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Geochemistry and Significance of Mafic Dyke Swarms in the Pozantı-Karsantı Ophiolite (Southern Turkey)

OSMAN PARLAK

Çukurova Üniversitesi, Jeoloji Mühendisliği Bölümü, TR-01330 Balcalı, Adana - TURKEY
(e-mail: parlak@mail.cu.edu.tr)

Abstract: The Pozantı-Karsantı ophiolite, which is one of a number of the Late Cretaceous oceanic lithospheric remnants in southern Turkey, is situated in the eastern Tauride belt and consists of three distinct thrust sheets: an ophiolitic mélange, a metamorphic sole, and an ophiolitic stratigraphic sequence. These units (except the ophiolitic mélange) are intruded by isolated microgabbro-diabase dykes at all structural levels. The dykes from the lower crustal rocks (cumulates) are subalkaline in character and chemically similar to island arc tholeiitic basalts and basaltic andesites. They are enriched in some LIL elements (Rb, Ba, K and Sr) and depleted in HFS elements (Nb, Ti, Y) relative to N-MORB. The presence of positive Th and LIL anomalies and a negative Nb anomaly, relative to the other incompatible elements, are thought to represent a subduction zone component. Tectonomagmatic discrimination diagrams based on the immobile trace elements suggest a suprasubduction zone environment for the origin of the mafic dyke swarms. All the evidence indicates that the mafic dykes from the lower crustal rocks (cumulates) in the Pozantı-Karsantı ophiolite formed in the same geodynamic environment (suprasubduction zone) as their host rocks did in the north of Tauride-Anatolide block during Late Cretaceous in the Neo-Tethyan ocean.

Key Words: Isolated dyke, Geochemistry, Supra-subduction zone, Pozantı-Karsantı ophiolite, Southern Turkey

Pozantı-Karsantı Ofiyolitlerini Kesen Mafik Daykların Jeokimyası ve Önemi (Güney Türkiye)

Özet: Güney Türkiye'deki Geç Kretase yaşlı okyanusal litosfer kalıntılarından olan Pozantı-Karsantı ofiyoliti doğu Toroslarda yüzeylemektedir ve ofiyolitik melanj, metamorfik dilim ve ofiyolitik kayaçlardan oluşan üç farklı bindirme diliminden meydana gelmiştir. Ofiyolitik melanj haricindeki diğer birimler değişik yapısal seviyelerde izole mikrogabro-diyabaz daykları tarafından kesilmektedirler. Kümülat kayaçları kesen dayklar subalkalen karakterde olup kimyasal olarak ada yayı toleyitik bazalt ve bazaltik andezitlere benzerlik gösterirler. Bu kayaçlar N-tipi MORB'a göre bazı LIL elementlerce (Rb, Ba, K, Sr) zenginleştirilmiş buna karşın bazı HFS elementlerce (Nb, Ti, Y) de tüketilmişlerdir. Özellikle Th ve LIL elementlerin pozitif ve Nb'un negatif anomalileri dalma-batma zonu bileşenini göstermektedir. İz element içeriklerine göre hazırlanan Tektonomagmatik diskriminasyon diyagramları daykların okyanus içi dalma-batma zonu (Suprasubduction) üzerinde oluştuğunu işaret ederler. Bütün verilerin ışığı altında Pozantı-Karsantı ofiyolitindeki kümülatları kesen izole diyabaz dayklarının ofiyolitik kayaçlarla aynı jeodinamik ortamda (okyanus içi dalma-batma zonu üzerinde) Geç Kretase sırasında Neotetis okyanusunda Torid-Anatolid platformunun kuzeyinde oluştuğu söylenebilir.

Anahtar Sözcükler: İzole dayk, Jeokimya, Dalma-batma zonu üstü, Pozantı-Karsantı ofiyoliti, Güney Türkiye

Introduction

The origin of the eastern Mediterranean ophiolites is controversial. Several authors suggested that the Late Cretaceous ophiolitic fragments in the eastern Mediterranean were formed in an arc-related (suprasubduction zone) tectonic environment (Pearce *et al.* 1984; Robertson 1994; Yalınız *et al.* 1996; Parlak *et al.* 1996, 2000), *whereas others argued that generation of the ophiolites occurred along a mid-ocean ridge system in the eastern Mediterranean (Lytwyn & Casey 1995; Dilek et al. 1999).* Juteau (1980) divided Turkish ophiolites into three belts based on their geographic-tectonic positions, the degree of metamorphism produced either in an oceanic setting or during the obduction process onto carbonate platforms, and their ophiolite pseudostratigraphy. These belts are referred to as the Northern Ophiolite Belt, Southern Ophiolite Belt and Tauride Ophiolite Belt. Approximately east-west trending Tauride belt ophiolites (from west to east: Lycian nappes, Antalya, Beyşehir-Hoyran nappes, Mersin, Alihoca, Pozantı-Karsantı and Pınarbaşı) in southern Turkey are located on both sides of the Tauride calcareous axis and are mainly characterized by sub-ophiolitic metamorphic rocks, ophiolitic mélange and thick (> 3 km) ultramafic-mafic cumulate rocks (Figure 1a) (Juteau 1980; Dilek & Moores 1990; Parlak 1996; Parlak *et al.* 2000; Dilek *et al.* 1999). These ophiolites are extensively intruded at all structural levels, with the exception of the ophiolitic mélange and Tauride platform rocks, by numerous mafic isolated diabase dykes. This indicates that dyke intrusions postdate the formation of the subophiolitic metamorphics and ophiolite but predate its final obduction onto the Tauride platform (Çakır *et al.* 1978; Thuizat *et al.* 1978; Parlak *et al.* 1995; Lytwyn & Casey 1995; Parlak & Delaloye 1996; Dilek *et al.* 1999).

