

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

Ender Sarıfakıoğlu

MTA Genel Müdürlüğü, Jeoloji Etütleri Dairesi, Ankara. e-mail: esarifakioglu@mta.gov.tr.

Keywords: *İzmir-Ankara-Erzincan Suture Zone, SSZ ophiolite, cumulate gabbros, fractional crystallization, plagiogranite, Turkey.*

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 TiO₂-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, Mihaliçcık, Tavşanlı, Orhaneli, and Harmançık 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 Türel, 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 proto-arc 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 epidiosites. 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.,

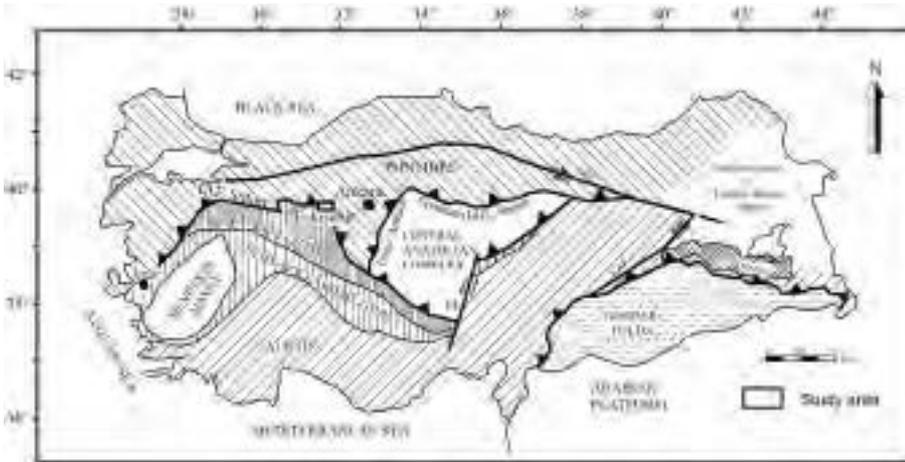


Fig. 1 - The tectonic sketch of Turkey showing the suture zones (after Okay, 1986).

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 km² and is situated immediately south of the IAESZ. In this region, the Dağköplü 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, calc-schists, 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 Dağköplü Ophiolite, greywacke, shale, and limestones occur, belonging to the Permo-Triassic Karakaya Complex. These units tectonically rest upon the mantle peridotites and ophiolitic mélangé (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 mélangé and metamorphic soles (amphibolites) developed as a thin sliver at the base. In the ophiolitic mélangé, 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 Mélangé, 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 mélangé around the Mayıslar Village; as a result the Tertiary sedimentary and pyroclastic rocks cover the former lithostratigraphic units.

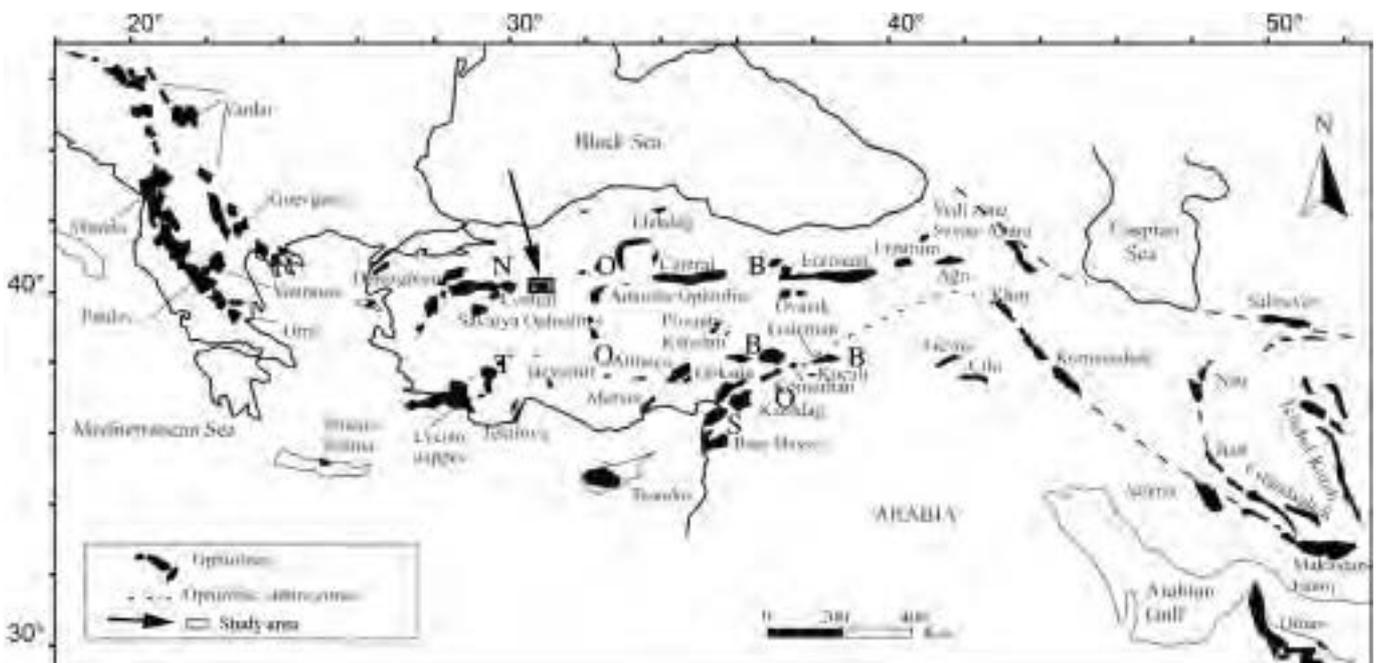


Fig. 2 - Distribution of Triassic-Cretaceous Neo-Tethyan ophiolites in the Eastern Mediterranean (revised from Dilek and Moores, 1990; Lippard et al. 1986). NOB: Northern Ophiolite Belt; TOB: Taurus Ophiolite Belt; SOB: Southern Ophiolite Belt.

