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Geology and petrography of gabbroic rocks from Khanozai Ophiolite, Northwestern Pakistan

Abdullah Popal[1*], M. Ishaq Kakar[1] and Mehrab Khan[2]
[1]Centre of Excellence in Mineralogy, University of Balochistan, Quetta, Pakistan
[2]Department of Earth and Environmental Sciences, Bahria University Karachi Campus, Pakistan
abdullahpopal5@gmail.com

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Abstract

The geology of Khanozai area is comprised of Indian Platform Sediments, the Suture Zone and Flysch Zone. The Khanozai Ophiolite Complex is a fragment of Zhob Valley ophiolites is marking the Suture Zone in the area and consists of mantle peridotite overlain by crustal ultramafic to mafic cumulate which is underlain by metamorphic sole rocks and mélange. The crustal section of the ophiolite comprises of both ultramafic to mafic cumulates. Ultramafic cumulates comprise repeated successions of dunite, pyroxenite and wehrlite while mafic cumulates consist of foliated to layered gabbros. The Khanozai gabbros cover about 60% area of the crustal plutonic rocks and have a lower transitional contact with the ultramafic cumulates. The gabbros (sensu lato) are classified as olivine gabbro, gabbronorite, olivine gabbronorite, norite and gabbro. The mineralogy of the gabbros indicates that they have both primitive and evolved components. The geochemistry indicates that the Khanozai gabbros are tholeiitic in nature and comprise both cumulate and non-cumulate mineral phases with olivine, pyroxenes and plagioclase being involved in fractionation. The cyclic series of ultramafic cumulates and gabbros has a different order, thickness, and structure in the crustal part of ophiolite and this possibly results from a variable supply of different magma compositions to the chamber. The structure of Khanozai Ophiolite' crustal section, with a well-developed plutonic sequence and absence of sheeted dyke indicate that these rocks may have formed in a tectonic setting with a slow spreading rate over different periods of time as a consequence of episodic low magma supply rates. These gabbros may have formed in a similar manner to the Semail Ophiolite' gabbros and imply that a well-developed ophiolitic sequence is rarely formed in a tectonic setting where the spreading and magma supply rates are not balanced.

Keywords: Ophiolite, crustal section, ultramafic cumulate, gabbros, classification.

Introduction

Gabbroic rocks are formed in the oceanic environment by decompression melting as a result of mantle upwelling and subsequent emplacement to the shallow levels to form the oceanic crust. These plutonic rocks, generally crystallized in the upper portion of a magma chamber and grade downwards into a cyclic series of ultramafic cumulate such as peridotite, websterite and pyroxenite. Gabbros (sensu lato) generally comprise a group of rocks, and consist of gabbro, norite, gabbronorite olivine gabbro anorthosite and troctolite. Gabbros are an integral part of ophiolites and should have a stratigraphic relationship with lower crustal and mantle sequences[1-3].

In Pakistan, the Zhob Valley ophiolites consist of the Muslim Bagh, Khanozai and Zhob ophiolites. The Muslim Bagh Ophiolite is one of the best studied ophiolites in Pakistan[4-7]. However, the ophiolite sequence of the Khanozai segment, the underlying mélange and the crustal section comprising ultramafic-to-mafic cumulates, are well-exposed, this ophiolite has not yet received the same degree of attention. This paper therefore reports the geology, petrography and major elements geochemistry of crustal gabbros from Khanozai Ophiolite in order to classify them and discuss their nature.

Regional Geological Setting

The geology of Khanozai–Muslim Bagh area can be divided into three distinct geotectonic terrains i. Calcareous zone passive margin sediments of the Indian plate; ii. The Suture Zone and iii. Flysch zone (Figure-1).

The tectonically lowermost zone is the Calcareous zone of the Indian plate passive continent margin consists of Triassic to Eocene sediments with abundant limestones, shales and lesser amounts of sandstones, marls and occasional conglomerates[8]. The Calcareous Belt is thrusted over by the suture zone; lying between theIndian plate and Afghan Block[9] (Figure-1) and consists of Khanozai Ophiolite Complex. The Khanozai Ophiolite has almost a complete ophiolite stratigraphy except the sheeted dykes and volcanic rocks with pelagic sediments is missing. The ophiolite is described in detail in the section that follows. The flysch zone unconformably overlies the ophiolite and situated to the north of the suture zone (Figure-1). It comprises of marine limestone, marl, shale, sandstone and conglomerate and progressively gives way to younger fluvial and lacustrine sedimentary successions[10].

Khanozai Ophiolite

The Khanozai Ophiolite Complex is located about 72km north of Quetta and is exposed about 5km E and S of Khanozai town (Figure-2). The complex consists of an ophiolitic rock sequence which is underlain by metamorphic sole rocks and mélange. The ophiolite sequence comprises mantle peridotite overlain by crustal ultramafic to mafic cumulates. The mantle section is mainly ultramafic tectonites and is dominated by harzburgite with minor dunite containing segregated chromite deposits. According to Ahmed[11] the Khanozai chromite is high grade, with Cr_2O_3 content varying from 49–53% and Cr–Fe ratio 3.4:3.6, however, that said the reserves are relatively small.

The crustal section of Khanozai Ophiolite comprises of both ultramafic and mafic cumulates (Figure-2). Ultramafic cumulates are composed of repeated successions of dunite, pyroxenite and wehrlite (Figures-3a and c). While the mafic cumulates (the topic of this paper) are foliated and layered gabbros (Figures-3d-e).

The dunite is brown, yellowish to reddish brown on weathered surfaces (Figuers-3a and c), and green to olive green on fresh surfaces. Mineralogically, the dunite comprises of olivine and serpentine with minor pyroxene and accessory spinel; chromite and magnetite. Chromite is found both as large segregated bodies and as an accessory mineral in dunite. Serpentine is mainly antigorite and lizardite, however, the chrysotile variety is not abundant in crustal dunite, however, chrysotile may be formed in dunite of the mantle section. Serpentine grains are broken and it is difficult to distinguish the boundaries between them. Serpentine is grey in colour and exhibits a mesh texture.

In the field, pyroxenite appears brownish to greenish on weathered surfaces (Figures-3a and c) and green on fresh surfaces. Under microscope, it is mineralogically, composed of diopside and chlorite with minor amount of olivine, enstatite, serpentine and magnetite. This rock is highly altered into chlorite and magnetite. Diopside has a euhedral to subhedral shape which has been altered to serpentine. Small anhedral crystals of olivine are arranged within phenocrysts of enstatite in a subpokilitic manner.

Wehrlite is quite altered and is only exposed in the southern part of crustal section (Figure-2). It is brown to black on both weathered and fresh surfaces and is composed of serpentine, olivine, pyroxene and spinel. It has been completely altered to serpentine; antigorite and lizardite and has an interlocking texture. The rock is medium to coarse-grained with large euhedral grains of olivine being found as relict cores surrounded by a mesh of serpentine, altered pyroxene and spinel. The rock shows granular hypidiomorphic and porphyritic textures. Wehrlite hosts iron deposits (comprising maghemite, Fe-clinochore and chromian spinal with high content of Ni) which has been determined to have formed by magmatic segregation[12]. The ore body is lenticular in shape and is about 6 to 10 m thick and extends 450 to 500 meters in length.

