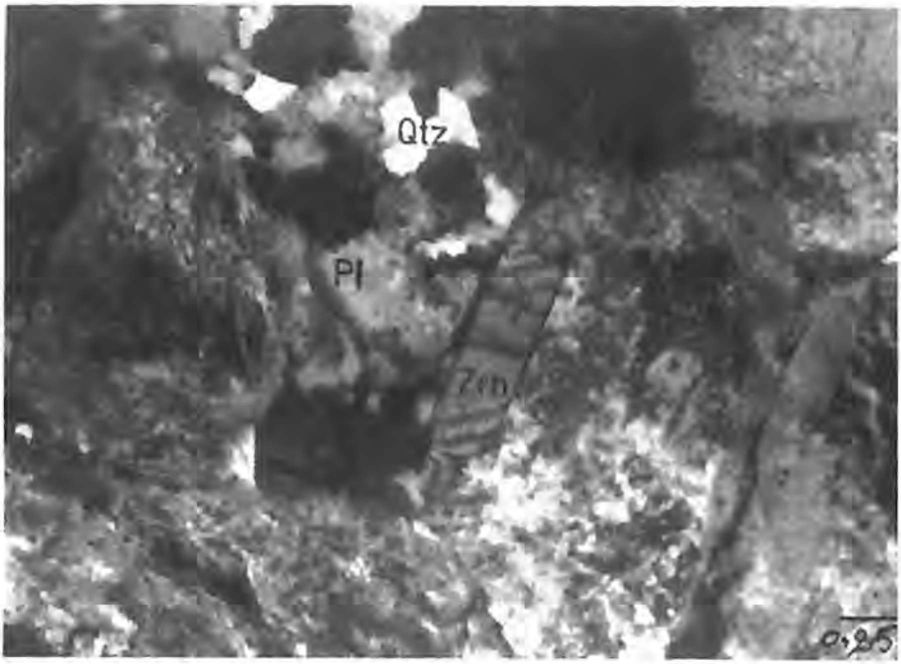


Plate 2. Photomicrograph of the Waziristan trondhjemite containing cloudy plagioclase, (Pl), anhedral quartz (Qtz) and an euhedral crystal of Zircon (Zrn). Crossed polars.

GEOCHEMISTRY AND TECTONIC SETTING

Thirteen samples were analysed for major and trace element compositions using a Regaku X-Ray fluorescence spectrometer (WD/XRF 3370) at the National Geoscience Research Centre, Geological Survey of Pakistan, Islamabad, Pakistan. The major element composition was determined on glass beads formed by mixing powder with lithium tetraborate in the 1:4 ratios. Total sample dissolution was achieved by melting at 1100°C. The trace elements were determined on powder pellet pressed at 20 tons.

Major and trace element analyses of the Waziristan trondhjemites are listed in Table 1. Chemical analyses support the petrographic observations that the majority of the rocks are trondhjemitic in composition. On the basis of normative Ab–An–Or ternary plot of O'Connar (1965), (Fig. 2) nine analyses classify as trondhjemite and four as tonalite. None of the analyzed rocks, according to this scheme of classification, qualifies as granite.

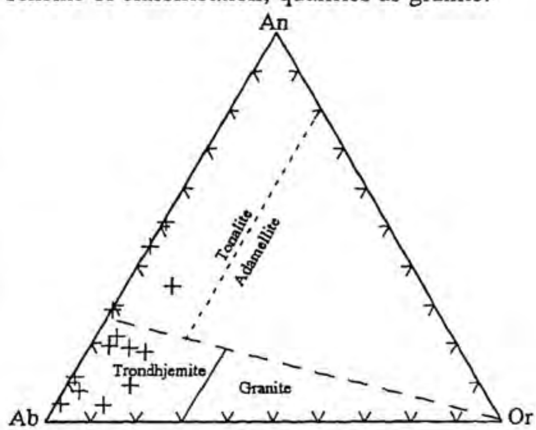


Fig. 2. An – Ab – Or diagram showing classification of the Waziristan trondhjemites (fields are after O' Connor et al., 1965).