The structure, petrology and geochronology of the mafic dyke swarms in some of the Tauride belt ophiolites (Mersin, Pozantı-Karsantı and Alihoca) have recently been studied by a number of researchers. Mafic dykes from all the structural levels of the Mersin ophiolite (Parlak *et al.* 1995; Parlak & Delaloye 1996; Dilek *et al.* 1999), mafic dykes from the mantle peridotite and metamorphic sole of the Pozantı-Karsantı ophiolite (Lytwyn & Casey 1995; Dilek *et al.* 1999) and mafic dykes from the mantle peridotites and the ultramafic cumulates in the Alihoca ophiolite (Dilek *et al.* 1999) show geochemical characteristics of island arc tholeiites (IAT). ^{40}Ar/^{39}Ar geochronology of these dykes yielded ages from 89.6±0.7 to 63.8±0.9 (Parlak & Delaloye 1996) and from 91.3±0.4 to 91.0±0.8 Ma (Dilek *et al.* 1999) for the Mersin, from 91.7±0.6 to 90.3±1.0 Ma for the Pozantı-Karsantı (Dilek *et al.* 1999), and 90.6±2.1 Ma for the Alihoca ophiolites.

This paper deals with the geochemistry of the mafic dykes cutting the lower crustal rocks (ultramafic-mafic cumulates) of the Pozantı-Karsantı ophiolite in southern Turkey to compare with previously published data from the Tauride belt and hence to explain the geodynamic environment of dyke generation in the Neotethyan ocean during Cenomanian-Turonian.

Geology of the Pozantı-Karsantı ophiolite

The Pozantı-Karsantı ophiolite, one of the Late Cretaceous oceanic lithospheric remnants in southern Turkey, is located in the western part of the eastern Tauride belt (Figure 1b) (Juteau 1980; Dilek & Moores 1990; Polat & Casey 1995). The Pozantı-Karsantı ophiolite, bounded by the left lateral Ecemiş fault to the west, the Tauride platform carbonates to the north and east, and unconformably overlain by the Neogene sediments to the south, covers an area of approximately 1300 km^2 (80 km in length and 25 km in width) (Bingöl 1978; Çakır 1978; Çataklı 1983; Tekeli *et al.* 1983; Polat & Casey 1995) (Figure 1b).

Ophiolite-related rock assemblages are characterized, structurally from bottom to top, by ophiolitic mélange, dynamothermal metamorphic sole, and oceanic lithospheric section (Figure 2). The late Campanian to Maastrichtian unmetamorphosed ophiolitic mélange is composed of a variety of igneous, metamorphic and sedimentary blocks structurally dispersed in a serpentinitic to pelitic matrix (Tekeli *et al.* 1983; Polat & Casey 1995). The Mid to Upper Cretaceous dynamothermal metamorphic sole displays a typical inverted metamorphic sequence grading from amphibolite facies, directly beneath the highly sheared harzburgitic tectonite, to lower greenschist facies near the mélange contact (Thuizat *et al.* 1978; Lytwyn & Casey 1995). The Pozantı-Karsantı ophiolite is composed of harzburgitic to dunitic tectonites, ultramafic and mafic cumulates, isotropic gabbro, sheeted dykes and pillow lavas (Bingöl 1978; Çakır 1978; Çataklı 1983). Swarms of microgabbro and diabase dykes cut the ophiolitic and the metamorphic sole units at different structural levels.