Gabbros

Field Features: The gabbroic rocks of Khanozai Ophiolite form rugged, High Mountain peaks and grade downwards into ultramafic cumulates which are in stratigraphic contact with the underlying mantle sequence. Both the geophysical and petrological Moho is exposed; with the geophysical Moho being identified by a rapid change from dunite into harzburgite while the petrological Moho is defined by the change from layered gabbro to dunite and wehrlite.

Gabbros cover about 60% area of the total area of the crustal plutonic rocks of Khanozai Ophiolite (Figure-2 and Figure-3b). Gabbros have a transitional contact with the ultramafic cumulates in the north and east, thrusted contact with sediments in the south and is concealed under alluvium in the west (Figure-2 and Figure-3b). The gabbroic rocks, generally trend SE–NW and dip about 30° to 45° either NE or SW. Structurally, they are classified into layered (Figure-3e) and foliated gabbro. The layering in the layered gabbros are defined by modal variations of olivine, pyroxene and plagioclase (Figure-3e), while the foliation in the foliated gabbro is marked by the preferred alignment of minerals; olivine, pyroxene and plagioclase. The thickness of bands in gabbroic rocks range from about 10-30cm while that of light and dark colour minerals in layered gabbros are about 1-10cm (Figure-3e). The gabbros of the upper and middle level are intruded in many places by pegmatite veins of gabbroic composition (Figure-3f). The gabbros can be classified as olivine gabbro, gabbronorite, olivine gabbronorite, norite and gabbro; they are described in detail below.

Petrography: Olivine Gabbro: The rock is mineralogically composed of plagioclase, clinopyroxene with minor amount of orthopyroxene, olivine and opaque minerals. Secondary minerals found are chlorite and serpentine. The plagioclase is more calcic; An_{70-73}. Texturally, the olivine gabbros are equigranular and sub-ophtic. Parting and zoning are very rare but considerable alteration is found in the rock.

Plagioclase crystals are subhedral to anhedral in shape, course-grained (2mm up to 3mm in size) and have no compositional zoning. The plagioclase crystals are elongate and unaltered and has characteristic polysynthetic twining. Boundaries between plagioclase and other neighboring minerals may be sharp and almost regular. Some mafic minerals and altered product have filled interstitial spaces among the plagioclase grains.

Clinopyroxenes are medium-grained, subhedral to anhedral in shape. A few grains of clinopyroxenes are broken and occupies interstitial spaces among other minerals. Sometimes smaller grains of clinopyroxenes occur in clusters.

Olivines are medium-grained, subhedral to anhedral in shape (Figure-4a) with irregular fractures and show high relief. Most of the olivine grains have been altered into serpentine and chlorite. Cracks are common in olivine and they exhibit clustering in a few thin sections.

The modal composition of olivine-gabbro is; plagioclase 49–52%, clinopyroxene 26–27%, orthopyroxene 6–7%, olivine 8–9% and others 7%-8%.

Gabbronorite: Mineralogically, the rock comprises plagioclase, pyroxene, olivine and a minor amount of serpentine, chlorite and magnetite. The whole rock textures observed are equigranular, ophitic to sub-ophitic. Plagioclase is more calcic with anorthite content of An_{70-72}. About 50-80% of olivine has altered into serpentine and chlorite. The grain size of secondary minerals like serpentine and chlorite is smaller than the primary minerals. Small anhedral grains of plagioclase and pyroxene fill the interstitial spaces.

Plagioclase crystals are anhedral to subhedral and are medium-grained. They are tightly interlocked, characteristic zebra strips and polysynthetic twinning is found in them. The Plagioclase grains are elongate and unaltered. Pyroxene grains enclose plagioclase and have an ophitic to sub-ophitic texture. Two sets of cleavages can be seen in a few pyroxene grains. Olivine can be recognized by its irregular fractures and high relief compared to pyroxene. Olivine seems mechanically deformed and shows no cleavage (Figure-4b).

The modal composition of gabbronorite is; plagioclase 51–58%, clinopyroxene 7–11%, orthopyroxene 23–28%, Olivine 4–5% and other minerals 6–9%.

Olivine Gabbronorite: Olivine Gabbro-noriteis composed of plagioclase, clinopyroxene, orthopyroxene, olivine and opaques with secondary minerals such as chlorite and serpentine. The textures identified in the rock are equigranular and holocrystalline. Olivines are medium-grained and are anhedral to subhedral in shape (Figure-4c). Most of the optical properties of plagioclase, clinopyroxene, orthopyroxene in the rocks is similar to those in gabbronorite.

The modal composition of olivine gabbronorite is; plagioclase 49–53%, clinopyroxene 14–15%, orthopyroxene 17–20%, Olivine 7–8% and other minerals 8–10%.

