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PETROLOGY AND ORIGIN OF PLAGIOGRANITES FROM THE DAĞKÜPLÜ (ESKİŞEHİR) OPHIOLITE ALONG THE İZMİR-ANKARA-ERZİNCAN SUTURE ZONE, TURKEY

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ABSTRACT

The İzmir-Ankara-Erzincan Suture Zone (IAESZ) formed through the closure of the northern branch of the Neotethyan Ocean that once separated the Sakarya Continent and the Anatolide-Tauride Platform and the subsequent collision of these two continental blocks during Late Cretaceous-Paleocene time. Mafic-ultramafic rocks representing oceanic lithosphere, metamorphic sole rocks, and ophiolitic mélange comprising oceanic and continental fragments and continental margin metamorphic and sedimentary rocks are preserved along the IAESZ.

A northward dipping subduction zone developed within the İzmir-Ankara-Erzincan Ocean, a northern branch of Neotethyan Ocean, in the Early Cretaceous. The suprasubduction zone (SSZ) ophiolites formed in this intra-oceanic setting. The Dağküplü Ophiolite was, like other ophiolite nappes in the region, thrust over the southern Anatolide-Tauride Platform. The Dağküplü Ophiolite, exhibiting an incomplete and inverted ophiolite suite, consists mostly of refractory peridotites (harzburgite and dunite) representing mantle unit and lesser dunite and wehrlite cumulates, pyroxenites, and massive-layered gabbros. The plagiogranite volumetrically constitutes about 10% of the entire ophiolitic rocks. Petrographic and geochemical data suggest that plagiogranites were generated from TiO_2-poor cumulate gabbros by fractional crystallization at a suprasubduction zone spreading center.

INTRODUCTION

Şengör and Yılmaz (1981) suggested that two oceanic basins, the northern and southern branches of the Neotethyan Ocean in the Eastern Mediterranean area, separated several continental blocks from each other. In Anatolia (Turkey), suture zones such as the Intra-Pontide Suture, the IAESZ, the Inner Tauride Suture Zone, and the Pötürge-Bitlis Suture Zone, developed by collisional tectonics from the Late Cretaceous to the Miocene. One of the most characteristic features of suture zones is that they include remnants of oceanic crust (Fig. 1).

Ophiolitic rocks cover extensive areas of the Alpine Orogenic Belt in Turkey (Fig. 2). These ophiolite bodies are found from north to south within the Northern Ophiolite Belt, the Taurus Ophiolite Belt, and the Southern (Peri-Arabian) Ophiolite Belt.

The Dağküplü Ophiolite is situated in the western part of the IAESZ (İzmir-Ankara section). The Dağküplü Ophiolite and its surroundings, namely the Sivrihisar, Mihalıççık, Tavşanlı, Orhaneli, and Harmancık ophiolites are known as the Central Sakarya Ophiolites, and represent the northern branch of Neotethys in an intraoceanic subduction zone during the Late Cretaceous (Asutay et al., 1989; Göncüoğlu et al., 2000; Özen et al., 2002; 2005; Önen, 2003; Bacak and Uz, 2003; Sarıfakıoğlu and Özen, 2004; Manav et al., 2004). The eastern part of IAESZ (Ankara-Erzincan section) includes the Edige, Kalecik, and Şabanözü Ophiolites within the Ankara Mélange (Akyürek et al., 1979; Çapan and Floyd, 1985; Tankut and Gorton, 1990; Tankut et al., 1998), Güneş (Divriği) Ophiolite (Yılmaz et al., 2001), Refahiye (Erzincan) Ophiolitic Mélange (Bektaş, 1982; Aktimur et al., 1995; Özen et al., 2006), Palandöken (Erzurum) and Ağrı Ophiolites.

Upper Cretaceous ophiolites in Turkey were generated by SSZ magmatic processes (Göncüoğlu and Türeli, 1994; Yalınız et al., 1996; 2000; Parlak et al., 1996; 2004; Beyarslan and Bingöl, 2000; Çelik et al., 2002; Özen and Sarıfakıoğlu, 2002; Vergili and Parlak, 2005; Bağcı et al., 2005). Pearce et al. (1984) proposed that this type of ophiolite could be formed during the initial stages of subduction prior to development of a volcanic arc in a SSZ setting. SSZ ophiolites indeed characterize three paleotectonic settings, i.e. pre-arc, forearc and backarc. Flower and Dilek (2003) and Dilek and Flower (2003) suggested that boninitic protoarc ophiolites form in response to mantle flow and slab-pull forces of subduction zones in arc-forearc settings. They report that these ophiolites include a high-temperature metamorphic sole, refractory peridotites, boninitic cumulates, plagiogranite bodies and high-temperature epidosites. They give Mirdita (Albania), Troodos (Cyprus), and Semail (Oman) ophiolites as examples (Pallister, 1981; Alabaster et al., 1982; Malpas and Langdon, 1984; Shallo, 1992; Cortesogno et al., 1998). Shervais (2001) speculated that rocks belonging to plagiogranite series formed particularly at the mature stage of ophiolitic life cycle containing birth, youth, maturity, death and resurrection stages.

In this paper, I describe the geological features of the lower units of the Dağküplü Ophiolite in western Turkey and present petrographic and geochemical data from cumulate gabbros and rocks of the plagiogranite series. Then, I give an interpretation of the generation and evolution of IAESZ ophiolites in the light of the above data.

REGIONAL GEOLOGY

The Anatolian Plate, located between the Eurasian and Arabian Plates, was divided into numerous microcontinents by the northern and southern branches of the Neotethyan Ocean. The Upper Triassic (upper Carnian) - Lower Cretaceous İzmir-Ankara-Erzincan Ocean, representing the northern branch of the Neotethyan Ocean, intervenes between the northern Pontides and southern Anatolide-Tauride Platform (Harris et al.,1994; Bragin and Tekin, 1996; Tekin et al.,

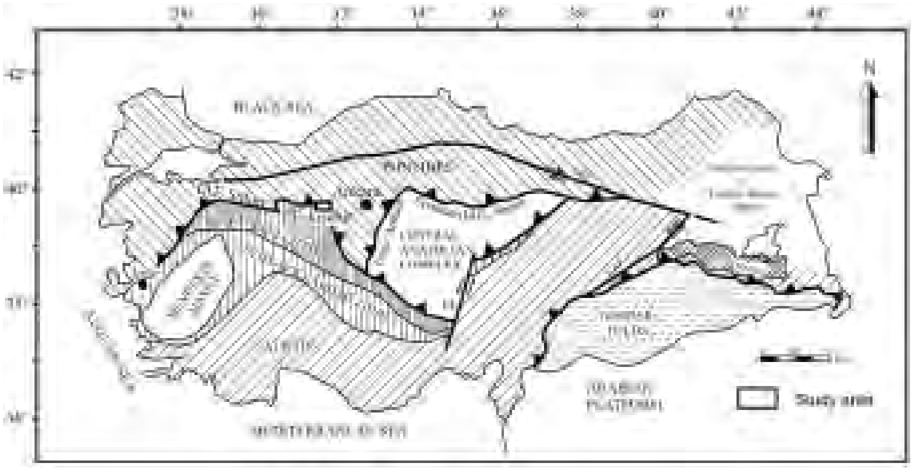

Fig. 1 - The tectonic sketch of Turkey showing the suture zones (after Okay, 1986).

2002). The intraoceanic subduction zone ophiolites were generated in the northern branch of the Neotethyan Ocean in the Late Cretaceous as arc products and throughout the Eastern Pontides by the plunging of this oceanic lithosphere underneath the Pontides (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Robertson, 1994; Okay et al., 2001).

The study area, which is located 15 km north of Eskişehir, covers about 750 km^2 and is situated immediately south of the IAESZ. In this region, the Dağküplü ophiolitic sequence, found as *en echelon* slabs, has been tectonically emplaced onto the Tavşanlı Zone metamorphic rocks at the northern margin of the Anatolide-Tauride Platform (Fig. 3). These metamorphic rocks, exposed in tectonic windows beneath the ophiolite nappe, include blueschists, greenschists, calcschists, metapelitic rocks, and marbles (Kulaksız, 1981; Okay, 1984; Göncüoğlu et al., 1996; Gözler et al., 1996). Okay and Keller (1994) reported the age of HP/HT metamorphism in the Tavşanlı Zone to be Late Cretaceous. North of the Dağküplü Ophiolite, greywacke, shale, and limestones occur, belonging to the Permo-Triassic Karakaya Complex. These units tectonically rest upon the mantle peridotites and ophiolitic mélange (Bingöl et al., 1975; Özen et al., 2002).

