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MINERALOGICAL, PETROGRAPHICAL AND GEOCHEMICAL CHARACTERISTICS OF ELDIVAN OPHIOLITE (ÇANKIRI) HARZBURGITIC TECTONITES

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ABSTRACT.- The Eldivan Ophiolite is located at the central part of the İzmir-Ankara-Erzincan Ophiolitic Belt which is between Şabanözü, Eldivan and Korgun towns. From bottom to top, units forming the ophiolite consist of volcano sedimentary and metamorphic series, tectonites, cumulates and sheeted dikes. Tectonites, which are the main subject of the study, are generally represented by harzburgites and occassionally consist of dunite, pyroxenolite and chromitite levels. In harzburgites which have traces of plastic deformation (foliation, lineation and folding), the minerals display a distinct orientation as a result of intra crystallographic dislocation and grinding mechanism. The degree of deformation decreases upwards. Less amount of clinopyroxene is encountered at lower levels of harzburgites which are composed of olivine (60-90%) and orthopyroxene (10-35%). There is also observed a decrease in the amount of orthopyroxene and an increase in chromite ratio towards upper levels. The composition of olivines is usually forsteritic and orthopyroxene is enstatitic and display a slight impoverishment in Mg content towards upper levels. However, there is observed a decrease in the amount of chrome but an increase in aluminum amount in upward direction. This situation can be explained as a result of primary composite of upper mantle and partial melting processes.

Key Words: Eldivan Ophiolite, harzburgite, chromite, olivine, tectonite.

INTRODUCTION

Ophiolites representing the segments exposing on the continent of oceanic lithosphere are important in terms of determining the petrological descriptions of the oceanic crust and the upper mantle which is difficult to investigate and to get information about the geodynamic evolution of the region which they occur.

İzmir - Ankara - Erzincan Suture Zone is the residual of İzmir - Ankara - Erzincan Ocean which occurs amongst Sakarya, Pontides and Kırşehir Blocks and Anatolide - Tauride platforms (Şengör and Yılmaz, 1981). This zone which starts from the north of İzmir at west and extends approximately 2000 km until the Georgian border at east (Okan and Tüysüz, 1999), continues namely as the Sevan-Akera Suture Zone at Caucasians (Khain, 1975; Adamia et al., 1977; Knipper, 1980). The NE-SW trending Eldivan Ophiolite occurring within the central parts of İzmir - Ankara - Erzincan Suture Zone (Figure 1a) represents the fragments of lithosphere belonging to the Neothethys Ocean which has started to rift towards the ends of Triassic and closed within the Upper Cretaceous - Lower Paleocene and there are several studies about its stratigraphy, tectonical environment and geochemical properties (Bailey and McCallien, 1953; Akyürek, ,1981; Tankut, 1984; Tankut and Gorton, 1990; Floyd, 1993; Önen and Hall 1993; Rojay et al 1995; Yalınız et al. 1998; Rojay et al. 2001; Rojay et al. 2004; Göncüoğlu et al. 2006; Dangerfield, 2008; Gökten and Floyd 2007; Çakır, 2009;). Units in the region are the rocks belonging to the Eldivan Ophiolites, Cenomanian and after Cenomanian aged cover rocks cropping out on them (Figure 1b).

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Eldivan Ophiolitic deposit from bottom to top is represented by volcano sedimentary series (basalt, radiolarite - chert - mudstone) and the overlying metamorphic series (amphibolite, epidosite, quartzite), tectonites (dunite, harzburgite, chromite), cumulates (dunite, pyroxenite, gabbro, diorite, plagiogranite) and plate dykes (Figure 2). All units within the deposit except volcanic series are cut by isolated diabase dykes. Among these units, volcano sedimentary series and metamorphics which crop out around close vicinity are not observed on the map (Figure 1) but were shown on the generalized columnar section (Figure 2). Mart, Karakoçaş and Hançılı formations which directly lie on the Eldivan Ophiolite and shown as cover units in figure 2 represent a tectonical relationship with this ophiolite. The unit named by Akyürek et al (1979, 1981) starts with conglomerate and sandstone layers forming by the sediments of the Eldivan Ophiolites at bottom and continues with the alternation of siltstone, sandstone, conglomerate and marn layers. Limestone layers are sporadically observed at the uppermost layers. Mart formation is the first unit that directly overlies the Eldivan Ophiolite. The age of the unit has been detected as Cenomanian - Turonian due to its fossil content (Akyürek et al., 1979). The other unit, Karakoçaş Formation is generally composed of reddish colored, coarse grained conglomerates and sandstones. The age of the units has been determined as Late Miocene due to its stratigra-

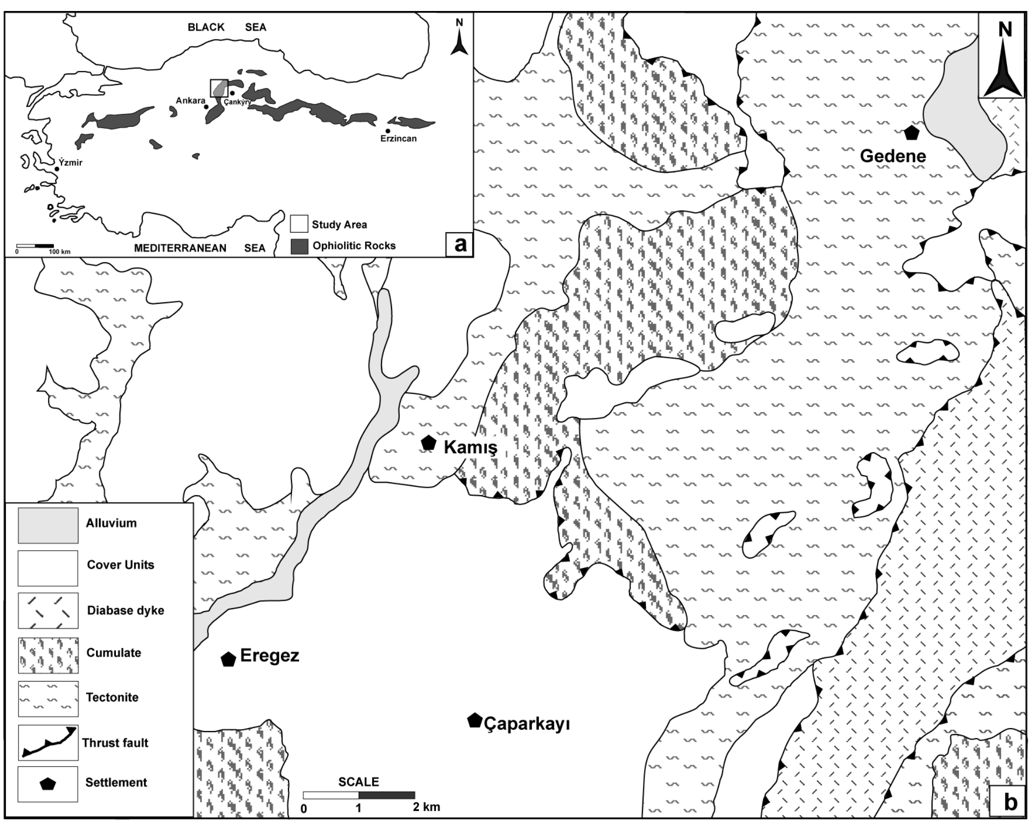

Figure 1- a) Map showing the location of study area in İzmir-Ankara-Erzincan belt, b) the simplified geological map of Eldivan Ophiolite and cover rocks observed in the study area (modified from Akyürek et al., 1979; Hakyemez et al., 1986).