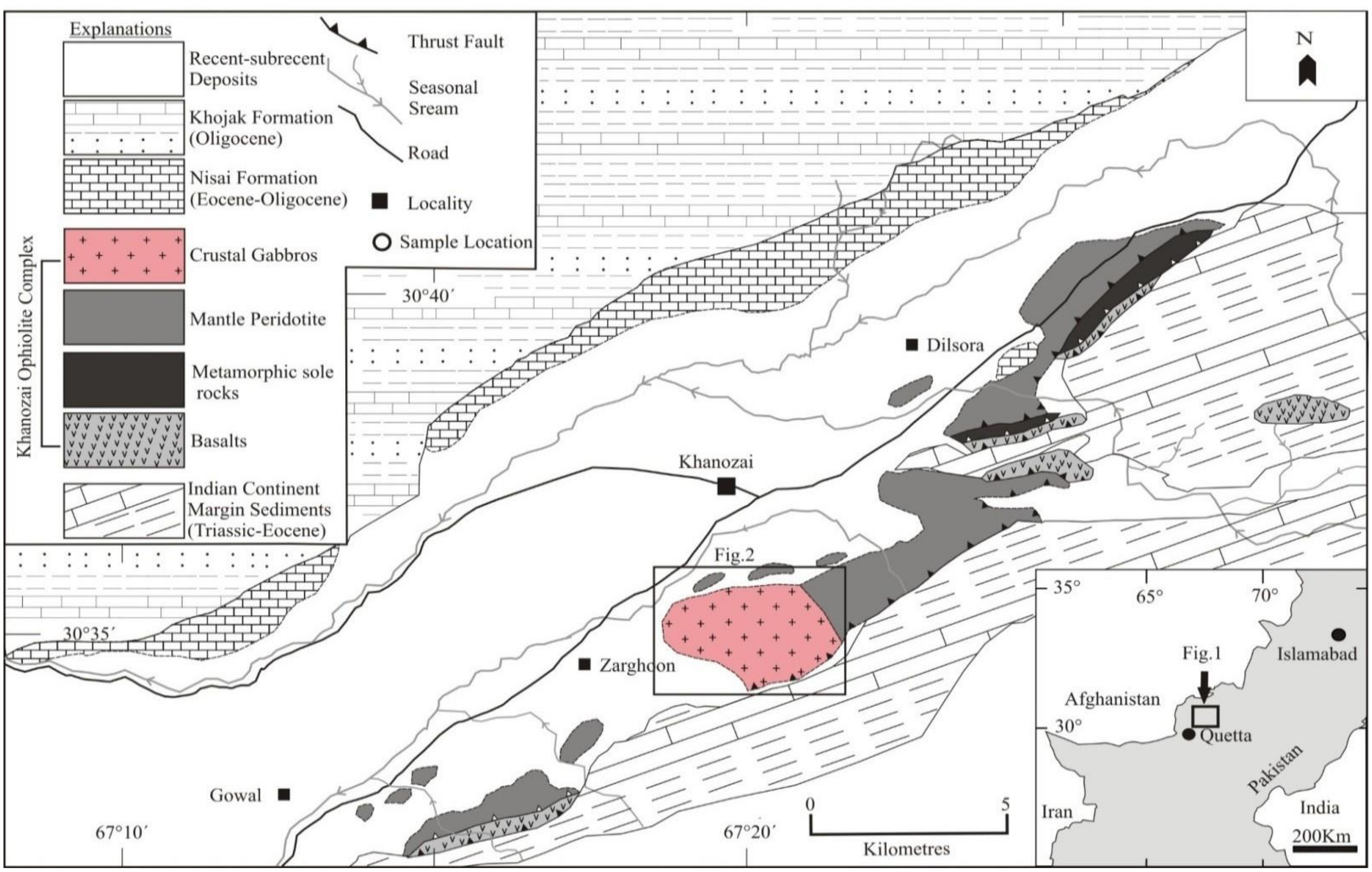


Figure-1: Geological map of Khanozai area showing Khanozai Ophiolite Complex and its overlying and underlying rock units (modified after[35]).

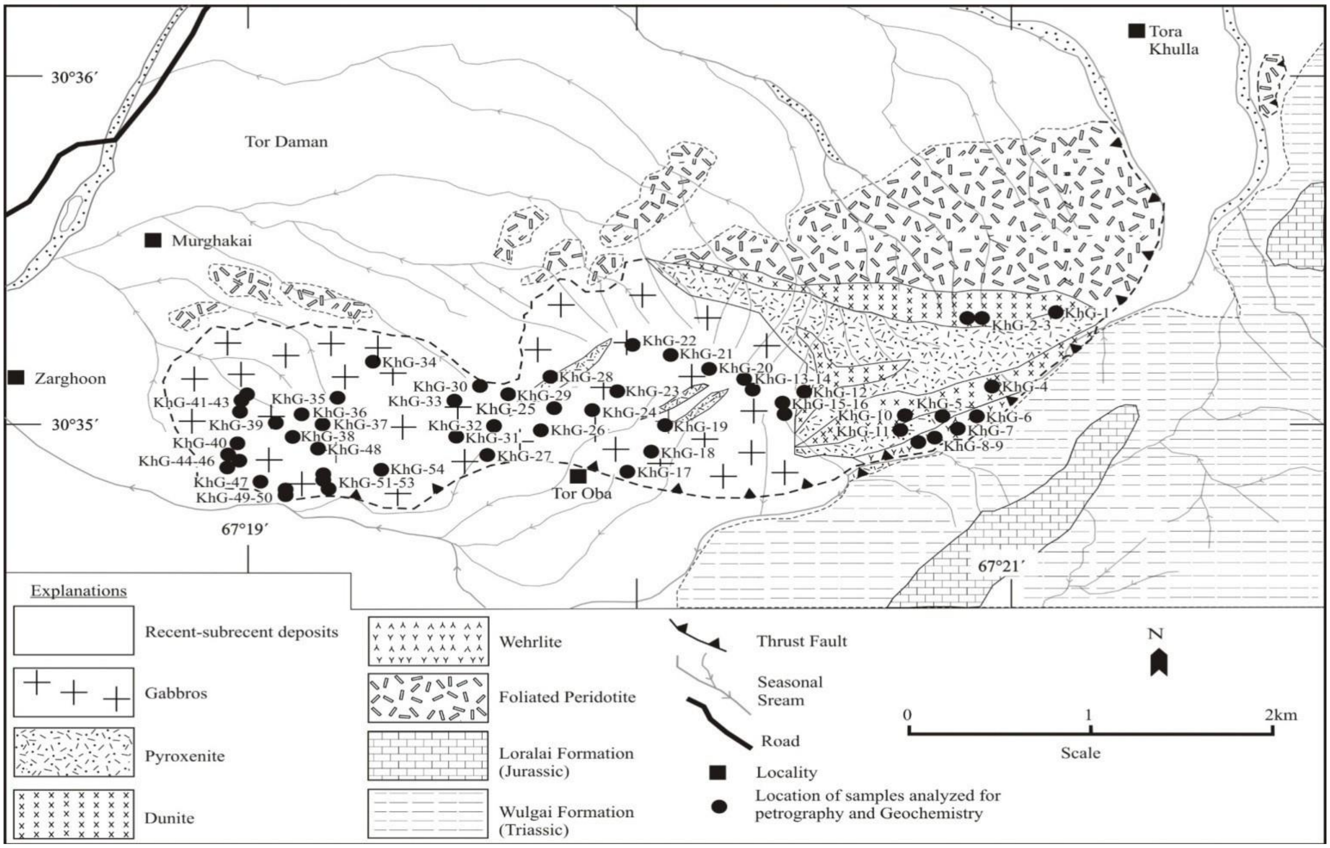


Figure-2: Geological map of crustal section of Khanozai Ophiolite.

Norite: Norite predominantly consists of plagioclase, orthopyroxene with a minor amount of clinopyroxene, olivine, magnetite, chlorite and serpentine. Mafic minerals have altered to magnetite, chlorite and serpentine. Plagioclase is calcic, the rock is holocrystalline, medium to course-grained, ranging in grain size from 1–3mm in diameter. The grain shape is subhedral to anhedral and almost equigranular. The rock exhibits interlocking and sub-ophitic texture (Figure-4d).

Plagioclase exhibits both simple–multiple twining and show low relief. Boundaries between plagioclase and other neighboring minerals are sharp and regular. A few grains of plagioclase are broken and they have no compositional zoning. Orthopyroxenes are medium-grained in size and give parallel extinction. They have low to medium relief and show two set of cleavages can easily be distinguished from clinopyroxenes by its parallel extinction, low relief and low order of interference colour. Clinopyroxene is medium-grained in size, subhedral to anhedral in shape. High relief and two sets of cleavages can easily be seen in clinopyroxenes. A few grains of clinopyroxenes seem to be broken and occupy interstitial spaces between the grains of other minerals. In a few thin sections, smaller grains of clinopyroxenes occur as clusters while in others clinopyroxenes grains are enclosed in plagioclase. Olivine are medium-grained in size and subhedral to anhedral in shape. They have been altered into serpentine and may be chlorite.