The ophiolite nappe was thrust over the Anatolide-Tauride Platform during the Maastrichtian-Paleocene while the ophiolitic mélange and metamorphic soles (amphibolites) developed as a thin sliver at the base. In the ophiolitic mélange, the pelagic-neritic limestone blocks of the Anatolide - Tauride Platform, radiolarian cherts, basalt blocks, and blocks of mafic-ultramafic rocks are all embedded in a matrix of pervasively sheared pelitic rocks and schistose serpentinite. The eastern part of the study area includes the components of the Karakaya Complex belonging to the Ankara Mélange, ophiolite fragments of Northern Neotethys, volcano-sedimentary and sedimentary rocks of a forearc basin as well as volcanics of the Galatean Arc Complex (Koçyiğit et al., 2003).

In the study area, peridotites of the ophiolitic sequence are intruded by the Eocene Yörükkaracaören granodiorite that was produced by thickening of continental crust related to the regional compression during the Paleocene collision of the Pontide Continent and the Anatolide-Tauride Platform. Lower Miocene volcanism affected the Cretaceous ophiolitic mélange around the Mayıslar Village; as a result the Tertiary sedimentary and pyroclastic rocks cover the former lithostratigraphic units.

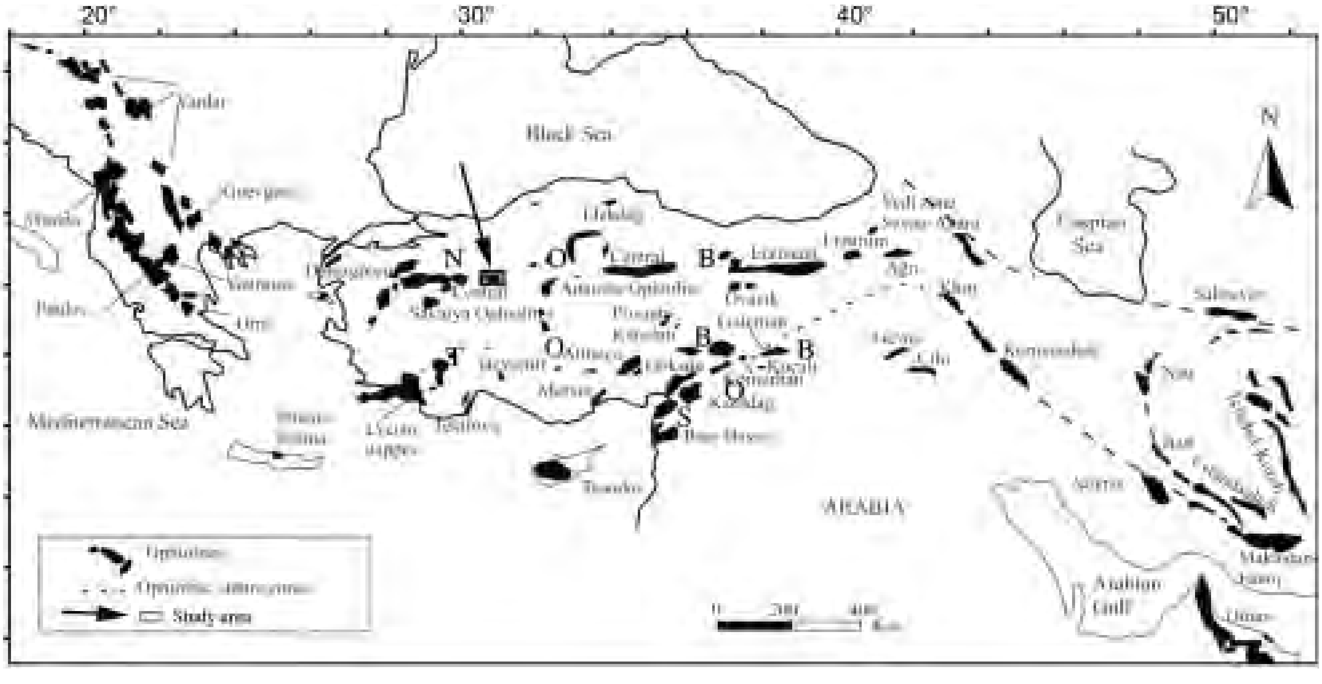

Fig. 2 - Distribution of Triassic-Cretaceous Neo-Tethyan ophiolites in the Eastern Mediteranean (revised from Dilek and Moores, 1990; Lippard et al. 1986). NOB: Northern Ophiolite Belt; TOB: Taurus Ophiolite Belt; SOB: Southern Ophiolite Belt.

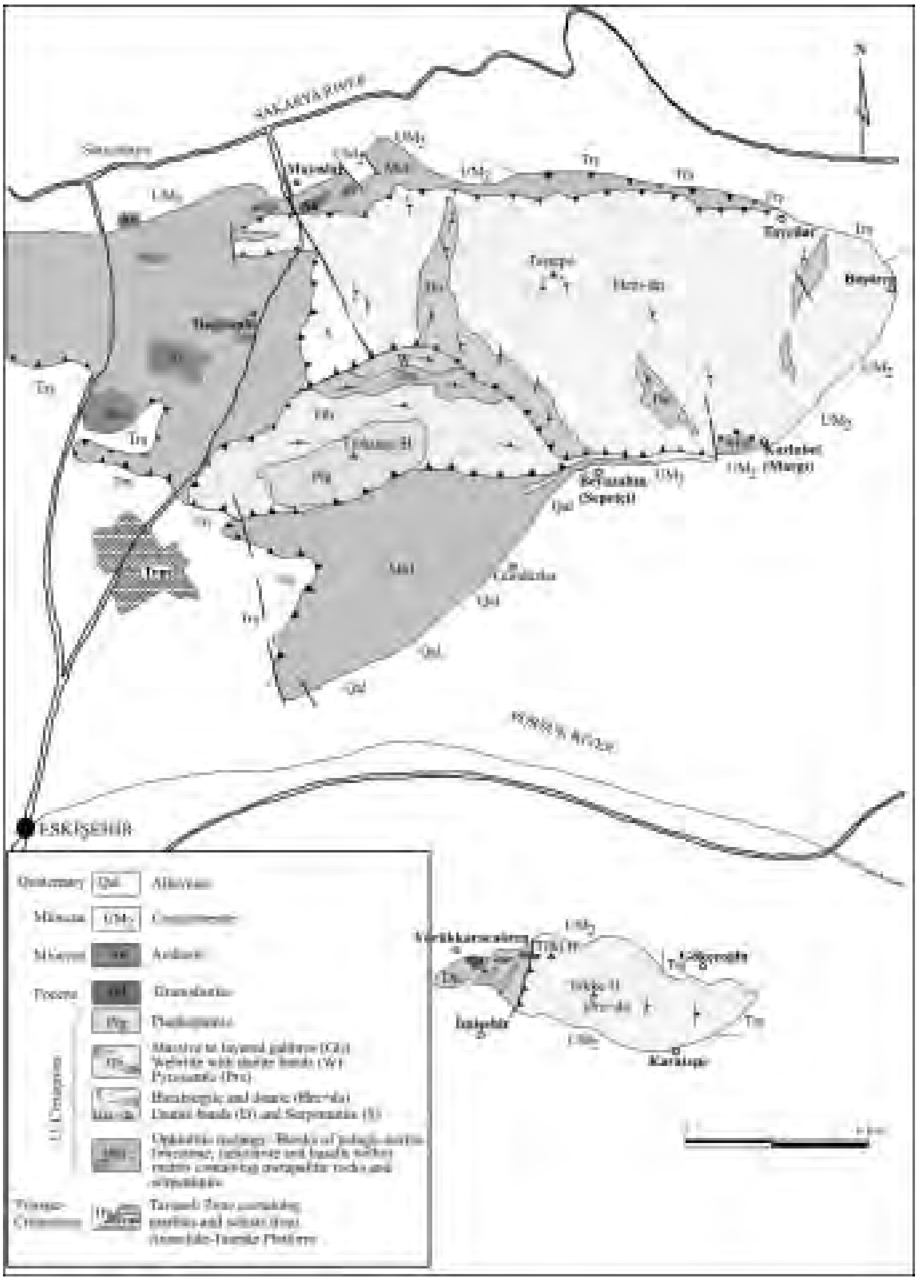

Fig. 3 - Geological map of the Dağküplü (Eskişehir) Ophiolite (after Özen et al. 2002).

