Geodinamica Acta 17/5 (2004) 349–361

Geodinamica Acta

Geodynamic significance of the Cretaceous pillow basalts from North Anatolian Ophiolitic Mélange Belt (Central Anatolia, Turkey): geochemical and paleontological constraints

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Received: 22/11/2003, accepted: 27/10/22004

Abstract

The most widespread blocks within the Cretaceous ophiolitic mélange (North Anatolian ophiolitic mélange) in Central Anatolia (Turkey) are pillow basalts, radiolarites, other ophiolitic fragments and Jurassic-Cretaceous carbonate blocks. The pillow basalts crop out as discrete blocks in close relation to radiolarites and ophiolitic units in Cretaceous ophiolitic mélange.

The geochemical results suggest that analyzed pillow basalts are within-plate ocean island alkali basalts. The enrichment of incompatible elements (Nb, Ta, Light REE, Th, U, Cs, Rb, Ba, K) demonstrates the ocean island environment (both tholeiites and alkali basalts) and enriched MORB.

Dated calcareous intrafills and biodetrital carbonates reveal an age span of Callovian—Early Aptian. The thin-shelled protoglobigerinids, belonging to the genus *Globuligerina*, in the calcareous intrafills between pillow basalt lobes indicates a Callovian—Barremian age interval, most probably, Valanginian to Late Barremian. The volcanic and radiolarite detritus-bearing orbitolinid—*Baccinella* biodetrital carbonates dated as Late Barremian-Early Aptian in age, were probably deposited around atolls and have a close relationship with the ocean island pillow basalts.

The results collectively support the presence of a seamount on the Neo-Tethyan oceanic crust during the Valanginian—Late Barremian and atolls during the Late Barremian-Early Aptian interval. The presence of an oceanic crust older than that seamount along the Northern Branch of Neo-Tethys is conformable with the geodynamic evolution of the Tethys.

Keywords: Seamount, Pillow basalt, Ocean Island Basalt, Late Barremian-Early Aptian, Ankara Mélange, Tethys

1. Introduction

The so-called "*Ankara Mélange*" belt [1] is one of the cornerstones of the İzmir-Ankara-Erzincan suture belt (IAES) in the understanding the evolution of Tethys in Anatolia (Turkey) (Fig. 1).

This tectonic belt (IAES) is a Mesozoic accretionary wedge that is characteristic of the central Anatolian terrain. The belt is made up of imbricate piles of various tectonic slices of Cretaceous North Anatolian ophiolitic mélange, Paleozoic-Triassic metamorphics and Triassic Karakaya complex with Cretaceous accreted basins (Fig. 2).

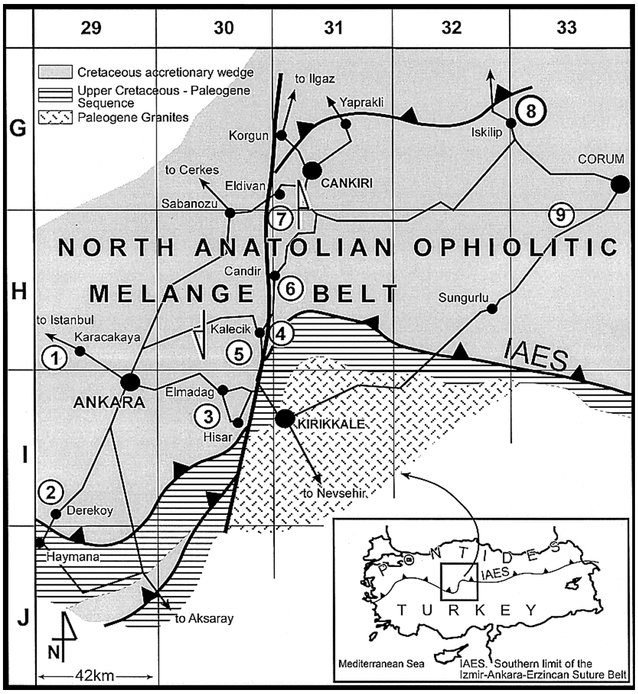


Fig. 1 The simplified tectonic map showing the main tectonic elements along the Mesozoic accretionary prism in the Ankara region and the research areas on 1: 100,000 scaled topographic maps. 1. Karacakaya (N of Ankara); 2. Dereköy (S of Ankara-Haymana); 3. Kılıçlar (E of Ankara-Elmadağ); 4. E of Kalecik (E of Ankara); 5. W of Kalecik (E of Ankara); 6. Çandır (NE of Ankara); 7. Eldivan (SW of Çankırı); 8. İskilip (NE of Çorum); 9. SW of Çorum.

