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Geology and geochemistry of the rocks of Ushiri Valley, District Dir, Northern Pakistan

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ABSTRACT: *The study area is lying in the north-western portion of the Kohistan arc terrane. This terrane is bounded by two suture zones of regional extent at its northern and southern sides, believed to be formed by obliteration of ancient oceanic basin. This arc experienced its first collision at its northern margin with the Karakorum plate at 90-80 Ma, and its second collision at the southern margin during Early Eocene with the Indian plate.*

Rocks of the study area are distinguished into two main lithological units: (1) Amphibolites and (2) Metadiorites/metagranodiorites. The amphibolites occupy the southern part of the studied area while metadiorite/metagranodiorites are exposed in the northern part of the study area. Both these rock units have intrusive contacts and exhibit local faulting and shearing. The amphibolites also host small patches of slightly metamorphosed gabbro-norites. The amphibolites are generally massive but also exhibit banding at places. They are intruded by quartz and quarrtzo-feldspathic veins especially in areas where shearing and faulting are intense. They are also intruded by the metadiorite / metagranodiorite in the form of small plugs. The metadiorites / granodiorites are medium to coarse-grained, massive in character and have xenoliths of amphibolites. Copper mineralization in the form of dissiminated grains of tetrahydrite and chalcopyrite and supergene enrichment in the form of malachite and azurite occur within quartz veins in limited areas.

Amphibolites are mainly composed of hornblende and plagioclase with subordinate amount of quartz and alkali feldspar. Biotite, muscovite, chlorite, epidote, apatite, sphene, rutile, calcite and opaque occur as accessories. The metagabbro-norites contain plagioclase, orthopyroxene and clinopyroxene as the dominant mineral constituents. The metadiorite, quartz-diorite and metagranodiorite are dominantly composed of plagioclase with variable proportion of quartz and alkali feldspar. The other minor constituents include biotite, hornblende, muscovite, apatite, sphene, zircon, garnet and opaque.

Chemically the amphibolites and metagabbro-norites are comagmatic. Their chemical characteristics favor the igneous parentage (i.e., host gabbro-norite) for the studied amphibolites. The major and trace elements study of these rocks suggests that these are of calc-alkaline nature and are formed by the arc magma within the subduction related environment. The chemical characteristics of the granitoid rocks (metadiorite/metagranodiorite) suggest that these are comagmatic and have close affinity towards the calcalkaline rocks, developed in island arc type of set up. Both the

amphibolites and gabbro-norites could be related to either Kamila amphibolites belt or Chilas Complex. The studied granitoids are, however, correlated with the stage II pluton of the Kohistan batholth.

INTRODUCTION

The study area covering ~ 110 km^2 in the central part of Dir district is generally known as the Usheri valley. It is bounded by latitude 35° 8' to 35° 13' north and longitude 72° 6' to 72° 14' east on the Survey of Pakistan toposheet No. 43-A\4. It is part of the north-western portion of the Kohistan arc terrain. The geology is comprised of a series of east-west trending units associated with two phases of post collisional plutonism (Zeitler, 1985; Treloar et al., 1989). The Kohistan arc terrane occupies the collision zone between the collided India and Karakoram plates (Fig.1). It is separated from the Karakoram Plate in the north by Main-Karakoram Thrust (MKT), from Indian Plate in the south by Main Mantle Thrust (MMT) and from the Nanga Parbat massif in the east by the Raikot fault. It remained a part of the Kohistan-Ladakh island arc system that developed as a results of the northward subduction of Neotethyan oceanic lithosphere during Late Jurassic to Cretaceous times (Honegar et al., 1982; Tahirkheli, 1979). The Ladakh arc terrane to the east has remarkable lithological and geochemical resemblance with the Kohistan arc terrane in the west suggesting their mutual continuity in the geological past. The two arcs got separated from each other by the doming of Nanga Parbat Haramosh during the last 10 Ma (Zeitler et al., 1985).

Hyden (1915) carried out preliminary geological work in district Dir that established a land mark foundation for subsequent geological work. In the adjacent areas of district Dir including the Barwa quadraugle, Kotegram and Akhagram quadrangle and Timargara quadrangle, Ahmad (1972), Khan and Saleemi (1972) and Arbab and Khan (1973) performed preliminary geological investigations. They have reported uneconomical copper mineralization in Barwa, Kambat and Usheri areas. Kakar et al. (1971) has prepared a geological map of the Jandul valley (area south-west of the study area) and also described a detailed geology of the area. The geological setup of Timargara and surrounding areas (areas south of the study area) of Dir district has been described by Chaudhary et al. (1974), Butt et al. (1980), Jan et al. (1983), Jan and Tahirkheli (1990) and Shah et al. (1999). Shah, et al. (1998) has also carried out stream sediments geochemical survey in Timargara and Jandul valley. Dir proper and surrounding areas, further north of the study area, have been geologically investigated in detail by Tahirkheli (1979; 1982), Hamidullah et al. (1990), Shah and Hamidullah (1994), Shah et al. (1994) and Sullivan et al. (1993).

This study is aimed to prepare a geological map of the area and to ascertain the possible origin of the studied rocks under investigation on the basis of mineralogical and geochemical studies.

LOCAL GEOLOGY AND FIELD ASPECTS

Amphibolite intruded by metadiorite / metagranodiorite, are widely exposed in the study area (Fig. 2). The former occupies the southern while the later covers, the northern part of the area. Occasionally amphibolites contain relics (small patches) of gabbro-norites. The former may occur as xenolith in the metadiorite / metagranodiorite in the north-western part of the study area (Fig. 2).

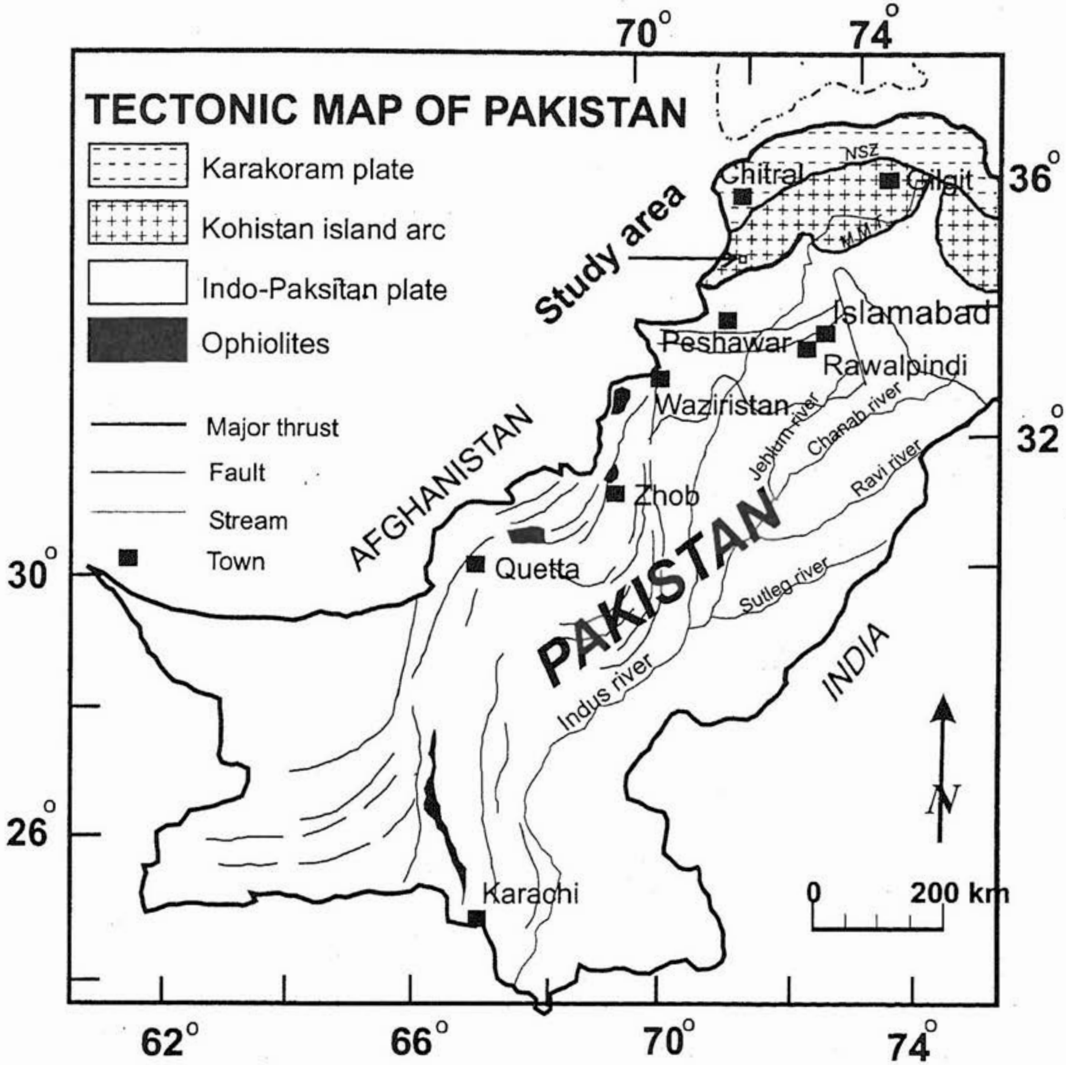

Fig. 1. Geological map of northern Pakistan.