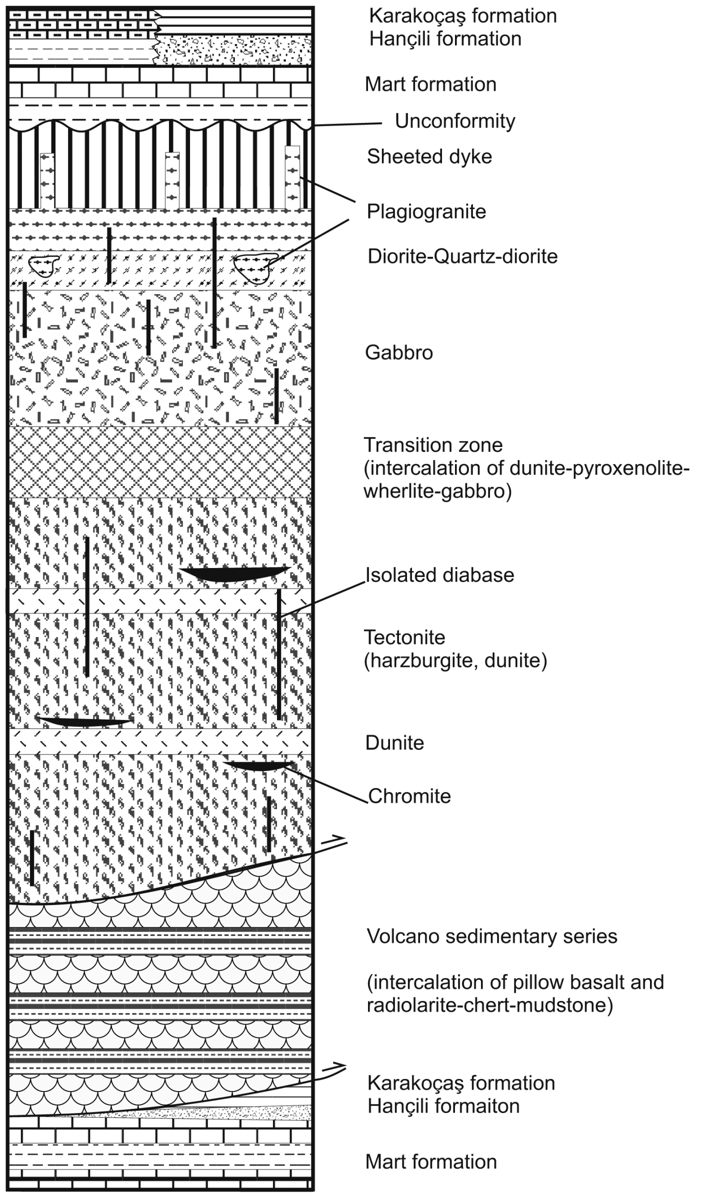

Figure 2- The tectono-stratigraphic columnar section of the Eldivan Ophiolite and units (after the settlement) (not to scale).

phical position. However, The Hançılı formation is composed of alternation of siltstone, marn, clayey limestone and tuff - tuffite. Sporadically, gypsium and coal layers were encountered. The Late Miocene age were detected from the samples taken from some coal layers by performing the pollen analysis (Akyürek et al., 1979). Mart, Karakoçaş and Hançılı formations unconformably overlie the Eldivan Ophiolite. Due to the post Miocene tectonism developed, it is observed that Eldivan Ophiolite had thrusted over Mart, Karakoçaş and Hançılı formations at some places (Figure 1 and 2).

In this study, it was aimed at detecting the geological and geochemical properties of peridotites of the Eldivan Ophiolite which have less been investigated so far. Within this scope, the geological map of the region was prepared and environments of formation of these rocks were determined analyzing the geochemistry of olivine, orthopyroxene and spinel minerals in samples taken from tectonites of the Eldivan Opholite.

TECTONITES OF THE ELDİVAN OPHIOLITES

Peridotites with tectonite texture form the most significant part of the Eldivan Ophiolite. Mylonitic and schistositic serpentines are clearly observed within the contact zone of tectonites that had thrusted over volcano sedimentary series. Tectonites are generally composed of harzburgites and sporadically constitute dunitic, chromitic and pyroxenolitic layers and have traces of plastic deformation. The rock has gained a distinctively foliated and lineated form due to gliding, grinding and recrystallization of intra crystals of minerals. Towards the upper levels the degree of deformation decreases, despite that; dunitic levels and chromite ores were frequently encountered. Harzburgite and dunitic tectonites were serpentinized at high levels.

As a result of petrographical studies of samples taken from tectonites, it was investigated that these units were formed by serpentinized harzburgites in general. Harzburgites forming tectonites constitute olivine (60-70%) (forsterite), orthopyroxene (enstatite) (20-30%), chromite ((3 -5%) and clinopyroxene (1-2%). Textural properties observed here are same as the common textural properties observed in harzburgites. Rocks are generally granoblastic in structure (Figure 3a) and in mosaic texture which small olivine minerals (product of recrystallization) have formed especially around peripheral zones of coarse olivine and pyroxene minerals were sporadically observed (Figure 3b). Tiny olivine crystals showing mosaic texture are in the form of surrounding the coarse crystals. Tiny olivine crystals that are the product of recrystallization show wavy extinction around some of the coarse olivine crystals that have the same extinction. This phenomenon indicates that the plastic deformation causing the wavy extinction continues after recrystallization too (Engin et al., 1980). Along cracks that have developed within olivines the serpentinization is obviously observed (Figure 3d). Olivines that are present as disseminated in small dimensions within the grain sizes of orthopyroxenes enclose orthopyroxene grains (See Figure 3a). Orthopyroxene minerals are generally in medium to coarse grained and disintegration along cleavages (Figure 3c) and thin clinopyroxene exsolution lamellae that have developed parallel to the planes of cleavage were sporadically observed (Figure 3d). Deformation lamellae (kink banding) were seldom observed in enstatite minerals that showed slight elongation (Figure 3e, 3f). Magnetisation at different proportions was observed around chromite minerals that had variable crystal sizes (Ferric chromite). Serpentinization along crack systems that developed in one or sometimes two ways was evident in minerals that had disintegrated as a result of deformation.

Within upper layers of tectonites, generally veins that have thickness in centimeter or decimeter scale and often pyroxenolites that are observed as phyllonite cut harzburgites in such a way to make a small angle with foliation plane. Pyroxenolite phyllonite made by solutions of the partial melting product have been folded during plastic deformation forming the foliation (Figure 4a).