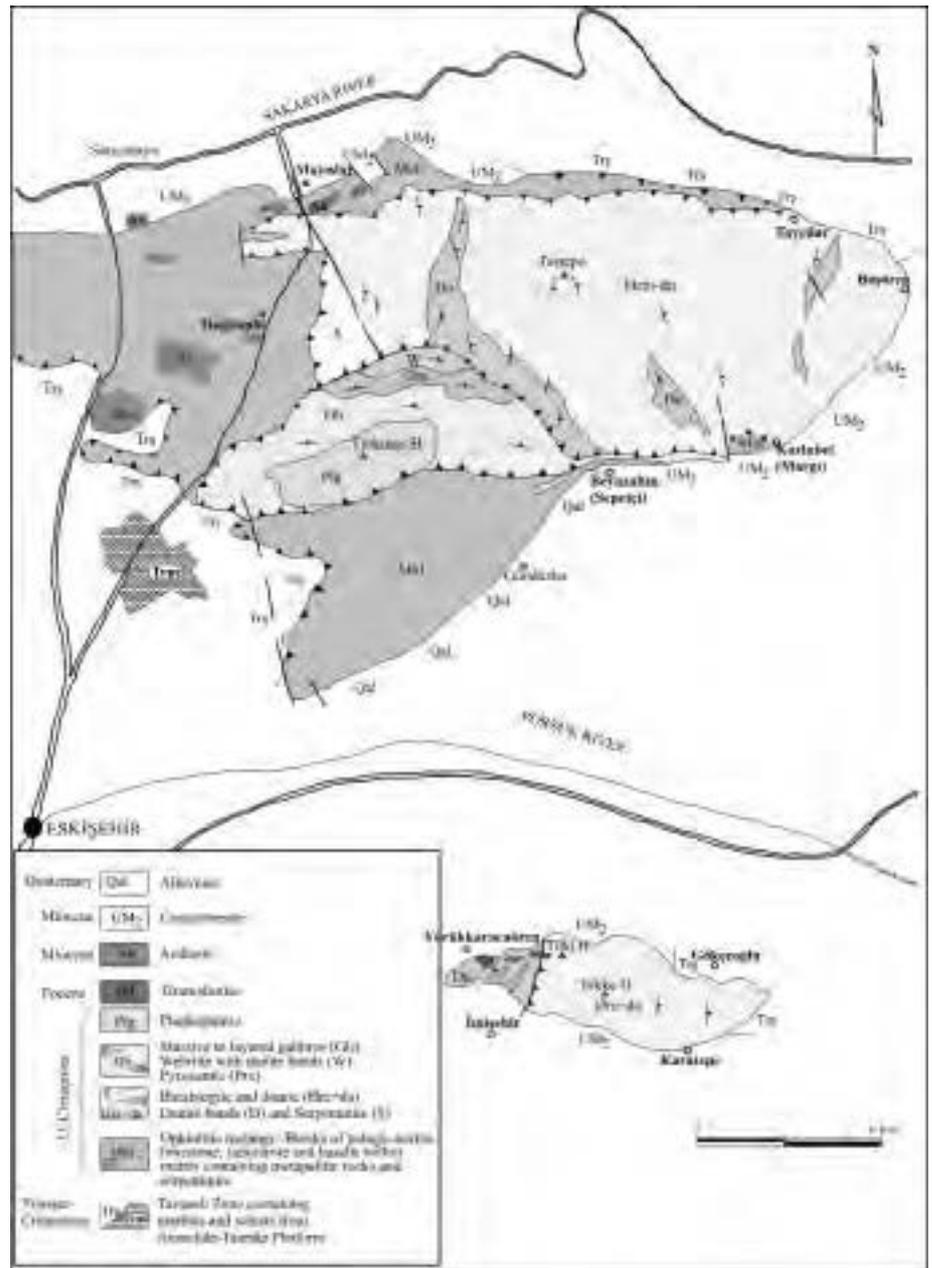


Fig. 3 - Geological map of the Dağköplü (Eskişehir) Ophiolite (after Özen et al. 2002).

The Dağköplü 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 normal-

ly 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 Dağköplü 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 gabbro-norite. 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 gabbro-norites 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 microporphyratic 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 crystallization (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 microgranophyric texture grades into spherulitic texture in which cryptocrystalline quartzofeldspathic minerals have a radiated/bunch-like appearance.

Plagiogranite rocks are locally cut by epidote 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 ($\text{Rb}/\text{Sr} < 0.015$) are different from those of continental trondhjemites ($\text{Rb}/\text{Sr} > 0.015$). Dramatic discrepancies are noticeable in REE contents of oceanic and continental granites (Coleman and Peterman, 1975; Hyndman, 1985).

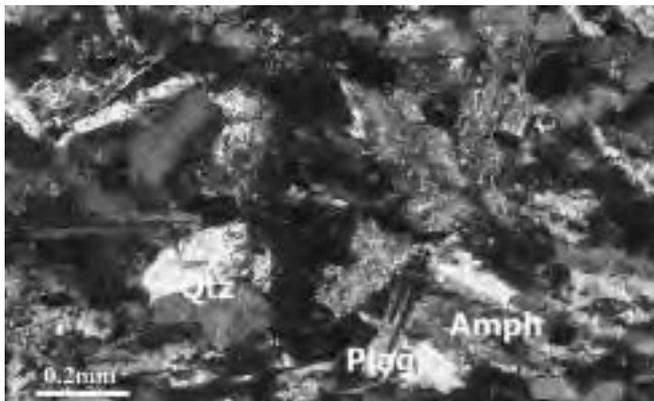


Fig. 4 - Photomicrograph (cross-polarized light) of the quartz diorites (Plag: Plagioclase; Qtz: quartz; Amph: amphibole).

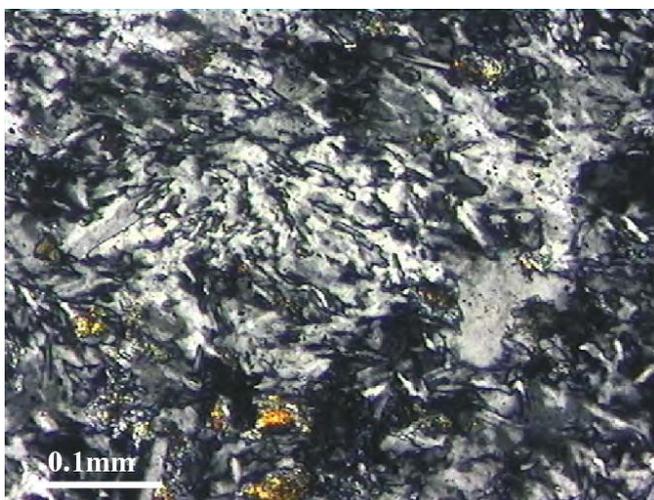


Fig. 5 - Photomicrograph of microgranophyric texture from the trondhjemites.

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 - $\text{FeO}^*/(\text{FeO}^* + \text{MgO})$ 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 seafloor 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.

Sample	Gabbros					
	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 ₂ O ₃	18.11	16.5	16.4	15.83	20.73	17.24
Fe ₂ O ₃	6.31	15.3	12.5	9.89	4.65	5.53
Cr ₂ O 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 ₂ O	1.07	1.62	0.71	0.52	1.4	1.21
K ₂ O	0.03	0.04	0.02	0.06	0.06	0.05
P ₂ O 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.

