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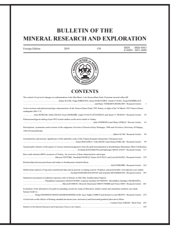

Geochemistry and tectonic significance of the ophiolitic rocks of the Yarpuz-Kaypak (Amanoslar, Osmaniye) area

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Research Article

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ABSTRACT

Yarpuz-Kaypak (Osmaniye) region, located in Amanos Mountains, contains harzburgitic tectonites and mafic cumulates. The tectonites are represented by serpantinized harzburgites, whereas the cumulates are characterized by gabbronorite and gabbro compositions. The crystallization order within the cumulates is clinopyroxene, orthopyroxene plagioclase and amphibole. The major element compositions of the tectonites and cumulate rocks are consistent with formation in an arc-related tectonic setting. Trace element concentrations of these rocks exhibit large ion litophile element enrichments. Both geochemical and petrographic evidence suggest that the tectonite and cumulate rocks from the Yarpuz-Kaypak (Osmaniye) region represent the remnants of an oceanic lithosphere that formed in a supra-subduction zone tectonic setting during the closure of the Southern Neotethyan ocean and emplaced onto the northern margin of the Arabian platform in Late Cretaceous.

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1. Introduction

The Tethyan evolution of Turkey covers two tectonic periods, the Paleotethys and Neotethys, which show continuity with each other in terms of time. The Paleotethys period took place between Carboniferous and Lias, having an effect particularly in Northern and Central Anatolia (Robertson and Ustaömer, 2009; Göncüoğlu et al., 2000, 2007; Okay, 2000). Whereas the Neotethys period affected the entire Anatolia between the Triassic and Miocene period, and continued its effect up to present time (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984). The Anatolian Plate is an important part of the Alpine-Himalayan orogenic belt which covers the remnants of E-W trending Neotethyan oceanic basins located between metamorphic massifs and/or platform carbonate sequences. The Neotethyan remnants from top to bottom are represented by ophiolites, metamorphic soles and ophiolitic mélanges (Şengör and Yılmaz, 1981; Dilek and Moores, 1990; Dilek et al., 1999; Floyd et al., 2000; Robertson, 2002). The Neotethys is composed of two oceanic basins, namely a northern branch and a southern branch (Şengör and Yılmaz, 1981). The northern branch covers the İzmir-Ankara-Erzincan ocean, Intra-Tauride ocean and Intra-Pontide ocean, whereas the southern branch covers the Berit and South Neotethyan oceans (Şengör and Yılmaz, 1981; Görür et al., 1984; Robertson and Dixon, 1984; Robertson et al., 2012, 2013*a*; Figure 1). As the Neotethys ocean started to close during the Late Cretaceous, ophiolites of both northern and southern branches emplaced over the passive continent margin to the south (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Yılmaz et al., 1993; Robertson, 2002; Robertson et al., 2006). The ophiolites, which have a significant place within the Neotethys evolution of Turkey, are of the supra-subduction zone (SSZ) type (Yalınız et al., 1996; Parlak et al., 1996, 2000, 2002,

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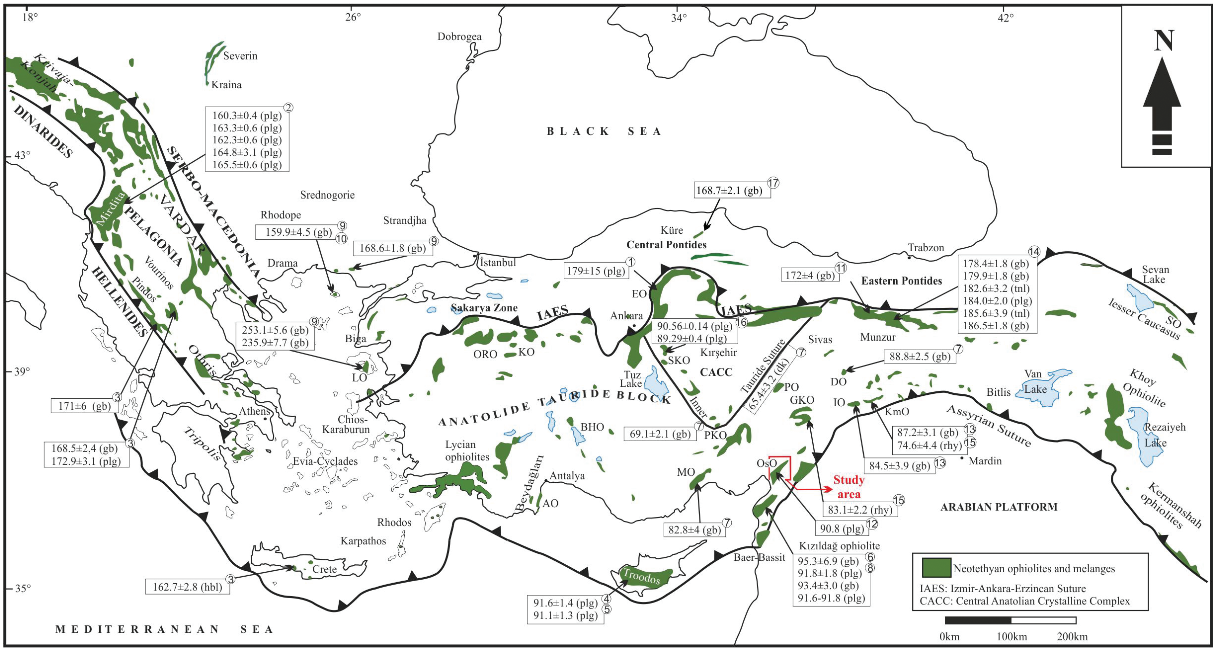

Figure 1- Tectonic map of the East Mediterranean Region showing the distribution of Neothetyan ophiolites and their relative U-Pb ages (after Dilek and Flower, 2003; Çelik et al., 2011). 1) Dilek and Thy 2006, (2) Dilek et al., 2008, (3) Liati et al., 2004, (4) Mukasa and Ludden 1987, (5) Konstantinou et al., 2007, (6) Dilek and Thy 2009, (7) Parlak et al., 2013, (8) Karaoğlan et al., 2013a, (9) Koglin, 2008, (10) Koglin et al., 2009, (11) Topuz et al., 2013, (12) Sarıfakıoğlu et al., 2012, (13) Karaoğlan et al., 2012, (14) Robertson et al., 2013b, (15) Karaoğlan et al., 2013b, (16) van Hinsbergen et al., 2016, (17) Alparslan and Dilek 2018. Abbreviations: LO: Lesvos Ophiolite, AO: Antalya Ophiolite, BHO: Beyşehir-Hoyran Ophiolite, ORO: Orhaneli Ophiolite, KO: Kınık Ophiolite, EO: Eldivan Ophiolite, MO: Mersin Ophiolite, PKO: Pozantı-Karsantı Ophiolite; OsO: Osmaniye Ophiolite, GKO: Göksun (Kahramanmaraş) Ophiolite, PO: Pınarbaşı Ophiolite, IO: Ispendere Ophiolite, DO: Divriği Ophiolite, KmO: Kömürhan Ophiolite, SO: Sevan Ophiolite, SKO: Sarıkaraman Ophiolite; plg: plagiogranite, gb: gabbro, dk: dike, tnl: tonalite, rhy: rhyolite.