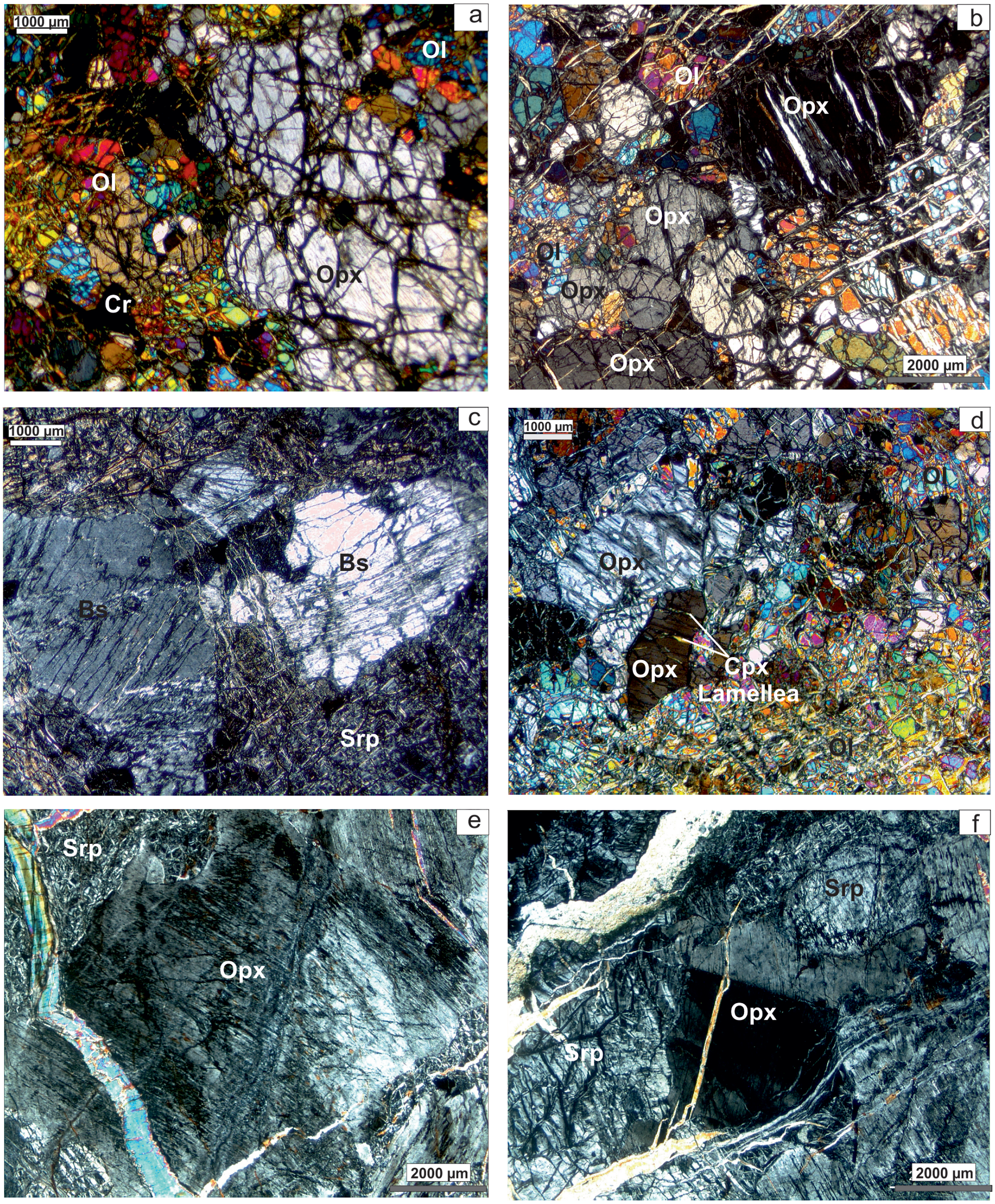

Figure 3- Thin-section images of harzburgites, a) granoblastic texture observed in harzburgites, b) tiny olivine minerals observed around the orthopyroxene, c) orthopyroxene minerals alterated to the bastite, d) exsolution lamellae of clinopyroxene among orthopyroxene minerals, e) and f) deformation lamellae observed in enstatite minerals (Ol: olivine, Opx: orthopyroxene, Cpx: clinopyroxene, Serp: serpentinite minerals, Cr: chromite, Bs: bastite).

Dunitic zones are observed as in lenses and bands at variable thicknesses generally in the upper layers of tectonites (Figure 4b). Olivine (90 -96%), orthopyroxene (1-3%) and chromite (3-5%) minerals are present in dunites. While olivines are observed as residuals in some thin sections (Figure 5a), these are seen as in tiny particles in nucleic parts of the sieve textured high level serpentinized samples. It is considered that the sieve structure that are widely observed in thin sections have developed in this way. Chromite minerals within dunites are available at higher proportions than harzburgites. It is accepted that the pull apart texture observed in chromites within dunites have developed as a result of tensional forces during plastic deformation (Engin et al., 1980) (Figure 5b).

Chromites that are present generally in dunitic and sometimes in harzburgitic zones show massive, nodular and dispersive distributions in rock. Typical elongation and orientation seen in chromite minerals can be observed in the rock (Figure 6). Flattening and elongation that could macroscopically be distinguished in minerals such as orthopyroxene and chromite indicate the presence of foliation planes in the rock.

Peridotites of the Eldivan ophiolite were largely serpentinized. Serpentines that generally show massive structure are covered by brown to yellow colored crust in centimeter thickness which has formed due to atmospheric leaching. These rocks that can be described by their massive and green to black colored views when broken represent a schistosic appearance at fault zones and along margins of diabase dikes. After serpentinization, the rock gains a mottled green colored, slippery and shiny view as a result of the period that has occurred in tectonically active zones.

Petrographical studies and X-RD analyses were performed in order to describe serpentine minerals. Chrysotile-γ, chrysotile-α and lizardite minerals were encountered during petrographical investigations of the samples taken (Figure 7). While chrysotiles are distinguished according to the crystallographic structures of minerals, lisardites are detected due to their massif form and are in the form of sieve texture. Due to the results of X-RD analyses, chromite, orthoserpentinite, forsterite and pyroxene minerals were encountered in addition to the minerals mentioned above (Figure 8). The presence of chrysotile, lizardite and antigorite minerals

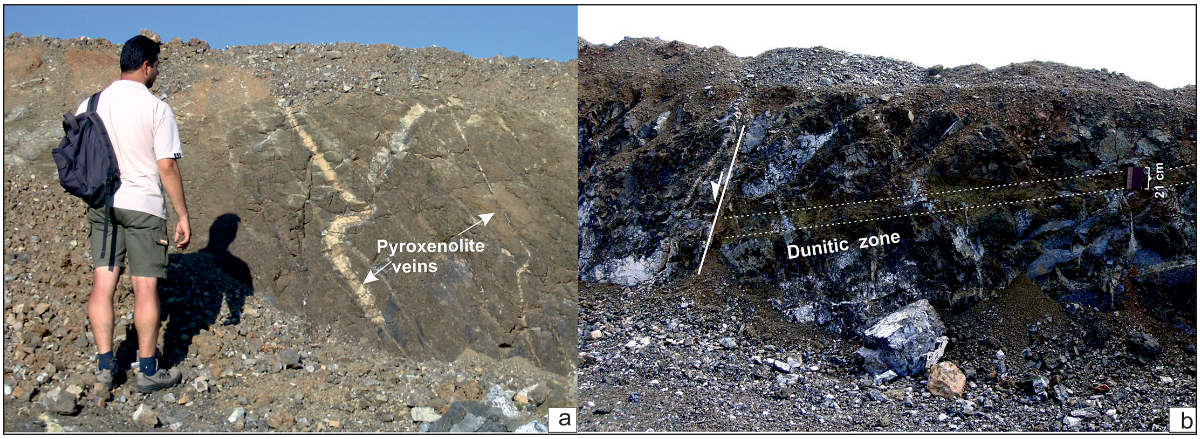

Figure 4- Within the tectonites of the Eldivan Ophiolite; a) folded pyroxenolite vein observed in harzburgite and b) Dunitic bands.

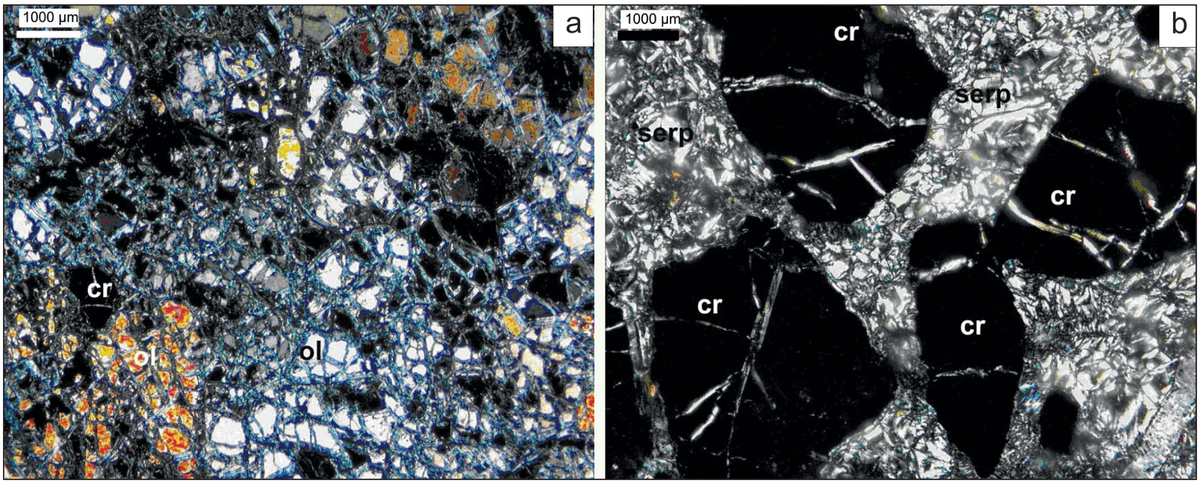

Figure 5- Minerals and textures observed in dunites, a) sieve texture, b) pull-apart structures in chromites (ol: olivine, serp: serpentinite, cr: chromite).

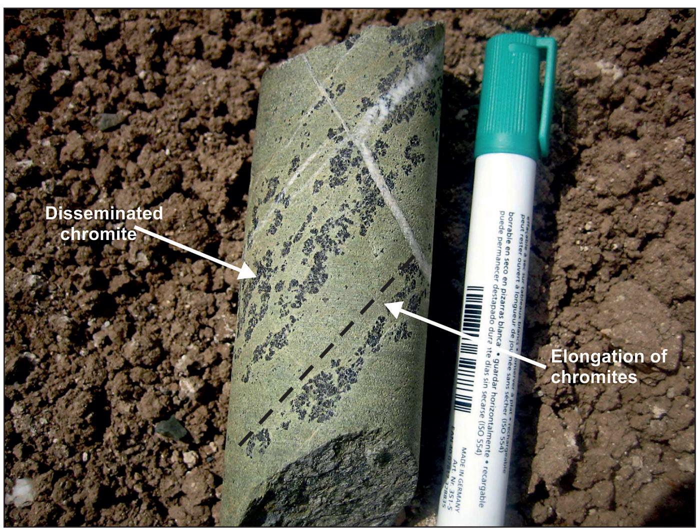

Figure 6- Flattened and elongated chromite minerals within dunitic zones in the Eldivan Ophiolite.

altogether indicates that the serpentinization has formed at a temperature of up to 500°C (Coleman, 1977).

