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Tectonic Implications of Some Cretaceous Pillow Basalts from the North Anatolian Ophiolitic Mélange (Central Anatolia-Turkey) to the Evolution of Neotethys

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Abstract: The most widespread blocks within the North Anatolian ophiolitic mélange of central Anatolia (Turkey) are ophiolitic fragments, Jurassic-Cretaceous carbonate blocks and pillow basalts. The blocks of pillow basalts have an immobile trace-element geochemistry that is characteristic of ocean-island alkali basalts. An N-MORB-normalized spider diagram shows a distinctive enrichment of most incompatible trace elements and exhibits a far greater range of absolute abundances than N-MORB. Selected incompatible-element contents and ratios of basalts show high Ba/Nb (~8), low Zr/Nb (~5) and low La/Nb (~0.5) relative to N-MORB. The presence of thin-shelled "*Protoglobigerina*" and *Cadosina* associated with miliolids and epistominid foraminifers indicates that the age of the pink biomicritic carbonates deposited between the pillow basalt lobes is within the Callovian–Hauterivian interval. Collectively, these results support the presence of a seamount on the Neotethyan oceanic crust and prove the presence of an older oceanic crust along the northern branch of Neotethys.

Key Words: Seamount, Geochemistry, Callovian-Hauterivian Interval, Tethys, Ankara Mélange

Kuzey Anadolu Ofiyolitik Melajına ait bazı Kretase Yastık Bazaltlarının Neotetis'in evrimindeki tektonik anlamı (Orta Anadolu, Türkiye)

Özet: Orta Anadolu'da yeralan Kuzey Anadolu Ofiyolitik Melanjı içinde ofiyolitik bloklar Jura-Kretase karbonat blokları ve yastık bazalt blokları en yaygın olanlarıdır. Yastık bazalt blokları, hareketsiz iz-elementleri jeokimyası açısından okyanus adası alkali bazaltları özelliğini gösterir. Bu bazaltlar, N-MORB örümcek diyagramı uyumsuz iz elementleri açısından belirgin bir zenginleşme göstermekte ve N-MORB'a nazaran oldukça geniş bir bolluk aralığı sunmaktadır. Seçilmiş uyumsuz-element içeriği ve bazalt oranları N-MORB'a nazaran yüksek Ba/Nb (~8), düşük Zr/Nb (~5) ve düşük La/Nb (~0.5) oranları gösterir. Miliolid ve epistominid foraminiferlerle birlikte ince kabuklu "*Protoglobigerina*"lerin ve *Cadosina* varlığı, yastık lav arası pembe renkli biyomikrit dolgularının yaşının Kalloviyen-Hotriviyen olduğunu göstermektedir. Bu sonuçlar toplu olarak değerlendirildiğinde, Neotetis okyanusal kabuğunu kesen bir denizaltı volkanının ve dolayısı ile Neotetis'in kuzey kolunda daha yaşlı bir okyanus kabuğunun varlığı ortaya çıkmaktadır.

Anahtar Sözcükler: Denizaltı tepesi, Jeokimya, Kalloviyen-Hotriviyen Aralığı, Tetis, Ankara Melanjı

Introduction

The evolution of Tethys is well recorded in Anatolia, especially along the İzmir-Ankara-Erzincan suture zone (İAES), which connects to the Vardar (Macedonia-Greece) and Sevan-Akera (Armenia) zones (Figure 1). The so-called "*Ankara Mélange*" belt, which was misinterpreted as a fragment of the Taurides (Bailey & McCallien 1950), is one of the cornerstones of the İAES necessary to understanding the evolution of Tethys (Figure 1).

The Cretaceous ophiolitic mélanges of the "Ankara Mélange" along the İAES, named the North Anatolian ophiolitic mélange (NAOM), are chaotic, tectono-sedimentary mixtures of various blocks of different ages and origins which were embedded in an intensely sheared, brecciated and partially mylonitized matrix associated with Cretaceous clastic basins. The chaotic nature and complex deformational style of the NAOM has not yet allowed precise recognition of the origin of Cretaceous ophiolitic mélanges along the İAES. The most

