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Mineralogy and Geochemistry of Titaniferous Gabbros of Ophiolitic Fanouj Zone (Sistan & Baluchestan, Iran)

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Abstract

Ophiolite complex in the west of Fanuj is 200 Km south west of Iranshahr in Sistan and Baluchestan province. This ophiolite complex lies in the uplift zone of the oceanic crust of Oman between Makran and Fanuj faults. Ophiolite of the west part of Fanuj is consisted of three parts including gabbro, diabase dikes and small quantity microdiorite masses. Ilmenite is the main mineral of titanium which along with magnetite has been formed independently or inter-crystalline way after crystallization of plagioclase, pyroxene and often along with amphibole in gabbro rocks. The formation of the broad gabbro masses which is associated with plagioclase and pyroxene crystallization in High Oxygen fugacity condition formed a fluid rich in iron and titanium during the formation of ferro gabbro rocks as the main host of the ilminite reserves. Gradual crystallization process and decrease in compatible elements such as Cr, Ni, Mg and increase in incompatible elements such as Mn، Na، Ti from the bottom to the upper parts of ophilite complex shows that the formation of the complex has been occurred through the process of crystal fractionation from a tholeiitic magma which is rich in titanium.

Keywords: ophiolite, Fanuj, gabbro, mineralogy, geochemistry

1. Introduction

Oceanic crust is consisted of Basaltic, dibasic dikes, gabbro, peridotite composites along with radiolarites and pelagic limestones that during the uplift process on oceanic crust all or a portion of it raises on the earth surface in the form of tectonic uplift and it is called ophiolite (Knipper, 1986; Nicolas, 1989; Boulin, 1991). Ophiolite is consisted of mafic and ultra-mafic rocks of the earth's crust and upper mantle which with respect to subduction areas they are moved (displaced) in a tectonic way and are replaced on lands and are regarded as a portion of the young oceanic crust or the back-arc basin. Basic rocks along with ultrabasic masses are of great importance in terms of mineralization of Iron and titanium. Bande Ziarat ophiolite in the south of Iran prossesses a high potential in terms of mineralization of Iron and titanium. Many studies have already been investigated ophiolite of Makran Zone (McCall, 1985; Proenza et al., 1999; Rollinson, 2005). Most of the studies have been investigated petrology, geochemistry of the main elements and their tectonic position and there have not been any studies on mineral geochemistry and their association with titanium minerals. The present study is the first scientific study on titanium-bearing gabbro of Makran ophiolite in Fanuj zone.

The ophiolite complex in the west of Fanuj includes mafic and ultra- mafic masses which mafic masses cover the most limit part of the study area. In this area, no outcropping is observed in ultra-basic rocks. Most of the study area of the west of Fanuj is consisted of gabbro which is produced to ilmenite and magnetite mineralization. In addition to gabbroic masses, some diabasic dikes are observed which have been exposed to various alteration. Diabasic dikes lack the ability to mineralize Iron and Titanium. But most of the study area of the west part of Fanuj is consisted of a gabbro unit which has been produced to ilmenite and Magnetite mineralization. Ilmenite-bearing gabbro masses in Kahnuj; Kerman has been already regarded as the most titanium-bearing gabbro in Iran. However, the studies conducted on gabbro masses of ophiolite in Makran Zone in the south of Sistan and Baluchestan in the east of Fanuj have shown that these gabbro masses have more advantages compared to Kahnuj Gabbro in terms of width, depth and Titanium grade (Falaknazi & Karimi, 2015). The present study tries to investigate mineralogical and geochemical characteristics of wide and high grade gabbro masses of Makran in Fanuj and the potential of the precious metals such as Titanium in rock masses.

2. Materials and Methods

2.1 Geological Position

Mafic masses in the west of fanuj (the study area) with an area of 60 square kilometers, is located 200 kilometers south west of Iranshahr, Sistan-Baluchistan and in terms of geological position it is situated in ophiolite complex at the top of Makran Zone in the South subduction of Jazmurian. Mafic masses in the west part of Fanuj are located above coastal Makran fault and below Fanuj Fault. The ophoilite masses in the west of Fanuj are consisted of gabbro massif, Diabasic dikes and less amount of Micro diorite. These massifs are surrounded by alluvial deposits of Quaternary period which in some low areas cover the gabbros. The only ophiolitic area in Iran that is similar to Fanuj ophiolite is mafic massifs of Bande Ziarat in Kahnuj which is associated with Sanandaj-Sirjan zone. Based on studies and proximity of the two ophiolite masses (Figure1), it can be concluded that mafic masses of Bande Ziarat are a portion of Fanuj ophiolite which have been detached from Makran area due to the tectonic activities and are laid in the border of Makran and Sanandaj-Sirjan. Gabbro units of ophiolite of the west of Fanuj are divided into three parts: lower, middle, and upper. Upper gabbro (gb) form the north central part of the area. This gabbro has a low height and is partly covered with alluvial deposits. Middle gabbro (gb2) covers different outcrops of the eastern part and the lower gabbro (gb1) is located in the western part almost as a highland. A series of diabasic dikes have been appeared in the south and north east of the studied area. It seems that the lower gabbro has reached to the highest point due to tectonic processes or greater thickness compared to other gabbro and has formed the highest gabbro massif. In contrast, middle and upper gabbro masses have been buried so that a large part of this gabbro is placed under alluvial deposits and partly are visible on the surface as outcrop (Figure 2).