The Cretaceous ophiolitic mélange is thrust onto a structural complex consisting of Triassic Karakaya complex and Paleozoic-Triassic metamorphics of “Sakarya Continent”, which are unconformably overlain by Jurassic-Cretaceous sequences of Pontide belt [2] (Fig. 2). The Cretaceous ophiolitic mélange is unconformably overlain by the Upper Cretaceous-Paleogene sequences in the north of Ankara. The Cretaceous ophiolitic mélange and structural complex thrust onto the Upper Cretaceous-Paleogene sequences along Kızılırmak section in the southeast of Ankara (Fig. 2). The southern Upper Cretaceous-Paleogene sequences unconformably overlie the Upper Cretaceous-Paleogene supra-subduction ophiolites and mélanges that are thrust onto the Paleogene granites of “Kırşehir Block” (Fig. 2). The tectonic slices are clearly thrust onto each other with a SE vergence in the central Anatolian terrain.

The Cretaceous ophiolitic mélanges of the so called “Ankara Mélange” along the IAES, here informally named as the North Anatolian ophiolitic mélange (NAOM), consist of Cretaceous ophiolitic fragments, Jurassic-Cretaceous carbonate and pillow basalt blocks set in highly sheared-mylonitized clastic matrix, tectonic slices of various imbricate nappes and thrust belt parallel siliciclastic Cretaceous basins (Fig. 2).

The pillow basalts that are the target of this research are found as isolated, detached blocks, or as blocks closely associated with radiolarites, or as lavas alternating with radiolarites and rarely with fossiliferous carbonates in NAOM from Çorum in the NE to the Haymana region in the SW (e.g. [2-6]).

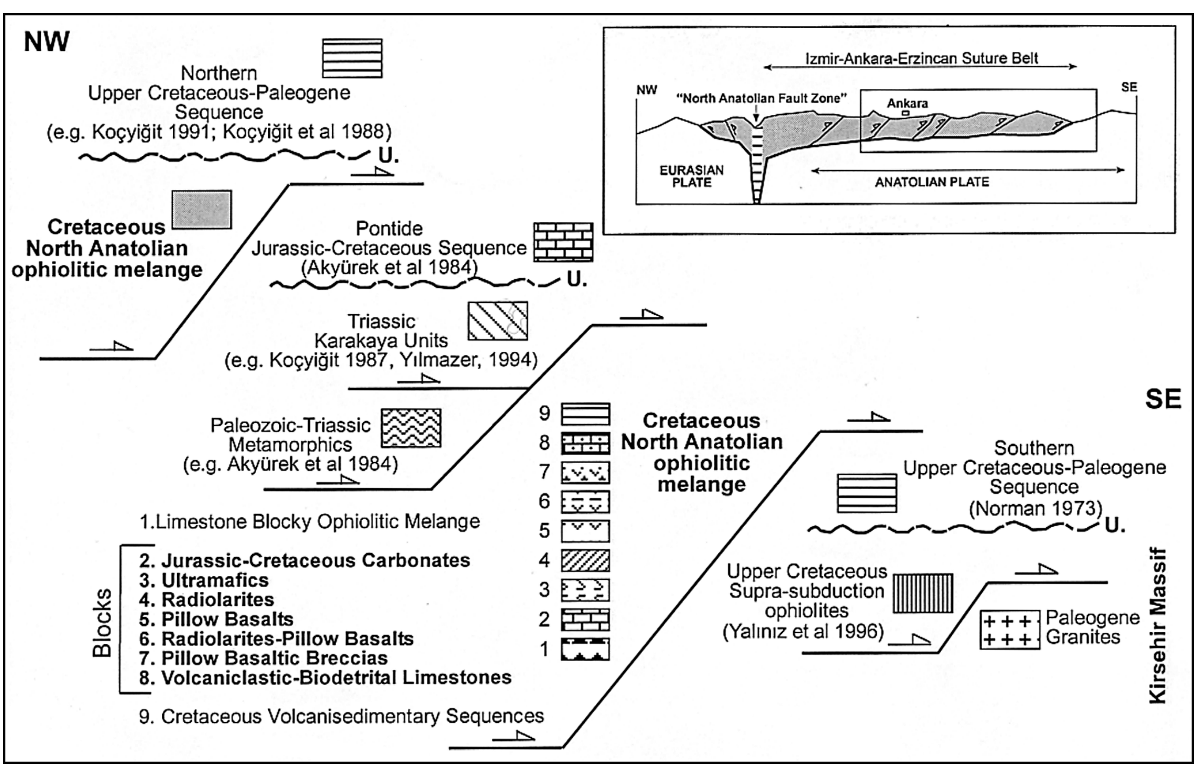


Fig. 2 Generalized sketch cross-section showing the major tectonic units of the Cretaceous Accretionary Wedge (IAES Belt) and North Anatolian Ophiolitic Mélange Belt in central Anatolia. U. Unconformity.

Geochemical analysis carried out on the pillow basalts suggested that the majority of them represent relicts of a seamount or seamounts [4-7]. However, the lack of age controls on the pillow basalts prohibits most researchers from stating if they were formed during a single episode or over a considerable time period relative to the associated ocean crust.

