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Geochemistry and petrogenesis of metavolcanic rocks in Gawuch and Drosh formations, Chitral, northern Pakistan

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ABSTRACT: Metavolcanic rocks constitute an important lithology in the study area. It occurs as two stratigraphic entities i.e., Gawuch and Drosh Formations. The Metavolcanic of the Gawuch formation are both porphyritic and very fine-grained. The porphyretic volcanics vary from fresh to highly altered and are commonly dissected by quartz and calcite veins. Volcanic rocks of Drosh Formation are massive to weakly foliated, fine-grained and commonly altered. The detailed geochemistry, mainly based on major and trace element, suggests that the metavolcanic rocks of the Gawuch formation are calc-alkaline, and those of Drosh Formation are tholeiitic in character. It is, therefore, suggested that the two groups of metvolcanics, despite difference in their petrological character, originated with a strongly subduction component.

INTRODUCTION

The study area occurs as a narrow elongated belt within the Drosh-Shishi area in the vicinity of Shyok suture zone, at the north-western margin of the Kohistan Island-arc terrane. According to Pudsey et al., (1985), it is divided into three stratigraphic units, which from bottom to top, include Gawuch Formation, Purit formation and Drosh Formation. Metabasalts / meta-andesites with common intercalation of carbonate lithologies (limestone and marble) form the cover sequence in this part of the Kohistan terran. These lithologies, include in the Gawuch Formation (Pudsey et al., 1985) are western equivalents of the better known Chalt-Yasin Group of Yasin and Hunza valleys (Tahirkheli et al., 1979; Petterson & Windley, 1991). The Gawuch Formation is abundantly intruded by sills of diorites and granodiorites composition belonging composition to the Early Eocene Lowari pluton of the Kohistan batholith. These minor intrusions of diorites and granodiorite in the Gawuch Formation, together with intimately associate quartz viens, host the copper mineralization in the Drosh-Shishi area.

Metavolcanic rocks constitute important lithologies in the study area. It occurs as two stratigraphic entities such as Gawuch Formation and Drosh Formation). The age difference between these two formations is unknown, but according to Pudsey et al. (1985), these are separated from each other by Purit Formation of fluviatile origin. In the context of the Kohistan geology, two groups of volcanic rocks are also identified by Pudsey et al.(1985) in the Shamran (Shandur Pass) area, to the east of presently studied area. The age relationship between the two groups of volcanics in the Shamran area is controversial; Pudsey et al. (1985) consider these to be stratigraphically below the Atine-Albian Yasin Group and thus lower Cretaceous in age, while Sullivian et al. (1993) differentiate the fresh volcanics of andesite-dacite-rhyolite composition from those metamorphosed to amphibolite-greenschist facies and assigned them an age of 58Ma on the basis of ^{40}Ar-^{39}Ar on

hornblende, equating them with the volcanic rocks in the Dir area (Sullivan et al., 1993; Shah & Hamidullah, 1994).

This study is conducted to understand the geochemical and petrological characters of the metavolcanic rocks of the Gawuch and Drosh formations of Chitral region in the context of their possible origin.

REGIONAL AND LOCAL GEOLOGICAL SETTING

In the northern Pakistan, the Shyok suture separates the Eurasian plate to the north from the Kohistan terrene to the south (Tahirkheli et al., 1979; Bard et al., 1980). The northern part of the Kohistan terrene comprises three principal tectonic unites, which from north to south include: 1) Shyok suture mélange, 2) sedimentary-volcano cover sequence and 3) Kohistan batholith. The Shyok suture mélange, as the name signifies, defines the collision zone between Kohistan and Eurasian plates and marks the closure of the northern branch of the Neotethys, termed as the Shyok ocean (Khan et al., 1994). It ranges from a razor-sharp fault to a 4km wide zone and consists of lenticular blocks of highly variable lithology including serpentinites, marbles, conglomerates, sandstones and basalts, mostly set in a pellitic matrix comprising slates of turbidite nature (Pudsey, 1986). In the Yasin area, limestone blocks are reported to contain fauna of Albian-Aptian (Early Cretaceous) age. The volcano-sedimentary cover sequence in the Kohistan terrene occurs as a lenticular belt of variable width squeezed between the Shyok suture in the north and the Kohistan batholith in the south. The sequence comprises a thick succession of metabasalts at the base (the Chalt volcanics; Petterson & windley, 1991) overlain by a succession of quartzites, limestones and turbidites (Pudsey et al., 1985; Pudsey, 1986), termed as the Yasin Group. The Yasin Group contains Early Cretaceous fauna and is marine in origin (Pudsey, 1986). Khan et al. (1994) have identified a succession of parageisses, schists and amphibolites (some containing pillow structures) called the Gilgit Formation occupying the base of the Chalt volcanics. The Kohistan batholith occupies the central spine of the Kohistan terrene and is intrusive into both of the above mentioned tectonic elements. The batholith is composite and consists of plutons of a wide range of compositions from gabbros, through diorites, tonalities and granodiorites to granites. The igneous activity related with the Kohistan batholith spans a time range of 102 to 29 Ma (Petterson & Windley, 1986).

