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Petrography and Mineralogy of Amphibolite Rocks in Penjween Complex, Northeastern Iraq

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***Abstract*— *Penjween igneous complex is situated in the northeastern part of the Iraqi Zagros Thrust Zone (IZTZ) which is considered as integral part of the Alpine-Himalayan Orogenic Belt of Cretaceous age. The amphibolite rocks exist in Penjween as pods of lensoid-shape of variable sizes (2-3m). These amphibolite pods are surrounded by sheared tectonized serpentinite and peridotite and one is in contact with amphibole-bearing gabbro dike. In addition, there is an albitite dyke in contact with the amphibolite. These amphibolites exhibit deformation and alteration which is evident by the existence of chlorite veins cutting through or as patches within these rocks. Petrographic observations reveal that the main mineral constituents are amphibole; both primary and secondary, plagioclase with accessory clinopyroxene, quartz, titanite, apatite, zircon and iron oxides. Secondary minerals include chlorite, epidote, secondary amphibole and iron oxides as a consequence of alteration. Dominated textures are porphyroblastic, poikiloblastic, nematoblastic , blasto-ophitic and blasto-subophitic which are inherited from the original rocks. Accordingly, two mineral assemblages are identified:*

1- *Hb. + plag. + cpx.± qtz. ± titanite ± zircon ± apatite ± iron oxides,*
2- *Hb. + plag. ± qtz. ± titanite ± apatite ± zircon ± iron oxides ± chl. ± sericite ± ep.*

The secondary assemblage is more altered. On the basis of Mg/(Mg+Fe)-Si per formula of the analyzed amphibole, two types of amphibole are observed; Mg-hornblende and tschermakite. Chemical analyses of the plagioclase grains give two types; oligoclase (An23.9 Ab75.9) and albite (An1.7 Ab97.9).

***Keywords*— Petrography, Amphibolite Rocks, Penjween Complex.**

I. INTRODUCTION

Penjween area is located within the Zagros Thrust Zone (ZTZ) which is considered part of the main Zagros Orogenic Belt (ZOB) that extends northwest-southeast from eastern Turkey through northern and northeastern Iraqi-Iranian border into northern Oman (Jassim and Goff, 2006; Moghadam and Stern, 2011). The Zagros Thrust Zone marks the boundary between the Zagros Folding in the west and the Zagros Suture Zone (ZSZ) in the east (Stocklin, 1968). It is 2000 km long deeply rooted possibly to the Moho depth according to geological and geophysical data (Agard et al., 2005, and Azizi and Moineraziri, 2009). Along this zone magmatic activity, dismembered ophiolite are apparent within Penjween area. The so-called Penjween ophiolite consists of both mantle sequences (ultramafic) and oceanic crustal sequences accumulate gabbros and volcanic rocks, (Al-Hassan and Habbard, 1985).

The study area is located in the northeastern part of Iraqi Zagros Thrust Zone and southwestern part of Penjween igneous complex. The Penjween igneous complexe is situated to the southwest of the Penjween Malkawa village about 40 km to the east of Sulaimani City, between latitude 35° 36′ 16.4″ - 35° 37′ 15.6″N and longitude 45° 54′ 40.4″ - 45° 55′ 59″ E (Fig. 1).

Twenty-five rock samples of amphibolite were studied using polarized microscope. XRD analysis for some of this amphibolite was also performed for further identification of minerals. Microprobe analysis was carried out to determine the chemical composition and to classify the samples.

II. PETROGRAPHY AND MINERALOGY OF AMPHIPOLITE ROCKS

Petrographic study showed that these rocks were subjected to different degrees of alteration, which resulted in the formation of secondary minerals such as chlorite, epidote and sericite. The secondary minerals replaced the primary ones and some of filled them vesicles and veins, within primary minerals using have lost some of their original characteristics. plagioclase (25-45%) and the accessory minerals is between (5-15%) of the total volume of the rocks.

The modal mineral abundance which are estimated by point counting are listed in table (1), and the details of XRD analysis are shown in figures (2) which carried out in Dalhousie University Earth Science department. In addition to microprobe analysis was carried out (at the cooperation research for center, Kanazawa University, Japan) to determine the chemical composition and to

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classify the samples. Characteristics of each mineral in the rock samples, are discussed as follows:

