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Petrography and Geochemical Relationships of the Ultramafic Rocks in Galalah area within Erbil Governorate, NE Iraq

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Abstract

The current research to study the petrography, mineralogy and geochemical relationships of the ultramafic rocks in the Galalah area within Erbil Governorate, at the Unstable Shelf in the Imbricate Zone, to determine the origin of the ultramafic rocks.

Dunite and Harzburgite are the most abundant rock bodies in the study area, and they represent most of the outer surface exposure of the ultramafic rock aggregates. The dunite rocks are characterized by pale brown color on the altered surface that is broken into olive green and dark green lithic. Dunite represents a homogenous lithologic feature that mainly consists predominately of olivine with accessory spinel and traces of orthopyroxene. While the harzburgite appears as a massive rock body consisting of olivine, orthopyroxene, and clinopyroxene. These rocks are mainly characterized by alteration to serpentinite, with accessory chromian spinel, secondary magnetite, chlorite, and talc.

The studied ultramafic rocks are predominately rich in ferromagnesian minerals of less silica content, and other major elements affected by serpentinization are causing the deviation of elements. They have a strong decrease in sodium and calcium oxides relative to MgO and verified the silica and alumina with MgO and a slight increase in iron oxide.

The low values of TiO_2 in dunite and harzburgite are characteristic property of the Alpine type ophiolites during the primary process of the mantle in its upper part, before the tectonic emplacement of the ultramafic rocks, and also due to partial melting degree for the asthenospheric mantle. The MREE depletion relative to HREE and LREE may be attributed to the hornblende absence and the presence of olivine and pyroxenes minerals and/or to the source rock features.

The U-shaped patterns of REE and their ratios are typical properties of ophiolitic ultramafic rocks, which are compatible with the supra-subduction zone. During the partial melting, the negative anomalies of Nb in ultramafic rocks with sequestration of the Nb concentration by sphene and ilmenite in various types of the source rocks have also been attributed to the crust contamination. These are also characterized by island arc conditions, and its depletion in the studied rocks may indicate the fore-arc tectonic environments

Keywords: Petrology, Mineralogy, Geochemistry, Ultramafic Rocks, Galalah area, NE Iraq

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العلاقات البتروغرافية والجيوكيميائية للصخور فوق القاعدية في منطقة كلالة ضمن محافظة اربيل، شمال شرقي العراق

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الخلاصة

تتضمن الدراسة الحالية صخارية ومعدنية و جيوكيميائية الصخور فوق القاعدية في منطقة كلالة ضمن محافظة أربيل ، شمال شرقي العراق. لتحديد أصل الصخور فوق القاعدية وعلاقاتها الجيوكيميائية.

صخور الدونيت والهارزبورجيت متوفرة بكثرة في منطقة الدراسة وتشكل في الغالب المنطقة الخارجية لتواجد تجمعات الصخور فوق القاعدية. كتلة صخرة الدونيت بنية شاحبة على السطح المتجوي يتحول إلى صخر أخضر زيتوني وأخضر داكن. صخور الدونيت لها خاصية صخرية متجانسة تتكون من االاولفين الزيتوني كمكون رئيس و السبنيل الكروم الإضافي وآثار من أورثوبايروكسين في بعض العينات. بينما أظهرت المشاهدات الحقلية للهارزبورجيت أنه جسم ضخم. المعادن المكونة لها هي الاوليفين الزيتوني ، والأورثوبايروكسين، والكلينوبايروكسين وهي عادة ما تكون مشوهة.

بسبب إثراء الصخور فوق القاعدية بالمعادن الغنية بالحديد والمغنسيوم ونضوب السيليكا والعناصر الرئيسة الأخرى ، فإن عمليات التغيير (التحول للسربنتين) مسؤولة أيضًا عن انحرافات العناصر، لا سيما الاستنفاد القوي للكالسيوم ، والصوديوم نسبة إلى MgO وكذلك تباين SiO_2 و Al_2O_3 مع MgO وتزيد بشكل طفيف مع Fe_2O_3. هذا واضح في للهارزبورجيت والدونيت الأكثر إثراءً بالمعادن المقاومة للصهر مثل الاولفين والأورثوبايروكسين والإسبينيل.

محتوى TiO_2 المنخفض في الدونيت والهارزبورجيت هو سمة من سمات الأفيوليت من نوع جبال الألب والعلاقة المنسوبة إلى عملية الوشاح الأولية في الوشاح العلوي ، قبل التمركز التكتوني للغطاء فوق القاعدي ، ودرجة الذوبان الجزئي لوشاح الاستينوسفير. قد يُعزى استنفاد MREE بالنسبة إلى LREE و HREE إلى عدم وجود الهورنبلند ووجود الاوليفين والبايروكسين و / أو طبيعة صخور المصدر.

تعتبر أنماط العناصر الأرضية النادرة على شكل حرف U وعلاقاتها النموذجية للصخور فوق القاعدية التي تتوافق مع المنطقة فوق الاندساس. أثناء الانصهار الجزئي فان الشذوذ السلبي لـNb في الصخور فوق القاعدية يعزى لعزل Nb بواسطة معدن الإلمنيت أو السفين في المصدر ذاته ، ويُعزى أيضًا إلى تهيؤ القشرة الفعال لإعداد الجزرالقوسية ؛ قد يكون نضوبه في العينات المدروسة يشير لبيئة منطقة الاندساس الفائق (لمقدمة الجزر القوسية).

1. Introduction

The Iraqi territorial part of the Zagros Imbricate Zone in northern and northeastern Iraq was formed due to many overriding nappes composed of ophiolite layered complexes, pillow lavas and Tertiary sedimentary succession [1]. All these groups are bounded by the crushing and thrusting zones [2]. Many researchers have studied the Iraqi Zagros Suture Zone (IZSZ) since it represents the collisional parts between northern part of Arabian and Iranian plates in the northeastern part and the Arabian and Turkish plates in the northern part [3].

A study of the Late Cretaceous(Hasanbag Group), and Paleogene (Walash-Naopurdan Group), and volcanic and subvolcanic rocks are considered as a vital subject for the northern and northeastern parts of Iraq to estimate the time of the collision stage between the Arabian and Iranian continental plates. Remnants of these mentioned units appear in three major nappes in the study area.

Nevertheless, some previous works [2, 1, 4, 5] suggested that volcanic and volcano sedimentary rocks exist in the Iraqi Zagros Imbricate Zone. In the northeastern part of Iraq, these rocks were called the Hasanbag, Walash and Naopurdan Groups.

The ultramafic rocks are one of the basic elements in the formation of ophiolite, essentially the lower part represented by the peridotite rocks, which in turn are considered the main family of ultramafic rocks, which are explained to be thrusting sheets for the ancient oceanic lithosphere, where subducted sheet above the continental lithosphere in the course of orogeny [5].

Ophiolites petrologic characteristics represent tectonic indicators and magmatic stages of the lithosphere generation and accretion. The peridotite rocks derived from the mid-oceanic ridges are mainly lherzolite rocks derived from the supra subduction zones (tectonic trench setting) that are mainly harzburgites [5]. The serpentine minerals are the major alteration phases of hydrated mafic and ultramafic rocks. Their physical behaviors are important in the geodynamic processes influencing the rheology of the subduction zones [6]. Therefore, serpentinites may have their importance in the dynamic emplacement of the high dense ultramafic rocks from the mantle throughout the light dense rocks of the continental lithosphere.

The study area lies between the Longitudes 44^{o} 49 - 44^{o} 50 E and Latitudes 36^{o} 36 - 36^{o} 37 N and is located within the Galalah area, about 150 km from Erbil governorate (Figure 1). Topographically, the area is mountainous, consisting of a number of parallel ranges within the Zagros Mountains. In the present study, four sections (G1, G2, G3 and G4) in the Galalah area are selected to determine the ultramafic rocks within the serpentinite rocks.

Figure 1: Location map of the studied area highlighted by the red rectangle shape.

2. Materials and methods

2.1 Fieldwork

During the reconnaissance fieldwork, the preferred and accessible area was surveyed, and 80 rocksamples have been collected from four selected sections near Galalah village.

2.2 Laboratory work

2.2.1 Petrographical and Mineralogical examination

- Thin sections are prepared and photographed in the laboratory of the Department of Geology, University of Ankara Golbasi Kampusu, Turkey. The purpose is to examine the samples petrographically under the polarized microscope to determine the mineral compositions, textures, and apply classification.
- Scanning Electron Microscopy (SEM-EDX) technique is used for measuring the mineral chemistry of selected samples in the laboratory of the Scientific Research Center for Soran University, Iraq.

2.2.2 Geochemistry analysis

- ICP-MS technique is used for the whole rock geochemistry. These analyses are carried out at the Department of Geology laboratories at University of Ankara, Golbasi Kampusu, Turkey.

3. Geological Setting of the research area

The Iraqi Zagros Imbricate Zone in the northern and northeastern parts of Iraq represents the Suture Zone between the north part of the Arabian Plate and Iranian Plate in the northeast part, and the Turkish Plate in the north part. Its area is approximately 4500 km^2 along the Turkey-Iraqi-Iranian borders. The Zagros Thrusting Zone in Iraq represents a part of the Zagros Orogenic Belt, which extends to 2000 km from the southeast of Turkey through the north of Syria and Iraq to the western and southern parts of Iran [7,8 and 9].

Buday and Jassim [4] developed the bipartite classification into tripartite subdivision classification based on the main of sedimentary succession, as follows:

1. External zone consists of Balambo-Tanjero and the Northern part of Thrusting Subzone represented by the unmetamorphic rocks deposited in the miogeosyncline depositional basin and affected by Laramide and Late- Alpine orogenic movements.
2. Central zone, which is represented by the Mesozoic and Tertiary successions associated with the volcanic activities, this comprises Qulqula– Khwakurk and the Penjwin– Walash Subzones.
3. Internal zone consists of Cretaceous shales and volcano- sedimentary metamorphosed successions.

Serpentinized ultramafic rocks occur as linear arrays in the Zagros Thrust Zone in Iraq. They extend from southwest to northeast as follows, ultramafic and serpentinized ultramafic rocks of Galalah (Figure 2). These subdivide the map according to the associated rock units into two groups [7]. Mafic bodies are associated with the ophiolite rocks, including Alana (Besha) ultramafic rock bodies and isolated serpentinized peridotites of Galalah, Choman, Rayat and Haj Omran. Nowadays, such a linear array of the metamorphosed ultramafic rock units is considered a lithological marker of the Suture Zone between these plates within the orogens, e.g., [10]; [11]; and [12].