The geology of the NW margin of the Kohistan terrene in Chitral including the Drosh-Shishi area related with this study, contains all the three tectonic elements outlined above. The Shyok suture mélange in this area comprises lenticular blocks of ultramafics, limestones etc. The volcano-sedimentary succession in this area is, however, much more complex than that of the Yasin-Hunza segment. Pudsey et al. (1985) recognized three formations, which from south to north include 1) Gawuch Formation, 2) Purit Formation and 3) Drosh Formation. The Gawuch Formation comprises metabasalts and limestones and is probably marine in origin while the Purit Formation comprising red conglomerates, sandstones and shale and is fluvial in origin (Pudsey et al., 1985). Occurrence of a succession of andesite/dacite volcanics of the Drosh Formation to the north and probably over the Purit Formation points to the possibility of a phase of Eocene volcanic event similar to that of Dir-Utror (Shah & Hamidullah, 1993: Shah & Shervias, 1999). Towards south the Gawuch Formation, the host of the copper mineralization, is in

contact with the Lowari pluton belonging to the Kohistan batholith. The contact, probably intrusive in origin, is now strongly sheared and is occupied by phyllites derived from metavolcanics of the Gawuch Formation through mylonitization. Much of the lower half of the Gawuch Formation is occupied by metabasalts, which are locally strongly sheared and transformed into phyllites. The upper half of the succession making the Gawuch Formation comprises commonly of intercalated metabasalts and limestone / marble. This part of the Gawuch Formation is additionally commonly intruded by sills of diorite and granodiorite composition which are themselves pervasively intruded by quartz veins. The contact between the Gawuch Formation and the overlying Purit Formation is occupied by a 10m thick band of marble.

FIELD RELATION

Metavolcanic rocks constitute important lithologies in the studied area (Fig. 1). These metavolcanics occur as two stratigraphic entities (i.e., Gawuch Formation and Drosh Formation). The age difference between these two formations is unknown. However, these are separated from each other by Purit Formation of fluviatile origin. Field observations during this study suggest that the Gawuch Formation of the Drosh-Shishi area has lithological similarities with the chalt volcanics and the Yasin group combined, and lower Cretaceous age may be assigned to the Gawuch Formation on the basis of this correlation.

Gawuch Formation: The Gawuch Formation consists of metavolcanics and sediments and it is about 2km thick in the Drosh-Shishi area. The basal part of the Formation comprises phyllites or greenschist facies metavolcanics. The upper half of formation contains metavolcanics together with common intercalations of metasediments like quartzites and marble. Most of the volcanics are probably andesites in composition and are strongly foliated and commonly altered. Tuffites are commonly associated with volcanics. They are fine-grained porcellaneous tuffites. Among the sediments, limestone occurs both as very thick units and as thinly interbeded limestone-phyllite-minor quartzite units. The Gawuch Formation is commonly intruded by plutons of diorites, granodiorites and granite composition belonging to Kohistan batholith. Other intrusions, include basic and andisitic dykes, are also present.

Drosh Formation: The Drosh Formation comprises a sequence of thickly bedded porphyritic andesites with phenocrysts of plagioclase, hornblend, and pyroxene. It is very well exposed along the road, south of Drosh. Some lava flows are highly vesicular and few are brecciated, some red shales are interbeded with the andesite flow. This Formation commonly overlies the Purit Formation.

