GEOCHEMISTRY AND TECTONIC SETTING OF METAMORPHIC SOLE ROCKS AND MAFIC DIKES FROM THE PINARBAŞI (KAYSERI) OPHIOLITE, CENTRAL ANATOLIA (TURKEY)

Özden Vergili* and **Osman Parlak****

** Maden Tetkik ve Arama Genel Müdürlüğü, 06520 Ankara, Turkey.*
*** Çukurova Üniversitesi, Jeoloji Mühendisliği Bölümü, 01330 Balcalı, Adana, Turkey (Corresponding author, e-mail: parlak@cukurova.edu.tr).*

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ABSTRACT

The Pınarbaşı ophiolite is located in Central Anatolia and emplaced onto the Tauride platform in Late Cretaceous. It comprises remnants of lower part of oceanic lithosphere, namely mantle tectonites tectonically underlain by high-grade metamorphic sole rocks and ultramafic to mafic cumulates. Number of isolated microgabbro-diabase and pyroxenite dikes cut the mantle tectonites at different structural levels. The mantle tectonites are dominated by harzburgite and dunite, whereas the cumulates consist of wehrlite, clinopyroxenite, olivine gabbro, troctolite and gabbronorite. The metamorphic sole rocks in the Pınarbaşı ophiolite crop out as thin slices beneath the sheared serpentinites and display inverted metamorphic gradient from amphibolite to greenschist facies. The rock types in the metamorphic sole are calcschists, epidote + plagioclase + amphibole schists, plagioclase + amphibole schists, amphibole schists, plagioclase amphibolites, amphibolites. The isolated microgabbro-diabase dikes are tholeiitic in character (Nb/Y = 0.03-0.07). The REE patterns, multi-element and tectonomagmatic discrimination diagrams suggest that the isolated dikes formed in a subduction-related environment. The metamorphic sole rocks exhibit two distinct geochemical features. The first group is alkaline (Nb/Y = 1.5-2.6), whereas the second group is tholeiitic (Nb/Y = 0.05-0.22) in nature. The REE patterns, multi-element and tectonomagmatic discrimination diagrams suggest that the protholith of the first group is similar to within-plate alkali basalts, whereas the second group is more akin to island arc tholeiitic basalts. All the evidences suggest that the Pınarbaşı ophiolite and the isolated dikes formed in a supra-subduction zone tectonic setting. The alkaline amphibolites were formed as a result of metamorphism of the seamount type basaltic rocks in intraoceanic subduction zone whereas the tholeiitic amphibolites were formed as result of intraoceanic thrusting in a supra-subduction zone (SSZ) basin during the closure of the Inner Tauride Ocean in Late Cretaceous.

INTRODUCTION

In the Anatolia (Turkey) several east-west trending ophiolitic bodies separated by carbonate platforms, metamorphic massifs and sedimentary basins crop out. These ophiolites are remnants of the Neotethyan oceanic domain which opened in Late Triassic and closed in Late Cretaceous between the Eurasian and Afro-Arabian plates (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Dilek and Moores, 1990). The ophiolites of the eastern Mediterranean region in southern Turkey are located along two lineaments, namely the “Bitlis-Zagros suture zone” and the “Tauride belt”. The Bitlis-Zagros suture zone includes complete and undeformed oceanic lithospheric remnants of southern branch of Neotethys such as Troodos in Cyprus, Kızıldağ in Turkey and Baer-Bassit in Syria (Fig. 1). By contrasts, the Tauride belt is characterized by dismembered ophiolitic units rooted to the north of Tauride platform (Şengör and Yılmaz, 1981; Dilek and Moores, 1990). These ophiolites are, from west to east, the Lycian, Beyşehir-Hoyran, Alihoca, Mersin, Pozantı-Karsantı and Pınarbaşı ophiolites (Fig. 1) (Juteau, 1980). The Tauride belt ophiolites are associated with metamorphic soles and ophiolitic mélanges. Both ophiolites and metamorphic soles are intruded by microgabbroic to diabasic dikes at all structural levels. Available petrographical and geochemical data on ophiolitic extrusives/intrusives suggest that the Neotethyan ophiolites in the eastern Mediterranean region formed in a SSZ-type environment (Pearce et al., 1984; Parlak et al., 1996; 2000; 2002; 2004; Yalınız et al., 1996; 2000a, 2000b; Floyd et al., 2000; Robertson, 2002; Saccani and Photiades, 2004).

The ophiolite-related metamorphic rocks in the eastern Mediterranean region have been extensively used to better understand P-T-t history and nature of the material accreted to the base of the mantle tectonites during intraoceanic subduction/thrusting of oceanic lithosphere (Lanphere et al., 1975; Spray and Roddick, 1980; Lanphere, 1981; Spray, 1984; Gnos and Peters, 1993; Önen and Hall, 1993; Hacker, 1994; Parlak et al., 1995; Dilek et al., 1999). The protolith of the metamorphic rocks show wide range of magma types, suggesting WPB, MORB and IAT geodynamic environments (Önen and Hall, 1993; Parlak et al., 1995; Floyd et al., 2000; Çelik and Delaloye, 2003). The isolated dikes are compositionally similar to island arc basalts and basaltic andesites (Lytwyn and Casey, 1995; Parlak and Delaloye, 1996; Dilek et al., 1999; Parlak, 2000; Çelik and Delaloye, 2003). Conventional K-Ar and ^{40}Ar-^{39}Ar age dating have been extensively used on the metamorphic soles and isolated diabase dikes from the Upper Cretaceous ophiolites in Turkey in order to constrain the age of intraoceanic thrusting and magmatism within the Neo-Tethyan oceanic basins before obduction onto continental margins (Thuizat et al., 1978; 1981; Dilek and Thy, 1992; Parlak et al., 1995; Parlak and Delaloye, 1996; 1999; Dilek et al., 1999; Çelik et al., 2004). The age of the intraoceanic thrusting has been constrained between 95 and 90 Ma whereas the age of mafic dike emplacement between 91 and 87 Ma. The age of intraoceanic thrusting and mafic dike emplacement throughout the entire Tauride belt occured in a less than 2-3 my time span (Parlak and Delaloye, 1999; Dilek et al., 1999).

The Pınarbaşı ophiolite, located in the eastern Taurides, is represented by ophiolitic mélange tectonically overlying

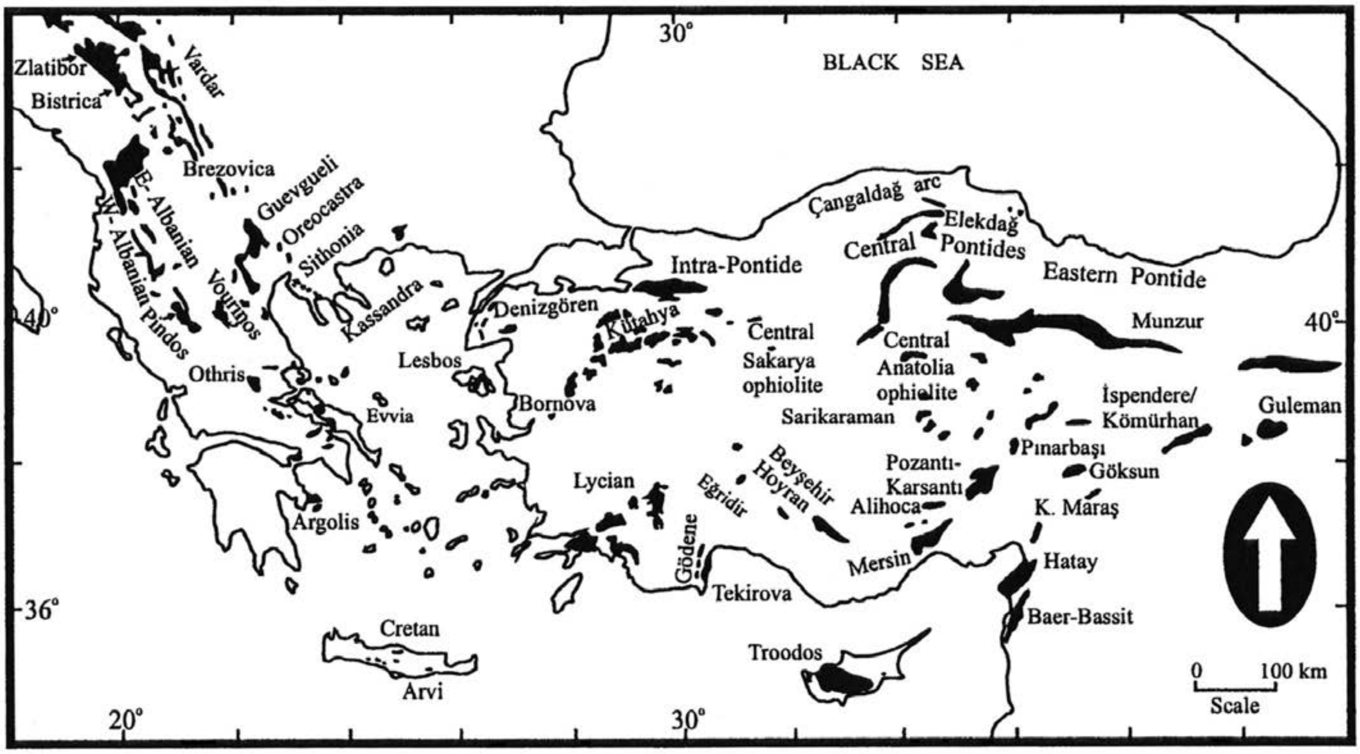

Fig. 1 - Distribution of the Neotethyan ophiolites in the eastern Mediterranean region (after Robertson, 2002).

the Tauride platform carbonates, well-preserved metamorphic sole rocks and ophiolitic unit. The ophiolitic units were intruded by microgabbro to diabase dikes (Figs. 2, 3). Detailed study on the geological, geochronological and geochemical features of the rock units in the Pınarbaşı ophiolite are lacking. The aim of this paper is (1) to present major and trace (including rare earths) element chemistry of the metamorphic sole and isolated dike rocks; (2) to investigate possible protoliths of the accreted material to the base of mantle tectonites during intraoceanic thrusting; (3) to give new isotopic age dating (K-Ar) of the metamorphic sole; and (4) to outline the geodynamic setting of the Pınarbaşı ophiolite during evolution of the Neotethyan oceanic area within the eastern Mediterranean tectonic frame.