Petrographic Summary

The primary mineral assemblages of the dykes have been modified by hydrothermal alteration processes characterized by hornblende (generally observed rimming relict clinopyroxenes) with albite, chlorite, sericite and epidote. The dykes generally exhibit intergranular to ophitic textures and consist mainly of plagioclase (60-65%), clinopyroxene (30-35%), amphibole (3-5%) and Fe-Ti oxides (≈1%). The dominantly holocrystalline texture and presence of very weak chilled margin features of these diabase dykes suggest that when dyke injection occurred the main ophiolite body was still hot. This observation is supported by the limited time interval (2-3 my) between the formation of the metamorphic soles and beginning of dyke emplacement in the Mersin and

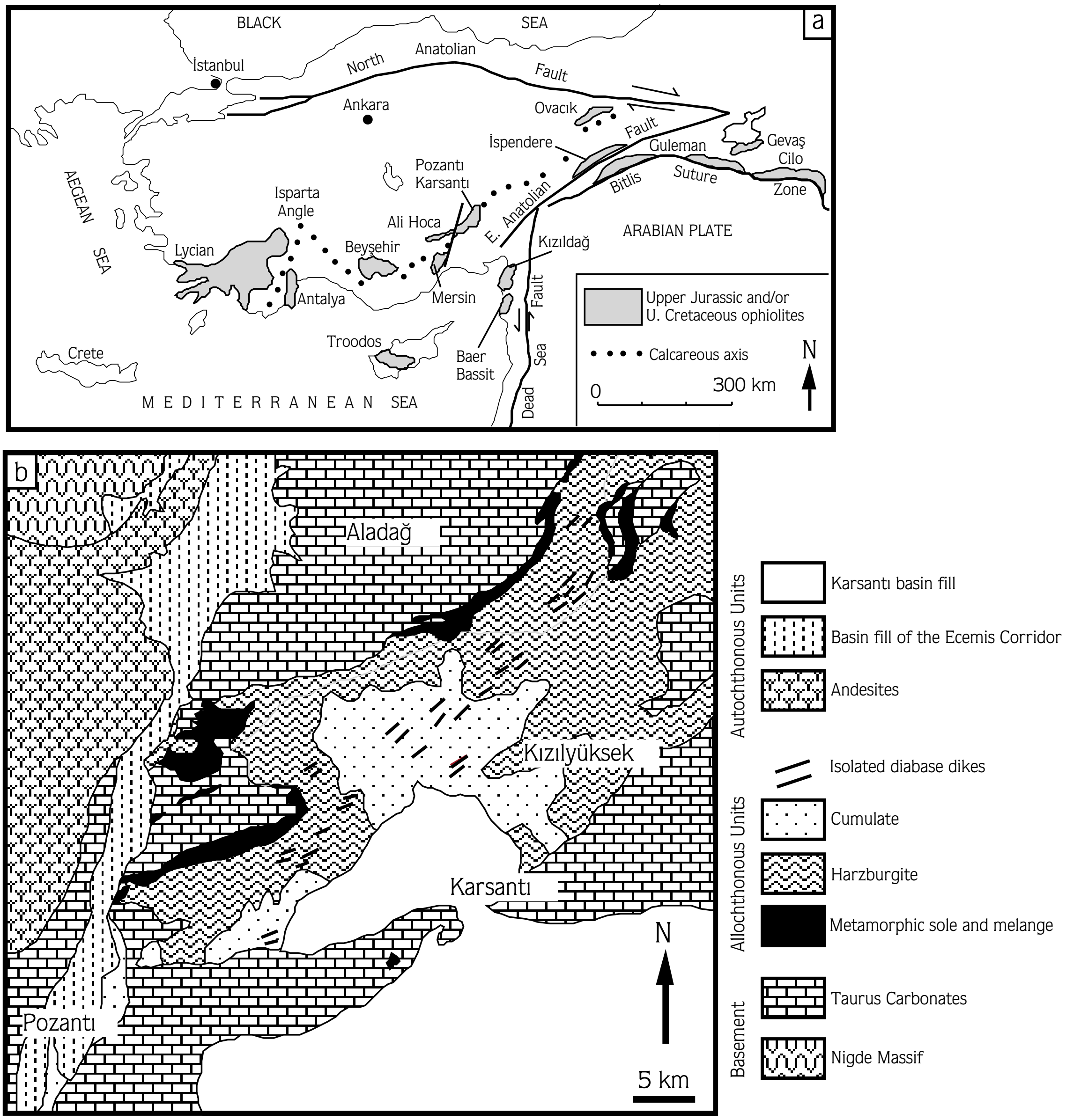

Figure 1. (a) Distribution of ophiolitic fragments in southern Turkey (Modified from Dilek & Moores 1990). (b) Geological map of the Pozantı-Karsantı ophiolite (Bingöl 1978).

Pozantı-Karsantı ophiolites (Parlak & Delaloye 1996; Dilek *et al.* 1999).

Analytical Method

A total of 11 samples from the isolated dykes were analysed for major and trace element contents. Major and trace element analyses were carried out at the University of Geneva. Major elements were determined by XRF spectrometer on glass beads fused from ignited powders to which $Li_2B_4O_7$ was added (1:5), in a gold-platinum crucible at 1150°C. Trace elements were analysed on powder pressed-pellets by the same method.