The Dağküplü Ophiolite, which covers an area of about 200 km² between the Yarımca and Mayıslar villages (Eskişehir province), displays a dismembered ophiolite sequence. The ophiolitic series mainly includes mantle peridotites, mafic-ultramafic cumulates and plagiogranites, forming a nappe about 4 km thick. The mantle peridotites consist mostly of harzburgites locally interlayered with dunites, while dunite bands showing alternations with wehrlite, pyroxenite and massive-layered gabbros occur as cumulates. The contacts between these ophiolitic subunits are commonly marked by faults related to shearing stress. The serpentinites and amphibolites are especially common along these shearing zones. The measurements from the dunitic bands transitional to harzburgites, from chromitite bands within dunite lenses, and magmatic layers composed of alternating light and dark levels in layered gabbros indicate that the ultramafic rocks mostly have internal structures striking N-S and dipping East, whereas the mafic rocks have internal structures striking E-W and dipping North (Fig. 3). This indicates that the mantle peridotites that would normally be present at the base of the sequence, tectonically rest upon the cumulates. This position implies that the ophiolitic sequence has been inverted during nappe thrusting.

The plagiogranites, exposed over an area of about 20 km² around Türkmen Tepe, occur as hypabyssal and/or near-surface intrusive rocks. The plagiogranites are associated with massive gabbros and identified by their glassy appearance and greenish gray colour in the field. The plagiogranites modally range from quartzdiorites to trondhjemites. The alteration zones within plagiogranite bodies occur as chlorite- and epidote-rich veinlets varying in thickness between 0.5 and 5.0 cm.

PETROGRAPHY

Mantle Peridotites

Mantle ultramafics consist mostly of harzburgite, representing the upper mantle in the Dağküplü Ophiolite. These rocks, are composed of 75% olivine and 25% orthopyroxene (enstatite) and exhibit porphyroclastic texture formed by plastic deformation. Olivine crystals usually have fractures and locally exhibit kink bands. Orthopyroxenes have bent crystals. The large porphyroclasts (up to 0.5 cm in size) of the broken and bent mafic minerals are surrounded by fine-grained olivines. Orthopyroxene crystals rarely exsolve clinopyroxene exsolution lamellae. Accessory chromites show elongation and hairline cracks (pull-apart texture) developed perpendicular to this orientation. Harzburgites contain minor dunite interlayers and lenses with scattered chromitite pods. They show massive, banded or disseminated textures, locally mined.

The mantle tectonites are cut by swarms of isolated diabase dykes with 20-75 cm thickness and a few tens of meters length, extending as discontinuous outcrops. Relict diabase texture shows that original plagioclases (labradorite) and mafic minerals (clinopyroxene) are altered to albite, chlorite, epidote, tremolite-actinolite, and calcite minerals. The hydrothermally altered diabases were affected by grade greenschist metamorphism.

The mantle peridotites are partly or entirely altered to serpentine minerals (lizardite and chrysotile) from olivines and bastite pseudomorphs from orthopyroxenes. Ultramafic rocks were thus generally transformed into serpentinites. Locally, yellowish and brownish coloured listwaenites are observed as veins along thrust planes between the ophiolite nappe and continental terranes, and in shear zones within ophiolite slabs. These alteration rocks produced by hydrothermal fluids passing through serpentinized peridotites mainly include quartz, carbonate minerals, chromian mica and Fe-hydroxide minerals. Magnetite and Cr-spinels are rare in the listwaenites. Also, the magnesite occurrences along fractures are found within olivine-rich dunites.

Mafic-ultramafic Cumulates

Mafic-ultramafic cumulates include wehrlite, dunite bands alternating with pyroxenite, massive-layered gabbro and minor gabbronorite. The gradual transition particularly between wehrlite and dunite bands is due to clinopyroxene content ranging from 10-40% in wehrlites exhibiting mesocumulate texture. Olivine and clinopyroxene are cumulus crystals whereas green aluminum rich spinels (hercynite) are intercumulus crystals.

Clinopyroxenites containing more than 75% clinopyroxene and having adcumulate texture occur as interlayers together with wehrlites, and as thin veins cutting ultramafic cumulates.

Gabbros in tectonic contact with ultramafic tectonites and ophiolitic mélange lie at the basal part of the Dağküplü Ophiolite sequence. The medium-and fine-grained layered gabbros are composed by alternating levels of mafic minerals (olivine and/or clinopyroxene) and plagioclases. They comprise about 55% plagioclase and 40% mafic minerals. The plagioclase crystals show extensive saussuritization by secondary albite, epidote and chlorite. Clinopyroxenes are commonly altered to tremolite-actinolite along cleavage planes, fractures, and crystal rims. Apatite and opaque Fe-Ti oxides are found as accessory minerals. Massive gabbros having adcumulus texture contain plagioclase (50-60%) and clinopyroxene (30-40%) crystals with addition of orthopyroxene (hypersthene), and grade into gabbronorites in places. In the coarse-to fine-grained gabbroic cumulates, the primary plagioclase crystals are usually partly replaced by albite, epidote, and chlorite. In several gabbro samples, the plagioclases are commonly variably altered to zeolite minerals and sometimes to hydrogrossular. Clinopyroxenes are usually completely replaced by tremolite-actinolite and minor chlorite. The mineral assemblages and textural features suggest that alteration of the cumulate gabbros from the Dağküplü ophiolite suite is attributable to low-grade ocean-floor hydrothermal metamorphism at temperatures between approximately 200° and 400°.

Plagiogranites

Plagiogranites occur as dykes, sills or small stocks within ophiolites representing oceanic lithosphere, especially between cumulate gabbros and sheeted dykes. The term “plagiogranite” includes various lithologies: albite granite, diorite, quartz diorite, trondhjemite, tonalite, keratophyre and albitite. These leucocratic rocks consist mainly of plagioclase and quartz with rare ferromagnesian minerals. K-feldspar is absent (Coleman and Peterman, 1975; Coleman and Donato, 1979).

The Dağküplü Ophiolite occurs above the ophiolitic mélange with tectonic contact. Near the tectonic contact, the plagiogranites of the Dağküplü ophiolite cover an area of 2.5 x 6.0 km around Türkmen Hill. The plagiogranites occur as high-level intrusive rocks like small stocks in magmatic contact with the cumulate gabbros. These felsic rocks have a greenish gray coloured glassy appearance in the field due to their mineralogical composition and alteration. Going from gabbros towards plagiogranites, rock samples have commonly graded to gabbro, quartz diorite, and trondhjemite by petrographic studies. The plagiogranites are locally cut by millimetric-centimetric veins filled with abundant epidote and chlorite.

The quartz diorites exhibit intergranular texture and contain approximately 50-55% plagioclase, 20-25% mafic mineral, 10% biotite (chloritized), and 5-7% quartz. The plagioclases have typically andesine composition. These rocks also contain opaque minerals, apatite and accessory zircon. Grain size ranges between 0.1 and 1.0 mm. Plagioclase crystals are mostly saussuritized due to hydrothermal alteration caused by sea water. Mafic minerals are chloritized and carbonatized (Fig. 4).