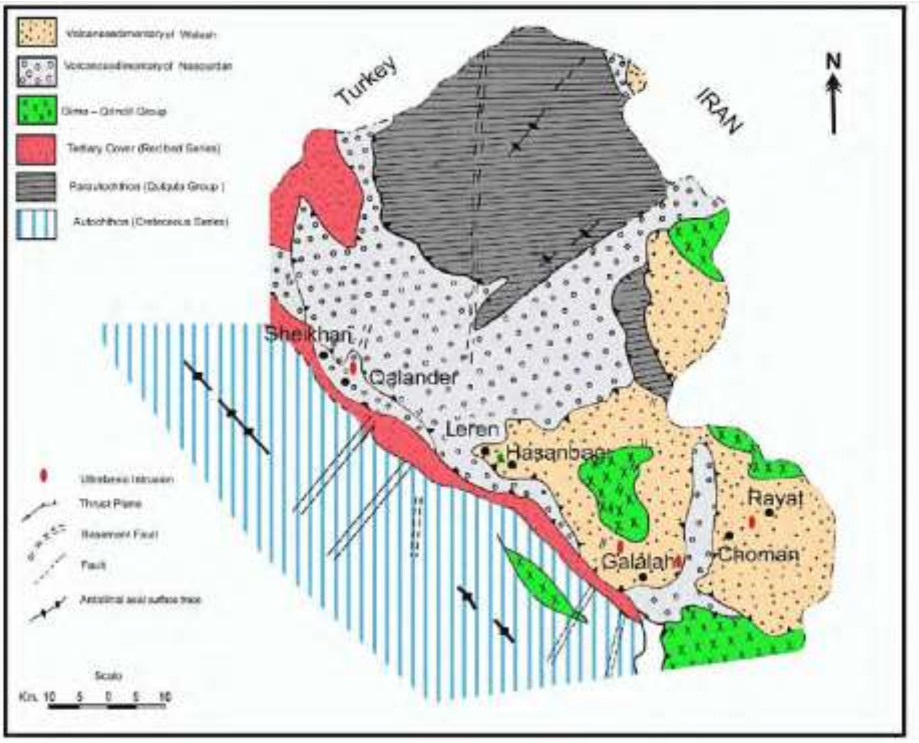

Figure 2: Geological map of the study area (Modified from [1])

4. Petrology and field observation

During the fieldwork done in the five selected sections, altered and deformed igneous rocks were described. The first section is characterized by three types of rocks. The first type comprises the ultramafic igneous rocks, with a black color that changes to dark gr; it it is a dunite, whose samples are mostly subjected to partial or complete alteration processes (Figure 3).

Figure 3: Ultramafic igneous rock, Dunite, sample G1a

The second type is serpentinite. The serpentinite rock is characterized by an enrichment in water and magnesium, greasy-looking and slippery feeling, light to dark green, which was generated by serpentinization process. The hydration and metamorphic processes of the mantle ultramafic rocks are particularly important within the seafloor spreading stage at the tectonic plate boundaries [4].

The present study includes two main types of serpentinites distinguished by their physical appearance as massive, sheared and brecciated serpentinite:

1) Massive serpentinite formed from dunites and harzburgites occurs as blocky resistant outcrops cut by joints. Weathered surfaces are yellowish to orange-red, and freshly broken surfaces show olive-green to olive-black color. Massive serpentinites are prevalent. (Figure 4A).

2) The progressive tectonic movements within the study area generate sheared and brecciated serpentinitesrea. The blocky serpentinites are characterized by crude foliation with smooth shiny surfaces having pale-green to yellow-green color. (Figure 4B).

Figure 4: A) Two successive layers of massive serpentinite interspersed in the middle a layer of sheet serpentinite, B) Breccia serpentinite

The third type of rocks is characterized by brown to reddish-brown color in the form of huge blocks with regular application, which are the Walash Volcano-sedimentary Series rocks, as they contain longitudinal breaks that have a significant effect in the process of breaking and separating them into parts and pieces (Figure 5).

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Figure 5: Walash Volcano-sedimentary Series, Serpentinite and Ultramafic rocks. Sample G1b and G1d.

From the main observations, the second and third sections are composed of black ultramafic rocks that were mostly subjected to decomposition processes and massive blocks containing serpentinite veins. As for the other type of rocks, it is a serpentinite that has two forms; the first one is in the form of a large mass surrounded by a thick layer of limestone (Figure 6), while the other forms are breccia pieces with a dark green color, and in the form of a layer separating the two layers of massive serpentinite. This is a clear indication of the effects of tectonic activity in the region (Figure 7).

Figure 6: Large mass of serpentinite surrounded by a thick layer of limestone

Figure 7: Brecciaed pieces layer between two layers of massive serpentinite

While in the fourth section, the rocks are mainly black ultramafic in the form of large and accumulated clumps of harzburgite and dunite with great amount of alterations. Some of them are surrounded by a thick layer of limestone estimated to have 20-30 cm thickness, which is believed to be either the remains of the original sedimentary layers present in the area before the igneous rocks erupted through it, or it is part of the mesmerizing offspring. It was broken by the tectonic movements and was bursting with ultramafic igneous rocks (Figure 8).

Figure 8: Harzburgite and dunite rocks with large amount of alteration. Samples G4a, G4b, G4d

Most base rocks identified in this section are subjected to the decomposition processes, e.g., talc mineral in the form of the white powder found on the surface of some of these samples (Figure 9). This is clear evidence of the decomposition processes these ultrabasic rocks are subjected to.

Figure 9: Talc in the form of white powder. Sample G4f

In addition to presence of other types, which are a large, superimposed clumps of uniform verticality containing longitudinal joints having a dark reddish-brown color which is Walash Volcano-sedimentary Series rocks (Figure10).

Figure 10: Walash Volcano-sedimentary Series rocks

5. Petrography and mineral chemistry

5.1 Dunite

Dunite rocks are characterized by homogenous lithologic property characteristic, which consist of olivine mineral as a main component, in addition to accessory chromian spinel and traces of the orthopyroxene minerals in some identified samples (Figure11).

According to the chemical analysis by microprobe technique, the selected olivine grains from the fresh dunite are forsterite olivine (Fo. $_{91.1}$). The olivine forms more than 90% with serpentinized olivine (Table 1). The dunites are affected by various degrees of the serpentinization process and exhibit typical mesh structure along with the fractures and outlines. The olivine is affected by alteration after it breaks down into smaller granules by tectonic effect and shearing stress. (Figure12). Hydrothermal solutions enter the spaces between the grains and form ureilite minerals. So, when OH is entered, it will turn the Fe^{+2} which is essential in the mineral composition of olivine to $Fe^{+3,}$ forming the secondary dark black magnetite and filling the spaces and channels between the granules of olivine (Figure13).

From the distribution of these granules and secondary magnetite, we can conclude that the granules of olivine have fractures due to shearing stress (Figure 12).

The orthopyroxene and clinopyroxene in little amounts (0 – about 3%). The pyroxene minerals are deformed by various stages of the alteration forming tremolite. The chromian spinel is the main accessory mineral in dunite and constitutes about 1 %. Chromian spinel is characterized often by euhedral to subhedral grains with opaque rims and fresh reddish-brown core.

Table 1: Minerals composition (in vol%) in dunite of the study area.

S. No.	**Olivine**		**Orthopyroxene**	**Clinopyroxene**	**Magnetite**	**Chromite**	**Talc**	**Chlorite**
	Residual Olivine	Serpentine						
G1a	90	3	3	0	2	1	0	1
G1b	88	6	3	0	0	3	1	0
G1d	89	5	2	0	1	4	0	0

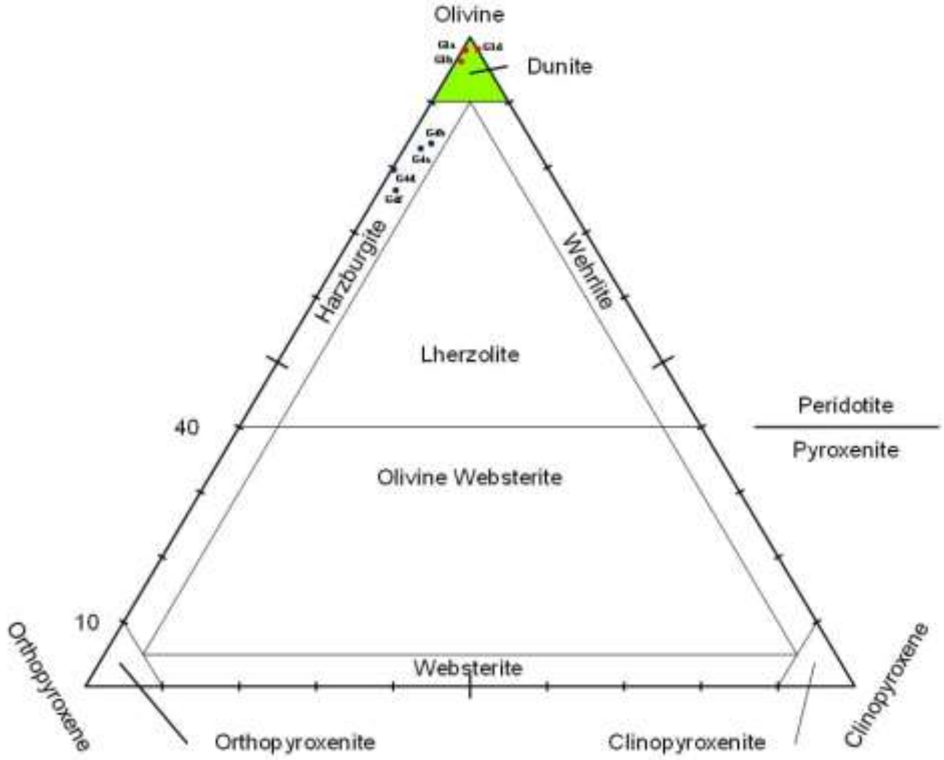


Figure 11: Nomenclature and classification of the ultramafic rocks in the studied area modified by [14] and [15].