TABLE 1. MAJOR AND TRACE ELEMENTS DATA (WT.% AND PPM) OF THE WAZIRISTAN TRONDHJEMITES

Samples	WT 1	WT 21	WT 33	WT 37	WT 42	WT 52	WT 62	WT 63	WT 76	WT 88	WT 120	WT 121	WT 201
SiO_2	73.67	71.71	75.26	60.47	75.16	77.13	77.17	79.70	74.17	77.75	77.34	77.00	77.23
TiO_2	0.26	0.27	0.14	1.28	0.35	0.10	0.14	0.11	0.12	0.20	0.17	0.19	0.28
Al_2O_3	13.46	12.80	12.74	13.87	12.75	12.93	12.51	11.65	13.07	12.13	12.46	12.67	12.45
Fe_2O_3	1.28	3.55	2.98	10.62	2.19	1.41	1.67	1.29	2.79	1.89	1.48	1.72	0.91
MnO	0.02	0.08	0.05	0.12	0.05	0.05	0.04	0.02	0.05	0.04	0.01	0.02	0.02
MgO	1.78	0.33	0.41	2.82	0.75	0.27	0.26	0.23	0.70	0.68	0.44	1.48	0.89
CaO	5.63	6.95	3.37	3.75	2.45	1.11	1.48	0.52	2.12	0.83	2.12	0.41	1.84
Na_2O	2.70	3.04	3.03	4.75	4.67	5.03	6.06	6.00	4.56	5.41	4.82	4.49	4.04
K_2O	0.07		0.82		0.44	1.33	0.09	0.11	0.80	0.32	0.41	0.80	1.09
P_2O_5	0.04	0.05	0.04	0.32	0.06	0.04	0.02	0.01	0.04	0.02	0.02	0.01	0.02
LOI	1.09	1.20	1.17	1.97	1.13	0.60	0.58	0.36	1.58	0.72	0.71	1.21	1.24
Sum	100.00	99.97	100.01	99.97	100.00	100.00	100.02	99.99	100.00	100.00	99.99	100.01	100.01
Nb	2	1	1	11	1	5	3	3	1	2	5	5	2
Zr	62	73	27	210	98	68	148	246	18	109	42	129	92
Y	16	31	5	72	39	22	62	93	4	38	10	4	4
Sr	194	364	606	193	167	69	97	39	396	145	111	59	198
Rb	4	3	15	3	5	34	4	4	16	5	10	18	21
Zn	5	15	23	29	11	16	14	3	18	15	4	14	3
Ni	81	1	1	4	1	1	1	1	1	1	1	1	3
Cr	52	17	13	1	1	15	1	3	1	5	1	1	1
V	1	30	< 1	24	15	1	3	1	10	7	2	1	8
Ba	53	15	133		105			41	143	102	101	130	96
Cu	2	3	4	1	4	4	3	1	22	1	26	5	2
Co	95	37	21	20	19	23	12	9	20	9	23	15	1
Ce	28	1	1	20	12	9	10	24	1	0	0	1	83
Th	2	1	1	1	2	3	2	2	1	2	1	1	1
Nd	15	2	2	19	13	9	18	17	1	7	6	6	29

(Table 1 continued)