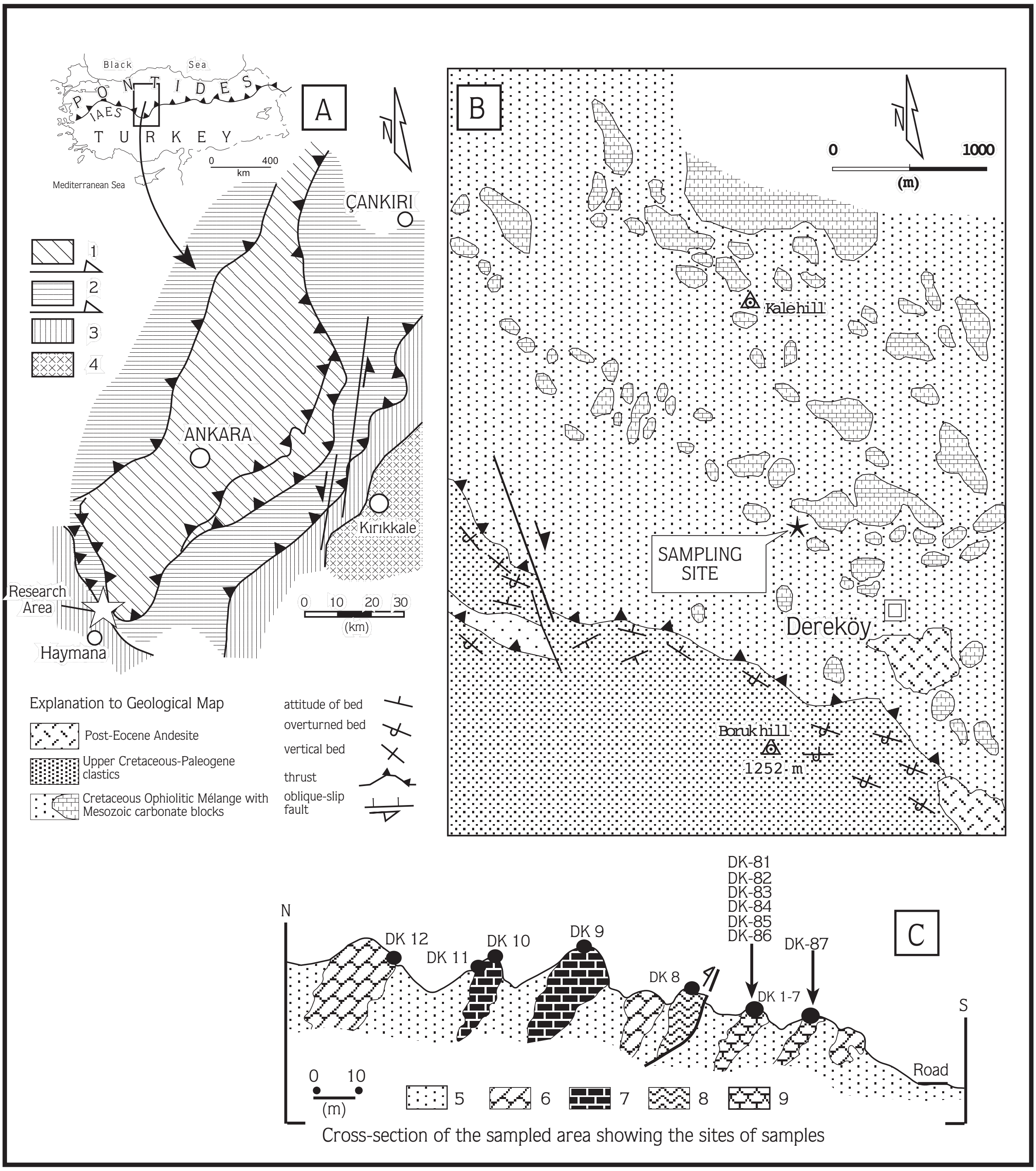

Figure 1. **(A)** Tectonic map showing the main tectonic elements along the Mesozoic accretionary prism in the Ankara region (modified from Boccaletti *et al.* 1966; Çapan & Buket 1975; Akyürek *et al.* 1984; Koçyiğit 1987). **(B-C)** Geological map (B) with a cross-section of the sampled area (C), showing the sample sites within the Cretaceous ophiolitic mélange, SW Ankara (Turkey). 1- Triassic complex, 2- Cretaceous ophiolitic mélange (NAOM), 3- Upper Cretaceous-Paleogene flysch, 4- Upper Cretaceous-Paleogene granitoids, 5- Matrix of the ophiolitic mélange, 6- recrystallized, brecciated Mesozoic limestones, 7- radiolaria-bearing Cretaceous limestones, 8- brecciated Jurassic limestones, 9- sampled pillow basalts, İAES; southern limit of İzmir-Ankara-Erzincan suture zone.