Geochemistry

The results of major and trace element analyses for the isolated diabase dykes of the Pozantı-Karsantı ophiolite are given in the Table 1. They are represented by high SiO_2 (44-53 *wt*%), MgO (5-11 *wt*%) and low TiO_2 (0.4-

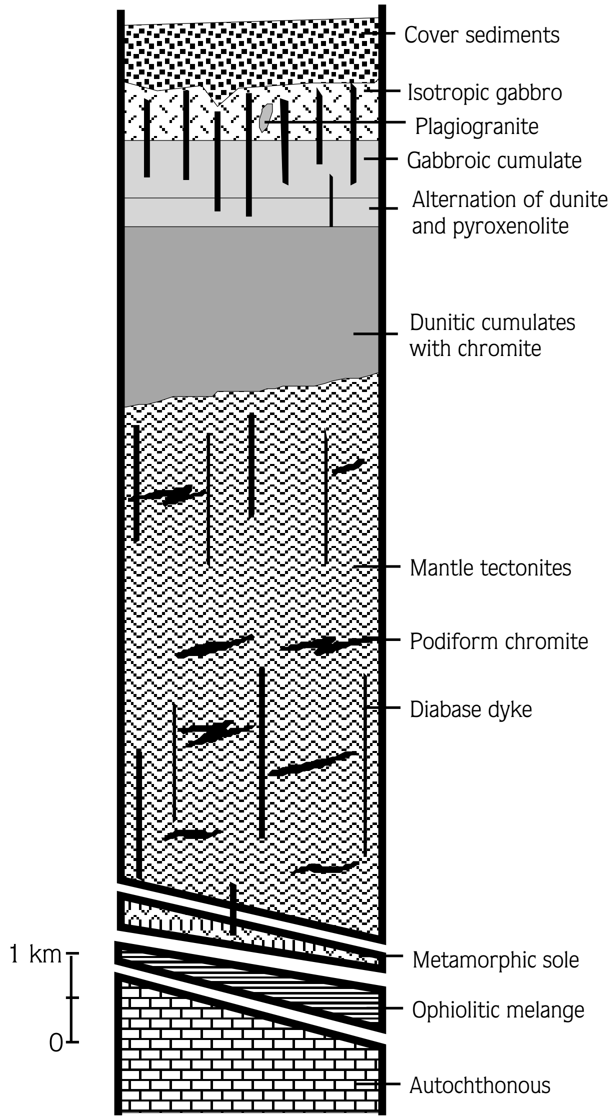

Figure 2. Synthetic log of the Pozantı-Karsantı ophiolite (Bingöl 1978).

1 *wt* %), MnO (0.12-0.19 *wt* %) and P_2O_5 (0.03-0.1 *wt* %). Trace element contents of the dykes vary in Zr (18-69 ppm), Nb (1-4 ppm), Y (13-30 ppm), V (255-375 ppm), and Hf (1-8 ppm). Some of the incompatible trace element ratios are as follows: Nb/Y= 0.04-0.25 [characteristic of subalkaline/tholeiitic basalts, Winchester & Floyd (1977)], Zr/Nb= 5-69, Zr/Y= 1.1-3.1, Ti/V= 7-20 (Table 1). The diabase dykes from the Pozantı-Karsantı ophiolite plot within the subalkaline/tholeiite field of Irvine & Baragar (1971), and are represented by subalkaline basaltic and basaltic-andesitic composition based on the SiO_2 versus incompatible trace element ratio Zr/TiO_2 diagram (Figures 3a & b) (Winchester & Floyd 1977). They exhibit variable degrees of low-grade secondary alteration effects that especially caused mobility in the large-ion-lithophile (LIL) elements (cf. Hart 1970; Humphris & Thompson 1978). The secondary alteration and element mobility are further confirmed by the wide variation in loss-on-ignition (LOI) values (Table 1), reflecting the contribution by secondary hydrated and carbonate phases. Selected incompatible elements such as Zr, Nb, Y, V and Ti have been considered relatively immobile during alteration processes and are thought to be reliable candidates to characterize petrological affinities and the past tectonic environment of volcanic suites (Pearce & Cann 1973; Floyd & Winchester 1975; Pearce & Norry 1979; Meschede 1986).

The Y and Zr contents of the isolated dykes from the Pozantı-Karsantı ophiolite crustal section are plotted against TiO_2 in Figures 4a and b together with the dykes from the Mersin ophiolite (Parlak & Delaloye 1996) and Pozantı-Karsantı ophiolite (Lytwyn & Casey 1995). The diabase dykes reported by Lytwyn & Casey (1995) are from the metamorphic sole and mantle tectonites.