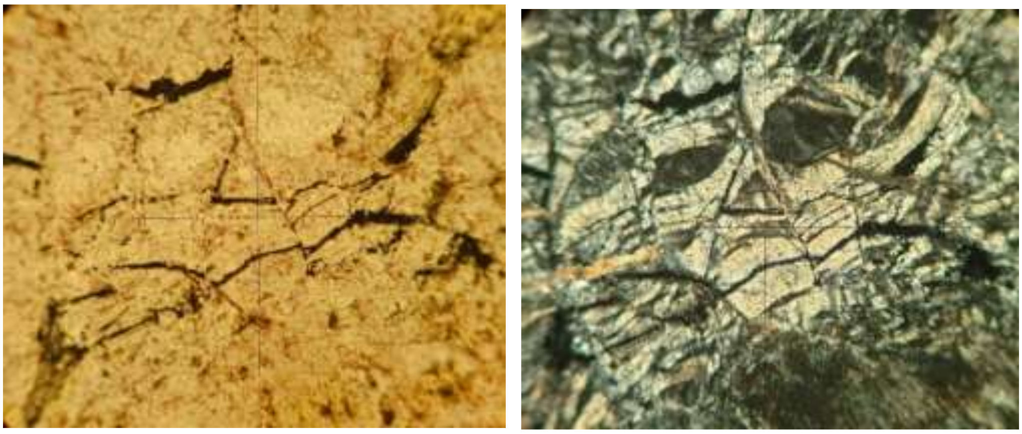


Figure 12: Alteration affecting olivine granules by variable degree of serpentinization and replaced by serpentine. G1a

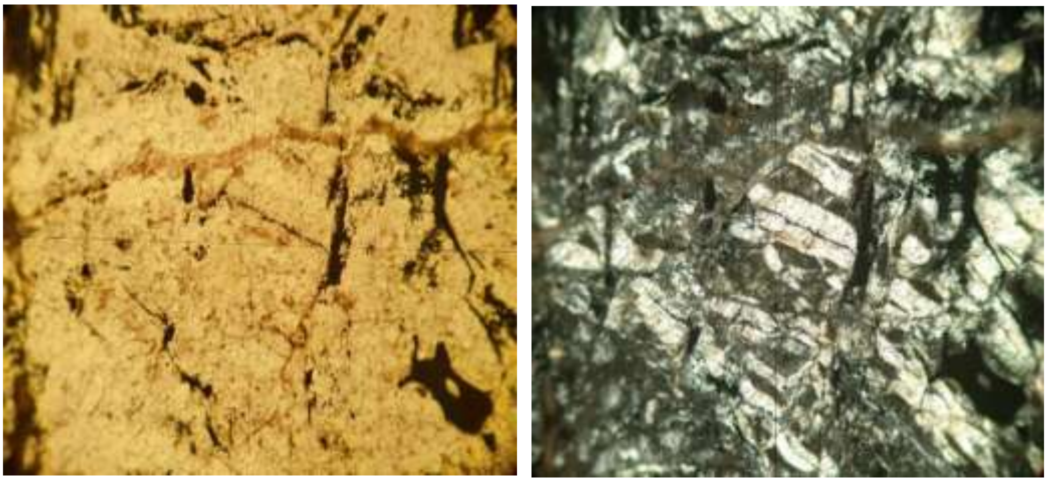


Figure 13: Secondary magnetite, a black color filling the spaces and channels between the granules of olivine. G1b and G1d.

5.2 Harzburgite

The harzburgite is a massive rock composed of various grain size of olivine (0.02- 1.2 mm). Olivine in serpentinized harzburgite is ranged between 73- 81% in addition to deformation of orthopyroxene and clinopyroxene (Table 2), (Figure 13).

Clinopyroxene is dominant and often associated with orthopyroxene, which occurred as discrete grain. Orthopyroxene percentage ranging between 12 to 20 Vol, is sometimes characterized by coarse grains with radial aggregates (Figure14). The harzburgite bodies are affected by various degrees of serpentinization. At the same time, the orthopyroxene is replaced by talc within the veins (Figure15), and clinopyroxene is replaced by actinolite in the form of acicular (Figure 16). The chromian spinal is characterized by vermicular to 0.6 – 1.7 mm subhedral grains.

Chromian spinel appears brown to reddish-brown under the transmitted polarizing microscope (Figure 17).

Table 2: Mineral composition (in vol %) in harzburgite of the studied area

S. No.	Olivine		Orthopyroxene	Clinopyroxene	Magnetite	Chromite	Talc	Actinolite
	Residual Olivine	Serpentine						
G4a	41	40	15	2	1	1	0	0
G4b	40	39	12	3	3	2	1	1
G4d	41	35	20	0	2	1	1	1
G4f	40	33	20	2	2	2	1	1

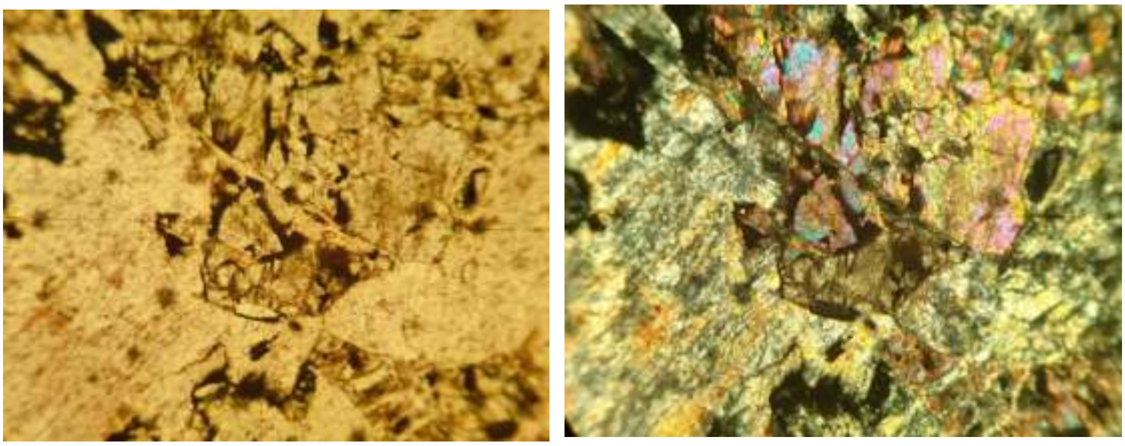


Figure 14: Alteration affecting orthopyroxene in harzburgite. Sample G4a

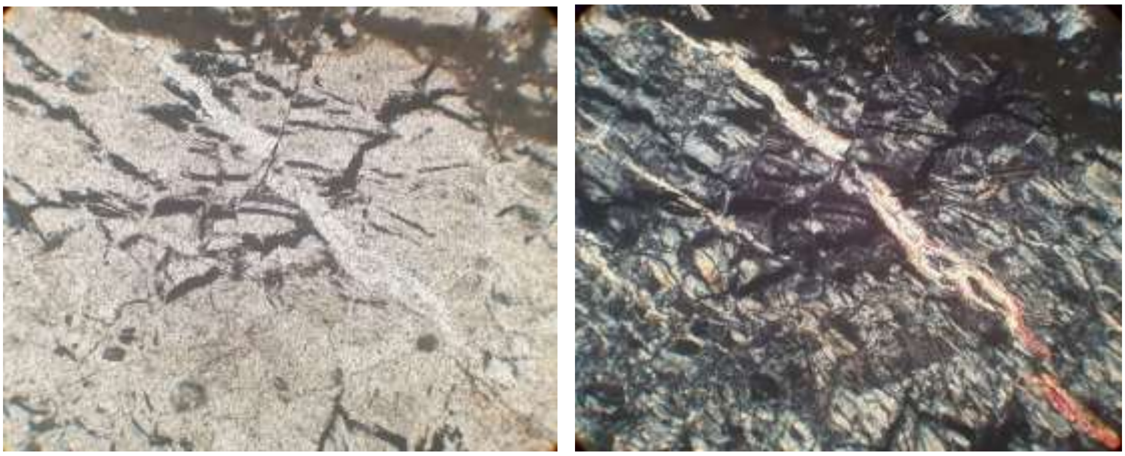
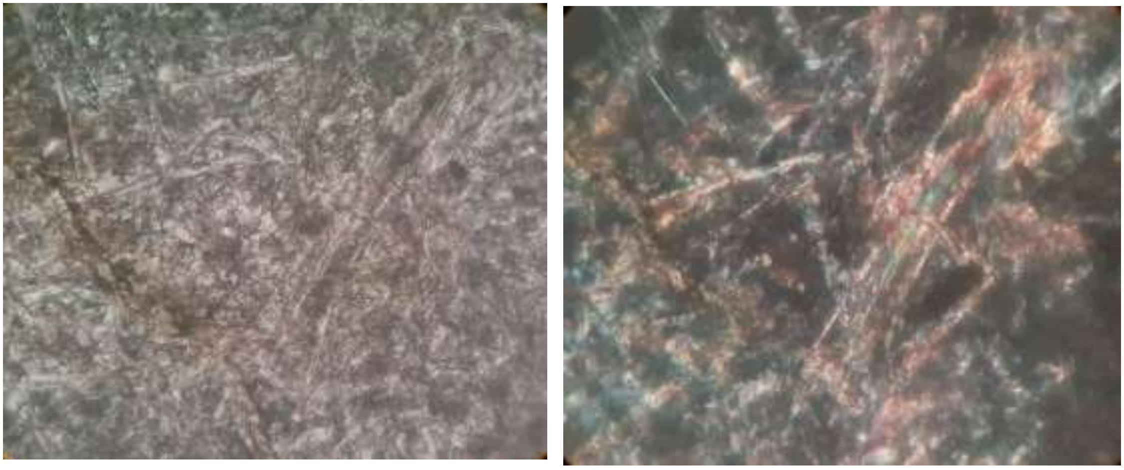