RESULTS AND DISCUSSION

Fifteen representative metavolcanic rock samples from the Gawuch Formation and three from that of the Darosh Formation were analyzed for major and trace elements. The major elements have been determined by atomic absorption spectrometry, at the National Centre of Excellence in Geology, University of Peshawar, while the trace elements have been determined by using Rigaku X-ray fluorescence (XRF) at the Geoscience Laboratory, Islamabad. The major element oxides in all the samples and the trace elements in some of these samples are given in Table 1 and the data has been graphically presented in figures 2 to 7.

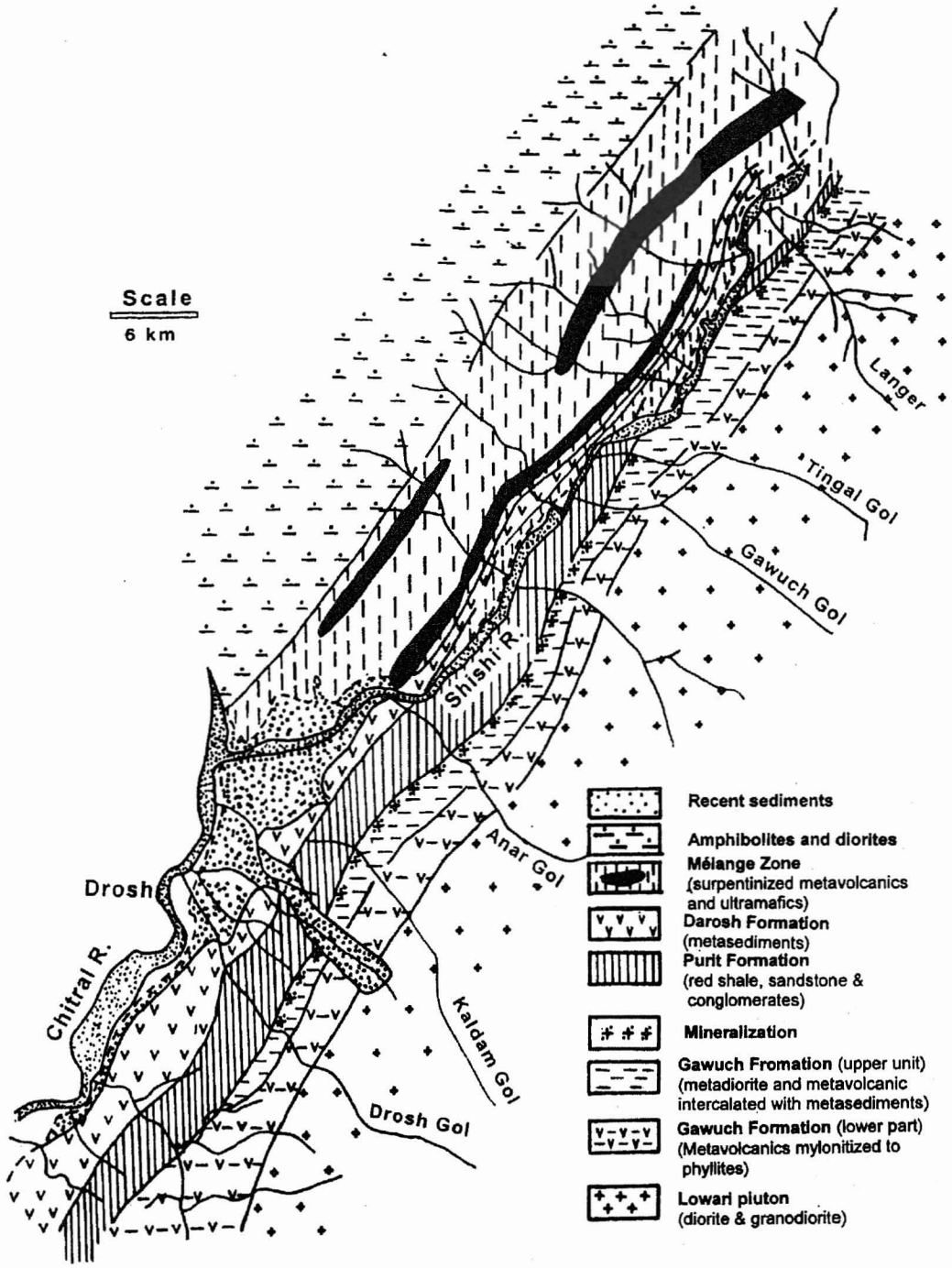

Fig. 1. Geological map of Drosh-Shishi area, Chitral, northern Pakistan (modified after Khan, 1997).

