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Petrology of the metabasites of Dezg ophiolite melange complex, southeast of Qayen, east of Iran

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ABSTRACT

The study area is located southeast of Qayen and in the northern part of the Sistan suture zone in the east of Iran and it is in real an ophiolitic complex with an approximate complete sequence and with a special metamorphic zone including metabasite rocks such as greenschist, epidote amphibolite, amphibolite and granulite in its eastern part. The metabasite rocks associated with ophiolite, have been affected by low to high-grade dynamo thermal regional metamorphism that has outcropped as a special metamorphic zone in the eastern part of ophiolite. On the base of geochemical diagrams most of these metamorphic rocks are a result of dynamothrmal regional metamorphism of primary pillow basaltic lavas and magmatic series of metabasite protoliths, which is tholeiitic. This composition is showing their relationship with MORB origin magma. The thermobarometric investigation done on these rocks show that these metamorphic rocks have been affected by metamorphism in maximum pressure of 3.9 – 5.3 Kbar and maximum temperature of 725±25 degrees of centigrade and in most extensive metamorphic position, changing of metamorphic pressure has been an important effect in paragenesis changes.

KEYWORDS

Petrology, metabasite, regional metamorphism, Qayen, Sistan suture zone

I. INTRODUCTION

The study area is a part of the Sistan suture zone (Tirrul et al., 1983) in east of Iran along the Northwest - Southeast and in the range of geographical lengths 60° 04' 11.11" to 60° 06' 57.47" east and latitudes 33°20' 25.27" to 33° 22' 02.93" at 1: 250,000 map of Shahrakht (Alavi Naeini, 1981) and at 1: 100,000 map of Ahangaran (Alavi Naeeini, 1981). The main aim of this research is to specify metamorphic position of an area that has not been done in this area to now. Because to present has not done any research project about metamorphism of this area that is the main idea of us to specify that in this area.

The study area is basically an ophiolite complex of the almost complete sequence of ultramafic to mafic igneous rocks (metamorphosed in part), radiolarites cherts and radiolarites (sometimes metamorphosed) and with a marked transitional zone in the eastern part. Metabasite rocks in ophiolitic complex influenced by regional dynamo thermal metamorphism from low to high grade. This metamorphism resulted in greenschist facies, epidote amphibolite, amphibolite and granulite that have appeared as a metamorphic zone in the eastern part of this ophiolite. The metamorphic grade of this complex band generally increases from west to east. Some of these rocks are the result of regional metamorphism of primary pillow lavas. Since, the study area is at the junction of the Lut and Afghan blocks (Helmand), in this paper we use the Sistan suture zone (Tirrul et al., 1983) for this structural unit. The heights of the area contain limestone with lower cretaceous and paleocene age located adjacent to the east of the study area. In the south of the area, a complex of tonalite and granodiorite appeared and in the west, igneous rocks belonging to the ophiolite complexes, most of which are peridotite. Granulite, amphibolite, epidote amphibolite and greenschist can be mentioned among the metamorphic rocks seen in the area (Fig. 1).

II. METHODS

To perform this research, after field study and sampling for petrographic and mineralogical investigations, from the metabasite samples of the study area, thin microscopic sections were prepared and their mineralogical and textural characteristics were determined by a polarizing microscope. In this study reaction textures in metamorphic rocks and also different mineral assemblages in different metamorphic rocks were specified to determine metamorphic facies and investigate metamorphic changes of these rocks with regard to the conversion of minerals to each other and finally different stages of their metamorphism, intensity and extent were determined and specified in the study area.