2009; Robertson, 2002; Çelik and Delaloye 2003, 2006; Vergili and Parlak, 2005; Bağcı et al., 2005, 2006, Rızaoğlu et al., 2006; Bağcı et al., 2008; Bağcı and Parlak, 2009; Sarıfakıoğlu et al., 2009; Dilek and Thy 2009), and their formation and emplacement, respectively, reflect the sequence of events that they shared since the Late Cretaceous.

Amanos mountains are characterized by having wide-spread ophiolitic rocks (Yılmaz et al., 1984). The ophiolitic nappes in the Amanos mountains are seen in the form of separated nappes and clips which cover an area of about 13.000 km^2 (Tekeli and Erendil, 1986). Many detailed petrological, geochemical and geochronological studies have been carried out particularly in the Kızıldağ (Hatay) ophiolite and in ophiolitic rocks of the Amanos mountains which constitute the northwest margin of the Arabian platform (Dubertret, 1955; Çoğulu, 1975; Parrot, 1973; Delaloye et al., 1980; Tinkler et al., 1981; Tekeli and Erendil, 1984; Selçuk, 1985; Pişkin et al., 1990; Dilek and Thy, 2009; Bağcı et al., 2005; 2008; Bağcı, 2013; Boulton et al., 2006; Parlak et al., 2013; Karaoğlan et al., 2013*a*; Tanırlı and Rızaoğlu, 2016).

The study area covers an area of about 40 km^2 in the vicinity of the Yarpuz-Kaypak district in the Osmaniye province. Studies on ophiolites cropping out in this region are limited, and Yılmaz et al. (1984) designated the ophiolites in the Central Amanos and around Osmaniye as Zorkun and Tozaklı ophiolites. Yapıcı (1990) has conducted a study on the geology and petrographic features of the ophiolitic rocks in the region. However, no studies on the geochemistry of ophiolitic sequence in the region, located in the north-northeast of the Amanos mountains, have been carried out so far. In the frame of this study, petrographical and geochemical features of the ophiolitic rocks cropping out in the Yarpuz-Kaypak (Osmaniye) region will be investigated in order to evaluate its tectonic setting and compare to similar units in the region, as well as to better understand processes for the oceanic crust formation in the southern branch of Neotethys.

2. Regional Geology

The Amanos-high in southern Turkey constitutes the northwestern margin of the Arabian platform and consists of allochthonous and autochthonous units formed between Precambrian and Quaternary. The South Anatolia Orogenic Belt formed as a result of collision of the Tauride and Arabian Platforms, and it is divided into three E-W trending main tectonic zones. From south to north, these are the Arabian Platform, the zone of imbrication and the nappe zone (Yılmaz, 1993). These three structural units are composed as follows: metamorphic massifs (Malatya, Bitlis and Pötürge metamorphic sequences), ophiolitic complexes and thick sedimentary sequence of the Arabian platform. The Arabian platform, which is represented by autochthonous sedimentary rock formations deposited from Early Paleozoic with small interruptions, includes the ophiolite nappes emplaced during Late Cretaceous and cover sediments formed between Late Cretaceous and Miocene. It is divided into three units, namely the lower autochthonous, the upper autochthonous and the allochthonous (ophiolite and mélange) units (Yılmaz, 1993; Yılmaz et al., 1993). Paleozoic clastic sediments of the autochthonous Arabian platform in Yarpuz-Kaypak (Osmaniye) form the basement of the study area in Amanos Mountains, trending SW-NE direction between Antakya and Kahramanmaraş (Figure 2). A carbonatic sequence consisting of Upper Jurassic and Lower Cretaceous dolomite and dolomitic limestones unconformably overlies this basement rocks (Dubertret, 1955; Atan, 1969; Yılmaz et al., 1984; Tekeli and Erendil, 1986). This unit is tectonically overlain by Upper Cretaceous ophiolitic units (Yılmaz et al., 1984; Yapıcı and İşler, 1991; Yılmaz et al., 1993). The sediments covering the ophiolitic nappes in the region are represented by Miocene clastic and carbonate-rich rocks (Gül, 1987; Terlemez et al; 1992). Pliocene rocks consisting of continental clastics and lagoon units and Quaternary basaltic volcanic rocks, alluviums and alluvium fans are the youngest units (Rojay et al. 2001).

The ophiolites observed in the study area are mainly composed of mantle tectonites and cumulate rocks. The tectonites, which cover wide areas in the region, are highly fractured and weathered with red to reddish colored coating, while fresh fracture surfaces

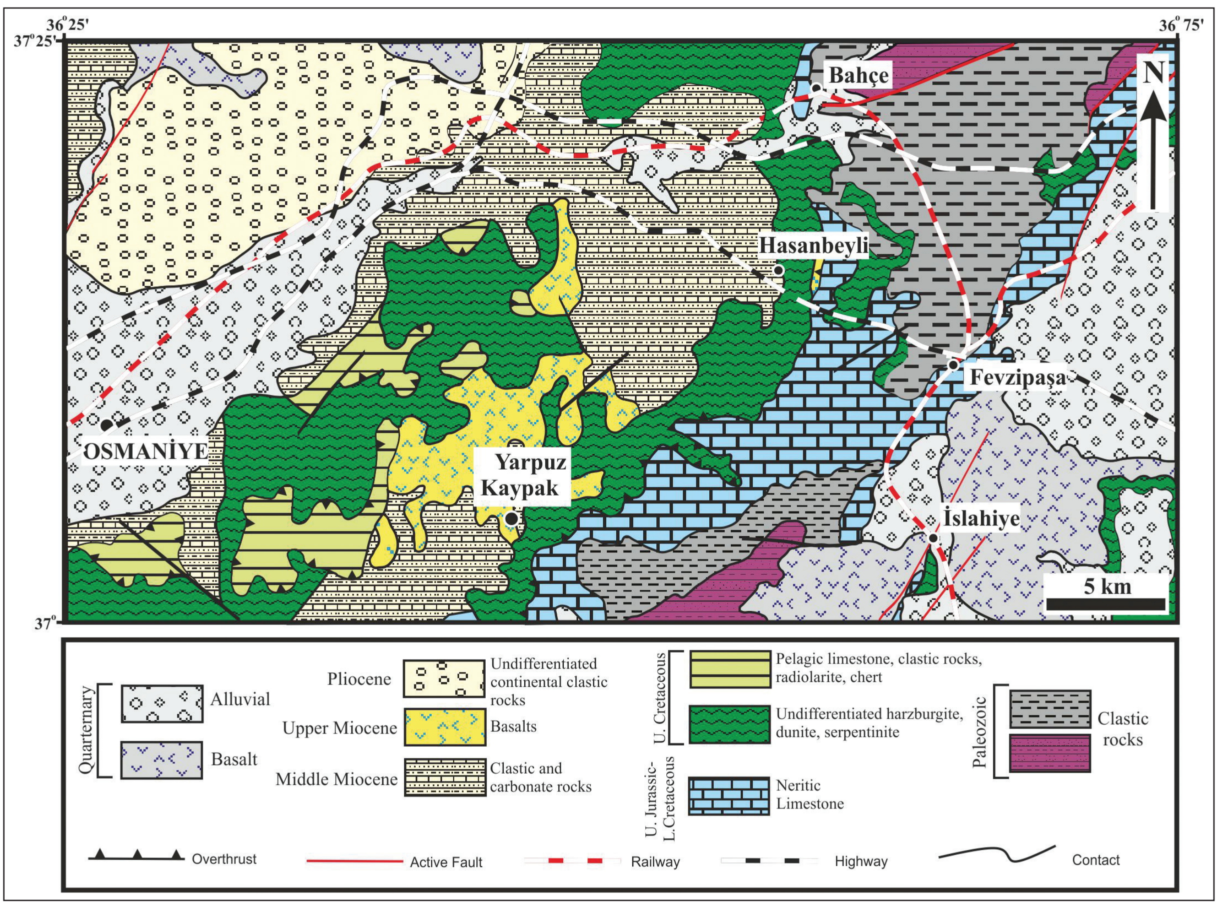

Figure 2- Simplified geological map of Yarpuz-Kaypak region (Ulu, 2002).

are dark green to greenish. The tectonites display structural features such as foliation and lineation, reflecting plastic deformation related to mantle flow. When highly serpentinized, they present greenish to dark black colors and oily brightness. Cumulates show fine to medium grain-size, hard-solid sharp-edged and exhibit cumulate structures such as magmatic banding-lamination.