The modal composition of the rock is; plagioclase 51–57%, clinopyroxene 8–10%, Olivine 3–5% and other minerals 7–8%.

Gabbro: Mineralogically, gabbro consists of plagioclase and clinopyroxene with minor olivine. It is medium to course-grained and exhibits an interlocking texture between plagioclase and clinopyroxene and has ophitic to sub-ophitic textures. In a few thin sections large grains of pyroxene and laths of plagioclase are embedded in a fine-grained groundmass. Typical textures identified are granular and poikilitic. Where the texture is poikilitic, clinopyroxene phenocrysts enclose the fine-grains/laths of plagioclase (Figure-4af).

Plagioclase is subhedral to anhedral in shape, with albite twinning. Clinopyroxene is medium to course-grained, subhedral to anhedral in shape. It is pleochroic with a medium to high reliefand it shows two sets of cleavages that can easily be seen in a few grains. Olivine is found interstitially amongst the plagioclase and clinopyroxenes. It is fine-grained having irregular fractures and has been altered partly into serpentine. Olivine is birefringent in gabbro and gives clear light pink color when seen in PPL.

Modal composition of Gabbro is; Plagioclase 62–54%, clinopyroxene 23–31%, orthopyroxene 4–80%, Olivine 3–4% and other minerals including opaque 4–9%.

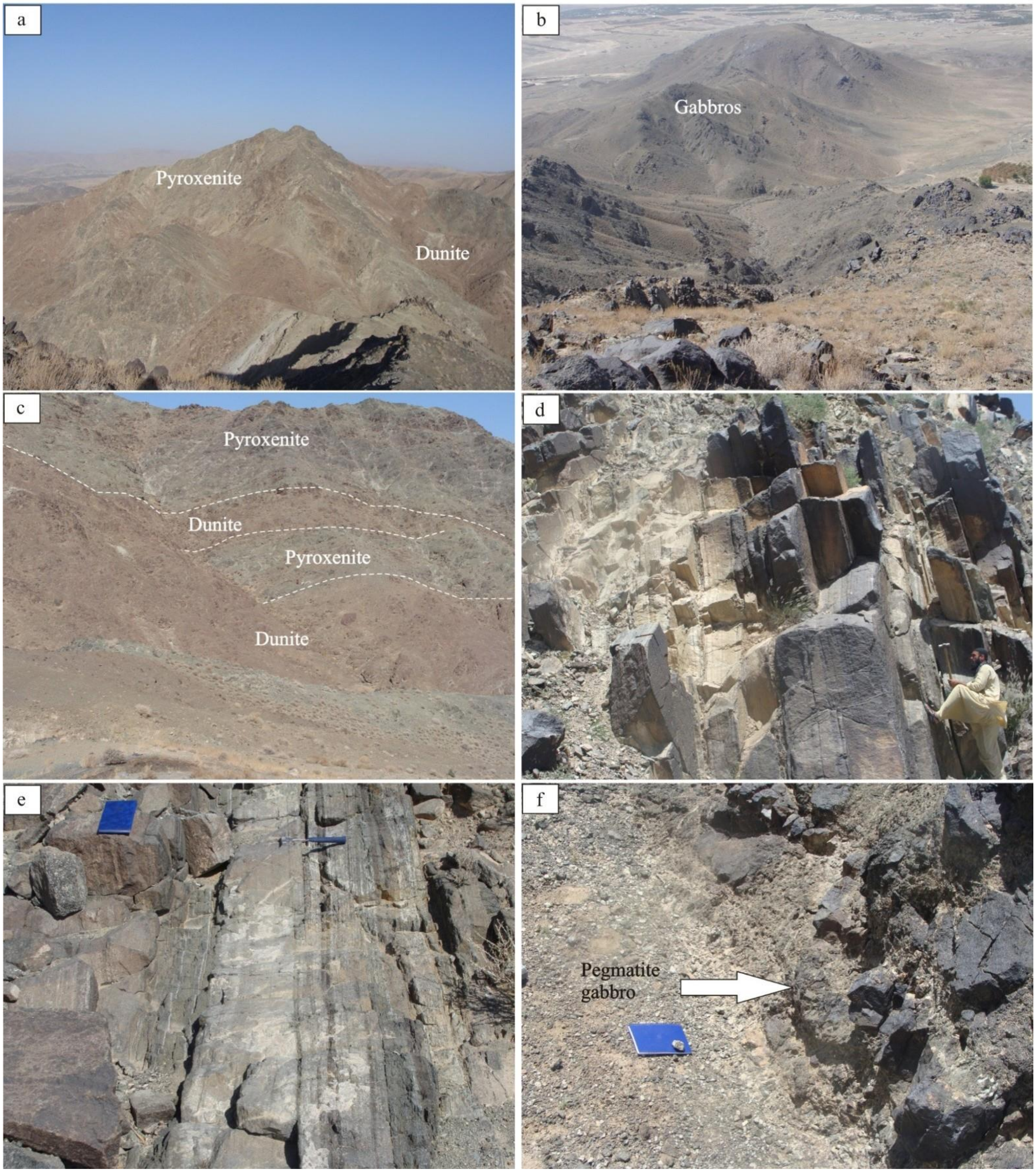


Figure-3a-f: Field Features of crustal rocks: **a)** Ultramafic cumulates dunite and pyroxenite exposed near Tora Khulla village. In figure, dunite can easily be recognized by its red color, while pyroxenite by its green color; **b)** An outcrop of gabbroic rocks near Zarghoon village; **c)** repeated succession of ultramafic cumulates dunite and pyroxenite; **d)** Inclined bands in gabbro; **e)** alternate layers of dark and light colour minerals in layered gabbro; **f)** a vein of pegmatite gabbro.