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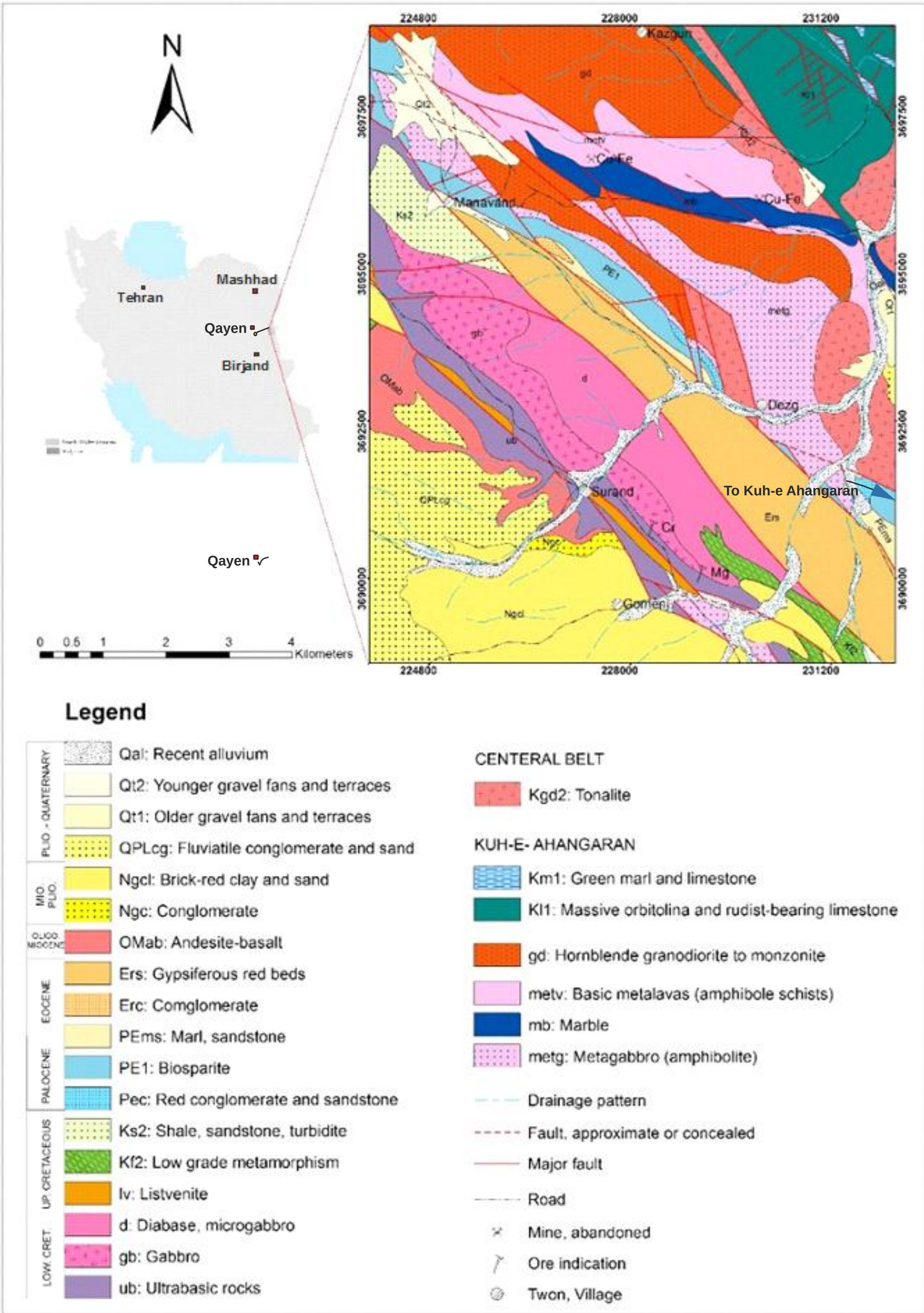

Fig. 1. Geological map of the study area (adapted from (Alavi Naeini, 1981)). On the map metg show greenschist, epidote amphibolite and some granulite facies rocks. The granulite is more in next to Dezg village.

To identify the type of minerals, investigate the chemical composition of minerals and perform thermobarometry studies on the studied metabasite rocks, thin polished sections were prepared and studied, and then point analysis by EPMA method was performed on the minerals of seven rock samples of metabasites, at the university of Munster, Germany, and the results are presented in Tables 1 and 2. To name the mineral accurately, Min Pet 2.02 software was used and the correctness of microscopic studies in mineral identification was confirmed. In addition, 11 samples of the studied rock samples for chemical decomposition by XRF and XRD methods were selected with regard to the highest level of metamorphism and were analyzed in the Geological and Mineral Exploration Labs of Iran.

III. PETROGRAPHY

A. GREEN SCHISTS

These rocks are fine grain crystals and the major minerals contain plagioclase, quartz, epidote, actinolite, carbonate, sphene and opaque minerals. Most of these rocks have the texture of Lepidogranoblastic and porphyroblastic (Fig. 2).

B. AMPHIBOLITES

Amphibolites exist in the eastern and northern parts of Dezg village and are one of the main units of metabasite in the region. Their major texture is nematoblastic and rarely granoblastic. They have relatively simple mineralogical composition and are mainly formed of hornblende and plagioclase. Basically, the rocks in the region have roughly equal amounts of hornblende and plagioclase minerals. In amphibolites with performed epidote, there is no biotite mineral and epidote is made of the reaction of water with hornblende and also saussurite plagioclase and contains amphibole minerals (tremolite ± hornblende ± actinolite) + plagioclase ± calcite ± chlorite ± opaque mineral (Fig. 3, A and B).