The pillow basalts in the mélange complexes play an important role in the identification of the ophiolitic mélanges. However, the use of them in dating the mélanges is limited. Relative dating of the ophiolitic mélanges in central Anatolia was attempted by bracketing them between dated accretionary basins situated structurally above the accreted ophiolitic slices [8-17], or by dating accreted ophiolitic slices situated structurally below [3, 10], or by dating the ages of radiolarite and radiolaria-bearing limestone blocks [18-19] or by the cross-cutting relationships between the ophiolitic slices and dated submarine volcanics [6, 20]. The ophiolitic mélanges are dated to be older than Campanian in central Anatolia [14].

The pillow basalts within the Triassic dismembered complex and the Cretaceous ophiolitic mélange were analyzed as a member of the same tectonic unit. Therefore, undated pillow basalts and their ophiolitic base, and geochemical studies on these, cannot alone define the real picture of the evolution of central Anatolian ophiolitic mélange terrain [4-5, 7, 21-23].

This paper aims to fulfill a gap in the understanding of the global tectonic evolution of the Neotethyan Ocean by geochemically analyzing the pillow basalts of the Cretaceous ophiolitic mélange (NAOM) in Central Anatolia (Turkey) and paleontologically dating these pillow basalts.

2. Sampling

Tectonically detached blocks of pillow basalts in the Cretaceous ophiolitic mélange were sampled from Karacakaya in the north to Haymana in the SW and to Çorum in the NE (Central Turkey) in 9 different areas (Fig. 1). Pelagic calcareous sediments accumulated between the lobes of the pillows (Fig. 3a), biodetrital carbonates with pillow basalt and radiolarite detritus and finally coralline carbonate lenses in a pillow basalt matrix are the targets of the paleontological analysis to correlate them with the geochemical results. The alternating radiolaria bearing pelagics with pillow basalts and the intrafills that are siliceous or highly altered cannot be paleontologically dated (Fig. 3b and 3c).

In the Karacakaya research area (north of Ankara) the sampling was carried out in Cretaceous mélange that is thrust onto a Triassic clastic sequence unconformably overlain by the northern belt (Pontide) Jurassic-Cretaceous sequences (Fig. 4). The Cretaceous ophiolitic mélange is unconformably overlain by a Campanian-Paleocene flysch sequence [14]. The biodetrital limestones, reefal carbonates, radiolarites alternating with pillow lavas and the pillow lavas with calcareous and siliceous intrafills were sampled in this research area (Fig. 4).

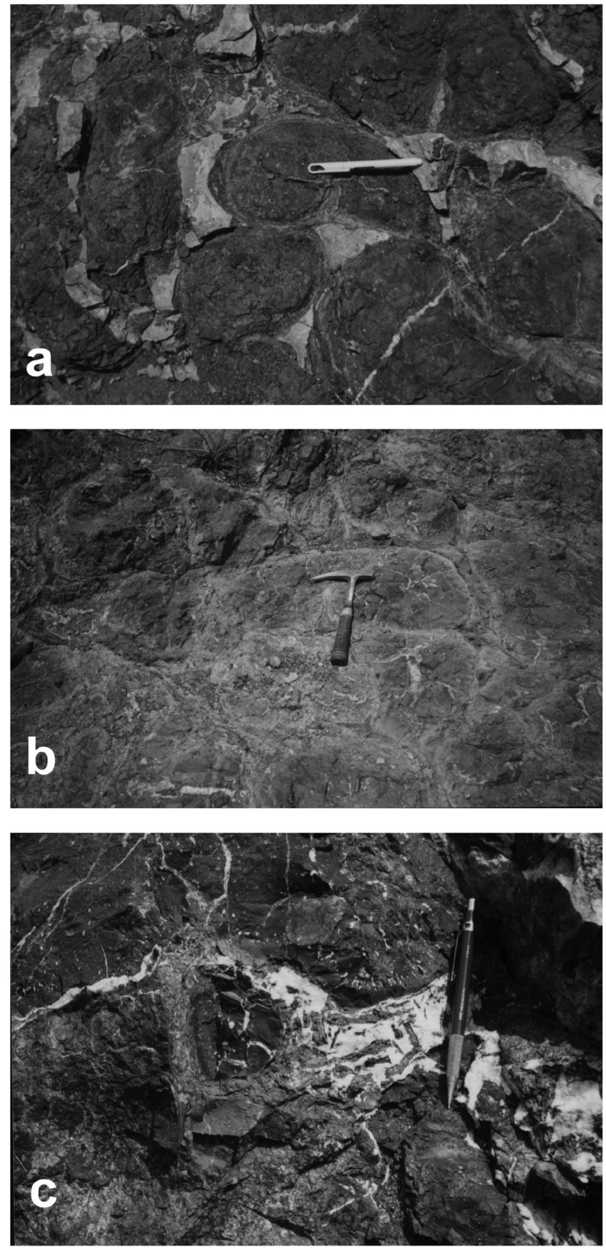


Fig. 3 Photographs showing various views of the pillow basalts. *a*. Pillow basalt lobes with intrapillow calcareous fills (Dereköy village, S of Ankara); *b*. Pillow basalt lobes with intrapillow siliceous fills (Karacakaya village, NW of Ankara); *c*. highly altered pillow basalts (Eldivan, NE of Ankara).