widely distributed blocks within the NAOM are the ophiolitic fragments, Jurassic-Cretaceous carbonate and pillow basalt blocks. The pillow basalts are found as isolated, detached blocks, or as blocks closely associated with radiolarites, or alternating with radiolarites and rarely with fossiliferous carbonates in the NAOM – from Çankırı to the Haymana region (e.g., Boccaletti *et al.* 1966; Akyürek *et al.* 1984; Çapan & Floyd 1985; Floyd 1993; Rojay *et al.* 2001). Previous research suggested that the majority of the pillow basalts represent relicts of a seamount (Çapan & Floyd 1985; Floyd 1993; Tüysüz *et al.* 1995; Rojay *et al.* 2001) and provides an important advance in the understanding the evolution of the northern branch of Neotethys.

Dating the ophiolitic mélanges was attempted by bracketing them between dated accretionary basins situated structurally above, and dated accreted ophiolitic slices situated structurally below (Blumenthal 1948; Boccaletti *et al.* 1966; Norman 1973; Batman 1978; Akyürek 1981; Çapan 1981; Ünalan 1981; Koçyiğit *et al.* 1988; Koçyiğit 1991; Rojay 1995; Rojay & Süzen 1997), and by dating the ages of radiolarite and radiolaria-bearing limestone blocks (Bragin & Tekin 1996). Yet undated pillow basalts and their ophiolitic base, and geochemical studies on these, cannot alone define the real picture of the evolution of Central Anatolian mélange terrain (Tankut 1984, 1990; Çapan & Floyd 1985; Tankut & Gorton 1990; Floyd 1993; Tüysüz *et al.* 1995).

This paper aims first at filling a gap in our knowledge pertaining to the dating of Tethyan oceanic crust by dating some pillow basalts within the Cretaceous ophiolitic mélange terrain in central Anatolia (Turkey), and second at determining the original tectonic environment prior to mélange development in order to constrain plate-tectonic models.

Data

Tectonically detached blocks of pillow basalts in the Cretaceous ophiolitic mélange were sampled from south of Ankara (Turkey) (Figure 1) where pelagic calcareous sediments have been trapped and accumulated between the lobes of the pillows (Figure 2). The dark purple pillow basalts have lobes up to 37 cm in diameter that are crosscut by calcite veins (Figure 2).

Petrography

Many of the basalt samples are strongly overprinted by secondary assemblages produced during initial ocean-floor hydrothermal alteration. However, relict features include the following primary textures: commonly vesicular, quenched-textured, and aphyric to weakly porphyritic texture with mainly plagioclase and subordinate clinopyroxene as phenocryst phases. In most thin sections, primary mineral phases and magmatic textures are strongly overprinted by low-grade secondary minerals, such as albite, chlorite, epidote, quartz, calcite, actinolite and iron oxides, indicative of greenschist-facies conditions. All of the basalts are invariably altered and replaced by the low-grade secondary assemblages.

Geochemistry

Relatively less altered samples of basalt were selected using the petrographic microscope, and later analyzed for major and selected trace elements (Table 1). All samples were analyzed on an ARL 8420 X-ray fluorescence spectrometer at the Department of Earth Sciences, Keele University (U.K.) and calibrated against both international and internal Keele standards of appropriate compositions.

Geochemical Discrimination

The samples show some degree of low-grade secondary alteration and as such can be expected to have suffered selected element mobility, especially involving the large-ion-lithophile (LIL) elements (e.g., Humphris & Thompson 1978). The wide range of loss-on-ignition (LOI), high CaO and low SiO_2 (Table 1) is a crude measure of the degree of alteration and reflects contributions by secondary hydrated and carbonate phases. Therefore, the following chemical assessments and tectonic-setting discrimination depend mainly on the high-field-strength elements (HFSE) that tend to be less mobile under low-grade alteration conditions (e.g., Humphris & Thompson 1978).