To compare all these data with present-day analogous data, the data from the Vanuatu island arc basalts (IAB) and North Fiji back-arc-basin basalts (BABB) are also plotted (Figure 4). These diagrams clearly show that the dykes from the Pozantı-Karsantı and the Mersin ophiolites are well correlated with arc compositions rather than back-arc representatives. On the Ti/Zr versus Zr diagram (Figure 4c) similar patterns are exhibited for the geochemical characteristics for both Mersin and Pozantı-Karsantı ophiolites. A normal-MORB normalized spider diagram of the dykes is presented in Figure 5. It shows an enrichment of LIL (e.g. Th, Rb, Ba, K) elements compared to HFS elements, confirming the subduction-related character of the isolated dykes of the Pozantı-Karsantı ophiolite. One of the most conspicuous features of this diagram is the positive anomaly for Th and negative anomaly of Nb (Figure 5). Note that Th enrichment and Nb depletion relative to other incompatible elements are considered to represent a subduction zone component (Wood 1980; Pearce 1983). Chemical discrimination for the tectonomagmatic environment of dyke rocks from the Pozantı-Karsantı and Mersin ophiolites, using selected geochemical discrimination diagrams based on immobile elements, are presented in Figure 6. All these diagrams are consistent

Table 1. Major and trace element analyses of the dyke swarms cutting the lower crustal rocks (ultramafic-mafic cumulates) of the Pozantı-Karsantı ophiolite (Southern Turkey).

Sample Wt %	Y-5	H-5	H-9	H-11	H-15	H-17a	H-17b	H-21	H-23	H-27	H-28
SiO_2	52.38	50.45	45.41	44.22	51.25	50.91	50.04	44.44	53.36	51.60	52.27
TiO_2	0.37	0.86	0.88	1.06	0.87	0.89	0.88	0.64	0.74	0.92	0.95
Al_2O_3	11.37	16.17	14.63	15.25	15.67	15.64	15.71	17.17	15.82	15.80	15.96
FeO*	10.43	9.34	9.50	10.20	9.92	9.77	9.92	7.32	9.64	10.75	10.31
MnO	0.19	0.16	0.15	0.17	0.17	0.17	0.17	0.12	0.17	0.18	0.17
MgO	11.29	7.34	6.87	5.92	6.92	6.95	7.05	4.96	5.40	6.16	6.25
CaO	11.00	10.40	19.08	18.90	10.14	10.00	10.29	21.16	7.28	8.84	10.44
Na_2O	0.83	3.05	0.15	0.33	3.35	3.36	3.03	0.13	5.00	3.63	2.54
K_2O	0.10	0.47	0.03	0.03	0.35	0.24	0.25	0.01	0.50	0.36	0.25
P_2O_2	0.03	0.09	0.09	0.10	0.08	0.08	0.08	0.05	0.11	0.08	0.09
LOI	2.33	2.14	3.61	3.50	1.53	2.35	2.22	4.21	2.23	1.92	1.05
Total	100.31	100.47	100.40	99.68	100.24	100.35	99.64	100.22	100.24	100.24	100.28
ppm											
Nb	4	1	2	2	1	1	2	1	1	1	2
Zr	18	53	53	65	51	52	53	32	69	52	57
Y	16	23	20	21	25	26	24	13	30	23	26
Sr	78	196	15	14	163	216	187	9	402	199	127
U	2	2	3	5	2	2	2	4	2	2	2
Rb	3	9	2	1	7	3	4	2	9	7	5
Th	2	2	2	2	2	2	2	2	2	2	2
Pb	22	10	18	16	10	7	12	15	8	12	13
Ga	13	16	14	15	18	17	18	21	16	18	18
Ni	144	81	60	44	47	41	45	37	35	40	39
Co	55	42	47	45	38	39	43	39	36	46	36
Cr	619	562	171	600	126	99	136	224	59	29	100
V	308	288	286	312	309	325	325	255	296	375	321
La	4	4	4	4	4	4	4	6	4	4	4
Ce	3	6	3	9	6	15	10	3	6	8	15
Nd	4	6	5	12	6	13	9	8	5	7	13
Ba	58	51	29	20	29	70	49	23	49	9	56
Hf	8	7	5	3	6	6	7	1	7	7	6
Sc	83	45	61	55	48	61	49	51	36	30	46
Nb/Y	0.3	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.1
Ti/V	7.2	17.9	18.4	20.4	16.8	16.4	16.2	15.1	15.1	14.7	17.7
Zr/Nb	4.5	53.0	26.5	32.5	51.0	52.0	26.5	32.0	69.0	52.0	28.5
Zr/Y	1.1	2.3	2.7	3.1	2.0	2.0	2.2	2.5	2.3	2.3	2.2

Total Fe is expressed as FeO*

with an island arc geodynamic setting, suggesting a suprasubduction zone origin during the melt injection into the already formed oceanic lithosphere.

Discussion and Implications

Lavas that erupted at destructive plate boundaries are commonly considered to be derived from mantle sources previously more depleted than the sources of mid-ocean ridge basalts (MORB), and are subsequently enriched by a subduction component in island arcs (Knittel & Oles 1995). The assumption of previously depleted sources is supported by the presence of harzburgites at the inner trench walls of several island arcs (Bonatti & Michael 1989) and the eruption of boninites, which undoubtly are derived from very depleted sources (Crawford *et al.* 1989). Magnesian olivine ($Fo_{92\text{-}94}$), Cr-rich chromite (Cr# >0.65) in primitive IAB and the low abundances of HFS elements confirm the initially depleted sources (Woodhead *et al.* 1993).