In the Dereköy research area (south of Ankara) the sampling is carried out in an imbricated Cretaceous ophiolitic mélange that is thrust by Triassic dismembered complex (Fig. 5). The Cretaceous ophiolitic mélange is thrust onto the Eocene sequence from north to south [10]. The biodetrital limestones and pillow basalts with calcareous intrafills were sampled.

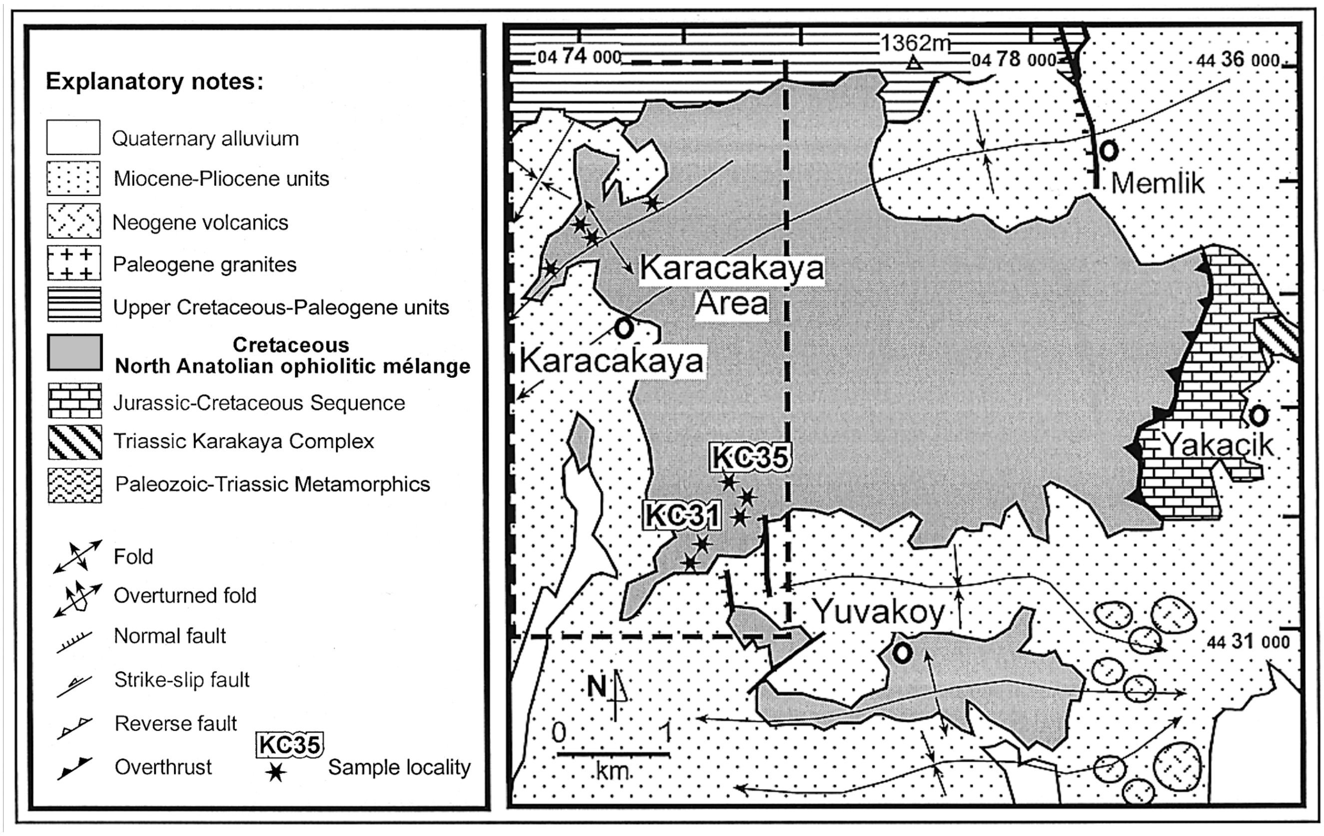


Fig. 4 Geological Map of the Karacakaya (NW of Ankara) (based on [14]). Geochemically analyzed sample locations: KC31 and KC35.