3. Analytic Method

Thirty-five samples were collected from the study area for petrographic and geochemical analyses. The thin sections were prepared for petrographic observations in the Thin Section Laboratory of the Geological Engineering Department of Çukurova University. The major-trace element analysis of 29 samples were carried out in the Geochemistry Laboratory of the Mineralogy Department of Geneva University, Switzerland. Major elements were measured by means of X-Ray Florescence (XRF) within the glass pellets which were prepared by adding 1/5 of sample and lithium tetraborate ($Li_2B_4O_7$) into platin-gold crucible at 1150 ^{o}C. Loss of ignition (LOI) values were calculated by taking the weight difference after heating the samples at 1000 ^{o}C. The trace elements were analyzed by means of pellets pressed by the same method.

4. Petrography

The samples were defined as mantle rocks (tectonites) and mafic cumulates as a result of the detailed petrographic determinations on thin sections prepared from the ophiolitic rock samples taken from the Yarpuz-Kaypak (Osmaniye) region.

The tectonites are represented by serpentinized harzburgites and display porphyroclastic (Figure 3a) and sieve textures. Olivine (70–75 vol%) is the most abundant mineral, where the sieve texture is observed, remained partially fresh. When completely serpentinized, tectonites show the typical sieve texture indicative of static replacement of olivine by serpentine (Figure 3b). Orthopyroxene (20-25 vol%) commonly highly replaced by bastite (Figure 3a-b). Furthermore, significant amount of disseminated and elongated chromite crystals observed in tile red color is seen within the rock.

Cumulate rocks are defined as gabbronorite and gabbro (Figure 3c-h). Plagioclase, clinopyroxene, orthopyroxene are observed as cumulus and intercumulus minerals in the cumulate rocks which represent adcumulate, mesocumulate and poikilitic textures. Plagioclase, which is the most abundant mineral of the gabbronorite, represent high degree of sericitization. Plagioclase, occurring as prismatic crystals with ambiguous polysynthetic twins and make ca. 45-50 vol% of the rock. According to the polysynthetic twin measures carried out in fresh mineral, the fact that the angle of extinction was determined as 30 ^{o}-35^{o} shows that the plagioclases have a composition ranging from labrador to bytownite. Orthopyroxene, clinopyroxene and amphibole constitute the dark colored minerals of the rock. Orthopyroxenes are polarized in grey tones and include clinopyroxenes in the form of exsolution lamellas. In some clinopyroxenes, h^1(100) twin is observed. Amphibole commonly constitutes the 8-10 vol% of the rock and it occurs as anhedral intercumulus phase.

Gabbro is commonly medium to coarse-grain sized and shows adcumulate texture. Polysynthetic twins are locally distinct in plagioclase which is the dominant mineral phase of the rock. Abundant ferromagnesian mineral is clinopyroxene, and orthopyroxene is locally encountered (gabbronorite). Some of the pyroxene crystals show alteration by uralitization.

Aforementioned textural and mineralogic features show that the crystallization order of mineral phases in the cumulate rocks are as follows: clinopyroxene → orthopyroxene → plagioclase → amphibole.

5. Whole Rock Geochemistry

Whole rock analysis results of the tectonites and the mafic cumulates from the Yarpuz-Kaypak (Osmaniye) region are given in table 1. LOI values are quite high (11,9-14,4 wt%) in tectonites, while they vary between 0,8-2,8 wt% in mafic cumulates. The variation in LOI values indicates that the studied rocks were affected by variable extent of alterations (e.g., serpentinization, uralitization, and sericitization) reflecting the contribution of secondary hydrated and carbonate phases (Rollinson, 1993). For petrologic interpretations, it is suggested to utilize the rare earth elements (REE) and the high-field-strength (HFS) elements generally considered relatively stable (immobile) during rock alteration (Pearce and Cann, 1973; Smith and Smith, 1976; Floyd and Winchester, 1978), in contrast to the mobility of major elements