Sample	Trondhjemites				Quartz Diorites			
	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
Al ₂ O ₃	12.37	11.91	12.63	12.36	13.07	12.86	14.51	14.72
Fe ₂ O 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 ₂ O	5.08	5.17	5.31	5.17	6.34	4.12	4.45	5.45
K ₂ O	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 ₂ O 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 ₂ O 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

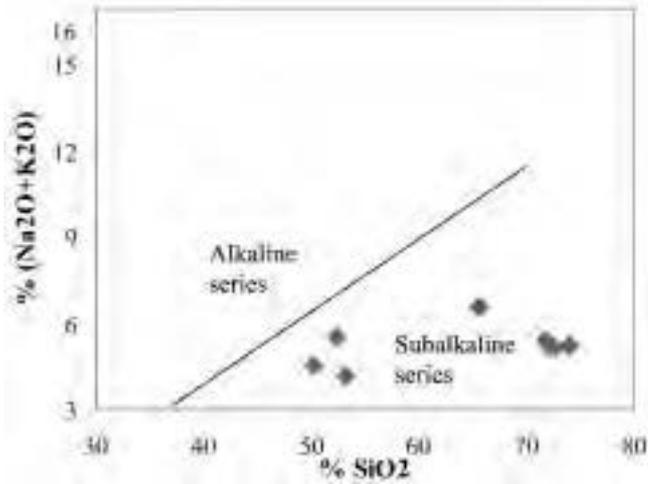


Fig. 6 - Plots of the major elements for the plagiogranites on the Alkali-Silica diagram (Irvine and Baragar 1971).

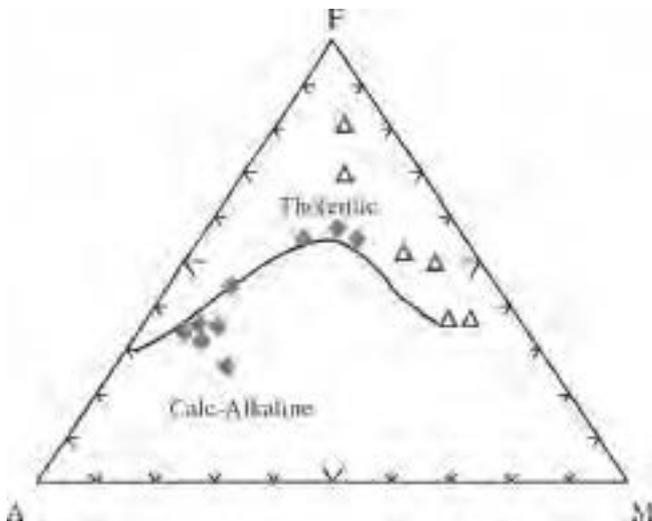


Fig. 7 - Distribution of gabbros (triangles) and plagiogranites (diamonds) from the Dağköplü Ophiolite on the AFM diagram (Irvine and Baragar 1971).

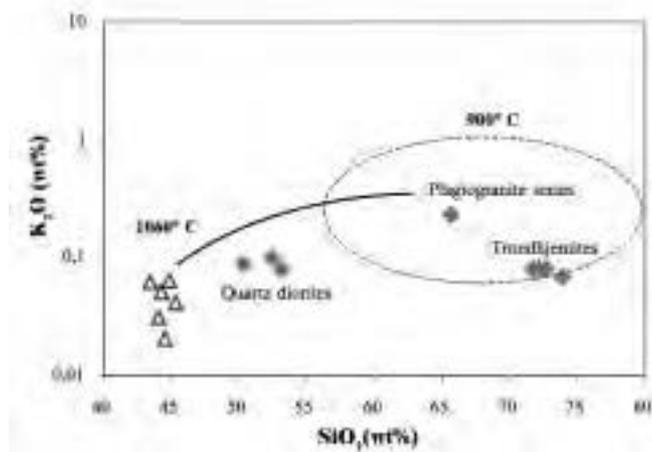


Fig. 8 - K_2O - SiO_2 diagram for gabbros and plagiogranites (Coleman & Peterman, 1975). Plagiogranites (diamonds) and Cumulate Gabbros (triangles) from the Dağköplü Ophiolite.

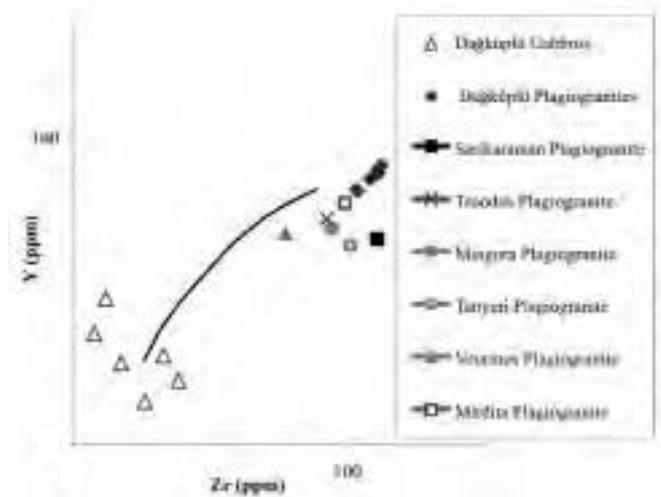


Fig. 9 - Plot of Y-Zr on Rollison (1993)'s diagram for cumulate gabbros and plagiogranites from the Dağköplü Ophiolite, and comparison with other Neotethyan plagiogranites in the Alpine Orogenic Belt: Sarikaraman (Floyd et al., 1998); Troodos (Coleman and Peterman, 1975); Mingora (Barbieri et al., 1994);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

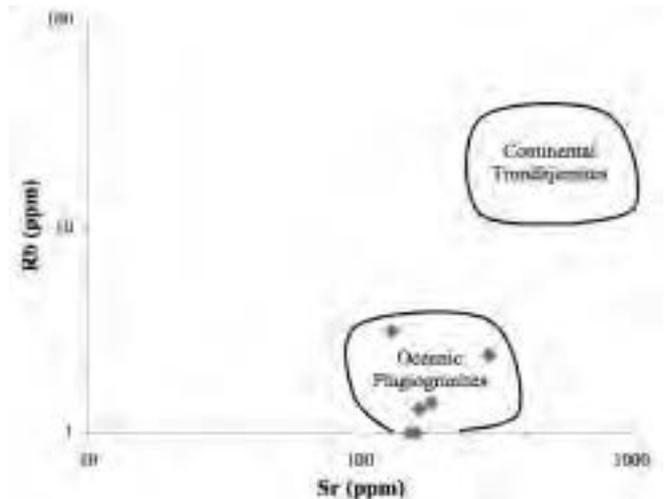


Fig. 10 - Plagiogranites from the Dağköplü Ophiolite on the Rb-Sr diagram (Coleman and Peterman, 1975).