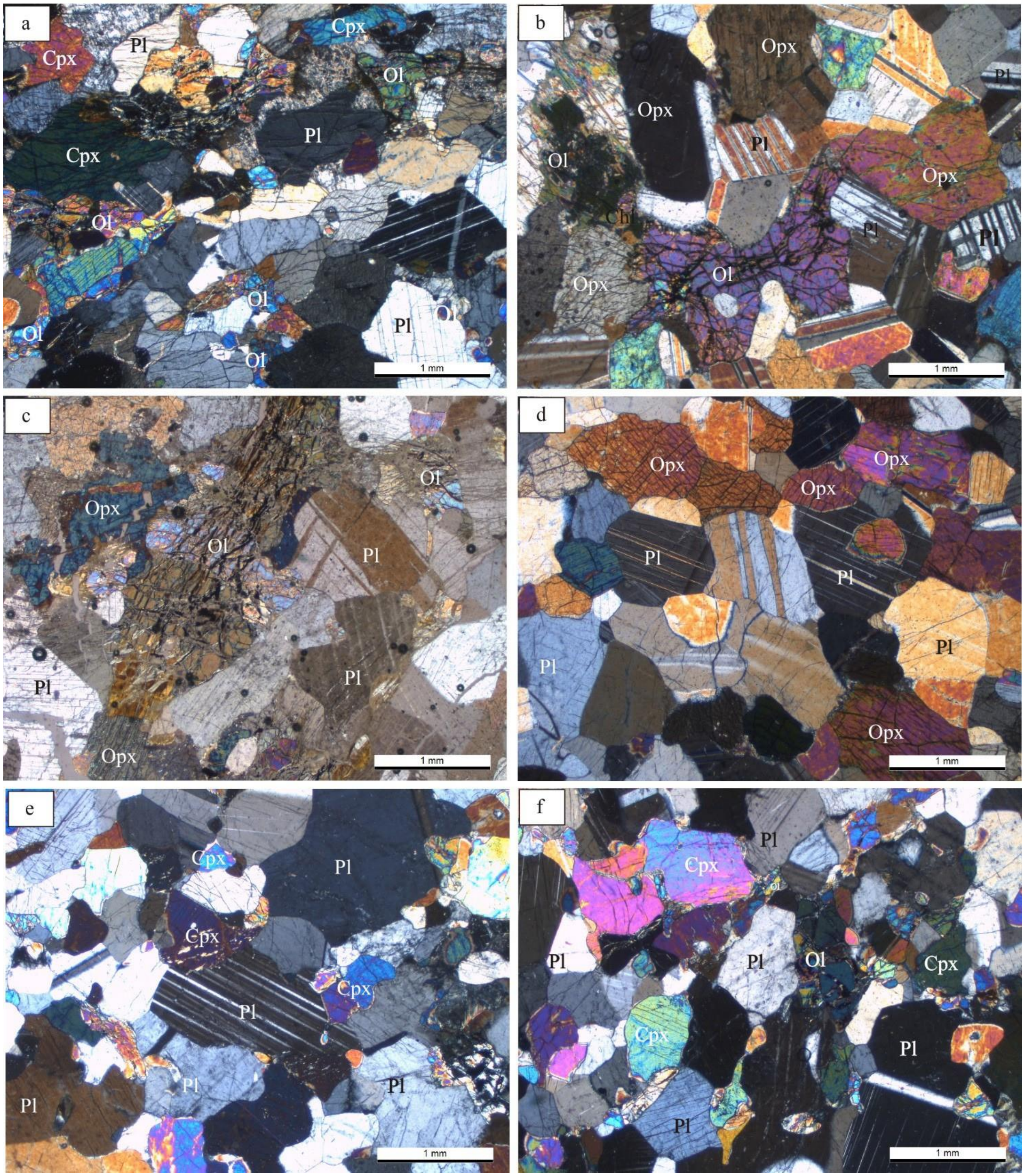
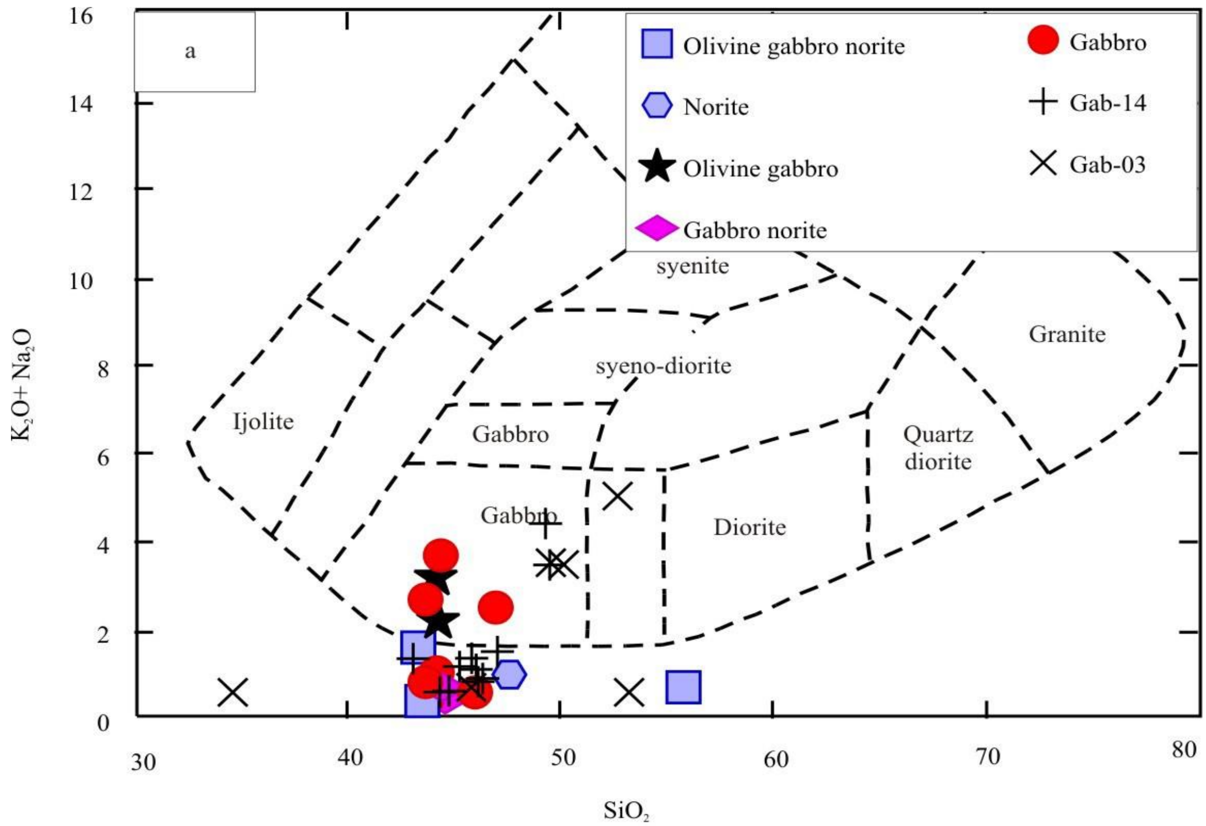


Figure-4a-f: Petrographic characteristics of gabbroic rocks: **a)** Olivine gabbro comprising plagioclase, clinopyroxene and altered olivine giving interlocking and partly sub-ophitic textures; **b)** Gabbronorite comprises anhedral-subhedral crystals of orthopyroxene (Opx), plagioclase (Pl) and olivine (Ol); **c)** Olivine gabbronorite contains large to small altered grains of olivine, with orthopyroxene and plagioclase resulting in an interlocking texture; **d)** Norite comprises medium to course-grained orthopyroxene, plagioclase and olivine with equigranular, interlocking and sub-ophitic textures; **e-f)** Gabbroic rocks are composed of plagioclase, clinopyroxene and minor olivine showing interlocking, inequigranular and sub-ophitic textures.