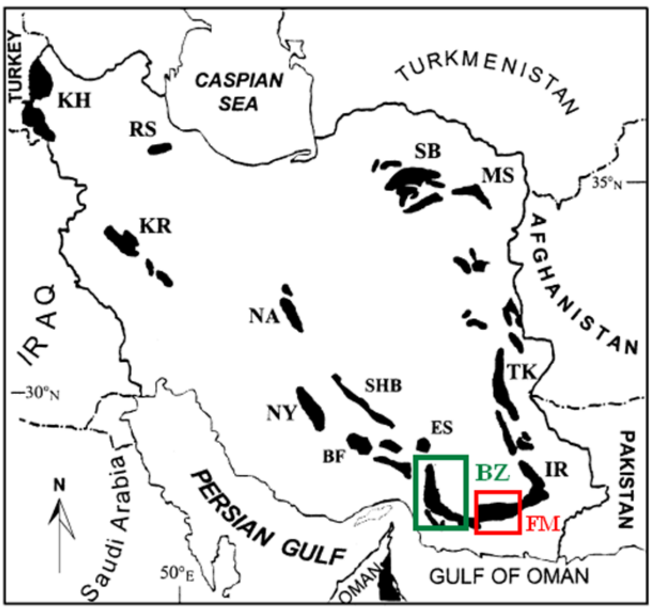


Figure 1. Locations of major Iranian ophiolites.Khoy (KH), Kermanshah (KR), Neyriz (NY), Naien (NA), Shahr-e-Babak (SHB), Baft (BF), Esphandagheh (ES), Band-e-Ziarat (BZ), Fanuj-Maskutan (FM), Iranshahr (IR), TchehelKureh (TK), Mashad (MS), Sabzevar (SB), Rasht (RS) (Pessagno et al., 2004)

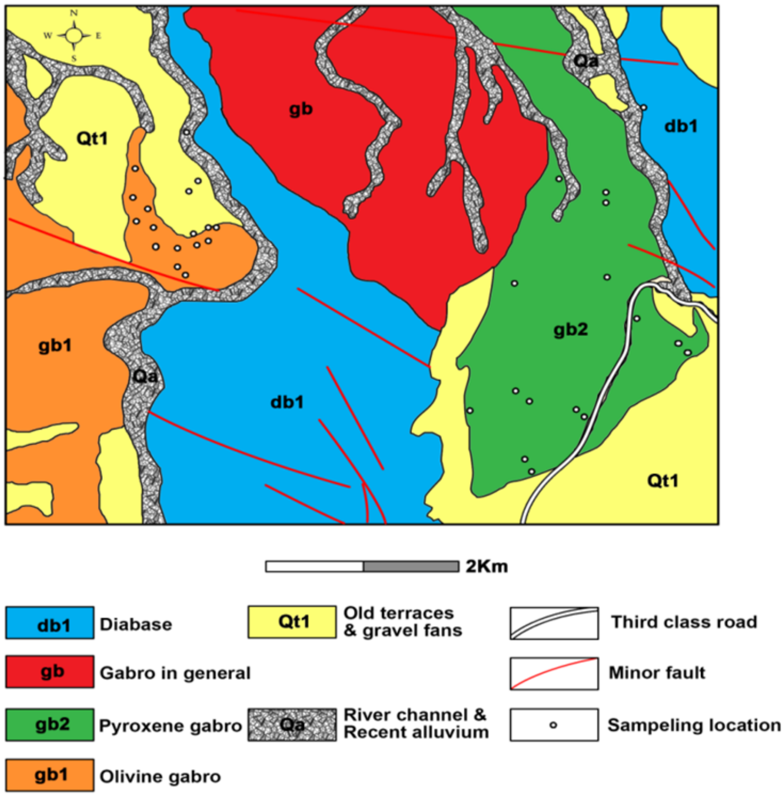


Figure 2. Geological Map of West Fanuj ophiolite complex (after Arshadi, 1987)

2.2 Data Analysis

Considering the presence of placer deposits i.e. ilmenite and magnetite in the alluvial of the west of the study area, and in order to access the source of this coarse- grained placers, sampling of alluvial placers was used to access the main source. Not far from the area, the source of alluvial placer of the west area was identified. The coarse-grained gabbro of the western area was identified as the source. Considering the low height of the gabbro of the eastern area and because some of them are covered with the recent alluvial deposits, sampling done from the surface outcrops. Samples taken from the explored area include: 20 thin sections, and18 polished sections, 13 analysis XRD, 12 ICP analysis and 17 XRF analysis which have been done in ZarAzma Persia Geochemistry laboratory.