Samples	WT 1	WT 21	WT 33	WT 37	WT 42	WT 52	WT 62	WT 63	WT 76	WT 88	WT 120	WT 121	WT 201
Sc	1	12	14	14	9	4	5	4	10	5	9	3	4
Ga	11	13	11	22	13	13	13	11	10	11	11	11	8
C I P W norm													
q	43.08	40.19	45.78	16.83	39.64	39.63	38.40	42.38	38.25	41.75	42.24	44.53	44.64
or	0.42	0.18	4.91	0.12	2.63	7.92	0.54	0.65	4.81	1.91	2.44	4.79	6.53
ab	23.12	26.11	26.00	41.38	40.04	42.87	51.64	51.01	39.30	46.18	41.13	38.54	34.63
an	24.68	21.50	16.69	16.94	11.92	5.28	6.70	2.53	10.45	4.02	10.48	2.00	9.12
c	-	-	0.84	-	0.28	1.30	-	0.74	0.96	1.43	0.28	3.74	1.34
di	2.64	11.42	0.06	0.06	-	-	0.48	-	-	-	-	-	-
hy	4.37	-	4.69	18.69	4.08	2.36	2.33	2.04	5.23	3.79	2.68	5.59	2.87
mt	0.34	0.86	0.70	2.69	0.57	0.34	0.41	0.31	0.66	0.47	0.36	0.43	0.27
il	0.50	0.51	0.27	2.50	0.67	0.19	0.27	0.21	0.23	0.38	0.33	0.37	0.54
ap	0.09	0.11	0.09	0.72	0.13	0.09	0.04	0.02	0.09	0.04	0.04	0.02	0.04

Key: LOI = loss on ignition; total iron as Fe_2O_3.

The Waziristan rocks are low-Al_2O_3 trondhjemites with high Na_2O and low K_2O contents like plagiogranitic analyses reported in oceanic and ophiolitic rocks (Maniar & Piccoli, 1989). The enormously high K-contents in some of the samples (WT 52–WT 201) cannot be attributed to alkaline feature and may be due to alteration. Four of the analyses contain rather high amounts of CaO (3.37–6.95 wt. %), but such amounts have been reported in ophiolitic plagiogranites from Fidalgo Island, Washington (Brown et al., 1979) 0and Karmoy, Norway (Pederson & Malpas, 1984). Three of the analyses also contain rather high Sr (364, 396 and 606 ppm).

Selected oxides and element relations are shown in Figure 3. Plots of Na_2O, Sr, Y, and Zr against CaO show that Na_2O and CaO are inversely related, whereas Sr increases with CaO. Ignoring three analyses with the highest CaO, Y, and Zr also show negative correlation with CaO. Although K_2O–CaO relation is not revealing, K_2O and Rb, and Zr and Y show strong positive correlations and a smooth trend expected in genetically related (differentiated) rocks. The low Rb also points out to their being differentiates rather than partial melts (Malpas & Longdon, 1987).

The petrology and composition of the plagiogranites/trondhjemites occurring in ophiolite suites is complicated by many factors. Therefore, their chemistry is difficult to interpret in terms of petrogenetic modelling and tectonic setting. Apart from complex genetic history, there is also the difficulty in sampling of granites of known setting by the time they are exposed. However, the lower degree of alteration in granitic rocks when compared with mafic rocks contour – balances these problems (Pearce et al., 1984). Plagiogranites in ophiolites have received less attention than volcanic rocks and sheeted dykes for determining the tectonic setting of the suite.

The distinction between the granites of various tectonic setting has been illustrated on the basis of major and trace elements by several workers. Pearce et al. (1984) showed that use of appropriate major and trace elements can enable to distinguish granites from different tectonic regimes. The Waziristan trondhjemites like ocean-ridge granites contain low Al_2O_3, K_2O, Rb and high Na_2O and in some case CaO, but the low Y + Nb is akin to those of island-arcs and back-arc basins.

Oceanic-ridge granite (ORG)-normalized multi-elemet pattern for the plagiogranite is presented in Fig. 4. In general, analyses with higher LILE contents tend to have lower HFSE contents and vice versa. Most samples contain higher amounts of LIL (K, Rb, Ba, Th) and lower of HFS (Nb, Ce, Zr, Y) elements than ORG, although a few samples are quite close to ORG for most of these elements. In general, granitic rocks generated in subduction-related/induced settings (volcanic arcs, Andean-type margins, and back-arc basins) have lower HFS and higher LIL element contents than those of oceanic environment do. The average Waziristan trondhjemites displays a pattern that is transitional between volcanic-arc and ocean-ridge granites (Pearce et al., 1984).