TABLE 1. GEOCHEMICAL DATA OF THE METAVOLCANICS FROM GAWUCH AND DROSH FORMATIONS

SAMPLE	KG2	KG7	KG8	KG9	KG12	KG15	KG172	KG210	GOG27
SiO_2	46.60	55.98	54.87	57.32	53.67	48.89	55.12	52.76	48.67
TiO_2	0.68	0.92	0.84	0.55	0.86	0.43	0.65	0.82	0.80
Al_2O_3	17.89	19.87	18.76	17.76	17.34	16.98	14.47	18.98	20.56
Fe_2O_3	5.65	5.18	6.11	4.12	6.11	8.18	8.94	5.34	5.12
MnO	0.15	0.07	0.07	0.09	0.08	0.11	0.13	0.09	0.07
MgO	3.41	3.59	4.46	3.68	4.43	10.28	6.17	3.32	5.04
CaO	11.93	3.39	4.27	4.60	5.07	8.88	5.67	5.19	7.20
Na_2O	1.69	1.85	0.79	0.54	0.80	1.57	3.29	0.72	3.88
K_2O	0.67	3.16	3.68	2.17	2.17	0.33	0.59	2.26	1.43
P_2O_5	0.13	0.17	0.17	0.25	0.23	0.12	0.15	0.17	0.27
LOI	10.47	4.43	5.20	7.10	8.67	2.86	4.82	9.57	5.50
Total	99.27	98.61	99.22	98.18	99.43	98.63	100.00	99.22	98.54
Nb		6				7	4		
Zr		130				136	73		
Y		42				18	17		
Sr		228				255	380		
Rb		40				18	26		
Cu		85				448	180		
Pb		62				47	42		
Zn		78				73	73		
Ni		80				176	45		
Cr		118				481	268		
V		426				306	395		
Ba		150				61	164		
CO		59				1173	48		
Th		4				999	2		
Sc		49				51	34		
Ga		8				7	12		
U		2					1		

The samples with KG, GOG, GR and GL prefixes are from the Gawuch Formation and DRO from the Drosh Formation

The classification of volcanic rocks of the studied area in terms of alkaline, tholeiite or calc-alkaline composition is presented in (Fig. 3). The studied volcanic rocks are essentially sub-alkaline although some samples, probably affected by alkali metasomatism, for some reason the studied rocks show some scatter when plotted on AFM diagram (Fig. 3c). This diagram, however, shows that volcanic rocks of the Drosh Foramtion are more iron-enriched than those of the typical calc-alkaline rocks of the Gawuch Formation. The best discrimination can be obtained by using the diagram e.g., SiO_2 vs FeO/MgO (Fig. 3b). In such a diagram, the Drosh volcanics plot as tholeiites while all the samples of the Gawuch Formation plot in the field of calc-alkaline basalt. A comparable result is achieved for these rocks when plotted in diagram of FeO(t) and TiO_2 vs FeO/MgO (Figs. 3d, e).