GEOLOGICAL SETTING

The Pınarbaşı ophiolite exposed in the eastern Tauride belt, crops out in an area of approximately 500 km^2 (25 km in length and 20 km in width) in the southern part of central Anatolia (Turkey). An imbricated stack of allochthonous thrust sheets lies tectonically on the eastern Tauride autochthonous units (Blumenthal, 1947; Tekeli et al., 1983; Polat and Casey, 1995). The allochthonous units can be divided into two, namely platform type carbonate-dominated lower thrust sheet and ophiolite related upper thrust sheet.

The Tauride autochthon in the eastern Tauride belt is represented by Geyikdağ unit of Özgül (1976). This tectonostratigraphic unit comprises rock assemblages ranging in age from Cambrian to Eocene. The lower allochthonous units in the study area include, from bottom to top, Gülbahar and Domuzdağ nappes respectively (Figs. 2, 3). The Gülbahar nappe rests tectonically on the Tauride autochthon in the southern part of the study area (Fig. 2) and ranges in age from Middle Triassic to Late Cretaceous. This unit comprises mafic volcanics, calciturbidites, radiolarite and chert bearing micritic limestone and cherty limestone (Şenel, 1997a; 1997b. The Domuzdağ nappe, having a tectonic contact with the Gülbahar nappe at the bottom and ophiolitic mélange at the top, comprises platform type carbonates (Fig. 2) deposited between Middle Triassic to Late Cretaceous (Şenel et al., 2002).

The upper thrust sheet is represented, in ascending order, by an ophiolitic mélange, a metamorphic sole and an ophiolite sequence (Figs. 2, 3). The Upper Campanian-Maastrichtian, unmetamorphosed ophiolitic mélange includes a wide range of igneous, metamorphic and sedimentary blocks enclosed in serpentinitic to pelitic matrix (Erkan et al., 1978). The igneous rocks in the mélange include serpentinized harzburgitic to dunitic tectonites, gabbroic cumulates, diabase dikes and volcanics. The metamorphic rocks in the mélange are represented by amphibolites. The sedimentary rocks are dominated by volcanogenic sandstone, radiolarite and shale. The ophiolitic mélange, tectonically overlain by metamorphic sole rocks near Büyükgürleğen in the central part of the study area, is in turn thrust onto the allochthonous units of the Tauride platform to the south (Fig. 2). The metamorphic sole is tectonically sandwiched between overlying harzburgitic tectonites and underlying ophiolitic mélange at Büyükgürleğen (Figs. 2, 3). Its thickness varies between 250 and 300 meters. The metamorphic sole displays inverted metamorphic zonation, grading from amphibolite facies directly beneath the highly sheared harzburgitic tectonite to greenschist facies near the mélange contact. The whole metamorphic sole is characterized by well developed foliation at both mesoscopic and microscopic scales within the amphibolite and greenschist facies rocks (Fig. 4a, b). The foliation patterns vary between 330/50NE and 045/35SE. The Pınarbaşı ophiolite crops out mainly in the northern part of the study area and is represented by lower parts of an oceanic lithosphere. Except sheeted dikes

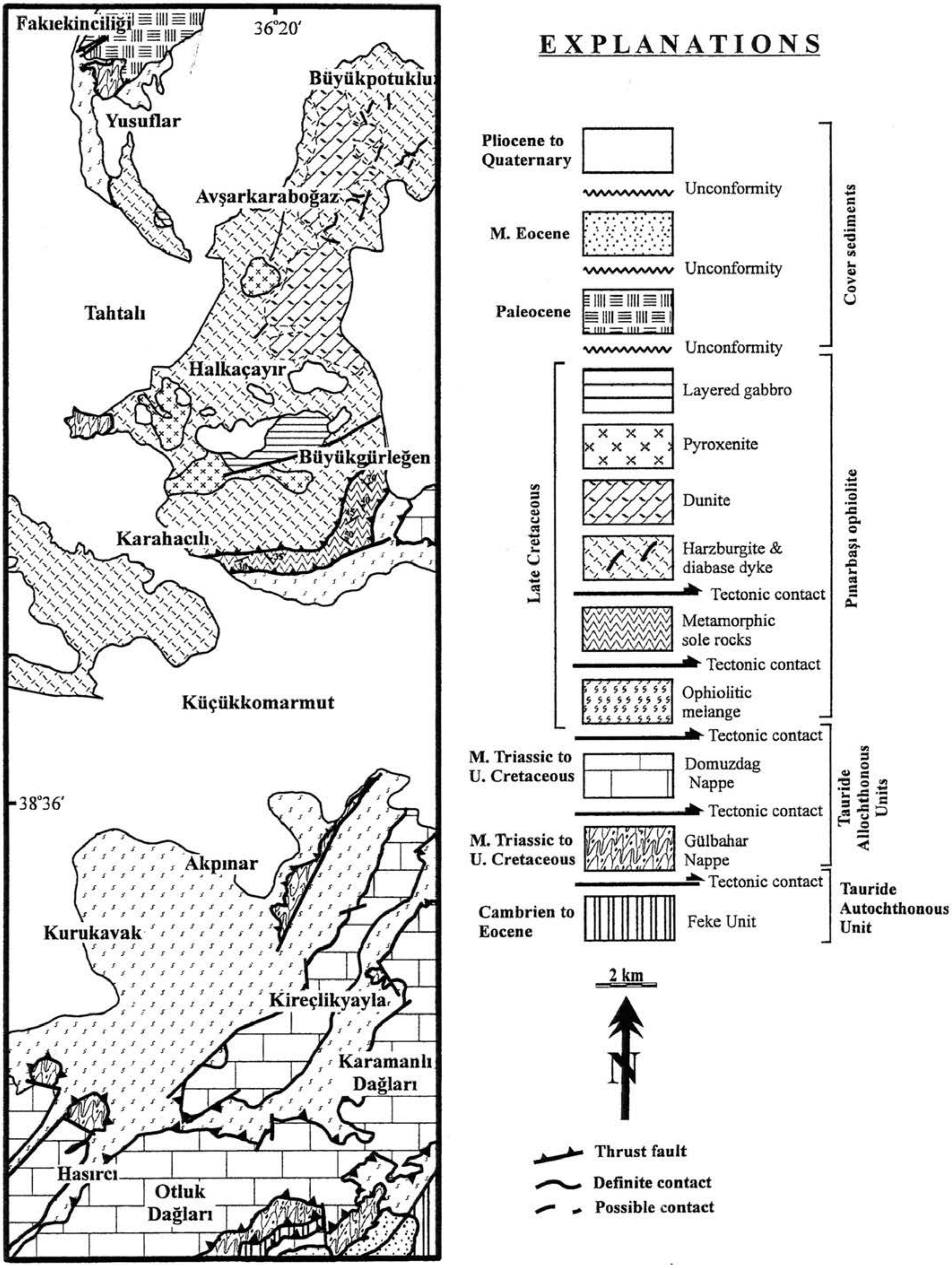

Fig. 2 - Geological map of the Pınarbaşı ophiolite and tectonostratigraphic units in the eastern Tauride belt.

and volcanics, it comprises harzburgitic to dunitic tectonites, ultramafic and mafic cumulates. Swarms of mafic dikes cut the mantle tectonites at all structural levels (Figs. 2, 3). Although dike emplacement within the metamorphic sole rocks of the Tauride belt ophiolite were reported in number of studies (Parlak et al., 1995; Parlak and Delaloye, 1996; Polat and Casey, 1995; Çelik and Delaloye, 2003; Dilek et al., 1999) the dikes are not observed in the metamorphic sole rocks of the Pınarbaşı ophiolite.

The oldest unit unconformably covering the Pınarbaşı ophiolite represented by Paleocene conglomerate, pebbly sandstone, sandstone and limestone, deposited in an environment transitional between alluvial fan and lagoon (Erkan et al., 1978) (Fig. 2). This indicates that the emplacement age of the Pınarbaşı ophiolite pre-dated the Paleocene.

PETROGRAPHY

The Pınarbaşı ophiolite is represented by mantle tectonites, ultramafic to mafic cumulates. The mantle tectonites are intruded by the microgabbro-diabase and pyroxenite dikes. The mantle tectonites are represented by harzburgites and dunites. The harzburgite shows granular texture and contains subhedral to unhedral olivine (75-80%) with a grain size between 0.7 and 1.7 mm, orthopyroxene (20-25%) with a grain size between 0.4 and 2.5 mm and chromite (< 1%) with a grain size up to 0.7 mm. The dunitic layers in the Pınarbaşı ophiolite, showing high amount of chromite, are represented by euhedral to unhedral olivine (95%) with a grain size between 0.8 and 1.7 mm and euhedral to subhedral chromite (5%) with a grain size between 0.5 and 1.2 mm.

The cumulate rocks are wehrlite, clinopyroxenite, troctolite, olivine gabbro and gabbro. The wehrlite has adcumulate texture and comprises clinopyroxene (55-60%) with a grain size between 0.4 and 2.7 mm, and totally serpentinized olivine (40-45%). The clinopyroxenite has adcumulate texture and consists of clinopyroxene (> 90%) with a grain size of 0.6 to 4.5 mm and orthopyroxene (> 10%) with a grain size of 1.5 to 3.5 mm, containing clinopyroxene exsolutions. The troctolite exhibits mesocumulate texture and is made up of subhedral to unhedral plagioclase (65-70%) with a grain size of 0.5 to 1.8 mm and of euhedral to subhedral serpentinized olivine (30-35%) with a grain size of 0.3 to 1 mm. The olivine gabbro displays an orthocumulate texture and is represented by subhedral serpentinized olivine (10-15%) with a grain size of 0.3 to 1.3 mm, subhedral to unhedral clinopyroxene (25-30%) with a grain size of 0.3 to 1 mm, subhedral to unhedral plagioclase (60-65%) with a grain size of 0.6 to 1.3 mm and opaque minerals. The gabbro has a mesocumulate texture and is characterized by subhedral to unhedral plagioclase (70-75%) with a grain size of 0.3 to 1.5 mm, subhedral clinopyroxene (20-25%) with a grain size of 0.3-1.2 mm and unhedral orthopyroxene (5-10%) with a grain size of 0.5-1.3 mm.