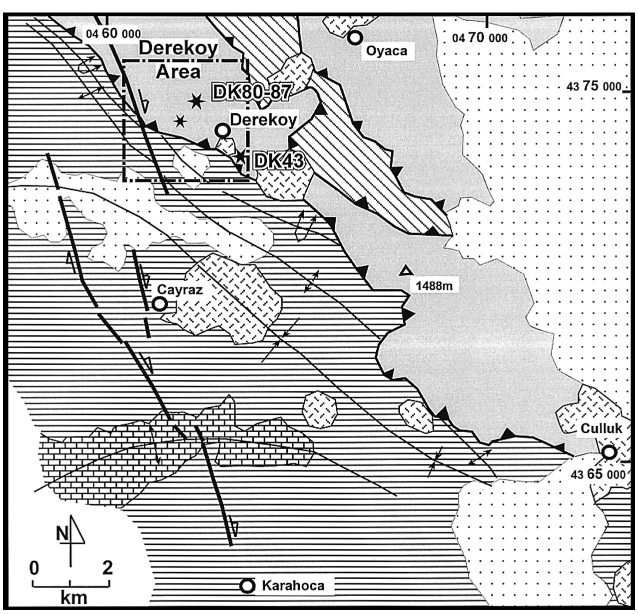


Fig. 5 Geological Map of the Dereköy (Haymana region, S of Ankara) (based on [10]). Geochemically analyzed sample locations: DK81 to 87 and DK43.

In between Elmadağ (east of Ankara) and Eldivan (Çankırı), the sampling is carried out in an imbricated Cretaceous ophiolitic mélange that is thrusted by Triassic limestone blocky dismembered complex (Fig. 6). The pillow basalts with siliceous intrafills in Kızıldağ mountain-Kılıçlar (Elmadağ), pillow basalts with siliceous intrafills, pillow basalts alternating with radiolarites and biodetrital limestones in Kalecik, pillow basalts with siliceous intrafills and biodetrital limestones in Çandır and pillow basalts with siliceous and calcareous intrafills in Eldivan mountain (Çankırı) are sampled (Fig. 6).

In between İskilip and southwest of Çorum (far northeast of Ankara), the sampling was carried out in a Cretaceous ophiolitic mélange thrust by Paleozoic-Triassic metamorphics (Fig. 7). Only the pillow basalts with siliceous and calcareous infills were sampled. The samples in Eldivan and İskilip areas are hydrothermally altered.

3. Petrography

Thin sections of pillow basalts were examined from nine different areas within the Cretaceous ophiolitic mélange (Fig. 1). The pillow basalts are mainly holocrystalline, and are aphyric or plagioclase-phyric and plagioclase-clinopyroxene-phyric with a low proportion of phenocrysts. They usually show intergranular texture and a few of them (K119, E of Kalecik and K21, W of Kalecik) have flow texture. Vesicular to amygdaloidal basalts are common.

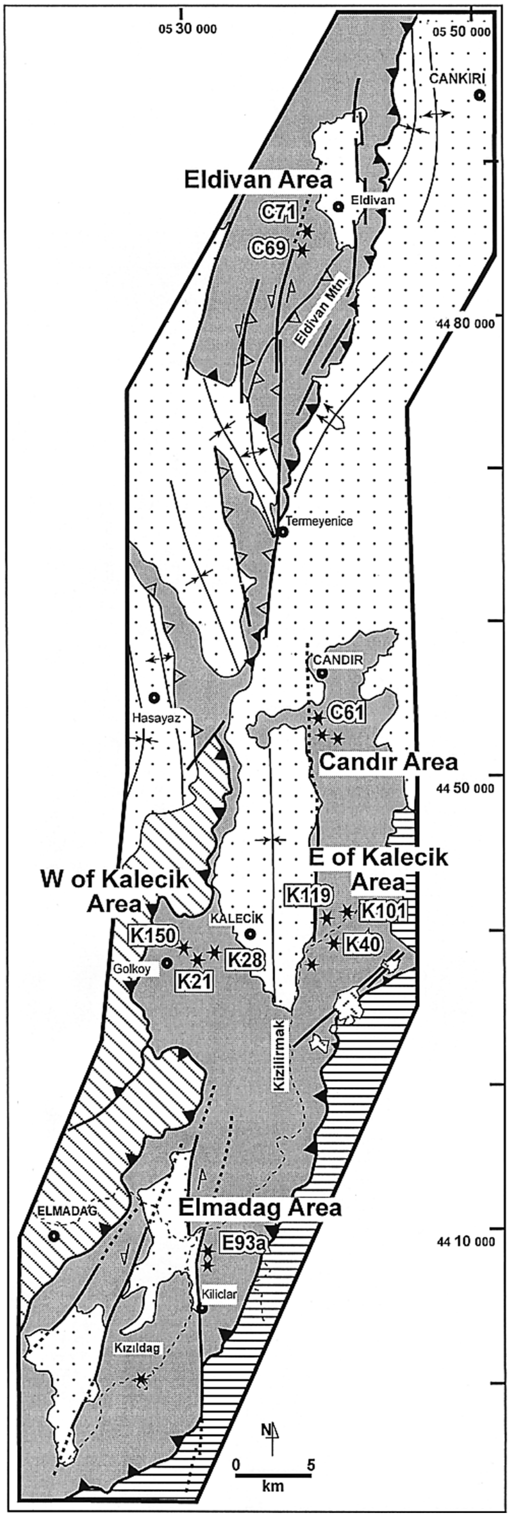


Fig. 6 Geological Map from Kılıçlar valley (SE of Elmadağ) (based on [2]) to Kalecik-Çandır (E of Ankara) (based on [2, 37]) and to Eldivan-Çankırı areas (NE of Ankara) (based on [38, 45]). Geochemically analyzed sample locations: E93a (Kılıçlar section), K40, K101 and K119 (E of Kalecik-Kızılırmak valley), K21, K28, K28c and K150 (W of Kalecik), C61 (Karanlık hill-Kurtköy stream, Çandır), C69 and C71 (NE of Lalelik hill, Eldivan).