MINERAL CHEMISTRY OF PERIDOTITES

As a result of mineralogical investigations point analyses were performed by means of EDS (Energy Dispersive Spectrometer) device on two fresh harzburgite samples (showing no alteration) belonging to Eldivan formation. In order to perform these analyses, JEOL - 6490 electron microscope, SQ analysis program and ZAF correction program have been used which are available at the Directorate of Sedimantology and Reservoir Geology of Turkish Petroleum

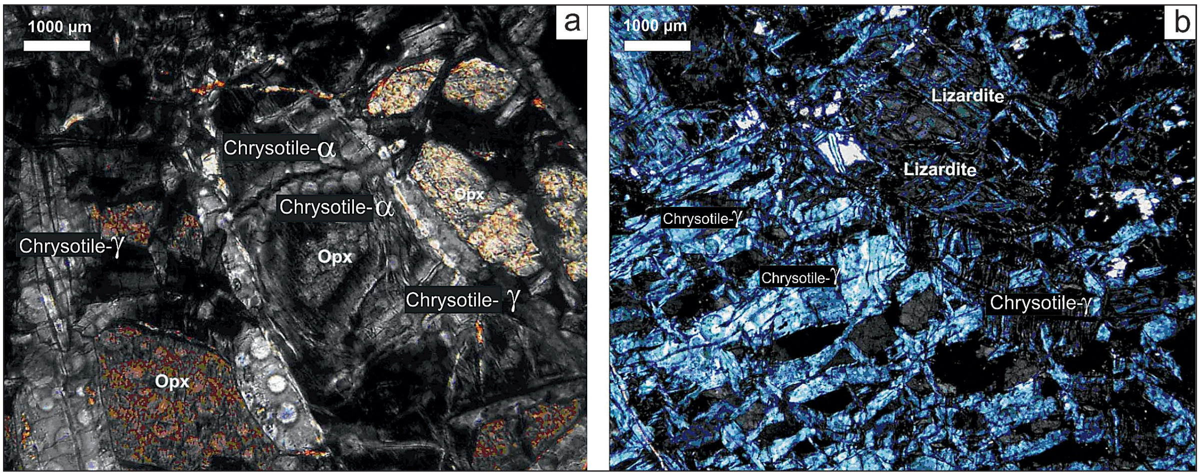

Figure 7- Thin-section views of serpentine group minerals, a) chrysotile - α ve chrysotile - γ minerals surrounding the orthopyroxene mineral, b) chrysotile - γ and lizardite minerals.

Corporation (TPAO). By this technique, the chemistry of minerals (olivine, orthopyroxene, clinopyroxene, spinel) in the rock were defined and their structural formulae were calculated by CALCMIN software.

Olivine minerals

According to the mineralogical chemistry analysis performed on olivine minerals in harzburgite samples belonging to Eldivan Ophiolite, forsterite constituents (Fo) of olivines and Mg# $(100^*(Mg/(Mg+Fe^{+2})))$ values range in between 88 - 92% and 90 - 94%, respectively (Table 1). Olivine minerals that have Fo_{88}-Fo_{92} values indicate excessively depleted harzburgite and dunite (Uysal et al., 2007).

Pyroxene minerals

Results of analyses obtained from orthopyroxene (Table 2) and clinopyroxene (Table 3) in harzburgites were assessed according to the En - Wo - Fs classification prepared by Morimoto (1989). According to this, it was determined that orthopyroxene minerals showed an abundance on behalf of enstatite due to their Mg contents (Figure 9a). However, clinopyroxene minerals were detected as in the character of diopside (Figure 9b).

Cr - Spinel minerals

Cr - spinels are accepted as one of the best indicators of partial melting period of mantle peridotites (Matsukage and Kubo, 2003; Tamura and Arai, 2006; Uysal et al., 2007). Cr_2O_3 values were detected as 32.09-48.43%, Al_2O_3 values as 12.14-19.89%, Fe_2O_3 values as 1.95-23.78%. However; MgO values were detected as 9.26-15.05% in chemical analyses of Cr- spinel minerals within harzburgites (Table 4). The large range observed in Fe_2O_3 and Al_2O_3 values indicate that chromites were subjected to alteration (Uysal et al., 2007 and Singh, 2009).

Cr - spinels were plotted on Al-$(Fe^{+3}$+2Ti)-Cr ternary diagram (Figure 10a) and on $100^*Mg/(Mg+Fe^{+2})$-$100^*Cr/(Cr+Al)$ diagram (Figure 10b) in order to understand its character. As a result it was seen that these samples fell into Alpine type peridotites. Chemical changes determined in Cr - spinels might be due to magmatic alterations or regional metamorphism (Cameron, 1975; Kimball, 1990). However, it was observed that Cr - Spinel minerals belonging to Eldivan

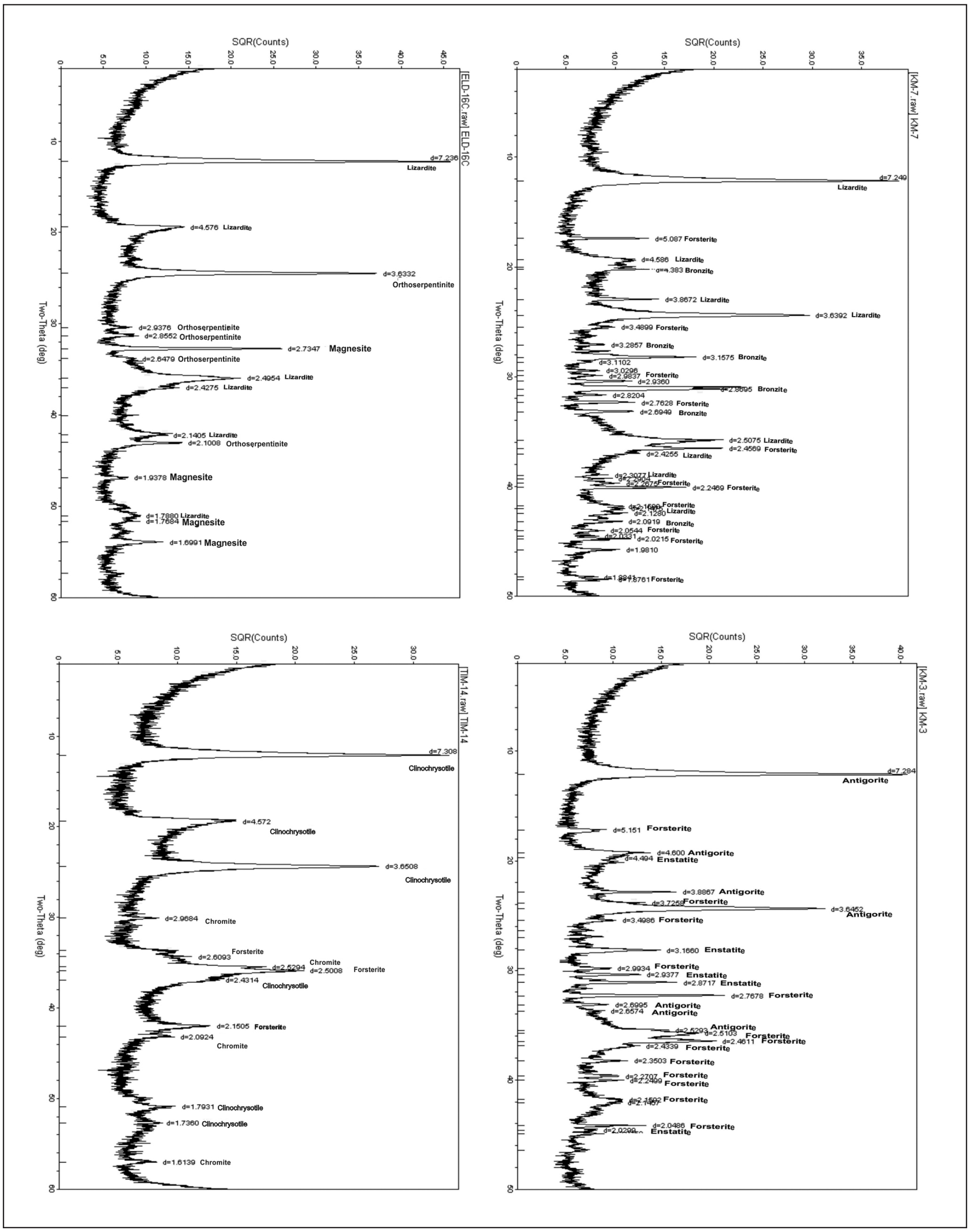

Figure 8- X-RD results taken from serpentine minerals of the Eldivan ophiolite. Chrysotile, lizardite, chromite, ortho-serpentine, forsterite and pyroxene minerals occur in ophiolitic rocks.