The trondhjemites consisting of felsic minerals contain less than 10% mafic minerals. These rocks, having aphanitic and microporphyritic textures, contain albite and quartz microcrystals. Plagioclase microphenocrysts are partly epidotized and chloritized. The primary mafic minerals are usually completely altered to secondary minerals. Some epidote (pistacite) is found as prismatic microphenocrystals forming next to clinopyroxenes. The chlorite lamellae derive from biotite or pyroxene. This may suggest that the primary mafic minerals were transformed to epidote and chlorite. In fine-grained trondhjemites, whose grain size ranges between 0.01 mm and 0.4 mm, microcrystals of albite and quartz exhibit a worm-like or lace-like intergrowth texture named “quartz-albite microgranophyre”, and suggestive of shallow depth crytallization (Fig. 5). This fabric and crystallization order suggest that plagioclase initially formed by magmatic processes. Coleman and Donato (1979) state that this texture is characteristic of oceanic plagiogranites from ophiolite complexes. The same rock samples show that the micro-granophyric texture grades into spherulitic texture in which cryptocrystalline quartzofelspathic minerals have a radiated /bunch-like appearance.

Plagiogranite rocks are locally cut by epidosite veins of hydrothermal origin. Epidosite veins are composed of quartz + chlorite + epidote minerals.

ANALYTICAL TECHNIQUES

A total of 14 samples from the cumulate gabbros (6) and plagiogranites (8) were analyzed for major, trace, and rare earth elements in the Acme Analytical Laboratories Ltd in Canada. Major element contents were determined from a $LiBO_2$ fusion by ICP-ES by using 5 grams of sample pulp. Trace and rare earth element contents were determined from a $LiBO_2$ fusion by ICP-MS by using 5 grams of sample pulp. The results of the analyses are presented in Tables 1 and 2.

GEOCHEMISTRY

In discriminating oceanic plagiogranites from continental granites, one of the most significant criteria is deficiency of potassium feldspar in their norms as a result of their K_2O contents being very low (0,07-0.64%) compared to the K_2O content of continental granites at over 3%. However, their Na_2O contents (2.0-5.3%) are high. Rb, Sr values of oceanic plagiogranites (Rb/Sr < 0.015) are different from those of continental trondhjemites (Rb/Sr > 0.015). Dramatic discrepancies are noticeable in REE contents of oceanic and continental granites (Coleman and Peterman, 1975; Hyndman, 1985).

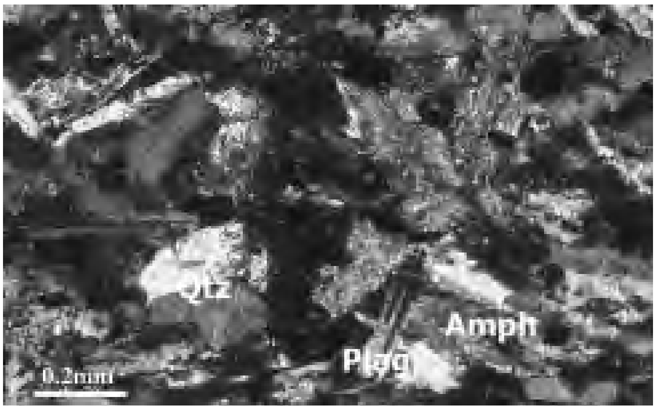

Fig. 4 - Photomicrograph (cross-polarized light) of the quartz diorites (Plag: Plagioclase; Qtz: quartz; Amph: amphibole).

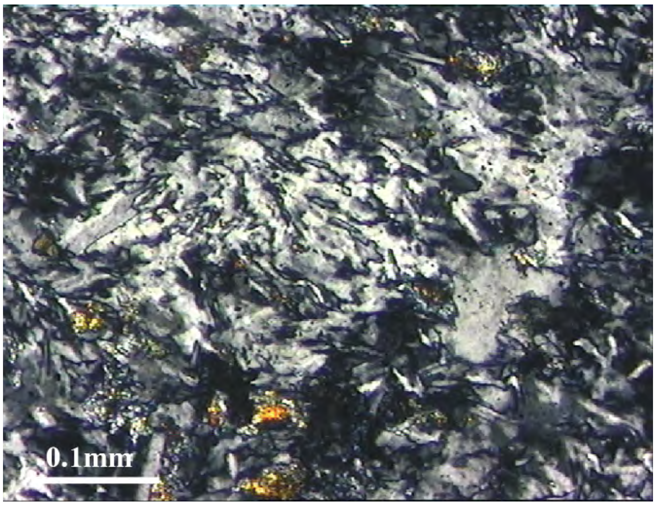

Fig. 5 - Photomicroph of microgranophyric texture from the trondhjemites.

On the basis of geochemical data, the petrogenesis of plagiogranites can be summarized as follows:

1- Na-metasomatism of K-rich acidic melts (Gilluly, 1933),
2- Generation of basic and acidic rocks from immiscible melts of silicate magma (Dixon and Rutherford, 1973),
3- Fractional crystallization of subalkaline basaltic magma at shallow depth in oceanic crust (Coleman and Peterman, 1975; Coleman and Danato, 1979),
4- Partial melting of mafic rocks in aqueous environments (Sigvalson, 1974) or anatexis of amphibolites (Pedersen and Malpas, 1984).

Stakes and Taylor (2003) proposed that large plagiogranite intrusions are generated by assimilation and fractional crystallization (AFC) of mafic rocks (gabbros, dykes) that have been subjected to hydrothermal alteration within oceanic crust.

On the Alkali-Silica Diagram in Fig. 6, gabbros and plagiogranites with low K_2O contents (0.07-0.23%) from the study area plot in the subalkaline field. On the AFM diagram, cumulate gabbros plot in the tholeiite field whereas plagiogranites plot near the tholeiite-calc-alkaline one (Fig. 7). Coleman and Peterman (1975)' diagram containing K_2O versus SiO_2 shows almost a linear compositional distribution from cumulate gabbros to quartz diorites and trondhjemites. This may reflect the fact that in the magma chamber plagiogranite series rocks have been generated by fractional crystallization from the relict melt after formation of mafic cumulates (Fig. 8). On the Y-Zr variation diagram, the differentiation trend of cumulate gabbros and plagiogranites is given for correlation with plagiogranites of ophiolites from the Neotethyan Ophiolites within the Alpine Orogenic Belt (Fig. 9). Coleman and Peterman (1975) differentiated continental trondhjemites and oceanic plagiogranites on the basis of their Rb and Sr contents. The trondhjemites from the Dağküplü ophiolite fall within the oceanic plagiogranite field (Fig. 10). The cumulate gabbros have low TiO_2 (< 0.5), low-Zr (1.4-5.8) and low Nb/Y ratios (0.05-0.26). According to the TiO_2-$FeO^*/(FeO^* + MgO)$ discrimination diagram (Serri, 1981), the gabbroic cumulates plot in the field of low-Ti ophiolites (Fig. 11). In addition, these rocks show boninite affinities on the TiO_2-Zr and Cr-Y diagrams (Figs. 12, 13). Low-Ti island arc tholeiites and boninite-like magmas denote a clear suprasubduction zone signature (e.g. Stern and Bloomer, 1992). Based on these geochemical features of the cumulate gabbros and the plagiogranites, it may be proposed that the Dağküplü ophiolite occurred in suprasubduction zone settings.

On the Nb-Zr diagram (after Leat et al., 1986), arc-related granites, namely plagiogranites are distinguished from post-collisional granitoids and/or late granitoids by their Zr/Nb ratios. The Dağküplü plagiogranites have low and uniform Nb content and show similar Zr/Nb ratios to other plagiogranites from Eastern Mediterranean Ophiolites (Fig. 14).

On a spider diagram normalised to ocean ridge granites (ORG), K and Rb are depleted, while Ba and Th show enrichment. Among the HFS elements, particularly Yb reflects depletion while Nb, Hf, and Zr show negative anomalies. Coleman and Donata (1979) suggested that hydrothermal metamorphism takes place in a subseafloor environment, induced by sea water during generation of plagiogranites, and that plagioclases have low K and Rb contents because this alteration depletes these elements. The plagiogranites of the Dağküplü Ophiolite show great compositional similarities to those from other Eastern Mediterranean Ophiolites (Fig. 15). These geochemical data suggest that the ophiolites of

Table 1 - Representative whole-rock chemical compositions of the gabbros from the Dağküplü Ophiolite.