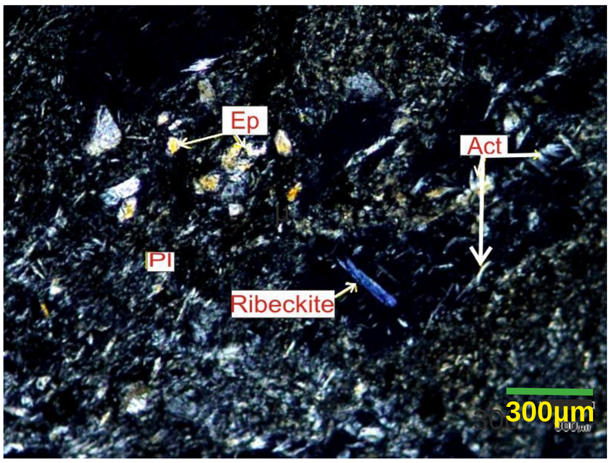

Fig. 2. Green schist with lepidogranoblastic texture (XPL)

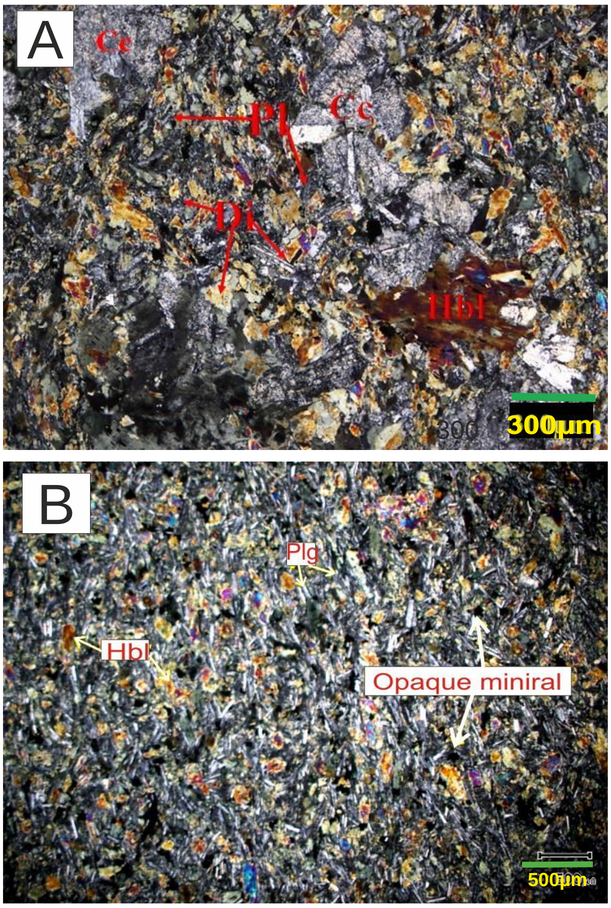

Fig. 3. A: Amphibolite (Hbld +Pl) with diopside from parent metabasite rock. Diopside is relict of parent rock. B: Amphibolites with weak foliation that just is seeing in thin section.

Amphiboles are from the important minerals that form these rocks. The importance of this mineral appears in the diversity of its composition with different metamorphic conditions. The composition of this mineral is from calcic amphibole. Prismatic amphibole composition from retrograde pyroxene metamorphism in the amphibolites, is actinolite, and needle-like amphiboles in feldspars and in- and around-actinolites are from magnesiohornblende type (Fig. 4). They are positioned within the metamorphic range (Leake at al, 1997). suggested the following reaction to form amphibole from diopside in retrograde metamorphism conditions:

$$5CaMgSi_2O_6 + H_2O \rightarrow Ca_2Mg_5Si_8O_{22}(OH)_2 + 3CaO + 2SiO_2$$

Diopside + Water → Amphibole + CaO + Silica

The composition of amphibole in amphibolite samples and epidote amphibolite is different and with some changes from each other. In amphibolites, amphiboles are hornbelende and plagioclases are rich in bytownite and in epidote amphibolites, amphiboles are from magnesium-rich hornblende to actinolite type (Fig. 3.B). Actinolite, ferroactinolite, tremolite and magnesia hornblende are calcic minerals according to the classification of (Leake at al, 1997).

In the case of metamorphic factor or other words changes of minerals in these rocks, it can be said that these types of rocks suffered metamorphism at the level of under greenschist facies (prehnite-actinolite facies) during the subduction process imposed on the region, and in fact, prehnite-actinolite facies metamorphic rocks in the areas of subduction and collision show that these rocks belong to the most shallow depth of mentioned areas (Esmaeili, 2014).

Large crystals of feldspars that remain of magmatic plagioclases are surrounded by tiny crystals of their own type. Tiny crystals around porphyroclasts show a gradual texture. In this way that the center of porphyroclasts to the margins they become smaller, equal, and more angled. So that in some cases only traces of albite twinning remain in them. The effects of dynamic metamorphism in these minerals can be seen as faceoff waves, recrystallization, mechanical twinning, and twinning bending. The amount of component of anorthite in plagioclase is located in the range of 75% < An < 98%. Plagioclases are in amphibolites with plagioclase rich in anorthite in kind of bytownite to anorthite (75 to 98 percent anorthite) (Fig. 5).