The dikes in the Pınarbaşı ophiolite are quite common and characterized by microgabbro-diabase and pyroxenite. The dikes have a sharp contact with host rocks and there is no chilled margins (Fig. 4). The pyroxenite dikes have a thickness ranging from 10 to 50 cm and show granular texture (Fig. 4c, d). They are made up of unhedral orthopyroxene (30-35%) with a grain size of 5.8 mm, unhedral clinopyroxene (65-70%) with a grain size of 0.3 to 4.5 mm and subhedral to euhedral chromite (~ 1%) (Fig. 4d). The microgabro-diabase dikes exhibit 20 cm to 2 m thickness and have subophitic texture (Fig. 4e, f). They comprise plagioclase (60-65%) with a grain size of 0.3 to 1 mm and clinopyroxene (35-40%) filling the gaps between plagioclases (Fig. 4f). The clinopyroxenes are partly transformed to amphibole.

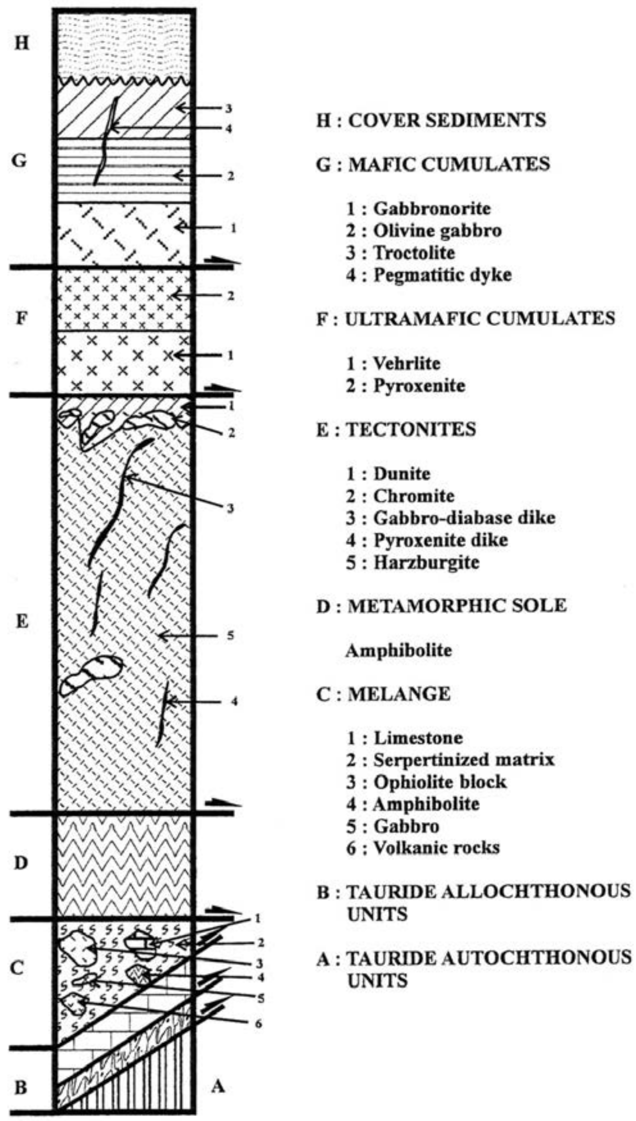

Fig. 3 - Synthetic log of the Pınarbaşı ophiolite and related tectonostratigraphic units.

The metamorphic sole rocks of the Pınarbaşı ophiolite comprise five mineralogical associations. These are (1) amphibolite, (2) plagioclase-bearing amphibolite, (3) plagioclase + amphibole schist, (4) epidote + plagioclase + amphibole schist and, (5) calcschist. The amphibolite displais granoblastic texture and is exclusively characterized by green hornblende (0.3- 1.5 mm). The plagioclase amphibolite rocks show a granoblastic texture represented by euhedral to subhedral brown hornblende (75%) with a grain size of 0.2 to 1.2 mm, subhedral plagioclase (25%) with a grain size of 0.2 to 1.2 mm, epidote and opaque minerals. The plagioclase + amphibole schist displays nematoblastic texture and exhibits well developed foliation due to the preferred orientation of hornblende (0.4 to 1.3 mm in size) and plagioclase (0.2 to 0.4 mm in size). The epidote + plagioclase + amphibole schist shows nematoblastic texture characterized by epidote (15-20%) with grain size of 0.3 mm, plagioclase (20-25%) with grain size of 0.3 to 0.6 mm and green to brown hornblende (55-60%) with a grain size of 0.2 to 1mm. The calcschist comprises alternations of calcite, quartz and amphibole mineral assemblages.

ANALYTICAL METHOD

A total of 30 samples from the metamorphic sole rocks (14) and isolated mafic dikes (16) were analysed for major and trace (including rare earths) elements in 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 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 to 3. Two amphibole separates (P217G and P225A) from the metamorphic sole were used for K-Ar isotopic age dating in Geochronology and Isotopic Geochemistry Lab of the Acme Analytical Laboratories Ltd in Canada. The K concentration was performed by ICP and the argon analysis was performed using the isotope dilution procedure on nobel gas mass spectrometry. The data is presented in Table 4.

GEOCHEMISTRY

The major, trace and rare earth element contents of the metamorphic sole rocks and isolated dikes are presented in

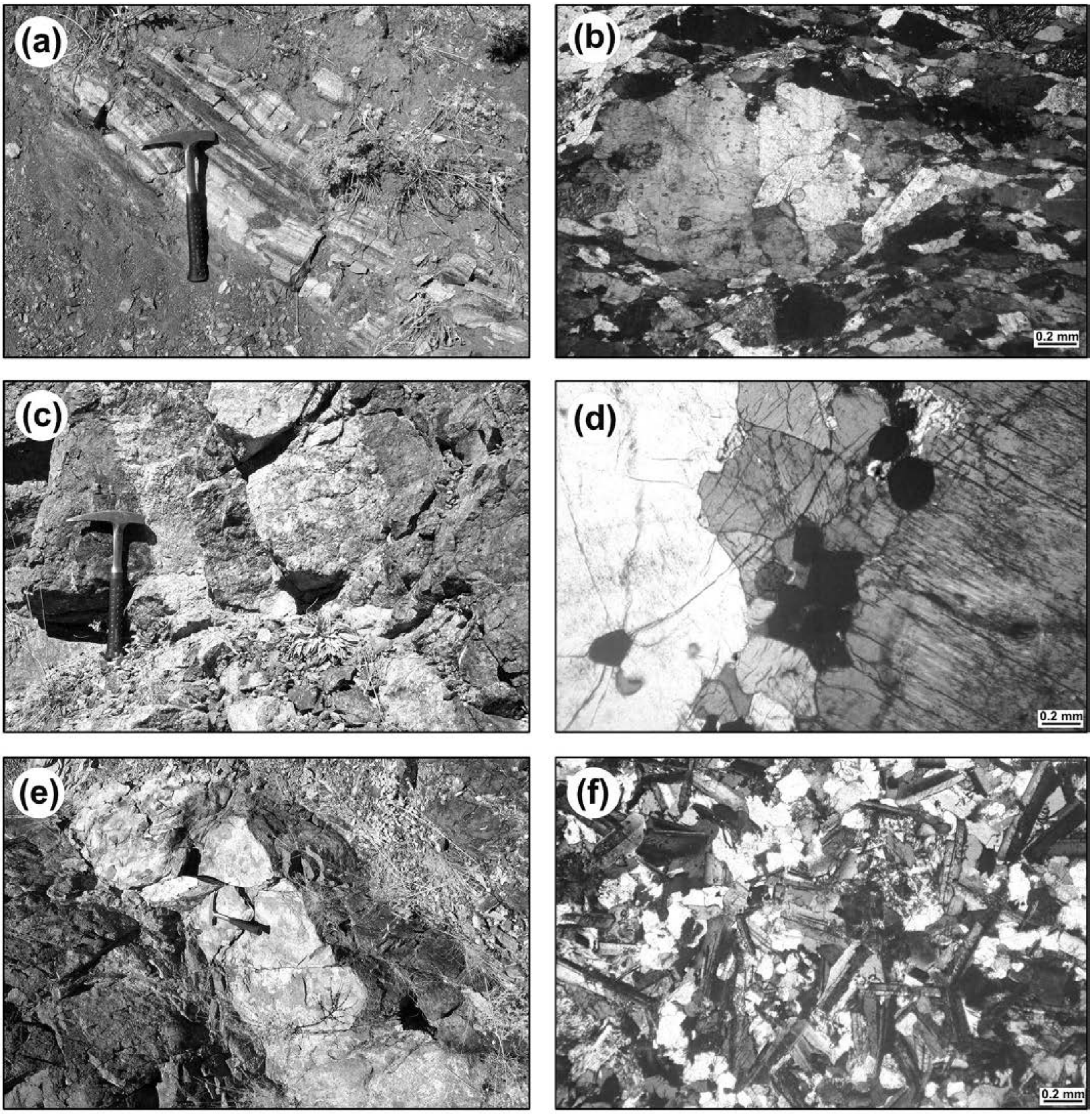

Fig. 4 - Field and petrographic views of the metamorphic sole (a and b), pyroxenite (c and d) and diabase (e and f) dikes in the Pınarbaşı ophiolite.

Tables 1 to 3. While most amphibolites have low LOI (< 2%), others contain LOI ranging up to 7.2% and isolated dikes have variable LOI ranging from 1.9 to 6.2%, suggesting that the wide variation in LOI is a crude measure of the degree of alteration and reflects the contribution by secondary hydrated and carbonate phases (Tables 1 and 2). Alteration can be expected to have caused selected element mobility, especially involving the large-ion-lithophile (LIL) elements (Hart et al., 1974; Humphris and Thompson, 1978; Thompson, 1991). Characteristic magmatic inter-element relationships are often maintained by those elements that are considered relatively immobile during alteration, such as high field strength (HFS) elements and the rare earth elements (REE) (Pearce and Cann, 1973; Smith and Smith, 1976; Floyd and Winchester, 1978). The interpretation of magmatic relationships and sources is thus dependent on these elements. Under some circumstances, such as the extensive carbonatization of metabasites, even the REE and HFS elements can be mobilized or their abundance diluted (Hynes, 1980), although no carbonate-bearing samples were included in this study.