Lytwyn & Casey (1995) and Dilek *et al.* (1999) suggested two distinct tectonic environments such as the mid-ocean ridge system for the main ophiolite body and the island arc environment for the dyke emplacement during the evolution of the Pozantı-Karsantı ophiolite. However, Parlak & Höck (1998) and Parlak *et al.* (2000)

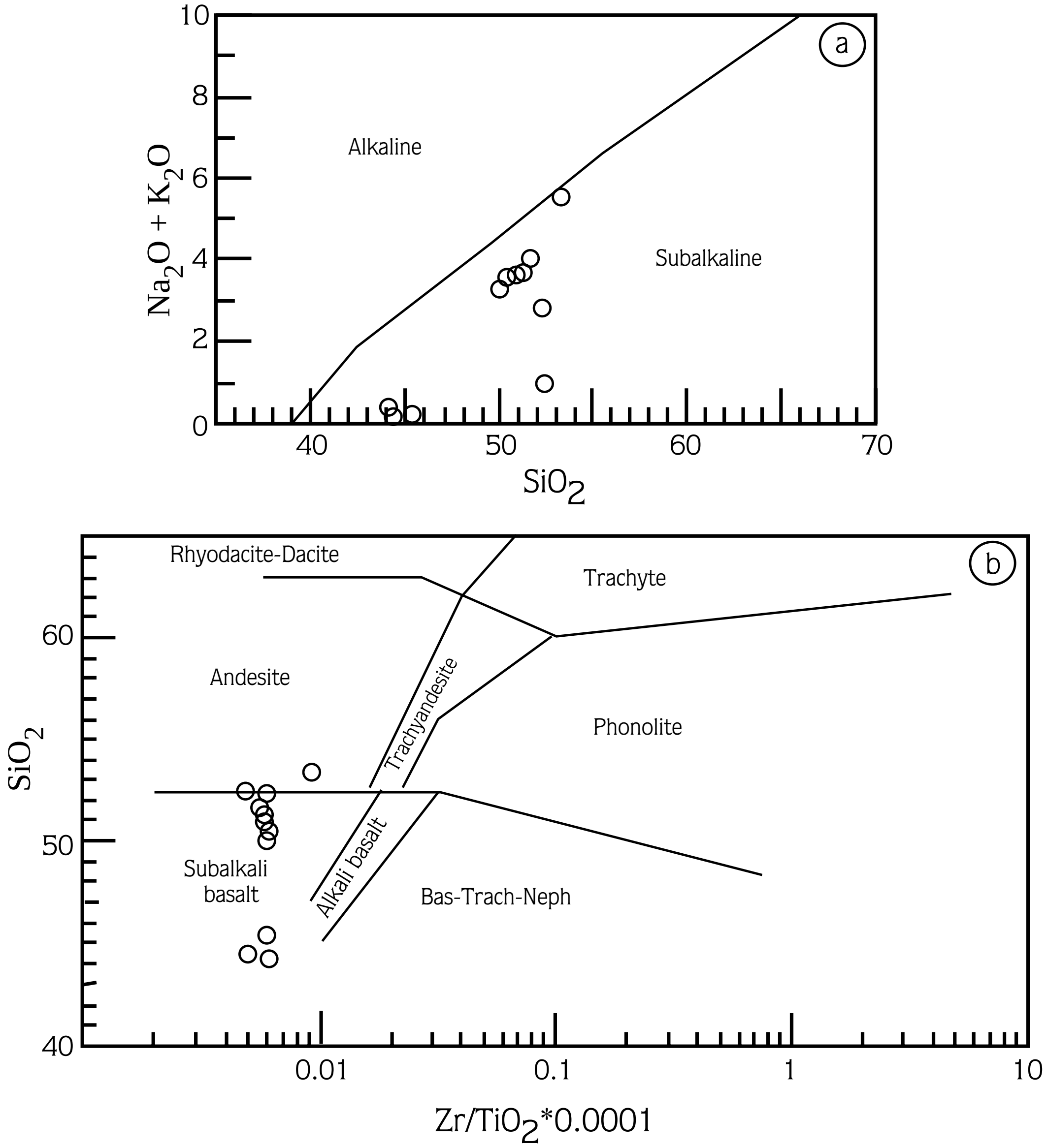

Figure 3. (a) Alkali-silica plots of the dyke rocks (after Irvine & Baragar 1971). (b) SiO_2 versus Zr/TiO_2 diagram showing the field of the dykes in the Pozantı-Karsantı ophiolite (after Floyd & Winchester 1978).

suggested an arc-like environment (suprasubduction) for the origin of the Pozantı-Karsantı ophiolite using data from the ultramafic and mafic cumulate rocks. Moreover, a suprasubduction zone origin for the eastern Mediterranean ophiolites has been suggested in other studies (Pearce *et al.* 1984; Robertson 1994; Parlak 1996). Thus, the mid-ocean ridge geodynamic environment of origin for the Pozantı-Karsantı ophiolite is not reliable in the light of both the eastern Mediterranean tectonic frame and the geochemistry of ophiolites in general.