C. Granulites

Granulite metamorphic facies is defined based on different mineral assemblages in protolith rocks with high temperature that is determined by the presence of orthopyroxene, whereas high-pressure border is related to the formation of the eclogite facies and emitting of the plagioclase. Characteristic of mafic granulites with the mineral assemblage of clinopyroxene and orthopyroxene is sometimes hornblende, plagioclase, garnet, biotite, potassium feldspar and quartz, which are located below the hornblende granulite facies and have basalt composition widely. Typically at first, Orthopyroxene in mafic amphibolite changing decomposes to hornblende, plagioclase, quartz, clinopyroxene and garnet, at the pressure of about 16 kilobars. Granulites of the region are located in the western part of Dezg village that tend to gray in a hand specimen and are fine grained. In microscopic examinations, it has topically Granoblastic texture and the effects of mineral recrystallization. Fig. 6 shows a granulite microscopic cross-section in the area.

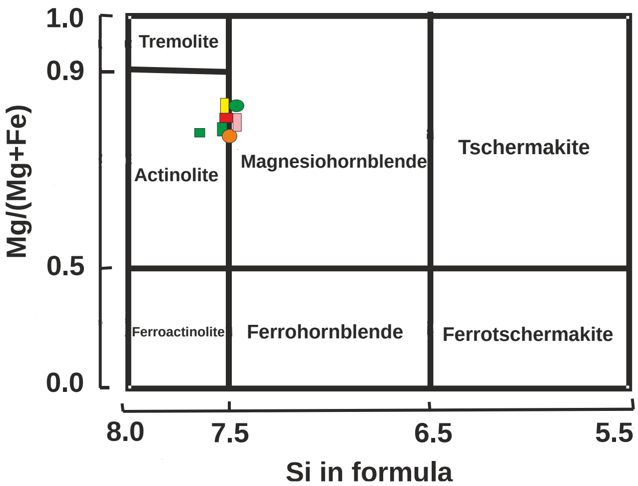

Fig. 4. Compositional range of calcic amphiboles available in metabasalts of Qayen (sample 36) in the diagram of Leake at al (1997).

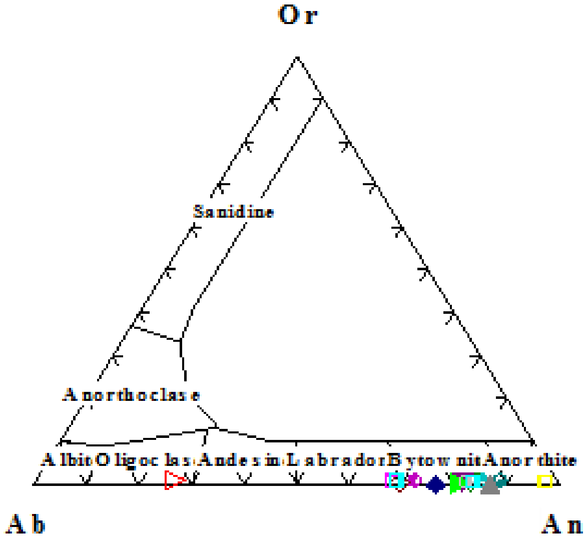

Fig. 5. Feldspars position in the samples of metamorphosed rocks in southeast of Qayen (Leake at al, 1997 ; Esmaeili, 2014).

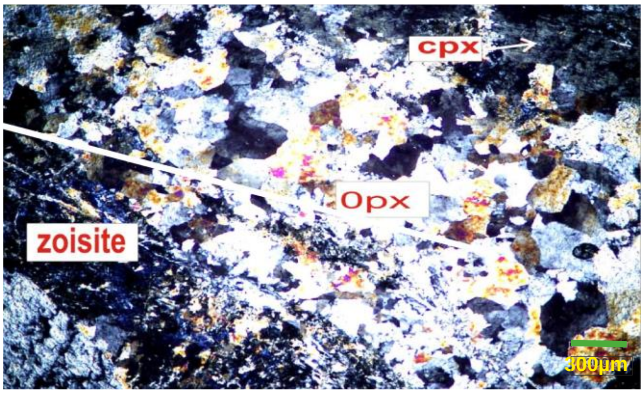

Fig. 6. Granulite with granoblastic texture located in the west of Dezg

IV. Geochemistry and mineral chemistry

To determine the chemistry of the magma and its evolution, chemical classification and diagnosis of protolith of metamorphosed rocks, determination of their tectonomagmatic setting, and also changes in the main elements, 5 samples of the metamorphosed rocks of the area were sent to the laboratory of Geological and Mineral Exploration of country (Iran) for chemical analysis by XRF which 3 samples from samples sent are related to metamorphosed gabbroic units and the other two samples are related to metamorphosed basaltic units which the results of these analyses are presented in Table 1.