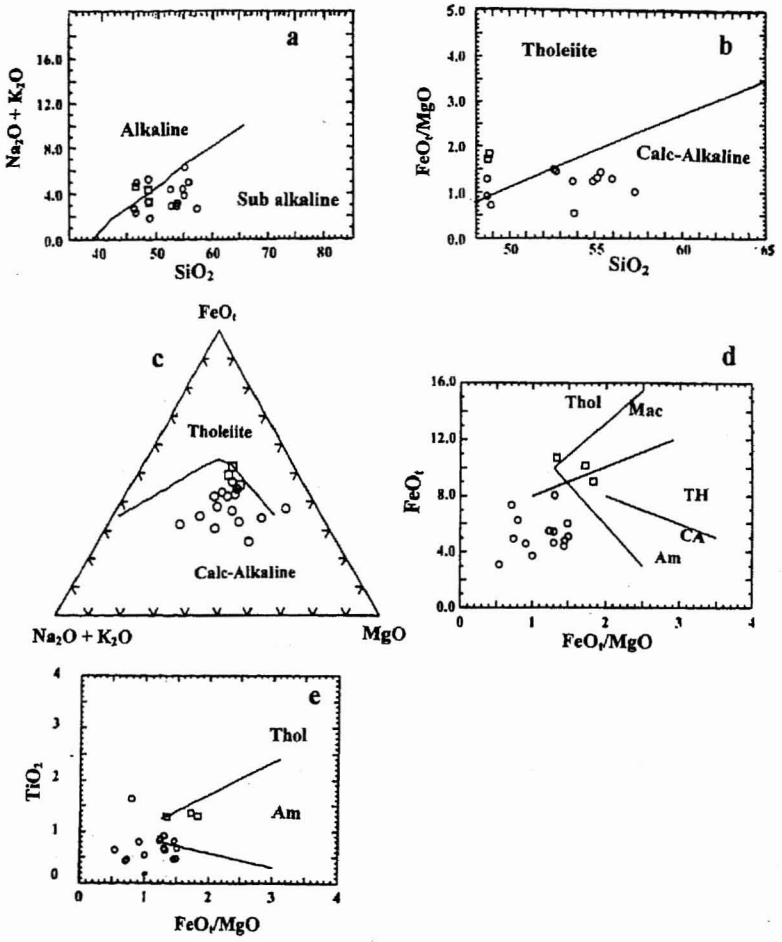

Fig. 3. Variation highlighting the calc-alkaline character of the volcanic rocks from the Gawuch Formation relative to the tholeiitic composition of the volcanic rocks from the Drosh formation. A). $Na_2O + K_2O$ vs SiO_2, b) FeO/MgO vs SiO_2, c) AFM diagram, d) FeO_t vs FeO_t/MgO and e) TiO_2 vs FeO_t/MgO. Majority of these diagrams are adopted from Irving and Bargar (1971). Symbols as for Fig. 2.

Trace Element: Trace element data of the volcanic rocks from the studied area is presented in the form of spider-diagrams where the data have been normalized to primordial mantle by using the normalization factor of Sun and McDonough (1989) (Fig. 4 & 5). Both the Drosh tholeiitic volcanics as well as the Gawuch calc-alkaline volcanics do not exhibit major differences in terms of inter-element ratios between the incompatible trace elements. Both have trace element patterns sloping towards right suggesting enrichment in the large-ion lithophile elements (LILE) relative to the high-field strength elements (HFSE). In both cases LILE show a greater scatter as compared to HFSE, probably reflecting the greater degree of mobilization in the former due to metasomatism, alteration or metamorphism. The only difference between the two groups of volcanics is in the Ti/Y (Gawuch = and Ti/Zr ratios. This difference is to be expected because the Drosh volcanics are tholeiitic in nature.

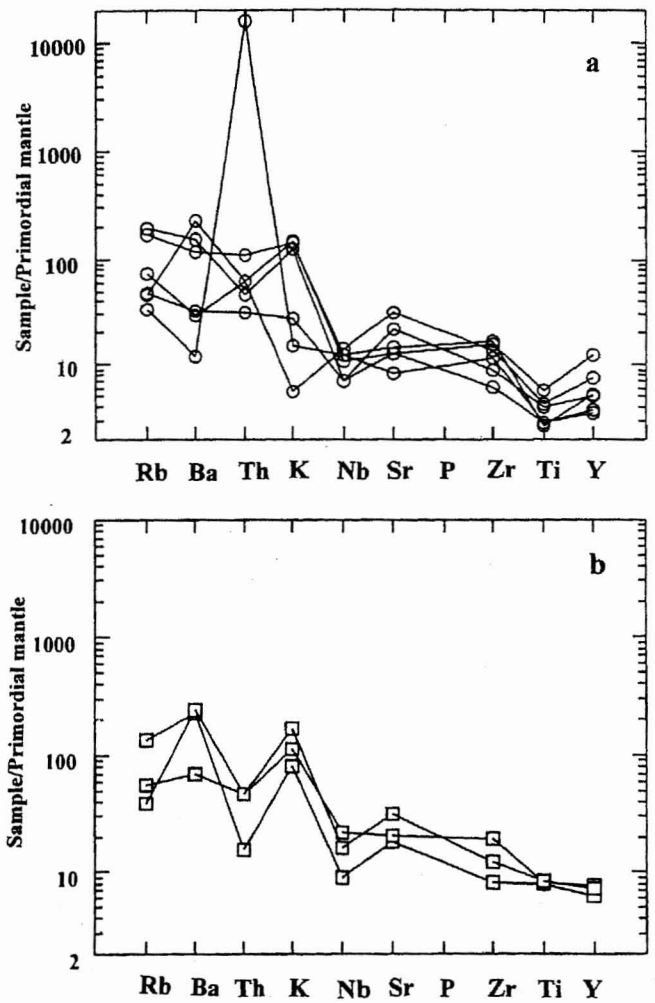

Fig. 4. Primordial mantle normalized spider diagrams for trace elements of the metavolcanics of the Gawuch Formation (a) and Darosh Formation (b).