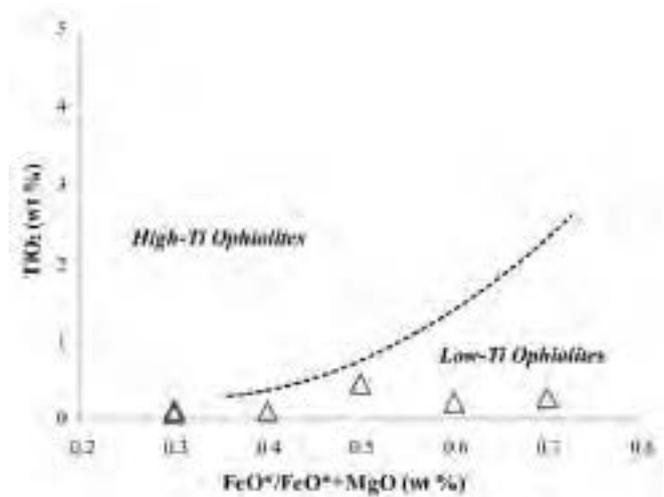


Fig. 11 - TiO_2 vs (FeO^*/FeO^*+MgO) discrimination diagram (after Serri, 1981) for gabbroic rocks from the Dağköplü Ophiolite.

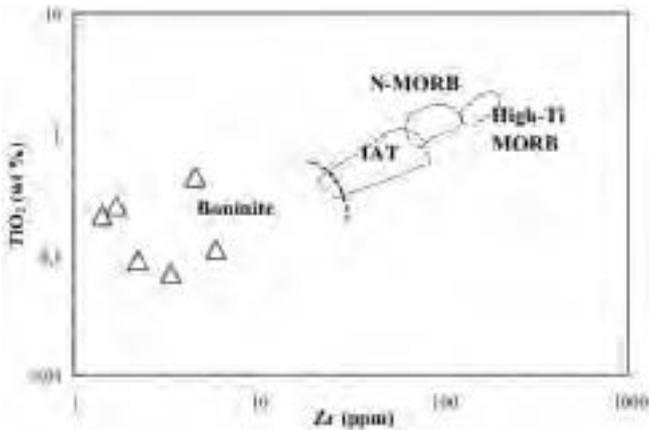


Fig. 12 - TiO_2 vs Zr diagram (after Capedri et al., 1980) for gabbroic rocks from the Dağköplü Ophiolite.

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 Dağköplü 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 Dağköplü 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 - Erzinçan 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 Dağköplü (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 2.5×6.0 km and occurring as small intrusive bodies originating at shallow depths, comprise quartz diorite and trondhjemite on the

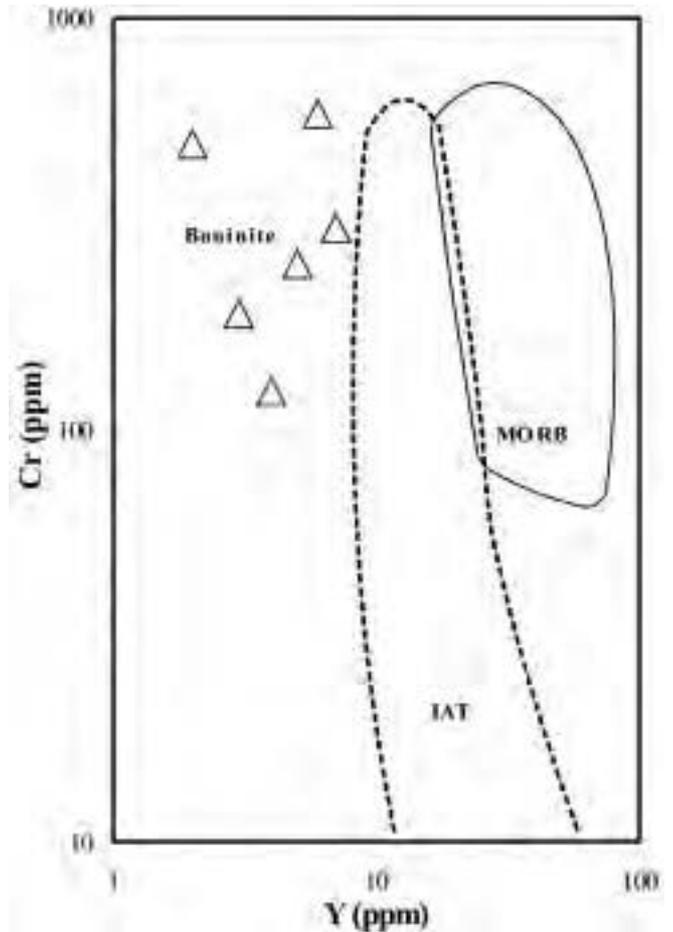


Fig. 13 - Plot of gabbros from the Dağköplü Ophiolite on the Cr vs Y discrimination diagram (after Pearce, 1982).

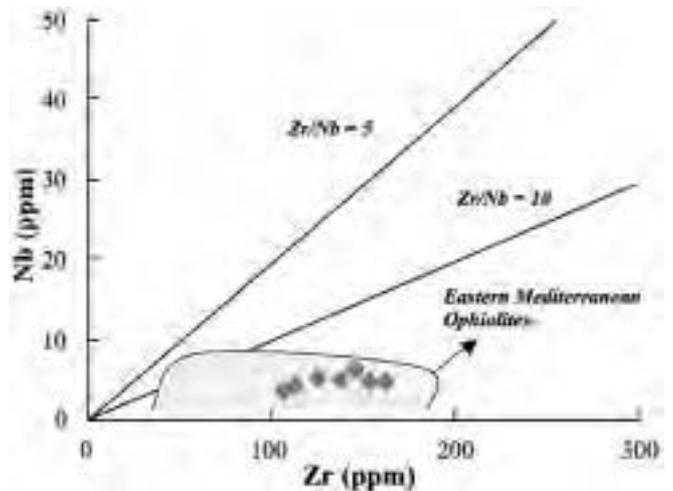


Fig. 14 - The investigated plagiogranites (diamond symbols) and other plagiogranites from Eastern Mediterranean Ophiolites on the Nb-Zr diagram (Leat et al., 1986).

basis of their mineral association. The ophiolitic mélangé occurs beneath the Dağköplü 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