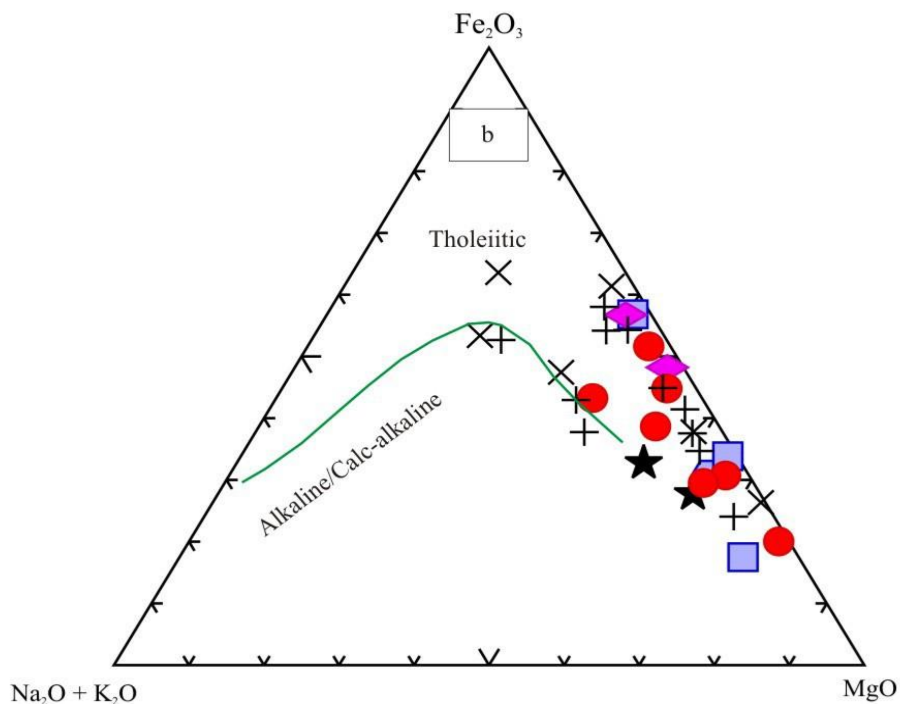


Figure-5a-b: Geochemical Classifications of gabbroic rocks: **a)** Total alkali versus SiO_2 plot[36] (**b)** AFM diagram[37]. **Key:** Pluses and crosses are the published data from Muslim Bagh Ophiolite gabbros[26,7]

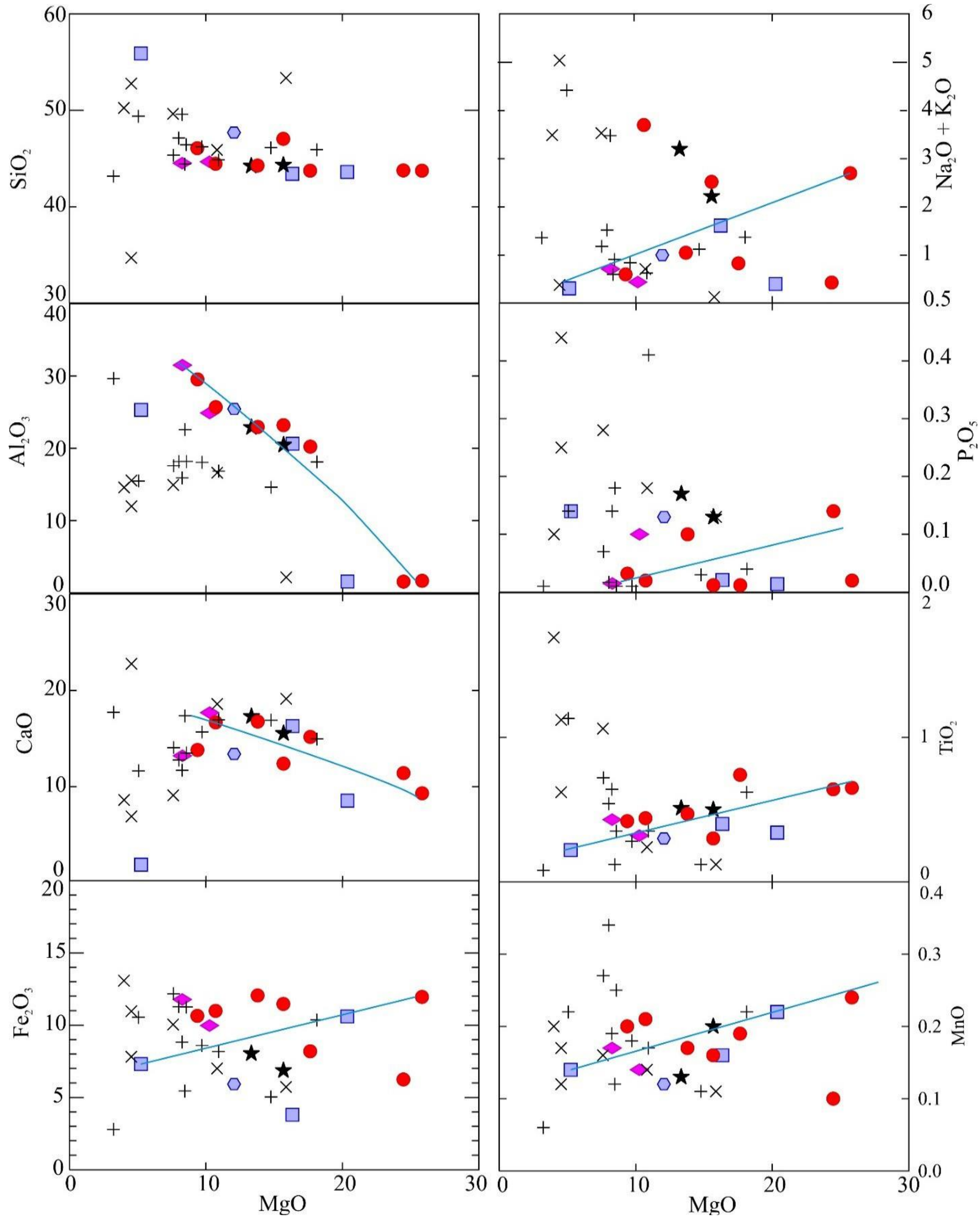


Figure-6: MgO versus selected major elements plots of Khanozai gabbros. **Key:** The symbols are the same as in Figure 5a.