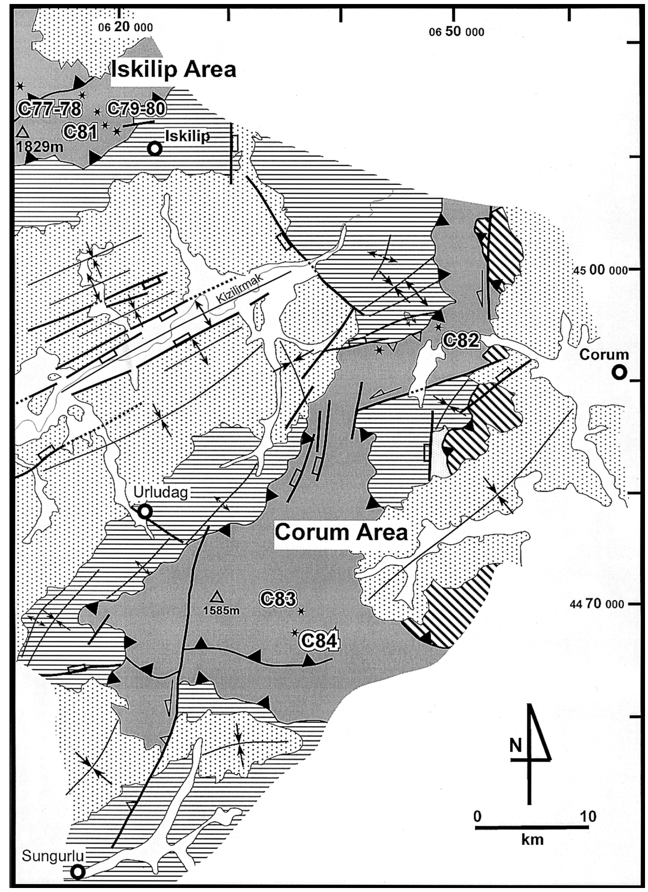


Fig. 7 Geological Map of the İskilip-Çorum area. Geochemically analyzed sample locations: C78 (Elmalıbeli-N of İskilip), C83 and C84 (E of Urludağı-SW of Çorum).

Different degrees of alteration are common to all basalts and are typically replaced by low-grade secondary assemblages. Albite-epidote-chlorite-calcite±zeolites assemblages indicate greenschist facies. There is also late-stage low-grade alteration with the development of replacive carbonate in the matrix, and calcite veinlets. When vesicles are present they are filled and rimmed by early chlorite and calcite.

4. Geochemistry

Samples of basaltic pillow lavas were collected from nine different areas, namely, Karacakaya (KC31 and KC35), Dereköy (DK81-87 and DK43), Kılıçlar (E93a), E of Kalecik (K40, K101 and K119), W of Kalecik (K21, K28, K150 and K28c), Çandır (C61), Eldivan (C69 and C71), İskilip (C78) and Çorum (C83 and C84) in Cretaceous ophiolitic mélange (Fig. 4, 5, 6 and 7). A number of petrographically selected samples for each research area have been analyzed for their major—trace — and rare earth elements by using ICP and XRF spectrometry in Royal Holloway, University of London, UK. The results are presented in Table I and the trace element ratios are given in Table II. They show relatively scattered plots on the FeO/MgO *vs.* Zr and Rb *vs.* Zr

Table 1
Major, trace, and rare earth element analyses (by ICP and *XRF) of pillow basalts.