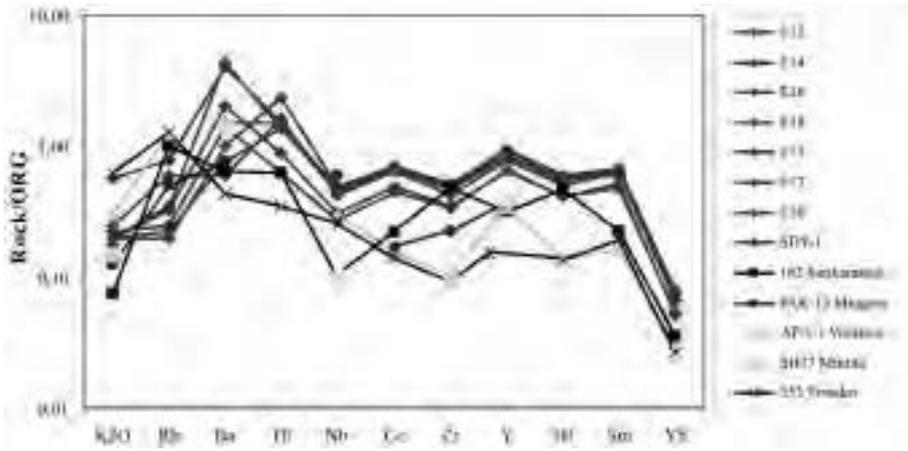


Fig. 15 - The investigated plagiogranites on the spider diagram normalized by Pearce et al. (1984) and comparison with other plagiogranites: Sarikaraman plagiogranites (Floyd et al., 1998); Mingora plagiogranites (Barbieri et al., 1994); Vourinos plagiogranites (Beccaluva et al., 1984); Mirdita plagiogranites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

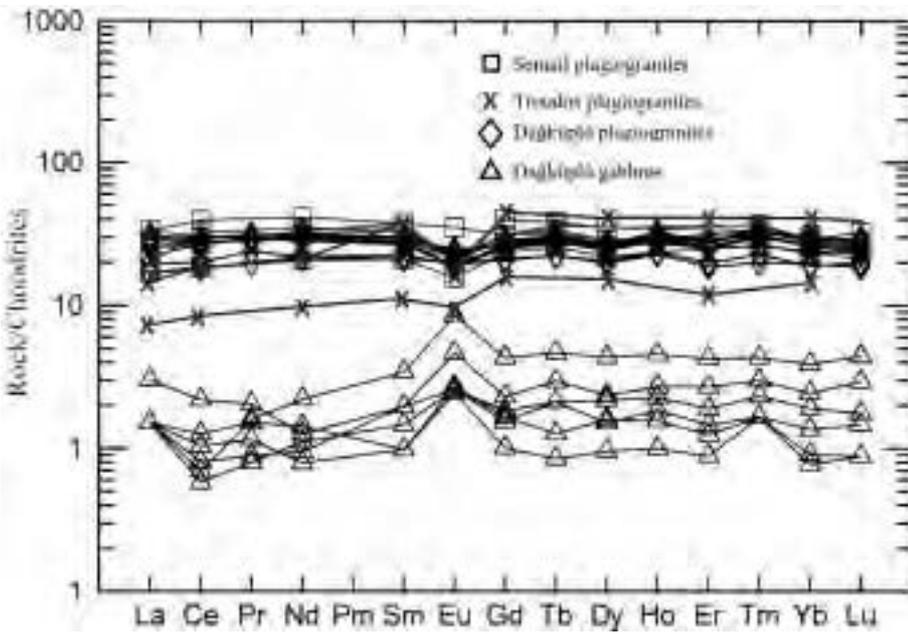


Fig. 16 - The investigated plagiogranites, compared with the Semail plagiogranites (Pallister and Knight, 1981) and Troodos plagiogranites (Kay and Senechal, 1976), spider diagram normalization after Nakamura (1974).

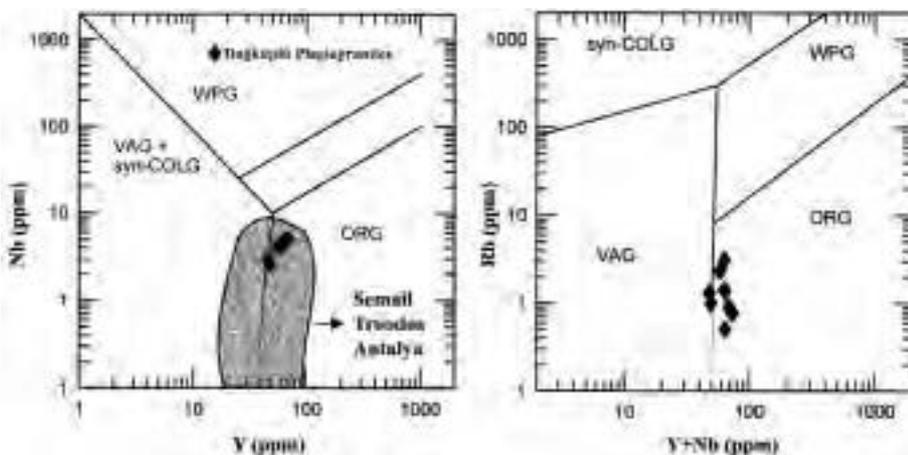


Fig. 17 - The Dağkılıç plagiogranites (diamond symbols) and the field of plagiogranites from Eastern Mediterranean Ophiolites on the Nb - Y and Rb - Y + Nb diagrams (Pearce et al. 1984). The field includes the Troodos (Aldiss, 1978), Semail (Alabaster et al., 1982), and Antalya plagiogranites (Cocherie,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

and high-field-strength element contents. The mafic cumulates representing oceanic crust of the Dağkılıç 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 (microgranophytic 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-

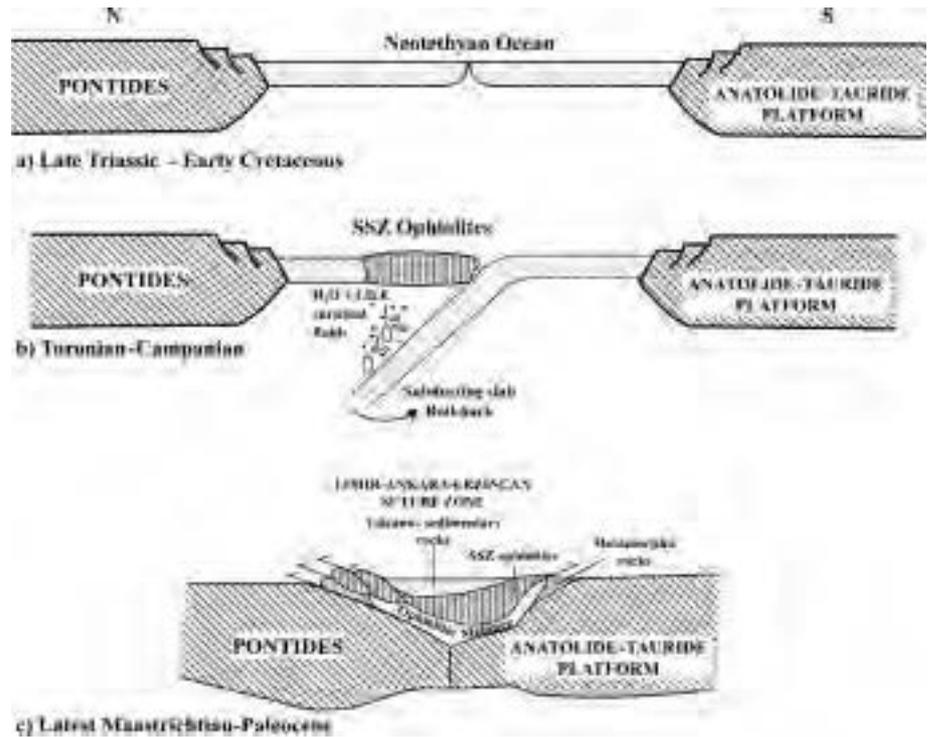


Fig. 18 - Tectonic sketch of the ophiolites genesis in the investigated area.