Figure 15: Veins of talc. Sample G4b



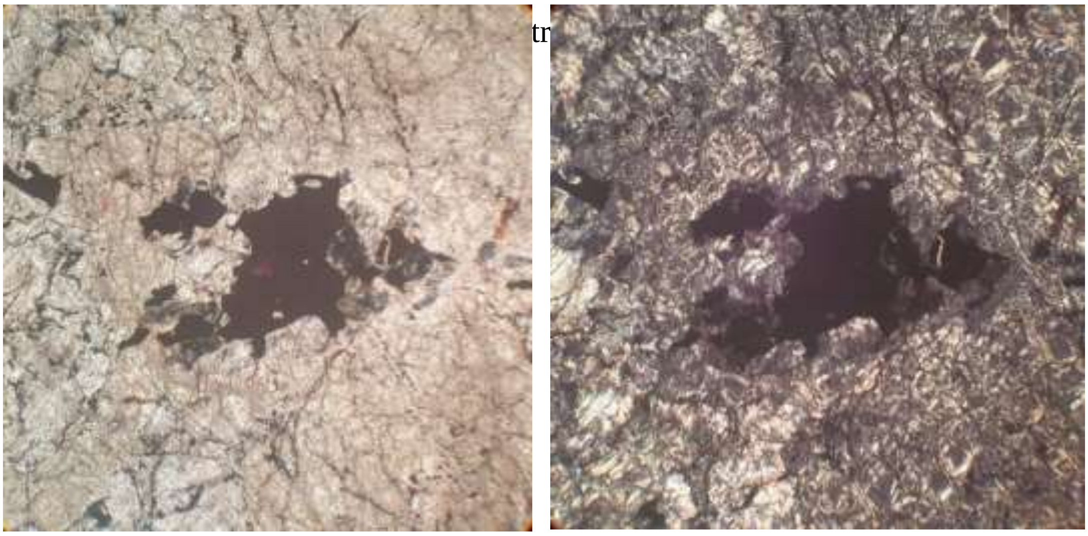


Figure 17: Brown to reddish brown chromian spinel. Sample G4f

6. Geochemistry of Ultramafic rocks

6.1 . Petrography and mineral chemistry

Ferric and ferrous iron in chromian spinels were calculated by assuming spinel stoichiometry formula. While in pyroxene and ferrous and ferric iron are calculated following [16], [17], respectively (Table 3).

Olivine as the main constituent in the peridotite; it is the major host mineral for iron, magnesium, and nickel. The Mg# (Mg/Mg+Fe2+) in olivine mineral reflects the composition of the whole rock, which is related to the degree of melt and depletion or enrichment in iron. The Mg# of olivine in dunite and harzburgite is 0.996 reflecting more iron enrichment nature (Table 3).

Olivine with chromian magnetite represents together a residual phase of peridotites in the mantel peridotites and the early precipitating phase from the primary magmatic stage. The ultramafic (samples G1a and G4a) and serpentinite in studied samples are characterized mainly by the forsterite olivine. The mineral chemistry of the olivine show that the olivine is richer in forsterite (Fo = 91), and this enrichment is given Cr#. These chemical trends sometimes start through or near the Olivine Spinel mantle array (Figure 18). The Cr# of chromian spinel does not display a positive correlation when correlated with the Fo component of coexisting olivine in peridotite rocks (Figure 18).

The orthopyroxene in dunite, harzburgite and serpentinite is represented by enstatite from $En_{94.5}$ -Fs_0 to $En_{99.9}$ – Fs_0. The orthopyroxene in harzburgite is more affected by the serpentinization altered to talc. At the same time, the clinopyroxene is a major host mineral for the sodium, titanium, calcium and chromium in the xenolith of the mantle and showing the solid-solution extending toward the orthopyroxene at high values of pressure and temperature within the mantle condition [18]. The Mg# of clinopyroxene in the studied samples ranges from 0.990 to 0.995. The high Mg# is related to the serpentinization (hydration) degree; therefore strongly serpentinization (hydration process) has high value of Mg#. All clinopyroxenes are characterized by poor Na_2O content and rarely exceeds up to 0.1wt.% (Figure 19 A and B). Since dunite in the study area is almost characterized by clinopyroxene-free, and the harzburgite contains a minimal amount of clinopyroxene (< 3%) (Table 4);

therefore, they are assumed to be highly depleted ultramafic rocks and have undergone a high degree of melting.

Table 3 Chemical composition of olivine in studied ultramafic and serpentinite rocks, the chemical composition determined based on (4) oxygen.

Oxides%	G1a	G4a	Ch4	Ry6	Hj6
SiO_2	55.87	54.03	51.35	52.1	54.12
TiO_2	0.01	0.01	0.03	0.23	0.03
Al_2O_3	0.01	0.34	0.9	1.02	0.92
FeO	0.1	0.34	0.82	1.8	0.44
MgO	43.98	45.28	46.85	44.85	44.48
Cr_2O_3	0.009	0.01	0.054	0.026	0.01
Total	99.99	100	100	100	100
Elements					
Si	1.242	1.224	1.230	1.193	1.219
Ti	0.00	0.00	0.001	0.004	0.001
Al	0.00	0.009	0.026	0.027	0.024
Fe^{+2}	0.006	0.006	0.016	0.035	0.008
Mg	1.508	1.529	1.482	1.531	1.493
Cr	0.001	0.002	0.001	0.001	0.02
Total	2.76	2.77	2.76	2.79	2.77
Fo	91.1	91.3	91.5	91.6	91.2
Cr#	1	0.182	0.036	0.036	0.455
Mg#	0.996	0.996	0.989	0.978	0.995

Table 4: Chemical composition of pyroxene in studied ultramafic rocks, the chemical composition determined based on (6) oxygen.

Oxides%	G1a	G4a	Ch4	Ry6	Hj6
SiO_2	55.46	53.84	51.33	49.79	53.63
TiO_2	0.01	0.01	0.031	0.22	0.033
Al_2O_3	0.01	0.33	0.92	0.97	0.91
FeO	0.11	0.33	0.82	1.72	0.44
MnO	0.18	0.023	0.003	0.183	0.004
MgO	43.65	45.12	46.83	42.87	44.08
CaO	0.45	0.35	0.031	3.45	0.88
Na_2O	0.11	0.01	0.0	0.75	0.033
K_2O	0.0	0.0	0.0	0.0	0.0
Total	99.98	100	99.97	99.95	100
Elements					
Si	1.826	1.751	1.670	1.636	1.761
Ti	0.00	0.00	0.001	0.005	0.001
Al	0.00	0.013	0.035	0.038	0.035
Fe^{+3}	0.003	0.009	0.022	0.047	0.012
Mn	0.005	0.001	0.00	0.005	0.00
Mg	2.142	2.213	2.271	2.100	2.158
Ca	0.016	0.012	0.001	0.121	0.031
Na	0.007	0.001	0.00	0.048	0.002
K	0.00	0.00	0.00	0.00	0.00
Total	4	4	4	4	4
Mg#	0.998	0.996	0.990	0.978	0.995

Mineral Chemistry	Wo = 0.74 En = 99.26 Fs = 0.00	Wo = 0.55 En = 99.45 Fs = 0.00	Wo = 0.05 En = 99.95	Wo = 5.47 En = 94.53	Wo = 1.41 En = 98.59

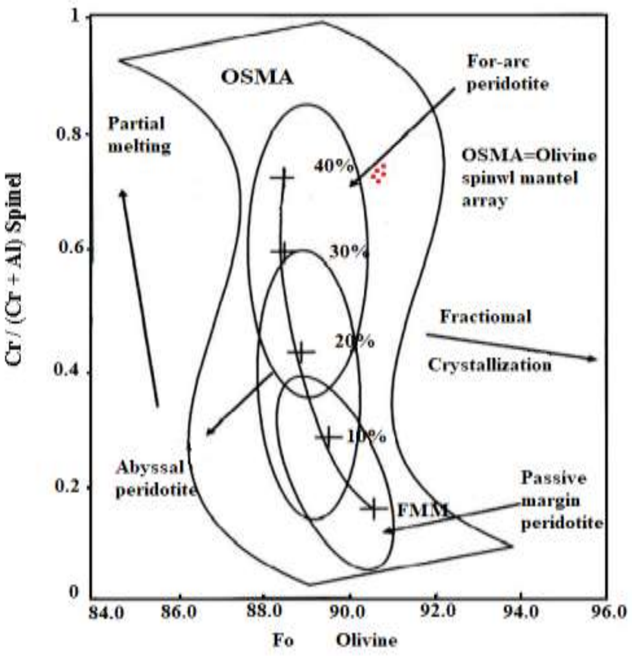
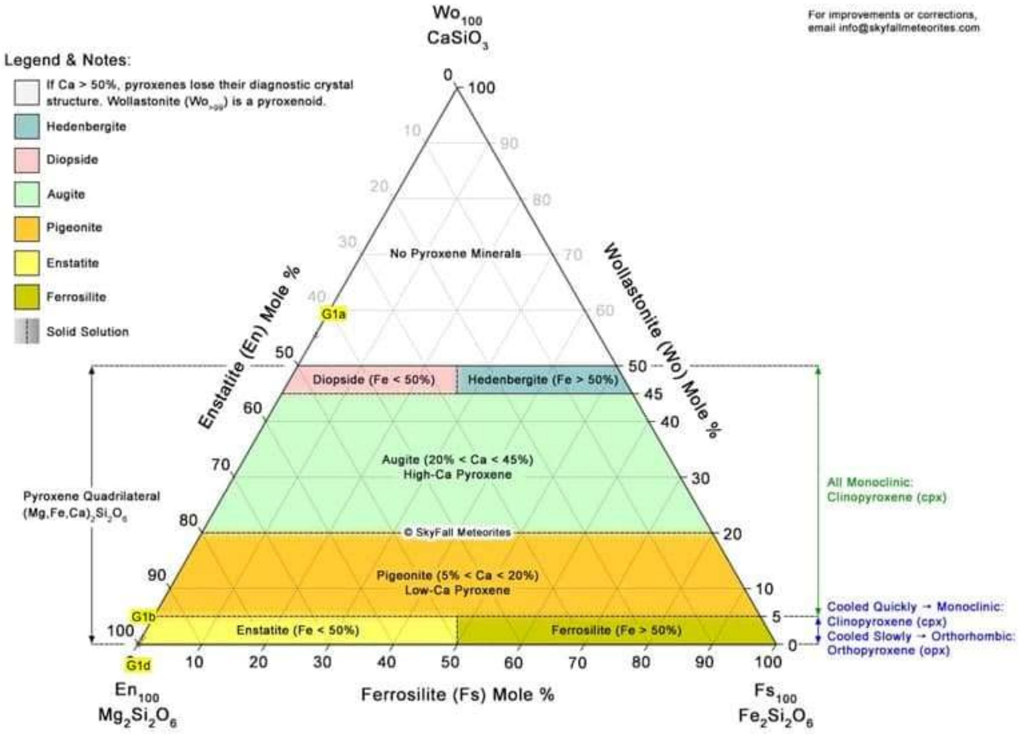


Figure 18: Geochemical relationship between Fo content of the olivine and the Cr# ratio of the chromain spinel in serpentinites, according to [19].