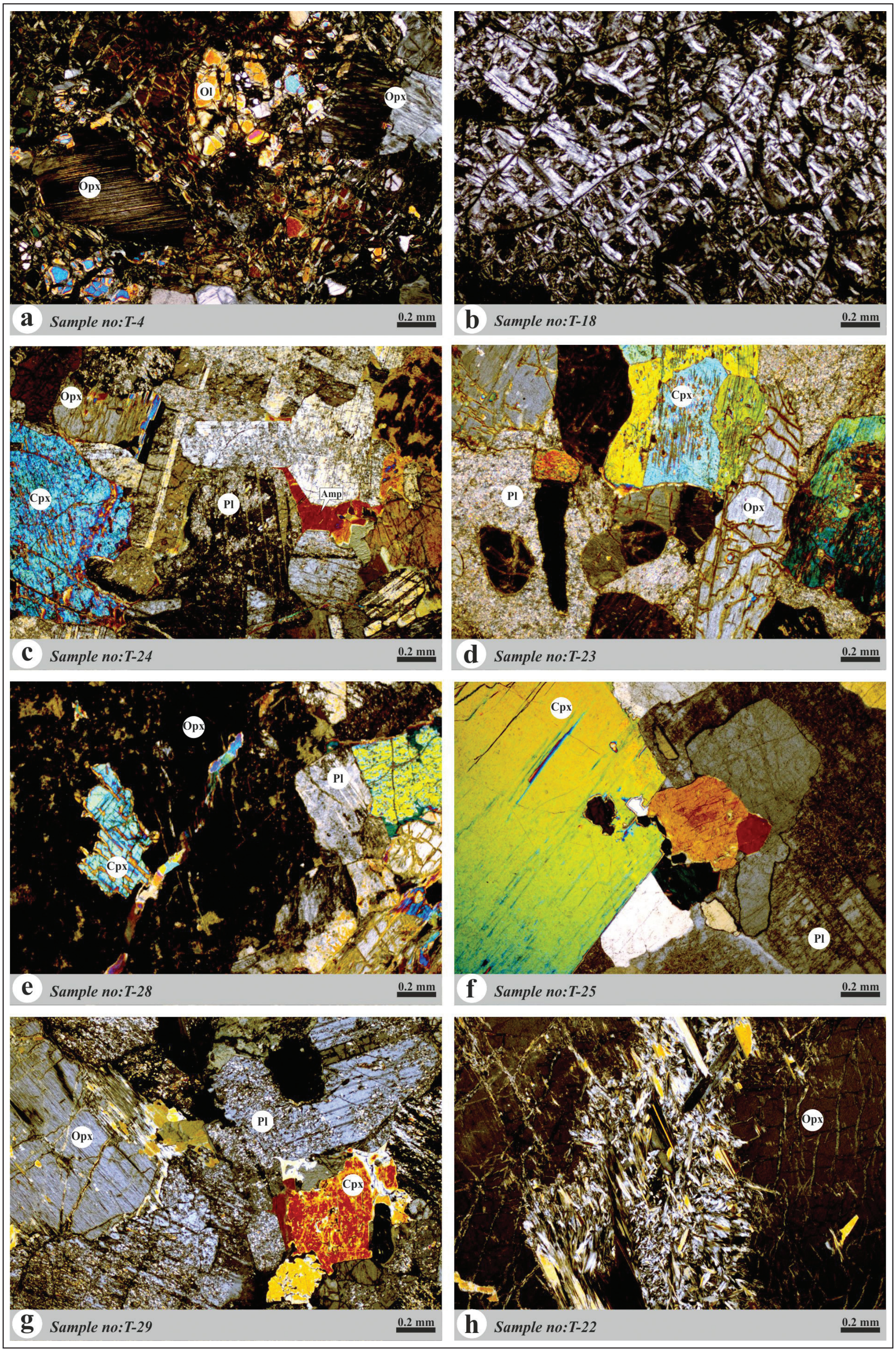

Figure 3- Thin section images of Yarpuz-Kaypakophiolites. (a) harzburgite showing porphyroclastic texture, (b) sieve texture, (c) gabbronorite showing adcumulate texture, (d-e) gabbronorite showing poikilitic texture, (f) adcumulate gabbro, (g) sericitization seen in plagioclases, (h) uralitization seen in pyroxenes, (Mineral abbreviations are taken from Whitney and Evans, 2010).

Table 1- Major (%) and trace (ppm) element contents of mantle tectonites and mafic cumulate rocks of Yarpuz-Kaypak region.

	Harzburgite																					Gabbronorite							Gabbro
Sample	**T 4**	**T 5**	**T 6**	**T 13**	**T 14**	**T 15**	**T 18**	**T 19**	**T 26**	**T 27**	**T 31**	**T 32**	**T 33**	**T 34**	**T 35**	**T 36**	**T 37**	**T 39**	**T 40**	**T 49**	**T 50**	**T 20**	**T 21**	**T 22**	**T 23**	**T 24**	**T 28**	**T 29**	**T 30**
SiO_2	39.17	38.90	39.92	39.94	40.20	39.05	38.48	39.69	40.23	39.50	38.10	39.04	39.85	39.21	39.47	39.40	39.06	39.37	38.60	39.30	39.34	51.85	48.96	48.39	49.21	47.96	47.63	48.53	45.88
TiO_2	0.01	0.01	0.02	0.04	0.01	0.03	0.03	0.02	0.02	0.01	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.08	0.06	0.04	0.13	0.09	0.11	0.10	0.10	0.18
Al_2O_3	0.78	0.68	0.97	0.85	0.89	0.81	2.87	0.88	1.18	0.89	3.23	1.26	0.70	0.83	0.90	0.77	0.66	0.81	0.91	1.55	1.83	7.82	13.53	6.73	14.42	18.69	17.59	18.89	9.79
tFe_2O_3	8.25	8.17	8.01	8.29	8.34	8.11	7.37	7.52	7.41	7.98	8.78	8.14	8.02	8.30	9.49	7.95	8.53	7.82	8.40	7.80	7.71	7.96	6.32	8.73	8.10	7.22	8.33	7.19	9.56
MnO	0.11	0.12	0.12	0.12	0.13	0.12	0.16	0.10	0.12	0.10	0.11	0.15	0.12	0.16	0.10	0.13	0.13	0.12	0.10	0.14	0.15	0.17	0.13	0.17	0.18	0.13	0.16	0.13	0.17
MgO	38.47	37.78	37.39	36.76	36.77	38.19	37.23	38.49	37.43	38.19	32.49	36.61	36.62	36.79	36.58	37.49	37.20	37.24	36.92	35.27	34.79	22.21	17.13	18.28	14.01	9.71	10.07	9.43	16.09
CaO	0.71	0.08	0.65	0.49	0.04	0.11	0.16	0.06	0.15	0.07	4.47	0.24	0.66	0.08	0.04	0.05	0.04	0.11	0.06	0.37	0.44	8.41	10.54	14.09	7.73	10.79	9.58	11.12	14.19
Na_2O	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	0.00	0.00	0.00	0.00	0.06	0.00	0.03	0.00	0.11	0.09	0.46	1.16	1.35	1.25	0.17
K_2O	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.79	0.74	0.02	2.71	1.41	1.71	1.08	0.03
Cr_2O_3	0.40	0.36	0.54	0.47	0.58	0.45	0.43	0.37	0.52	0.40	0.43	0.54	0.45	0.54	0.40	0.46	0.42	0.40	0.46	0.42	0.45	0.26	0.19	0.27	0.16	0.02	0.03	0.02	0.23
NiO	0.33	0.35	0.32	0.36	0.36	0.35	0.32	0.37	0.32	0.34	0.28	0.30	0.35	0.35	0.31	0.35	0.34	0.34	0.35	0.36	0.33	0.07	0.06	0.05	0.04	0.02	0.03	0.02	0.05
P_2O_5	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
LOI	12.00	13.38	12.23	13.16	13.23	13.38	13.03	12.99	12.91	12.82	11.86	13.09	13.02	13.49	12.50	13.00	13.68	13.81	13.68	14.30	14.40	0.77	1.03	2.79	2.22	1.93	2.37	2.23	2.65
Total	100.11	99.71	100.05	100.40	100.45	100.50	99.96	100.36	100.20	100.18	99.69	99.34	99.72	99.70	99.72	99.50	99.98	99.97	99.61	99.53	99.58	100.36	98.79	99.74	99.33	99.14	98.94	99.99	98.99
Ba	74	80	82	104	114	94	89	90	96	85	77	81	80	108	92	89	85	94	91	93	98	163	124	26	35	33	24	42	<9<
Rb	3	3	4	4	4	4	4	3	4	5	5	3	4	4	4	3	4	3	4	4	4	20	19	5	69	39	45	30	4
Sr	9	1	4	4	2	6	2	2	2	3	3	<1<	3	2	2	1	1	1	1	2	4	141	206	14	311	301	388	303	24
Y	2	2	3	2	3	3	3	3	3	2	3	2	3	3	2	3	3	2	3	3	3	4	4	9	6	7	6	5	8
Zr	14	16	16	16	16	16	17	17	17	17	15	17	16	16	16	16	16	16	16	16	15	6	4	12	3	5	5	5	10
Nb	10	10	10	11	11	11	10	10	10	10	9	10	11	11	11	10	11	10	11	10	10	4	<1<	5	<1<	<1<	<1<	<1<	3
Th	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	<2<	3	3	2	<2<	2	<2<	3
Pb	18	18	19	20	22	20	19	21	21	22	23	21	22	20	23	20	22	20	21	19	19	14	10	19	9	7	9	8	16
Ga	3	2	2	3	2	3	4	3	3	4	4	3	3	3	2	3	2	2	2	4	4	5	7	7	10	13	11	12	9
Zn	43	48	45	42	57	56	49	40	44	39	39	45	49	63	37	51	47	44	43	48	57	43	37	54	47	42	49	41	62
Ni	1366	1445	1273	1419	1408	1375	1240	1350	1203	1272	1320	1233	1357	1440	1332	1341	1394	1310	1431	1478	1376	373	302	260	239	122	149	122	304
V	45	37	59	38	87	44	76	41	64	48	87	52	42	64	51	59	56	53	51	59	82	165	125	202	170	181	199	168	222
Cr	2929	2543	3766	2709	3667	3225	2635	2219	3602	2511	2951	3334	3010	3984	2684	3112	2543	2850	3451	3058	3564	1921	1189	1604	876	116	169	215	1517
Hf	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<	<1<
Sc	31	33	45	42	66	35	72	32	64	46	62	57	30	55	25	65	27	41	43	31	43	76	47	65	42	35	32	34	52
Co	120	133	121	133	130	133	131	135	123	128	119	126	136	142	114	134	135	127	141	132	127	60	49	59	48	40	49	40	63
U	<2<	<2<	<2<	<2<	<2<	2	<2<	<2<	2	2	2	<2<	<2<	<2<	<2<	<2<	2	<2<	<2<	<2<	2	<2<	2	3	<2<	<2<	2	<2<	2
La	<4<	4	7	<4<	<4<	<4<	<4<	<4<	11	7	9	10	9	<4<	<4<	5	6	<4<	11	5	8	<4<	13	5	<4<	5	7	9	<4<
Ce	<3<	<3<	<3<	<3<	<3<	10	<3<	<3<	<3<	<3<	<3<	12	<3<	<3<	6	20	<3<	3	23	16	<3<	9	10	9	4	13	9	11	5
Nd	<4<	<4<	<4<	<4<	<4<	<4<	<4<	<4<	<4<	<4<	<4<	<4<	<4<	7	<4<	6	<4<	9	<4<	5	<4<	9	<4<	6	<4<	7	4	<4<	<4<