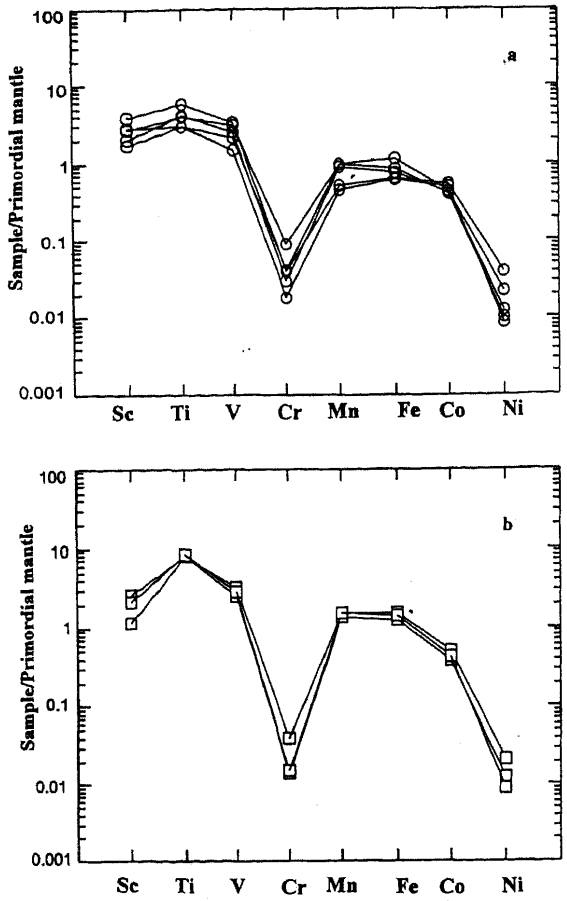

Fig. 5. Primordial mantle normalized transitional element patterns for the metavolaconic rocks of the Gawuch Formation (a) and Drosh Formation (b). Symbols as for Fig. 2.

The transitional elements like Sc, Ti, V, Cr, Mn, Fe, Co and Ni are also plotted in the form of primordial mantle-normalized spidergrams. Again the two groups of rocks show broadly similar patterns. The tholeiites of the Drosh Formation are characterized by positive anomalies for Ti compared to absence of such an anomaly in the case of the Gawuch calc-alkaline volcanics. Similarly Fe and Mn peaks are slightly higher in the case of Drosh volcanics compared to those of the Gawuch Formation. Compared to the primordial mantle, Cr and Ni are extensively depleted in the studied volcanics probably due to the role of olivine and clinopyroxene fractionation. Sc, V and Ti are only slightly enriched compared to the primordial mantle while Fe, Mn and Cu are slightly to moderately depleted relative to the primordial mantle.

Tectonic Setting

The discrimination diagrams used during this study, are primarily meant for highly fresh rocks devoid of phenocrysts. Unfortunately, volcanic rocks in terranes like Kohistan have little chance of escaping alteration and metamorphism due to their involvement in collision tectonics of Karakoram and

Almost all the analyzed samples (except one of Drosh Formation) plot within the field of calc-alkaline basalt when plotted in the triangular diagram (Ti-Zr-Sr) of Pearce and can, 1973 (Fig. 6c). In the binary plot of Zr vs Ti (Pearce & Cann, 1973) all the three samples of the Drosh Formation plot in the field of ocean-floor basalts, while the samples of the Gawuch Formation generally plot in the fields of calc-alkaline basalts (Fig. 6d). In the Zr vs Zr/Y plot (Pearce & Norry, 1979), surprisingly none of the analyzed samples plot as island arc basalts. Rather two plot as MORB and rest as within-plate basalts (Fig 6e). On the Ti vs V plot (Shervais, 1982), the Gawuch Formation samples have a Ti/V ratio of 10 which classifies them as true island arc basalts. The samples of Drosh Formation, on this plot show a Ti/V ratio of ~20 which is transitional between the island arc and ocean-floor basalts (Fig. 6f).