Table 1- The results of analysis and cation values of olivine mineral in harzburgites belonging to the Eldivan Ophiolite.

	KM-2			Mİ-13		
X	1.00	2.00	3.00	4.00	5.00	6.00
SiO_2	42.50	39.89	41.76	41.93	41.40	38.14
TiO_2	0.14	0.23	0.11	0.14	0.13	0.26
Al_2O_3	0.01	0.04	0.09	0.17	0.02	0.05
Cr_2O_3	0.11	0.14	0.00	0.00	0.00	0.00
FeO	7.44	9.19	9.11	9.12	8.77	5.42
Fe_2O_3	0.00	0.35	0.00	0.00	0.00	6.11
MgO	48.37	48.31	48.41	48.36	49.34	49.60
CaO	0.15	0.25	0.21	0.13	0.12	0.20
Total	98.72	98.38	99.69	99.85	99.79	99.78
Cation=3, Fe^{2+}/Fe^{3+}, valance=8						
	KM-2			Mİ-13		
Fe_2	0.1539	0.1908	0.1871	0.1871	0.1793	0.1114
Mn	0.0030	0.0092	0.0064	0.0032	0.0044	0.0077
Mg	1.7832	1.7883	1.7712	1.7696	1.7980	1.8183
sum6	1.9400	1.9883	1.9647	1.9600	1.9818	1.9375
Si	1.0508	0.9907	1.0250	1.0292	1.0121	0.9380
Ti	0.0025	0.0042	0.0021	0.0025	0.0024	0.0048
Al	0.0003	0.0011	0.0026	0.0048	0.0006	0.0013
Cr	0.0022	0.0027	0.0000	0.0000	0.0000	0.0000
Fe_3	0.0000	0.0065	0.0000	0.0000	0.0000	0.1130
V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ca	0.0041	0.0066	0.0055	0.0035	0.0032	0.0053
sum4	1.0600	1.0117	1.0353	1.0400	1.0182	1.0625
Fo	92.0571	90.0368	90.4480	90.4376	90.9323	88.4677
Fa	7.9429	9.9632	9.5520	9.5624	9.0677	11.5323
Mg#	92.0551	90.3593	90.4458	90.4380	90.9321	94.2271

Ophiolites fell into MORB type peridotite region in Al_2O_3-Fe^{+2}/Fe^{+3} diagram (Kamenetsky et al., 2001) (Figure 11).

GEOCHEMICAL PROPERTIES OF TECTONITES

Total rock analyses for 5 samples taken from harzburgites were performed by XRF and ICP - MS devices in ACME laboratories (Canada). When results of major oxide analyses were investigated, it was observed that SiO_2 values and MgO values had ranged in between 44- 47% and 41 - 45%, respectively. However, FeO values were determined as ranging in between 8 - 9% (Table 5). It is seen that all samples are rich in Mg and were clustered in metamorphic peridotite

Table 2- The results of analysis and cation values of orthopyroxene minerals in harzburgite samples belonging to the Eldivan Ophiolite.

	K-02									Mİ-13				
	1-3	1-1	2-3	4-2	4-3	4-4	4-5	5-1	5-2	1-3	2-5a	4-1	6-1	6-3
SiO_2	55.38	52.67	55.98	55.40	51.58	49.09	55.15	51.19	52.82	50.90	52.37	50.33	51.36	51.30
TiO_2	0.11	0.30	0.22	0.15	0.12	0.22	0.11	0.11	0.20	0.00	0.16	0.28	0.00	0.00
Al_2O_3	2.66	2.43	2.12	2.55	2.39	0.41	2.64	2.30	2.93	1.67	2.49	2.39	1.62	1.80
Cr_2O_3	0.67	1.40	0.46	0.30	0.80	0.14	0.53	0.77	0.69	0.69	0.90	0.59	0.83	0.47
FeO	4.09	6.00	5.41	2.23	3.42	4.20	1.55	4.81	1.19	3.68	2.02	2.82	2.41	2.40
Fe_2O_3	2.35	4.78	1.02	3.38	5.25	8.95	3.85	6.59	6.31	6.12	6.04	5.50	5.95	5.22
MnO	0.16	0.13	0.22	0.00	0.00	0.00	0.24	0.31	0.20	0.00	0.24	0.11	0.30	0.42
MgO	33.13	29.80	33.04	34.65	35.50	37.10	34.62	32.47	35.38	36.23	35.50	36.92	37.63	38.32
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	1.05	1.63	0.67	0.67	0.72	0.20	0.71	1.36	0.99	0.21	0.65	0.28	0.39	0.33
Na_2O	0.36	0.41	0.38	0.33	0.33	0.39	0.35	0.00	0.00	0.29	0.00	0.61	0.00	0.40
Total	99.97	99.54	99.52	99.65	100.10	100.69	99.76	99.92	100.69	99.78	100.37	99.84	100.49	100.64

Valences = 12, cations = 4, Fe^{2+}/Fe^{3+}- All calculations made of with modelling OPX (Brandelik and Massonne, 2004)

	1-3	1-1	2-3	4-2	4-3	4-4	4-5	5-1	5-2	1-3	2-5a	4-1	6-1	6-3
Si	1.9152	1.8717	1.9439	1.9075	1.7767	1.6447	1.8982	1.7988	1.8184	1.7223	1.8030	1.6778	1.7240	1.7239
Al_T	0.0848	0.0000	0.0561	0.0925	0.0000	0.0000	0.1018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sum4	2.0000	1.8717	2.0000	2.0000	1.7767	1.6447	2.0000	1.7988	1.8184	1.7223	1.8030	1.6778	1.7240	1.7239
Al_O	0.0235	0.1017	0.0308	0.0111	0.0969	0.0162	0.0053	0.0952	0.1188	0.0666	0.1167	0.1147	0.0642	0.0785
Ti	0.0028	0.0081	0.0057	0.0038	0.0031	0.0056	0.0030	0.0029	0.0052	0.0000	0.0042	0.0070	0.0000	0.0000
Cr	0.0183	0.0392	0.0126	0.0081	0.0218	0.0036	0.0144	0.0214	0.0188	0.0720	0.0244	0.0156	0.0344	0.0389
Fe_3	0.0613	0.1278	0.0267	0.0876	0.3435	0.7046	0.0997	0.2801	0.2152	0.4359	0.2445	0.5394	0.4534	0.4607
Fe_2	0.1183	0.1784	0.1572	0.0641	-0.1274	-0.5099	0.0445	-0.1414	-0.0342	-0.3021	-0.0582	-0.4410	-0.3670	-0.3657
Mn	0.0046	0.0038	0.0065	0.0000	0.0000	0.0000	0.0070	0.0093	0.0059	0.0000	0.0069	0.0032	0.0086	0.0118
Mg	1.7081	1.5790	1.7102	1.7786	1.8226	2.1027	1.7763	1.5439	1.8156	1.9788	1.8218	2.0338	2.0684	2.0142
Ni	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ca	0.0391	0.0620	0.0248	0.0249	0.0412	0.0073	0.0263	0.3899	0.0364	0.0075	0.0367	0.0101	0.0140	0.0117
sum6	2.0000	2.1283	2.0000	2.0000	2.2233	2.3553	2.0000	2.2012	2.1816	2.2777	2.1970	2.3222	2.2760	2.2761

components	1-3	1-1	2-3	4-2	4-3	4-4	4-5	5-1	5-2	1-3	2-5a	4-1	6-1	6-3
X-ENS_ORTHO	0.8085	0.6957	0.8348	0.8398	0.7029	0.5919	0.8297	0.3898	0.7674	0.6965	0.7509	0.6768	0.7292	0.7106
X-FERROSILITE	0.0560	0.0786	0.0767	0.0303	0.0491	0.1435	0.0208	0.0357	0.0144	0.1064	0.0240	0.1468	0.1294	0.1290
X-Al_ENS_B	0.0118	0.0133	0.0154	0.0055	0.0632	0.1696	0.0026	0.0530	0.0314	0.1055	0.0402	0.1037	0.1059	0.0988
X-CPX	0.0391	0.0620	0.0248	0.0249	0.0412	0.0073	0.0263	0.3899	0.0364	0.0075	0.0367	0.0101	0.0140	0.0117
X-NA_CPX	0.0239	0.0283	0.0255	0.0219	0.0217	0.0251	0.0235	0.0000	0.0000	0.0191	0.0000	0.0394	0.0000	0.0259
X-REST	0.0608	0.1487	0.0228	0.0776	0.3466	0.6887	0.0971	0.3090	0.2421	0.4888	0.2766	0.5243	0.4920	0.4796

Table 3- The results of analysis and cation values of the clinopyroxene minerals in harzburgites belonging to the Eldivan Ophiolite (valence=12, cation=4).