Table 1. The results of XRF analyses

Sample/ Formula	35	18	28	23	26
SiO_2	50.8	52.5	53	46.7	50.3
Al_2O_3	14.3	13.6	6.30	15.3	11.1
Fe_2O_3	10.3	12.4	10.9	12.8	10.6
MgO	5.90	4.70	13.5	4.70	10.5
CaO	12.3	11.6	12.5	16.4	13.0
SO_3	0.10	0.10	<0.10	0.10	0.20
K_2O	0.30	0.01	<0.10	0.20	0.10
Na_2O	2.90	3.00	0.40	1.30	0.90
TiO_2	1.00	0.70	0.40	0.70	0.70
MnO	0.20	0.10	0.20	0.20	0.30
P_2O_5	0.20	0.10	<0.10	0.10	0.10
Cr_2O_3	<0.10	<0.10	0.20	<0.10	0.20
NiO	<0.10	<0.10	0.10	0.00	<0.10
L.O.I	1.35	0.61	2.04	0.94	1.56
Total	99.85	99.71	99.84	99.44	99.66

In addition, in order to identify types of minerals, chemical composition analysis of minerals and Termobarometric studies on metabasite rocks, polished thin sections were prepared and analyzed and then Point analysis was done by EPMA method on minerals of 7 metabasite rock samples in the university of Munster in Germany, the results of which are presented in Tables 2 and 3.

V. Chemical composition of minerals in metamorphosed rocks

In this part, th chemistry of minerals of metabasites which analyzed are decomposed by microprobe electron in the metamorphosed rocks of the studied area has been provided.

Amphiboles

Amphiboles are among the important minerals that form amphibolites. The importance of this mineral appears in the variety of its composition in different conditions. Prismatic amphibole composition from retrograde metamorphism of existing pyroxene in amphibolites is actinolite, and the needle-like amphiboles existing in feldspars and in- and around-actinolites are in the type of magnesiohornblende (Fig. 4).

The composition of amphibole is different in amphibolite and epidote amphibolite samples from each other and also shows some changes from each other. In the amphibolites with plagioclase rich in bytownite, amphiboles are magnesium actinolite. Actinolite, ferroactinolite, tremolite, and magnesio-hornblende are calcic minerals according to the classification of Leake et al. (1997).

VI. Magmatic series of protolith of metabasite rocks

The set of above-mentioned issues and also the results of petrography and chemistry of minerals emphasize the dependency of primary rock for most of these rocks to tholeiitic basalts of mid-ocean ridges. However, secondary changes such as sodium metasomatism in seafloor certainly create trivial changes in the initial composition of the protolith of these rocks, the magmatic series of initial rocks of these metabasites is tholeiitic. According to the chart AFM, the initial rock of these metabasites can belong to diagonal basaltic magma. Jensen graph in Fig. 7 confirms the tholeiitic position of the studied rocks.

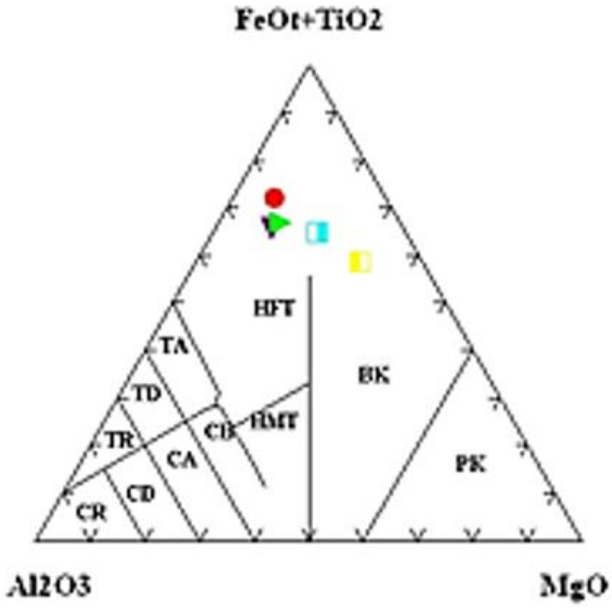

Fig. 7. Tholeiitic-komatiitic chart to differentiate primary magmatic rocks of metabasite series (Leake, 1965)

Based on the graphs of different tectonic settings of basalts (Jensen, 1976; Mullen, 1983), Fig. 8 shows the chemical composition of protoliths for these metabasites in the mid-ocean ridge basalt (MORB) and island arc tholeiites. According to the graphs in Fig. 8, the magma series of primary rocks for these metabasites is tholeiitic. Therefore, according to the chemical classification of these rocks, their primary rock could belong to diagonally basaltic magma. Generally, with regard to the Jensen graph in Fig. 9, the composition of these metabasites is in the range of oceanic tholeiitic basalts.