This is further corroborated when the Nb vs. Y (Fig. 5) and Rb vs. Y + Nb (Fig. 6) relationships of the rocks are compared with granites of different tectonic regimes. According to Pearce et al. (1984), these relations can discriminate effectively between granites formed within- plate, volcanic-arc, ocean-ridge and collision environments. As can be seen in Figures 5 and 6, most of the Waziristan trondhjemites plot in the field of volcanic-arc but some in ocean-ridge granite field. This duality, as pointed earlier in this paper for some other elements also, may be related to a complex origin such as ocean-ridge and island-arc or a back-arc basin. The geochemistry of the associated mafic rocks favours a back-arc basin origin for the Waziristan Ophiolite (Khan, 2000; Khan et al., 2001a, b), therefore, the trondhjemites assuming a coeval formation, may also have developed in such a setting rather than in an island-arc.

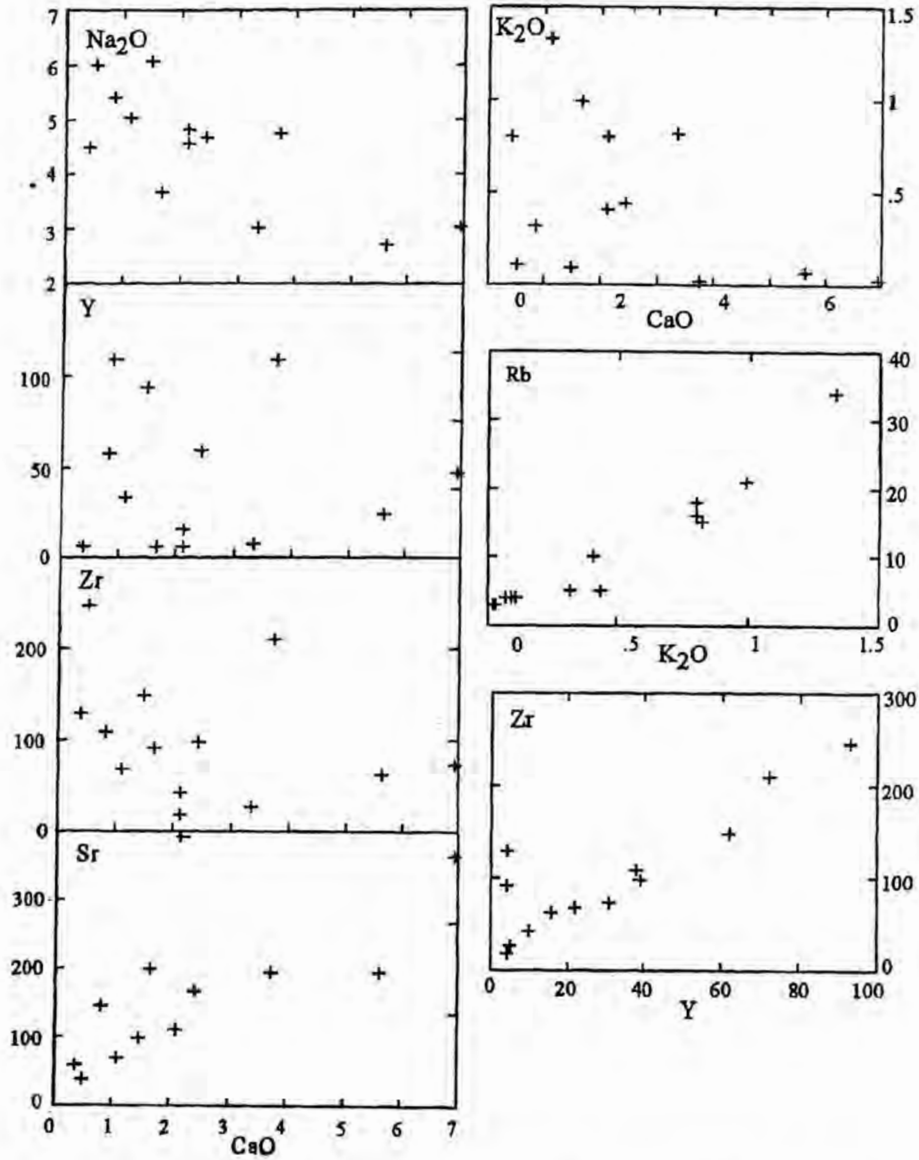


Fig. 3. Major and trace element variation plots showing fractionation in the Waziristan trondhjemites.