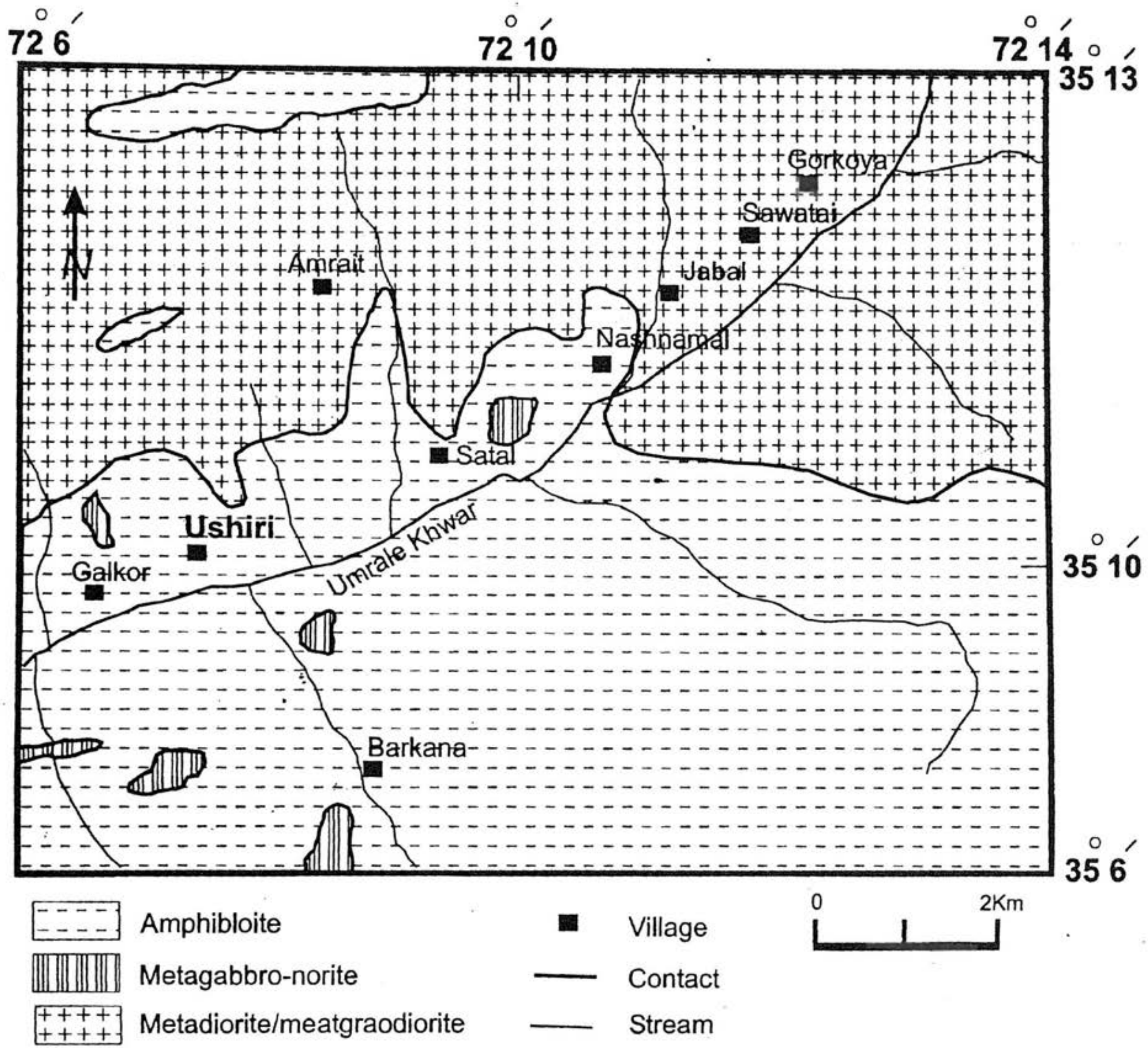

Fig. 2. Geological map of Ushiri valley, district Dir, NWFP, Pakistan.

Amphibolites

Amphibolites are the medium to coarse-grained, massive (banded at places) and foliated rocks with greenish-grey to green color on fresh surface and brownish green on weathered surface. Foliations generally strike E-W NW-SE and dip (30° to 60°) towards north and north-east respectively. These rocks are intruded by the metadiorite / metagranodiorite that exhibit chilled margins at contacts. Along such contacts amphibolites are also relatively fine-grained (hornfelsic) and have high concentration of hornblende. At places aplite dikes are noticed within these amphibolites. The origin of such a rock combination has been desenbed in detail by Hamidullah and Ahmad (1992) while studying the amphibolite of Mahak in Swat. In the study area these rocks are sheared and have attained schistocity along the shear zones where the microveins of epidote have developed. Moderate to strong banding and microfolding is common along the shear zones. Quartz and quartzo-feldspathic veining is the common features of these amphibolites. Quartz veins are generally barren but ocassionally mineralized with tetrahedrite, chalcopyrite, malachite and azurite. At such zones the host amphibolite appears like a gossan with redish brown weathered surface. Dark colored patches, containing high concentration of hornblende (>95%), are present at many places within the amphibolites. These form coarse-grained bodies of various shapes and sizes.

Amphibolites have variable proportion of plagioclase and hornblende. Generally those with plagioclase >60% have greenish-grey color and those with hornblende 60% have dark green color. The banded varieties also behave similarly. Highly tectonized quartzite with microfolds, is present within this unit at various places. Small angular to subangular xenoliths of quartzite is another feature of these amphibolites.

Gabbro-norites

Gabbro-norites occur as small size patches and xenoliths/relics within the amphibolites at various place (Fig.2). These are medium to coarse-grained, homogenous and less foliated rocks of dark grey to greenish grey color on fresh surface and light brown to yellowish-brown on weathered surface. At some places these rocks appear as hemogeneous as some amphibolites are, indicating a genetic link between the two types of rocks. It appears that the gabbro-norite rocks represent protolith of amphibolite which have suffered negligible metamorphism. They have retained primary texture and mineralogy and are, therefore, remnants of large bodies which have been mostly transferred to amphibolite. At certain places, microveins of quartz are common in these rocks. (see Hamidullah et al., 1990).

Diorites, quartz-diorites and grandiorites

Shown as one unit on the map these rocks have covered mainly the northern part of the study area and also occur as small plugs within the amphibolites (Fig.2). These are medium to coarse - grained massive rocks of greenish - gray to dark – gray colour on fresh surface and of brownish – gray colour on weathered surface. These exhibit moderate to weak foliation, generally trending north-east and south-east and south-west. Diorite quartz diorite and granodiorite are not easily distinguishable in the field. However, the latter one contains high contents of quartz and feldspar and is lighter in colour relative to the other two (Fig.2). Quartz and epidote veins have developed along micro-fractures in these rocks at certain places whereas xenoliths of amphibolites are also noticed occasionally.

Quartz veins and aplite dikes with microbands of fine grained garnet along contacts are very common in these rocks. Though generally barren the quartz veins, show copper mineralization in the form of tetrahedrite, chalcopyrite and supergene enrichment represented by malachite and azurite.

PETROGRAPHY

Amphibolites

In thin sections, these amphibolites are medium – to coarse-grained, inequigranular and hypidioblastic to subidioblastic in texture. Hornblende and plagioclase are the dominant minerals while orthoclase and quartz occur as minor constituents. Biotite, muscovite, chlorite, epidote, apatite, sphene, rutile, calcite and opaque occur as accessories.

Hornblende (32 to 60%) is generally light-green to dark-green in color, however, grains ploechroic from bluish-green to light-brown are also noticed. Most of the hornblende grains enclose fine-grained rounded to subrounded quartz which imparts a sieve or papermesh texture to the amphibole grains. This quartz probably represent the silica released during the transformation of some mafic phases (i.e., proxene) to hornblende. Botite occurs as core to hornblende grains in certain instances and the former has transformed to chlorite occasionally. Hornblende grains have developed a fabric, especially in amphibolites occurring along the shear zones.

Plagiclase (30 to 50%) ranges from oligoclase to andesine, however, some albitic grains also occur. It is partially altered to sericite, epidote and carbonates, containing, pseudomorphs and relics of plagioclase.

Biotite (1 to 10%) pleochroic from brown to light-brown and in some cases from light green to dark green occurs. Both these varities have shreds or exolusions of magnetite. Biotite is usually present as flakes and boundless in association with hornblende and opaque phases. Some time biotite and hornblende are intergrown, indicating simultaneous crystallization of both the phases. In some cases, the biotite encloses small flakes of muscovite while in others, it is by itself enclosed within hornblende. Both biotite and muscovite flakes exhibit kinking and bending due to deformation.

Orthoclase (2 to 5%) occurs as a subhedral, medium – grained phase, that has partially or completely altered to kaolinite, sericite and muscovite etc. Quartz is present as inclusions within hornblende and also as anhedral individual grains within the interstices of plagioclase. Fibrous amphibole, mainly trimolite/actinolite, (trace to 3%) occurs as light-green to colorless elongated grains.

Chlorite (trace to 20%) is generally present in association with opaque phase along fractures. It is usually replaced along margins by fibrous amphibole and hornblende. In few cases the replacement of chlorite by biotite along margins is also noticed. Epidote (trace to 2%) usually occurs as alteration product of plagioclase, mainly in the form of granular aggregates. However, in few cases prismatic grains of bluish-grey colour (probably zoisite) have also been noticed. Sphene, apatite and rutile (in traces) are present in most of the samples as accessory minerals. Opaque phase (magnetite titanomagnetite; trace to 1%) occur as irregular mass, and disseminated grains with leucoxene surrounding certain grains.