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 Dağköplü 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 Dağköplü plagiogranites are analogous to epidotes 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 Dağköplü Ophiolite reflect similar features to those of forearc settings.

Based on field observations and geochemical data, the Dağköplü 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.

ACKNOWLEDGEMENTS

This research was supported by The General Directorate of Mineral Research and Exploration grant (project 16AE35-2002). I would like to thank H. Özen for his comments and help in field studies. I am very grateful to L. Gaggero and Y. Dilek whose critical reviews greatly improved the quality of this paper. I also thank V. Bortolotti and R. Tribuzio for valuable suggestions and editorial comments.

REFERENCES

- Akyürek B., Bilginer E., Çatal E., Dağar Z., Soysal Y. and Sunu O., 1979. Eldivan- Şabanözü (Çankırı) dolayında ofiyolit yerleşmesine ilişkin bulgular. *Jeol. Mühendisliği*, 9: 1-4.
- Aktimur T.H., Sariaslan M., Yurdakul M.E., Mutlu G., Ölçer S., Turşucu A., Aktimur S., Keçer M. and Yıldırım T., 1995. Erzinan Dolayının jeolojisi. MTA Report, 9792 (yayınlanmamış).
- Alabaster T., Pearce J.A. and Malpas J., 1982. The volcanic stratigraphy and petrogenesis of the Oman ophiolite complex. *Contrib. Mineral. Petrol.*, 81: 168-183.
- Aldiss D.T., 1978. Granitic rocks of ophiolites. Ph.D. Thesis. Open Univ., UK.
- Asutay H.J., Küçükayman A. and Gözler Z., 1989. Dağköplü (Eskişehir Kuzeyi) Ofiyolit Karmaşığının stratigrafisi, yapısal konumu ve kümülatların petrografisi. *MTA Dergisi*, 109: 1-8.
- Bacak G. and Uz B., 2003. Dağardı Güneyi (Kütahya) ofiyolitinin jeolojisi ve jeokimyasal özellikleri. *İTÜ Dergisi*, 2 (4): 86-98.
- Bagcı U., Parlak O. and Höck V., 2005. Whole-rock and mineral chemistry of cumulates from the Kızıldağ (Hatay) ophiolite (Turkey): clues for multiple magma generation during crustal accretion in the southern Neotethyan Ocean. *Mineral. Mag.*, 69 (1): 53-76.
- Barbieri M., Caggianelli A., Di Florio M.R. and Lorenzoni S., 1994. Plagiogranites and gabbroic rocks from the Mingora ophiolitic mélange, Swst Valley, NW Frantier Province, Pakistan. *Mineral. Mag.*, 58: 553-556.