	Gabbros					
Sample	**EG-2**	**EG-4**	**EG-5**	**EG-6**	**KG-2**	**KG-3**
Oxide wt%						
SiO_2	44.19	45.34	44.6	44.86	43.55	44.36
TiO_2	0.09	0.26	0.21	0.44	0.07	0.11
Al_2O_3	18.11	16.5	16.4	15.83	20.73	17.24
Fe_2O_3	6.31	15.3	12.5	9.89	4.65	5.53
Cr_20_3	0.072	0.028	0.018	0.037	0.085	0.045
MgO	10.23	6.49	8.05	9.15	11.31	12.98
CaO	14.37	11.39	13.52	14.27	13.64	14.32
Na_2O	1.07	1.62	0.71	0.52	1.4	1.21
K_2O	0.03	0.04	0.02	0.06	0.06	0.05
P_2O_5	0.02	0.05	<0.01	0.01	<0.01	<0.01
MnO	0.15	1.01	0.63	0.16	0.08	0.1
LOI	5.2	1.8	3.2	4.5	4.3	3.9
SUM	99.87	99.83	99.81	99.74	99.95	99.85
Trace ppm						
Ba	5	8	5	14	10	6
Ni	167	257	112	71	431	374
Sc	29	45	44	53	14	22
Co	54.6	58.3	52.6	48.1	40	44.5
Cs	<0.1	0.2	<0.1	<0.1	0.2	0.3
Ga	13	18.4	15.7	11.6	9.9	8.2
Hf	<0.5	<0.5	<0.5	<0.5	<0.05	<0.05
Nb	<0.5	<0.5	<0.5	<0.5	<0.05	<0.05
Rb	0.7	1	<0.5	3	1.6	1.4
Sr	156.1	164.3	156.9	130.8	312.4	184.1
Ta	0.9	<0.1	0.3	<0.1	<0.1	<0.1
Th	<0.1	<0.1	<0.1	1.2	0.3	<0.1
V	99	468	458	325	39	61
W	63.7	82.6	51.4	41.6	3.1	51.6
Zr	2.2	1.7	1.4	4.5	3.3	5.8
Y	3.4	9	5.3	3.8	1.9	2.6
REE ppm						
La	<0.5	<0.5	<0.5	1	<0.5	0.6
Ce	<0.5	0.6	0.7	1.9	0.9	1.1
Pr	0.09	0.18	0.10	0.23	0.13	0.17
Nd	0.7	1.4	0.6	0.8	0.5	0.9
Sm	0.3	0.7	0.4	0.4	0.2	0.2
Eu	0.20	0.66	0.36	0.2	0.19	0.21
Gd	0.43	1.20	0.64	0.51	0.28	0.46
Tb	0.10	0.22	0.14	0.1	0.04	0.06
Dy	0.52	1.50	0.81	0.75	0.33	0.55
Ho	0.13	0.32	0.19	0.16	0.07	0.11
Er	0.33	0.96	0.61	0.43	0.2	0.28
Tm	0.05	0.13	0.09	0.07	<0.05	<0.05
Yb	0.30	0.86	0.54	0.42	0.17	0.2
Lu	0.05	0.15	0.10	0.06	0.03	0.03

Table 2 - Representative whole-rock chemical analyses of the plagiogranites from the Dağküplü Opholite.

	Trondhjemites				**Quartz Diorites**			
Sample	**E.12**	**E.14**	**E.16**	**E.18**	**E.21**	**E.17**	**E.20**	**SDY.1**
Oxide wt%								
SiO_2	72.68	73.9	71.74	72.2	65.62	53.19	50.28	52.45
AI_2O_3	12.37	11.91	12.63	12.36	13.07	12.86	14.51	14.72
Fe_2O_3	3.87	3.44	4.05	4.44	7.61	11.87	11.74	11.66
MgO	0.67	0.58	0.7	0.82	1.35	3.3	4.35	3.41
CaO	2.72	2.2	2.46	2.26	2.49	6.59	8.32	7.62
Na_2O	5.08	5.17	5.31	5.17	6.34	4.12	4.45	5.45
K_2O	0.08	0.07	0.08	0.08	0.23	0.08	0.09	0.1
TiO_2	0.28	0.27	0.29	0.28	0.85	1.61	1.56	1.55
P_2O_5	0.03	0.01	0.02	0.02	0.2	0.16	0.17	0.19
MnO	0.04	0.03	0.04	0.04	0.06	0.15	0.17	0.16
Cr_20_3	0.003	0.007	0.004	0.007	0.005	<0.001	0.005	0.003
LOI	1.5	1.7	2.2	1.7	1.9	5.6	3.9	2.2
SUM	99.32	99.3	99.53	99.39	99.52	99.54	99.55	99.52
Trace ppm								
Ba	38.3	76.4	49.9	215.5	202.3	102.2	70.2	30
Ni	<20	<20	<20	<20	<20	<20	43	21
Sc	15	14	15	15	17	28	32	28
Co	56.3	113.7	58.9	49.6	66	43.3	39.1	33.6
Cs	0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1
Ga	19.5	16.3	18.8	17.4	16.5	19.2	20.5	21
Hf	5.3	5.1	5.4	5.3	4.9	3.7	3.7	4.5
Nb	4.9	4.6	4.9	4.6	4.4	3.1	2.7	4.2
Rb	0.9	0.5	0.8	1.4	3.1	1.3	1	2.4
Sn	1	1	<1	1	<1	1	<1	1
Sr	117.4	188.1	220.6	187.8	84.7	149.4	200.9	277.8
Ta	0.4	0.5	0.4	0.4	0.4	0.2	0.2	0.3
Th	1.1	1.2	1.9	1.1	1.2	0.7	0.5	1.3
U	0.9	0.8	0.9	0.7	0.4	0.3	0.2	0.4
V	6	5	<5	<5	50	261	322	257
W	406	714.9	360	325.3	422.7	115.1	50.9	101.7
Zr	165.7	163.3	175.9	168.1	161	118.1	115	146
Y	64.3	59.4	67.1	59.6	59.2	45.5	46.7	54.7
REE ppm								
La	9.6	9.5	10.2	9.7	8.5	6.5	5.6	8.7
Ce	24.1	23.6	25.1	23.7	22.9	17.3	15.6	22.6
Pr	3.15	3.29	3.49	3.26	3.39	2.68	2.24	3.46
Nd	18.7	17.8	19	18.4	19.9	13.7	13.8	19
Sm	5.5	5.4	6.1	5.8	6.1	4.3	4.6	5.7
Eu	1.48	1.46	1.64	1.43	1.88	1.54	1.48	1.78
Gd	7.37	7.05	7.85	6.93	7.47	5.72	5.91	7.43
Tb	1.31	1.31	1.45	1.27	1.34	1.06	1.04	1.42
Dy	9.22	8.3	9.3	8.93	8.63	6.74	7.08	8.83
Ho	2.16	1.99	2.27	2.09	2.08	1.6	1.66	1.92
Er	6.13	5.81	6.31	5.78	5.68	4.22	4.5	5.63
Tm	1	0.93	1.02	0.94	0.9	0.6	0.68	0.79
Yb	6.2	5.79	6.48	5.79	5.76	4.31	4.17	5.22
Lu	0.95	0.91	0.99	0.91	0.88	0.63	0.68	0.8

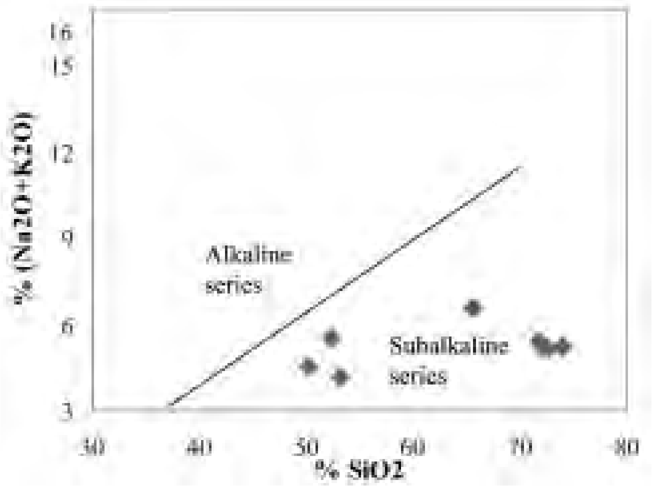

Fig. 6 - Plots of the major elements for the plagiogranites on the Alkali-Silica diagram (Irvine and Baragar 1971).