	Karacakaya		Dereköy		Elmadağ	Kalecik East				Kalecik West			Çandır	Eldivan		İskilip	Çorum	
(wt%)	KC31	KC35	Ave.	DK43	E93a	K40	K101	K119	K21	K28	K150	K28c	C61	KC69	C71	C78	C83	C84
SiO_2	43.90	45.12	32.21	48.16	39.44	50.43	52.89	47.14	55.26	44.98	40.92	41.49	44.18	46.81	47.22	44.14	47.39	43.69
Al_2O_3	13.53	13.48	1.62	15.02	14.44	17.18	17.07	16.20	15.85	13.34	14.93	14.57	14.10	14.84	15.70	21.22	14.48	14.35
TiO_2	2.26	1.90	11.40	1.98	1.94	1.18	2.71	2.48	2.97	2.65	1.64	2.57	2.54	2.16	2.45	0.79	2.65	2.70
Fe_2O_3	9.48	8.98	7.84	11.67	8.53	9.42	11.64	12.61	10.32	11.09	9.52	9.70	10.92	12.31	13.30	4.87	12.08	11.97
MnO	0.11	0.22	0.31	0.13	0.12	0.12	0.14	0.12	0.04	0.24	0.10	0.16	0.16	0.11	0.14	0.12	0.13	0.15
MgO	5.45	6.44	3.17	4.65	3.23	3.60	1.37	2.85	1.02	7.05	1.59	4.09	4.54	2.29	2.04	2.33	4.70	5.27
CaO	11.86	11.79	23.76	11.06	13.53	7.34	2.62	5.57	3.49	8.68	13.10	11.57	11.34	9.68	7.67	11.44	8.65	8.98
Na_2O	4.89	4.50	2.37	3.10	2.67	4.56	4.81	4.20	6.17	3.59	3.38	4.43	3.85	4.03	5.89	4.12	4.01	3.04
K_2O	0.62	0.56	0.96	0.27	2.59	1.38	2.66	0.98	1.71	2.23	1.91	0.70	1.91	1.30	0.47	0.70	0.77	0.67
P_2O_5	0.29	0.21	0.35	0.18	0.58	0.09	0.74	0.64	0.66	0.43	0.55	0.37	0.39	0.32	0.34	0.11	0.31	0.29
LOI	7.61	6.80	16.02	3.76	12.93	4.68	3.35	7.01	2.50	5.71	12.36	10.34	6.05	6.13	4.78	7.11	4.82	8.89
Mg#	0.53	0.59	0.44	0.44	0.43	0.43	0.19	0.31	0.16	0.56	0.25	0.46	0.45	0.27	0.23	0.49	0.44	0.47
(ppm)																		
Ba*	202	150	167.66	97	357	95	348	111	212	766	245	176	489	90	46	142	142	150
Co	43	41	—	40	32	38	34	30	34	45	21	42	42	34	39	14	41	41
Cr*	189	352	240	346	180	275	118	45	97	200	22	81	160	240	247	206	103	89
Cu*	86	82	54	68	30	28	38	19	28	75	19	26	42	12	38	12	55	52
Li	19	13	—	7	20	14	9	10	11	26	11	21	21	26	23	19	8	8
Ni*	106	112	61.33	86	83	86	64	11	18	116	21	47	103	66	68	42	84	81
Sc*	26	30	—	35	17	47	15	9	15	22	7	18	19	32	34	18	27	27
Sr*	312	182	349	138	396	172	368	353	401	354	244	558	801	152	196	357	373	333
Rb*	8.1	3.2	18	2.3	51.8	24.3	59.4	15.1	22.5	16.9	63.7	10.1	28.8	29.7	7	10.1	16.1	14.3
V*	251	217	143.33	272	146	267	155	95	138	237	88	221	213	291	323	130	257	252
Y*	22.5	23	18.5	47.8	24.3	29.7	27.9	35	43.1	24.9	28.5	23.1	26.3	42.7	47.8	15.8	27.6	26.9
Zn*	83	87	90.83	94	87	109	237	114	237	84	88	103	81	67	103	36	109	106
Zr*	156	122	100.66	148	229	74	396	257	256	207	250	171	211	185	201	65	219	215
Nb*	34.5	20.7	20	6.5	54.9	3	95	62.4	38.4	42.1	78.6	39.8	41.6	24.4	26.1	8.6	30	29.6
Th*	2.7	1.4	1.83	0.2	5.7	0.2	8.9	4.1	2.7	4.2	8.2	3.2	3.7	1.6	1.8	0.2	2.7	1.9
Ga*	15.9	17.5	15.33	17	14	14.7	27.9	19.5	18.1	16.4	16.1	16.7	16.7	18	16.2	13	20	19.3
Pb*	0.9	0.7	16.67	1.7	1.9	1.1	4.1	3.3	4.1	1.9	3.9	1.6	1.9	0.8	1.7	0.4	2.4	2.2
La*	18.8	14	10.5	6	39.9	2	64.9	44.2	27.7	30.3	49.8	23.7	27.4	15.2	14.5	6.8	21.3	20.4
Ce*	45.3	41	34.83	20.2	79.4	8.7	137.6	94.8	70.2	76	102	53.8	61.4	38	38.8	14.9	55.9	52.8
Nd*	23.4	0.9	18.17	15.9	32.3	9.1	59.5	42.5	40.9	30.9	40.2	27.5	30.4	24.5	24.2	8.3	29.9	27.2
Sm	8.6	7.6	—	9.1	8.7	5.7	13.7	11.6	13.4	11	8.8	9.1	10.3	11.3	11.6	3.6	9.6	10.7
Eu	1.7	1.3	—	1.9	1.7	1	2.6	2.2	2.6	2	1.8	1.6	1.9	1.8	2.1	0.7	1.8	1.8
Dy	4.8	5.4	—	8.1	4.5	5.3	5.7	6	7.7	6.5	4.9	4.9	5.6	7.5	7.8	3.5	5.9	5.4
Yb	2.2	2.2	—	5.3	1.7	3.3	1.3	2.2	2.8	2.3	2.2	1.8	2.5	4.1	4.4	1.5	2.6	2.3

Table 2
Trace element ratios of the pillow basalts.