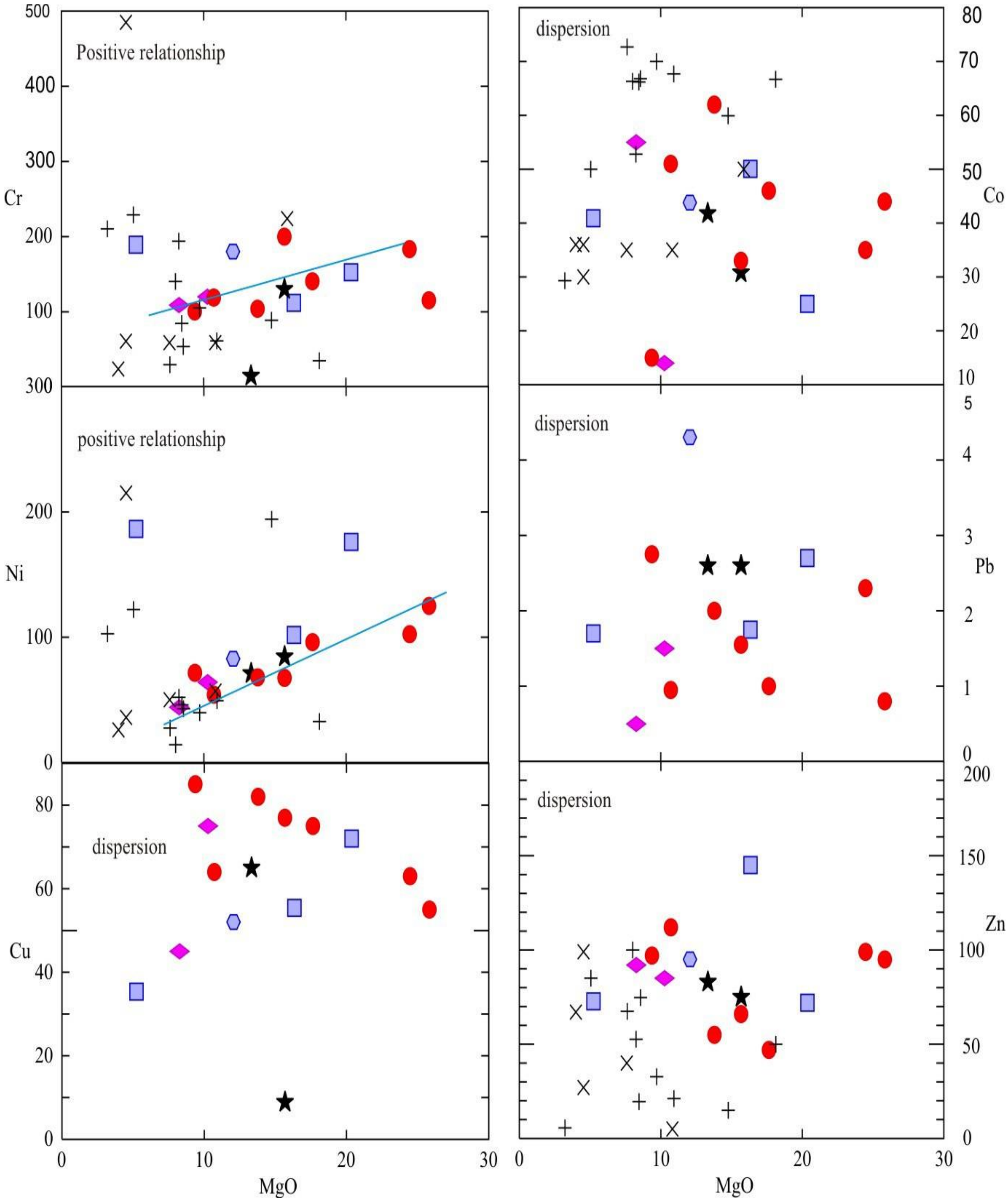


Figure-7: MgO versus selected trace elements plots of the Khanozai gabbros. **Key:** The symbols are the same as in Figure-5a.

Table-1: Major elements (wt %) and trace elements (ppm) data of Khanozai gabbros.

Rock	Ol	Ol		Ol	Ol	Gab		Ol			Gab				
Type	Gab	Gab	Nor	Gab	Gab	nor	Gab	Gab	Gab	Gab	nor	Gab	Gab	Gab	Gab
	nor	nor						nor							
Sample	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG	KhG
no.	12	13	17	18	22	26	30	31	36	37	40	43	46	48	50
SiO2	55.9	43.4	47.69	44.33	44.22	44.66	43.77	43.6	44.27	47.04	44.52	43.74	44.46	46.07	43.74
Na2O	0.3	1.2	0.6	2.1	3	0.43	0.42	0.3	0.7	2.5	0.67	0.8	3.1	0.52	2.3
K2O	0.01	0.41	0.4	0.12	0.2	0.01	0.01	0.1	0.35	0.02	0.04	0.03	0.6	0.08	0.4
MgO	5.24	16.34	12.06	15.68	13.33	10.27	24.47	20.36	13.79	15.67	8.27	17.64	10.71	9.37	25.83
Al2O3	25.3	20.63	25.44	20.45	22.89	24.88	1.55	1.57	22.95	23.2	31.49	20.23	25.69	29.53	1.67
P2O5	0.14	0.021	0.13	0.13	0.17	0.1	0.14	0.014	0.1	0.012	0.015	0.012	0.02	0.032	0.02
CaO	1.92	16.3	13.39	15.54	17.29	17.69	11.42	8.55	16.77	12.4	13.21	15.17	16.68	13.82	9.33
TiO2	0.22	0.4	0.3	0.5	0.51	0.32	0.64	0.34	0.47	0.3	0.43	0.74	0.44	0.42	0.65
Fe2O3	7.3	3.8	5.91	6.86	8.04	9.97	6.24	10.6	12.05	11.46	11.77	8.19	10.98	10.64	11.95
MnO	0.14	0.16	0.12	0.2	0.13	0.14	0.1	0.22	0.17	0.16	0.17	0.19	0.21	0.2	0.24
LOI	0.1	0.41	0.03	0.1	0.11	0.05	0.06	0.07	0.08	0.012	0.21	0.07	0.08	0.05	0.04
Total	96.57	103.1	106.1	106.01	109.9	108.52	88.82	85.724	111.7	112.8	110.8	106.8	113	110.7	96.2
Cr	189.15	112	180.1	130.1	14.85	120.1	183.4	152.65	104.1	200	108.95	140.7	118.95	100.5	115.4
Co	40.9	50.05	43.8	30.8	41.8	14	35	25	62	33	55	46	51	15	44
Ni	186.4	101.75	82.8	84.5	71.1	64.05	102.4	176	67.95	67.5	44.05	96.05	54.05	71.6	125
Cu	35.35	55.4	52	8.9	65	75	63	72	82	77	45	75	64	85	55
Zn	72.7	145	95	75	83	85	99	72	55	66	92	47	112	97	95
Cd	1.2	0.6	1.95	1.7	0.45	0.85	0.75	1	0.95	1.8	1.45	0.55	0.25	1.15	0.7
Pb	1.7	1.75	4.3	2.6	2.6	1.5	2.3	2.7	2	1.55	0.5	1	0.95	2.75	0.8

Note: Fe2O4 is total iron, LOI is Loss on ignition. Ol-Gab-Nor =Olivine Gabbronorite, Nor = Norite, Ol-Gab = Olivine gabbro, Gab-nor = Gabbronorite, and Gab = Gabbro

Geochemistry

Analytical Method: Fifteen sample of gabbroic rocks are analyzed for major and selected trace elements geochemistry. First of all, we removed the weathered surfaces from the samples and cleaned them up, then the fresh parts of these samples were crushed in a jaw crusher and made the power by using a mill with a tungsten carbide surfaces to the size of < 200 mesh or < 0.074mm. The powder was dried and heated up to 900°C in a porcelain crucible for two hours to determine Los on ignition (LOI). To determine major elements the sample powder was mixed with flux of lithium tetra-borate (sample flux ratio of

1:5) and the resultant glass was pressed into a disc. Major element compositions were determined using Philips Wave Dispersive X-ray Fluorescence (WD/XRF) at the National Center of Excellence in Geology, University of Peshawar, Pakistan. To determine the concentration of trace elements such as Cr, Co, Ni,Cu, Zn, Cd and Pb, the samples were digested by using aqua-regia (3HCl:1HNO_3) and hydrofluoric acid (HF)[13,14]. The analyses for trace elements were carried out using the Perkin Elmer-700 graphite furnace Atomic Absorption Spectrometer (AAS) in the geochemistry laboratory of the National Centre of Excellence in Geology, University of Peshawar, Pakistan. The geochemical data are reported in Table-1.