Gabbro-norites

Petrographically the gabbro-nortite are dominantly composed of plagioclase, clinopyroxene and orthopyroxene, with occasional occurrence of hornblende and biotite, as secondary phases. Qúartz, sphene, apatite, chlorite, epidote and opaque occur as minor constituents. The rock has hypidiomorphic to idiomorphic texture with ophitic arrangement of certain minerals. Plagioclase (58 to 62%) is the dominant mineral ranging in composition from andesine to labradorite. It is medium-to coarse-grained subhedral to euhedral and is generally fresh but partially altered grains are also present.

Orthopyroxene (15 to 18%) is pleochroic from pink to green or colorless and is indicating to be hypersthene or bronzite. Clinopyroxene (12 to 16%) is medium - to coarse-grained, colorless, non-pleochroic, and has been classified as augite on the basis of optical properties. Clinopyroxene and orthopyroxene generally exist together and are occasionally, replaced by chlorite and hornblende along margins. Corona structures with core of orthopyroxene, middle rim of chlorite that may be missing occasionally, and the outermost rim of hornblende are noticed. Both types of pyroxene contain exolved magnetite and or tintanomagnetit in the form of disseminated grains or striation, oriented paralld to cleavages.

Hornblende (4 to 6%) occurs as light green to green prismatic grains with rounded to subrounded inclusions of quartz indicating a peper mesh/seive texture. The quartz grains may be requesting the release of silica during the transformation of pyroxene to hornblende. Biotite ($<1\%$) is pleocthroic from light-brown to dark-brown and occurs as elongated flakes in association with opaque phase. Fine-grained opaque phase (magnetite/titanomagnetite) is usually found in dissemination, however, irregular grains are also noticed.

Diorite/quartz-diorite

In thin sections, it is mainly composed of plagioclase with minor amount of orthoclase, quartz, biotite, muscovite and hornblende. Sphene, apatite, zircon, garnet and opaque occur as accessories. Kaolinite, sericite, muscovite, epidote carbonates and chlorite occur as alteration product. The rock has subhedral anhedral grains with hypidioblastic to allutrioblastic texture, and has developed a fabric in certain parts.

Plagioclase (An_{34-45}) varies between 45-73 by modal percent. It is subhedral to anhedral with some sections generally fresh, and others with partial alternation along margins and fractures and occasionally at cores to sericite and eopidote. Severely altered grains have left behind relics and pseudomorphs of plagioclase in a matrix of sericite, epidote and carbonate. In samples from the sheared zone the plagioclase porphyroblsts are mortared and rotated, with biotite and muscovite swirled around them imparting geneissosity to the rock. Orthoclase (15 to 30%) is mainly interstitial to plagioclase and shows alteration to kaolinite and muscovite. Quartz (3 to 10%) is also interstitial and strained.

Biotite (3 to 12%), pleochroic from brown to light-brown and occasionally from green to light-green, occurs together with subordinate muscovite. Epidote (trace to 5%) generally occurs as small granular aggregates, however, prismatic grains with high birefregent colors are also noticed. It seems to be secondary after plagoiclase. A few small fractured grains of garnet are also noticed in proximity to the opaque phase that is occasionally surrounded by chlorite. Hornblende (trace to 10%) of light-green to green colour occurs as prismatic grains. Microfractures in these rocks, when present, are filled by quartzo-feldspathic and carbonate material. Sphene, apatite, zircon and opaque (magnetite/titanomagnetit) are present in traces.

Granodiorite

Mainly composed of orthoclase (~40%) plagioclase (25-30%) and quartz (20-25%) with minor amount of biotite, muscovite, and epidote and with garnet, zircon and opaque occuring as accessories, granodiorite has a hypidioblastic texture. Orthoclase when fresh indicates undurlose extinction and vermicular intergrowths. It is usually altered to kaolinite, sericite and muscovite.

Plagioclase (An_{12-22}) is usually zoned in normal and reverse fashion indicated by the onset of alteration either for core or margins to epidote, sericite and carbonates. Epidote has also grown along its fractures. Quartz is interstitial and shows pressure shadows due to strain.

Biotite (~3%) and muscovite (~2%) occur together interestedly to feldspar. It is pleochroic from light-green to green and light-brown to brown. Epidote (up to 1%) occurs as granular aggregates after feldspar and also in the vicinities of biotite, muscovite together with the disseminated magnetite. Small rounded and fractured grains of garnet are also rarely present.

Granodiorite when tectonized, has rotated and mortered large grains (porphyroblast) of feldspare and quartz surrounded by large flakes of biotite and muscovite within a fine-grained felsic matrix, indicating a gneissose texture. Extensive mylonization has lead the rock to retain only a few relics of plagioclase and orthoclase within the fine-grained matrix of epidote, serecite, muscovite, kaolinite and carbonates.

ROCK GEOCHEMISTRY

Representative samples of amphibolites, gabbro-norites, diorites/quartz-diorite and granodiorite from the studied area were subjected to geochemical analysis in order to establish their genetic and evolutionary characters. Keeping in view the field relationships and the petrographic features of various types of rocks of the area, two main groups, a) amphibolites and gabbro-norites and b) diorite/quartz-diorite and granodiorite have been treated separately (Tables 1,2).

SiO_2, TiO_2 and P_2O_5 were determined by UV/visible spectrophotometer while rest of the major and trace elements were determined by Atomic Absorption Spectrophotometer. Gold, after extraction with MIBK, was determined by using the electrothermal Atomic Absorption, equipped with HGA-600 graphite furnace. Loss on Ignition (LOI) was determined in duplicate by heating about 2 grams powdered sample at 950°C overnight. All these analyses were performed in the geochemistry laboratory of the National Centre of Excellence in Geology, University of Peshawar.

a. Amphibolties and Gabbro-norites

On the TiO_2 vs SiO_2 plot of Tarney (1977) all the amphibolites and gabbro-norite samples occur is igneous filed where as on the C vs mg plot and on the C+ 100mg + al-alk triangular plot of Leak (1964) these data fallow the magmatic trend shown for the middle stage differentiation of Karoo dolerite (Fig 3a-c) indicating an igneous parentage.

Both major and trace elements of the studied amphibolites and the gabbro-norites are plotted against SiO_2 in Figures 4 and 5 respectively. It is evident from these diagrams that many of the major and trace elements display well defined smooth variation trends against SiO_2 which further confirm the magmatic character of the protolith of the studied amphibolites. The gabbro-norites have more or less similar behavior as that of amphibolites in these diagrams (Figs. 4 & 5) and are considered as cogenetic.

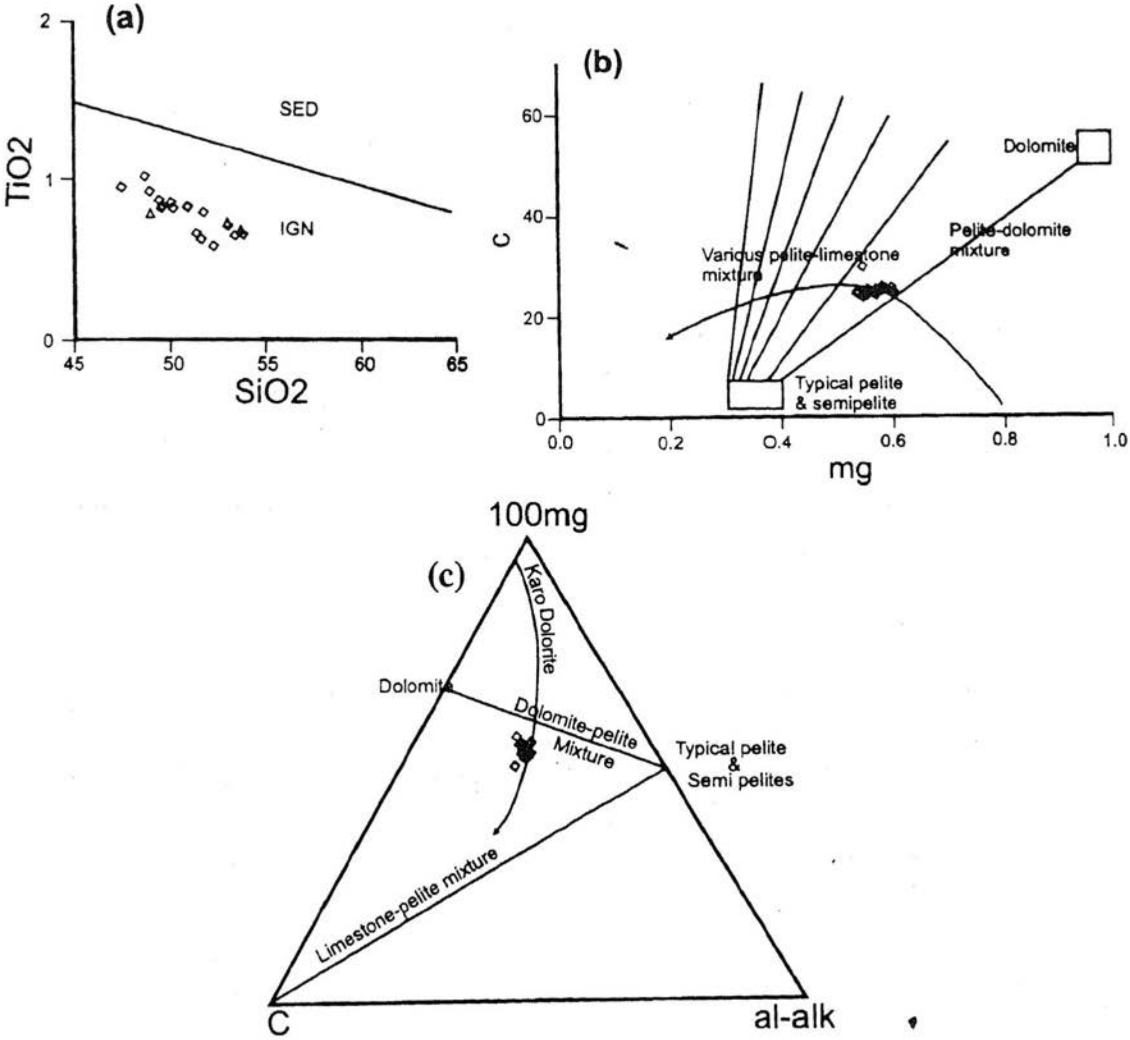

Fig. 3. (a) TiO_2 vs SiO_2, (b) niggli c vs mg and (c) c – 100 mg – al – alk plots of the amphibolites and gabbro-norites. Fields and trends are after Tarney (1977), Leake (1964) and Leake (1960), respectively. Symbols as in Figure 4.