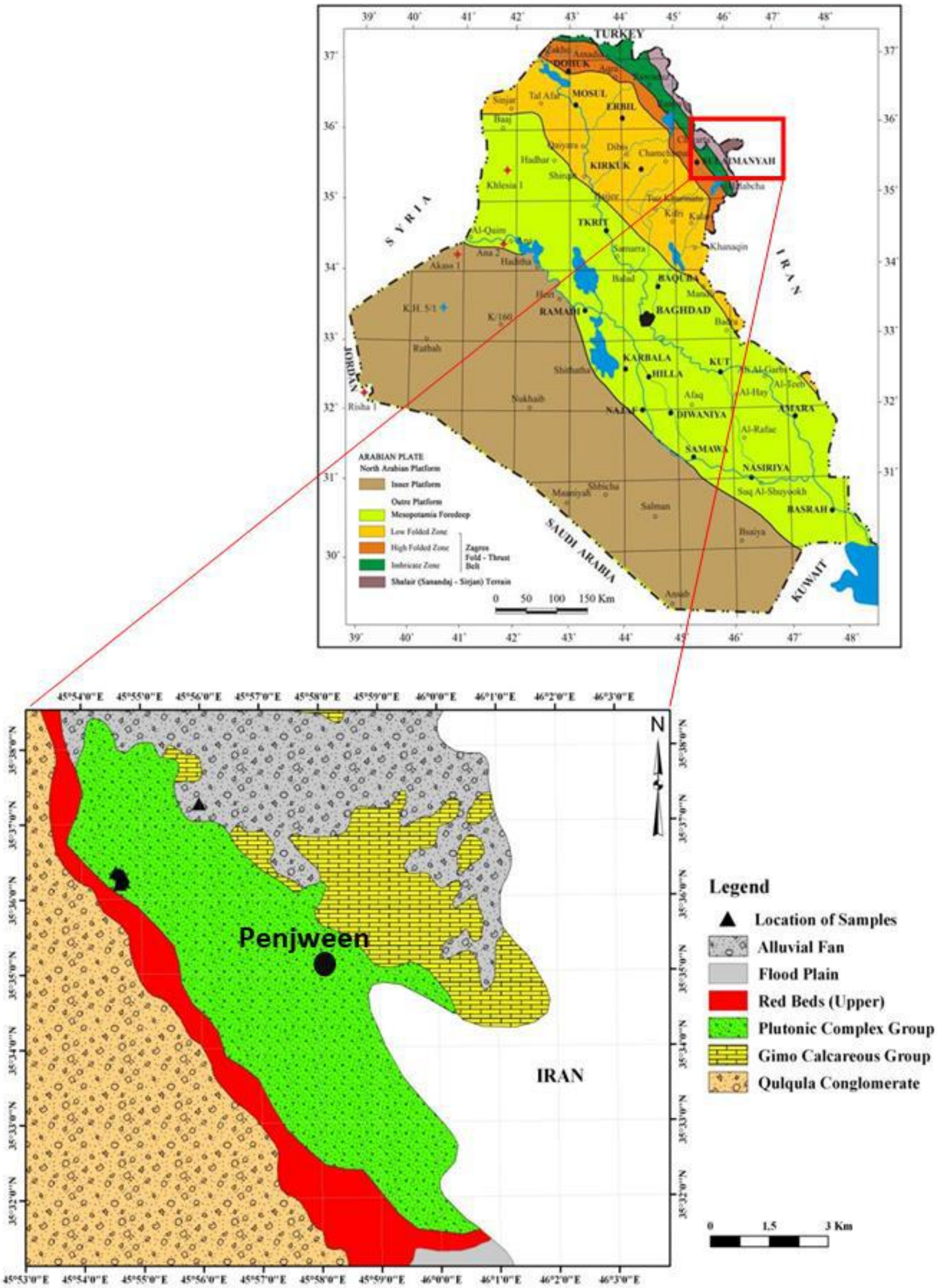

Fig. 1: Geological map of Penjween igneous complex, showing the location of study samples, after Jassim and Goff, 2006

III. AMPHIBOLE MINERALS

Petrographic study show that amphibole minerals, both primary and secondary are the major phases of these amphibolites with an average of 50%. The primary amphiboles are characterized by euhedral to subhedral grains, coarse to medium, with well-developed cleavage.

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The presence of primary and secondary amphiboles is supported by geochemical analysis of these minerals which will be discussed in mineral chemistry. According to the extinction angle and XRD analysis, hornblende is the main amphibole mineral. Prismatic hornblende crystals occur as mostly subhedral to euhedral, with pleochroism mostly brown to green, and high relief. Cross basal section shows two sets of cleavage, rhombic crystals few or no inclusions and oxidation with limited or no sub-grain development at margin (Plate 1.a & 1.b).

On the other hand, secondary amphiboles are found as subhedral to anhedral crystals and show remnant of original pyroxenes with opaque oxidation mark along the rims and the cleavage traces, (Plate 1.c & 1.d). Thirty-two amphibole spots were analyzed (Table 2). The results were plotted on (Mg/Mg+Fe+3) vs. Si diagram of Leak et al. (1997) in order to determine the amphibole type. Accordingly two compositionally distinct amphiboles were recognized; hornblende rich in magnesium (magnesium hornblende) and tschermakite (Fig. 3) .

Table.1: Modal analyses of the studied rocks in Penjween complex

Sample No.	pA1.1	pA1.2	pA2.1	pA2.2	pA2.3	pA4.1	pA4.2	pA4.3	pA5.1	pA5.2	pA5.3	pA8	pA9
Amphibole	59	60	60	66	60.89	60.2	58.9	57.7	55	60	55.8	63	50
Plagioclase	31.2	31.2	30.1	30.6	30.46	25	25.9	25.3	40.1	28.9	38.2	35.2	40.28
Clinopyroxene	3.1	3.1	3	0	2.8	10.2	5.2	8.93	1.2	5.2	1.00	0	0
Quartz	2.1	2.8	2	2.8	0.88	1.6	0.6	3.4	0	1.6	0	1.8	0
Zircon	0	0	0	0	0.6	0	0	2.1	1.9	0	1.5	0	2.3
Apatite	2.3	3	2.1	1.2	0	0	0	3.3	0	0	0	0	0
Sphene	1.3	2	0	0	3.71	2.2	3	1.9	0	2.2	0	0	0
Opaque minerals	1	2	1.9	1.2	0.8	0	0	0	1.8	0	2	1	1.2
Sum	100	100	100	100	100	100	100	100	100	100	100	100	100

Sample No.	pA10.1	pA10.2	pA11.1	pA11.2	PA11.3	pA12.1	pA12.2	pA14	pA15	pA16	pA17	pA20
Amphibole	58.6	60.6	59.3	60	59.9	55.6	50.6	55.6	50	55	42.6	65
Plagioclase	35.8	30	37.2	35.2	35	42	42	27.8	45	45	36.3	31
Clinopyroxene	0	0	0	0	0	1.2	1.2	10.2	1.2	1.2	15.1	2.7
Quartz	1.3	1.3	1.2	1.2	1.2	1	1	2.9	1.8	1.8	0	1.4
Zircon	0	0	0	0	0	0	0	1.3	0	0	0	1.3
Apatite	4.3	5	2	2	2	0	0	1.2	1	0	2.9	0
Sphene	0	0	1.3	2	2	0	0	0	0	1.7	1.8	0
Opaque minerals	0	0	1	1	1	0	0	1	1.2	1.3	1.3	0
Sum	100	100	100	100	100	100	100	100	100	100	100	100

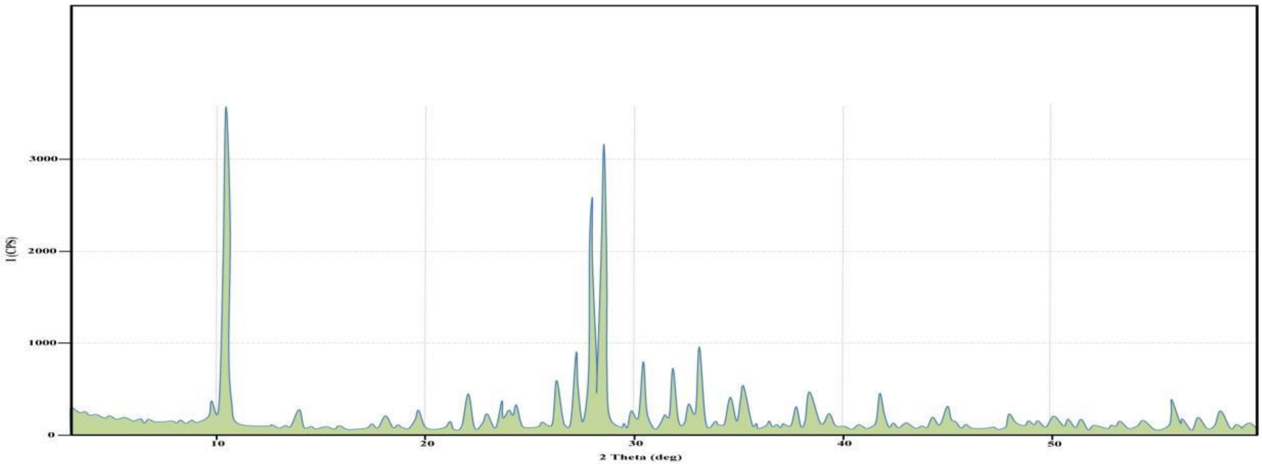

Fig.2 XRD analysis of amphibolite rock in Penjween complex for sample (pA11).