Based on stable trace element distributions, two geochemically distinguishable igneous suites have been recognized within the metamorphic sole rocks of the Pınarbaşı ophiolite (Fig. 5). The Nb/Y versus Ti/Y diagram of Pearce (1982) clearly shows that the amphibolites are characterized by both tholeiitic and alkaline protoliths, displaying similarities to the other metamorphic soles beneath the Tauride ophiolites (Parlak et al., 1995; Çelik and Delaloye, 2003; Lytwyn and Casey, 1995) (Fig. 5). The alkaline amphibolites comprise high amount of Zr (111 to 501 ppm), Nb (32.7 to 95.8 ppm), Y (18.6 to 44.2 ppm), Th (1.3 to 9.9 ppm), Hf (3.6 to 9.8 ppm), TiO_2 (2.15 to 4.21%) and P_2O_5 (0.23 to 0.9%) relative to the tholeiitic amphibolites (Zr: 34.2 to 75.5 ppm, Nb: 1.4 to 6.8 ppm, Y: 17.7 to 30.7 ppm, Th: 0.1 to 0.4 ppm, Hf: 1 to 2.1 ppm, TiO_2: 0.68 to 1.33%, P_2O_5: 0.08 to 0.17%) (Table 1).

The isolated dikes cutting the mantle tectonites are tholeiitic in nature as dikes in the other Tauride ophiolites (Parlak et al., 1995; Parlak and Delaloye, 1996; Lytwyn and Casey, 1995; Çelik and Delaloye, 2003) (Fig. 5), and the concentrations of elements such as Zr (48.3 to 84.8 ppm with the exception of one sample 1.8 ppm), Nb (0.8 to 2 ppm), Y (23.3 to 34.3 ppm with the exception of one sample 3.6 ppm), Th (0.1 to 0.5 ppm), Hf (1.4 to 2.6 ppm), TiO_2 (0.13 to 1.54 wt.%), P_2O_5 (0.02 to 0.13 wt.%) are very similar to the tholeiitic amphibolites of the Pınarbaşı ophiolite. Ratios of some selected incompatible elements also suggest that the isolated dikes and tholeiitic amphibolites may have been originated from a same magma source, differently from the alkaline amphibolites (Tables 1 and 2).

The rock classification diagram of Pearce (1996) based on Zr/Ti versus Nb/Y shows that the metamorphic sole rocks and isolated dikes are exclusively basaltic in composition, except one trachyandesitic sample in alkaline amphibolites (Fig. 6).

The Fig. 7 illustrates the diversity in the amphibolites in terms of variable Ti/V and Zr/Y ratios. For example, the alkaline amphibolites are characterized by high Ti/V (47.96 to 89.92) and Zr/Y (5.97 to 14.03) ratios whereas the tholeiitic amphibolites present low Ti/V (20.97 to 34.34) and Zr/Y ratios (1.23 to 2.61). The isolated dikes display similar geochemical behaviour as the tholeiitic amphibolites in terms of Ti/V (18.36 to 25.15, except one sample with 7.42) and Zr/Y (2.06 to 2.47, except one sample with 0.5) ratios (Fig. 7).

The Fig. 8a presents two ratios (Ce/Y vs Zr/Nb) of pairs of elements of different degrees of incompatibility. On this plot, the extension of melting increases from upper left to lower right. Thus the protolith of the alkaline amphibolites is thought to have been formed as a result of smaller degrees of melting whereas the protolith of the tholeiitic amphibolites show higher degrees of melting. The isolated dike samples also show higher degrees of melting as tholeiitic amphibolites (Fig. 8a). Ce/Sm versus Sm/Yb ratios are plotted in Fig. 8b together with OIB and MORB compositions. The high Sm/Yb and Ce/Sm ratios of the alkaline amphibolites suggest that they were derived from melting of OIB-like enriched mantle source whereas the low Sm/Yb and Ce/Sm ratios of the tholeiitic amphibolites and isolated dikes suggest derivation from a more depleted MORB-like mantle source (Fig. 8b).

The chondrite normalized REE patterns of the metamorphic sole rocks and isolated dikes are presented in Fig. 9. The isolated dikes have slightly LREE-depleted to flat, un-

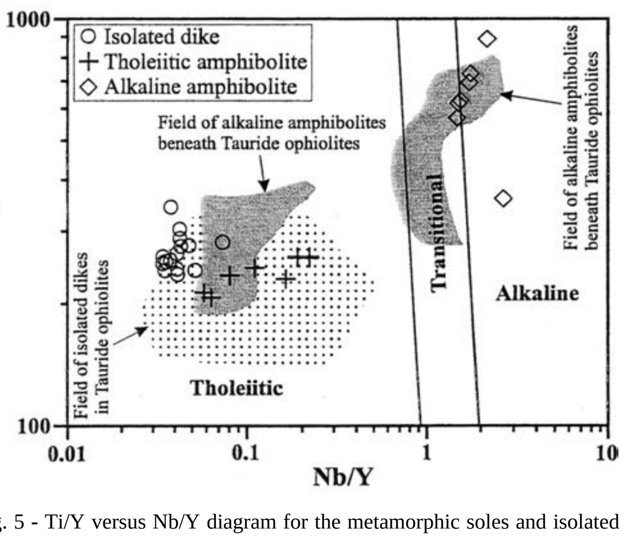

Fig. 5 - Ti/Y versus Nb/Y diagram for the metamorphic soles and isolated dikes of the Pınarbaşı ophiolite (after Pearce, 1982). Field of metamorphic soles and mafic dikes from the Tauride ophiolites are from Parlak et al. (1995), Lytwyn and Casey (1995), Dilek et al. (1999), Parlak (2000) Çelik and Delaloye (2003).

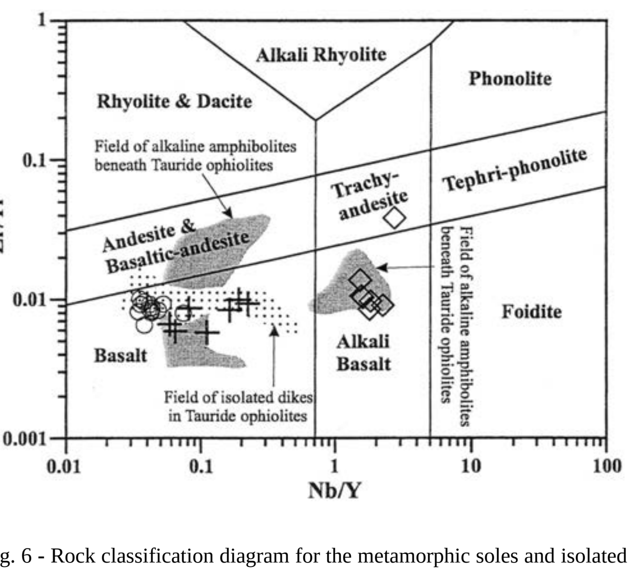

Fig. 6 - Rock classification diagram for the metamorphic soles and isolated dikes from the Pınarbaşı ophiolite (after Pearce, 1996). Data for the metamorphic soles and mafic dikes from the Tauride ophiolites are the same as in Fig. 5.

Table 1 - Major and trace element contents of the metamorphic sole rocks by ICP-ES.

Sample	P-211B	P-215B	P-215C	P-217B	P-224A	P-225A	P-235A	P-212A	P-217F	P-217G	P-221A	P-221B	P-223A	P-223C
SiO_2	45.70	48.32	44.19	43.20	43.55	46.95	45.45	48.46	48.15	43.28	46.82	48.88	43.40	48.10
TiO_2	3.78	2.15	2.51	4.21	2.16	2.79	2.68	0.85	1.16	1.02	1.14	0.68	1.14	1.33
Al_2O_3	11.38	15.80	10.70	14.32	10.99	11.83	12.96	15.10	14.87	14.42	15.13	15.12	13.79	15.50
FeO*	11.89	11.04	12.70	15.54	10.98	12.20	12.12	9.85	12.46	11.01	9.50	8.54	12.21	9.69
MgO	6,30	4.88	14.66	5.40	9.09	8.75	7.11	7.42	7.17	10.10	5.59	6.79	11.33	7.05
CaO	14.77	9.93	9.94	9.58	12.07	11.59	13.16	13.06	10.03	16.29	16.83	14.74	13.48	11.61
Na_2O	2.60	4.18	2.13	2.89	2.52	2.74	2.30	2.57	2.55	1.09	1.78	2.04	1.73	3.35
K_2O	0.96	1.29	0.18	2.11	0.15	0.58	0.80	1.31	1.88	0.52	0.74	1.55	0.45	1.00
P_2O_5	0.56	0.63	0.52	0.90	0.23	0.52	0.41	0.08	0.10	0.09	0.16	0.12	0.11	0.17
MnO	0.16	0.20	0.17	0.21	0.14	0.16	0.16	0.15	0.24	0.17	0.15	0.14	0.23	0.14
Cr_2O_3	0.03	0.02	0.09	< 0.001	0.09	0.07	0.04	0.07	0.03	0.7	0.03	0.06	0.08	0.03
LOI	1.00	1.50	2.00	1.40	7.20	1.30	2.60	1.10	1.20	1.60	2.20	1.00	1.80	1.90
SUM	99.20	100.03	99.85	99.82	99.20	99.52	99.84	100.07	99.88	99.69	100.10	99.71	99.80	99.90
Ba	509	690	29	386	51	99	215	252.00	139.00	18.00	94.00	321.00	30.00	159.00
Sc	24	16	30	23	46	30	31	39.00	46.00	45.00	37.00	37.00	46.00	37.00
Ni	115	55	409	< 20	125	205	184	161.00	75.00	173.00	82.00	111.00	349.00	85.00
Co	45.70	31.0	65	38.6	48.1	52.1	49.1	48.7	44.7	50.60	37.6	37.3	64.2	35.4
Cs	< 0.1	0.7	0.1	0.2	< 0.1	0.1	3.1	0.7	< 0.1	< 0.1	< 0.1	0.2	0.3	12.0
Ga	19.2	25.4	18.2	24.4	15.1	16.8	19.3	14.4	17.5	16.0	15.3	12.9	17.2	16.5
Hf	6.3	9.8	5.1	9.1	3.6	5.2	4.8	1.3	1.8	1.5	2.1	1.0	1.4	2.0
Nb	55.7	95.8	37.7	66.7	32.7	40.9	39.8	1.4	2.4	1.9	5.0	2.9	3.1	6.8
Rb	12	23.7	1.7	25.1	2.4	6.4	13.6	30.6	37.2	2.4	11.6	19.3	3.0	17.1
Sr	548.4	812.9	207.4	457.3	343.6	272.8	401.5	282.7	89.0	145.0	402.6	206.2	84.6	402.0
Ta	3.1	3.8	2.4	4,0	1.7	2.4	2.3	< 0.1	0.1	0.1	0.3	0.2	0.1	0.4
Th	3.8	9.9	1.3	6.8	3	3.2	3.3	0.1	0.3	< 0.1	0.1	0.3	0.2	0.4
U	3.1	3.1	0.8	2.1	0.6	0.8	0.8	< 0.1	0.7	0.5	0.1	0.2	0.2	0.4
V	310	207	237	281	270	256	258	243	297	259	199	193	279	234
Zr	207.3	501,0	157,0	351.5	111,0	164.2	172.3	34.2	60.6	36.4	68.7	34.6	39.8	75.5
Y	25.3	35.7	23.9	44.2	18.6	22.8	25.9	23.9	29.6	29.5	26.3	17.7	27.9	30.7
Pb	1.8	3.7	0.5	1.2	1.8	0.7	0.8	0.3	0.3	0.2	0.6	1.2	0.6	0.7
Ti/V	73.10	62.27	63.49	89.82	47.96	65.34	62.27	20.97	23.41	23.61	34.34	21.12	24.50	34.07
Zr/Y	8.19	14,03	6.57	7.95	5.97	7.20	6.65	1.43	2.05	1.23	2.61	1.95	1.43	2.46

Total Fe is expressed as FeO*. < means below detection limit.