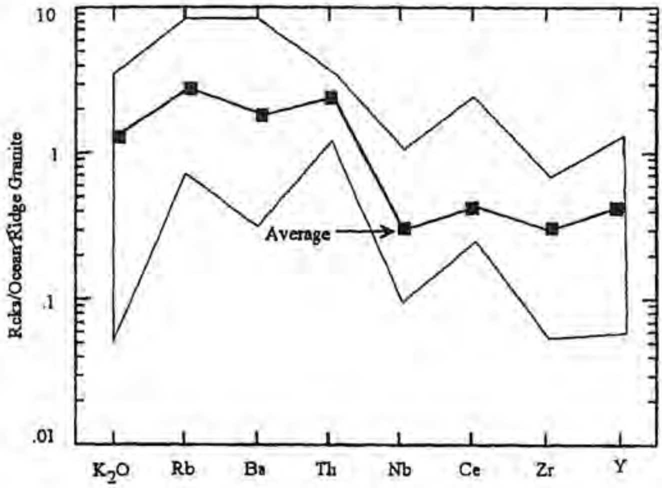
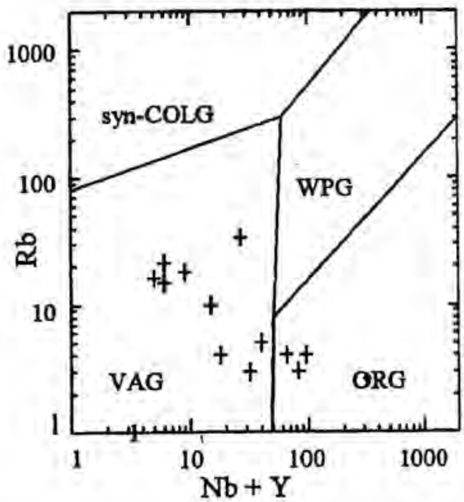


Fig. 4. Mid-ocean ridge normalized spidergram for Waziristan trondhjemites (after Pearce et al., 1984). Shaded area covers all the analysed rocks. Two abnormally low values for Ba and K_2O and one high Ba value have been ignored in the average.



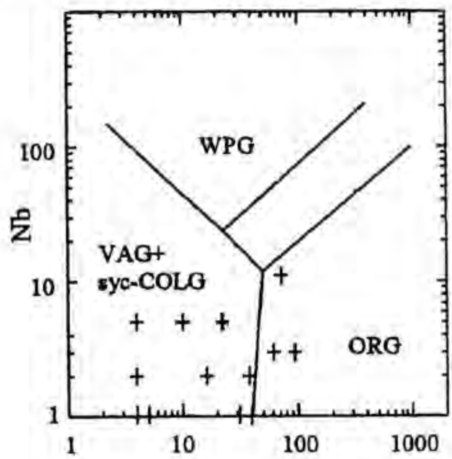


Fig. 5. Nb vs. Y plot for Waziristan trondhjemites (fields are after Pearce et al., 1984). Key: WPG=within-plate granite, VAG=volcanic-arc granite, syn-COLG=syn-collision granite, ORG=ocean-ridge granite.

Fig. 6. Rb vs Nb+Y plot for Waziristan trondhjemites (fields are after Pearce et al., 1984). Key: abbreviations as in Figure 5.