Table.2: Amphibole chemical analyses. Formula calculated on the basis of 23 oxygenes.

Element	A1.1	A1.2	A1.3	A1.4	A1.5	A1.6	A1.7	A1.8	A2.1	A2.2	A2.3	A2.4	A2.5	A2.6	A2.7	A2.8
SiO2	39.68	40.04	41.07	39.38	41.21	45.30	48.40	45.13	38.98	38.92	41.28	39.77	40.37	42.35	43.05	40.99
TiO2	3.08	2.40	2.68	1.76	1.96	0.43	0.28	0.56	2.36	2.37	0.72	1.82	1.60	0.61	0.73	1.67
AL2O3	14.15	13.71	12.85	14.93	13.52	10.70	7.97	11.52	15.43	15.51	12.10	14.59	14.86	14.07	13.18	13.65
FeO	12.78	12.84	12.59	13.40	12.51	10.53	9.45	10.79	12.39	12.54	12.00	11.81	11.85	11.39	10.78	11.50
MnO	0.19	0.20	0.19	0.20	0.20	0.17	0.13	0.19	0.15	0.18	0.19	0.15	0.19	0.19	0.17	0.16
MgO	12.09	12.33	12.68	12.03	12.67	15.04	16.20	14.50	12.08	12.18	13.40	12.45	12.42	13.80	13.90	12.96
CaO	11.52	11.66	11.14	11.47	11.61	12.01	12.46	11.76	11.47	11.55	11.01	11.40	11.27	11.71	11.58	11.35
Na2O	3.37	3.16	3.45	3.36	3.32	2.97	2.16	3.10	3.61	3.55	3.16	3.58	3.79	3.81	3.50	3.68
K2O	1.08	1.11	1.02	0.90	0.75	0.21	0.15	0.20	0.82	0.83	0.53	0.69	0.45	0.20	0.20	0.55
Total	97.95	97.45	97.68	97.44	97.77	97.59	97.61	97.81	97.32	97.64	94.47	96.30	96.80	98.48	97.27	96.53
Cr2O3	0.00	0.00	0.00	0.00	0.00	0.20	0.39	0.02	0.03		0.02	0.01	0.01	0.33	0.13	
Si	5.84	5.82	6.31	5.99	6.03	6.19	6.33	6.13	6.40	6.48	5.82	5.99	5.93	5.98	6.01	5.92
Al	2.72	2.73	2.18	2.59	2.62	2.42	2.28	2.41	2.09	2.01	2.73	2.76	2.76	2.68	2.64	2.49
Fe	1.55	0.02	1.53	1.49	1.48	1.39	1.33	1.44	1.23	1.19	1.56	1.34	1.38	1.36	1.37	1.59
Ti	0.27	0.27	0.08	0.21	0.18	0.07	0.08	0.19	0.09	0.06	0.27	0.09	0.11	0.10	0.10	0.35
Mn	0.02	2.71	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mg	2.69	1.85	3.05	2.79	2.76	3.00	3.04	2.89	3.30	3.34	2.71	2.92	2.90	3.01	2.99	2.69
Ca	1.84	1.03	1.80	1.84	1.80	1.83	1.82	1.82	1.80	1.78	1.86	1.79	1.85	1.81	1.85	1.84
Na	1.05	0.16	0.94	1.04	1.10	1.08	1.00	1.07	0.99	0.99	1.01	1.16	1.17	1.17	1.13	0.97
K	0.16	0.16	0.10	0.13	0.09	0.04	0.04	0.10	0.03	0.03	0.14	0.05	0.05	0.05	0.08	0.21
Mg/(Mg +Fe^{+2})	0.63	0.99	0.67	0.65	0.65	0.68	0.70	0.67	0.73	0.74	0.63	0.68	0.68	0.69	0.69	0.63
Type	Tschermakite	Tschermakite	Tschermakite	Tschermakite	Tschermakite	Mg-Hb	Mg-Hb	Mg-Hb	Tschermakite	Tschermakite	Tschermakite	Tschermakite	Tschermakite	Tschermakite	Tschermakite	Tschermakite

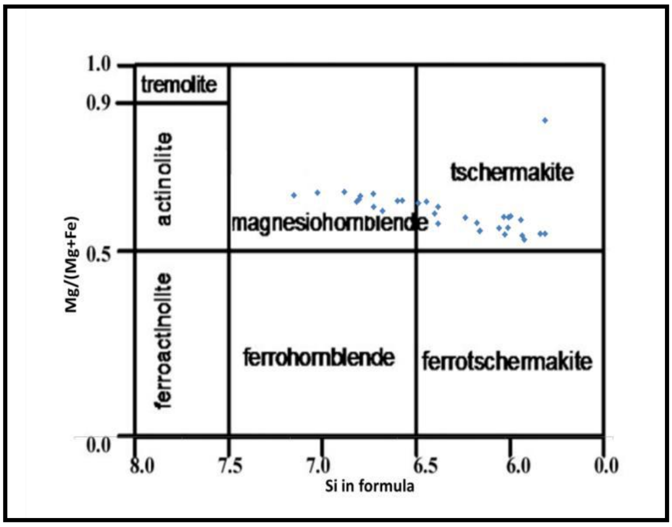

Fig.3: Amphibole classification diagram in the analyzed amphiboles of study rocks, proposed by Leak et al. (1997), Mg, Fe+3, Si are per formula.

Some of the hornblende crystals show zoning due to the change of the composition from the core toward the rim, (Plate 1.e). Hornblende generally show undulose extinction, and secondary twining (Plate 1.f). All these are deformational features.

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Table.2: Plagioclase chemical analyses. Calculated on the basis of 8 oxygens.