tFe_2O_3: total iron; LOI: loss on ignition and large-ion lithophile elements (LIL) commonly attributed to alteration (Hart et al., 1974; Humphris and Thompson, 1978; Thompson, 1991). Therefore, the high field strength elements are utilized in order to define the petrologic features of the rocks.

Tectonites are the most depleted rocks and have composition characterized by low SiO_2 (38,1-40,2 wt%), Al_2O_3 (0,7-3,2 wt%), Fe_2O_3 (7,4-9,5 wt%), CaO (0-4,5 wt%), Sr (1-6 ppm), Ga (2-4 ppm), V (38-87 ppm), and high Ni (1203-1478 ppm) and Cr (2219-3984 ppm). Whereas the mafic cumulates is represent ed by high SiO_2 (45,9-51,8 wt%), Al_2O_3 (6,7-18,9 wt%), Fe_2O_3 (6,3-9,6 wt%), CaO (7,7-14,2 wt%), Sr (14-388 ppm), Ga (5-13 pmm), V (125-222 ppm), low Ni (122-373 ppm) and Cr (116-1921 ppm).

When we analyze the variations in major oxide values of the tectonites and mafic cumulates of the ophiolite sequence with respect to the MgO content (Figure 4a-d); SiO_2, Al_2O_3, CaO have a negative trend from tectonites to the mafic cumulates. The selected

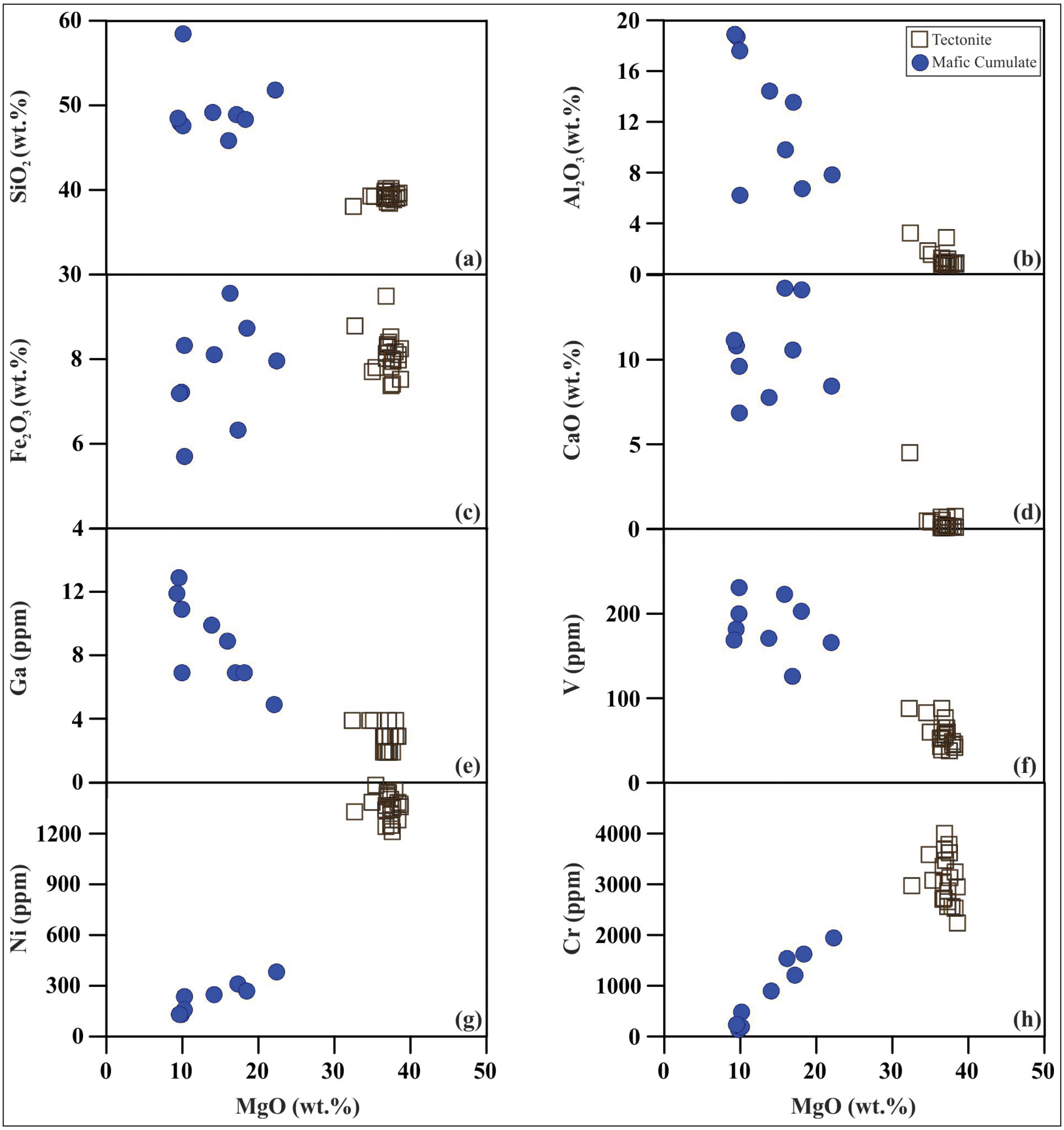

Figure 4- Variations between MgO and major-trace element contents in the Yarpuz-Kaypak ophiolites.

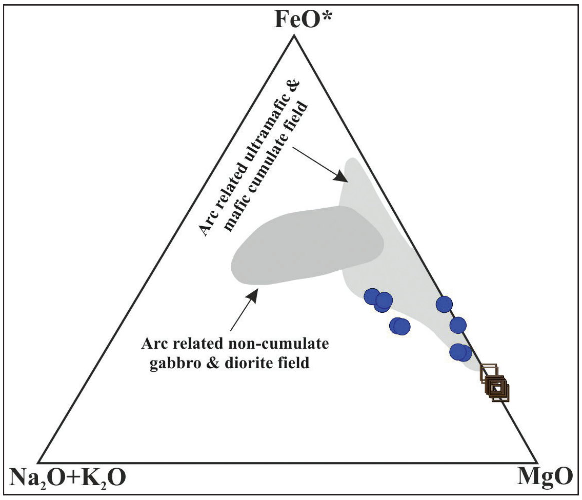

Figure 5- AFM diagram of mafic cumulates of Yarpuz-Kaypak ophiolites. Fields of cumulate and non-cumulate rocks are from Beard (1986). Symbols are as in figure 4.