VII. THERMOBAROMETRY

Amphibole forms double-chain silicates that have considerable diversity in terms of chemical composition and mineralogy structure. The variety of structural and chemical composition causes them to be able to get formed in a wide range of different types with different conditions of temperature, and pressure. Amphiboles exist almost in all felsic, intermediate and mafic igneous rocks and have a wide range of temperature (315 - 400 ° C) and pressure (1 -23kb).

Calibration of amphibole - plagioclase: since the use of geothermometer-barometers in which amphibole has a major part because of the complexity in the composition of amphiboles, the existence of several non-combination between the end members of these minerals and the error in estimating Fe+3/2Fe from microprobe data, there are some problems (Pearce et al., 1984); Therefore in order to identify the thermodynamic conditions governing the formation of amphibolites, amphibole combination based thermometer-barometers are highly used (Droop, 1987).

The distribution of Al and Na elements in amphibole minerals is a function of pressure and therefore these elements can be used to determine metamorphic pressure. The value of Ti in silicate minerals especially amphiboles, micas, and pyroxenes is a function of temperature. Yet, different methods are presented to determine metamorphic pressure from the composition of calcic amphiboles. Droop (1987) determined the pressure range for the formation of these minerals based on the value of Ti and Al of amphibole minerals. In this graph, the amphiboles in the Dezg area are located in the range of medium pressure (Fig. 10).

The obtained pressure for amphibolites by amphibole–plagioclase thermometer-barometer confirms medium pressure (Fig. 11). With regard to the abnormal high value of anorthite in plagioclases of epidote amphibolites and as the result high value of the ratio of plagioclase Ca to hornblende Al, the points of introducing this mineral in graph is out of the range and doesn't present vivid results of temperature and pressure (Hynes, 1982). The temperature obtained for matabasites in the Dezg area was obtained using an experimental thermometer of amphibole - plagioclase (Plyusnina, 1982), 25 ± 725 ° C for amphibolites and 20 ± 490 ° C for epidote – amphibolites (Fig. 12).

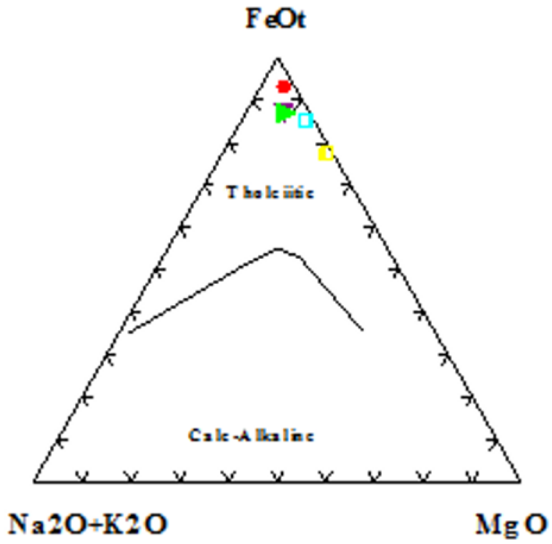

Fig. 8. AFM graph to determine the probable primary rocks magmatic series of metabasite (Esmaeili, 2014)

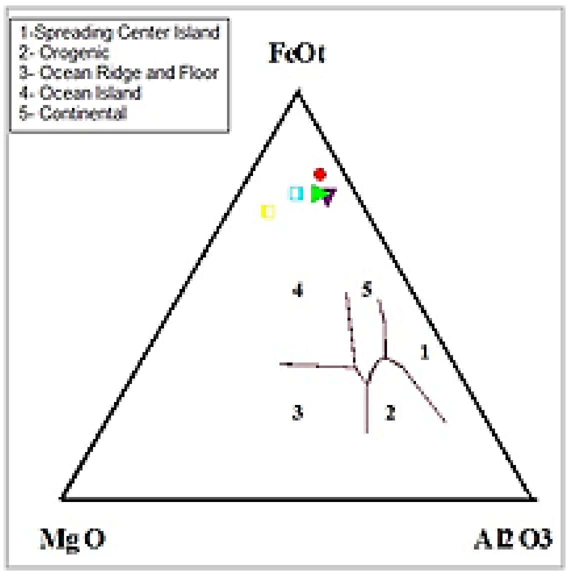

Fig. 9. Tholeiitic-komatiitic chart to differentiate primary magmatic rocks of metabasite (Jensen, 1976)