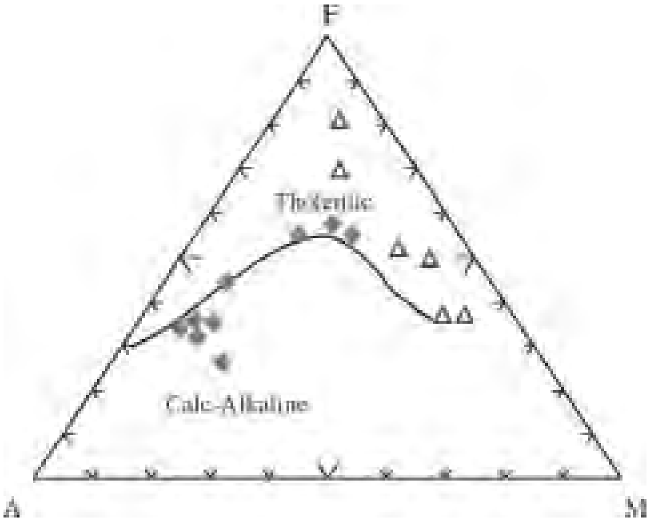

Fig. 7 - Distribution of gabbros (triangles) and plagiogranites (diamonds) from the Dağküplü Ophiolite on the AFM diagram (Irvine and Baragar 1971).

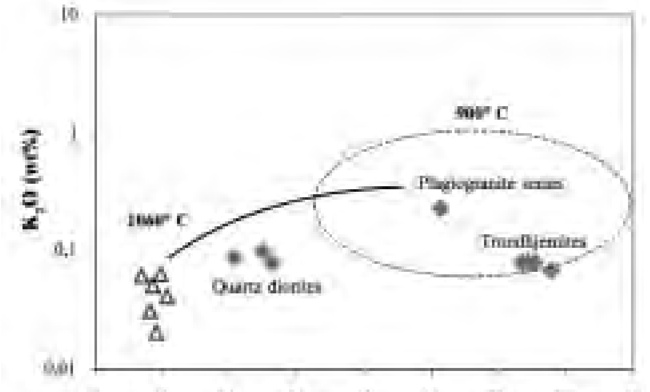

Fig. 8 - K_2O-SiO_2 diagram for gabbros and plagiogranites (Coleman & Peterman, 1975). Plagiogranites (diamonds) and Cumulate Gabbros (triangles) from the Dağküplü Ophiolite.

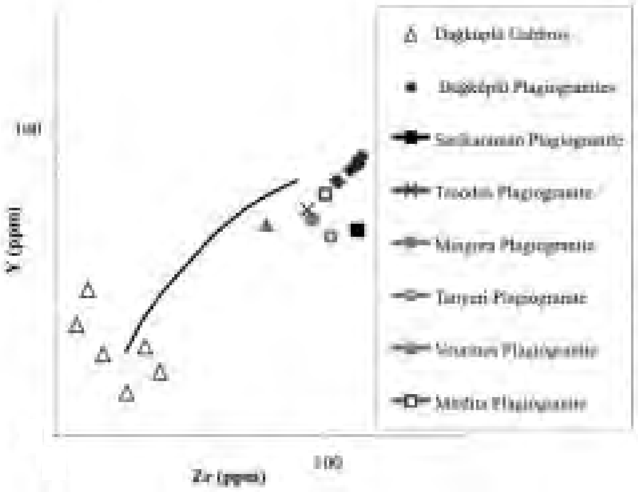

Fig. 9 - Plot of Y-Zr on Rollison (1993)'s diagram for cumulate gabbros and plagiogranites from the Dağküplü Ophiolite, and comparison with other Neotethyan plagiogranites in the Alpine Orogenic Belt: Sarikaraman (Floyd et al., 1998); Troodos (Coleman and Peterman, 1975); Mingora (Barbieri et al., 1994); Tanyeri (Bektaş, 1982); Vourinos (Beccaluva et al., 1984); Mirdita (Beccaluva et al., 1994).

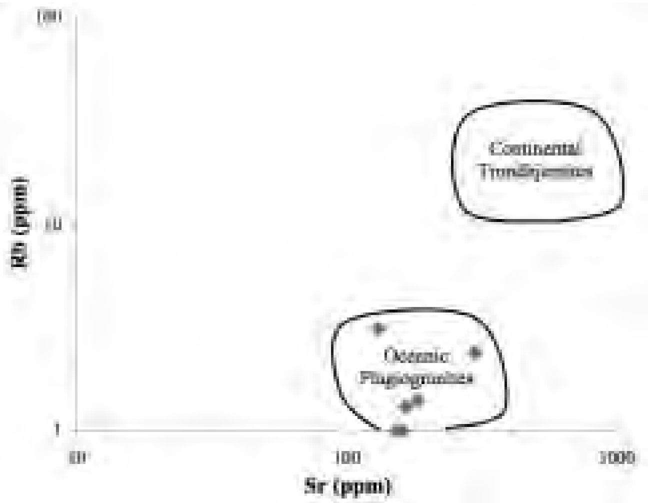

Fig. 10 - Plagiogranites from the Dağküplü Ophiolite on the Rb-Sr diagram (Coleman and Peterman, 1975).

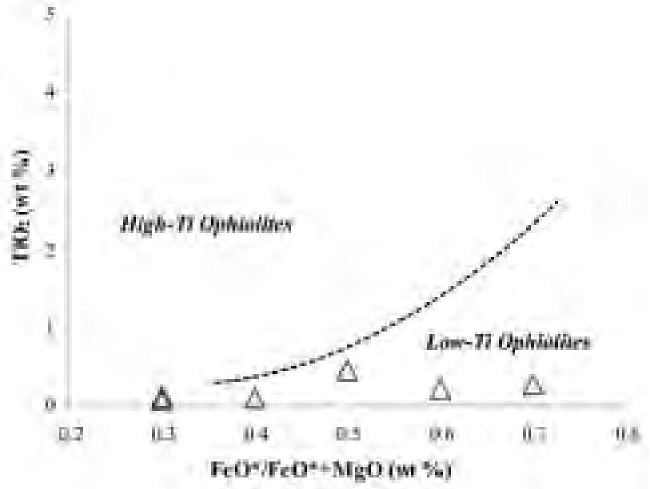

Fig. 11 - TiO_2 vs (FeO*/FeO*+MgO) discrimination diagram (after Serri, 1981) for gabbroic rocks from the Dağküplü Ophiolite.

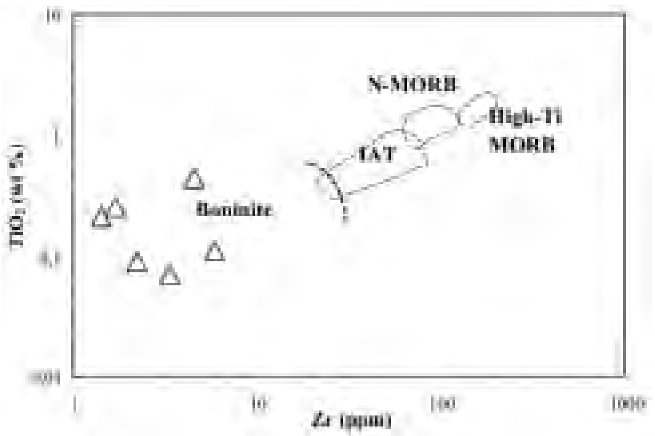

Fig. 12 - TiO_2 vs Zr diagram (after Capedri et al., 1980) for gabbroic rocks from the Dağküplü Ophiolite.