3. Results and Discussion

3.1 Minerology of Fanuj Ophiolite

In mineralogical point of view, ophiolite of the west of Fanuj contains rock forming minerals of the mafic masses such as pyroxene, plagioclase, and amphibole and in some altered areas minerals such as chlorite and epidote, montmorillonite and prehnite (table1). In addition to rock forming minerals, ophiolites in this area contain precious metal minerals such as ilmenite, magnetite in rock units (gb1 and gb2), and hematite, pyrite and negligible amount of copper carbonate in diabase unit (db1).

Two out of the three gabbro massifs which were studied in mineralogical and geochemical points of view are important due to the presence of ilmenite and magnetite. Most of the constituent minerals of the gabbro in Fanuj's west ophiolite are pyroxene and plagioclase. In fact, the amount of these two rock forming minerals is different in various gabbro units. So that the west gabbro has a higher percentage of clinopyroxene compared to plagioclase. The presence of clinopyroxen in the gabbro of ophiolite in the west of Fanuj leads to higher formation of metal minerals such as ilmenite and magnetite in an inter-crystalline form in the pyroxene (Figure3a) and they also lead to independent formation of Titanomagnetite in the spaces between pyroxene and plagioclase minerals (Falaknazi & Karimi, 2015). In general, as clinopyroxene crystallization occurs in higher pressure, it becomes richer than TiO_2 and Na_2O and also will have more magnesium. The reason for this is that by increasing the pressure, the necessary temperature for clinopyroxene formation increases compared with Olivine and plagioclase and crystallization of clinopyroxene is likely to occur in a liquid which is still rich in magnesium and slightly detached (Bender, 1978). Ophiolite rich in titanium is geochemically more similar to rocks of original oceanic basins or back-arc basins that occure in middle to late stage of oceanic rift opening. While the poor kind which is formed due to magma crystallization represents the early stages of oceanic opening (Serri, 1981; Hawkins, 1980; Church, 1977; Anant, 2001). According to the microscopic studies and the results of XRD analysis, pyroxene in this ophiolite is mostly augite type which is because of great importance compared to orthopyrone due to its high frequency and also more formation of metallic minerals such as ilmenite and magnetite. The content of Ti and Al of clinopyroxene depends on the activities of the silica which has been crystalized from it. And on the other hand, it depends on the ratios of these elements which has increased respectively in tholeiitic, peralkaline and alkaline magmas (Le Bas, 1962; Kushiro, 1960). In some parts of gabbro mass, intergrowth of ilmenite and magnetite can be seen as exolution (Figure 3b) and emulsoid (Figure 3c) textures along with pyroxene mineral. This reflects simultaneous crystallization of pyroxene and metallic minerals and also orthomagma nature of metal storage of the area. The gabbro unit (gb1) that covers the south and the east of the study area, unlike the gabbro of the west, the ratio of plagioclase is higher than pyroxene. In this mass, plagioclases lack the zoning. The lack of zoning and uniformity of plagioclase compositions during crystallization requires the balance between crystal and magma and replacement of Ca by Na and Al by Si to maintain the balance between cations. In other words, zoning indicates that balance establishment was slower than crystallization (Atherton, 1994). Lower content of pyroxene mineral in the rock reduces the percentage of metallic minerals. Generally, plagioclase in gabbro mass of the west of Fanuj is mostly Ca-plagioclase. Plagioclase of basic rocks has variable chemical composition that changes between bytownite to andesine (Deer et al., 1991**)**. There are two theories to explain high calcium plagioclase. The first theory is a magma with very high ratios of $13<CaO/Na_2O$ (Bender, 1978; Jaques, 1981; Green, 1972). The second theory is crystallization of high calcium plagioclase because of high vapor pressure of water in the crystallizing magma process (Johannes, 1978). Because of the significant amount of amphibolite in this gabbro, the second theory seems more plausible here. Unlike the west gabbro, amphibole mineral can be seen in the minerological compositions of the east and south gabbro as well as pyroxene and plagioclase. Metalic minerals i.e. ilmenite and magnetite have been formed in the texture of amphibole of the gabbro (Figure 3d). In the samples taken from two gabbro units in the west of Fanuj almost in all of them metalic minerals ilmenite and magnetite are placed next to each other. This also show orthomagmatic nature of the ilmenite reserves (Figure3e). Ferrogabbro pegmatites can be seen in some parts of the gabbro mass (gb2) which is similar to the other gabbro in mineralogy point of view (Figure 3f). The fact that mineralogy of pegmatitegabbro is identical with its host gabbro shows that they are in balance with the host gabbro (Beard & Day, 1986). There is a diabase unit in the south and north east of the studied area that in mineralogical point of view isn’t slightly different from the area gabbro but has different because of the presence of certain metallic minerals. These diabase masses are mostly outcrop at the surface of the earth as diabase dikes. The chemical analysis shows their affinity to MORB basalts (McCall, 1997). The diabasic dikes are mostly consisted of plagioclase and amphibole minerals and a little pyroxene. That’s why they are more hydrated compared to gabbros. The fluid trapped in the stage after comulate along with the entrance of a fluid rich in water in the magma column form the amphibole and leads to copper mineralization (Tribuzio et al, 2000). Oxides, hydroxides, and iron sulfide, including hematite, goethite and pyrite are metallic minerals in these basic dikes.In this area, hematite mineral has boxwork texture (Figure 3g) and goethite mineral has colloform texture (Figure 3h). This indicates formation of mineral at low temperatures as epigenetic. Pyrite mineral in diabasic dikes are almost euhedral and changing into iron oxide at the margin. This shows that the mineral pyrite has been formed in depth and reduction condition and then placed at oxidation conditions.