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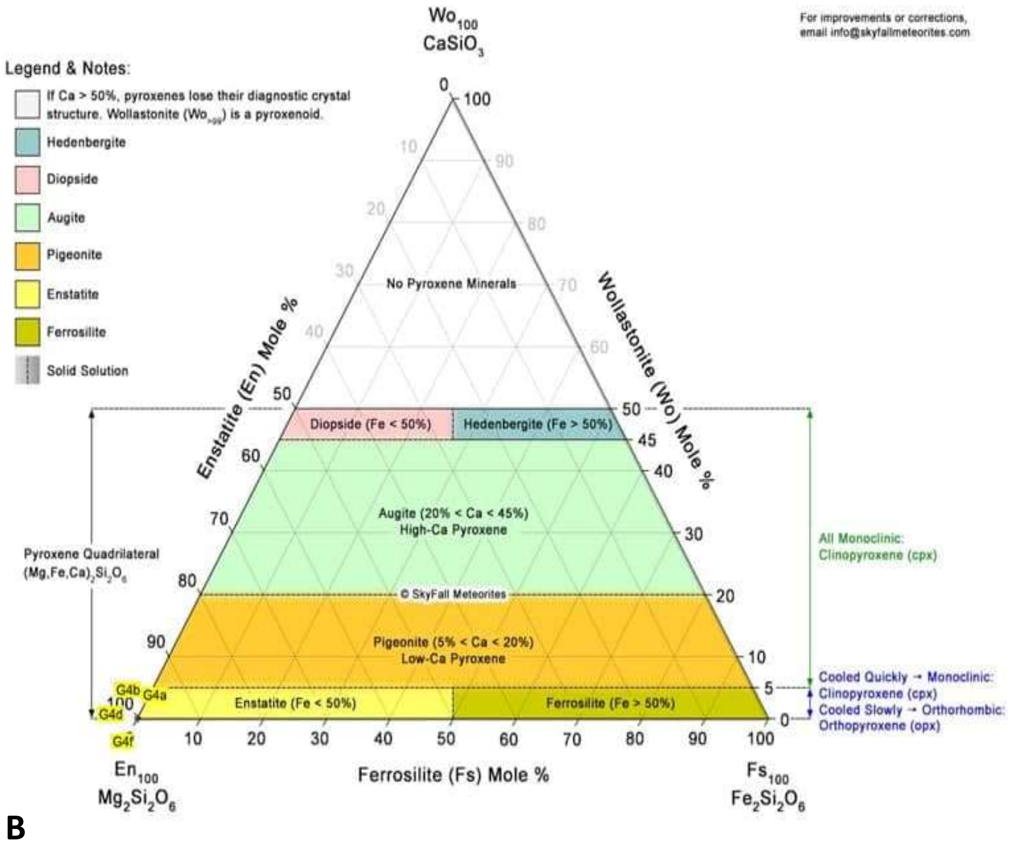

Figure 19: Pyroxene compositions of A. dunite, B. harzburgite rocks according to Wo, En, Fs classification diagram after [20].

6.2 Accessory chromite composition

Chromite series include Magnesiochromite and chromite based on whether the trivalent ion is Fe, Al or Cr. The magnetite minerals (ƛ-Fe_2O_3) and ulvo spinel ($Fe^{2+}TiO_4$) have the spinel structure; the previous has a cation deficiency while $2Fe^{3+}$ - $Fe^{2+}Ti^{4+}$ replacement was occurring in the latter [21]. Chromian magnetite is sensitive monitors of compositional change due to partial melting, melt differentiation and/ or oxidation [19]. Before interpreting spinel compositions as petrogenetic indicators for the mafic magma, such variations must be assessed. The results of chromain spinel analyses are given in (Table 5).

Chromian magnetite from serpentinite have Cr# (0.557- 0.796) and Mg# (0.328- 0.456). The Cr# has a slight change or even constant in the studied serpentinite. The formed serpentine around the chromite crystals cause more magnesium in serpentinite and decrease the spinel's magnesium values. The chromite crystals in serpentinite from all studied samples show a wide range of Cr_2O_3 content (40.5 – 51.31 wt.% (Table 5). There are three stages that have been recognized for spinel in the studied area.

The chemical composition of the opaque minerals is chromite is known if the ratio of $Cr_2O_3 > Al_2O_3+Fe_2O_3$ and spinel if the $Fe_2O_3 < Al_2O_3+FeO$, whereas of the magnetite if $Fe_2O_3>Al_2O_3+FeO$ [22]. All analyzed opaque minerals in the ultramafic rocks (dunite and harzburgite) of the studied samples are chromian magnetite and secondary magnetite (Figure 20).

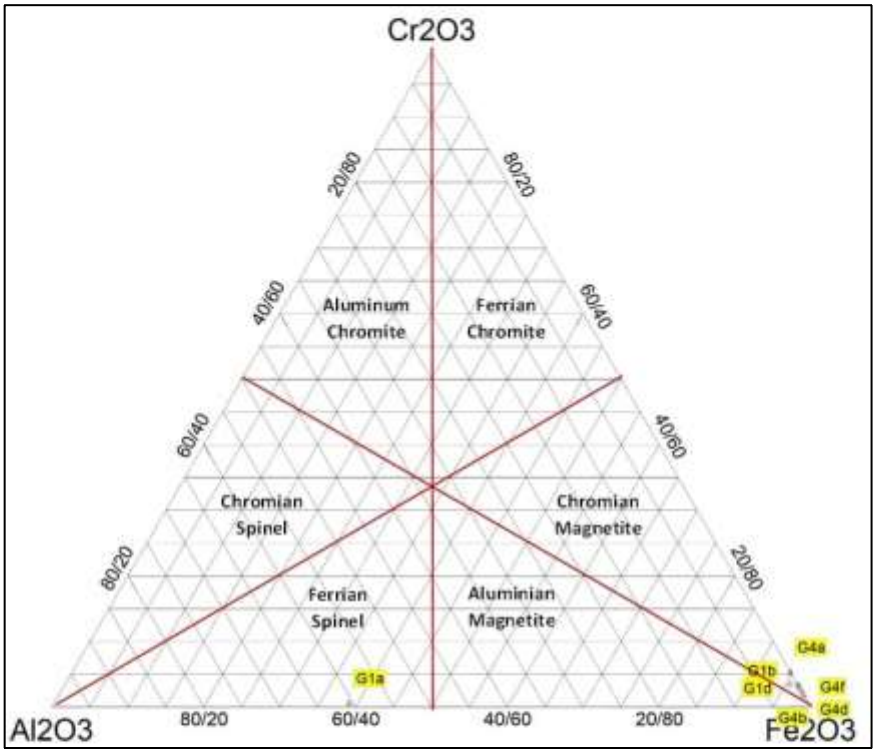

Figure 20: Cr_2O_3-Al_2O_3-Fe_2O_3 diagram for the minerals opaque in the ultramafic bodies of the studied area.

Table 5: Composition of the chromain magnetite in studied ultramafic and serpentinites, the chemical composition identified based on (4) oxygen.

Oxides%	G2a	Ch3	Ry1	Hj1
SiO_2	0.44	0.5	0.3	0.39
TiO_2	0.01	0.12	0.07	0.01
Al_2O_3	9.51	14.85	17.8	21.63
FeO	22.12	20.01	21.2	20.19
Fe_2O_3	9.88	8.85	8.15	7.38
MnO	0.22	0.47	0.4	0.19
MgO	6.5	8.9	8.3	9.7
CaO	nd	nd	nd	nd
Na_2O	nd	nd	nd	nd
Cr_2O_3	51.31	45.3	42.95	40.5
Total	99.99	99	99.2	99.99
Elements				
Si	0.015	0.016	0.01	0.012
Ti	0.00	0.003	0.002	0.00
Al	0.38	0.576	0.684	0.804
Cr	1.374	1.179	1.107	1.009
Fe^{+2}	0.627	0.551	0.578	0.532
Fe^{+3}	0.252	0.219	0.2	0.175
Mn	0.006	0.013	0.011	0.005
Mg	0.328	0.437	0.403	0.456
Total	2.982	2.994	2.995	2.993
Cr#	0.796	0.672	0.618	0.557
Mg#	0.344	0.442	0.412	0.462
Fe^{+2}#	0.657	0.558	0.589	0.539
Fe^{+3}#	0.127	0.111	0.101	0.088

6.3 Major and trace elements Geochemistry

The geochemistry of studied ultramafic rocks (dunite and harzburgite) exhibits the following ranges of the content of the major oxide: SiO_2 (37.46 – 47.05 wt%), TiO_2 (0.0012-0.299 wt%), MgO (14.88 - 41.68 wt%) and Fe_2O_3 (8.164-14.66 wt%). Ni content range between (1 – 2072 ppm). The average magnesium numbers {=(Mg#) 100* (MgO / MgO + FeO)} for the bulk rock, are 73.7 in dunite and 75.1 in harzburgite.

The Harker variation diagrams of the major element against MgO wt % as a fractionation index are displayed in (Figure 21). They show a poor negative correlation pattern of MgO with SiO2, Fe2O3 and K2O, while Al2O3, CaO, and TiO2 show a nearly positive correlation.

Clinopyroxene, orthopyroxene and spinal are the only contain Al_2O_3. In the studied samples, average Al2O3 contents in dunite and harzburgite are 0.464 and 0.007 wt%, respectively (Table 6). These concentrations are not close to the mean values of Al_2O_3 which is given by Coleman [23], which are 0.35 % in dunite and 0.89 % in harzburgite, because of the effect of serpentinization processes on the MgO content of the ultramafic protolith compared to the other oxides [24]. It acts as an index of depletion [25, 26].