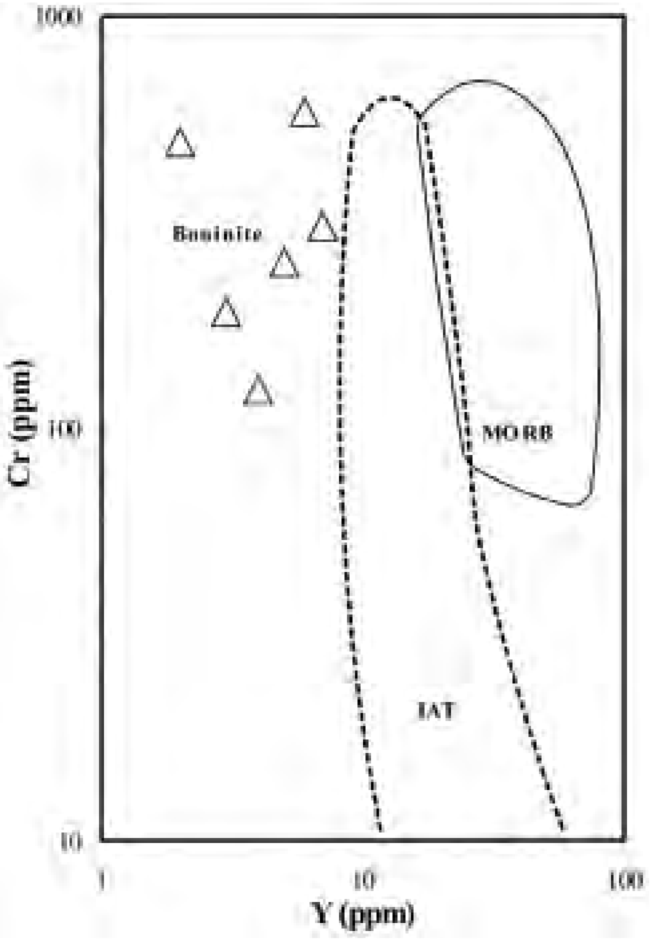

Fig. 13 - Plot of gabbros from the Dağküplü Ophilite on the Cr vs Y discrimination diagram (after Pearce, 1982).

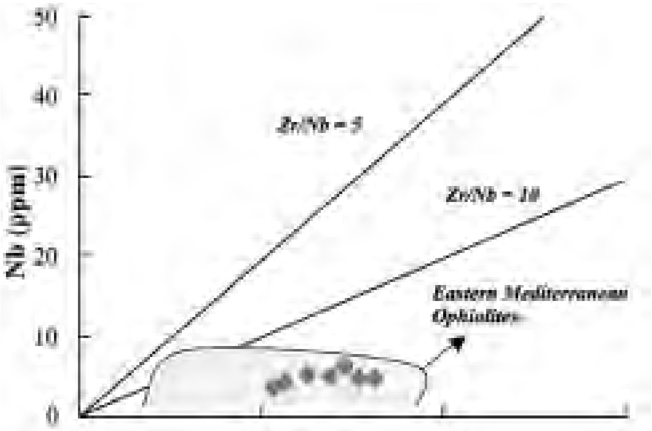

Fig. 14 - The investigated plagiogranites (diamond symbols) and other plagiogranites from Eastern Mediterranean Ophiolites on the Nb-Zr diagram (Leat et al., 1986).

the present study derived from a magma having IAT-like petrochemistry in a suprasubduction setting.

In the chondrite-normalized spider diagram, the gabbros and plagiogranites from the Dağküplü Ophiolite have a pattern similar to those of the Semail (Oman) Ophiolite and Troodos (Cyprus) Ophiolite (Fig. 16). It is clearly seen that REE contents increase from gabbros to plagiogranites. This suggests that these rocks derived from a common parent magma. The REE values of plagiogranites, except for Eu, are aligned along a subhorizontal line. Eu shows a positive anomaly in cumulate gabbros. Increase in SiO_2, but decrease in MgO and CaO contents, excess of Na_2O, and a negative Eu anomaly in plagiogranites indicate plagioclase (albite) crystallization.

On the Nb-Y and Rb-Y + Nb diagrams, plagiogranites from the Dağküplü Ophiolite plot in the ORG field or at the boundary with other Neotethyan suprasubduction zone ophiolitic plagiogranites (Fig. 17).

DISCUSSION AND CONCLUSION

A north-dipping intra-oceanic subduction zone developed within the İzmir - Ankara - Erzincan Ocean that separated the Sakarya Continent from the Anatolide-Tauride Platform. With hydrous fluids moving towards the mantle wedge over the subducted slab, wet melting began in the depleted mantle along the subduction zone. The melt produced generated SSZ-ophiolites rising upwards along fracture zones in the upper plate, induced by flow and slab-pull forces generated in the mantle wedge (Fig. 18). As continent-continent collision occurred immediately after generation of SSZ ophiolites 10 My or less duration in the study area and surroundings, fragments of forearc oceanic lithosphere were thrust over the Anatolide-Tauride Platform (Göncüoğlu et al., 2000; Okay et al., 2001).

The Upper Cretaceous Dağküplü (Eskişehir) Ophiolite within the IAESZ in northwestern Anatolia exhibits an incomplete and inverted suite. It consists mainly of harzburgites and less frequently lenses and bands of dunites in harzburgites as refractory mantle peridotites (with high MgO contents). The dunite layers alternating with wehrlites, pyroxenites and massive-layered gabbros occur as cumulates. The plagiogranites covering an area of 2.5 x 6.0 km and occurring as small intrusive bodies originating at shallow depths, comprise quartz diorite and trondhjemite on the basis of their mineral association. The ophiolitic mélange occurs beneath the Dağküplü Ophiolite and displays a chaotic structure, with blocks of several lithologies embedded in a fine-grained and highly sheared matrix as well as amphibolites of metamorphic sole as thin slivers.

The gabbroic cumulates have island-arc tholeiite or possibly boninite-related affinities with their low TiO_2, REE

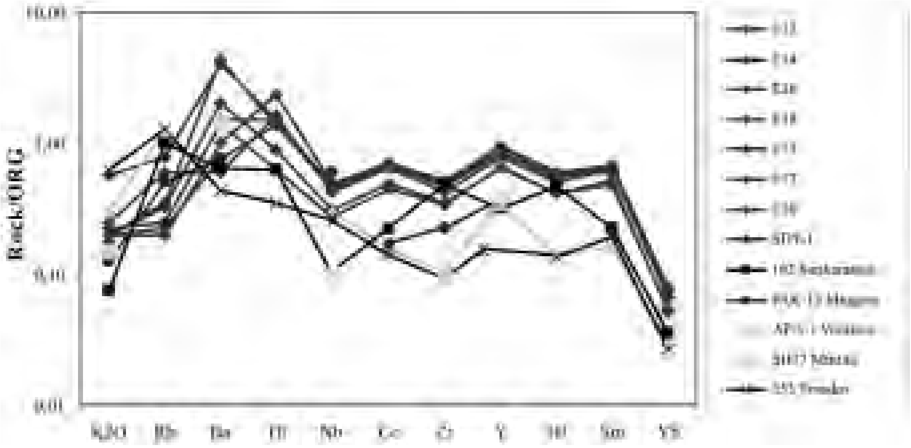

Fig. 15 - The investigated plagiogranites on the spider diagram normalized by Pearce et al. (1984) and comparison with other plagiogranites: Sarikaraman plagiogranites (Floyd et al., 1998); Mingora plagiogranites (Barbieri et al., 1994); Vourinos plagiogranites (Beccaluva et al., 1984); Mirdita plagiogranites (Beccaluva et al., 1994); Troodos plagiogranites (Coleman and Peterman, 1975).