Table 2 - Major and trace element contents of the metamorphic sole rocks by ICP-ES.

Sample	P-214A	P-217A	P-220B	P-220C	P-222A	P-227C	P-228F	P-229B	P-238C	P-239A	P-240C	P-241A	P-241B	P-241C	P-242E	P-245B
SiO_2	52.88	42.76	50.71	50.25	50.93	52.58	51.07	52.58	52.43	50.06	49.69	51.27	49.35	50.32	48.34	50.11
TiO_2	1.27	0.13	1.14	1.04	1.08	1.48	1.39	0.98	1.46	1.08	1.03	1.06	1.51	1.15	1.12	1.54
Al_2O_3	14.89	15.78	15.27	15.05	15.24	14.66	15.09	15.18	14.76	14.95	14.69	14.76	14.44	15.49	15.48	14.72
FeO*	11.12	4.98	9.77	9.75	9.62	11.31	10.97	10.38	11.47	10.27	9.97	10.05	11.92	10.64	9.82	11.71
MgO	4.67	10.54	7.33	7.75	7.41	4.59	6.06	5.86	5.19	6.19	5.14	5.99	6.48	5.78	7.48	5.32
CaO	8.01	18.94	8.48	8.86	9.25	7.77	9.08	9.28	9.17	9.43	9.48	7.18	7.49	8.03	9.92	7.74
Na_2O	3.05	0.45	2.59	2.46	2.35	4.53	3.50	2.46	3.10	3.84	5.25	5.11	3.47	4.65	3.13	4.31
K_2O	0.25	< 0.02	0.15	0.13	0.13	0.30	0.23	0.24	0.10	0.30	0.05	0.28	1.08	0.10	0.21	0.61
P_2O_5	0.11	0.02	0.07	0.08	0.10	0.11	0.11	0.06	0.11	0.08	0.05	0.08	0.10	0.10	0.10	0.13
MnO	0.15	0.08	0.13	0.14	0.14	0.17	0.17	0.15	0.17	0.15	0.15	0.15	0.17	0.16	0.15	0.18
Cr_2O_3	0.00	0.08	0.01	0.01	0.02	0.00	0.01	< 0.001	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
LOI	3.70	6.20	4.30	4.50	3.80	2.70	2.30	3.00	1.90	3.70	4.50	4.20	4.10	3.60	4.10	3.30
SUM	100.11	99.99	99.98	100.05	100.08	100.23	100.00	100.18	99.88	100.07	100.02	100.16	100.14	100.04	99.90	99.69
Ba	66	22	89	139	78	167	78	85	21	32	18	41	90	58	200	40
Sc	35	37	38	39	38	34	38	40	36	36	34	36	38	36	38	38
Ni	21	178	46	62	54	32	42	55	25	39	34	37	36	34	56	55
Co	31.7	39.3	32.7	33.9	34.4	31.10	34.2	36.7	35.4	31.4	33.7	33.4	32.6	35.3	34.1	34.2
Cs	< 0.1	< 0.1	< 0.1	0.1	0.2	< 0.1	< 0.1	0.2	< 0.1	0.3	0.1	0.2	0.5	0.2	< 0.1	0.2
Ga	19.4	5.6	16.3	15.1	17.1	17.9	18	17.1	18.8	15.7	16.2	16	16.9	15.7	18.7	18.3
Hf	2.2	< 0.5	2	1.4	1.8	2.2	2.3	1.8	2.6	2.2	2	1.7	1.9	1.7	1.9	2.5
Nb	2	< 0.5	0.9	1.1	1.4	1.4	1.3	0.8	1.3	1.1	0.9	0.9	1	1.2	1	1.3
Rb	3.5	0.6	2.1	1.4	2.2	3	3.6	4.9	0.6	5.3	0.9	6.2	27.9	4	4.4	8.3
Sr	137.8	71.9	127.5	167.9	132	153.6	162.3	111.9	129.7	143	91.6	104.8	158.6	169.2	211.7	195
Ta	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1
Th	0.3	< 0.1	< 0.1	< 0.1	0.3	0.4	0.3	< 0.1	0.5	0.3	0.2	< 0.1	< 0.1	0.5	0.4	0.1
U	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.1	< 0.1	< 0.1	< 0.1	0.2	0.1	< 0.1	0.1	0.2	< 0.1
V	341	105	296	263	272	358	335	320	348	297	303	292	400	329	308	389
Zr	61.1	1.8	56.4	57.9	60.5	78	72.4	48.3	84.8	56.3	62.7	58.9	59.7	58	56.1	74.8
Y	27.0	3.6	26.3	26.4	26.8	32.2	31.4	23.4	34.3	26.6	25.6	25.1	26.3	24.9	23.3	30.4
Pb	0.5	0.2	0.6	0.6	0.5	0.5	0.4	0.8	0.3	0.6	0.6	0.4	0.3	0.7	1.0	0.4
Ti/V	22.33	7.42	23.09	23.71	23.80	24.78	24.87	18.36	25.15	21.80	20.38	21.76	22.63	20.96	21.80	23.73
Zr/Y	2.26	0.50	2.14	2.19	2.26	2.42	2.31	2.06	2.47	2.12	2.45	2.35	2.27	2.33	2.41	2.46

Total Fe is expressed as FeO*. < means below detection limit.

Table 3 - REE contents of the metamorphic sole rocks and isolated dikes by ICP-MS.

	Isolated dikes															
Sample	**P-214A**	**P-217A**	**P-220B**	**P-220C**	**P-222A**	**P-227C**	**P-228F**	**P-229B**	**P-238C**	**P-239A**	**P-240C**	**P-241A**	**P-241B**	**P-241C**	**P-242E**	**P-245B**
La	3.20	< 0.50	2.90	2.60	3.00	4.10	3.70	2.30	3.70	2.60	2.70	2.70	3.20	3.00	2.90	3.50
Ce	9.40	0.50	8.10	7.90	8.50	11.10	9.40	5.90	10.90	7.60	7.60	7.80	7.90	8.30	8.10	10.60
Pr	1.49	0.09	1.30	1.28	1.36	1.84	1.60	0.99	1.89	1.32	1.31	1.28	1.47	1.36	1.30	1.78
Nd	7.80	0.40	6.70	7.00	7.00	9.50	8.50	5.70	10.70	6.50	6.80	7.10	8.70	9.20	7.90	9.60
Sm	2.50	0.30	2.50	2.50	2.40	3.50	3.20	1.90	3.30	2.60	2.60	2.60	2.80	2.40	2.40	3.30
Eu	1.04	0.17	1.01	0.99	1.03	1.18	1.28	0.90	1.30	0.95	0.97	1.00	1.06	0.94	0.95	1.30
Gd	3.60	0.50	3.43	3.63	3.33	4.51	4.36	3.08	5.12	3.59	3.76	3.48	4.05	3.76	3.43	4.82
Tb	0.74	0.10	0.65	0.67	0.71	0.85	0.82	0.56	0.85	0.67	0.63	0.73	0.69	0.62	0.64	0.79
Dy	4.50	0.73	3.96	3.93	4.33	5.30	5.24	3.68	5.70	4.28	4.37	4.54	4.43	4.15	4.05	5.31
Ho	0.82	0.12	0.79	0.80	0.84	0.98	0.99	0.74	1.20	0.88	0.85	0.86	0.89	0.88	0.86	1.13
Er	2.96	0.39	2.73	2.63	2.85	3.48	3.42	2.39	3.65	2.98	2.89	2.94	2.83	2.73	2.73	3.50
Tm	0.39	< 0.05	0.37	0.43	0.39	0.42	0.49	0.37	0.56	0.44	0.43	0.39	0.44	0.41	0.37	0.48
Yb	2.27	0.24	2.39	2.30	2.44	3.23	2.53	2.22	3.06	2.54	2.65	2.33	2.59	2.42	2.27	3.18
Lu	0.35	0.05	0.32	0.33	0.34	0.46	0.45	0.36	0.45	0.38	0.51	0.39	0.43	0.33	0.32	0.44

	Alkaline amphibolites							Tholeiitic amphibolites						
Sample	**P-211B**	**P-215B**	**P-215C**	**P-217B**	**P-224A**	**P-225A**	**P-235A**	**P-212A**	**P-217F**	**P-217G**	**P-221A**	**P-221B**	**P-223A**	**P-223C**
La	44.20	66.30	27.60	60.20	23.10	31.20	28.40	2.60	3.20	3.10	5.40	3.70	3.70	8.00
Ce	84.40	113.30	59.90	118.40	49.10	66.60	64.60	5.90	7.60	6.70	11.70	6.90	8.60	18.20
Pr	10.06	12.74	7.18	14.24	5.68	7.98	7.81	1.01	1.36	1.26	1.85	1.04	1.35	2.50
Nd	39.70	48.40	28.50	57.10	24.00	32.10	34.20	5.50	7.30	7.20	9.00	4.80	6.70	12.30
Sm	7.60	9.60	5.80	12.20	4.90	6.40	6.80	2.00	2.70	2.50	2.80	1.50	2.60	3.40
Eu	2.42	2.86	1.89	3.81	1.67	2.12	2.18	0.82	1.01	0.99	1.00	0.68	0.98	1.31
Gd	7.70	9.48	6.02	11.67	5.19	6.64	7.00	3.06	3.78	4.02	4.0	2.12	3.81	4.71
Tb	0.97	1.23	0.82	1.64	0.70	0.87	1.00	0.60	0.74	0.67	0.65	0.42	0.67	0.81
Dy	4.86	6.25	4.61	8.68	3.81	4.69	4.84	3.61	4.43	4.36	3.90	2.50	4.31	4.65
Ho	0.84	1.15	0.81	1.49	0.52	0.77	0.85	0.81	1.08	0.93	0.86	0.55	0.95	0.96
Er	2.25	3.39	2.31	4.20	1.79	2.09	2.44	2.71	3.40	2.74	2.54	1.81	2.91	3.05
Tm	0.32	0.48	0.31	0.55	0.26	0.25	0.32	0.35	0.45	0.47	0.41	0.29	0.47	0.46
Yb	1.82	2.88	1.76	3.09	1.18	1.35	1.89	2.48	2.82	2.89	2.66	1.71	2.80	2.53
Lu	0.23	0.40	0.22	0.43	0.18	0.19	0.25	0.33	0.42	0.40	0.39	0.25	0.43	0.38

< means below detection limit.