Table 6: ICP-MS analysis representatively of the dunite and harzburgite for the studied samples

Rock type	Dunite			Harzburgite			
Sample No.	**G1a**	**G1b**	**G1d**	**G4a**	**G4b**	**G4d**	**G4f**
SiO2	37.46	46.32	47.05	44.31	46.19	45.62	44.97
TiO2	0.299	0.0012	0.0115	0.0073	0.0084	0.0077	0.0069
Al2O3	12.72	0.0067	0.1121	0.0079	0.0072	0.0066	0.0064
Cr2O3	0.114	0.384	0.3832	0.7287	0.425	0.248	0.3641
Fe2O3	8.164	12.025	10.567	13.071	12.181	13.839	14.66
MnO	0.184	0.1320	0.1177	0.0839	0.1258	0.1245	0.1337
MgO	14.88	40.33	40.96	41.68	40.91	40.04	39.34
CaO	26.12	0.106	0.765	0.0729	0.1036	0.0816	0.1714
Na2O	0.049	0.037	0.038	0.039	0.039	0.039	0.0399
Total	99.99	99.43	100.0	100.0	99.99	100.0	99.69
Traces (ppm)							
Ni	1	2072	1972	44.9	13.1	8	17.9
Cr	1751	2842	2127	1267	1054	1023	1159
Sc	0.2	0.2	0.2	0.6	0.2	0.2	1.2
Ba	7.4	8.1	13.5	13.1	17.6	7	7.1
La	10	7.1	24.1	18.1	14.2	12.8	14.6
Ce	3.3	9.7	9.6	3.9	2.9	2.7	3
V	10	19	13.4	17	15.7	11	12.3
Pb	0.6	0.6	0.4	0.4	0.4	0.4	0.4
Th	8.7	0.6	0.6	6.6	17.8	6.9	6.7
Zn	7	40.7	29.4	2.2	2.1	2	2.2
Zr	3.5	3.4	3.2	2.9	2.6	2.5	2.2
Ga	0.5	2.1	2.1	0.6	0.4	1	1.2
Y	13.7	0.4	0.4	3.4	3.9	3.1	3.3
Cu	31.1	9.4	24.6	43	40.2	38.7	35.6
Nb	3.5	2.6	2.6	2.3	2.8	2.3	2.5
Sr	10.5	1.5	1.4	0.4	0.4	0.4	0.4
Rb	24.6	0.2	0.2	0.9	1.6	0.2	1.6

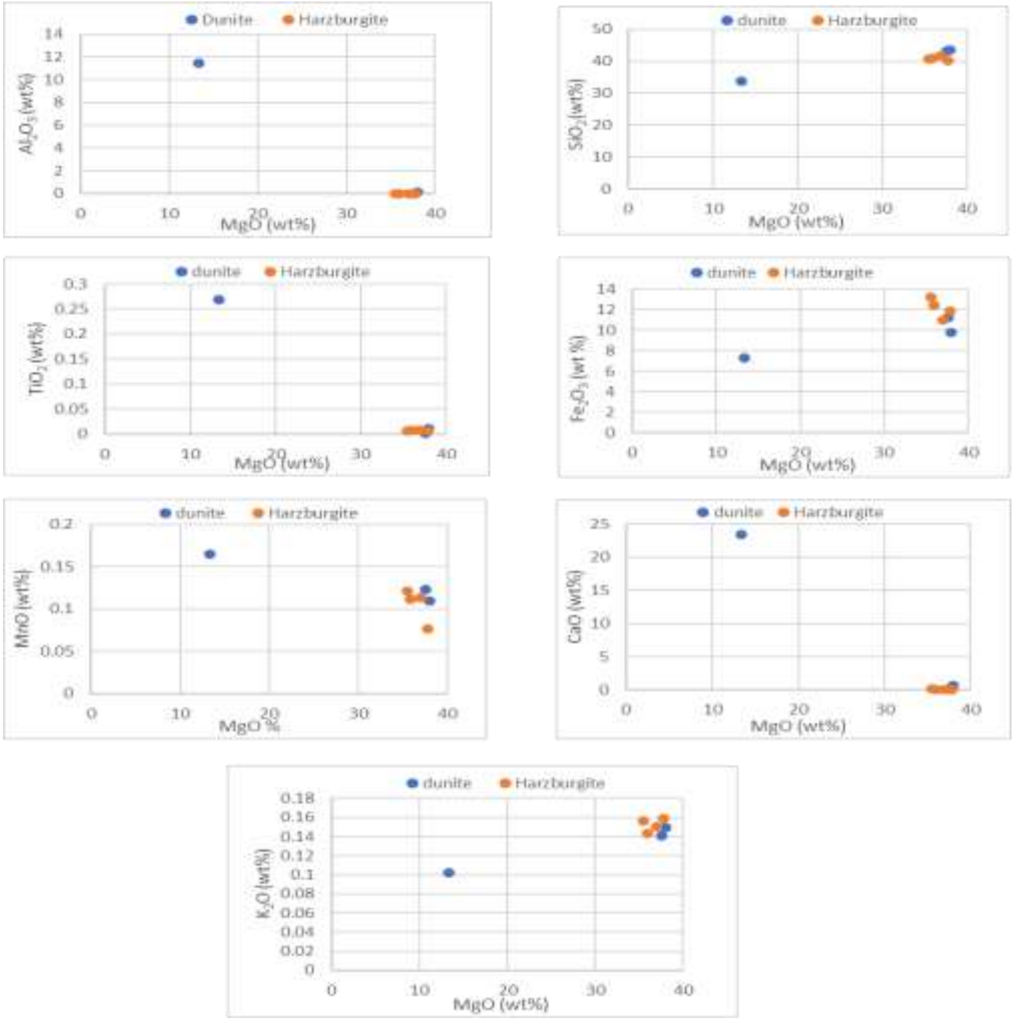

Figure 21: Harker diagrams for Galala ultramafic rocks show some oxides' trends against MgO.

6.4 Trace element Geochemistry

The average Ni content of dunite is 1348.33 ppm and in harzburgite is 20.98 ppm. The chemical behavior for Ni is appeared increases with increasing MgO content (Figure 22). Thus, the trend has been interpreted as the Ni values are mainly with the olivine mineral and less extending in the orthopyroxene [27], and using the field observations of the dunite and harzburgite (Figure 22). The positive and negative correlation patterns of Ni in dunite and harzburgite respectively and the positive for both in V.

The Cr content in dunite rock ranges from 1751 to 2842 ppm, and in harzburgite rock ranges from 1023 to 1267 ppm (Table 6). Cr content in the dunite and harzburgite mainly functions of the modal amounts of chromite and orthopyroxene. The negative trends of Sc - MgO and the positive trends of V- MgO and Ga- MgO in the ultramafic rocks (Figure22).

The ultramafic rocks are characterizing by low values of Zr and Y < 4 ppm excepting sample G1a (Table 6), the Zr---MgO and Y---MgO showing negative correlations (Figure 22). Y and Zr are incompatible high field strength elements (HFS), which means it is preferred to be concentrated in the melt rather than in minerals [28]. This means the early formed minerals in basic magma, such as olivine and pyroxene, will be depleting in Y and Zr.

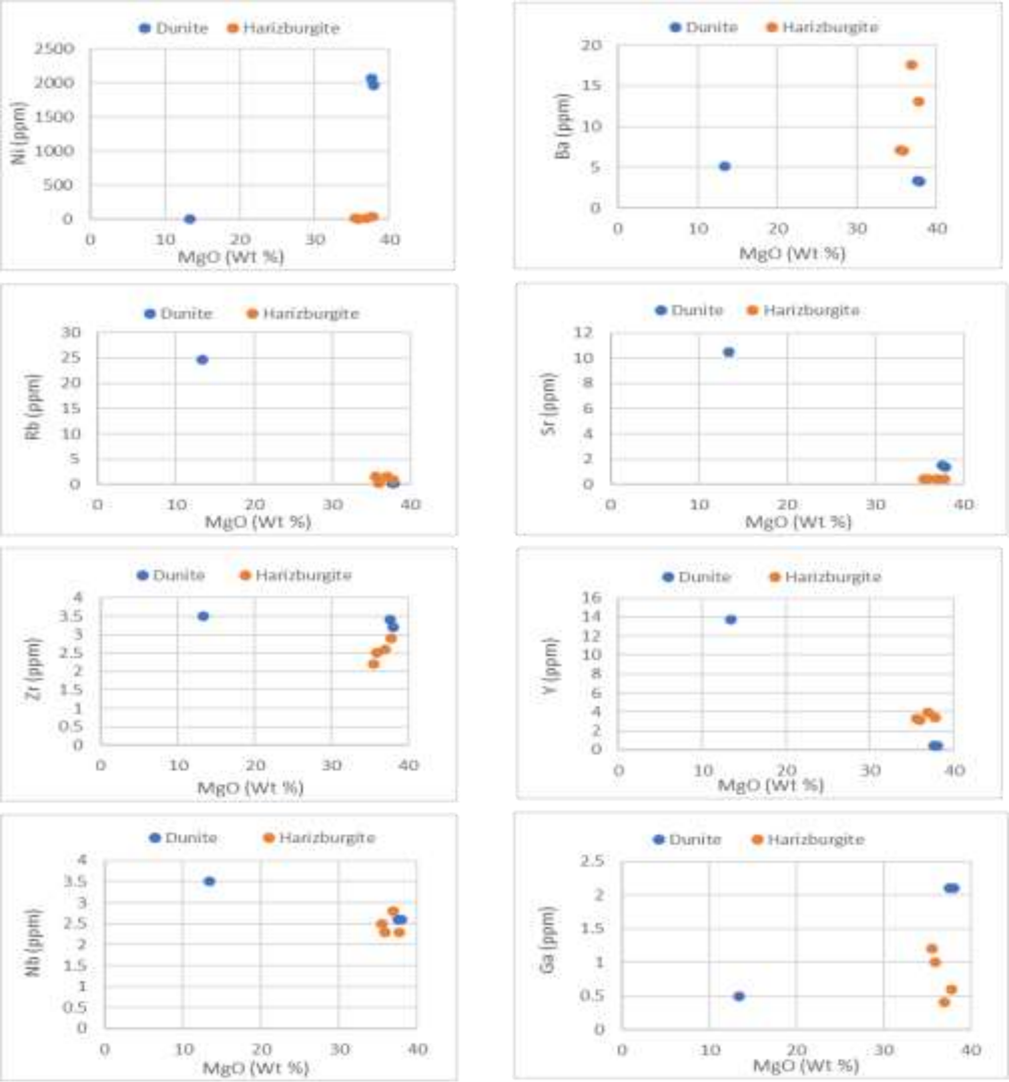

Figure 22: Diagram showing plots of MgO versus Trace elements for the studied samples.

The highly incompatible elements (HIE) among the lithophile trace elements (Rb, Ba, Nb, and Th) are dispersed strongly in the diagrams of magnesium covariation. The trends of the scattering mode of Ba, Nb, Zr, Th, and Ga (Figure 23) attribute to their incompatible during the melting of the mantle. The ultramafic rocks are very low values of K_2O content. The low Rb content values don’t show any relationships with MgO content (Figure 23).