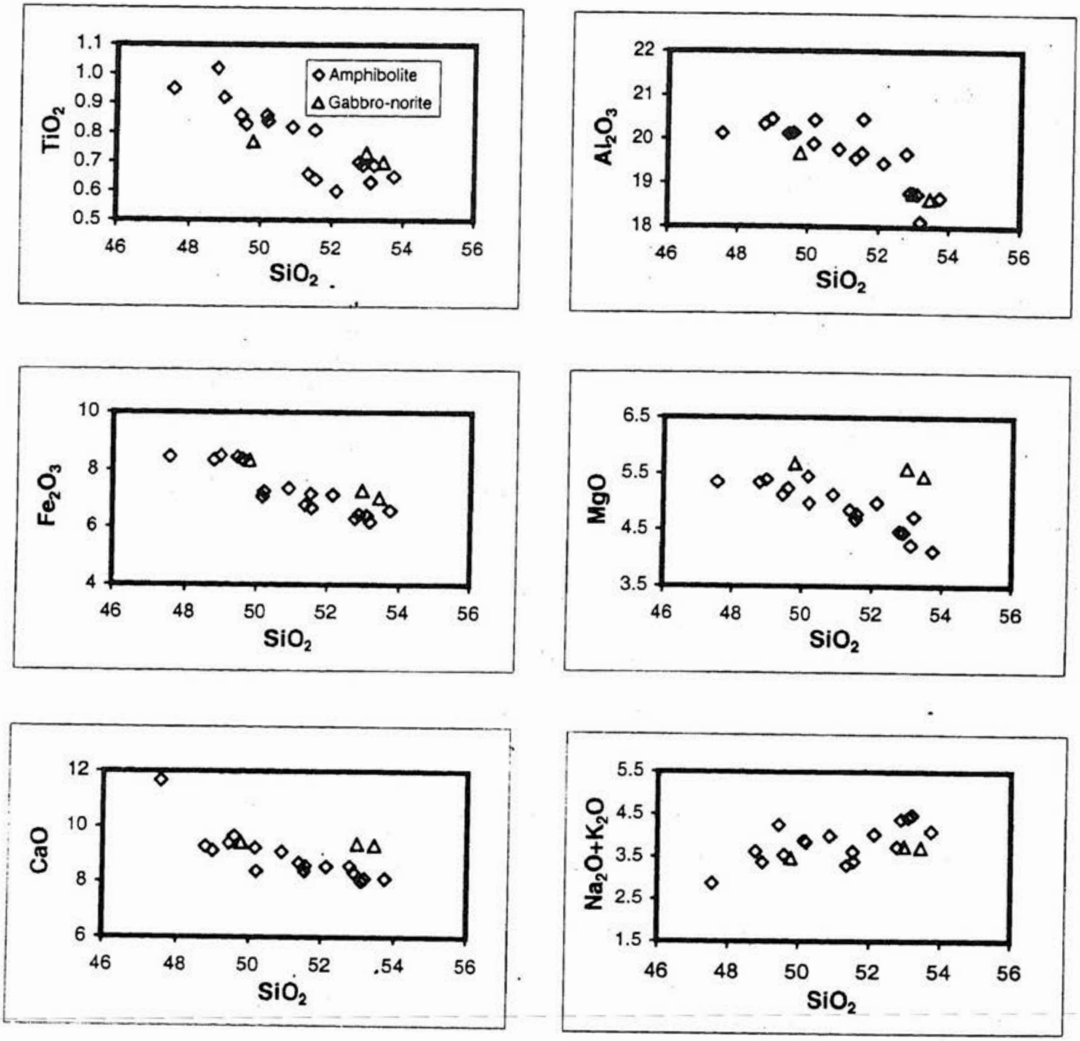

Fig. 4. Plot of various oxides against SiO_2 for the amphibolites and gabbro-norites of the Ushiri valley, central Dir.

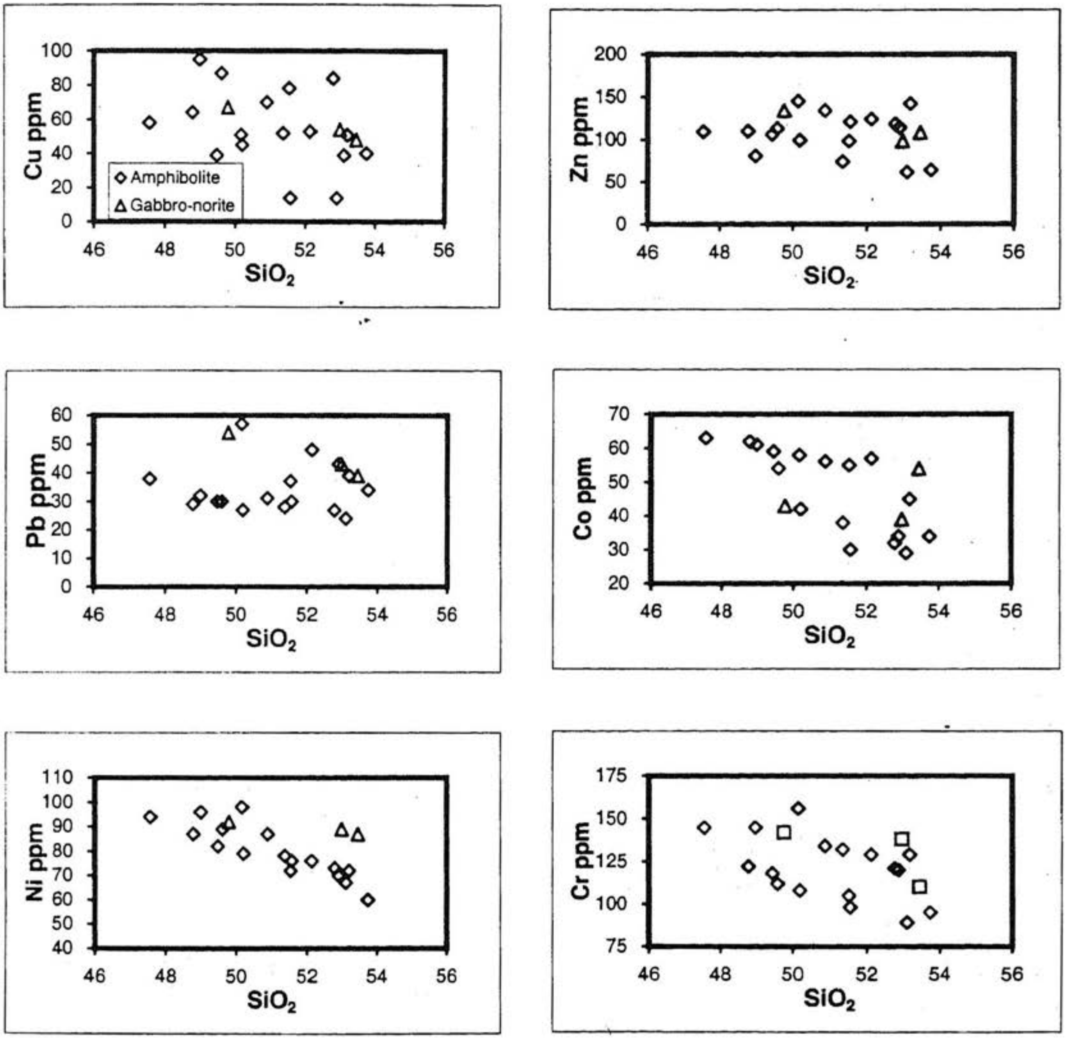

Fig. 5. Plot of various trace elements against SiO_2 for the amphibolites and gabbro-norites of the Ushiri valley, central Dir.