Using relatively immobile trace elements, the basalts show the following broad characteristics: (a) a high abundance of incompatible trace elements (e.g., Nb= 20), (b) high Nb/Y ratios (≅ 1) characteristic of alkaline basalts (Figure 3a) (Winchester & Floyd 1977), and (c) low Zr/Nb (≅ 5), La/Nb (≅ 0.5), TiO_2/Zr (≅ 86), P_2O_5/Ce ratios (≅ 49), and high Ba/Nb ratios (≅ 9.6) (Table 2). Overall,

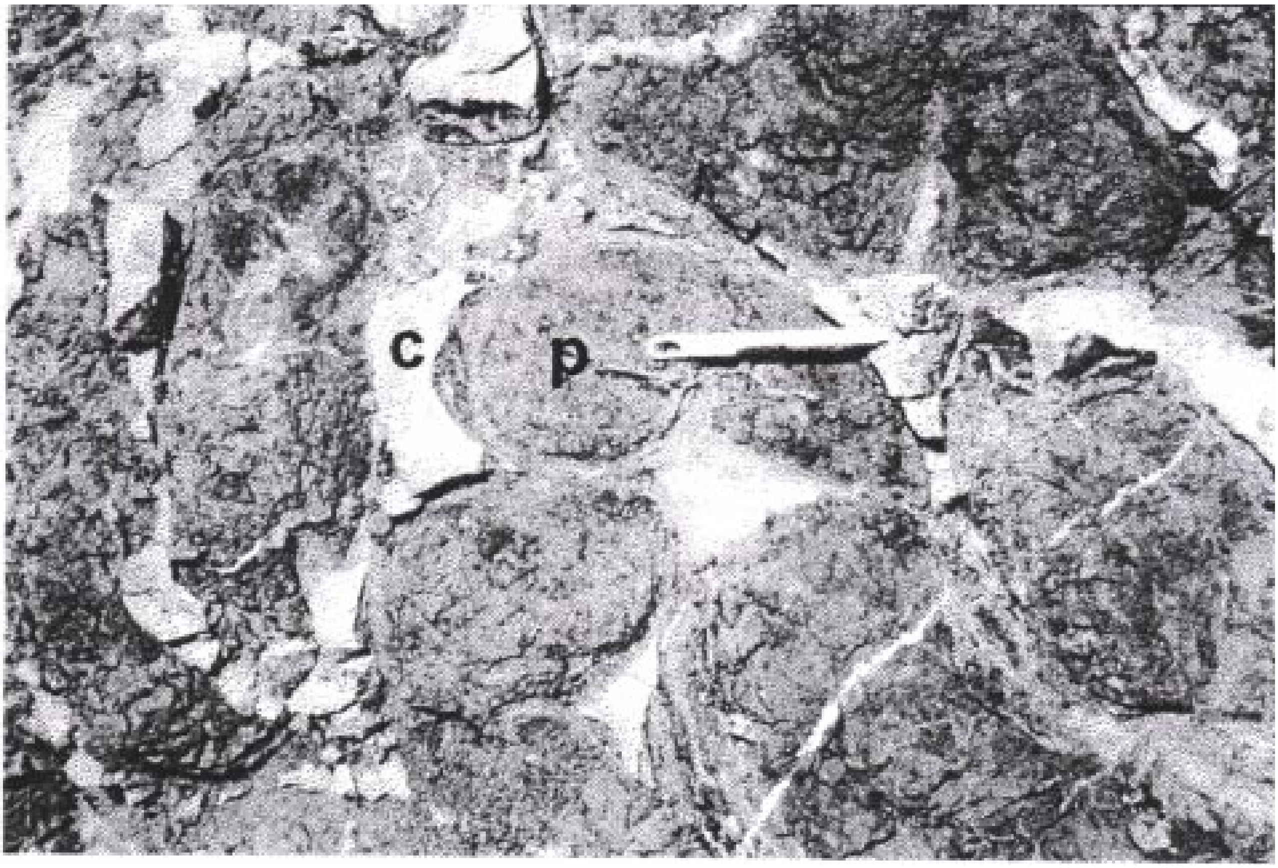

Figure 2. Photograph showing the pillow basalt lobes (p) with interpillow calcareous sediments (c) (Dereköy village, south of Ankara).

the incompatible elements and/or ratios indicate that the basalts exhibit an enriched alkaline chemistry similar to oceanic island basalts (OIB) typically erupted in "within-plate" tectonic environments (Figure 3b, c, d).

Their enrichment with respect to the more stable incompatible elements, such as Th, Nb, Ce, P, Zr and Ti, is also depicted in N-MORB normalized multi-element diagrams (Figure 3e). These samples exhibit a far greater range of absolute abundances than N-MORB, as is reflected by the typically humped patterns akin to OIB.