	K-02						Mİ-13		
Comment	1-2	1-6	2-1	2-5	2-6	5-3	1-7	2-8	5-8
SiO_2	53.02	51.28	50.27	47.96	50.84	53.54	47.69	46.55	47.54
TiO_2	0.15	0.20	0.14	0.30	0.22	0.10	0.16	0.30	0.38
Al_2O_3	2.90	2.56	2.15	2.12	2.25	2.84	2.71	2.06	2.65
Cr_2O_3	0.95	1.00	0.87	0.73	1.03	0.65	0.93	0.97	0.00
Fe_2O_3	0.05	2.51	2.27	3.24	3.04	0.00	2.93	3.28	3.03
FeO	2.08	0.00	0.00	0.00	0.00	2.16	0.00	0.00	0.00
MnO	0.17	0.13	0.29	0.27	0.24	0.10	0.12	0.22	0.36
MgO	16.91	16.01	16.28	15.54	16.95	18.69	17.68	14.75	16.09
CaO	23.56	25.84	27.27	29.23	25.13	20.68	27.44	31.99	29.92
Na_2O	0.20	0.46	0.21	0.29	0.22	0.44	0.00	0.07	0.00
K_2O	0.02	0.02	0.02	0.19	0.08	0.00	0.08	0.13	0.00
Total	100.00	100.00	99.78	99.87	100.00	99.19	99.73	100.33	99.96
Si	1.9267	1.8701	1.8366	1.7564	1.8541	1.9427	1.7359	1.7052	1.7353
Al_T	0.0733	0.0000	0.0000	0.0000	0.0000	0.0573	0.0000	0.0000	0.0000
sum4	2.0000	1.8701	1.8366	1.7564	1.8541	2.0000	1.7359	1.7052	1.7353
Al_O	0.0509	0.1100	0.0927	0.0915	0.0969	0.0641	0.1162	0.0890	0.1139
Ti	0.0042	0.0055	0.0037	0.0084	0.0061	0.0027	0.0044	0.0082	0.0105
Cr	0.0273	0.0288	0.0252	0.0213	0.0297	0.0187	0.0266	0.0282	0.0000
Fe3	0.0013	0.0688	0.0624	0.0894	0.0834	0.0001	0.0803	0.0903	0.0831
Fe2	0.0632	0.0000	0.0000	0.0000	0.0000	0.0654	0.0000	0.0000	0.0000
Mn	0.0053	0.0040	0.0090	0.0083	0.0075	0.0031	0.0036	0.0069	0.0110
Mg	0.9161	0.8702	0.8868	0.8482	0.9215	1.0110	0.9591	0.8056	0.8758
Ca	0.9171	1.0097	1.0676	1.1472	0.9819	0.8039	1.0702	1.2557	1.1703
Na	0.0137	0.0322	0.0149	0.0207	0.0152	0.0310	0.0000	0.0049	0.0000
K	0.0008	0.0007	0.0010	0.0088	0.0038	0.0000	0.0037	0.0060	0.0000
sum6	2.0000	2.1299	2.1634	2.2436	2.1459	2.0000	2.2641	2.2948	2.2647
Na_start	0.0137	0.0322	0.0149	0.0207	0.0152	0.0000	0.0000	0.0049	0.0000

(ultramafite tectonite) zone when these were plotted in order to define the differentiation grades of samples at Al_2O_3-CaO-MgO diagram made by Coleman (1977) (Figure 12). The term "metomorphic peridotite" can also be named as "tectonic harzburgite", "harzburgite type", "Alpine type ultramafic" (Jackson and Thayer, 1972).

When Cr_2O_3-NiO values obtained as a result of geochemical analyses of tectonites in the study area were plotted on the discrimination diagram of Irvine and Findlay (1972), it was seen that all samples were condensed over the region of "Alpine type peridotite" (Figure 13). When major oxide analysis results obtained from rocks in the region were plotted on Ringwood's (1975)

Table 4- The results of analysis of chromite minerals samples in peridotites of the eldivan Ophiolites (chrome spinel analyzes and Fe^{+2} and Fe^{+3} value were standardized using Droop (1984) equation. Cation number were taken as 24 in all analyses).

sample	KM-2						MI-13				
Probe No	1-1	2-2	2-4	2-6	3-2	4-5	1-3	1-4	2-3	3-5	4-2
Cr_2O_3	37.14	27.91	33.98	31.87	26.11	33.55	39	34.43	38.34	37.85	34.11
Al_2O_3	27.91	40.96	31.56	36.64	41.08	34.01	27.74	31.73	23.01	29.01	26.32
TiO_2	0.14	0.12	0.05	0.093	0.09	0.07	0.14	0.08	0.06	0.08	0.04
FeO	11.34	13.44	13.71	11.35	15.46	18.61	11.37	13.38	16.8	15.6	12.06
Fe_2O_3	7.25	0.23	5.91	1.86	1.03	0.96	4.24	4.95	9.26	3.73	11.59
MgO	16.72	16.17	15.28	17.27	14.25	12.37	15.26	15.43	12.63	13.24	15.27
MnO	0.05	0.24	0.25	0.03	0.34	0.12	1.99	0.11	0.13	0.38	0.6
NiO	0	0	0	0	1.13	0	0	0	0	0.57	1.39
Total	100.69	99.13	100.74	99.24	99.67	99.9	99.92	100.05	100.49	100.41	101.77
Cr	6.8825	4.9862	6.2587	5.7479	4.6989	6.2628	7.3328	6.3652	7.4512	7.1456	6.3751
Al	7.7146	10.9116	8.6695	9.8531	11.0252	9.4661	7.778	8.7454	6.6694	8.167	7.3369
Ti	0.0485	0.0316	0.0088	0.0395	0.0497	0.0503	0.0608	0.0035	0.0593	0.0054	0.0774
Fe3+	1.2792	0.0389	1.037	0.3185	0.1761	0.1702	0.7584	0.8702	1.7123	0.6695	2.0622
Fe2+	2.249	2.5393	2.6887	2.1676	2.9435	3.6755	2.2706	2.6293	3.5007	3.1219	2.4539
Mg	5.8418	5.4457	5.3045	5.87	4.8356	4.3509	5.4084	5.3766	4.6273	4.7119	5.3793
Mn	0.0105	0.0467	0.05	0.005	0.0648	0.0247	0.4001	0.0217	0.0269	0.0767	0.1202
Ni	0	0	0	0	0.2067	0	0	0	0	0.1091	0.2638
Total	24.0261	24	24.0171	24.0016	24.0005	24.0005	24.0091	24.012	24.0471	24.0071	24.0687
Mg/Mg+Fe2+	0.5863	0.4049	0.467	0.4883	0.3462	0.3311	0.5382	0.4727	0.455	0.4174	0.5494
Cr/Cr+Al	0.4715	0.3136	0.4193	0.3684	0.2988	0.3982	0.4853	0.4212	0.5277	0.4666	0.4649
Fe3+/ (Cr+Al+Fe3+)	0.0806	0.0024	0.065	0.02	0.0111	0.0107	0.0478	0.0545	0.1082	0.0419	0.1307

Al_2O_3-MgO diagram, it was seen that all samples were clustered over less depleted pyrolite zone (Figure 14).