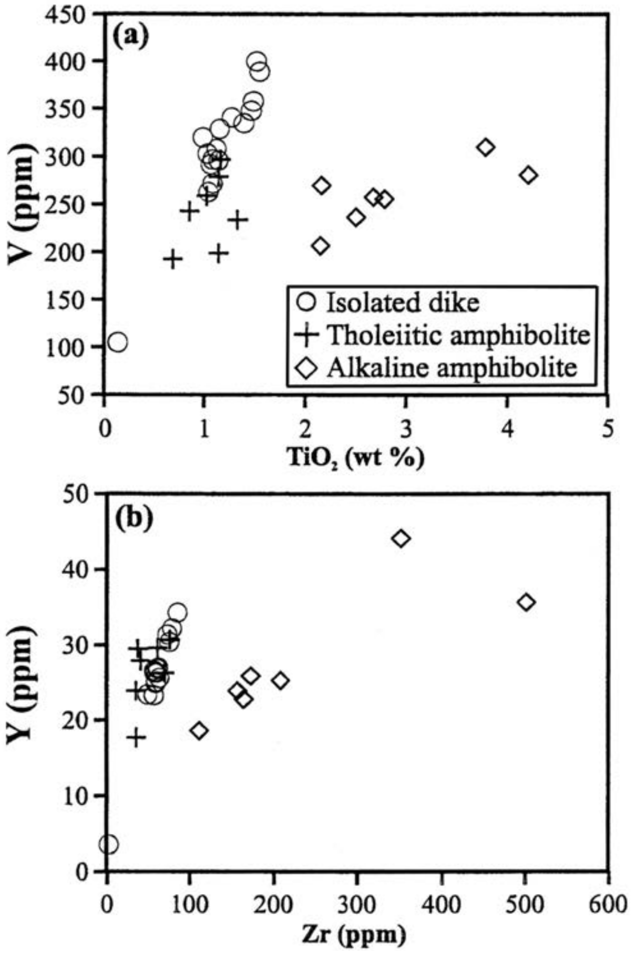

Fig. 7 - Characterization of metamorphic sole rocks and isolated diabase dikes in terms of variable Ti/V (a) and Zr/Y (b) ratios.

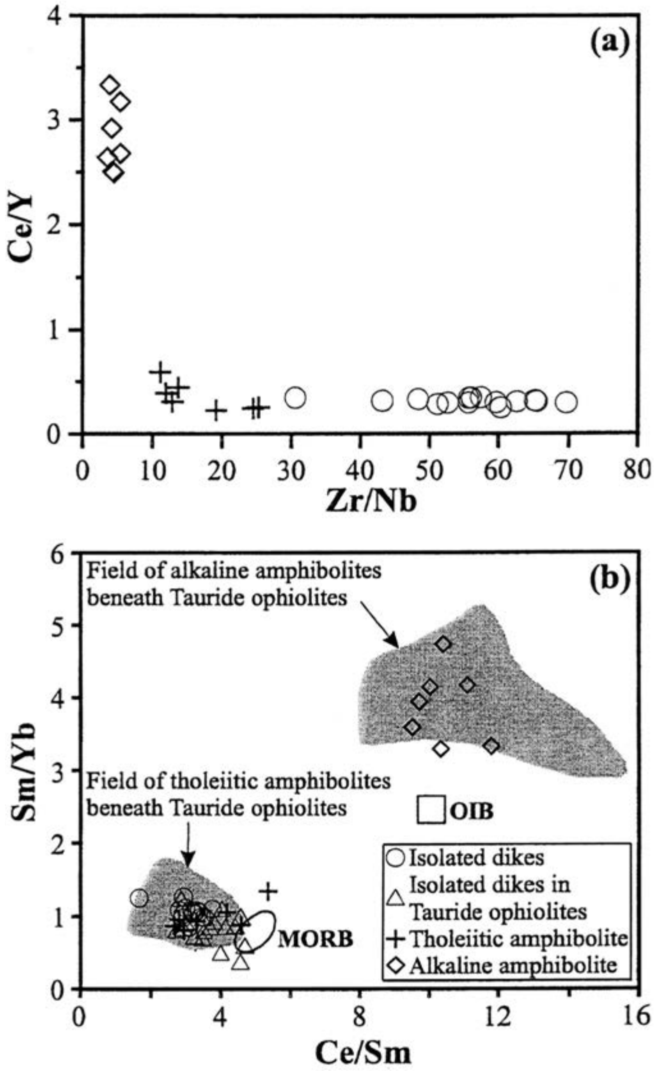

Fig. 8 - Source characteristics and degree of partial melting based on (a) Ce/Y versus Zr/Nb and (b) Ce/Sm versus Sm/Yb diagrams for the metamorphic soles and isolated dikes in the Pınarbaşı ophiolite. Data for the metamorphic soles and mafic dikes from the Tauride ophiolites are the same as in Fig. 5.

differentiated patterns (La_N/Yb_N=1.05 to 0.73) and display similar REE patterns to isolated dike in the Tauride belt ophiolites (Parlak et al., 1995; Lytwyn and Casey, 1995; Parlak and Delaloye, 1996; Çelik and Delaloye, 2003). These mainly flat-lying REE patterns are typically found in island arc tholeiitic series, namely in Papua New Guinea, Solomon Island, Macquarie Island (Jakes and Gill, 1970), and suprasubduction zone type ophiolites in Turkey (Parlak, 1996; Parlak et al., 2000; 2004; Parlak and Robertson, 2004; Yalınız et al., 1996; 2000a; 2000b). The metamorphic sole rocks display two distinct REE patterns (Fig. 9b). The alkaline amphibolites exhibit LREE enriched patterns (La_N/Yb_N = 10.78 to 17.42) whereas the tholeiitic ones exhibit flat REE patterns (La_N/Yb_N = 0.75 to 2.27). The alkaline amphibolites display similarity to LREE-enriched patterns of ocean island basalts (Sun and McDonough, 1989) whereas the tholeiitic amphibolites are more akin to flat-lying REE patterns of basaltic rocks formed in a subduction related settings. These two REE patterns are common in other metamorphic soles beneath the Tauride belt ophiolites, which are interpreted as basaltic volcanics formed in mid-ocean ridge (MORB), within plate (WPB) and island arc (IAT) settings and were metamorphosed during intraoceanic subduction in Neotethyan oceanic basin (Parlak et al., 1995; Lytwyn and Casey, 1995; Dilek et al., 1999; Çelik and Delaloye, 2003).

The N-MORB normalized multi-element diagrams for the isolated dikes, alkaline and tholeiitic amphibolites are presented in Fig. 10. Some features stand out for the isolated dikes in the Pınarbaşı ophiolite: (a) enrichment in LIL (i.e. Rb, Ba, Th, K) elements, (b) positive Sr and Pb anomalies, (c) negative Nb and P anomalies and (d) flat patterns of HFS elements relative to N-MORB (Fig. 10a). Th within the LIL element group is a relatively stable and reliable indicator, whose enrichment relative to other incompatible elements is taken to represent the subduction zone component (Wood et al., 1979; Pearce, 1983). Moreover, the negative Nb anomaly may indicate a subduction-related tectonic setting for the isolated dikes (Arculus and Powel, 1986; Yogodzinski et al., 1993; Wallin and Metcalf, 1998). The alkaline amphibolites can be directly compared chemically with ocean island basalt (OIB) and show similar multi-element patterns to the amphibolites from the base of the Tauride belt ophiolites (Sun and McDonough, 1989; Parlak et al., 1995; Lytwyn and Casey, 1995; Çelik and Delaloye, 2003) (Fig. 10b). The tholeiitic amphibolites exhibit many similarities to the isolated mafic dikes in terms of LIL element (i.e. Rb, Ba, Th, K) enrichment, Nb depletion, flat patterns of HFS elements relative to MORB (Fig. 10c). All the evidence suggests that the protolith of the tholeiitic amphibolites were formed in a subduction related setting.

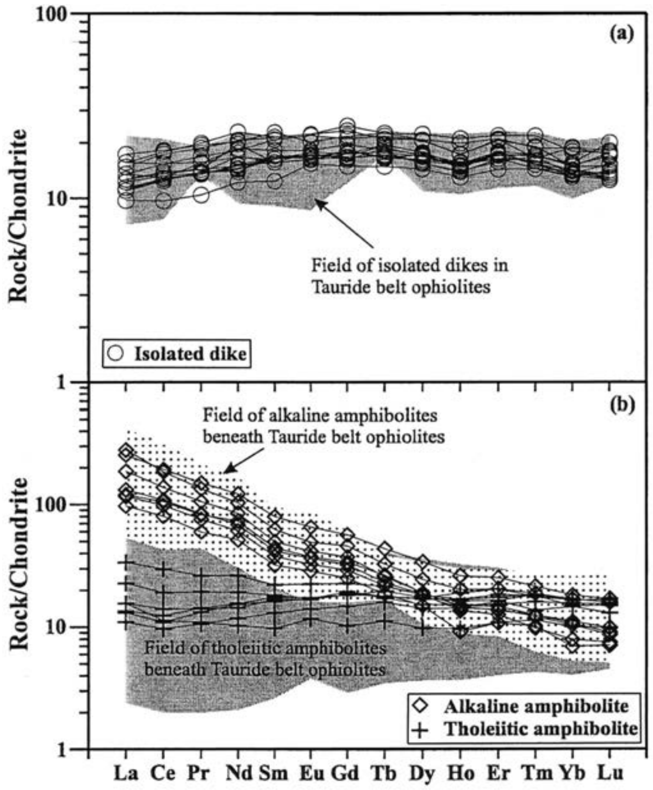

Fig. 9 -. Chondrite normalized REE patterns of the isolated dikes (a) and metamorphic soles (b) of the Pınarbaşı ophiolite (normalizing values are from Sun and McDonough, 1989). Data for the metamorphic soles and mafic dikes from the Tauride ophiolites are the same as in Fig. 5.