TABLE 1. MAJOR AND TRACE ELEMENT DATA ALONG WITH C.I.P.W. NORMS AND NIGGLI VALUES FOR THE AMPHIBOLITE AND GABBRO-NORITE FROM USHIRI VALLEY, CENTRAL DIR

Amphibolites									
S.No.	US25	US27	US30	US33	US36	US47	US49	US50	US52
SiO_2	50.88	53.19	52.13	50.16	52.89	47.56	51.36	54.56	53.10
TiO_2	0.82	0.69	0.60	0.86	0.69	0.95	0.66	0.64	0.63
Al_2O_3	19.76	18.12	19.45	19.88	18.78	20.12	19.56	20.45	18.75
Fe_2O_3	7.34	6.18	7.12	7.06	6.45	8.45	6.77	6.67	6.41
MnO	0.14	0.12	0.15	0.13	0.12	0.14	0.14	0.16	0.11
MgO	5.12	4.73	4.96	5.45	4.45	5.34	4.85	4.78	4.23
CaO	9.08	8.12	8.56	9.23	8.34	11.67	8.69	8.58	8.02
Na_2O	2.89	3.25	2.94	2.84	3.20	2.09	2.40	2.50	3.08
K_2O	1.10	1.23	1.09	1.03	1.18	0.78	0.89	0.88	1.34
P_2O_5	0.25	0.20	0.26	0.21	0.21	0.28	0.18	0.20	0.21
L.O.I	2.15	3.13	1.98	1.14	1.45	3.13	2.17	1.58	3.05
Total	99.83	99.11	99.34	98.36	97.96	100.90	97.87	98.16	99.08
Trace elements in ppm (except Au)									
Cu	70	51	53	51	14	58	52	14	39
Pb	31	39	48	57	43	38	27	30	24
Zn	134	142	124	145	114	109	74	121	61
Ni	87	72	76	98	70	94	78	76	67
Cr	134	129	129	156	120	145	132	98	89
Co	56	45	57	58	34	63	38	30	29
Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Au (ppb)	3	4	2	0	0	4	7	8	3

(Table 1continued)

C.I.P.W. Norms									
S.No.	US25	US27	US30	US33	US36	US47	US49	US50	US52
Q	1.07	4.40	2.93	0.27	4.16	0.00	5.83	5.37	5.14
Or	6.71	7.62	6.67	6.31	7.28	4.76	5.54	5.42	8.30
Ab	25.18	28.79	25.69	24.85	28.19	18.21	21.33	22.01	27.27
An	38.80	32.67	37.85	39.76	34.76	44.49	41.98	43.02	34.92
Di	4.87	6.67	3.64	5.08	5.68	10.90	1.76	0.00	4.32
Hy	19.14	16.45	19.96	19.41	16.37	13.45	20.04	20.53	16.64
Ol	0.00	0.00	0.00	0.00	0.00	3.24	0.00	0.00	0.00
Mt	1.48	1.27	1.44	1.43	1.32	1.70	1.39	1.36	13.31
Il	2.19	1.67	1.34	2.42	1.76	2.62	1.72	1.58	1.55
Ap	0.56	0.46	0.59	0.47	4.08	0.63	0.41	0.45	0.48

Niggli Values									
si	133	151	141	130	149	115	142	141	153
al	30	30	31	30	31	29	32	33	32
fm	35	34	35	35	33	35	34	34	32
c	26	25	25	26	25	30	26	25	25
alk	9	11	10	9	11	6	8	8	11
k	0.20	0.20	0.20	0.19	0.20	0.20	0.20	0.19	0.22
mg	0.58	0.60	0.58	0.60	0.57	0.55	0.58	0.58	0.56
Mg#	58.02	60.26	58.08	60.46	57.75	55.59	58.66	58.67	56.66

(Table 1 continued)

Amphibolite								
S.No.	US58	US60	US64	US65	US70	US72	US84	US89
SiO_2	53.74	49.59	52.78	48.98	51.53	48.78	49.45	50.20
TiO_2	0.65	0.83	0.70	0.92	0.81	1.02	0.86	0.84
Al_2O_3	18.67	20.14	19.67	20.45	19.68	20.34	20.12	20.43
Fe_2O_3	6.58	8.36	6.30	8.49	7.16	8.33	8.44	7.24
MnO	0.14	0.13	0.12	0.18	0.14	0.15	0.16	0.15
MgO	4.12	5.23	4.47	5.39	4.68	5.34	5.12	4.97
CaO	8.12	9.64	8.57	9.12	8.38	9.28	9.39	8.38
Na_2O	3.06	2.76	2.90	2.68	2.87	2.81	3.11	2.95
K_2O	1.04	0.78	0.83	0.68	0.75	0.81	1.14	0.88
P_2O_5	0.19	0.21	0.18	0.28	0.20	0.27	0.28	0.19
L.O.I	1.90	2.09	2.63	3.93	1.72	1.89	1.65	3.21
Total	98.25	100.05	99.34	101.42	98.19	99.34	99.95	99.73

Gabbro-norites			
S.No.	US31	US32	US35
SiO_2	53.45	49.78	52.98
TiO_2	0.70	0.77	0.73
Al_2O_3	18.65	19.67	18.78
Fe_2O_3	7.03	8.34	7.28
MnO	0.15	0.13	0.12
MgO	5.45	5.68	5.59
CaO	9.34	9.42	9.38
Na_2O	2.94	2.74	2.99
K_2O	0.78	0.72	0.75
P_2O_5	0.26	0.21	0.21
L.O.I	1.42	1.36	1.45
Total	100.25	99.17	100.33

Trace elements in ppm (except Au)								
Cu	40	87	84	95	78	64	39	45
Pb	34	30	27	32	37	29	30	27
Zn	64	113	118	81	98	110	106	99
Ni	60	89	73	96	72	87	82	79
Cr	95	112	121	145	105	122	118	108
Co	34	54	32	61	55	62	59	42
Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Au (ppb)	0	2	5	0	7	4	1	3

Trace elements in ppm (except Au)			
Cu	48	67	54
Pb	39	54	43
Zn	108	134	98
Ni	87	92	89
Cr	110	142	138
Co	54	43	39
Ag	<0.5	<0.5	<0.5
Au (ppb)	2	4	6

TABLE 2. MAJOR AND TRACE ELEMENT DATA ALONG WITH C.I.P.W. NORMS OF DIORITES / QUARTZ-DIORITES AND GRANODIORITES FROM USHIRI VALLEY, CENTRAL DIR

Diorites / quartz diorites

S.No.	US15	US17	US69	US44	US42	US11	US13	US73
SiO_2	55.51	56.78	53.10	54.34	57.56	60.10	60.23	61.78
TiO_2	0.54	0.52	0.86	0.65	0.40	0.57	0.41	0.61
Al_2O_3	20.36	20.12	20.23	20.34	19.89	18.98	18.78	18.34
Fe_2O_3	5.11	4.89	5.56	5.00	5.12	4.47	4.86	3.21
MnO	0.14	0.12	0.10	0.09	0.08	0.08	0.05	0.08
MgO	3.23	3.32	4.18	3.32	2.56	2.79	2.23	2.82
CaO	7.56	6.98	8.34	7.98	7.17	6.45	6.45	6.08
Na_2O	3.14	3.24	2.66	2.88	3.25	3.56	3.42	3.45
K_2O	0.74	0.75	.70	0.72	0.78	0.86	0.83	0.92
P_2O_5	0.84	0.58	0.62	0.52	0.42	0.54	0.36	0.32
L.O.I	1.94	1.78	3.45	1.34	1.45	1.23	1.43	1.75
Total	99.11	99.08	99.80	97.18	98.68	99.63	99.05	99.36

Trace elements in ppm (except Au)

Cu	48	56	78	53	67	104	87	84
Pb	32	31	37	34	42	51	41	29
Zn	76	68	95	115	89	91	71	81
Ni	34	54	59	48	37	39	41	46
Cr	26	43	54	39	28	33	32	38
Co	63	59	68	61	59	47	43	36
Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Au (ppb)	4	0	6	8	3	2	0	11

C.I. P.W. norms

Q	13.45	14.62	10.24	12.22	15.35	17.70	18.94	20.90
Or	4.53	4.58	4.32	4.47	4.77	5.19	5.05	5.59
Ab	27.47	28.29	23.47	25.55	28.40	30.72	29.75	29.97
An	33.18	31.89	39.00	37.99	33.97	29.10	30.54	28.88
Di	2.70	2.74	1.45	1.60	1.70	1.77	1.41	1.39
Hy	14.66	14.56	17.26	14.66	13.05	13.32	11.72	10.71
Mt	1.04	0.99	1.14	1.03	1.04	0.89	0.98	0.65
Il	1.06	1.02	1.71	1.30	0.79	1.11	0.80	1.19
Ap	1.90	1.31	1.41	1.19	0.95	1.20	0.81	0.72

(Table 2 continued)

Granodiorites									
S.No.	US10	US19	US20	US24	US38	US39	US40	US41	US45
SiO_2	65.89	66.78	64.10	64.23	64.29	63.21	64.34	64.67	66.67
TiO_2	0.36	0.37	0.45	0.40	0.47	0.37	0.56	0.40	0.30
Al_2O_3	16.98	16.12	17.89	17.64	17.68	17.78	17.76	17.89	16.87
Fe_2O_3	3.10	3.13	3.14	3.32	3.88	3.45	3.05	3.38	2.67
MnO	0.08	0.07	0.07	0.08	0.08	0.08	0.07	0.08	0.07
MgO	1.75	1.23	1.21	1.12	1.22	1.22	1.25	1.08	0.78
CaO	4.71	4.60	4.99	4.16	4.13	4.13	4.57	4.74	4.61
Na_2O	4.45	4.52	4.70	4.65	4.50	4.50	4.21	4.12	4.50
K_2O	1.32	1.34	1.21	1.22	1.26	1.26	1.21	1.32	1.54
P_2O_5	0.67	0.63	0.40	0.71	0.63	0.63	0.32	0.48	0.62
L.O.I	1.05	1.05	1.23	1.34	1.21	1.12	1.21	1.17	1.10
Total	100.36	99.84	99.39	98.87	99.35	97.80	98.55	99.333	99.11

Trace elements in ppm (except Au)

Cu	45	34	65	32	48	52	73	39	45
Pb	34	33	40	29	44	35	39	28	36
Zn	28	46	34	37	28	42	36	32	41
Ni	22	18	16	16	17	19	16	15	14
Cr	27	21	19	18	18	20	17	17	16
Co	47	49	56	61	66	48	34	48	29
Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Au (ppb)	4	8	2	6	0	7	10	8	4