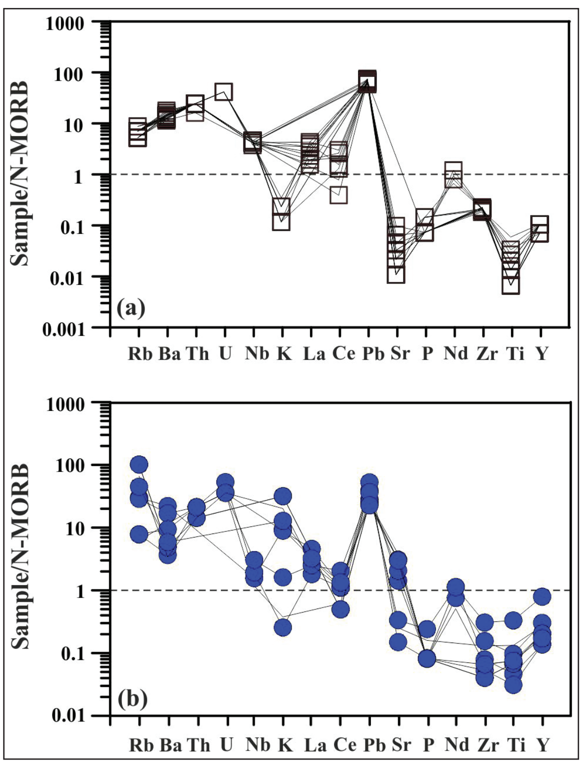

Figure 6- N-MORB normalized spider diagrams for the tectonites and mafic cumulates of Yarpuz-Kaypak ophiolites. Normalized values from Sun and McDonough, 1989. Symbols are as in figure 4.

trace elements such as Ga and V display a negative trend, whereas Ni and Cr display a positive trend with increasing MgO (Figure 4e-h). In AFM diagram (Beard, 1986), from mafic cumulates, there is an enrichment from MgO to FeO (Figure 5). N-MORB normalized spider diagrams for the tectonite and mafic cumulate rocks (Figure 6a-b) indicate that there is an enrichment in large ion lithophile (LIL) elements (Rb, Ba, Th) and depletion in high field strength (HFS) elements.

6. Discussion

6.1. Petrogenesis

The petrography and geochemistry of crustal rocks belonging to the ophiolite sequence observed in Yarpuz-Kaypak (Osmaniye) region indicate evidence of fractional crystallization. The increase in SiO_2, Al_2O_3 and CaO in mafic cumulate rocks (Figure 4a, b, d) shows that olivine and pyroxene minerals decrease while plagioclase mineral increases, due to magma differentiation. The Ga element shows a negative relationship with MgO (Figure 4e) since the Ga is incompatible in olivine. Existence of V in clinopyroxene (Ross et al., 1954; Borisenko, 1967; Ballantyne, 1992) is consistent with the higher amounts of V in mafic cumulates with respect to tectonites (Figure 4f); the Sr increasing in mafic cumulates (Table 1) suggests higher amount of plagioclase crystallization (Grove and Baker, 1984; Beard, 1986). The high content of compatible trace elements such as Ni, Cr within tectonites (Figure 4g-h) with respect to the lower content in mafic cumulates indicate that olivine, spinel and clinopyroxene fractionated in the studied rocks. All the cumulates with low content of HFS elements such as Zr, Y, Nb (Table 1), indicate high proportion of cumulus minerals and a small amount of intercumulus liquid, as supported by textural evidence. Furthermore the spider diagram of cumulate rocks suggests that the LIL elements (Rb, Ba, and Sr) have been enriched by hydrous solutions derived from a subducting oceanic slab (Pearce, 1982; Arculus and Powel, 1986; Yogodzinski et al., 1993; Wallin and Metcalf, 1998).

The geochemical features of the cumulate rocks belonging to the studied ophiolitic sequence (Figure 4, 5, 6) exhibit similarities with those of the Kızıldağ (Hatay) ophiolite cumulate gabbro formed in the supra-subduction zone fore-arc environment (Bağcı et al., 2005; Dilek and Thy, 2009), the ultramafic-mafic cumulates from the ophiolitic rocks of the south of Kahramanmaraş province (Bağcı, 2013; Tanırlı and Rızaoğlu, 2016), and the mafic cumulates of Kuluncak (Malatya) ophiolite (Camuzcuoğlu, et al., 2017). Moreover, the geochemical features of the mantle tectonites exhibit close similarity to depleted residual mantle peridotites from suprasubduction zone (SSZ) settings (Uysal et al., 2012; Saka et al., 2014).

Ophiolites are commonly classified as mid-ocean ridge ophiolites (MORB) and supra-subduction zone (SSZ) ophiolites depending on their internal structures and composition, geochemical and tectonic features, (Pearce et al., 1984; Shervais, 2001; Robertson, 2002; Saccani and Photiades 2004; Arai et al., 2006; Pearce, 2008). Dilek and Furnes (2011) made a new classification of the ophiolites as subduction-related and non-subduction-related ophiolites; these authors classified the subduction-related ophiolites as subduction zone (SZ) and volcanic arc (VA) ophiolites, whereas classified the non-subduction-related ophiolites as continental margin (CM), mid-ocean ridge (MOR) and mantle plume (P) ophiolites. They also classified the supra-subduction zone ophiolites (SSZ) as back-arc (BA), fore-arc (FA), oceanic back-arc (OBA) and continental back-arc (CBA) ophiolites.

Supra-subduction zone ophiolites in general are formed in the first stages of the intra-ocean subduction. The crustal rocks of the supra-subduction zone ophiolites have the geochemical characteristics of island arcs. The distinct features are as follows: mantle series are highly depleted, there are more common presence of podiform chromite deposits, clinopyroxene crystallizes before plagioclase, wehrlite is relatively dominant compared to troctolite in the cumulate series. Most of the best preserved ophiolites in the orogenic belts are of the SSZ-type (Pearce et al., 1984). In SSZ-type ophiolites, clinopyroxene typically crystallizes before plagioclase (Pearce et al., 1984; Hébert and Laurent 1990; Parlak et al., 1996, 2000, 2002; Bağcı et al., 2005, 2006; Bağcı, 2013). The crystallization order of the minerals within the cumulate rocks in the Yarpuz-Kaypak (Osmaniye) region is clinopyroxene + orthopyroxene + plagioclase + amphibole, and exhibits the similarities with cumulate rocks formed in the supra-subduction zone environments.