DISCUSSION

The origin and evolution of magma leading to crystallization of granitic rocks is complicated by many factors: partial melting of great variety of source material, involvement of continental crust, crystal fractionation/ accumulation (and possible removal of trace element-rich minor phases), and redistribution and loss of elements by volatile fluxing. Granitic rocks can also undergo post-magmatic, mineralogical and chemical modifications due to hydrothermal activity, metasomatism, and sea-water circulation in oceanic environment (Spooner & Fyfe, 1973; Liou & Ernst, 1979; Pearce et al., 1984; Lecuyer et al., 1990; Barbieri et al., 1994). On the whole the major oxides are little affected by metamorphic events except during high-grade when mobilization/ partial melting occurs (Pearce et al., 1984). The high Na_2O and very low K_2O contents in the Waziristan rocks can be due to exchange with sea-water or to the magmatic vapour-phase transport and removal of K_2O (Siston & Byerly, 1980). But there is a positive relation between Rb and K_2O, and a negative correlation between CaO and Na_2O. So there is a good possibility that it is inherited from a parent magma or source region that was depleted in K_2O (Floyd & Winchester, 1975; Borsi et al., 1998).

Despite numerous studies, there is no general consensus about the nature of genetic lineage from gabbros to sheeted dykes, basalt, and granites. Thus, distinct hypotheses have been proposed for the origin of granitic rocks in the ophiolite suites: fractional crystallization from a more mafic magma (Tsikouras et al., 1998; Bosri et al., 1998); crystallization and filter pressing (Wildberg, 1987); liquid immiscibility (Dixon & Rutherford, 1979); partial melting of basic rocks under hydrous conditions (Garlech et al., 1981; Pederson & Malpas, 1984). But geochemical studies, especially REE and immobile elements, have been applied by various workers to decipher the tectonic regimes prevailing during the generation of plagiogranites. Particularly significant are: high Y concentration in the normal ocean-ridge granites and some within-plate granites, high Nb in within-plate granites, and high Rb in syn-collisional granites and some within-plate granite.

The trondhjemites from the studied area mostly portray chemical characteristics of volcanic-arc granites but with drift towards normal ocean-ridge granites in few cases. It has been documented by several workers, especially Pearce et al. (1984), that plagiogranites/ trondhjemites of subduction-induced/related oceanic regimes/marginal basins display geochemical patterns not too dissimilar to volcanic-arc granite. As such a back-arc basin environment is suggested for the origin of Waziristan trondhjemites. These rocks are similar in petrography, occurrence and chemistry to those of Andaman ophiolite belt in Bay of Bengal. They too have been regarded as differentiation product of a low-K tholeiitic magma derived from a mantle source in a supra-subduction zone tectonic setting (Jafri et al., 1995). The transitional geochemical characteristics of volcanic rocks and sheeted dykes from the Waziristan Ophiolite between mid-ocean ridge basalt and island-arc tholeiite lends further support to a supra-subduction zone (back-arc basin) environment for the origin of these trondhjemites (Khan, 2000; Khan et al., 1998a, b; 2001a,b). Systematic variation between various elements displayed in Figures 4 and 5, generally low Rb contents, and close association of tonalities-trondhjemites with mafic rocks (gabbros) suggest magmatic lineage. It is likely that the suite is derived from a mafic magma through the process of crystallization differentiation.

Acknowledgements: We are indebted to Mr. S. Hasan Gauhar, Director General, Geological Survey of Pakistan, Quetta, who provided financial support for this research work. We are also thankful to Mr. Muhammad Sakhawat, Superintending Geophysicist, National Geoscience Research Centre, Islamabad, for providing logistics and laboratory facilities. Thanks are due to Dr. M. Zafar, Dr. Arshad Ali, Dr. Iffat Jabeen and Rubab Anwar, for extending their co-operation in executing this job. Due thanks are extended to the political administration at Miran Shah, North Waziristan Agency, for providing lodging and security arrangements.

REFERENCES

Barbieri, A., Caggianelli, M. R., Di Floro, M. R. & Lorezoni, S., 1994. Plagiogranite and gabbroic rocks from the Mingora ophiolite melange, Swat valley, NW Frontier Province, Pakistan. Min. Mag., 58, 553-566.

Barker, F. & Millard, H. T. Jr., 1979. Geochemistry of trondhjemite and three associated rocks, Norway. *In*: Trondhjemite, dacite and related rocks (F. Barker, ed.). Development in Petrology, 6. Elsevier Sci. Publ. Co., New York, 6, 517-529.