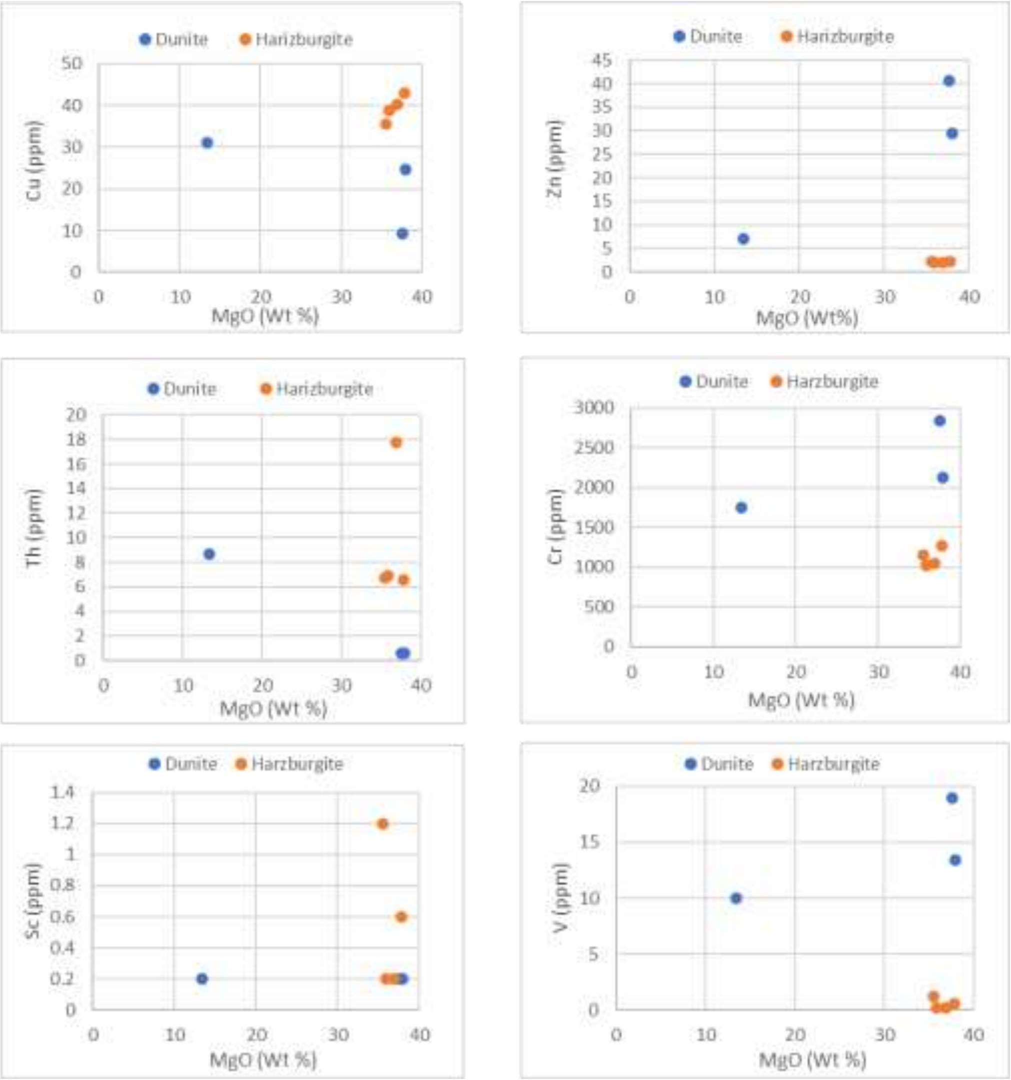

Figure 23: Trace elements versus MgO plots for the studied ultrabasic rocks (dunite and harzburgite).

6.5 Geochemistry of rare earth elements (REE)

The REEs represent the immobile elements during the low grade of metamorphism, weathering and hydrothermal alteration. The source rocks chemistry largely controls the patterns of REE. The REE analysis values of the ultramafic rocks in the studied area are listed in Table (7). The chondrite-normalized REE patterns of the ultramafic rocks are presented in the Figures (24A, 24B), using normalizing values according to [29].

The dunite and harzburgite rocks are represented by a pronounced slightly V-shaped depletion in the middle REE (La/Yb), (Gd/Yb), (La/Sm), (Tb/Yb) relative to the enrichment in the light REE (La-Sm) and depletion in the heavy REE (Ho-Lu). On the other hand, the Island Arc (IA) sources show LREE enrichments. The LREE -enriched patterns can be modelled based on a reaction between MORB-source (spinel lherzolite) and LREE-rich fluid of subducted- slab. A reaction between garnet lherzolite) and LREE-rich fluid of subducted-slab is characterized by depleted MREE [29].

Table 7: REE analysis (ICP-MS) results of the ultramafic rocks (dunite and harzburgite) in the studied area.

Rock type	Dunite	Dunite	Dunite	Harzburgite	Harzburgite	Harzburgite	Harzburgite
Sample No.	G1a	G1b	G1d	G4a	G4b	G4d	G4f
La	10	7.1	24.1	18.1	14.2	12.8	14.6
Ce	3.3	9.7	9.6	3.9	2.9	2.7	3
Pr	0.02	0.12	0.31	0.03	0.04	0.01	0.02
Nd	0.01	0.07	0.12	0.05	0.16	0.07	0.05
Sm	0.01	0.03	0.02	0.01	0.04	0.01	0.02
Eu	0.01	0.01	0.01	0.01	0.02	0.01	0.02
Gd	0.01	0.02	0.01	0.01	0.04	0.02	0.01
Tb	0.001	0.005	0.002	0.002	0.005	0.003	0.007
Dy	0.02	0.02	0.02	0.01	0.07	0.02	0.01
Ho	0.001	0.005	0.003	0.006	0.006	0.004	0.003
Er	0.01	0.02	0.01	0.02	0.06	0.03	0.01
Tm	0.001	0.006	0.004	0.001	0.004	0.002	0
Yb	0.01	0.02	0.02	0.02	0.04	0.01	0.01
Lu	0.002	0.01	0.004	0.01	0.02	0.006	0.007

The U-shaped REE patterns and these ratios are typical of ophiolitic ultramafic rocks [13], which are compatible with the supra-subduction zone [30]. The residual ultramafic rocks from SSZ (for-arc setting) always exhibit a U-shaped chondrite normalized pattern [31, 32].

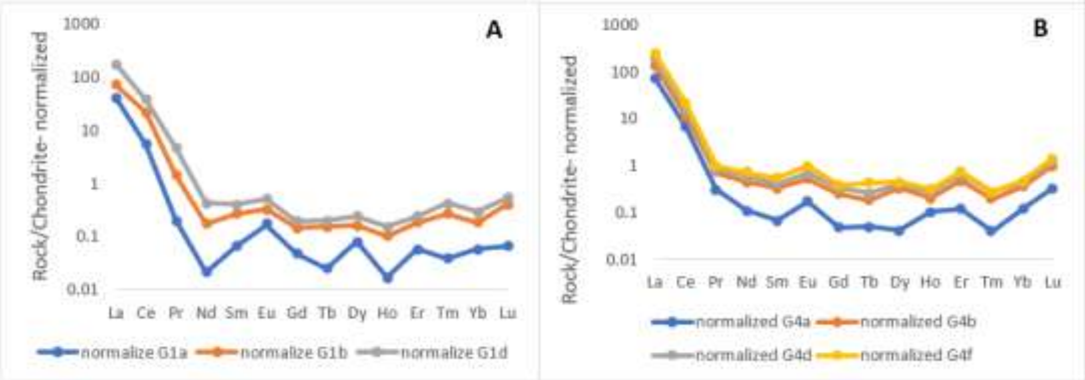

Figure 24: REE chondrite- normalized patterns of A. dunite B. harzburgite the studied area.

Chondrite – normalized spider diagram for the studied dunite and harzburgite ultramafic rocks shows enrichment (negative anomaly) in the large ion lithophile elements (LILEs) such as (Ba and Sr) (Table 7) relative to the high field strength elements (HFSEs) like (Nb, Y, Zr and Hf). All the ultramafic study samples display negative Nb and Pb anomalies and generally flat patterns, near or above unity for the Tb to Lu elements (Figure 25A, 25B).

The negative anomalies of Nb and Pb indicate to the involvement of the mantle source rocks that have been affected by the subduction and the tectonic environment within the supra subduction zone (fore-arc condition), according to Kim et al., [33] and Hofman [34]. During the partial melting, the negative anomalies of Nb in ultramafic rocks to sequestration of Nb by ilmenite or sphene minerals in the various source [35]. Nb represents one of the incompatibility elements with a high sensitivity to the island arc conditions; its depletion in the study samples may indicatean supra subduction zone (fore-arc) environment.

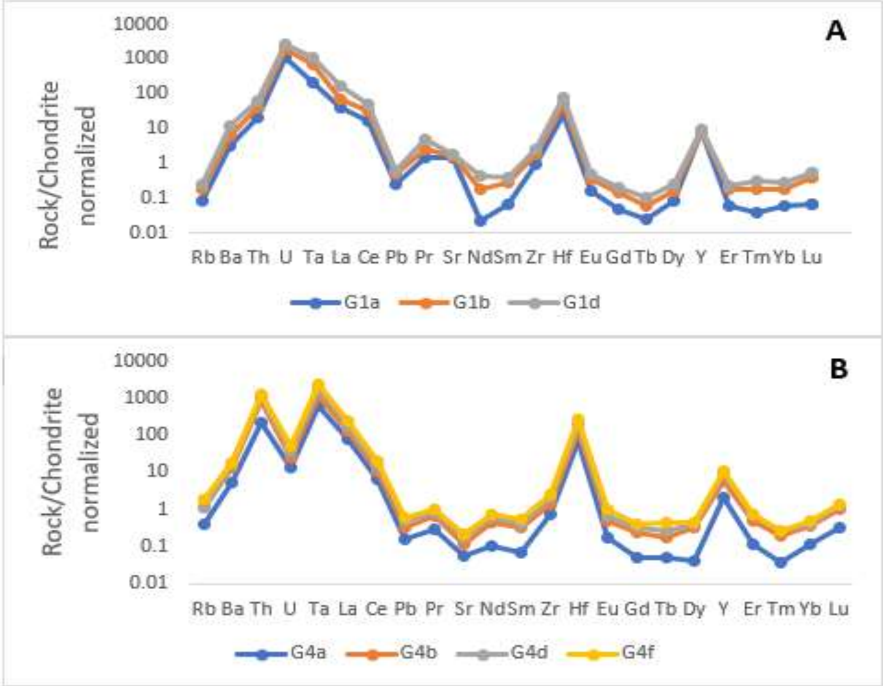

Figure 25: Trace and REE Chondrite- normalized element patterns (spider diagram) of the A. dunite B. harzburgite in the studied area.