- Beccaluva L., Coltorti M., Premti I., Saccani E., Siena F. and Zeda O., 1994. Mid-ocean Ridge and suprasubduction affinities in the ophiolitic belts of Albania. *Ofioliti*, 19: 77-76.
- Beccaluva L., Ohnenstetter D., Ohnenstetter M. and Paupy A., 1984. Two magmatic series with island arc affinities within the Vourinos ophiolite. *Contrib. Mineral. Petrol.*, 85: 253-271.
- Bektaş O., 1982. Tanyeri (Erzincan) ofiyolitli karışığına ait trondjemitlerin paleotektonik konumu ve kökenleri. *K.Ü. Yerbilimleri Dergisi*, 2: 39-59.
- Beyarslan M. and Bingöl A.F., 2000. Petrology of a supra-subduction zone ophiolite (Elazığ, Turkey). *Can. J. Earth Sci.*, 37: 1411-1424.
- Bingöl E., Akyürek B. and Korkmazer B., 1975. Biga yarımadasının jeolojisi ve Karakaya Formasyonunun bazı özellikleri. *Cumhuriyetin 50. Yılı Yerbilimleri Kong.*, p. 70-76.
- Bragin N.Y. and Tekin K., 1996. Age of radiolarian-chert blocks from the Senonian Ophiolitic Mélange (Ankara, Turkey). *Island Arc*, 5: 114-122.
- Capedri S., Venturelli E., Bocchi E., Dostal J., Garuti G. and Rossi A., 1980. The geochemistry and petrogenesis of an ophiolite sequence from Pindos, Greece. *Contrib. Mineral. Petrol.* 7: 189-200.
- Cocherie A., 1978. *Geochimie des terres rares dans les granitoids*. Ph.D. Thesis. Rennes Univ., France.
- Coleman R.G. and Donato M.M., 1979. Oceanic plagiogranites revisited. In: F. Barker (Ed.), *Trondhjemites, dacites, and related rocks*. Elsevier, Amsterdam, p. 149-168.
- Coleman R.G. and Peterman Z.E., 1975. Oceanic plagiogranites. *J. Geophys. Res.*, 80: 1099-1108.
- Cortesogno L., Gaggero L., Jomo E., Marroni M., Pandolfi L. and Shtjefanaku D., 1998. The gabbroic complex of the western ophiolitic belt, northern Albania, an example of the multilayered sequence in an intermediate spreading oceanic ridge. *Ofioliti*, 23: 49-64.
- Çapan U.Z. and Floyd P.D., 1985. Geochemical and petrographic features of metabasalts within units of the Ankara Mélange, Turkey. *Ofioliti*, 10: 13-18.
- Çelik Ö.F., Chiaradia M. and Delaloye M., 2002. Geodynamic significance of doleritic and amphibolitic dikes near Yeşilova (SW Turkey) Inferred from major, trace, REE and pb isotopes. 1th Intern. Symp. Faculty Mines (İTÜ) Earth Sci. Engineer. Abstr., p. 140.
- Dixon S. and Rutherford M.J., 1979. Plagiogranites as late-stage immiscible liquids in ophiolite and mid-ocean ridge suites: An experimental study. *Earth Planet. Sci. Lett.*, 45: 45-60.
- Dilek Y. and Moores E.M., 1990. Regional tectonics of the Eastern Mediterranean ophiolites. In: I. Malpas, E.M. Moores, A. Panagiotou and C. Xenophontas (Eds.), *Ophiolites - Oceanic crustal analogues*. *Proceed. Symp. "Troodos 1987"*. Geol. Survey Dept., Cyprus, p. 295-309.
- Dilek Y. and Flower M.F.J., 2003. Arc-trench rollback and forearc accretion: 2.A model template for ophiolites in Albania, Cyprus, and Oman. In: Y. Dilek and P.T. Robinson (Eds.), *Ophiolites in Earth history*. *Geol. Soc. London. Spec. Publ.*, 218: 21-41.
- Flower M.F.J. and Dilek Y., 2003. Arc-trench rollback and forearc accretion: 1.A collision-induced mantle flow model for Tethyan ophiolites. In: Y. Dilek and P.T. Robinson (Eds.), *Ophiolites in Earth history*. *Geol. Soc. London. Spec. Publ.*, 218: 21-41.
- Floyd P.A., Yalınız M.K. and Gönçüoğlu M.C., 1998. Geochemistry and petrogenesis of intrusive and extrusive ophiolitic plagiogranites, Central Anatolian Crystalline Complex, Turkey. *Lithos*, 42: 225-241.
- Gilluly J., 1933. Replacement origin of the albite granite near Sparta, Oregon. *U.S. Geol. Survey Prof. Paper*, 175C, p. 63-81.
- Gönçüoğlu M.C. and Türeli T.K., 1994. Petrology and geodynamic interpretation of plagiogranites from Central Anatolian ophiolites. *Turk. J. Earth Sci.*, 2: 195-203.
- Gönçüoğlu M.C., Turhan N., Şentürk K., Uysal Ş., Özcan A. and Işık A., 1996. Orta Sakarya'da Nallıhan-Sarıcakaya arasındaki yapısal birliklerin Jeol. Özellikleri. MTA Report, 10094 (yayınlanmamış)
- Gönçüoğlu, M.C., Turhan N., Şentürk K., Özcan A., Uysal Ş. and Yalınız K., 2000. A geotraverse across northwestern Turkey: tectonic units of the Central Sakarya region and their tectonic evolution. In: E. Bozkurt, J.A. Winchester and J.D.A. Piper (Eds.), *Tectonics and magmatism in Turkey and the surroundings area*. *Geol. Soc. London Spec. Publ.*, 173: 139-161.
- Gözler Z., Cevher F., Ergül E. and Asutay H.J., 1996. Orta Sakarya ve güneyinin jeolojisi. MTA Report, 9973 (yayınlanmamış).
- Harris N.B.W., Kelley S. and Okay A.I., 1994. Post-collision magmatism and tectonics in northwest Anatolia. *Contrib. Mineral. Petrol.*, 117: 241-252.
- Irvine T.N. and Baragar W.P.A., 1971. A guide to the chemical classification of the common volcanic rocks. *Cont. J. Earth Sci.*, 8: 523-548.
- Kay R.W. and Senechal R.G., 1976. The rare earth geochemistry of the Troodos ophiolite complex. *J. Geophys. Res.*, 81: 964-970.
- Koçyiğit A., Winchester J.A., Bozkurt E. and Holland G., 2003. Saraçköy volcanic suite: Implications for the subductional phase of arc evolution in the Galatean Arc Complex, Ankara, Turkey. *Geol. J.*, 38: 1-14.
- Kulaksız S., 1981. Sivrihisar kuzeybatı yöresinin jeolojisi. *Yerbilimleri*, 8: 103-124.
- Leat P.T., Jackson S.E., Thorpe R.S. and Stillman C.J., 1986. Geochemistry of bimodal basalt-subalkaline/peralkaline rhyolite provinces within the southern British Caledonides. *Geol. Soc. London Spec. Publ.*, 143: 256-273.
- Lippard S.J., Shelton A.W. and Gass I.G., 1986. The ophiolite of Northern Oman. *Geol. Soc. London, Mem.*, 11.
- Malpas J. and Langdon L.G., 1984. Petrology of the Upper Pillow Lava suite, Troodos Ophiolite, Cyprus. In: I.G. Gass, S.L. Lippard and A.W. Shelton (Eds.), *Ophiolites and oceanic lithosphere*. *Geol. Soc. London Spec. Publ.*, 13: 155-167.
- Manav H., Gültekin A.H. and Uz B., 2004. Geochemical evidence for the tectonic setting of the Harmancik ophiolites, NW Turkey. *J. Asian Earth Sci.*, 24: 1-9.
- Milsom J., 2003. Forearc ophiolites: a view from the western Pacific. In: Y. Dilek and P.T. Robinson (Eds.), *Ophiolites in Earth history*. *Geol. Soc. London Spec. Publ.*, 218: 507-515.
- Nakamura N., 1974. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. *Geochim. Cosmochim. Acta*, 38: 757-775.
- Okay A.I., 1986. High-pressure/low-temperature metamorphic rocks of Turkey. *Geol. Soc. Am., Mem.*, 164: 333-347.
- Okay A.I. and Kelley S., 1994. Jadeite and chloritoid schists from northwest Turkey: tectonic setting, petrology and geochronology. *J. Metam. Geol.*, 12: 455-466.
- Okay A.I., 1984. Kuzeybatı Anadolu'da yer alan metamorfik kuşaklar. *Ketin Sempozy.*, 1984, p. 83-92.
- Önen A.P., 2003. Neotethyan ophiolitic rocks of the Anatolides of NW Turkey and comparison with Tauride ophiolites. *Geol. Soc. London Spec. Publ.*, 160: 947-962.
- Özen H., Gültaşlı Ö.F., Çolakoğlu A., Sayak H., Sarıfakıoğlu E., 2002. Ofiyolitlere bağlı cevherleşmelerin araştırılması. Proj., 16AE-35. MTA Report (basımda).
- Özen H., Sarıfakıoğlu E., Başta Ö., Çolakoğlu A., Sayak H. and Gültaşlı Ö.F., 2005. Orhaneli (Bursa) ofiyolitinin jeolojisi ve petrografik özellikleri. In: İ. Akkuş and Ö. Dumanlılar (Eds.), 58. Türkiye Jeol. Kongr. Bildiri Özetleri, p. 47-50.
- Özen H., Çolakoğlu A., Sayak H., Dönmez C., Türkel A., Odabaşı İ., Sarıfakıoğlu E. and Winchester J.A., 2006. Erzincan'ın kuzeyindeki ofiyolitlere ait tektonit-kümülat kayaçların petrojenezine bir yaklaşım. *Türkiye Jeol. Kurultayı. Bildiri Özetleri*, 59: 100-101
- Özen H. and Sarıfakıoğlu E., 2002. Dağküplü ofiyoliti ile Sivrihisar (Eskişehir) dolayındaki ofiyolitlerin petrografisi ve jeokimyası. *Jeol. Mühendisliği Dergisi*, 26 (1): 33-40.
- Pallister J.S., 1991. Structure of the sheeted dike complex of the Se-mail Ophiolite near Ibra, Oman. *J. Geophys. Res.*, 86: 2661-2672.