Element	P1.1	P1.2	P1.3	P1.4	P2.1	P2.2	P2.3	P2.4
SiO2	60.52	61.33	57.40	61.02	66.90	66.31	66.36	65.30
TiO2	0.02	0.00	0.03	0.00	0.05	0.00	0.03	0.04
AL2O3	24.82	24.14	21.84	24.16	20.87	20.357	21.02	20.4
Cr2O3	0.01	0.00	0.03	0.00	0.02	-	-	-
FeO	0.03	0.18	0.06	0.13	0.25	0.19	0.15	0.17
MnO	0.00	0.00	0.01	0.01	0.01	0.01	-	0.01
MgO	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.02
CaO	5.68	4.60	4.18	4.21	0.22	0.42	0.58	0.38
Na2O	9.28	10.33	9.22	10.65	13.17	12.43	12.33	12.98
K2O	0.04	0.05	0.06	0.05	0.07	0.18	0.08	0.07
NiO2	0.01	0.00	0.00	0.00	0.01	-	-	-
Total	100.42	100.63	92.82	100.24	100.74	100.41	99.87	99.96
Si	2.69	2.72	2.75	2.72	2.93	2.91	0.02	2.89
Ti	0.00	-	0.00	0.00	0.00	0.00	-	-
Al	1.30	1.26	1.23	1.27	1.03	1.08	1.31	1.10
Cr	0.00	-	0.00	-	0.00	-	-	-
Fe	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.01
Mn	-	-	0.00	-	0.00	0.00	0.00	0.00
Mg	0.00	-	-	0.00	0.00	0.00	0.00	0.00
Ca	0.27	0.22	0.21	0.20	0.01	0.02	0.00	0.02
Na	0.80	0.89	0.86	0.92	1.12	1.06	0.01	1.11
K	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
NI	0.00	-	-	0.00	0.00	-	-	-
Total	5.06	5.10	5.06	5.11	5.11	5.08	5.33	5.12
Type	Oligoclase	Oligoclase	Oligoclase	Oligoclase	Albite	Albite	Albite	Albite
An, Ab and Or %	An_{38} Ab_{62} $Or_{0.3}$	An_{20} Ab_{80} $Or_{0.2}$	An_{20} Ab_{80} $Or_{0.3}$	An_{18} Ab_{82} $Or_{0.2}$	An_{1} Ab_{98} $Or_{0.3}$	An_{2} Ab_{97} Or_{1}	An_{6} Ab_{97} $Or_{0.4}$	An_{2} Ab_{98} $Or_{0.4}$

Both secondary and primary amphibole grains in studied samples show partial alteration and oxidation along the rims and cleavage traces (Plate 1.d, 2.a & 2.b). Altered hornblende shows granular inclusions of epidote and some of them are partially or completely altered to chlorite (Plate 2.b & 2.c).

IV. PLAGIOCLASE MINERALS

Plagioclase minerals are the prevalent component next to hornblende with an average of 35% and occurs as prismatic anhedral - subhedral crystals of irregular shapes and variable sizes (Plate 3.a & b). According to the extinction angle, the composition of plagioclase ranges from albite to oligoclase (Fig.3), which is confirmed by electron microprobe and (XRD) analysis and chemical analysis where the formula was calculated on the basis of 8 oxygens (Table. 2). Plagioclase grains show polysynthetic twining but some lack twinning due to small size of grains. This agrees with that was mentioned by Nesse (2000) that twining in plagioclase may be absent in small grains particularly in metamorphic rocks (Plate 3.c). Some plagioclase grains show alteration partially into kaolinite (Plate 3.d), sercite and epidote (Plate 3.e & 3.f).

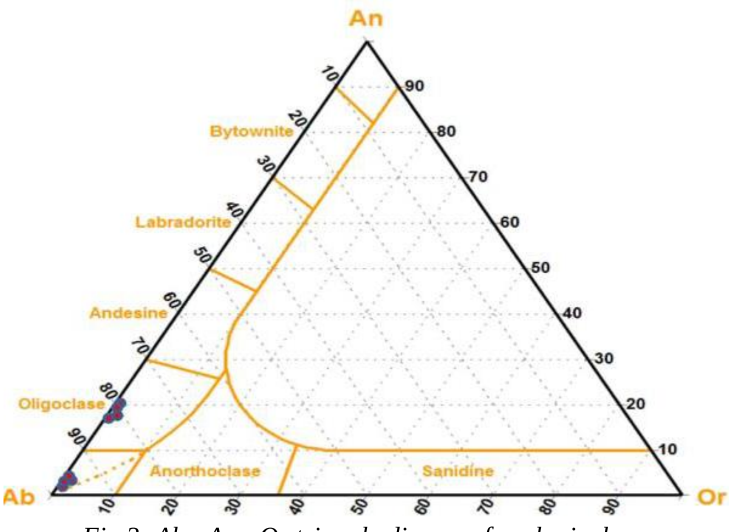

Fig.3: Ab - An - Or triangle diagram for plagioclase classification, proposed by Deer et al. (1963).

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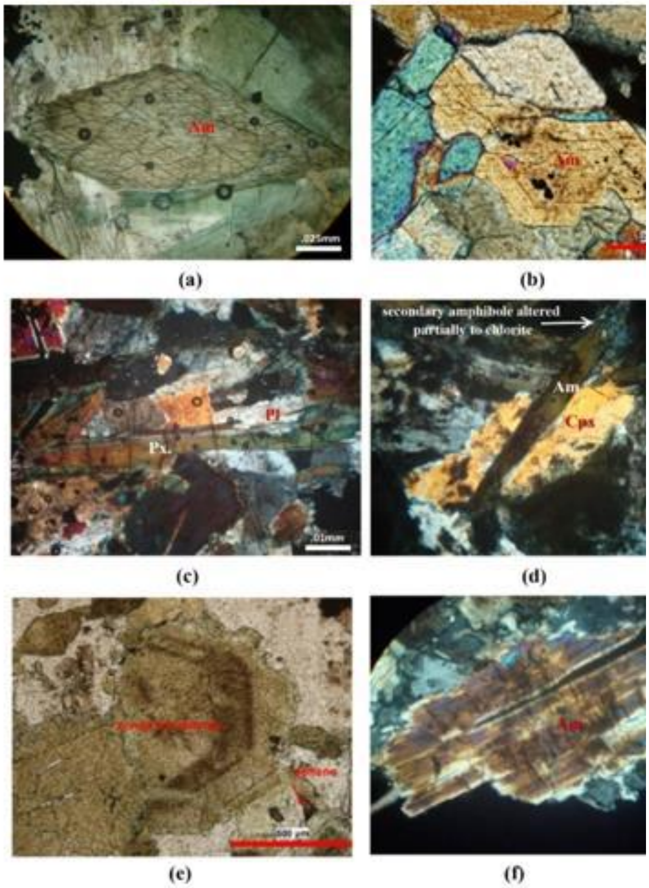
Plate (1)



(a) (b) (c) (d) (e) (f)

Plate (1.a): Photomicrograph of sample (pA4) , (X.N.) showing primary amphibole enclosed by secondary amphibole.

Plate (1.b): Photomicrograph of sample (pA5) , (X.N.) showing primary amphibole partially altered along the cleavage .