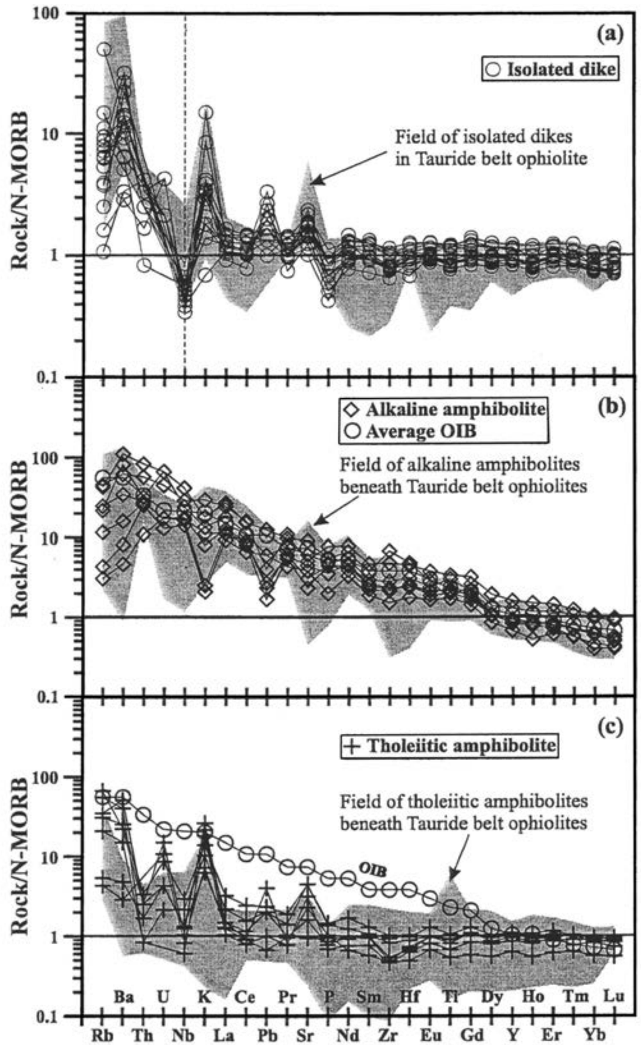

Fig. 10 - N-MORB normalized spider diagram for the isolated diabase dikes (a), alkaline amphibolites (b) and tholeiitic amphibolites (c) of the Pınarbaşı ophiolite (normalizing values are from Sun and McDonough, 1989). Data for the metamorphic soles and mafic dikes from the Tauride ophiolites are the same as in Fig. 5.

The Fig. 11a presents Nb/Th ratio versus Y for the isolated dikes in the Pınarbaşı ophiolite as well as the dikes in other Tauride ophiolites. It is clear that Nb/Th ratio records the development of the negative Nb anomaly as seen in the multi-element diagram (Fig. 10a). This suggest that the isolated dikes of the Pınarbaşı ophiolite formed in a subduction related environment (except one sample), consistent with other mafic dikes of the Tauride ophiolites (Fig. 11a). The Th/Yb versus Ta/Yb ratio-ratio plot is designed to discriminate between depleted mantle (MORB) and enriched mantle (intraplate) sources (Pearce, 1982). Addition of a subduction chemical component by slab-derived fluids/melts results in an increase in Th/Yb in the mantle source as shown by the arrow in Fig. 11b. On this plot the metamorphic sole rocks of the Pınarbaşı ophiolite exhibit two different magma sources. The first one is characterized by enriched mantle source/intraplate basalts and the second one is represented by depleted mantle source modified by addition of subduction component (Fig. 11b). In terms of the chemical discrimination of tectonic environment, the differences and similarities between the alkaline, and tholeiitic amphibolites and mafic dikes are exhibited in Fig. 12. Zr/Y versus Zr diagram of Pearce and Norry (1979) and Nb-Zr-Y triangular diagram of Meschede (1986) show that the tholeiitic amphibolites and mafic dikes plot in suprasubduction zone tectonic setting whereas the alkaline amphibolites plot in the within plate environment (Fig. 12a, b).

DISCUSSION

The Upper Cretaceous Neotethyan paleogeography of the eastern Mediterranean region suggests three different branches of oceanic basins separated by continental fragments and platform carbonates. These are northern Neo-Tethys, southern Neo-Tethys and Inner Tauride ocean (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984; Görür et al., 1984; Dilek et al., 1999). The Pınarbaşı ophiolite is located within the Tauride belt in southern Turkey. Although there have been number of studies on the origin of the Tauride ophiolites, their root zone is still debatable. Göncüoğlu et al. (1996-1997) suggested that the Tauride ophiolites formed in suprasubduction zone tectonic setting in the northern branch of Neotethys and were thrust onto the Kırşehir-Niğde metamorphic massifs, then onto the Bolkardağ/Aladağ carbonate platforms, in the Late Cretaceous (Fig. 13). According to some models, all the Upper Cretaceous Tauride ophiolites are interpreted as remnants of a single vast ophiolite thrust sheet generated within Neotethys, to the north of Tauride carbonate platform, the Inner Tauride Ocean of Görür et al. (1984) (Özgül, 1976; 1984; Monod, 1977; Şengör and Yılmaz, 1981; Lytwyn and Casey, 1995; Polat and Casey, 1995; Polat et al., 1996; Dilek and Whitney, 1997; Collins and Robertson, 1998; Dilek et al., 1999; Parlak and Robertson, 2004). They concluded that the Tauride ophiolites formed above a N-dipping intra-oceanic sub-

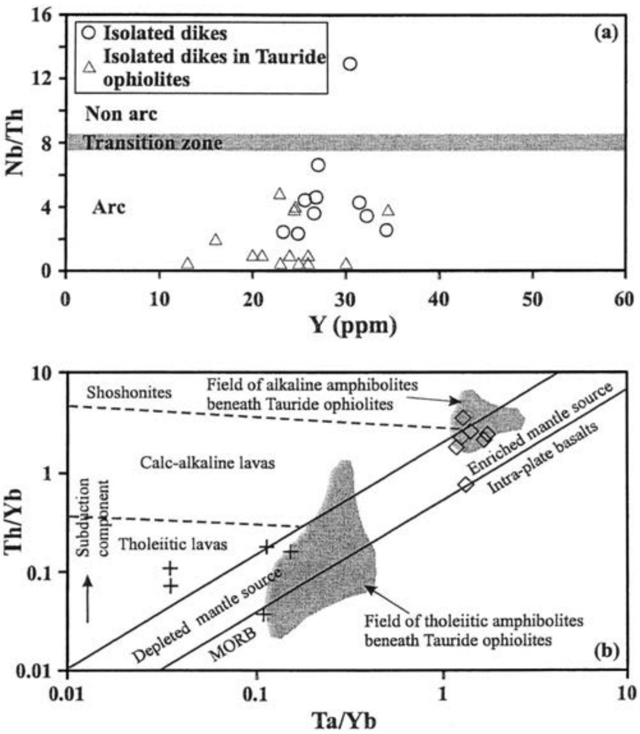

Fig. 11 - (a) Nb/Th versus Y diagram (after Jenner et al. 1991), showing the typically arc-like signature of the isolated diabase dikes. (b) Ta/Yb versus Th/Yb diagram (after Pearce, 1982) for the metamorphic sole rocks and isolated dikes of the Pınarbaşı ophiolite. Data for the metamorphic soles and mafic dikes from the Tauride ophiolites are the same as in Fig. 5.

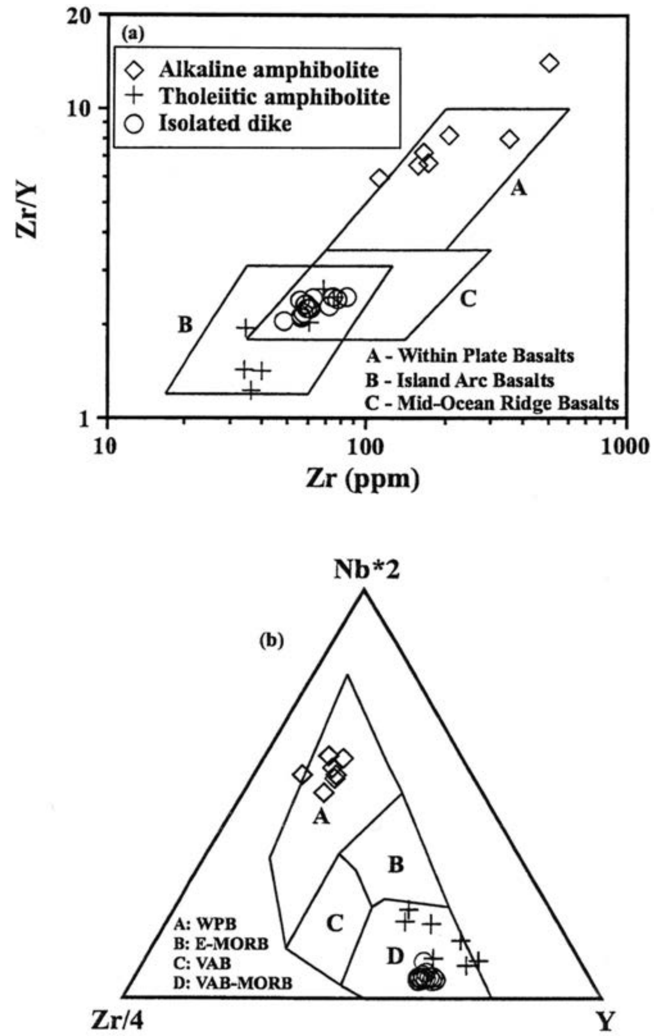

Fig. 12 - Tectonomagmatic discrimination diagrams for the metamorphic sole rocks and isolated diabase dikes of the Pınarbaşı ophiolite. (a) after Pearce (1979) and (b) after Meschede (1986).