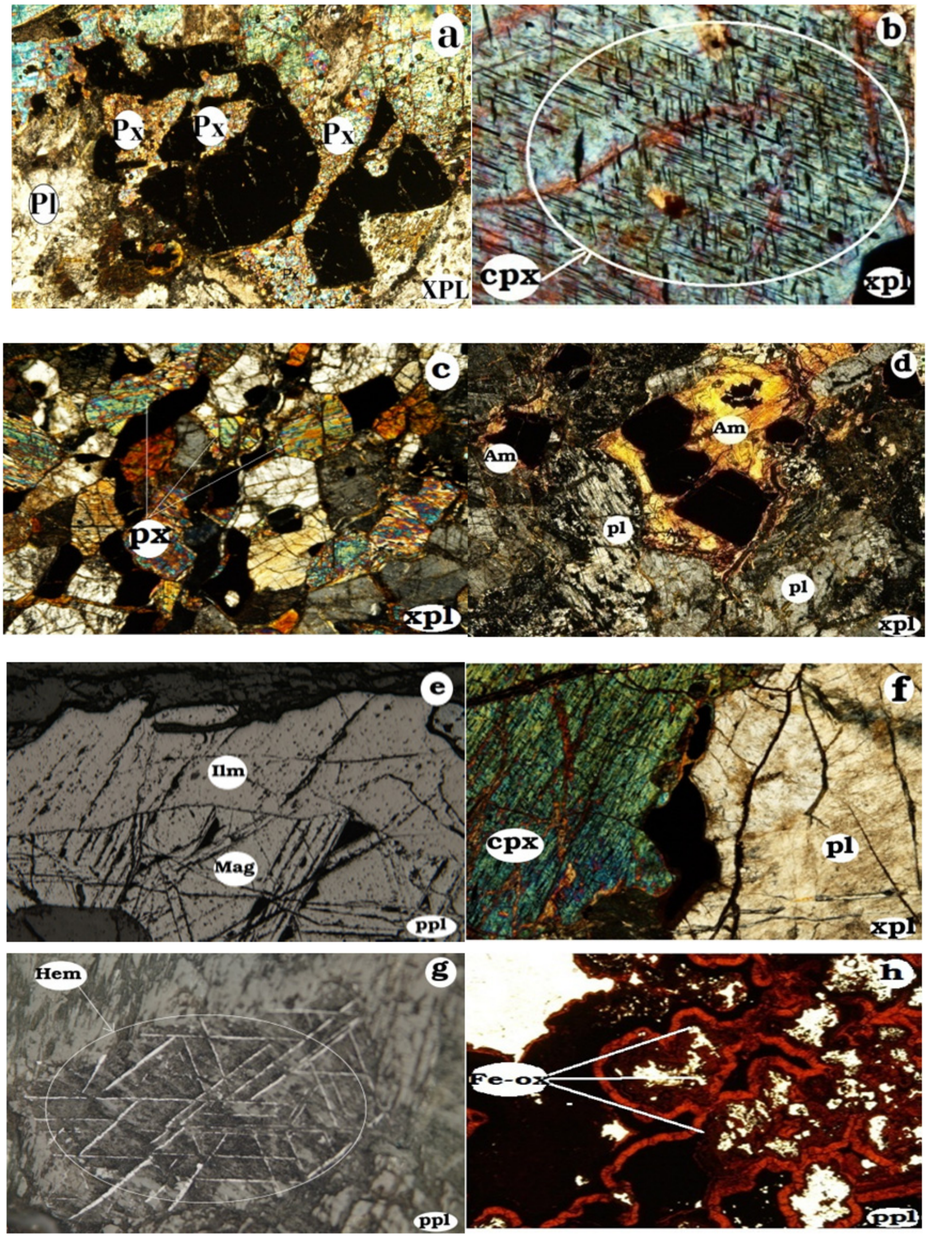


Figure3. (a) The presence of metalic minerals of ilmenite and magnetite in coarse graine gabbros of the west area both independently and in the texture of pyroxene mineral. (b) The formation of the lamellar structure by ilmenite and magnetite minerals within the clinopyroxene. (c) A view of emulsoid texture of ilmenite and magnetite in the spaces between the minerals pyroxene. (d) The formation of ilmenite and magnetite in the texture of amphibole mineral in the medium to fine grained gabbros of the south and east of Exploration area. (e) Intergrowth texture of ilmenite and magnetite in gabbro west of Fanuj. (f) The image of pegmatites ferrogabbros in the south and east of exploratory area. (h) The formation of boxwork texture in the Hematite of altered areas of diabasic dikes in the Fanuj ophiolite. (g) Formation of colloform iron hydroxides at low temperature in altered diabasic masses

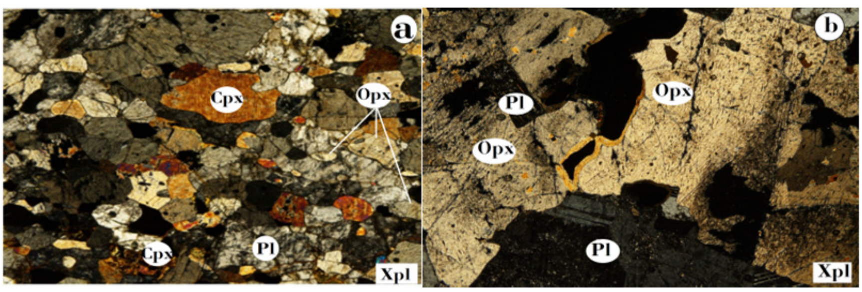
Table 1. The results of analysis by XRD

Sample	Major phase	Minor phase	Trace phase
Fn1	Anorthite-Augite	Magnetite-Cholorite-Hornblende	-----------