Fine-grained doleritic to gabbroic dykes cutting the basal metamorphic sole and the mantle tectonites in the Pozantı-Karsantı ophiolites are geochemically similar to the tholeiites and basaltic andesites of island arc affinities (Lytwyn & Casey 1995). In this study, the dykes intruding the lower crustal section (both ultramafic and mafic cumulates) of the Pozantı-Karsantı ophiolite exhibit similar geochemical character to the Pozantı-Karsantı and the Mersin ophiolites (Figures 4, 5 & 6). All the lines of evidence in this and previous studies show that in the north of the Anatolide-Tauride platform the Pozantı-Karsantı ophiolite originated at the beginning of the Late Cretaceous in a suprasubduction zone tectonic setting related to the north-dipping subduction of the northern branch of the Neo-Tethyan ocean. This intra-oceanic subduction led to the formation of a metamorphic sole followed by dykes intruding both the metamorphic sole and the oceanic crust. The Pozantı-Karsantı ophiolite continued to accrete mélange after the dyke emplacement and was finally obducted over the Tauride platform during Late Cretaceous or Early Paleocene time (Lytwyn & Casey 1995; Polat & Casey 1995). The geochemistry of the dyke rocks suggests that the primary magma intruding the Pozantı-Karsantı ophiolite is compositionally similar to those observed in modern island arc tholeiitic sequences.

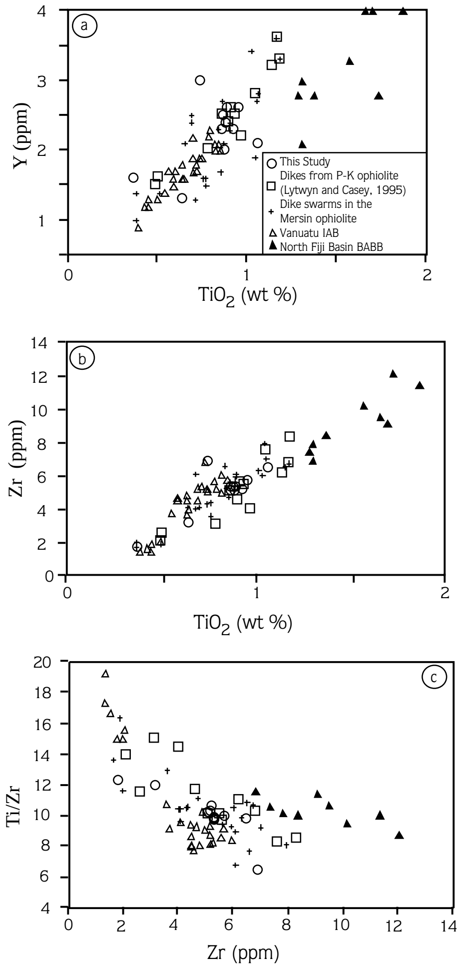

Figure 4. (a) Y and (b) Zr versus TiO_2 (c) Ti/Zr versus Zr plots of the mafic dyke swarms in the Pozantı-Karsantı ophiolite. Data for IAB and BABB are from Knittel & Oles (1995). Data from the Pozantı-Karsantı and the Mersin ophiolite are from Lytwyn & Casey (1995) and Parlak & Delaloye (1996), respectively.

Acknowledgements

The author thanks Prof. Michel Delaloye and Fabio Capponi for XRF analysis in the Mineralogy Department at the University of Geneva (Switzerland). Dr Peter floyd and an anonymous reviewer are greatly acknowledged for their critical and constructive comments. This study is supported by Çukurova University Research Foundation (Project Number: MMF.2000.22).

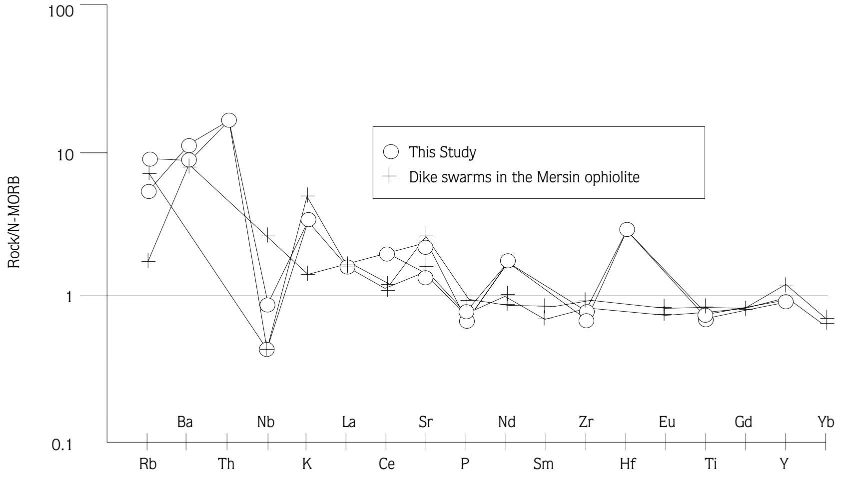

Figure 5. Primitive Mantle normalized trace element patterns of the dykes from the Pozantı-Karsantı and the Mersin ophiolites (Parlak & Delaloye 1996). Primitive Mantle values are from Sun & McDonough (1989).