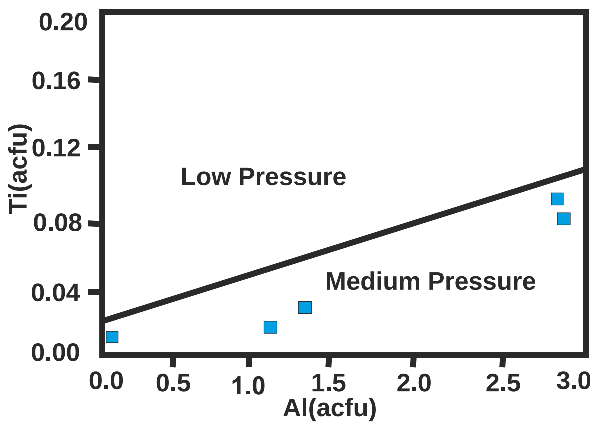

Fig. 10. Ti versus *Al* diagram from amphibole minerals adapted from (Droop, 1987)

Table 2. The results of point analysis of amphibole in metabasites of southeast Qayen

Column1	hbl1	Column 2	Column 3	Column 4	Column 5	Column 6
SiO_2	43.36	43.60	4503	45.41	44.37	44.17
TiO_2	0.34	0.39	0.19	0.14	0.03	0.54
Al_2O_3	16.53	10.97	10.55	9.92	14.83	12.43
Cr_2O_3	0.00	0.00	0.03	0.06	0.01	0.00
FeO	12.48	13.80	14.38	14.17	10.54	21.19
MnO	0.04	0.17	0.56	0.44	0.28	0.37
MgO	12.20	14.04	13.72	11.83	12.19	8.69
CaO	10.75	12.52	10.67	13.65	13.59	9.60
Na_2O	1.23	2.03	2.99	1.33	0.21	1.29
K_2O	0.20	0.53	0.02	0.19	0.18	0.12
Total	97.13	98.05	98.06	97.14	96.23	98.40
(O) p.f.u.	23.00					
Formula (corr)	23(O)	23(O)	23(O)	23(O)	23(O)	23(O)
Si	6.143	6.338	6.466	6.777	6.474	6.365
Ti	0.036	0.042	0.013	0.015	0.004	0.059
Al	2.760	1.879	1.786	1.745	2.549	2.111
Cr	0.000	0.000	0.003	0.007	0.001	0.000
Fe_3+	1.243	0.791	1.134	-0.123	0.152	1.695
Fe_2+	0.236	0.688	0.593	1.891	1.134	0.858
Mn	0.005	0.021	0.068	0.056	0.035	0.045
Mg	2.577	3.042	2.937	2.632	2.651	1.867
Ca	1.632	1.950	1.642	2.183	2.124	1.482
Na	0.338	0.572	0.832	0.386	0.060	0.360
K	0.036	0.098	0.003	0.036	0.034	0.022
Total	15.006	15.620	15.477	15.604	15.218	14.865
Mg/(Mg+Fe_2(	0.916	0.774	0.832	0.582	0.701	0.685
Fe_2/(Fe_{tot}(	0.159	0.528	0.343	1.070	0.881	0.336
Al/(Al+Fe_3+Cr)(	0.690	0.704	0.611	1.071	0.943	0.555

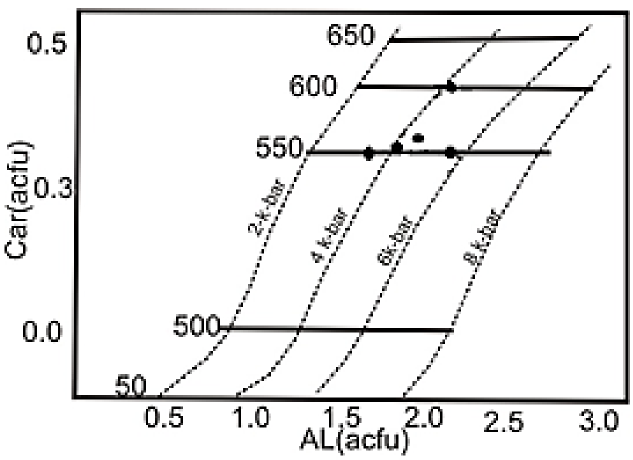

Fig. 11. Hornblende - plagioclase P-T diagram to determine amphibolites temperature and pressure range (Hynes, 1982)