In terms of their ages and geodynamic environment of formation, the ophiolites observed along the Alpine-Himalayan orogenic belt are divided into two groups, namely the Western and the Eastern Mediterranean ophiolites. In the Western Mediterranean, there are ophiolites remaining in the west of Albania, Hellenides and Dinarides. These ophiolites are of Jurassic age and formed in mid-ocean ridge settings (MORB) (Koller and Höck, 1990). In the Eastern Mediterranean belt, there are Pindos, Vourinos (Greece), Troodos (Cyprus) ophiolites, all ophiolites in Turkey, Baer-Bassit (Syria) and Oman ophiolites further towards southeast. The ophiolites in Turkey have a crystallization age of Late Cretaceous in general. However, it has been stated that there are ophiolites and metamorphic soles with Early-Middle Jurassic age in the central and eastern section of İzmir-Ankara-Erzincan Suture Zone (Çelik et al., 2011; Topuz et al., 2013; Robertson et al., 2013*a*). All of the Turkish ophiolites formed in a variety of tectonic settings within a SSZ environment, including back-arc, arc and fore-arc. There does not exist any MORB-type ophiolite body in the Turkish part of the eastern Mediterranean region. Most MORB-type oceanic crust was subducted, or preserved only as dismembered thrust sheets or blocks in ophiolitic mélange (Robertson, 2002). Recent studies performed on mantle rocks of ophiolites in southwest Turkey have shown that compositions of mantle rocks from different tectonic environments are the results of different styles of depletion and refertilization events and varying degrees of partial melting (Aldanmaz et al., 2009; Aldanmaz, 2012; Uysal et al., 2012).

Except for one rock (T-31), the fact that the mantle tectonites in the study area have quite low CaO and Al_2O_3 values indicates the relationship with Ca depletion during serpentinization process (Coleman, 1963; Puga et al., 1999; Li et al., 2004; Palandri and Reed 2004; Shervais et al., 2005). On this diagram (Figure 7a) the studied rocks are very depleted in Al_2O_3 and CaO and similar to fore-arc peridotites (Ishii et al., 1992; Pearce et al., 1992). Abyssal peridotites formed by the extraction of relatively low melt fractions (3-15%) under dry melting conditions (Dick and Bullen, 1984; Johnson et al., 1990; Niu, 1997, 2004; Jean et al., 2010) while peridotites from the mantle wedge above subduction zones are depleted, and formed by the extraction of relatively large melt fractions (> 20%) in hydrous melting conditions (Ishii et al., 1992; Parkinson et al., 1992; Arai, 1994; Parkinson and Pearce, 1998; Pearce et al., 2000; Uysal et al., 2012). The partial melting trend (Niu, 1997) and the Al_2O_3 and MgO contents of tectonites are shown in figure 7b. It has been observed that most of the samples are the remnants of 15-25% partial melting compared to the primary mantle. The low MgO content of the tectonites is related to the MgO depletion by the alteration caused by the sea water (Niu, 2004). Low CaO and Al_2O_3 values (Table 1) of the tectonites of the Yarpuz-Kaypak (Osmaniye) region show that tectonite samples are partially the remnants of high-grade partial melting, and resemble to the subduction-related fore-arc peridotites (Parkinson and Pearce, 1998). With these features, mantle peridotites of the study area represent similarities with mantle rocks of Pozantı-Karsantı ophiolite in the South Turkey (Saka et al., 2014).

According to the AFM diagram (Beard, 1986), the mafic cumulate rocks display enrichment from MgO to FeO and plot within the field of arc-related ultramafic-mafic cumulate rocks, suggesting their subduction related origin (Figure 5).

Existence of plagioclases with high An content in the mafic cumulates indicates high water vapor pressure (P-H_2O) (Arculus and Wills, 1980; Sisson and Grove, 1993; Panjasawatwong et al., 1995) and large Ca/(Ca+Na) ratio in the magma during crystallization (Jaques, 1981; Sisson and Grove, 1993). The formation of amphibole mineral in the hydrous magmas conditions of the arc regions is a likely process (Jakes and White, 1972; Arculus and Wills, 1980; Foden, 1983; Hébert and Laurent, 1990). The presence of amphibole and An-rich plagioclase in the mafic cumulates of Yarpuz-Kaypak (Osmaniye) region indicate hydrous environment during the oceanic crust development, and represent similarities to supra-subduction zone ophiolites of Eastern Mediterranean (Hébert and Laurent, 1990; Parlak et al., 1996, 2000; Bağcı et al., 2005, 2006; Rızaoğlu et al., 2006; Sarıfakıoğlu et al., 2009; Bağcı, 2013; Tanırlı and Rızaoğlu, 2016; Camuzcuoğlu et al., 2017) and gabbroic rocks of island arcs (Arculus and Wills 1980; Dupuy et al., 1982; Beard, 1986; Debari and Coleman, 1989; Fujimaki, 1986; DeBari et al., 1987).

6.2. Geodynamic Environment

Depending on the spreading of South Atlantic Ocean at the end of Early Cretaceous, the regime in the Neotethys oceanic basin situated between Eurasian and African plates shifted from divergent to convergent regime (Livermoore and Smith, 1984; Savostin et al., 1986). As a result of this convergent regime, a northward subduction started in the southern branch of the Neotethys. Cold and dense Triassic-Cretaceous aged oceanic lithosphere segment subducted northward into asthenosphere and enabled the formation of SSZ-type ophiolites within the intra-ocean subduction zone. Two ophiolite belts, namely the southern and northern belts, trending about NE-SW are presently observed in the Southeast Anatolia.

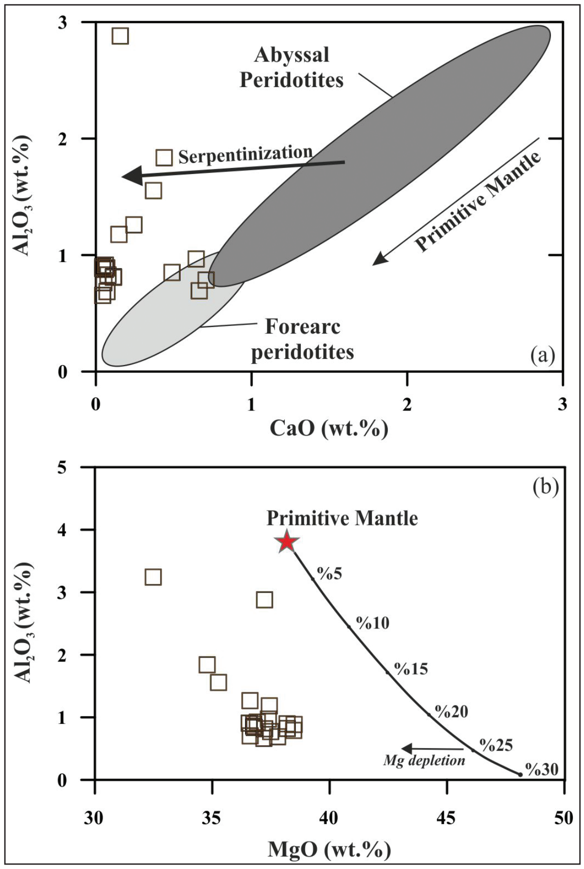

Figure 7- (a) Variations of whole rock Al_2O_3 contents with respect to CaO contents in all tectonites of Yarpuz-Kaypak ophiolitic sequence; the fields of abyssal and fore-arc peridotites and mantle depletion trend have been taken from Ishii et al. (1992) and Pearce et al. (1992). (b) Variations of whole rock Al_2O_3 contents with respect to CaO contents; the depletion trend of the primitive mantle and partial melting have been taken from Niu (1997). Symbols are as in figure 4.