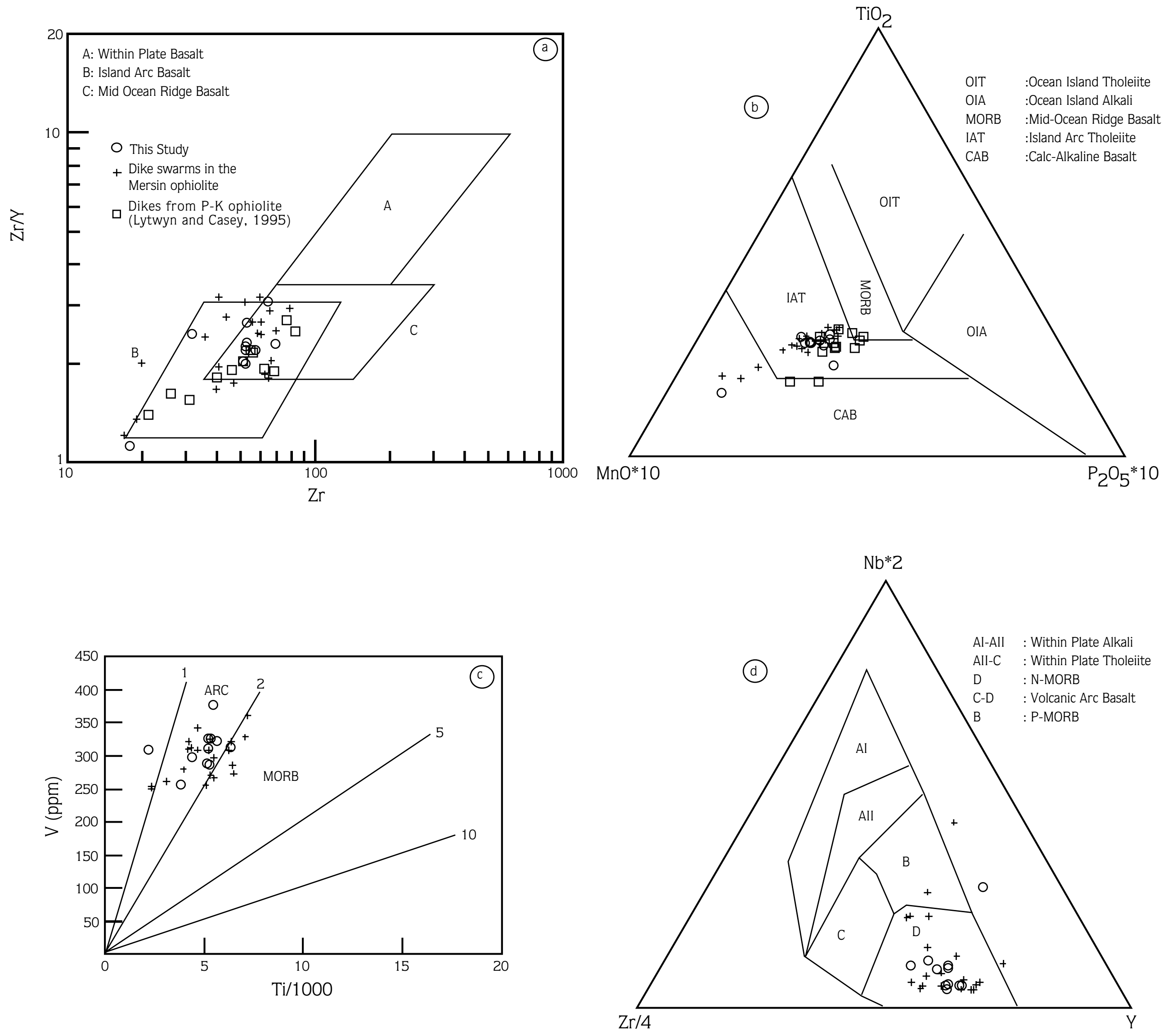

Figure 6. Selected tectonomagmatic discrimination diagrams for the mafic dykes of the Pozantı-Karsantı ophiolite (a) after Pearce & Norry (1979) (b) after Mullen (1983) (c) after Shervais (1982) (d) after Meschede (1986).

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Received 06 March 2000; revised typescript accepted 15 June 2000