Fn2	Albite- Augite	Cholorite	Ilmenite- Hornblende
Fn3	Albite	Cholorite- Augite-Prehnite	Hornblende
Fn4	Albite- Augite	Cholorite	Ilmenite
Fn5	Albite- Augite	Cholorite- Hornblende	----------
Fn7	Anorthite-Montmorillonite	Magnetite-Illite- Augite- Ilmenite	Cholorite- Hornblende- Magnetite
Fn8	Albite	Augite- Cholorite- Hornblende- Montmorillonite	Magnetite- Ilmenite
Fn11	Anorthite-Augite	Magnetite- Cholorite- Montmorillonite	----------
Fn13	Magnetite- Ilmenite - Augite	Cholorite- Hematite- Albite	----------
Fn14	Magnetite- Ilmenite-Hematite	-----------	Quartz
Fn15	Anorthite-Augite	Cholorite- Ilmenite- Magnetite	---------
Fn16	Anorthite-Augite	Cholorite- Ilmenite- Magnetite-Magnesite	Hematite- Hornblende
Fn17	Albite- Augite-Ilmenite	Magnetite- Cholorite- Hornblende	Hematite

Table 2. The results of major oxides by XRF analysis and elemental analysis using ICP, Medium to fine grained ferrogabbros of East area(Fn 1 ...... Fn 5). Transformed diabase mass (Fn6), fine grained Alluvial placer fine (Fn 7 ... ..Fn10). Coarse grained alluvial placer (Fn11 ... .Fn14). Coarse-grained and high-grade gabbro of West of the studied area (Fn15, Fn16, Fn17)