In MgO/SiO_2-Al_2O_3/SiO_2 diagram (Figure 15), the MgO/SiO2 value in abyssal peridotites systematically decreases due to loss in MgO during the degradation period at the sea bottom (Snow and Dick, 1995; Niu, 2004, Paulick et al., 2006). MgO/SiO_2 decrease with Al_2O_3 increase can be explained by the process of suction of the melt at the thermal boundary layer (Niu, 2004; Paulick et al., 2006).

DISCUSSION AND RESULTS

As a result of geological, mineralogical and geochemical studies carried out in harzburgitic tectonites belonging to Eldivan Ophiolites, it was determined that these units represented the residual mantle after partial melting. Within tectonites, the increase in dunitic zones, gabbro and pyroxenolith phyllonites from bottom to top was interpreted as the partial melting grade had increased towards top. As a result of assessment of the chemical and all rock analyses of minerals forming peridotites of the Eldivan Ophiolite, it was considered that these rocks had been

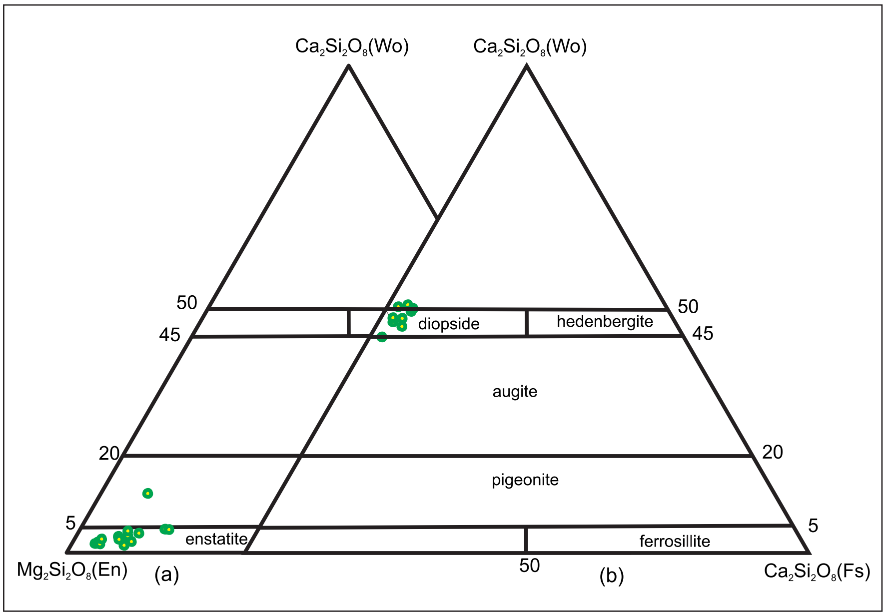

Figure 9- En-Wo-Fs distribution diagrams of (a) orthopyroxene and (b) clinopyroxene minerals in harzburgite samples of the Eldivan Ophiolite (after Morimoto, 1989

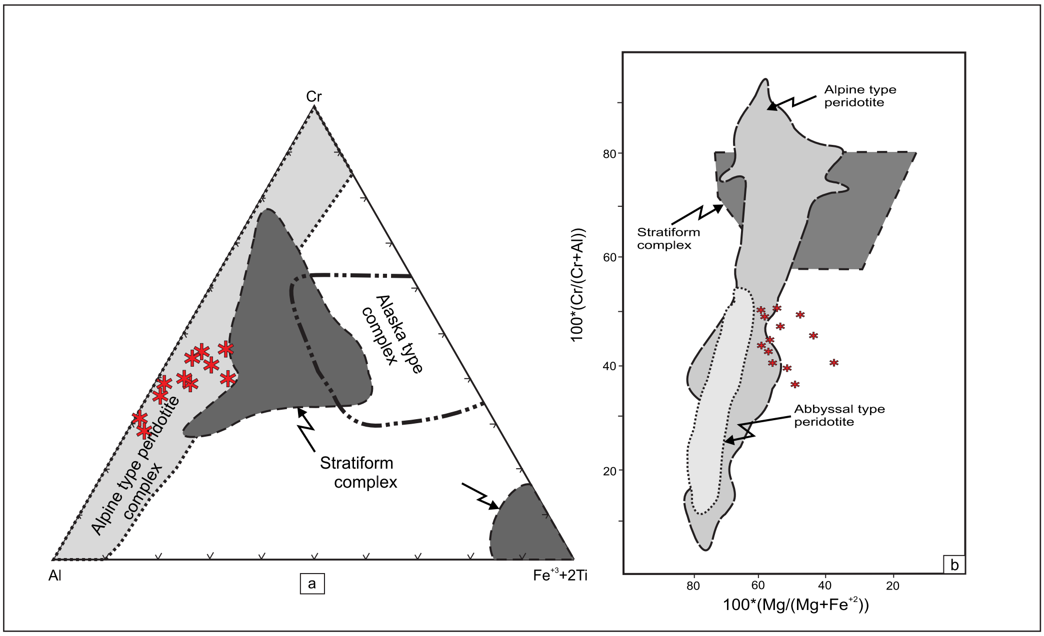

Figure 10- Plot diagrams of Cr-spinels of the Eldivan Ophiolite. a) Al-(Fe^{+3} + 2Ti)-Cr (modified from Jan and Windley, 1990), b) 100*Cr/(Cr+Al) ile 100*Mg/(Mg+Fe^{+2}) (modified from Dick and Bullen, 1984).

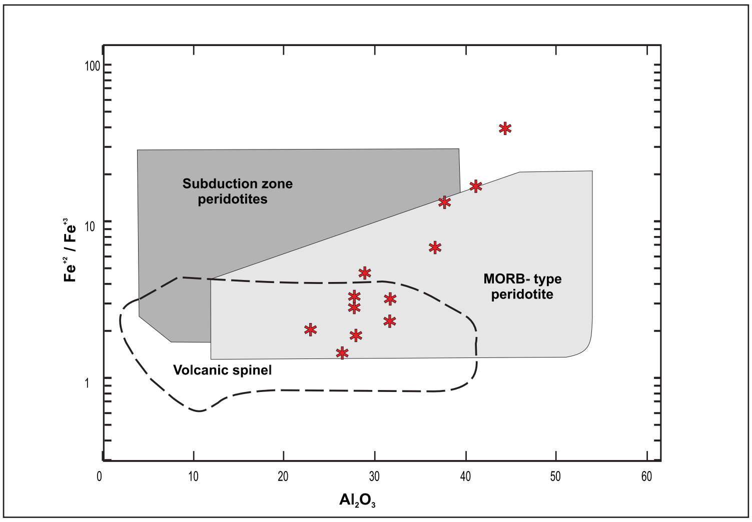

Figure 11- Display of Cr-spinel minerals on Fe^{+2}/Fe^{+3} - Al_2O_3 diagram (modified from Kamenetsky et al., 2001).

Table 5- The resutls of major oxide analyses of peridotites of the Eldivan Ophiolite.

	KM-1	KM-2	KM-3	KM-5	KM-7	KM-9	SB-3	SB-6
SiO_2	41.32	37.65	41.79	37.99	42.49	43.21	40.38	42.21
Al_2O_3	1.07	0.15	1.18	0.14	1.45	0.98	1.25	0.73
Fe_2O_3	8.15	8.55	8.2	8.9	7.79	8.24	6.98	8.55
MgO	38.1	38.92	37.83	37.26	37.46	38.23	39.11	38.79
CaO	1.46	0.59	1.34	0.39	1.41	1.41	0.62	0.81
Na_2O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K_2O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TiO_2	0.01	0.03	0.01	0.02	0.03	0.03	0.03	0.04
P_2O_5	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MnO	0.12	0.11	0.12	0.11	0.12	0.12	0.16	0.15
NiO	0.27	0.31	0.26	0.31	0.25	0.28	0.35	0.38
Cr_2O_3	0.398	0.222	0.409	0.206	0.423	0.362	0.182	0.218
LOI	8.41	12.8	8.18	14.01	7.92	8.14	7.44	7.61
H_2O-	0.47	0.97	0.55	1.17	0.7	1.01	0.41	0.89
H_2O+	8.56	11.24	8.35	11.61	8.19	8.59	9.13	8.63
Ba	<5	<5	<5	<5	<5	<5	<5	<5
Sr	2	23	2	15	<2	2	18	21
Zr	<5	10	<5	<5	<5	<5	5	5
Y	<3	<3	<3	<3	<3	<3	<3	<3
Sc	12	5	12	5	13	12	12	12
Cu	0.003	<0.001	0.001	<0.001	0.002	0.002	0.003	0.004
Co	0.01	0.012	0.01	0.011	0.009	0.012	0.009	0.016