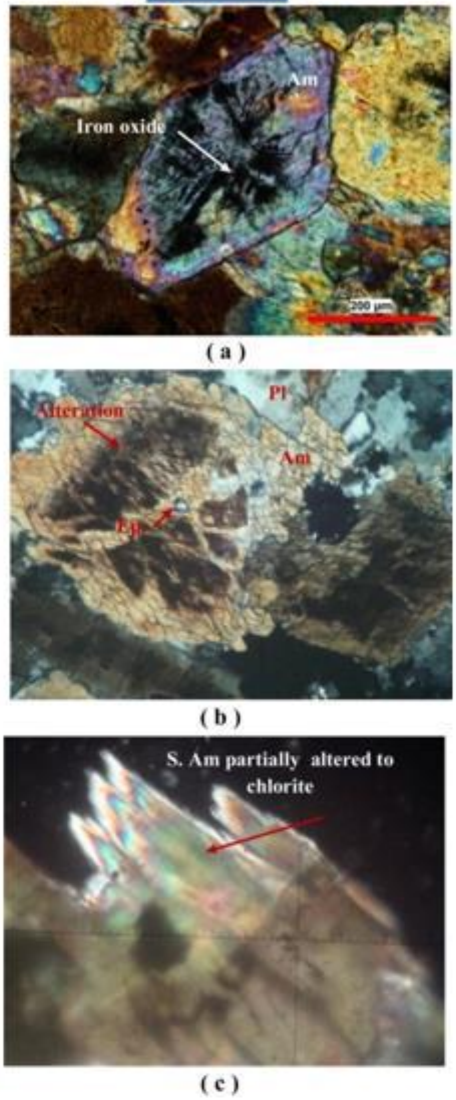
Plate (1.c): Photomicrograph of sample (pA11) (X.N.) showing secondary amphibole enclosed by partially in plagioclase .

Plate (1.d): Photomicrograph of sample (pA12) (X.N.) showing secondary amphibole altered partially to chlorite , interestial clino-pyroxene crystals.

Plate (1.e) : photomicrograph of sample(pA2) (X.N.) , showing zoning with brown core and a green rim similar to the fibrous amphibole in the matrix.

Plate (1.f): Photomicrograph of sample (pA1) (X.N.) , showing secondary twining in amphibole.

Plate (2)



(a) (b) (c)

Plate(2.a):Photomicrograph of sample (pA1) (X.N.), showing oxidiation along the cleavage of amphibole.

Plate(2.b): Photomicrograph of sample (pA2) (X.N.) , showing alteration of amphibole to chlorite with fine epidote grains.

Plate(2.c):Photomicrograph of sample (pA2) (X.N.), showing amphiboles grain partially altered to chlorite.

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Plate (3)

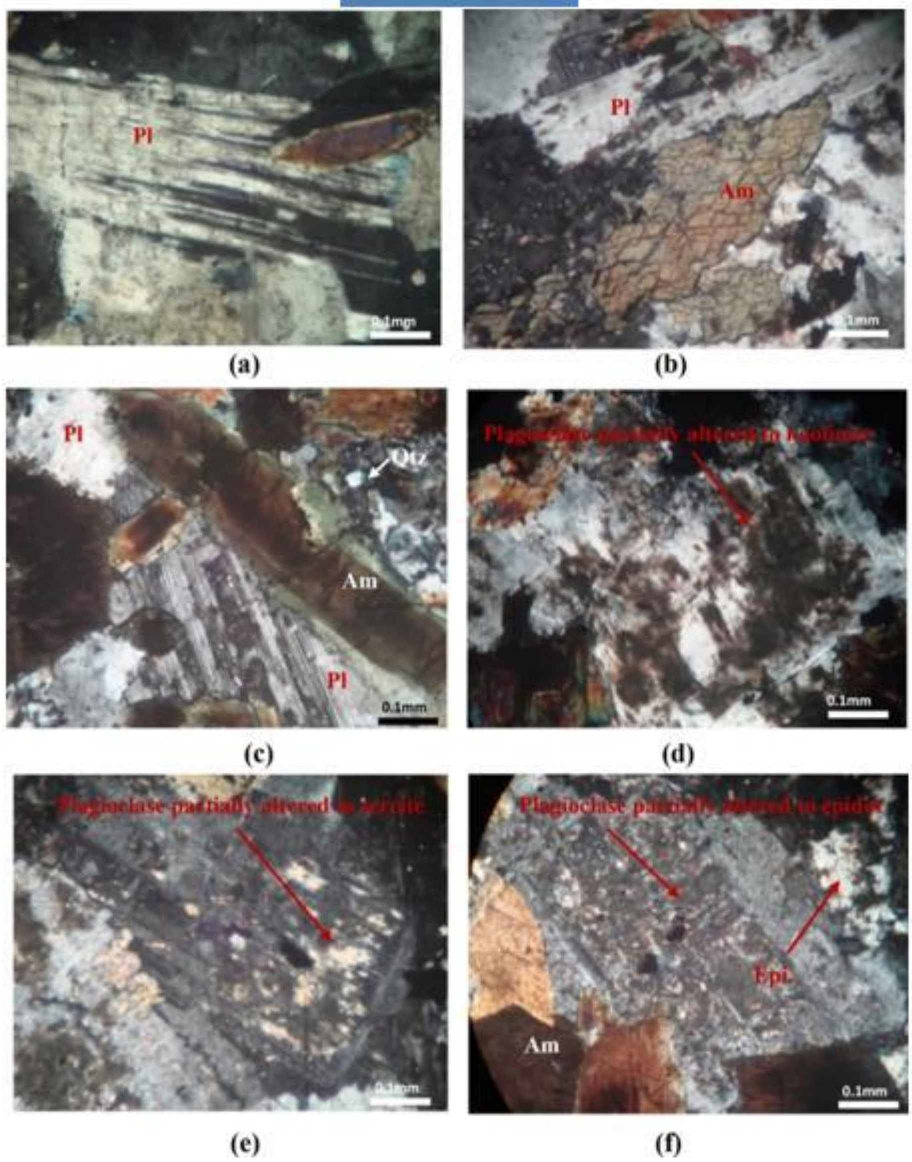

Plate (3.a): Photomicrograph of sample (pA12) (X.N.), showing relatively fresh plagioclase crystal.
Plate (3.b): Photomicrograph of sample (pA11) (X.N.), showing polysynthetic twining in plagioclase crystals which surrounding of secondary amphibole .
Plate (3.c): Photomicrograph of sample (pA2) (X.N.), showing coarse and fine grain plagioclase enclosed by partially secondary amphibole, and fine quartz grains.
Plate (3.d): Photomicrograph of sample (PA1) (X.N.), showing phenocrystalls of plagioclase crystals are partially altered to kaolinite.
Plate (3.e): Photomicrograph of sample (PA2) (X.N.), showing plagioclase crystals altered to sericite.
Plate (3.f): Photomicrograph of sample (PA1) (X.N.), showing plagioclase crystals are altered to epidote .