Sample%	Fn1	Fn2	Fn3	Fn4	Fn5	Fn6	Fn7	Fn8	Fn9	Fn10	Fn11	Fn12	Fn13	Fn14	Fn15	Fn16	Fn17
SiO_2	46.6	43.81	42.31	40.55	43.04	51.64	43.33	44.09	45.81	45.04	11.58	11.19	8.72	2.41	36.09	36.49	29.32
TiO_2	2.98	2.53	3.9	4	3.58	1.77	4.46	4.52	3.98	3.81	15.07	15.05	16.56	18.59	8.4	7.37	11.76
FeO	13.07	13.88	17.97	19.14	18.05	10.77	20.21	19.05	16.17	16	62.71	63.35	66.71	75.3	25.65	26.45	37.55
Al_2O_3	15.04	14.57	14.52	12.24	12.41	14.69	13.15	13.31	16.3	14.23	4.13	4.19	3.2	1.69	9.89	13.06	8.92
CaO	10.65	11.16	11	11.02	11.53	5.42	8.76	8.94	8.07	10.18	3.17	3	1.93	0.56	9.78	8.18	7.02
K_2O	0.18	0.07	0.13	0.14	0.13	0.24	0.17	0.14	0.28	0.14	0.05	0.05	0.05	0.05	0.11	0.14	0.11
MgO	4.95	7.14	3.64	5.26	6.37	5.56	3.88	3.75	2	4.57	1.68	1.64	1.69	0.55	5.41	3.26	2.93
MnO	0.21	0.15	0.17	0.21	0.18	0.22	0.25	0.25	0.17	0.18	0.5	0.49	0.41	0.49	0.28	0.26	0.28
Na_2O	3.33	2.57	2.98	2.55	2.54	5.16	3.61	3.75	4.86	3.54	0.53	0.53	0.62	0.12	1.92	2.96	2.09
CuO	......	......	......	......	......	3.03	......	......	......	......	......	......	......	......	......	......	......
LOI	2.55	3.97	3.23	4.52	2	4.2	1.9	1.89	1.57	2.1	<0.01	<0.01	<0.01	<0.01	2.31	1.37	<0.01
Total %	97.01	95.88	96.62	95.23	97.83	98.5	97.88	97.8	97.37	97.69	99.42	99.49	99.98	99.76	97.37	98.17	99.98
ppm																	
Cr	51	42	34	96	2076	17	72	41	102	125	136	97	81	132	142	111	73
CO	38	41	46	49	62	67	47	41	35	48	48	52	90	63	61	50	54
V	233	341	501	427	577	178	325	412	355	369	518	3986	4315	3577	201	354	306
Ni	27	38	39	50	73	24	68	21	14	23	24	57	46	86	44	41	10
Cu	64	48	73	130	121	20810	51	46	1115	76	78	112	98	81	152	140	279
P	0.15	0.02	0.02	0.12	0.02	0.1	0.08	0.09	0.3	0.05	0.02	0.05	0.02	0.02	0.02	0.16	0.02
S	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zn	115	130	122	132	116	203	190	188	170	112	115	117	360	185	187	179	286
Pb	15	17	13	20	22	7	12	22	14	16	14	52	77	43	28	28	42
As	1.8	1.6	1.9	1.9	1.7	1.9	1.3	1.8	1.5	1.4	1.6	1.4	1.7	1.6	1.4	1.5	1.5
Cd	0.17	0.16	0.17	0.19	0.19	0.17	0.16	0.19	0.18	0.19	0.18	0.17	0.16	0.15	0.21	0.19	0.19
Ba	24	20	23	26	25	35	28	63	53	21	24	32	29	31	21	29	16