Paleontology

Thin-shelled "*Protoglobigerina*" (possibly *Globuligerina*) sp., *Spirillina* sp., *Lenticulina* sp., epistominid foraminifers, nodasarids, agglutinated foraminifers, miliolids, *Cadosina* sp., crinoids, ammonoids and echinoid plates are identified from pink, biomicritic calcareous infillings between the lava lobes of pillow basalts (interpillow calcareous sediments) (Figure 2).

The presence of thin-shelled "*Protoglobigerina*" and *Cadosina* associated with miliolids and epistominid foraminifers indicates a Callovian-Hauterivian age (Altıner 1991; Altıner & Özkan 1991). In addition, the absence of calpionellids may suggest a much narrower interval – as Callovian to pre-late Tithonian interval – for the deposition of these biomicrites in the Haymana region.

Discussion and Conclusions

The pillow basalt blocks within the ophiolitic mélanges play an important role in identifying age relationships between the ophiolitic units and depositional environments prior to the development of the ophiolitic mélanges (Figure 4).

In general, the pillow basalts are geochemically well studied, and the presence of Cretaceous seamounts was proved in the region between Kırıkkale (SE of Ankara) and Çankırı (NE of Ankara) during the Mesozoic (Figure 1) (Çapan & Floyd 1985; Floyd 1993; Tüysüz *et al.*

Table 1. Alkali pillow basalts from the Cretaceous ophiolitic mélange (southern Ankara region; Dereköy, Haymana).

Major Oxides	DK-81	DK-82	DK-83	DK-84	DK-85	DK-86	DK-87
SiO_2	31,35	31,39	31,69	35,12	32,12	34,1	32,62
TiO_2	1,59	1,59	1,59	1,79	1,65	1,69	1,62
Al_2O_3	11,31	11,33	11,44	12,36	11,53	11,56	11,24
Fe_2O_3	7,53	7,42	7,54	10,29	7,86	8,96	7,73
MnO	0,3	0,3	0,3	0,16	0,34	0,27	0,33
MgO	3,14	3,14	3,18	2,6	3,13	3,28	3,15
CaO	24,37	24,29	24,32	17,25	24,96	20,99	23,61
Na_2O	2,22	2,20	2,24	3,13	2,37	2,51	2,7
K_2O	0,89	0,89	0,91	1,62	0,79	1,32	0,96
P_2O_5	0,34	0,34	0,34	0,44	0,33	0,40	0,36
LOI	16,7	16,81	16,71	15,15	15,71	14,1	16,06
Total	99,85	99,7	100,27	99,91	100,8	100,19	100,39
Trace Elements (ppm)							
Cr	264	267	271	237	258	217	163
Cu	55	55	53	40	56	51	54
Ga	14	15	17	15	16	16	14
Nb	19	20	20	22	20	20	21
Ni	65	63	65	77	60	66	49
Pb	18	18	18	15	15	15	16
Rb	16	16	17	35	15	27	17
Sr	352	355	351	315	358	340	338
Th	2	0	2	1	1	4	2
V	141	147	160	143	150	131	131
Y	19	19	18	21	19	17	19
Zn	93	93	92	103	86	92	89
Zr	100	100	99	106	101	105	99
Rare Earths							
Ba	161	170	169	278	140	185	181
La	9	12	9	9	9	12	12
Ce	45	30	21	29	40	34	39
Nd	20	20	11	17	14	21	23
Cl	98	110	132	90	76	52	86
S	104	104	103	92	92	87	82
P_2O_5	0,38	0,38	0,37	0,46	-	-	-
TiO_2	1,19	1,18	1,19	1,49	-	-	-