It is now evident from the above mentioned discrimination diagrams that the volcanic rocks from the studied area yield unequivocal results. The majority of the metavolcanic rocks of the Gawuch Formation represent calc-alkaline nature formed in island-arc setup. The volcanics of Drosh Formation, on the other hand, are mostly defined as tholeiites either of an island arc affinity or that of the ocean-floor origin. A more precise assessment of the tectonic setting of igneous rocks can be obtained by using multi-element diagrams (Holms, 1985). Primordial-mantle normalized trace-element patterns of the volcanics from both Gawuch and Drosh Formations are compared with each other and with the patterns of MORB, island arc tholeiite, calc-alkaline basalts and within plate basalts (Fig. 7). The trace-element patterns of the Drosh and Gawuch volcanics are characterized by certain characteristic (e.g., negative Nb anomaly) which are mutually consistant and closely comparable to subduction-related rocks.

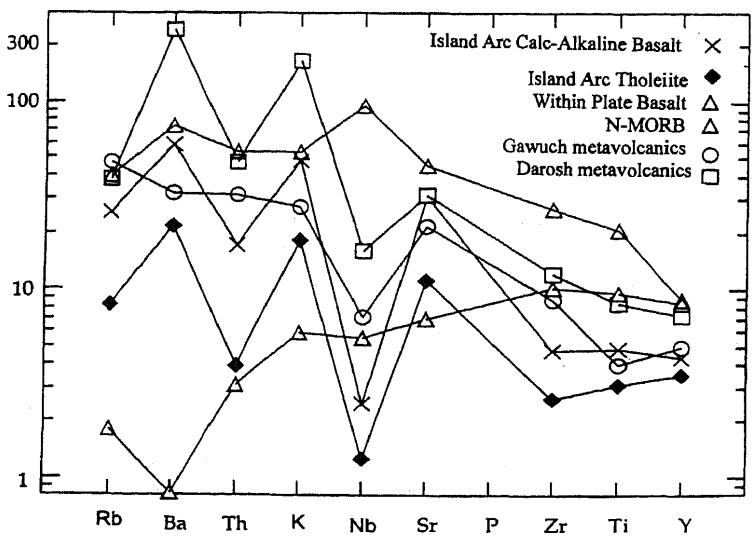

Fig. 7. Primordial mantle normalized trace element patterns of the representative metavolcanics of the Gawuch and Drosh formations compared with volcanic rocks from different types of tectonic settings.

Geochemical data, including both major and trace elements, have been used to characterize the petrology and tectonic setting of the igneous rocks of the area. Metavolcanic rocks belonging to Gawuch and Drosh Formations show different petrological lineage, the former arc calc-alkaline while the latter are clearly tholeiitic. This raised the possibility that the volcanic rocks of the Drosh Formation, which are closely associated with the mélange zone, could have tectonically escaped from the oceanic floor closed at the site of the Shyok suture. Detailed treatment in terms of mantle-normalized trace element patterns and discrimination diagrams involving immobile trace elements, however, suggests that the two groups of volcanics, despite their different petrological character, originated with a strong subduction component. The present data are, however, not sufficient to deduce the exact position of these volcanics within the Kohistan arc system i.e., back arc volcanic arc or fore arc. It may be noted that calc-alkaline and tholeiitic volcanics occur together in the entire Chalt volcanic belt in north Kohistan (Peterson & Windley, 1995). Sullivan et al. (1993), in the context of Shamran part of the Chalt volcanic belt, suggested that calc-alkaline volcanics may be younger than the tholeiitic volcanics, correlatable with the Eocene volcanics of Utror (Kalam) and Dir area. This cannot be applied to the studied area around Drosh, since here the calc-alkaline Gawuch Formation volcanics are reletively highly metamorphosed than the tholeiitic Drosh volcanics. Precise age determinations using radiometric systems like Ar^{40}-Ar^{39} (amphibole) and U-Pb (zircon) are needed to resolve the relationship between calc-alkaline and tholeiitic volcanics in northern Kohistan.

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