C.I.P. W norms

Q	22.75	24.20	19.62	22.86	22.91	24.29	23.73	24.00	24.32
Or	7.89	8.05	7.32	7.43	7.63	7.31	7.38	7.98	9.26
Ab	38.01	8.81	40.60	40.45	38.92	34.93	36.67	35.60	38.68
An	19.21	9.03	22.65	16.49	16.78	20.24	21.23	20.86	19.17
Di	1.26	0.36	0.73	2.87	2.96	2.90	2.02	2.24	0.90
Hy	8.09	6.82	6.69	6.85	7.70	7.50	6.54	6.78	5.19
Mt	0.61	0.62	0.63	0.67	0.78	0.70	0.62	0.68	0.53
Il	0.69	0.71	0.87	0.78	0.91	0.73	1.10	0.78	0.58
Ap	1.48	1.40	0.89	1.60	1.41	1.41	0.72	1.07	1.38

TiO_2, Fe_2O_3, Al_2O_3, CaO and MgO exhibit well defined negative correlation while the Na_2O + K_2O show positive correlation with SiO_2 during fractionation. MnO and P_2O_5 have more or less constant behavior with change in SiO_2 (Fig.4). Among the trace elements Ni, Cr and Co show well defined negative correlation while Pb, Zn and Cu have greater scatter with increasing SiO_2 during fractionation (Fig.5). The trace elements have also been plotted against the major oxides for which they have greater affinity (Fig.6). This diagram clearly indicates that the Cr and Ni have positive correlation with MgO and Co has positive correlation with Fe_2O_3. This major and trace element behavior of the studied rocks during fractionation is the characteristic feature of magmatic differentiation. By looking at the variation trends (especially of CaO, MgO, CaO, Cr and Ni vs SiO_2) very carefully, it can be concluded that the clinopyroxene and plagioclase have played an important role in the formation of these rocks. The negative differentiation trends for TiO_2 and Fe_2O_3 (t) further signify crystallization of magnetite / titanomagnetite / or hornblende which is the characteristic feature of calalkaline magmas (see Miyashiro, 1977; Green & Pearson, 1980).

Major oxides vs SiO_2 plot for amphibolites and gabbor-norites show regular and parallel variation indicating differentiation and a genetic relationship between the two types. Al_2O_3, CaO, MgO, Fe_2O_3 and TiO_2 decrease with SiO_2 and with differentiation where as Na_2O + K_2O behave the opposite (Fig. 4). Such trends are typical of basaltic differentiation with olivine $\pm$ pyroxenes + plagioclase + magnetite on the liqudus and feldspar and quartz concentrating towards the end of the Bowen reaction series. More or less regular negative trends of these rocks on Co, Cr and Ni vs SiO_2 (Fig. 5) plots also suggest the above interpretation. Olivine, pyroxene and magnetic fractionate is these rocks is also indicated by the positive correlation of Ni and Cr vs MgO and Co vs. Fe_2O_3 plots (Fig.6). The magnetite fractionation may also points the magma type being tholeiitic.

On the other hand Cu, Pb and Zn are scattered and against SiO_2 (Fig. 5a-c) indicating the control of other factors on these elements during the evolutionary process of the rocks under current investigation (Hamidullah 1987; Pearce & Norry, 1979).

Diorites/quartz – diorites and granodiorites
Chemical data together with CIPW norms of diorites/quartz-diorites and granodiorites of the study area are shown in Table 2. Using Harker diagrams for understanding the trend of magmatic fractionation in these rocks the data plots are shown in Figure 7. Negative correlation of CaO, Al_2O_3, MgO, FeO_3, MnO, TiO_2 and P_2O_5 with SiO_2 and a positive correlation of the total alkalies with SiO_2 points to a trend of comagmetic rocks. The control of plagioclasc + hornblende / clinopyrone, biotite, magnetite/titanmagnetite and some apatite fractionation in a liquid leaving behind alkali feldspar and quartz rich residual liquids is typical of granodiaritic magmatic trends. Trace elements also reflect similar characters as shown by major elements (Figs. 8,9).

DISCUSSION

It is evident from the mineralogical and textural features of the studied amphibolites that these are formed from an igneous rock of gabbro or gabbro – norite composition during prograde regional metamorphism. This rock has been subjected to greenschist facies metamorphism for a limited time, which is indicated by the presence of chlorite, tremolite/actinolite, epidote and plagioclase of oligoclase to andesine composition. This was then followed by the amphibolite facies condition during regional metamorphism which is evident from the development of high proportion of hornblende and also progressive replacement of chlorite and tremolite/actinolite along the margins by hornblende. This whole paragenetic sequence suggests that the pyroxene, plagioclase and opaque phases within the protolith have played an important role in the development of existing mineralogy and texture of these amphibolites. The relics of clinopyroxene/ orthopyroxene and plagioclase within the amphibolites were the two dominant liquidus phases and are considered to be the original gabbro-norite assemblage. This suggests that the studied gabbro-norites could be the protoliths of the amphibolites of the area. The local scale replacement of pyroxene by chlorite and edpidote and then by hornblende along the margins and the presence of prismatic grains of metamorphic hornblende, having inclusions of quartz, within the gabbro-norites are the evidences of systematic transformation of greenschist to amphibolite facies condition. The studied gabbro-norites are, therefore, the relics of protolith within these amphibolites. These may have escaped the regional metamorphism by any reason and, therefore, have retained the original texture and mineralogy.

All the studied rock types when plotted in the AFM diagram of Irvine and Baragar (1971; Fig. 10a) and on the Ti vs Cr diagram of Pearce (1975; Fig. 10b) suggest that they are volcanic arc basalts derived from the differentiation of a calcalkaline magma.

On the MgO, Al_2O_3 and FeO (total iron recalculated as FeO) plot of Pearce et al. (1977) shown in Figure 10c, the analyses of all the studied rocks fall within the field of orogenic basalts suggesting their origin in island arc setting.

The metaluminous, peraluminous and peralkaline granitoids have been distinguished on the basis of Shand's index (molar Al_2O_3 / Na_2 O + vs molar Al_2 O_3 /Ca + Na_2O + K_2O) of Maniar and Piccoli (1989). We were able to come up with a conclusive classification for our granodioritic rocks of the studied area. The majority of granodiorites plot within peraluminous field while a few occur in metaluminous field (Fig. 11a). Maniar and Piccoli (1989) have distinguished granatoids of various tectonic environments by using binary and ternary diagrams (Fig. 11b, c & d). The studied granodiorites are distinguished as either island arc granitoids (IAG), continental arc granitoids (CCG) or post-orogenic granitoids (POG) of group 1 of Maniar and Piecoli (1989). This clearly indicates that the studied granodiorites at least display orogenic characteristics.

The tectono – discrimination diagrams clearly suggest that the studied rocks have close affinity to the calalkaline rocks developed in the subduction related compressional environments mostly related to island arcs. In this scenario the rocks of the area could be the result of the fractionation of a magma formed by either the partial melting of the oceanic crust of the Indian plate or the partial melting of the periodotitic mantle wedge above the descending slab of the subducted oceanic crust at the base the Kohistan arc.

To identify a confirm relation of studied amphibolites and gabbro-norites either with the rocks of Kamila amphibolite belt or Chilas complex, further detail trace element and REE studies are needed to be done on the studied rocks. Gabbro-norites similar to the studied ones occur within the northern part of Kamila amphibolites belt of Kohistan island

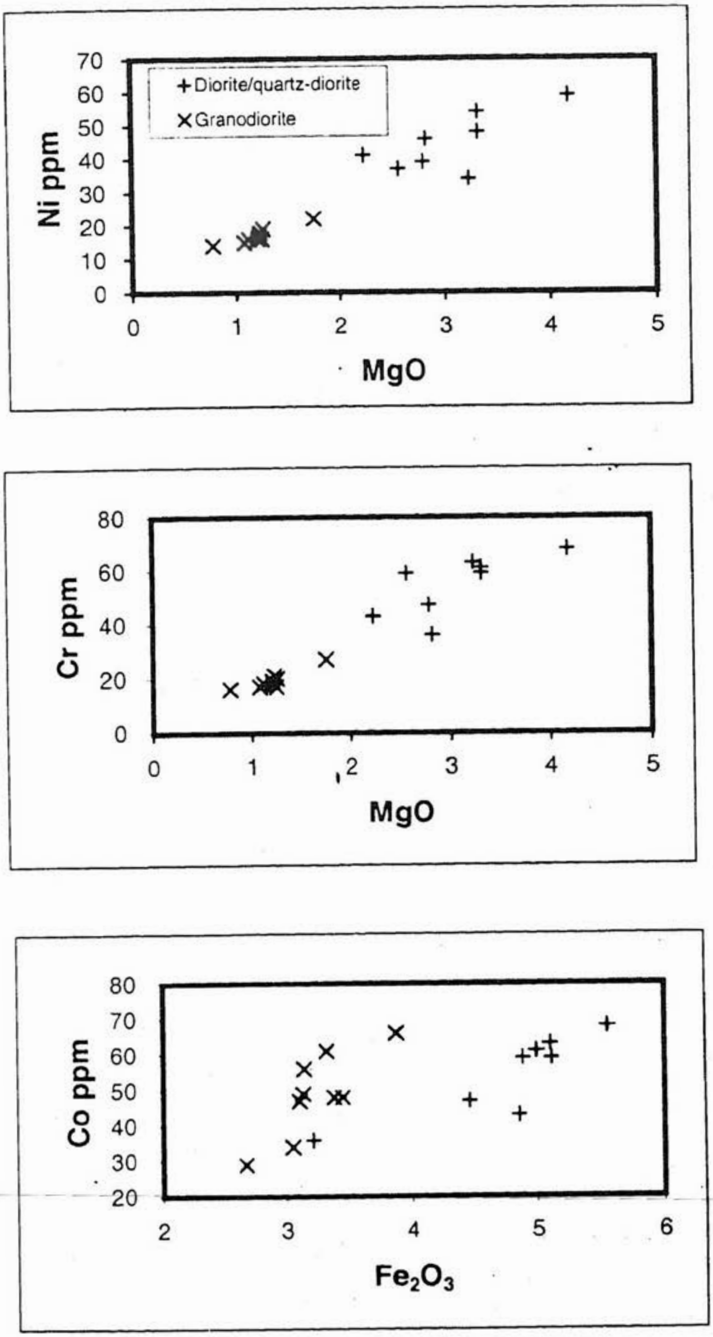

Fig. 6. Ni and Cr vs MgO and Co vs Fe_2O_3 plots for the amphibolites and gabbro-norites of the Ushiri valley, central Dir.