- Pallister J.S and Knight R.J., 1981. Rare-Earth element geochemistry of the Semail Ophiolite near Ibra, Oman. *J. Geophys. Res.*, 86: 2673-2697.
- Parlak O., Delaloye M. and Bingöl E., 1996. Mineral chemistry of ultramafic and mafic cumulates as an indicator of the arc-related origin of the Mersin ophiolite (south Turkey). *Geol. Rund.*, 85: 647-61.
- Parlak O., Höck V., Kozlu H. and Delaloye M., 2004. Oceanic crust generation in an island arc tectonic setting, SE Anatolian orogenic belt (Turkey). *Geol. Mag.*, 141 (5): 583-603.
- Pearce J.A., 1982. Trace element characteristics of lavas from destructive plate boundaries. In: E.S. Thorpe (Ed.), *Andesites*. Wiley, New York, p. 525-548.
- Pearce J.A., Lippard S.J. and Roberts S., 1984. Characteristics and tectonic significance of supra-subduction zone ophiolites In: B.P. Kokelaar and M.F. Howells (Eds.), *Marginal basin geology*. *Geol. Soc. London Spec. Publ.*, 13: 74-94.
- Pedersen R.B. and Malpas J., 1984. The origin of oceanic plagiogranite from the Karmoy ophiolite. *Cont. Mineral. Petrol.*, 88: 36-52.
- Robertson A.H.F and Dixon J.E., 1984. Introduction: aspects of the geological evolution of the Eastern Mediterranean. In: J.E. Dixon and A.H.F. Robertson (Eds.), *The geological evolution of the Eastern Mediterranean*. *Geol. Soc. London Spec. Publ.*, 17.
- Robertson A.H.F., 1994. Role of the tectonic facies concept in orogenic analysis and its application to Tethys in the Eastern Mediterranean region. *Earth Sci. Rev.*, 37: 139-213.
- Rollinson H., 1993. Using geochemical data: Evaluation, presentation, interpresentation. Longman Group, UK, 352 pp.
- Sarıfakioğlu E. and Özen H., 2004. The petrogenesis of the ophiolites from the Central Sakarya (Eskişehir-Turkey). In: A.A. Chatzipetros and S.B. Pavlides (Eds.), 5th Intern. Symp. Eastern Mediterranean geology. *Proceed.*, p. 286-287.
- Schiffman P. and Smith B.M., 1988. Petrology and oxygen-isotope geochemistry of a fossil seawater hydrothermal system within the Solea graben, northern Troodos Ophiolite, Cyprus. *J. Geophys. Res.*, 93: 4612-4624.
- Serri G., 1981. The petrochemistry of ophiolitic gabbroic complexes: a key for the classification of ophiolites into low-Ti and high-Ti types: *Earth Planet. Sci. Lett.*, 52: 203-212.
- Shallo M., 1992. Geological evolution of the Albanian ophiolites and their platform periphery. *Geol. Rund.*, 81: 881-694.
- Shervais J.W., 2001. Birth, death, and resurrection: the life cycle of suprasubduction zone ophiolites. *Geochem., Geophys., Geosyst.*, 2, Paper N.: 2000GC000080.
- Sigvalson G.E., 1974. The petrology of Hekla and origin of silicic rocks in Iceland, In: *The eruption of Hekla 1947-1948*. *Island. Soci. Sci.*, 1, 44 pp.
- Stakes D.S. and Taylor H.P.JR., 2003. Oxygen isotope and chemical studies on the origin of large plagiogranite bodies in northern Oman, and their relationship to the overlying massive sulphide deposits. In: Y. Dilek and P.T. Robinson (Eds.), *Ophiolite in Earth history*. *Geol. Soc. London Special Publ.*, 218: 315-351.
- Stern R.J. and Bloomer S.H., 1992. Subduction zone infancy: Examples from the Eocene Izo-Bonin-Mariana and Jurassic California arcs. *Geol. Soc. Am. Bull.*, 104: 1621-1636.
- Şengör A.M.C and Yılmaz Y., 1981. Tethyan evolution of Turkey: a plate tectonic approach, *Tectonophysics*, 75: 181-241.
- Tankut A. and Gorton M.P., 1990. Geochemistry of a mafic-ultramafic body in the Ankara Mélange, Anatolia, Turkey: Evidence for a fragment of oceanic lithosphere. In: J. Malpas, E.M. Moores A., Panayitow and A. Xenophontos (Eds.), *Ophiolites-oceanic crustal analogues*. *Proceeda*.
- Tankut A., Dilek Y. and Önen P., 1998. Petrology and geochemistry of the Neo-Tethyan volcanism as revealed in Ankara Mélange, Turkey. *J. Volcan. Geoth. Res.*, 85: 265-284.
- Tekin U.K., Göncüoğlu, M.C. and Turhan N., 2002. First evidence of Late Carnian radiolarians from the İzmir-Ankara suture complex, Central Sakarya, Turkey: implications for the opening age of the İzmir-Ankara branch of Neo-Tethys. *Geobios*, 35: 127-135
- Vergili Ö. and Parlak O., 2005. Geochemistry and tectonic setting of metamorphic sole rocks and mafic dikes from the Pınarbaşı (Kayseri) Ophiolite, Central Anatolia (Turkey). *Ofioliti*, 30: 37-52.
- Yılmaz, K.M., Floyd, P. and Göncüoğlu M.C., 2000. Geochemistry of volcanic rocks from the Çiçekdağı Ophiolite, Central Anatolia, Turkey, and their inferred tectonic setting within the northern branch of the Neotethyan Ocean. In: E. Bozkurt, J.A. Winchester and J.D.A. Piper (Eds.), *Tectonics and magmatism in Turkey and surroundings area*. *Geol. Soc. London Spec. Publ.*, 173: 203-218.
- Yılmaz M.K., Floyd P.A. and Göncüoğlu M.C., 1996. Supra-subduction zone ophiolites of Central Anatolia: geochemical evidence from the Sarıkaraman Ophiolite, Aksaray, Turkey. *Mineral. Mag.*, 60: 697-710.
- Yılmaz H., Arıkal T., Yılmaz A., 2001. Güneş ofiyolitinin (Divriği-Sivas) jeolojisi. 54th Türkiye Jeol. Kongr., *Proceed. N.* 54-65.

Received, May 11, 2006
Accepted, June 3, 2007