The south belt includes Troodos (South Cyprus), Baer-Bassit (Syria), Tekirova (Antalya), Kızıldağ (Hatay), Amanos (Osmaniye), Koçali (Adıyaman) ophiolites. These ophiolites were formed at Southern Neotethys between Bitlis-Pütürge metamorphic and Arabian platform (Figure 8). The northern belt includes Göksun (Kahramanmaraş), İspendere (Malatya), Kömürhan and Guleman (Elazığ) ophiolites. These ophiolites were formed in the Berit Ocean which was developed between Bitlis-Pütürge and Tauride platform (Figure 8) (Robertson et al., 2012, 2013*a*; Karaoğlan et al., 2013*b*). Although the ophiolites of both belts were formed at intra-ocean subduction zones, they represent differences in terms of tectonic relationship, ophiolite stratigraphy, petrography and petrologic features (Parlak et al., 2009). The northern belt ophiolites are tectonically overlain by the Tauride (Malatya-Keban) platform at the top and in turn overthrust Middle Eocene Maden Complex at the bottom contact. Moreover, the northern belt ophiolites and theTauride platform were cut by Late Cretaceous-Eocene I-type calk-alkaline arc granitoids (Parlak, 2006; Rızaoğlu et al., 2009; Karaoğlan et al., 2016; Nurlu et al., 2016). The Kızıldağ (Hatay), Koçali (Adıyaman) and Baer-Bassit (Syria) ophiolites of the southern belt are directly emplaced over the Arabian Platform and no granitoid intrusion is seen (Selçuk, 1981; Robertson, 1986). The Bitlis metamorphic massif, which shows widespread outcrops in the southern of northern belt ophiolites, carries the traces of high pressure-low temperature (HP/LT) metamorphism.The Kesandere (Bitlis) eclogitic rocks underwent HP peak metamorphism in Late Cretaceous (84.4±0.9 – 82.4±0.9 My) under the conditions of 19-24 kbar and 480-540^{o}C (Oberhansli, 2013). Furthermore, glaucophane-rich blueschist rocks have undergone (HP/LT) metamorphism in Late Cretaceous (Ar-Ar: 79-74 My) under 10-11 kbar and 350-400^{o}C (Oberhanslı et al., 2012). This data indicates that the Bitlis metamorphics had undergone subduction and HP/LT metamorphism in Late Cretaceous age. Therefore, some researchers have suggested that there might be development of two different oceanic basins (the Berit ocean and the

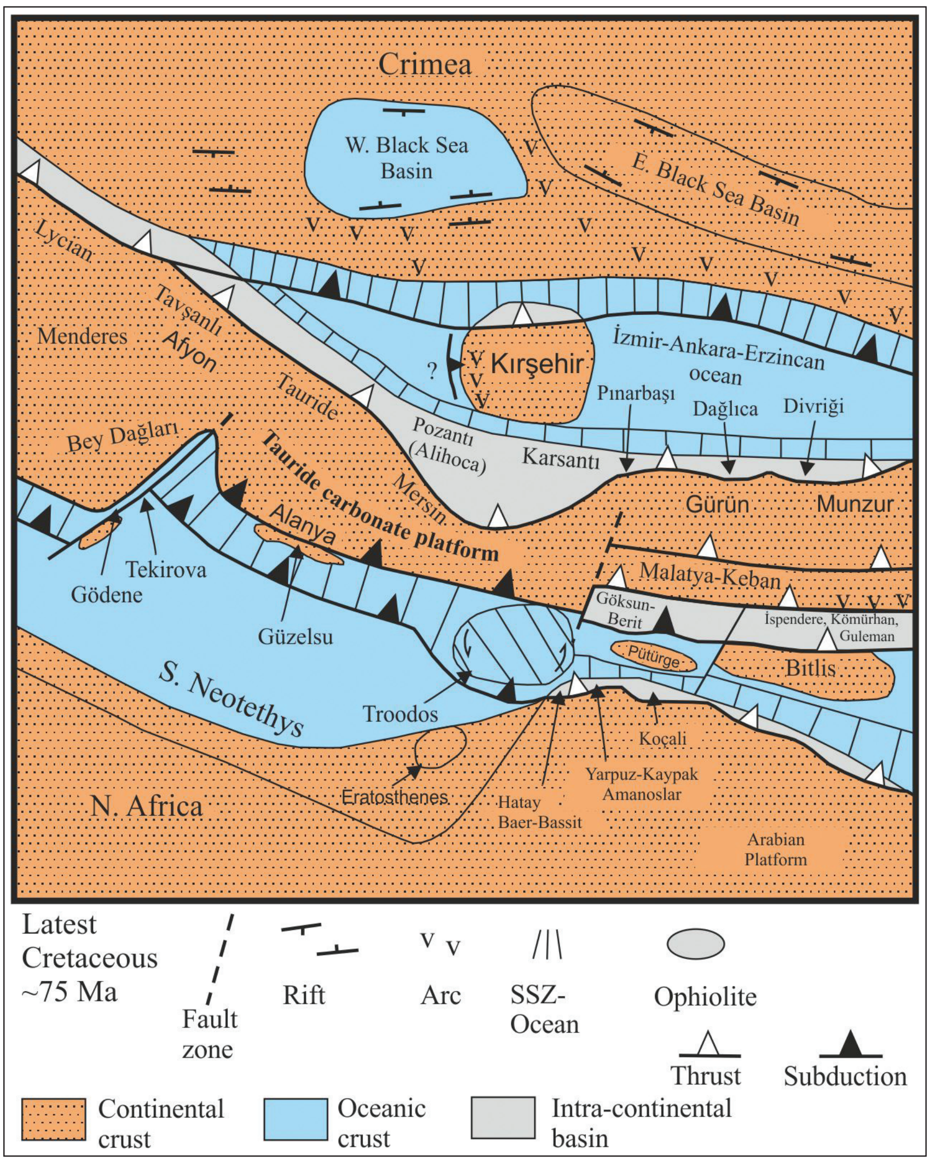

Figure 8- Late Cretaceous Paleogeography around the study area. Subduction zone (SSZ-type) ophiolites emplaced on the passive continental margin to the south (Arabian platform and microcontinents). On the other hand, arc volcanism accompanying the subduction is seen in Pontides, Southeast Turkey and North Cyprus (Robertson et al., 2012).

Southern Neotethys ocean) to the northbetween Bitlis/Pütürge continent and the Tauride platform and to the south between Bitlis/Pütürge continent and the Arabian platform (Robertson et al., 2012, 2013*a*).

Our results, in addition to general models for the life cycle of ophiolites (Shervais, 2001; Pearce, 2003) and a number of tectonic models related to the southeast Anatolian orogen (Yazgan and Chessex, 1991; Yılmaz et al., 1993; Beyarslan and Bingöl, 2000; Robertson et al., 2007) point that Yarpuz-Kaypak (Osmaniye) ophiolites in Amanos Mountains were formed in a supra-subduction zone environment and emplaced onto the passive continental margin of Arabian plate from the southern branch of Neotethys during Late Cretaceous.

7. Conclusions

(a) Yarpuz-Kaypak (Osmaniye) ophiolites are represented by harzburgitic mantle tectonites and mafic cumulate rocks.

(b) Mafic cumulates are composed of gabbronorite and gabbro; displaying adcumulate, mesocumulate and poikilitic textures.

(c) Major and trace element geochemistry of the harzburgitic tectonites and mafic cumulates indicate an intra-oceanic subduction-related setting.

(d) The petrographic and geochemical data obtained from this study suggest that Yarpuz-Kaypak (Osmaniye) ophiolites were formed in an intra-ocean subduction zone during closure of southern branch of Neotethys during Late Cretaceous and emplaced onto the northern margin of Arabian platform.

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