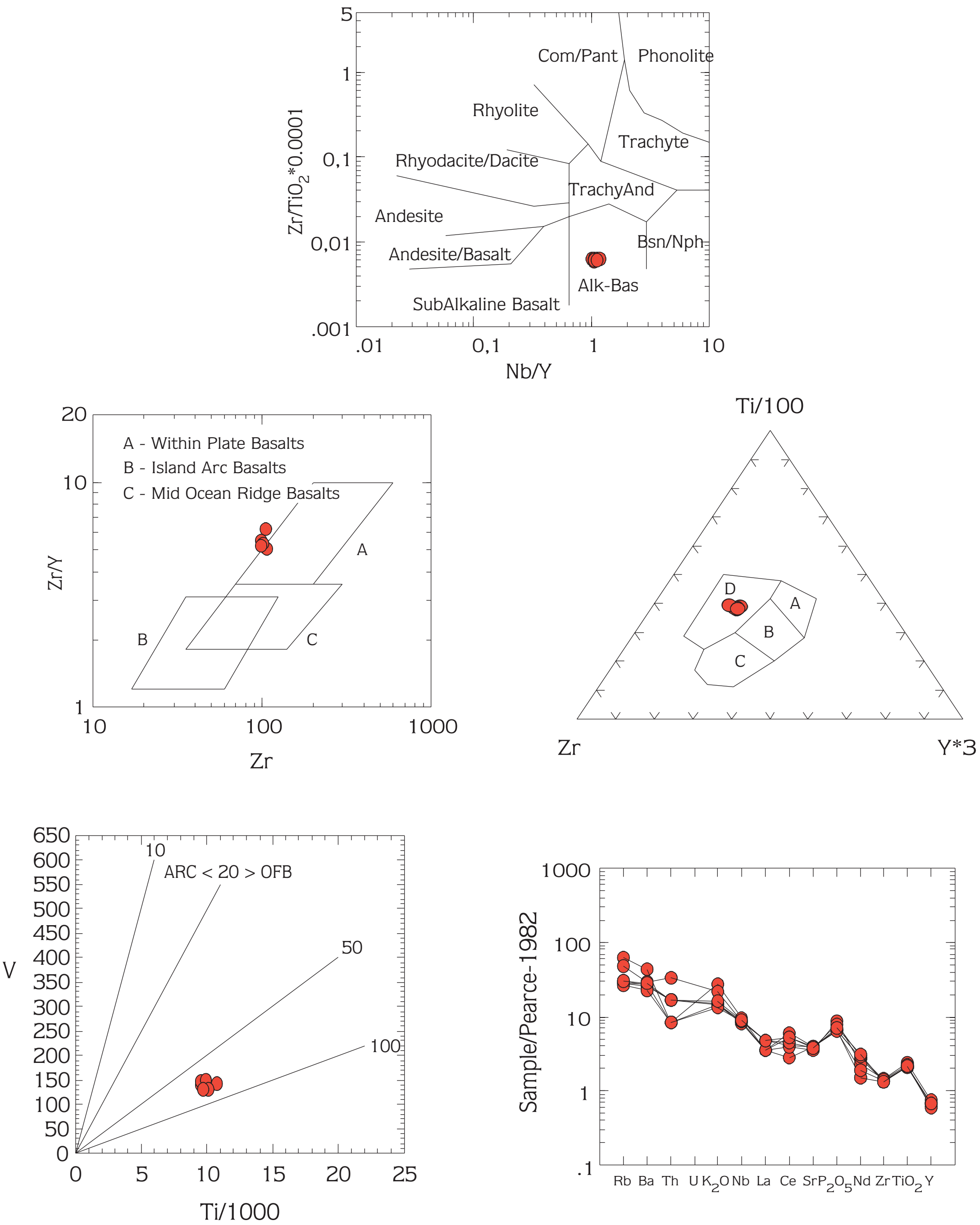

Figure 3. Discrimination and multi-element diagrams for the samples indicating within-plate alkali basalts. **(a)** Zr/TiO_2-Nb/Y diagram, after Winchester & Floyd (1977). **(b)** Zr/Y-Zr diagram, after Pearce & Norry (1979). **(c)** Ti-Zr-Y diagram, after Pearce & Cann (1973). **(d)** V-Ti/1000 diagram after Shervais (1982). **(e)** N-MORB normalized multi-element plot, normalized factors are from Sun & McDonough (1989).

1995; Rojay *et al.* 2001). The present survey also supports the presence of a seamount in the Haymana region (S of Ankara) during the latest Jurassic-Early Cretaceous. However, we were unable to identify reefal carbonate blocks, as possible remnants of atolls, within the ophiolitic mélange unit in the Haymana region that would add support to our geochemical results.