duction zone (SSZ-type) between the Anatolides to the north and Tauride carbonate platform to the south (Fig. 13). There are number of lines of evidences, supporting that the ophiolites emplaced over the Tauride carbonate platform were derived from an oceanic basin located between the Tauride platform to the south and the Anatolides to the north. These are as follows: the Central Anatolian ophiolites may differ lithologically and chemically from those emplaced onto the Tauride platform. There are a number of isolated dismembered ophiolites, structurally above the Kırşehir and Niğde metamorphic massifs (Yalınız and Göncüoğlu, 1998; Floyd et al., 2000). The overall stratigraphy is as follow: the ophiolite begins with ultramafic rocks overlain by layered and isotropic gabbros, followed by plagiogranite, then dolerite dykes, pillow basalts and acidic extrusives. An epiophiolitic sediment of middle Turonian-early Santonian age is given by Yalınız (1996). Both ophiolites and overlying sediments were then intruded by postcollisional quartz monzonite dated at 81-67 Ma (Yalınız et al., 1999). Geochemical data indicate that the basalts and dolerites of the volcanic sequence are of IAT type, whereas the subsequent dolerite dikes have compositions more akin to N-MORB (Yalınız et al., 1996). The Tauride ophiolites display more intact ophiolite stratigraphy. A thick pile of residual mantle section dominated mainly by harzburgite are tectonically underlain by dynamothermal metamorphic soles exhibiting inverted metamorphic gradient from amphibolite to greenschist facies, well-preserved ultramafic and mafic cumulates with a thickness over 3 km, isotropic gabbros, basaltic pillow lavas and associated sediments. Isolated dolerite/diabase dikes intruded the Tauride ophiolites and their structurally underlying metamorphic soles. Both the basaltic rocks in the volcanic sequence and the isolated diabase dikes intruding ophiolites are of IAT type (Parlak and Delaloye, 1996; Parlak, 2000; Elitok, 2001; Çelik and Delaloye, 2003). Dilek and Whitney (1997) and Okay (1989) mentioned the presence of HP/LT metamorphics locally along the northern edge of the Bolkardağ platform and in Tavşanlı (Kütahya) region, suggesting that the leading edge of the Tauride platform was subducted and exhumed. Robertson (2002) suggests that if the Kırşehir/Niğde metamorphics was belonging to the Tauride platform, a large amount of continental crust would have to be subducted. There is a very scarce evidence of regional HP/LT metamorphism within the Kırşehir/Niğde metamorphic units. The geological setting and the geochemical features of the Tauride ophiolites suggest the existence of an oceanic basin from Late Triassic to Late Cretaceous located between Tauride platform to the south and the Anatolides to the north (Fig. 13).

The Neotethyan ophiolites in the eastern Mediterranean region are of supra-subduction zone type (Pearce et al., 1984; Robertson, 1998; 2002). The opening of the South Atlantic in the Early Cretaceous resulted in a very rapid convergence between Eurasia and Africa (119-95 Ma) in the Tethyan region (Dewey, 1988). This convergence regime originated the inception of the intraoceanic subduction in the Neotethyan ocean basins. During this intraoceanic subduction the oceanic crust, formed between the Late Triassic and the Early Cretaceous, was metamorphosed and accreted to the base of the overriding oceanic lithosphere, forming the metamorphic soles beneath the Neotethyan ophiolites between Yugoslavia and Oman. As subduction proceded, the supra-subduction zone type ophiolites were formed above the north dipping subduction zones in different oceanic basins of the Mediterranean region and followed by emplacement of nappes of ophiolites, metamorphic soles and ophiolitic mélanges, onto platforms. K-Ar isotopic age determinations on two amphibole separates from the metamorphic sole rocks at the base of the Pınarbaşı ophiolite yielded ages ranging from 102.2±2.9 to 107.3±3 Ma (Table 4). These ages are older than those of Mersin (Parlak and Delaloye, 1999; Dilek et al., 1999), Aladağ (Dilek et al., 1999), Lycian, Antalya and Beyşehir (Çelik et al., 2004) ophiolites determined by $^{40}Ar/^{39}Ar$ technique. These older ages determined by the K-Ar method may suggest the effects of excess Ar in the samples (Table 4) and should be treated by caution. We believe that if the samples had dated by $^{40}Ar/^{39}Ar$ method the effects of excess Ar would be eliminated and yielded more reliable ages. On the other hand, the present results overlap the time interval of the compressional regime between Eurasian and African plates (Dewey, 1988).

All the geochemical evidence suggests that the Pınarbaşı ophiolite was formed above a north-dipping subduction zone between the Taurides to the south and Anatolides to the north, similar to other ophiolites in the Tauride belt. During the intraoceanic subduction or thrusting, the SSZ-type volcanic rocks detached from the front of the over-riding Pınarbaşı ophiolite and the seamount type alkaline volcanic rocks from the top of the subducting plate entered into the subduction zone and metamorphosed up to amphibolite facies. These rocks were then accreted to the base of the Pınarbaşı ophiolite during obduction onto the Tauride platform. The geochemistry of the metamorphic sole rocks show that two types of protoliths were involved during subduction/accretion. The first one includes alkaline amphibolites showing within plate basalts (WPB) geochemical affinity whereas the second one consists of tholeiitic amphibolites with island arc tholeiite (IAT) affinity. The within plate alkali basalts were reported from the

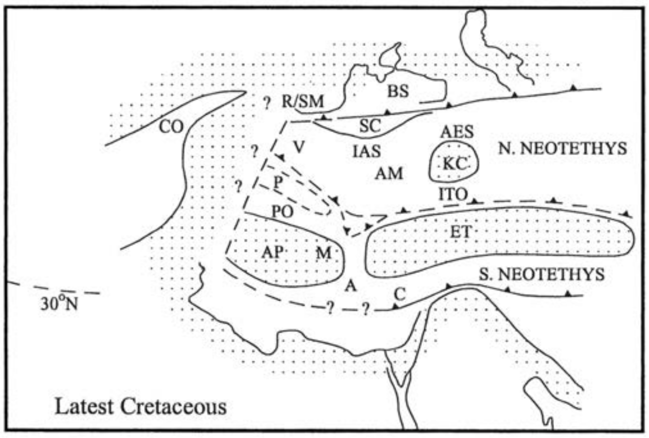

Fig. 13 - Simplified paleogeographic sketch map of the eastern Mediterranean during Late Cretaceous (from Robertson, 2002). Key to letters: A- Antalya, AES- Ankara-Erzincan suture zone, AM- Ankara Mélange, AP- Apulia, BS- Black Sea marginal basin, C- Cyprus, CO- Carpatian ocean, IAS- Izmir-Ankara suture zone, ITO- Inner Tauride ocean, K- Kırşehir/Niğde metamorphic massif, M- Menderes metamorphic massif, P- Pelagonian, PO- Pindos Ocean, R/SM- Rhodope/Serbo-Macedonian, SC- Sakarya metamorphic massif, V- Vardar.

Table 4 - K-Ar isotopic age results of the amphibolites from the metamorphic sole rocks.

Sample	$^{40}Ar_{rad}$, nl/g	% K	% $40Ar_{air}$	Age (Ma)
P217G	2.07	0.49	10.90	107.3 ± 3.0
P225A	1.72	0.43	11.40	102.2 ± 2.9

different part of the Neotethyan oceanic domains such as the Mersin ophiolite mélange (Parlak et al., 1995; Parlak and Robertson, 2004) and the North Anatolian ophiolitic mélange (Rojay et al., 2001). These rocks are Late Jurassic-Early Cretaceous in age and suggest the presence of a seamount which has been thought to be metamorphosed in amphibolite facies during intraoceanic subduction. The IAT type basaltic rocks are expected to be sited in the upper part of the overriding ophiolite pseudostratigraphy. These lavas could be interpreted as the protoliths for tholeiitic amphibolites that formed during the intraoceanic thrusting in the supra-subduction basin, during the closure of the Inner Tauride ocean in the Late Cretaceous. The age of IAT type volcanics were reported as early-middle Turonian to early Santonian by Yalınız et al. (2000b). The isolated dikes of the Pınarbaşı ophiolite are not observed intruding the metamorphic sole rocks. They are only seen in mantle tectonites. These dikes exhibit a subduction-related influence and can be interpreted as the product of the earliest stages of oceanic arc volcanism.

CONCLUSIONS

The field, geochemical and geochronological data obtained in this study suggest following conclusions:

(1) The Pınarbaşı ophiolite comprises three tectonic units represented, in ascending order, by the ophiolitic mélange, the metamorphic soles and the ophiolite unit. They exhibit similar geological, petrographical and geochemical features to ophiolites in the other parts of the Tauride belt. Therefore the Pınarbaşı ophiolite is believed to have been originated within the Inner Tauride ocean above a north-dipping subduction zone (SSZ-type) and obducted onto the Tauride platform in the Late Cretaceous.

(2) The isolated dikes intruding the mantle tectonites exhibit tholeiitic affinity. The major, trace and REE geochemistry of the dikes show that they formed in a subduction-related environment and indicate their derivation from an island arc tholeiite (IAT).

(3) The metamorphic sole rocks beneath the Pınarbaşı ophiolite crop out as thin slices beneath the sheared serpentinites and display inverted metamorphic gradient from amphibolite to greenschist facies. The rock types in the metamorphic soles are calcschists, epidote + plagioclase + amphibole schists, plagioclase + amphibole schists, amphibole schists, plagioclase amphibolites, amphibolites.

(4) The metamorphic sole rocks exhibit two distinct geochemical features. The first group is alkaline (Nb/Y = 1.5-2.6), whereas the second group is tholeiitic (Nb/Y = 0.05-0.22) in nature. The REE patterns, multi-element and tectonomagmatic discrimination diagrams suggest that the protholith of the first group is similar to within plate alkali basalts, whereas the second group is more akin to island arc tholeiitic basalts.

(5) The alkaline amphibolites were formed as a result of metamorphism of the seamount type basaltic rocks in intraoceanic subduction zone, whereas the tholeiitic amphibolites were formed as result of intraoceanic thrusting in a suprasubduction zone (SSZ) basin.

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