Classification: The Khanozai Ophiolite' gabbros are classified by plotting on total alkali versus SiO_2 diagram (Figure-5a). All the samples fall almost within the gabbro field confirming their gabbroic characteristics (Figure-5a). Most of the gabbro samples have very low values of total alkali and SiO_2. The Khanozai Ophiolite' gabbro are also plotted on AFM diagram (Figure-5b) and shows that these gabbros are tholeiitic in nature (Figure-5b). AFM diagram also shows low values of total alkali and high values of Fe_2O_3 and MgO.

Major Elements Characteristics: The Khanozai gabbros have variable concentration (wt. %) of SiO_2 (43–56), Na_2O (0.3–3), K_2O (0.01–0.6), Na_2O + K_2O (0.31–3.6), P_2O_5 (0.01–0.17), Al_2O_3 (2–31), Fe_2O_3 (4–12), MgO (3–26), CaO (2–18), normal concentration of MnO (0.1–0.24), and low concentration of TiO_2 (0.2–0.7) compare to average composition of MORBs[15] and all MORBs' mean[16].

In order to determine the fractionation trends of Khanozai gabbros, all major elements and available trace elements data are plotted against MgO (Figures-6 and 7). In Figure-6; MgO shows, a positive correlation with TiO_2, a weak positive correlation with Fe_2O_3 and MnO, Na_2O + K_2O, and P_2O_5, a negative correlation with Al_2O_3 and a weak negative correlation with SiO_2 and CaO. While in Figure-7; MgO shows a scattered trend when plotted against the trace elements such as Cu, Zn, Pb and Co and shows positive correlation with Cr and Ni.

Discussion

The gabbros are an integral part of crustal section of an ophiolite which are formed in a magma chamber by crustal fractionation processes. The Khanozai ophiolite is a segment of Zhob Valley Ophiolites and has a well-developed plutonic sequence in its crustal section comprises of both ultramafic to mafic cumulate rocks. The sheeted dykes and basaltic cover with associated pelagic sediments is missing from the ophiolite. Such characteristics of the plutonic part of the crustal section are also reported from almost all the major ophiolites of the world including the ophiolite of the Tethys's Ocean region, such as Semail Oman[17-19] Troodos Cyprus[20,21] Kizildag and Pozanti–Karsanti Turkey[22,23] Pindos Greece[24], Xigaze Tibet, China[25], Bela and Muslim Bagh Pakistan[26,27].

The plutonic sequence of crustal part of Khanozai Ophiolite comprises a cyclic series of ultramafic cumulates; dunite, pyroxenite and wehrlite that grade upward into mafic cumulates or gabbros. The gabbros identified are olivine gabbro, gabbronorite, olivine gabbronorite, norite and normal gabbro. Each cycle of the repeated series has different rock sequence, thickness, and structure, this is possibly due to the different timing of crystallization of constituent minerals resulting from the differential supply of magma to the chamber[28]. The mineralogy of gabbros indicate that they are enriched in olivine, which has crystallized at all levels of the gabbroic sequence suggesting that they were formed by several pulses of magma during a continuous period of crustal growth. These also indicate that the Khanozai gabbros may have formed over differing spans of time as a consequence of different magmatic episodes. Such characteristics of plutonic sequence of crustal section are also reported from the Muslim Bagh Ophiolite[26,4]. These features of the Khanozai and Muslim Baghgabbros suggest that they are not formed in a large magma chamber[29-31] and may have formed either by magmatic processes like that of the glacier model and/or sheeted sill model proposed for ophiolitic gabbros[18,32-34].

The major element geochemistry of Khanozai' gabbros can only reveal a limited amount of information about their nature and origin, and more trace element and REEs data will be necessary in order to identify their tectonic setting, petrogenesis, magma source, melting depths, and possible subduction input. In the classification of Khanozai gabbro, the low values of alkalis and SiO_2 may be due to alteration and/or can also be explained by the cumulate nature of these rocks. While the high values of Fe_2O_3 and MgO may due to the higher contents of ferromagnesian minerals especially olivine in these rocks. The positive and weak positive correlation of MgO with TiO_2, Fe_2O_3, MnO, Na_2O+K_2O, and P_2O_5, Cr and Ni, negative and weak negative correlation with Al_2O_3, SiO_2 and CaO, show clear fractionation trends. The scattered trend of MgO against the trace elements such as Cu, and Zn, Pb and Co are likely to indicate the presence of some cumulus phases in these rocks.

The major element composition of Khanozai' gabbros indicate that these rocks are oceanic and tholeiitic in nature (Figure-5a-b), and their (major elements) characteristics are similar to an average composition of MORBs (White and Klein[15] and all MORBs' mean Gale et al.[16]) with slightly higher contents of Fe_2O_3 and MgO which indicate that these rocks are not very evolved, and are relatively primitive, in nature. On the other hand, these rocks also contain more fractionated components such as norite and gabbronorite. Therefore, their geochemistry indicate that these rocks have both cumulate and non-cumulate mineral phases and that the minerals; olivine, pyroxenes and plagioclase are involved in fractionation processes (Figure-6,7).

The architecture of the crustal section of Khanozai Ophiolite with a well-developed plutonic sequence and absence of sheeted dyke complex indicates that these rocks may have formed in a tectonic setting of a slow spreading rate over differing spans of time as a consequence of a pulsed low magma supply rate. Our field features and petrographic data also suggests; (1) that these rocks may have formed in a manner similar to the models proposed for the formation of Semail Ophiolite' gabbros[18-20,34] (2) That well-developed crustal sequences are rarely formed in a tectonic setting where the extension rate and magma supply rate are not balanced[2].

Conclusion

The crustal part of Khanozai Ophiolite has a cyclic repetition of ultramafic cumulates, comprising dunite, pyroxenite, and wehrlite that grades upwards into mafic cumulates or gabbros. The mafic cumulates are identified as olivine gabbro, gabbronorite, olivine gabbronorite, norite and gabbro that are structurally, both layered and foliated. The mineralogy of gabbros show that they have both primitive and fractionated components, having major element geochemical signatures indicative of oceanic tholeiites with both cumulate and non-cumulate mineral phases and that olivine, pyroxene and plagioclase are involved in fractionation. The configuration of the crustal section of Khanozai Ophiolite with a well-developed gabbroic sequence indicates that these rocks may have formed either by the magmatic processes of the "gabbro glacier model" and/or "sheeted sill model"; as proposed for the Semail Ophiolite's gabbros. Therefore these gabbros may be the product of their tectonic setting in a slow to ultra-slow-spreading environment rate where the extension and magma supply rate are seldom balanced.

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