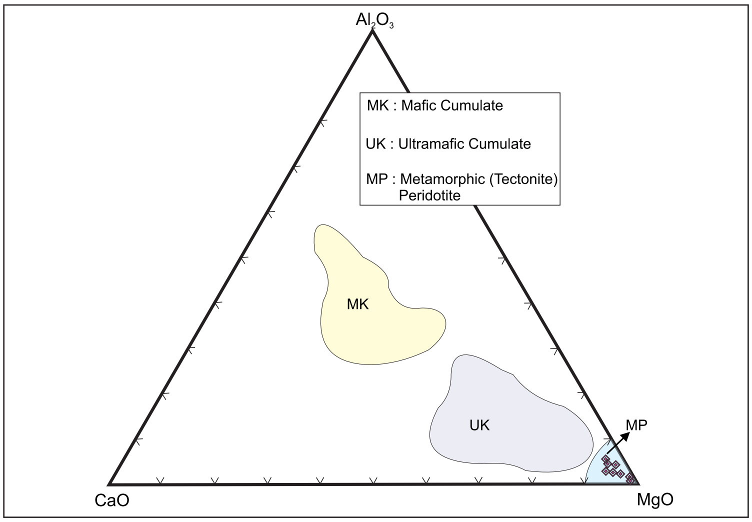

Figure 12- The plots of ultramafic rocks on CaO-Al_2O_3-MgO ternary diagrams belonging to the Eldivan Ophiolite (after Coleman, 1977).

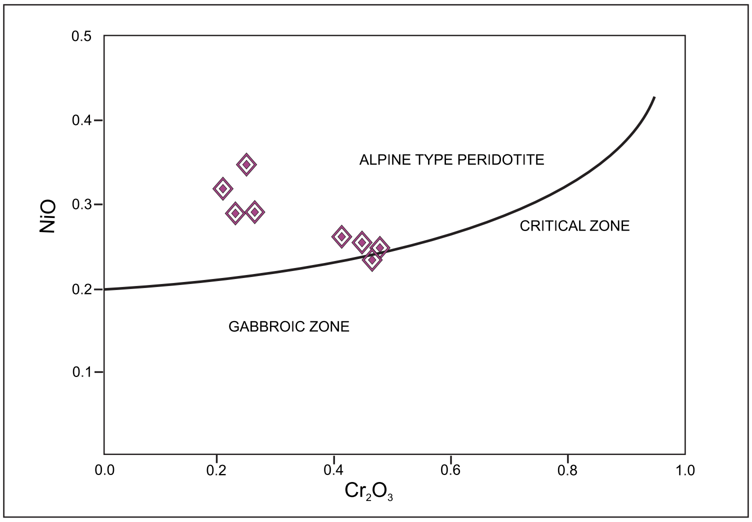

Figure 13- The plots of tectonite samples of the Eldivan Ophiolite on Cr_2O_3 - NiO diagram (after Irvine and Findlay, 1972).

derived by a low grade partial melt from a tholeiitic melt (for instance MORB). As a result of all rock chemical analyses, Mg proportions to be in high and Al and Ca proportions to be in low values show that rocks developed by the low grade partial melting of the primary mantle source and by its excess consumption. The percentage of Mg# in olivine minerals to be approximately 90 - 94% interval indicates that the origin of olivines occurring in peridotites is also mantle source.

When the formation of depleted harzburgite and dunites have reasons such as melting,

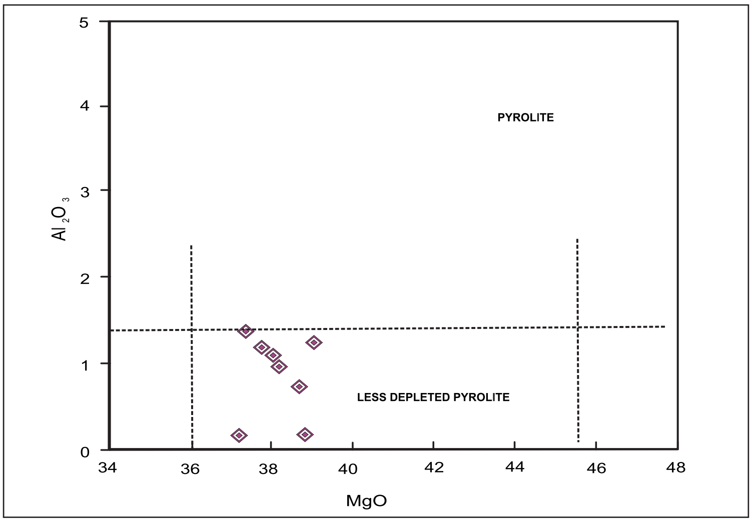

Figure 14- The distribution tectonites of the Eldivan Ophiolite on Al_2O_3-MgO diagram (after Ringwood, 1975).

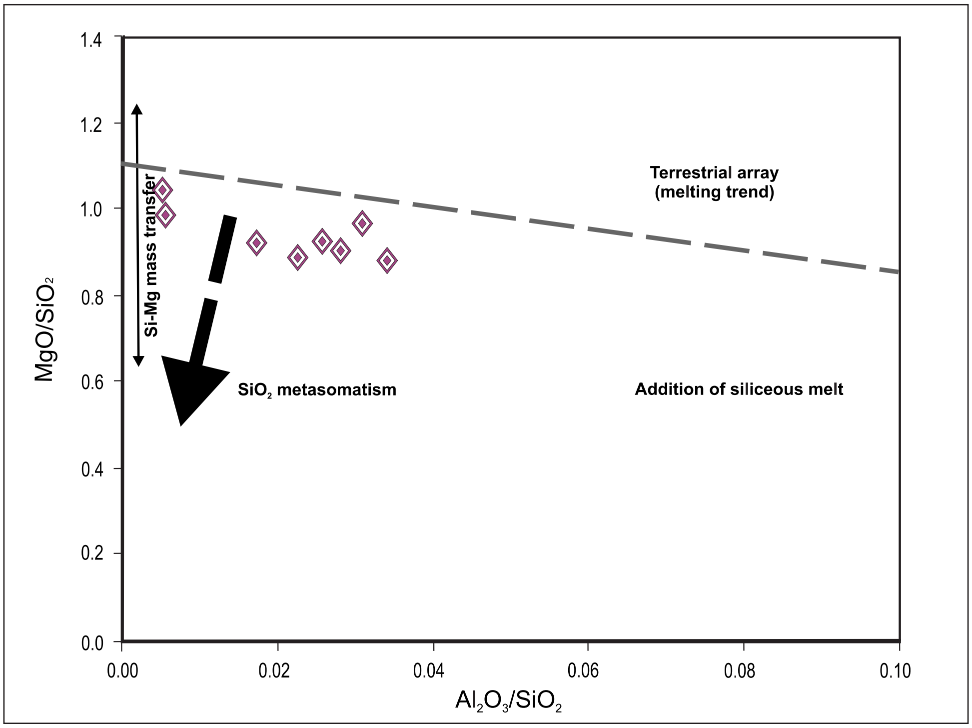

Figure 15- The diagram showing the plots of harzburgitic tectonites of the Eldivan Ophiolites on MgO/SiO_2 - Al_2O_3/SiO_2 diagram. Examples shown in the diagram present a parallelism with the boundary shown as dotted line and defined by the terresterial region (Jagoutz et al., 1979). The geochemistry of the samples is controlled by their modal mineralogical compositions and hydrothermal alterations (from Paulick et al., 2006).

mantle - melting interaction and mantle metasomatism are considered (Kelemen et al, 1992; Zhou et al., 1996; Uysal et al., 2007), it is inferred that harzburgite and dunite samples of the Eldivan Ophiolite were depleted rocks at different grades. Besides, number of Cr# in tectonite samples to be at variable proportions is one the best examples of he partial melting grade in mantle peridotites (Dick and Bullen, 1984; Arai, 1994; Tamura and Arai, 2006; Uysal et al., 2007).

Dunite and harzburgites are typical residuals of mantle melting in pyrolitic model (Wilson, 1993; Blatt and Tracy, 1996). The occurrence of residual type harzburgite and dunites depleted by Al_2O_3 in mid oceanic ridges too (Bacak and Uz, 2003) indicates that tectonites of the Eldivan Ophiolites were formed by depleted mantle.

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