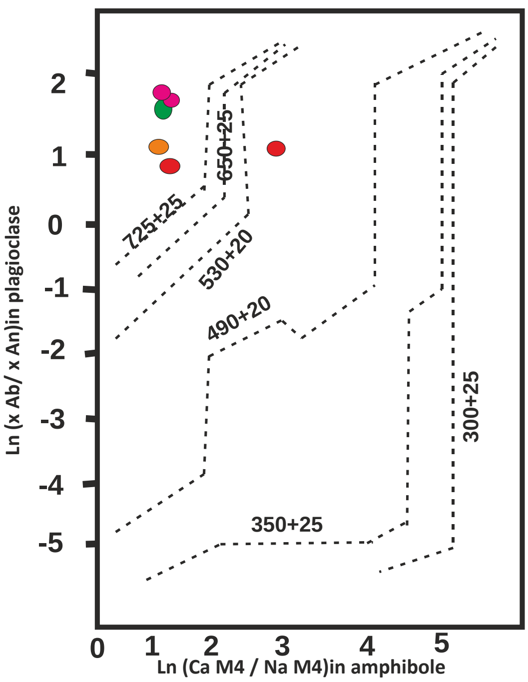

Fig. 12. Ln (X An / X Ab) graph in plagioclase against Ln (Ca M4 / Na M4) in amphibole for calculating the amount of metamorphic temperature (Plyusnina, 1982)

Table 3. The results of point analysis of plagioclase of southeast of Qayen

	ab1	6153-fsp1	6153-fsp2	6153-fsp3	6153-fsp5	6153-fsp6
SiO_2	68.11	49.17	48.65	45.72	45.65	45.97
TiO_2	0.00	0.02	0.03	0.05	0.00	0.00
Al_2O_3	19.29	30.67	31.71	33.69	33.45	32.59
Cr_2O_3	0.04	0.00	0.00	0.02	0.01	0.00
FeO	0.05	0.30	0.23	0.31	0.32	0.65
MnO	0.06	0.00	0.00	0.00	0.02	0.02
MgO	0.00	0.00	0.00	0.00	0.01	0.05
CaO	0.21	14.89	15.63	18.05	17.65	17.33
Na_2O	11.95	3.03	2.65	1.20	1.42	1.58
K_2O	0.02	0.06	0.05	0.02	0.06	0.01
Total	99.73	98.13	98.95	99.06	98.59	98.22
Norm .factor	2.637	2.798	2.779	2.797	2.810	2.822
Formula	$(O)_8$	$(O)_8$	$(O)_8$	$(O)_8$	$(O)_8$	$(O)_8$
Si	2.989	2.290	2.250	2.128	2.135	2.159
Ti	0.000	0.001	0.001	0.002	0.000	0.001
Al	0.998	1.684	1.729	1.848	1.844	1.804
Cr	0.001	0.000	0.000	0.001	0.001	0.000
Fe++	0.002	0.012	0.009	0.012	0.012	0.025
Mn	0.002	0.000	0.000	0.000	0.001	0.001
Mg	0.000	0.000	0.000	0.000	0.001	0.004
Ca	0.010	0.743	0.775	0.900	0.884	0.872
Na	1.017	0.374	0.238	0.108	0.129	0.144
K	0.001	0.003	0.003	0.001	0.004	0.001
Total	5.020	5.006	5.005	5.001	5.009	5.011
Na / (Na+K+Ca)	0.989	0.267	0.234	0.107	0.127	0.142
K(/ Na+K+Ca)	0.001	0.003	0.003	0.001	0.004	0.001
Ca(/ Na+K+Ca)	0.010	0.728	0.763	0.892	0.870	0.858

VIII. CONCLUSIONS

Based on chemistry of various metamorphic rocks of the study area, the results are as follows:

- The composition of spectrum amphiboles is obtained from retrograde metamorphism of pyroxene in actinolite amphiboles and needle amphibolites in feldspar in and around actinolites is of hornblende.

- Amphiboles of the studied amphibolite are in metamorphic amphiboles area.

- Charts for chemical classification show the chemical composition of the original basalt rock for metabasite.

- Magmatic series of protoliths metabasite are tholeiitic. This shows the status of their relationship with diagonal parental magma.

- Based on different charts of the tectonic setting of basalts, protoliths-metabasites are placed in MORB.

- Based on microprobe data and determining temperature-pressure, rock units of the area are of medium pressure and temperature type. Temperature calculated for amphiboles in metabasite is about 725 ± 25oC for them to be formed and calculated pressure is about 3.9 to 5.3 kb showing the depths of 12-15 km.

- Epidote amphibolite facies metamorphic rocks are the result of progressive metamorphic basalt and basaltic pillow lavas in the process of subduction. Metamorphosed amphibolite facies rocks in the study area consist of amphibolites from progressive metamorphism of basaltic pillow lavas ophiolite that may have formed during the subduction process in the study area. Granulite facies metamorphic rocks have had a similar fate that confirms the high grade metamorphism in the area.

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