The ophilites of the study area include rock massifs of gabbro family such as gabbronorite (Figure 4a), norite (Figure 4b) and coarse grained gabbro (Figure 4c). In addition to gabbro, diabasic dikes can be seen in some areas. Dikes have been exposed to alteration process in some areas. In the altered zones, copper mineralization of carbonate type has been occurred (Figure 4d). In Fanuj ophiolite, except for mafic masses, 4km away from the study area, ultra mafic massifs can be observed. Although gabbro masses in the west and east part of the studied area has many similarities in terms of rock forming and metallic minerals but significant geochemical difference have been acknowledged in the process of rock formation. Microscopic and field studies and the results of XRF and ICP analysis show that fanouj gabbros have been formed in different depth. So that gabbro of the west area (gb1) shows coarser- grained texture compared to that of eastern part (gb2). This shows that the western gabbro is formed in deeper areas. In addition to this, the results of XRF analysis indicates that the western gabbro is richer than those of eastern area in terms of presence of TiO_2 and FeO. The high grade of Ti is one of the features of MORB ophilotes. Therefore, the high grade of Ti in the studied gabbro indicates that its clinopyroxen has been crystalized from a Titanium-rich magma. Contrary to high level of TiO_2 and FeO, this course–grained gabbro has less SiO_2 and Al_2O_3 compared to the eastern area. In the west of the studeid area as well as the coarse-grained gabbro which contain 12% TiO_2, there is placer which is below the gabbro complex and contain 18% TiO_2. As mineral placer i.e. ilmenite and magnetite, the minerals have been accumulated due to erosion and degradation of heavy minerals and sediments deposition. The low grade-placer deposits are easily mining due to looseness of their composites. TiO_2 grade of fine-to medium grained gabbro do not exceed 4% but due to high resourses of Ti is economic. Because this area is of oceanic crust (MORB) and its iron is of magnetite type, it can be concluded that the accumulated Ti is of orthomagmatic type. As it is illustrated in table2 in all the areas with high level of Al_2O_3, SiO_2, the amount of TiO_2 and FeO is reduced (gb2). But in the gabbro mass of western area (gb1) this is quite opposite to that of eastern area. The presence of clynopyroxene reduces the level of Al_2O_3 and SiO_2 and increases TiO_2 and FeO level. As MgO decreases, SiO_2 increases and as the silica content decreases FeO increases. As such there is reverse correlation between them. These changes are due to their replacement in the structure of ferromagnesian in the early stages of segregated magma crystallization. While Na_2O, K_2O, and CaO show increase with raise in amount of SiO_2 and decrease due to increase of Al_2O_3. (gb2) which shows natural process of segregation(Harker, 1909).Crystallization of oceanic basalts in low pressure leads to the formation of 82% clinopyroxene and olivines coxist with Mg and 74% of orthopyroxenes coexist with Mg (Elthon, 1982). The table show high correlation of TiO_2 and FeO. This shows the presence of titanium in the ferromagnesium minerals of area such as pyroxene and amphibole (Figure 4e). It can be said that minor presence of P_2O_5 oxide in the gabbro masses leads to crystallization of magnetite along with ilmenite. High level of P_2O_5 in magma limits crystallization of magnetite compared to ilmenite (Toplis, 1994; Zhou, 2005). But the negative correlation of TiO_2-$SiO_2$and TiO_2-Al_2O_3 indicates the presence of titanium oxide in gabbro which is mostly consisted of ferromagnesium minerals and less silica and have lower plagioclase in their composition (Figure 4 f, g). Negative correlation of FeO-SiO_2 and FeO-Al_2O_3 oxides is also normal in igneous rocks. Because according to Bowen's reaction series, first magnesium and iron bearing minerals formed in magma and in the final stages of magmatic crystallization, acidic elements such as Al and Si penetrate to the mineral composition(Figure 4 h, i). Oxides Al_2O_3 and SiO_2 which determines the acidity of igneous rocks show a high correlation (Figure4 j). The results of ICP analysis also shows the formation of the two masses of gabbro occurred at different depths and the gabbros of the east have been separated from those of the west due to magmatic segregation. So that the ratio of heavy elements (Cr، Ni، Co) of orthomagmatic masses in coarse grained gabbro of the west is two times more than medium or fine grained gabbros of the east. This shows the early formation of the west gabbros of the study area and penetration of heavy metallic elements to crystal lattice of gabbro minerals. Due to reduction of this elements and increase Al and Si in residual magma, magmatic differentiation occurred, and at the lower depth compared to west gabbro have been formed. Fractional crystallization along with crustal contamination is an important process during the evolution of magma (De Paolo, 1981). Exceptmetal elements Ti and Fe that are commercially available in the area, vanadium can be seen economically in some parts especially those which are rich in titanium. Parallel behavior of V with Ti in crystallization process is a positive sign of Ti distribution in ilmenite or titanomagnetite without being influenced by secondary alterations (Kerrich, 1997). The amount of sulfur element in all of the samples is less than 50 ppm and almost metalic elements are as oxide which represents high oxygen fugacity in this magma.