V. ACCESSORY MINERALS

The accessory minerals include clinopyroxene, quartz, zircon, apatite, titanite (sphene) which are found frequently associated with hornblende and plagioclase (Plate 4). In addition the mineral pyroxferroite is found as few grains in some sample (PA1, PA2 and PA11). Clinopyroxene (augite) is rare and uncommon in studied rocks, making about 7.5% of the total volume of the rocks, it characterized by prismatic and subhedral to anhedral-shaped crystals and fine to medium grain size. According to the optical properties it is augite. The clinopyroxenes are mostly altered into secondary amphibole and the relics of the original clinopyroxene are very rare (Plate 4.a & 4.b). Quartz is subequant, with

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gently curved boundaries making not more than 3% by volume of the rock. They are very fine scattered within the amphibolite (Plate 3c & 4d). Zircon occurs as an accessory mineral in the studied samples with an average of about 1 % and it is very fine elongated grain. It is colorless under transmitted light microscopy with very high interference colors (Plate 4.c).

Apatite are fine grains, high relief parallel extinction, making about an average of 1.6 % (Plate 4.d).

Plate (4)

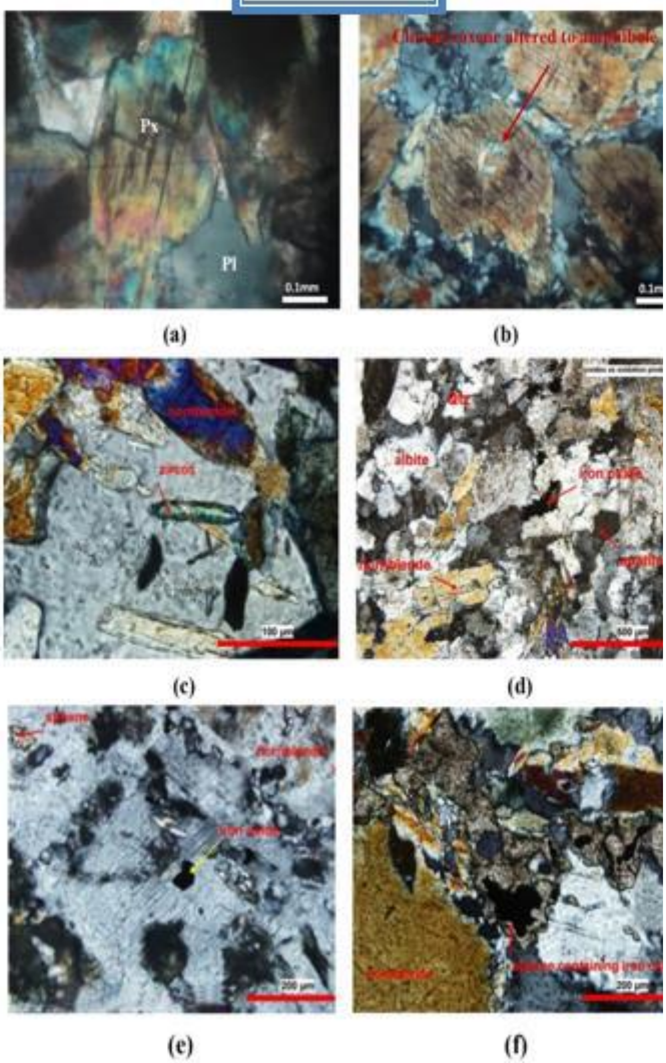

Plate (4.a): photomicrograph of sample (PA1) (X.N.), showing fresh clinopyroxene crystal.
Plate (4.b): photomicrograph of sample (PA1) (X.N.), showing clinopyroxene partially altered to secondary amphibole.
Plate (4.c): photomicrograph of sample (PA12) (X.N.), showing elongated crystals of zircon.
Plate (4.d): photomicrograph of sample (PA10) (X.N.), showing enhedral crystals of apatite, quartz, and secondary iron minerals.
Plate (4.e): photomicrograph of sample (PA14) (X.N.), showing subhedral grain of sphene , also showing primary euhedral grain of iron oxide .
Plate (4.f): photomicrograph of sample (PA14) (X.N.), showing sphene containg iron mineral .

Sphene is characterized by being anhedral to subhedral with very high relief and dark brown color, ranging about 1% (plate 4.e, f). Sphene presence of indicates high temperature condition. Raase et al., 1986 in Celik and Dal, 2006 have proposed that as temperature rises amphibole will be enriched in Ti, thus, sphene could be a temperature indicator. Opaques including iron oxides are of two types; primary euhedral-subhedral (Plate 4e) and secondary disseminated aggregates of very fine grain associated with alteration of pyroxene to secondary amphiboles. There is generally a strong association between oxide- rich regions and highly deformed and altered regions (plate 4.c &4.f).

VI. ALTERATION MINERALS

The main alteration product of the mafic minerals that are found in the studied rocks, is chlorite which appeared as patches of platy shape scattered in the ground mass. It appears in the majority of studied rocks as alteration product of pyroxene and amphibole, due to chloritization process (Plates 2.c & 5.a). Also appeared as veins (Plate 5.b), as well as xenoliths within amphibolite pods (Plate 6). Petrographic study indicates that these xenoliths are chlorite "clinochlore" apparently derived from the alteration of diopside which is found as small remnants within the chloritized grains. This is enhanced by XRD analysis (Fig. 4). Epidote is appeared as small anhedral crystals or sometimes as a small patches in the groundmass, and as inclusions in altered plagioclase and hornblende (Plate 3.f). Sericite as alteration product of plagioclase is colorless and appears as small patches inside plagioclase (Plate 3.e). Sometimes, the plagioclase is completely replaced by sericite.

Sericite forming process starts with the beginning of plagioclase alteration where the hydrothermal fluids penetrate, leading to the formation of sericite. When sericite growth halts, other minerals like epidote forms by increasing alteration intensity and temperature of hydrothermal alteration (Al- Cholmaky, 2002) .

VII. TEXTUREW OF AMPHIBOLITES

Although Penjween amphibolite rocks were subjected to secondary processes, they are characterized by preserving some of their protolith textures and mineralogical properties. In general the amphibolite rocks in the study area are characterized by coarse, holocrystalline,

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hypidiomorphic grains (Plate 7). The textures recognized in these rocks are:-

- Porophyroblastic texture

The prophyroblastic texture is one of the most common texture in metamorphic rocks, referring to grains of distinctly different sizes. Where large porphyroblasts of hornblende and plagioclase embedded in a fine grained groundmass (Plate 7.a & b).