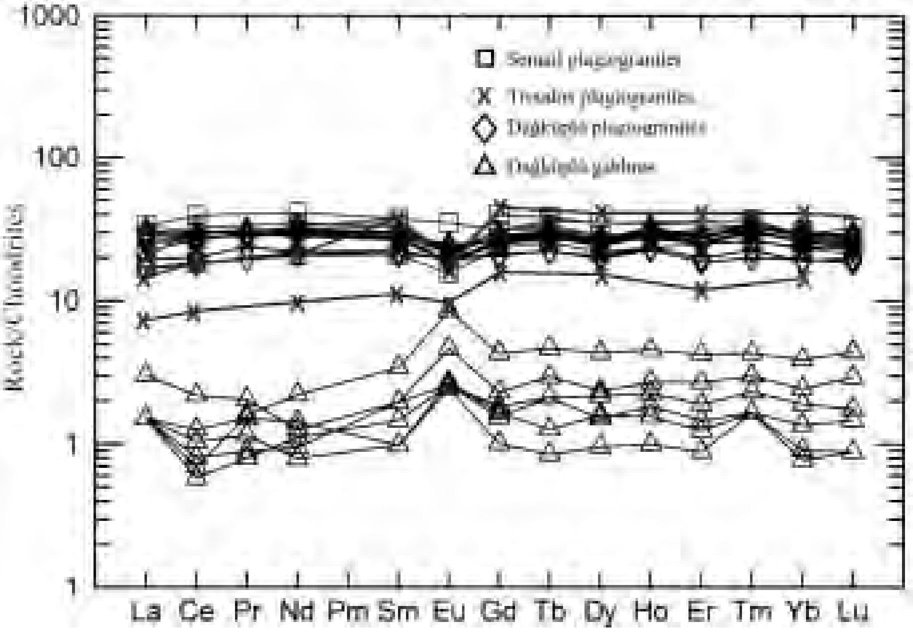

Fig. 16 - The investigated plagiogranites, compared with the Semail plagiogranites (Pallister and Knight, 1981) and Troodos plagiogranites (Kay and Senechal, 1976), spider diagram normalization after Nakamura (1974).

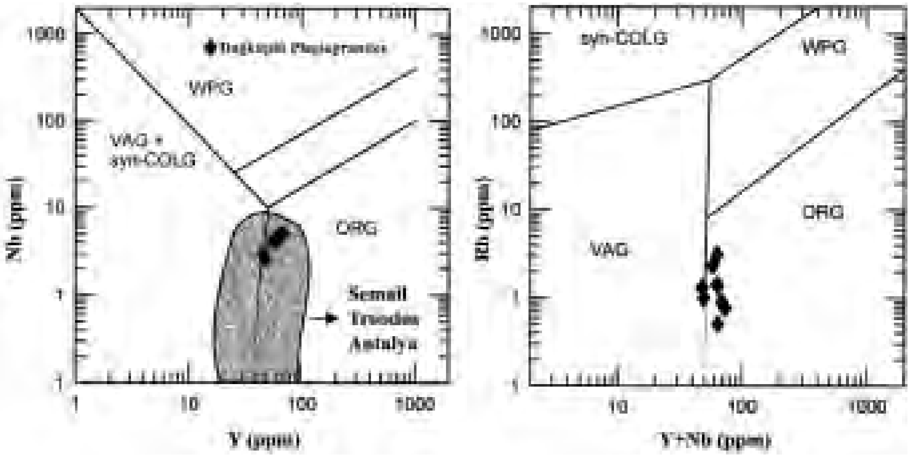

Fig. 17 - The Dağküplü plagiogranites (diamond symbols) and the field of plagiogranites from Eastern Mediterranean Ophiolites on the Nb – Y and Rb – Y + Nb diagrams (Pearce et al. 1984). The field includes the Troodos (Aldiss, 1978), Semail (Alabaster et al., 1982), and Antalya plagiogranites (Cocherie, 1978).

and high-field-strenght element contents. The mafic cumulates representing oceanic crust of the Dağküplü Ophiolite are crosscut by small plagiogranites with epidote- and chlorite-rich veins. The studied plagiogranites have low K_2O, Rb, Sr and high Na_2O contents, strikingly similar to other oceanic plagiogranites from Eastern Mediterranean Ophiolites. Their covariations of Rb, Nb and Y exhibit similarities to those of oceanic plagiogranites from Neotethyan ophiolites. The plagioclase and quartz show intergrowths (micro-granophyric texture) in trondhjemites, and the increase in SiO_2, K_2O, Y and Zr values from gabbros towards plagiogranites reflect that plagiogranites generated by silicic relict melt of basaltic magmas are cogenetic with gabbros and they form a coherent fractionation trend. The small pla-

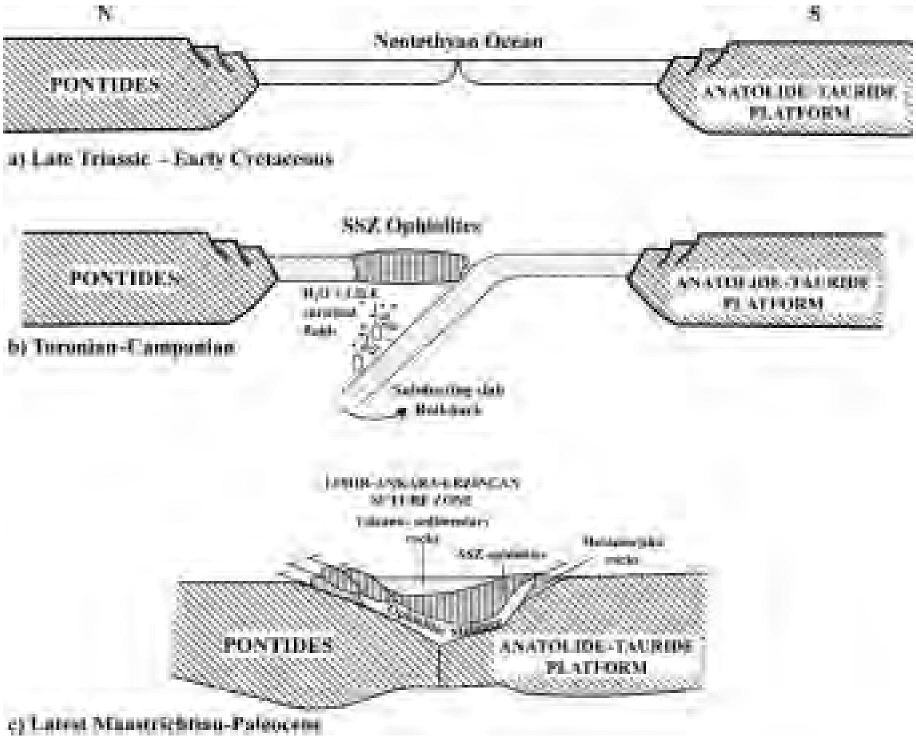

Fig. 18 - Tectonic sketch of the ophiolites genesis in the investigated area.

giogranite intrusions in the Semail (Oman) and Troodos (Cyprus) Ophiolite described by Aldiss (1978) and Stakes and Taylor (2003) have been interpreted as formed due to crystal fractionation and SiO_2- rich igneous differentiation from a hydrous basaltic melt.

On a multielements spider diagram, the plagiogranites from the Dağküplü Ophiolite are slightly enriched in some LILE (Ba, Th) but depleted in HFSE with respect to ORG. Normalized REE patterns display an overall increase from gabbros to plagiogranites, suggesting their cogenetic origin, similar to those from suprasubduction ophiolites in the Eastern Mediterranean Belt. The epidote- and chlorite-rich veins observed as hydrothermal alteration zones in the Dağküplü plagiogranites are anologous to epidosites hosted in plagiogranites described in the Semail and Troodos Ophiolites (Schiffman et al., 1998; Stakes and Taylor, 2003). These alteration rocks have been interpreted to form under conditions of oceanic hydrothermalism in suprasubduction zone settings.

Milsom (2003) reported arc tholeiites, boninites, and acidic rocks from forearc ophiolites, while Pearce et al. (1984) and Shevais (2001) regard the presence of plagiogranite series rocks in any ophiolite sequence as indicating forearc-type ophiolites. Furthermore, Flower and Dilek (2003) examine proto-ophiolites produced in arc-forearc settings. These ophiolites commonly include plagiogranites, abundant epidote bearing alteration rocks, boninitic rocks, refractory mantle peridotites and metamorphic soles. So the small plagiogranite bodies and the gabbros of the Dağküplü Ophiolite reflect similar features to those of forearc settings.

Based on field observations and geochemical data, the Dağküplü Ophiolite was generated in a short-lived subduction zone and sea-floor spreading center within the İzmir-Ankara Ocean and exhibits characteristics of forearc ophiolites. It completed the “ophiolite life cycle” of Shervais (2001) in which the maturity stage contains oceanic plagiogranites, and then it was emplaced onto the Anatolide-Tauride Platform as a result of continent-continent collision.

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