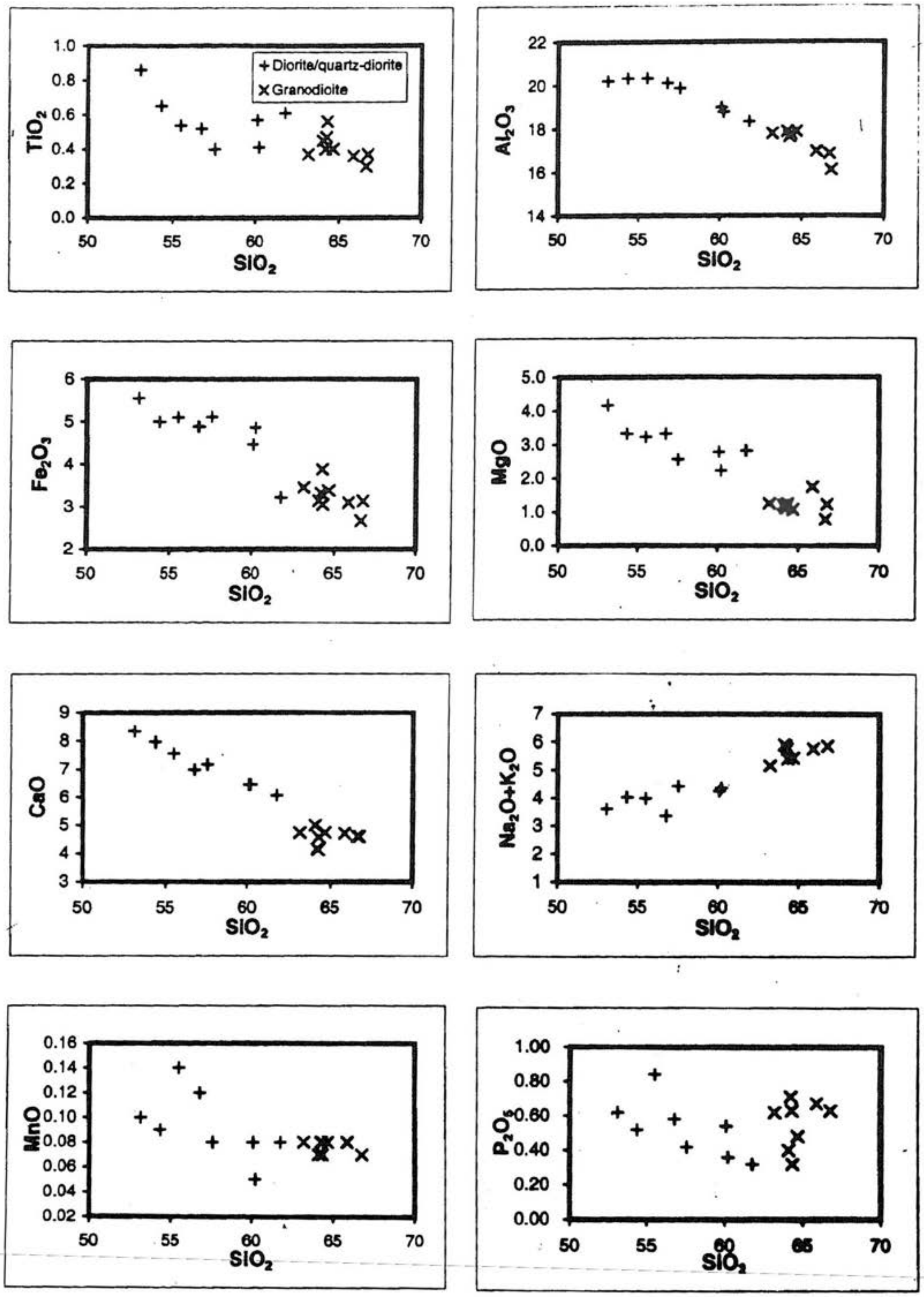

Fig. 7. Plot of various oxides against SiO_2 for the diorites/quartz – diorites and granodiorities of the Ushiri valley, central Dir.

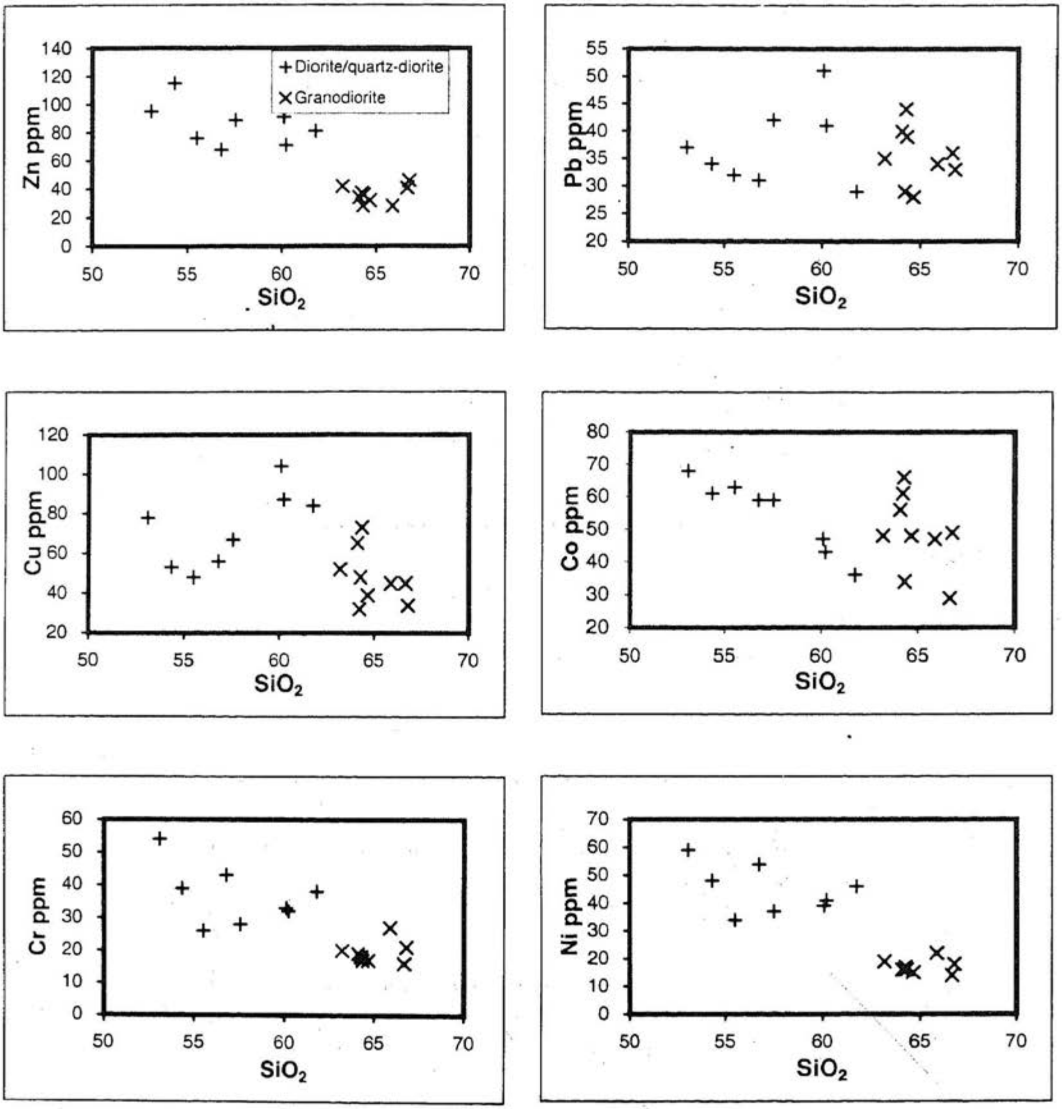

Fig. 8. Plot of various trace elements against SiO_2 for the diorites/quartz-diorities and granodiorites of the Ushiri valley, central Dir.