Beck, R. A., Sercombe, W. J. & Burbank D. W., 1996. Late Cretaceous ophiolite obduction and Paleocene India-Asia collision in the western most Himalaya. Geodinamica Acta, Paris, 9, 114-44.

Borsi, H., Petrini, J. Y., Cortescini, L., Gaggero, L. & Cripini, L., 1998. Modelling of plagiogranite gneiss and implications for the evolution of the Ligurian-piedmont ocean basin. Neues Jb. Miner, Montash, 218-220.

Brown, E. H., Bradshaw, J. Y. & Mustoe, G. E., 1979. Plagiogranite and Karatophyre in ophiolite on Fidalgo island, Washington. Geol. Soc. Am. Bull., 90, 493-507.

Cassaigneau, C., 1979. Contribution a I' etude des sutures Inde-Eurasie. La zone de suture de Khost dans le Sud-Est de l'Afghanistan. I' l'Obduction Paleocene et la tectonique tertiare: Unpublished Ph. D. dissertation, Univ. Sciences and Techniques of Languedoc, Montpellier, France.

Coleman, R. G. & Peterman Z, E., 1975. Oceanic Plagiogranite. J. Geophy. Res., 80, 1099-1108.

Coleman, R. G. & Donato, M. M., 1979. Oceanic plagiogranite revised. *In*: Trondhjemites, dacites, and related rocks (F. Barker, ed.), Development in Petrology, 6. Elesevier Sci. Publ. Co., New York, 149-168.

Dixon, S. & Rutherford, M. J., 1979. Plagiogranites as late-stage immiscible liquids in ophiolite and mid-ocean ridge suites: an experimental study. Earth Planet. Sci. Lett., 45, 45-60.

Floyd, P. A. & Winchester, J. A., 1975. Magma types and tectonic setting discrimination using immobile elements. Earth Planet. Sci. Lett., 27, 211-218.

Garlech, D. C., Leeman, W. P. & Lallemant, H. G., 1981. Petrology and geochemistry of plagiogranite in Canyon Mountain Ophiolite, Oregon. Contrib. Mineral. Petrol., 77, 82-92.

Gnos, E. & Nicolas, A., 1996. Structural evolution of the northern end of Oman Ophiolite and enclosed granulites. Tectonophys., 254, 111-137.

Gnos, E., Immenhauser, A. & Peters, Tj., 1997. Late Cretaceous/Early Tertiary convergence between the Indian and Arabian plates recorded in ophiolites and related sediments. Tectonophys., 271, 1-19.

Himmelberg, G. R., Loney A. & Caig, J. T., 1986. Petrogenesis of the ultramafic complex at the Blashke Island.

southeastern Alaska. U. S. Geol. Surv. Bull., 1662, 14.

Jafri, S. H., Charan, S. N. & Govil, P. K., 1995. Plagiogranite from the Andaman ophiolite belt, Bay of Bengal, India. J. Geol. Soc. London, 152, 681-687.

Jan, M. Q., Windley, B. F. & Khan, A., 1985. The Waziristan Ophiolite: General Geology and Chemistry of Chromite and Associated Phases. Econ. Geol., 80, 294-306.

Khan, A., Wahabudin, & Shah, M. R., 1982. Preliminary report on ophiolite occurrence in part of Waziristan, NWFP, Pakistan. Geol. Surv. Pak., Inf. Rel., 129, 23.

Khan, S. R., 2000. Petrology and geochemistry of a part of the Waziristan Ophiolite Complex, NW Pakistan. Unpublished Ph. D. thesis. Univ. Pesh. Pakistan, 253.

Khan, S. R., Khan, M. A., Jan, M. Q. & Khan, T., 1998a. Trondjhemites from the Waziristan Ophiolite Complex, NW Pakistan. Abstract: 13th Himalaya-Karakoram-Tibet Workshop, Pakistan. Geol. Bull. Univ. Peshawar, Spec. Issue, 31, 98-99.