- Granoblastic texture

Granoblastic texture is common in these rocks where well-developed coarse amphibole grains appeared surrounded by unoriented arrays of tabular plagioclase (Plate 7.c & 7.d).

Porphyroblastic texture and granoblastic textures are considered a common textures in amphibolite from Beysehir ophiolitic melange Central Taurides; Turkey, (Gelik and Dela Loye, 2006)

- Blasto-ophitic texture

Ophitic and sub-ophitic texture in studied rocks is regarded as relict texture which gives useful information about the origin and pre- metamorphic history that inherited from the parent of igneous rocks. It occurs when a relatively large crystal of amphibole completely encloses individual plagioclase laths (Plate 7.e), or plagioclase enclosed completely by the secondary amphibole (Plate 7.f).

- Grano-nematoblastic texture

This texture appeared as hornblendes grains aligned in such a way that impart sort of lineation with interstitial plagioclase (Plates 3.b & 4.b). Some hornblende porphyroblasts contain numerous small randomly oriented very fine inclusions forming poikiloblastic texture (Plate 2.b). Grano-nematoblastic textures are considered common in amphibolite from the ophiolitic mélange beneath the Yarlurg Zangbo ophiolites, Xigoze area, Tibeti, (Carl Guilmelte, 2005).

VIII. MINERALS ASSEMBLAGES OF AMPHIBOLITE ROCKS

According to petrographic study, the amphibolite rocks have variable mineral parageneses, which are affected by secondary processes. The primary minerals were partially altered due to these processes, which produce new minerals that replace the primary ones. However, the primary mineral assemblages can be observed as primary amphiboles and relicts of clinopyroxene. Accordingly these amphibolites are characterized by the following mineral assemblages:

1. **1.** Hornblende+plagioclase+clinopyroxene ∓ quartz ∓ sphene ∓ zircon ∓ apatite ∓ ironoxide minerals.

This mineral assemblage is characterized by the presence of fine prismatic xenomorphic clinopyroxene crystals which are subhedral to anhedral. The textures of this assemblage are porphyroblastic and blastophitic.

2. **2.** Hornblende + plagioclase ∓ quartz ∓ sphene ∓ apatite ∓ zircon ∓ iron oxide minerals ∓ chlorite ∓ sericite ∓ epidote.

This mineral assemblage is widespread in the studied amphibolite rocks. The rocks that have this assemblage show different textures such as porphyroblastic, granoblastic and nematoblasic textures, and the grains are medium to large in size. Hornblende is partially altered to chlorite and plagioclase which appears in prismatic euhedral - subhedral form altered to sericite, and epidote that exist as fine crystals, scattered within the major phases. The intensity of alteration in this assemblage is more than that in the first assemblage by the presence of alteration products (chlorite, sericite, epidote).

Plate (5)

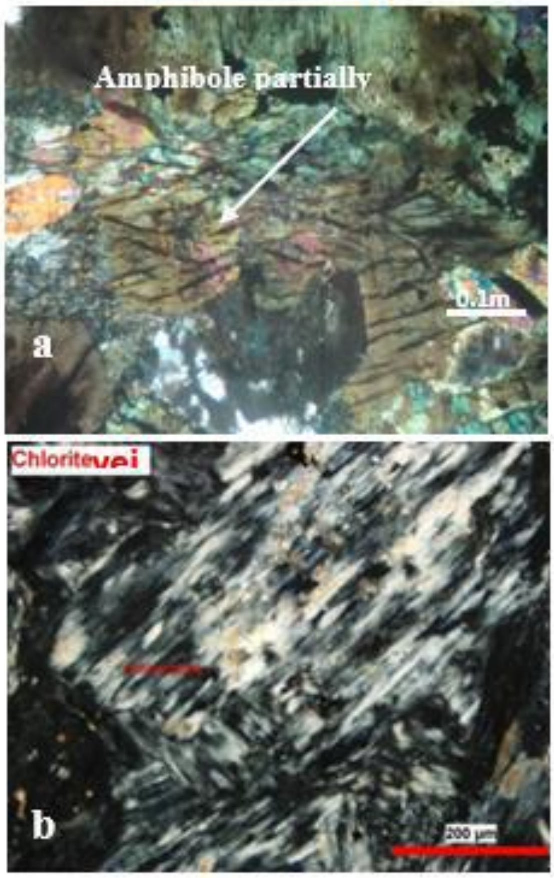

Plate (5.a): photomicrograph of sample (PA2) (X.N.), showing secondary amphibole partially altered to chlorite
Plate (5.b): photomicrograph of sample (PA4) (X.N.), showing chlorite veins.

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Plate (6)