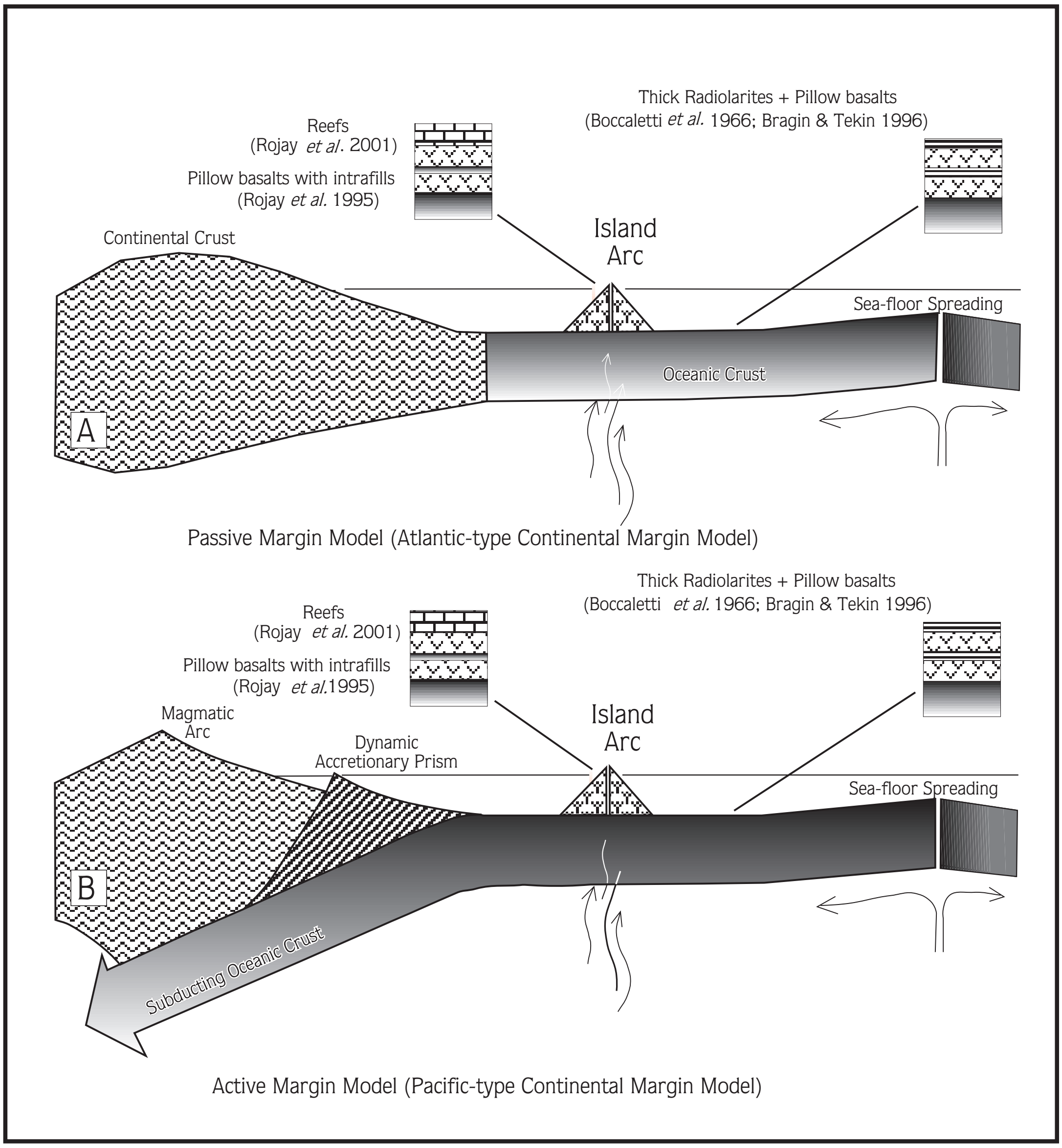

Figure 4. Schematic cross-sections showing possible relationships between oceanic crust and a seamount during the Cretaceous evolution of the northern branch of the Neotethys. Two possibilities indicate that the age of the seamount should be younger than the present oceanic crust. However, it is well documented that the oceanic crust should be younger than Liassic as that is the time of rifting in the northern branch of Neotethys. The second cross-section (B) – the model with northward subduction – is a much less favorable case for the Jurassic-Early Cretaceous evolution of the realm.

The chemical features suggest that the basalt samples are incompatible-element-enriched alkaline basalts similar to those found in oceanic islands (OIB). In view of the association of a high proportion of alkaline basalts of “ocean-island basalt” character, these basalts were presumably derived from a plume source. OIB are derived from the incompatible-element-enriched portions of the reservoir such as those associated with “mantle plumes”. As a result, the basalts that were sampled have an alkaline chemistry reflecting an ocean-island basalt setting may represent the products of an intra-plate hot spot on oceanic crust.