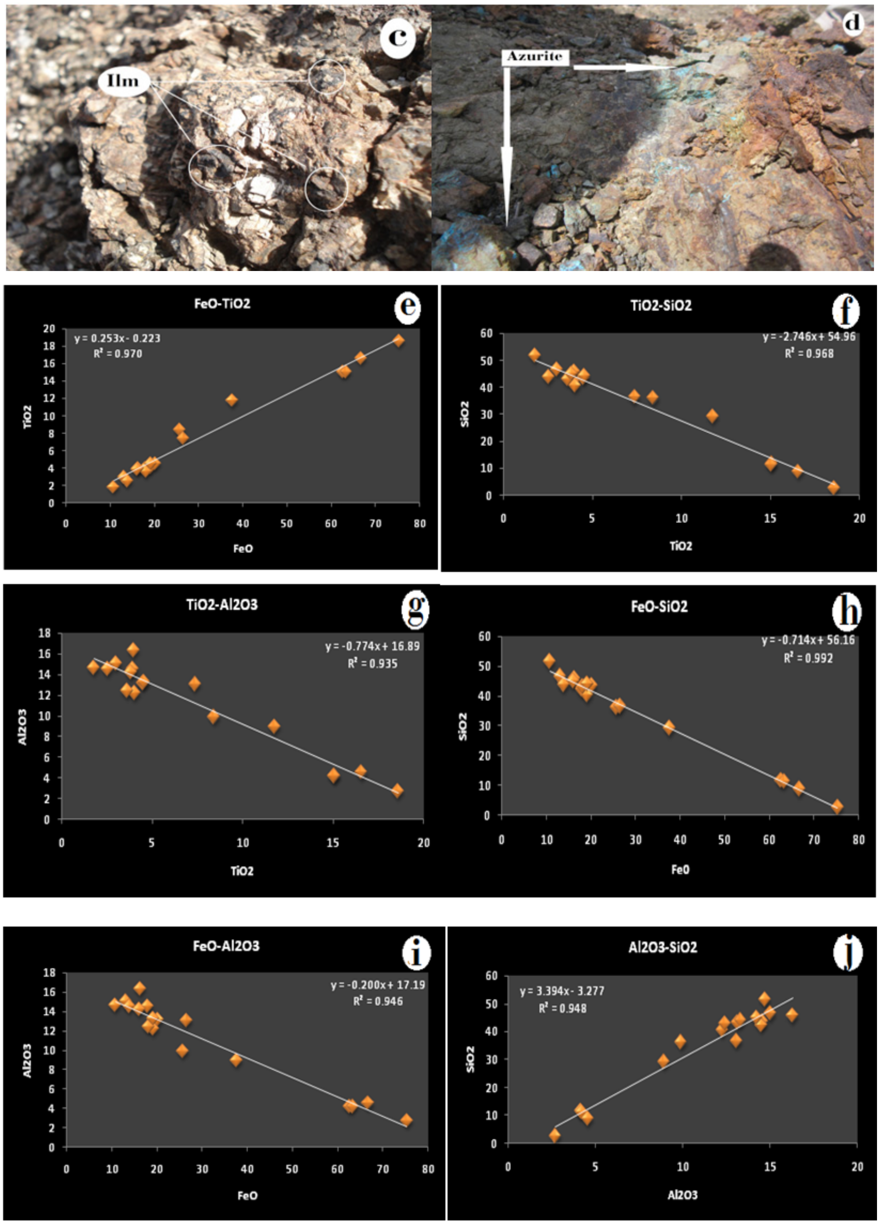


Figure 4. (a) A thin section of a gabbronorite in the study area. (b) Presence of orthopyroxene and plagioclase minerals in the norite in ophiolite rocks West Fanuj. (c) Coarse-grained and high-grade ferrogabbros containing ilmenite mineral. (d) The image of altered diabasic dikes and copper mineralization. (e) High correlation between FeO and TiO_2 oxides shows orthomagmatic nature of titanium storage in the West of Fanuj. (f, g) Negative correlation of acidic oxides SiO_2-Al_2O_3 and TiO_2 oxide in mafic masses. (h, i) Negative correlation of FeO and Fe oxides SiO_2-Al_2O_3 indicates intergrowth of Fe and Ti minerals in the gabbros of West Fanuj. (j) Positive correlation of SiO_2-Al_2O_3 oxides that determines the rock acidity

4. Discussion and Conclusion

The western part of Fanuj ophiolite is entirely consisted of basic masses. In mineralogical point of view, it is consisted of minerals specific to basic masses such as pyroxene, plagioclase, and amphibole and in some areas which have been exposed to alteration is also consisted of mierals such as epidote and chlorite. Ilmenite- bearing gabbro of Fanuj is divided into two groups. The two gabbro masses are similar to each other in respect of rock forming minerals but have difference in structure, texture and the grade of ilmenite and magnetite in the gabbro. Variation in the structure and the texture of gabbro rocks is due to depth and crystallization time of basic magma with its low viscosity inside the earth plutonic environment. Metal minerals (ilmenite and magnetite) have been formed both independently and as lamellar inclusion in the texture of ferromagnesium minerals such as clinopyroxen and amphibole. High amount of TiO_2 in the clinopyroxene of the area may show that the gabbro has been formed under high pressure. Tetrahedral and octahedral aluminum distribution position in minerals is a good criterion to estimate the pressure which is imposed on the formation of pyroxene-bearing igneous rocks. Microscopic studies and the results of ICP analysis show that moving from depth to the surface in the gabbro mass, ferrromagnesium minerals and heavy elements such as Ni, Ti, Fe, and Cr are reduced and the components of acidic rocks such as Si, Al, and plagioclase minerals are increased. So the maximum grade of ilmenite and magnetite is devoted to underlying coarse- grained gabbro (gb1) which has had a slow crystallization. But with the segregation of magma and gradual and Fractional crystallization of pyroxene and calcium- bearing plagioclase, the residual magma is rich with Al and Si and form the gabbro called (gb2) which crystalized in a lower surface. This gabbro is cost-effective due to the presence of ilmenite and magnetite, but because it is formed in a lower depth and also due to the high content of Al and Si has a lower grade of Ti (grade between 2.9 to 3.6). Thus the gabbro unit (gb1) in terms of width and the gabbro unit (gb2) in terms of grade (grade rangers from 7.4 to 11.8) are regarded as the most important gabbro units of the western of Fanuj and respectively in both unit, Ilmenite is economically the most important. Placers of the coarse-grained gabbro of the west of the study area are very important and cost effective in terms of their grade. The grade of TiO_2 in these placers reaches to 18% and the grade of FeO reaches to 75%. Besides ilmenite, magnetite can also be extracted as a byproduct in cost -effective gabbro masses.

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