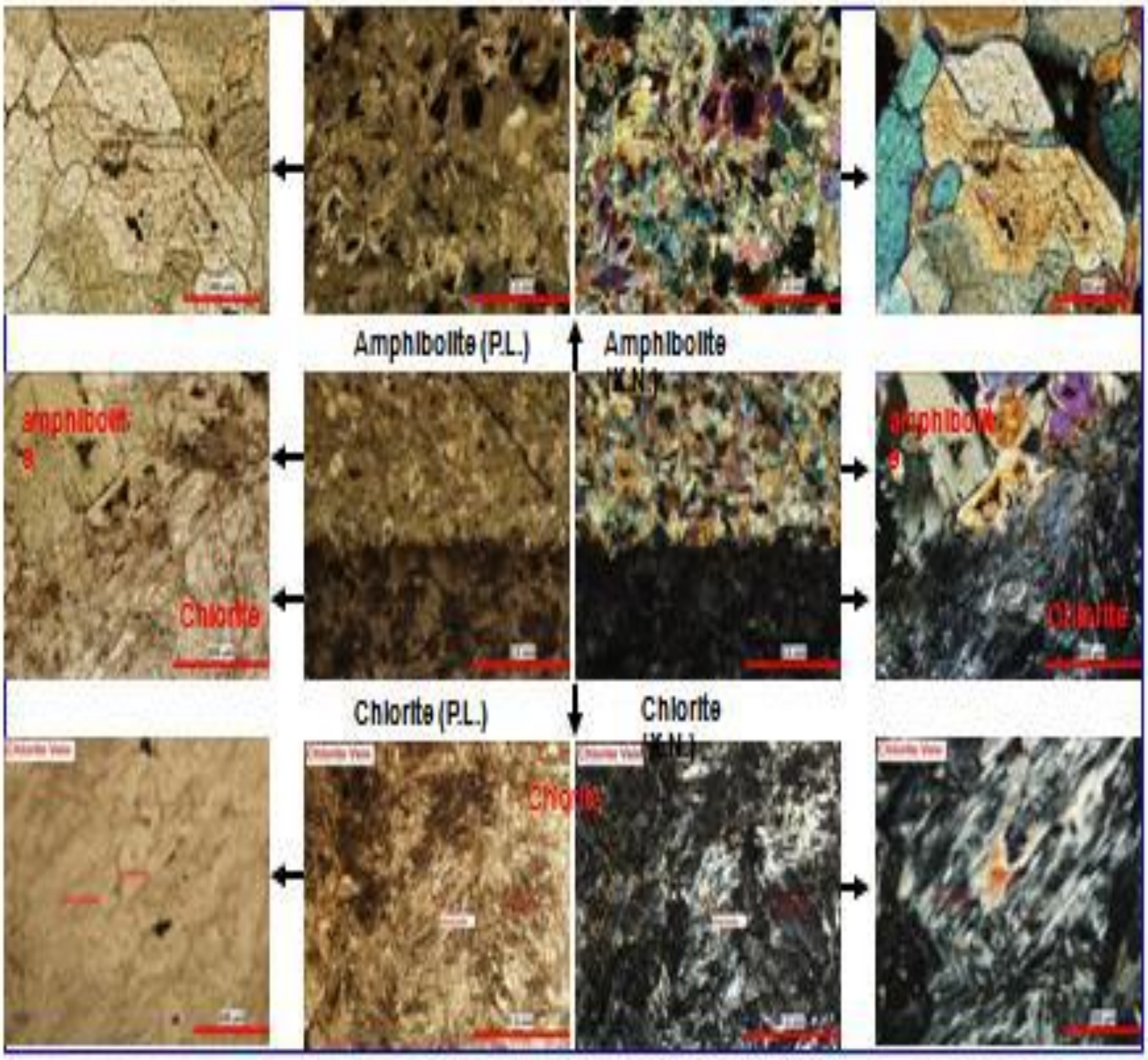

Plate (6) photomicrograph of different parts of the sample (PA5) (X.N.), showing the rock consists of two parts the main rock is amphibolite in sharp contact with chlorite xenolith .

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Plate (7)

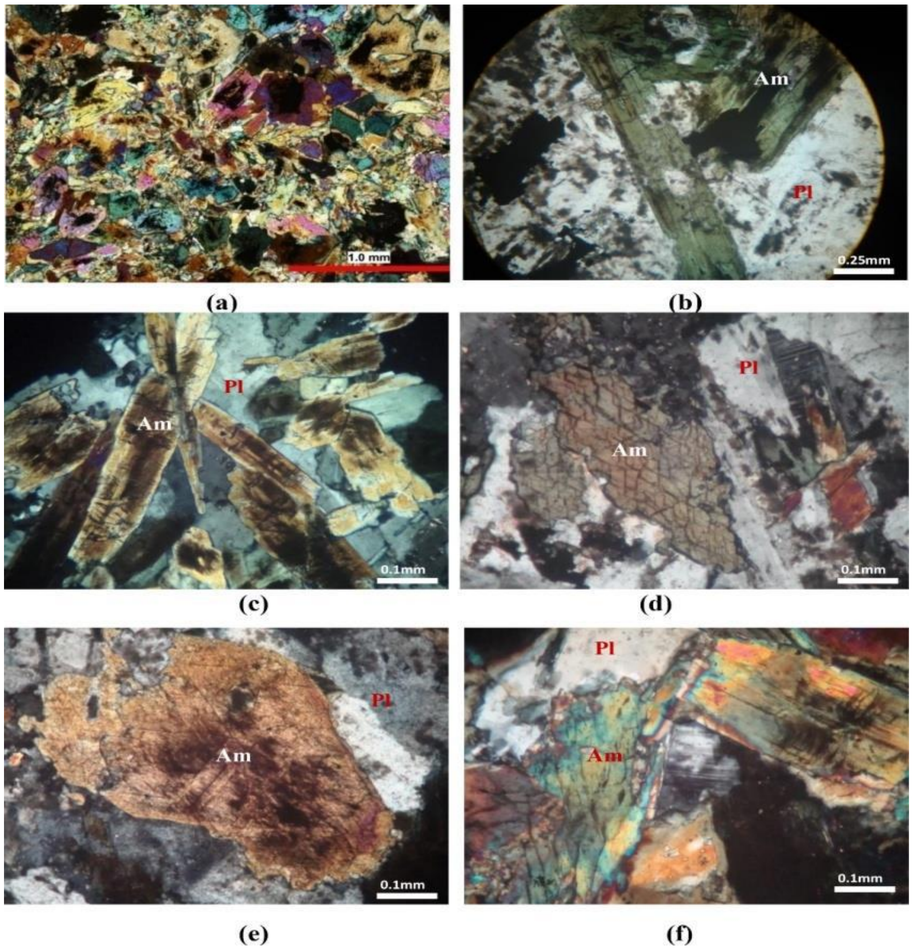

Plate (7.a): Photomicrograph of sample (PA1) (X.N.), showing hypidomorphic, granular, porphyeroblastic texture in amphibolite rocks.

Plate (7.b): Photomicrograph of sample (PA11) (X.N.), showing porphyroblastic texture. Phenocrysts of hornblende embedded in plagioclase groundmass.

Plate (7.c): Photomicrograph of sample (PA12) (X.N.), showing granoblastic texture, secondary amphibole surrounded by unoriented tabular plagioclase.

Plate (7.d): Photomicrograph of sample (PA16) (X.N.), showing ganoblastic texture, phenocrysts of primary amphibole surrounding the plagioclase crystals.

Plate (7.e): Photomicrograph of sample (PA11) (X.N.), showing blasto ophitic texture, primary amphibole is completely enclosed in the plagioclase .

Plate (7.f): Photomicrograph of sample (PA1) (X.N.), showing blasto sub-ophitic texture, amphibole partially enclosed by the plagioclase.

IX. CONCLUSIONS

Petrographic study revealed that the major mineral constituent are amphibole(hb) + plagioclase(Ab87 An12.8) + some accessory minerals such as sphene, zircon, apatite, iron oxides and rarely quartz. These rocks had been subjected to hydrothermal alteration losing their primary component with the appearance of cilnopyroxene as a relict. Secondary minerals are chlorite, epidote, sericite and secondary amphibole. The main texture is granoblatic, porphyroblastic, blasto-ophitic, nematoplastic and poikiloblastic textures and some hornblende show zonation .Microprobe analyses show that the amphiboles have a calcic composition and are represented by tschemercite and Mg-hornblende. Plagioclase composition ranges between albite and oligoclase.This diagram revealed two types of plagioclase ranging between oligoclase (An23.9 Ab75.9 Or0.2) and albite (An1.7 Ab97.9 Or0.4). Based on petrographic study and chemical analyses, this range of plagioclase composition is considered the dominant and characteristic of amphibolite rock composition.

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