In addition, the chemical features of the samples are also similar to those proposed by Winchester & Floyd

(1977) and Floyd (1991) indicating the presence of OIB-type rock units within the Cretaceous ophiolitic mélange in the Ankara region (Table 2).

Table 2. Comparison of some generalized geochemical ratios of pillow basalts from southern Ankara (SANK) with some from N-MORB and OIB settings (N-MORB and OIB average ratios are from Floyd 1991).

	N-MORB	OIB	SANK
Zr/Nb	>30	<10	4,98
Ba/Nb	2,7	7,3	9,6
La/Nb	1,1	0,8	0,5
Ti/Zr	103	61	86
K/Rb	1067	368	458
P/Ce	69	34	49

A chemical comparison of the various tectonic settings suggests an intraplate volcanic environment of an alkaline ocean-island basalt setting for the Dereköy (Haymana) pillow basalts (Figure 3, Table 2).

The only relative age dating on the pillow basaltic components of the ophiolitic mélange was presented by Boccaletti *et al.* (1966) from east of Ankara on carbonates that are closely associated with pillow basalts. Their results support the Early-Late Jurassic up to Neocomian (?) - Aptian interval (p. 495, figure 7 in Boccaletti *et al.* 1966). The carbonate fills between pillow lobes upon which we have concentrated our studies have been well illustrated but were previously undated. The carbonates and radiolarites that alternate with pillow basalts are dated as Early to Late Jurassic, whereas the carbonates overlying the pillow basalt sequence are assigned to the Neocomian (?) to Aptian time span (Boccaletti *et al.* 1966).

Their results on the relative dating of pillow basalts agree with our findings on the age of those pillow basalts dated as Callovian to Hauterivian. The presence of thin-shelled "*Protoglobigerina*" and *Cadosina* within the intrapillow carbonate fills indicates a Callovian to Hauterivian age, where the absence of calpionellids suggests only a Callovian to pre-late Tithonian interval for the deposition of these biomicrites at Dereköy. Moreover, there are additional important results that may contribute to our understanding of the evolution of the region: (i) the radiolaria-bearing limestone and radiolarite blocks are dated in an age range of late Norian to late Albian-Turonian (Bragin & Tekin 1996); (ii) Middle Jurassic radiolarites are missing in the region (Bragin & Tekin 1996); (iii) the Callovian-Kimmeridgian span is presumed to be too early for the evolution of a seamount in an evolving young oceanic crust in Mesozoic Tethys due to the present well-documented Triassic and Liassic regional discordances (e.g., Koçyiğit 1987; Koçyiğit *et al.* 1991; Altıner *et al.* 1991; Rojay & Altıner 1998); and (iv) the presence of bioclastic limestones dated in an age range of late Barremian-early Aptian are presumed to be atolls present in the north Ankara region based on the presence of an orbitolinid and *Baccinella* fauna with volcanic detritus (Rojay *et al.* 2001).

However, the radiolaria-bearing limestone and radiolarite blocks dated in an age range of late Norian to late Albian-Turonian (Bragin & Tekin 1996) does not mean that the Neotethyan oceanic basin existed from the Triassic onward unless Triassic to Cretaceous radiolarian fauna and associated oceanic crust are well-documented and are clearly interrelated. If this is not the case, there might have been different oceanic basins in the Mesozoic Tethyan realm that diminished progressively over time.

Our results are: (1) the pillow basalts are ocean-island alkali basalts with high Nb/Y (≅ 1), low Zr/Nb (≅ 5), low La/Nb (≅ 0.5), low Ti/Zr (≅ 86), low P/Ce (≅ 49) and high Ba/Nb (≅ 9.6) ratios (Table 2); (2) the age of pink biomicritic limestone deposited between the lobes of pillow basalts corresponds to the Callovian-Hauterivian interval. The above results collectively support the presence of a seamount in the Dereköy (Haymana region) of the Central Anatolian terrain during the Callovian-Hauterivian interval. This, in turn, proves the presence of oceanic crust that was older than the age of the seamount along the northern branch of Neotethys (Figure 4). The regional discordance – the Liassic discordance throughout the northern belt – indicates that sea-floor spreading must have operated from the Liassic on in the northern Neotethyan belt. Therefore, the age of the oceanic crust should be younger than Liassic in the region. However, blocks of reefal carbonates from the Callovian-Hauterivian interval (representing atolls which could have developed around the seamount/seamounts) were not detected in the area south of Ankara.

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