Khan, S. R., Khan, M. A., Jan, M. Q. & Khan, T., 1998b. Major and trace elements geochemistry of volcanic rocks from part of the Waziristan Ophiolite, NW Pakistan: its implications and tectonic evolution. Abstract: 13th Himalaya-Karakoram-Tibet Workshop, Pakistan. Geol. Bull. Univ. Peshawar, Spec. Issue, 31, 100.

Khan, S. R., Jan, M. Q. & Khan, M. A., 2001a. Tectonic evolution of the Waziristan Ophiolite, NW Pakistan. Abstract: 16th Himalaya-Karakoram-Tibet Workshop, Austria. J. Asian Earth Sci., 19, no. 3A, 35.

Khan, S. R., Jan, M. Q., Khan, M. A. & Khan, T., 2001b. Geochemistry and petrogenesis of the sheeted dykes in Waziristan Ophiolite NW Pakistan and their tectonic implications. Abstract: 16th Himalaya-Karakoram-Tibet Workshop, Austia. J. Asian Earth Sci., 19, no. 3A, 35.

Lecuyer, C., Brouxel, M. & Albarede, F., 1990. Elemental fluxes hydrothermal alteration of the Trinity ophiolite, (Caledonia, U. S. A.) by sea water. Chem. Geol., 89, 87-115.

Liou, J. G. and Ernst, W. G., 1979. Ocean ridge metamorphism of the east Taiwan ophiolite. Contrib. Mineral. Petrol., 68, 335-348.

Malpas, J. & Longdon, G. S., 1987. The Kennack Gneisses of the Lizard complex, Conwall, England: partial melts produced during ophiolite emplacement. Canadian J. Earth Sci., 24, 1966-1976.

Maniar, P. D. & Piccoli, P. M., 1989. Tectonic discrimination of granitoids. Geol. Soc. Am. Bull., 101, 635-643.

O'Connor, J. T., 1965. A classification for quartz-rich igneous rocks based on feldspar ratios. U. S. Geol. Surv. Prof. Pap., 525-B, 79-84.

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

Pederson, R. B. & Malpas, J. O., 1984. The origin of oceanic plagiogranites from the Karmoy ophiolite, Western Norway. Contrib. Mineral. Petrol. 88, 36-52.

Penrose Conference, 1972. Penrose field conference on ophiolites. Geotimes, 17, 24-25.

Peters, T. & Kamber, B. S., 1994. Peraluminous, potassium-rich granitoids in the Semail ophiolite. Contrib. Mineral. Petrol., 118, 229-38.

Robinson, J., Beck, R., Gnos, E. & Vincent, R., 2000. New structural and stratigraphic insights for northwestern Pakistan from field and Landsat Thematic Mapper data. Geol. Soc. Am. Bull., 112, no. 3, 364-374.

Sinton, J. M. & Byerly, G. R., 1980. Silicic differentiates of abyssal oceanic magmas: evidence for late-magmatic vapour transport of potassium. Earth Planet. Sci. Lett., 47, 423–430.

Spooner, E. T. C. & Fyfe, W. S., 1973. Sub-sea floor metamorphism, heat and mass transfer. Contrib. Mineral. Petrol., 42, 287–304.

Tapponnier, P., Mathauer, M., Proust, F. & Cassaigneau, C., 1981. Mesozoic ophiolites, structure and large-scale tectonic movements in Afghanistan. Earth Planet. Sci. Lett., 52, 355–371.

Treloar, P. J. & Izatt, C. N., 1993. Tectonics of the Himalayan Collision between the Indian plate and the Afghan Block: a synthesis. In: Himalayan Tectonics (P. J. Treloar, & M. P. Searle, eds.). Geol. Soc. Lond., Spec. Publ., 74, 69–87.

Tsikouras, B., Hatzipanagiotou, K. & Seynou, K. St. 1998. Plagiogranite and leucogranite relationship in an ophiolite of the Tethys ocean (Samothraki, N. Aegean, Greece). Neues, Jb., Monatsh., 13, 13–35.

Wilberg, H. G. H., 1987. High level and low-level plagiogranites from the Nicoya ophiolite complex, Costa Rica, Central America. Geol. Rundsch., 76/1, 285–301.