8. Conclusions

1. Clinopyroxene, orthopyroxene and chromian magnetite represent the only minerals containing Al_2O_3. That means of Al_2O_3 content in dunite and harzburgite are ranging from 0.0064 to 12.72% Al_2O_3. These amounts are not close to the mean values of Al_2O_3 because of the effects of the serpentinization processes on the MgO content of the ultramafic protolith compared to the other oxides. This is an index of depletion. High values of MgO and low concentrations of Al_2O_3, CaO, TiO_2 and incompatible elements that preferentially partition into the phase liquified during the partial melting stage and /or due to the source rocks' nature.
2. The ultramafic rocks are enriched in ferromagnesian minerals and depleted in silica and other elements during the serpentinization processes. This is true in harzburgite and dunite, which are more enriched in the refractory minerals such as olivine, orthopyroxene and spinel.
3. The low TiO_2 content in both dunite and harzburgite is characteristic for the Alpine type ophiolites, for the tectonic emplacement of the ultramafic rocks, and the degree of the partial melting of asthenosphere mantle.
4. Because the dunite and harzburgite in the studied samples do not containing abundant plagioclase modal; therefore, the positive anomaly of Eu may be related to the hydrothermal effects and decomposition of the clinopyroxene.
5. The U-shaped REE patterns and these ratios are typical of the ophiolitic ultramafic rocks, which indicate the supra subduction condition.
6. During partial melting, the negative anomalies of Nb in the ultrabasic rocks appear due to sequestration of the Nb by ilmenite or sphene minerals, which is sensitive to the island arc condition and may be indicative of SSZ (for-arc) environment.

References

[1] T. Buday, "*The regional geology of Iraq, Stratigraphy and palenogeography". edited by Kassab, I.M. and Jassim S.Z., Dar Al- Kutibpulblishing house, Mosel, Iraq,* 445p., 1980.

[2] C. M. G. Bolton, "The geology of the Rania area" Manuscript report No.271, *GEOSURV.* Baghdad, 1958.

[3] K. J. A. Asawd, N. R. H.Aziz., and H. A. Koyi, "Cr-spinel compositions in serpentinites and their implications for the petrotectonic history of the Zagros Suture Zone, Kurdistan Region". Iraq. *Geological Magazine,* vol.148, pp. 802-818, 2011.

[4] T. Buday, and S. Z. Jassim, "*The regional Geology of Iraq, Vol. 2, Tectonism, Magmatism and Metamorphism" edt. By Kassab, I., M. and Abass, M., J., Geological Survey and Mineral Investigation, Baghdad Iraq,* 352 p., 1987.

[5] S. Z. Jassim, and C. Goff (eds), "*Geology of Iraq". Dolin Prague and Moravian Museum Brno*. 341 pp., 2006.

[6] S. Guillot, K. H. Hattori, J. D. Sigyer, T. Nagler, A. Auzende, "Evidence of hydration of the mantle wedge and its role in the exhumation of eclogites". *Earth and Planetary Science Letters*, vol. 193, pp.115-127, 2001.

[7] Y.O. Mohammad, H. Maekawa, F.L. Ahmmad, "Mineralogy and origin of Mlakawa albitite from Kurdistan region, northeastern Iraq". *Geosphere*. Dec 1; vol. 3, no. 6, pp. 624-45, 2007.

[8] C.M.G. Bolton, "Geological map-Kurdistan Series, scales 1:100000, sheet K5, Choarta (Chwarta)". Site Inv. Co. report, NIMCO Lib. Unpublished report, 1957.

[9] S. M. Awadh and Y. Kettanah, "Petrology, Geochemistry and Tectonical Environment Of The Shalair Metamorphic Rock Group and Katar Rash Volcanic Group, Shalair Vally Area, Northeastern Iraq" *Iraqi Journal of Science*, vol.49, no.1, pp. 149-158, 2008.

[10] R. S. Dietz, "Collapsing continental rises: an actualistic concept of geosynclines and mountain building". *The Journal of Geology*. 1; vol. 71, no. 3, pp. 314-33, 1963.

[11] E. M. Moores, "Ancient suture zones within continents". *Science,* vol. 213, no. (4503), pp. 41-6, 1981.

[12] J. F. Dewey, J. M. Bird, "Mountain belts and the new global tectonics". *Journal of geophysical Research*, vol. 10;75, no. 14, pp. 2625-47, 1970.

[13] Y. Lee, "Geotectonic significance of detrital chromian spinel A review". *Geosci. Jour*. vol. 3, pp. 23-29, 1999.

[14] M. G. Best, "*Igneous petrology". Blakwell Science, Inc*., 443p., 2001.

[15] M. K. Bose, "*Igneous petrology". first edition, the world Press Private Limited, Calcutta*, 567p., 1997.

[16] W.F. Bohlen, D.F. Cundy and J.M. Tramontano, "Suspended material distributions in the wake of estuarine channel dredging operations". *Estuarine and Coastal Marine Science, j,* pp. 699-711, 1979.

[17] B. E. Leak, A. R. Woolley, C. E. S, Arps, W. D. Birch, M. C., Gilbert, J. D. Grice, F. C. Hawthorne, Kato, A., Kisch, H.J., Krivovichev, V.G., Linthout, K., Laird, J. Mandarino, J.A., Maresch, W.V., Nickel, E.H., Rock, N.M.S., Schumacher, J.C., Smith, D.C., Stephenson, N.C.N., Ungaretti, L., Whittaker, E.J.W., Youzhi, G., "Nomenclature of Amphiboles: Report of the sub-committee on amphiboles of the international mineralogical association" *Commission on new minerals and mineral names. Amer. Mineral.,*vol. 82, pp. 1019-1037,1997.

[18] T. Kohler and G. P. Brey, "Calcium exchange between olivine and clinopyroxene calibrated as geothermobarometer for natural peridotites from 2-60 kb with applications" *Jour. Geochim. Cosmochim. Acta.*, vol. 54, pp. 2375-2388, 1990.

[19] S. Arai, "Compositional variation of olivine-chromain spinel in Mg-rich magma as guide of residual spinel peridotite" *Jour. Volcanol. Geoth. Res*., vol. 59, pp. 279-293, 1994.

[20] C. Klein and Jr. C. S. Harlbut, "*Manual of Mineralogy". John Wiley and Sons, New York*, 681 P., 1993.

[21] N. R. Hama Aziz, "Petrogenesis, Evolution, and Tectonics of the Serpentinites of the Zagros Suture Zone, Kurdistan Region, NE Iraq". Thesis, university of Sulaimania, 250 p., 2008.

[22] R. E. Stevens, "Composition of Some Chromites of the Western Hemisfere Amer" *Min*., vol. 29, pp. 1-34, 1944.

[23] R. G. Coleman, "*Ophiolites". Springer-Verlag*. pp. 100–101. ISBN 978-3540082767, 1977.

[24] I. J. Parkinson, and J. A. Pearce, "Peridotites from the Izu-Bonin-Mariana forarc (ODP Leg 125): Evidence for mantle melting and melt- mantle interaction in asuprasubduction zone setting". *Jour. Of Petrology*, vol. 39, pp. 1577-1618, 1998.

[25] F. A. Frey, C. J. Suen, and H.W. Stockman, "The Ronda high temperature peridotite: geochemistry and petrogenesis". *Geochem. Cosmochim. Acta*, vol. 49, pp. 1469-2491, 1985.

[26] F. Melcher, T. Meisel, J. Puhl, F. Koller, "Petrogenesis and geotectonic setting of ultramafic rocks in the Eastern Alps: constraints from geochemistry". *Lithos,* vol. 65, pp. 69-112, 2002.

[27] H. R. Pfeiler, "*Major and trace element discrimination diagrams to determine possible protoliths of orogenic ultramafic rocks". Universite' de Lausanne*, 1990.

[28] T. A. Mirza, "Petrogeness of the Mawat Ophiolite Complex and The Associated Chromitite, Kurdistan Region, NE Iraq". Ph. D. Thesis, university of Sulaimania, 189 p., 2008.

[29] H. ST. C. O'Neill and H. Palme, "*Composition of the silicate Earth: implications for accretion and core formation. In The Earth's Mantle: Structure, Composition, and Evolution- the Ringwood". volume (ed l, Jackson) Cambridge University Press Cambridge*, pp 3-126. 1998.

[30] F. R. Hama salh, "Petrochemistry, Petrogenesis and tectonic setting of the Pauza ultramafic rocks- Bulfat complex north-east Iraq". Kurdistan region, MSc. Thesis, University of Sulaimani, 115p., 2004.

[31] I. J. Parkinson, J. A. Pearce, M. F Thirlwall, K. T. M. Johnson, and G. Ingram, "Trace element geochemistry of peridotites from the Izu-Bonin-Mariana, Forearc, LEG 125, Proceeding of the Ocean Drilling Program, *Scientific Results*, vol. 125, pp. 487-506. 1992.

[32] F. Melcher, T. Meisel, J. Puhl, and F. Koller, "Petrogenesis and geotectonic setting of ultramafic rocks in the Eastern Alps: constraints from geochemistry". *Lithos,* vol. 65, pp. 69-112, 2002.

[33] J. Kim, R. Coish, M. Evans and Dick, "Supra-subduction zone extensional magmatism in Vermont and adjacent Quebec: Implication for early paleozoic\ Appalachian tectonics". *Jour. Geological Society of America*, vol. 115, no. 12, pp. 1552-1569, 2003.

[34] A.W. Hofmann, "Sampling mantle heterogeneity through oceanic basalts: Isotopes and trace elements, In Holland, H. D. ana Turekian, K. K. (Eds.), Treatise on Geochemistry". *Elsevier Pergamon, Amsterdam – Boston*, vol. 2, pp. 61-101, 2004.

[35] M. K., Bose, "*Igneous petrology". first edition, the world Press Private Limited, Calcutta*, 567p., 1997.