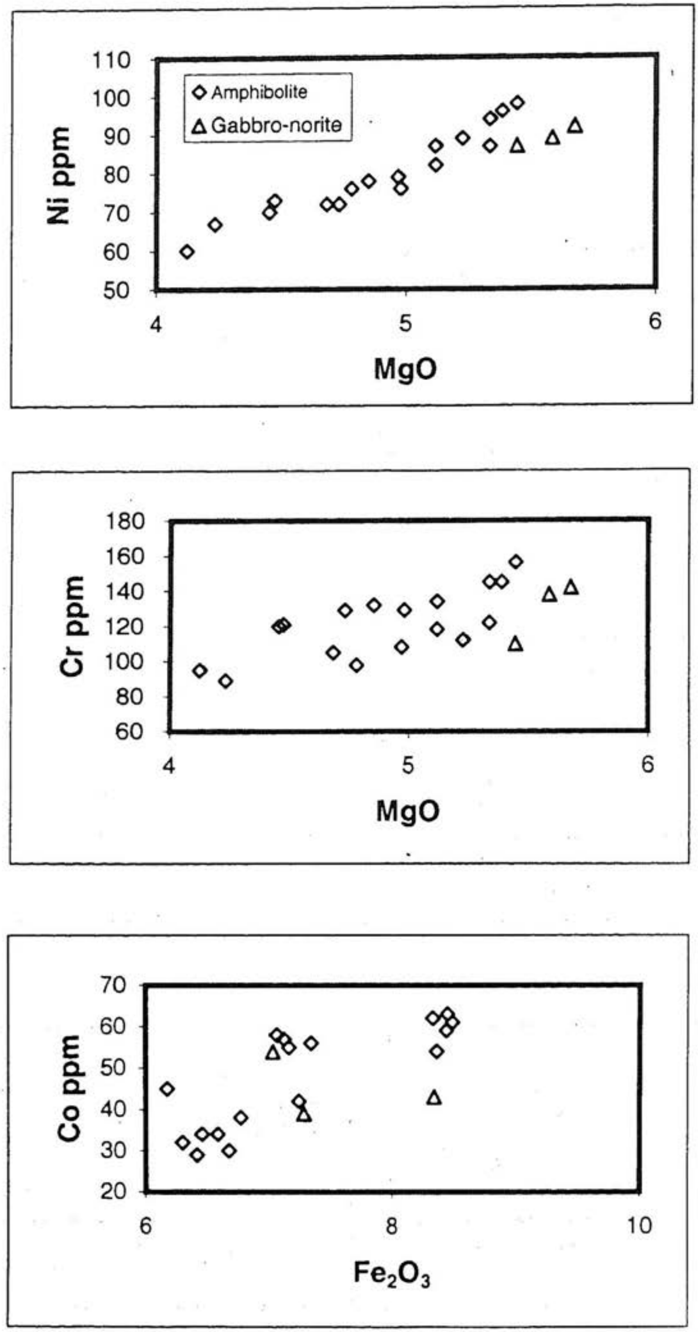

Fig. 9. Ni, and Cr vs MgO and Co vs Fe_2O_3 plots for the diorites/quartz-diorites and granodiorites of the Ushiri valley, central Dir.

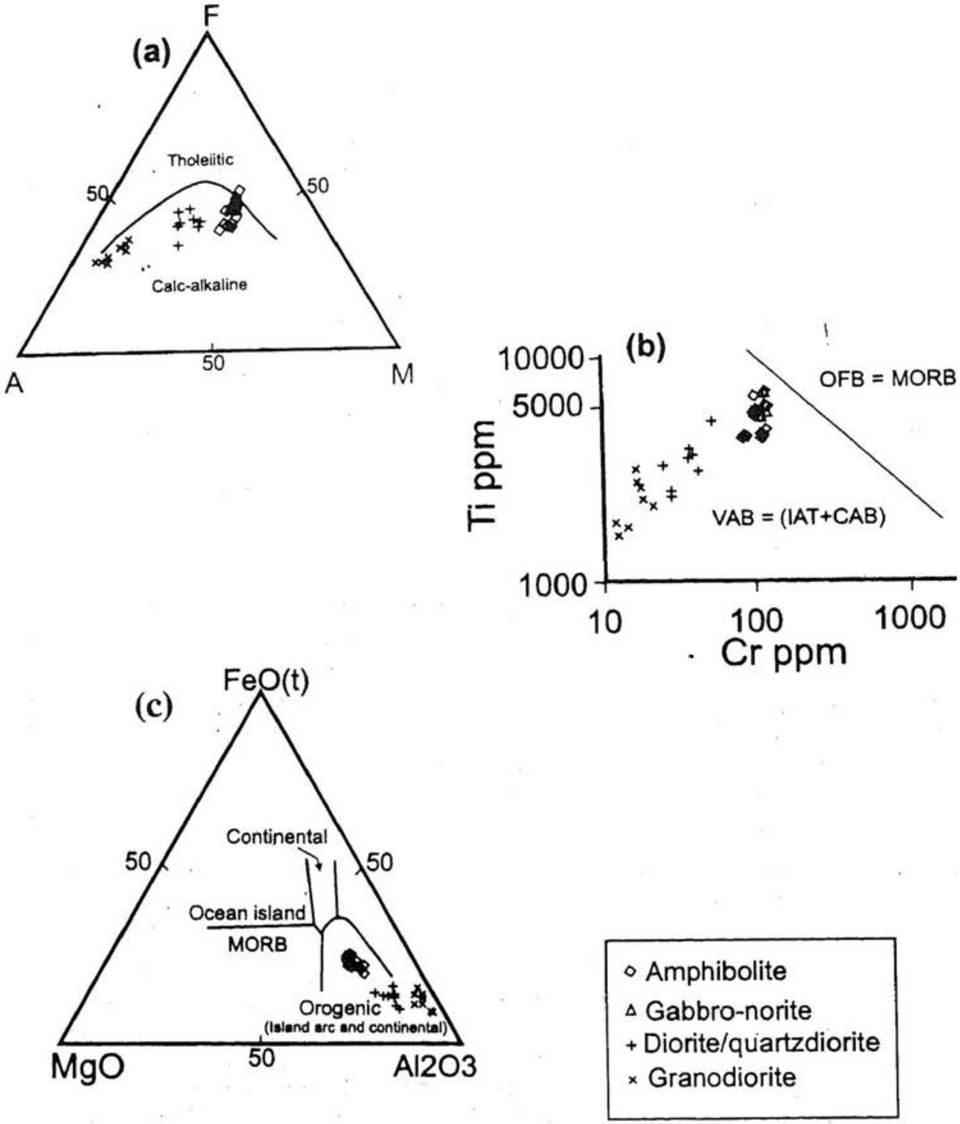

Fig. 10. Tectonomagmatic discrimination diagrams: a) AFM plot (after Irvin & Baragar, 1971), b) Ti vs Cr plot (after Pearce, 1975) and c) MgO-FeO (t) – Al_2O_3 plot (after Pearce et al., 1977) for the studied rocks of Dir valley.

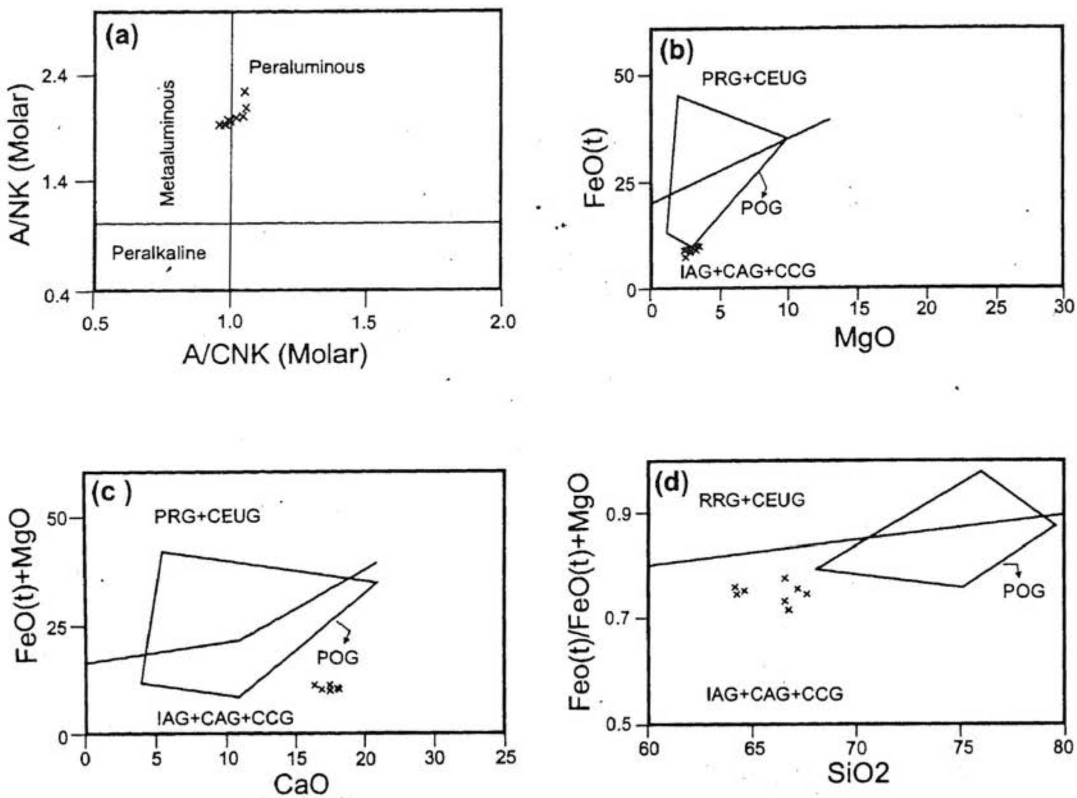

Fig. 11. Discrimination diagram for the diorites/quartz-diorites and granodiorites of the Ushiri valley, central Dir (after Maniar & Piceoli, 1989). For orogenic granitoid rocks IAG=Island 'Arc Granitoids, CAG=Continental Arc Granitoids, CCG=Continental Collision Granitoids, POG=Post Orogenic Granitoids and for anorogenic granitoids RRG=Rift Related Granitoids, CEUG=Continental Epirogenic Granitoids and OP=Oceanic Plagio Grenitoids symbols as in Figure 7.

arc and have been considered as part of Chilas complex gabbro-norites by Treloar et al. (1996). The granatoid rocks (diorite and granodiorite) of the studied area can be, on the other hand, correlated with the stage II pluton of the Kohistan batholith of Peterson and Windley (1985).

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