	Karacakaya		Dereköy		Elmadağ	Kalecik East			Kalecik West				Çandır	Eldivan		İskilip	Çorum	
	KC31	KC35	Ave.	DK43	E93a	K40	K101	K119	K21	K28	K150	K28c	C61	KC69	C71	C78	C83	C84
Zr/Nb	4.5	5.9	4.98	23	4.2	24.7	4.2	4.1	6.7	4.9	3.2	4.3	5.1	7.6	7.7	7.6	7.3	7.3
Ba/Nb	5.9	7.3	9.6	15	6.5	31.7	3.7	1.8	5.5	18.2	3.1	4.4	11.8	3.7	1.8	16.5	4.7	5.1
La/Nb	0.5	0.7	0.5	0.9	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.7	0.6	0.6	0.8	0.7	0.7
Ti/Zr	87	92	86	79	49	95	40	56	70	76	38	89	71	70	73	73	71	72
P/Ce	28	22	49	39	31	45	23	39	42	25	23	29	28	37	38	32	23	23
K/Rb	635	1427	458	975	401	468	363	522	638	1090	242	567	545	363	557	575	387	372
K/Ba	26	30	49	23	58	120	62	71	68	24	63	33	32	120	85	41	44	35
Rb/Sr	0.026	0.018	0.052	0.017	0.131	0.141	0.161	0.043	0.056	0.048	0.261	0.018	0.036	0.195	0.036	0.028	0.043	0.043
Zr/Rb	19	38	5.6	64	4.4	3.1	6.7	17	11	12	3.9	17	7.3	6	29	6	14	15
Zr/Y	6.9	5.3	5.4	3.1	9.4	2.5	14.2	7.3	5.9	8.3	8.8	7.4	8.0	4.3	4.2	4.1	7.9	8.0
$(Ce/Yb)_N$	5.7	5.2	-	1.1	7.9	0.7	29.4	7.3	7.0	9.2	12.9	8.3	6.8	2.6	2.5	2.8	6.0	6.4
$(La/Yb)_N$	6.1	4.6	-	0.8	16.8	0.4	35.8	54.6	7.1	9.5	16.2	9.4	7.9	2.7	2.4	3.3	5.9	6.4

diagrams indicating chemical alteration of the rocks as exemplified by the presence secondary phases. Therefore, incompatible elements, like Ti, P, Zr, Y, REE, are used to determine the primary chemical features of these rocks.

Chemically, the basaltic pillow lavas have a mostly alkaline character as exhibited by Zr/TiO_2 *vs.* Nb/Y, TiO_2 *vs.* Zr/P_2O_5, and Nb/Y *vs.* Zr/P_2O_5 diagrams (Fig. 8a, b, c). However, these diagrams also show that samples from Kalecik (K40), Dereköy (DK43), Eldivan (C69, C71), İskilip (KC78), and Çorum (C83, C84) have some tholeiitic features. On the Nb *vs.* Zr diagram (Fig. 9a), low Zr samples may be the most primitive basalts as they also have relatively high Cr and Ni contents. For example, Dereköy samples have high values, whereas Kalecik and Elmadağ samples have relatively low Cr and Ni values. Cr and Ni contents (since they are the most primitive stable trace elements) are taken to approximate the parental melt compositions (instead of Mg number of basalts since it is susceptible to alteration effects). Cr and Ni contents are (Cr: 22-352 ppm, Ni: 11-116 ppm) are well below primary melt compositions (> 400 ppm Ni, > 1,000 ppm Cr) [24] and may suggest high-pressure mantle mafic fractionation or low-pressure mafic fractionation of olivine and clinopyroxene in the crust. Using Zr as a stable fractionation index both Ni and Cr contents decrease with progressive fractionation. Elmadağ (Kılıçlar) and Eldivan samples have also low Cr and Ni contents as documented by Floyd [5] either.

The variation in Zr/Y ratios may reflect variable partial melting of a homogeneous garnet-bearing source (Fig. 9b). The variation can be used to find the relative degrees of melting. For the pillow basalts of the Cretaceous ophiolitic mélange, there is an increasing degree of partial melting from west of Dereköy to Kalecik, Eldivan and İskilip. Basalts from Dereköy, İskilip and Eldivan have the most primitive parental compositions and represent the highest degree of melting. It is assumed that the La/Nb ratio for each area is identical with the ranges from 0.6 to 0.9 indicating a mantle source of broadly the same composition. This ratio has a value of 0.77 for the Kılıçlar section in Floyd, 1993 [5].

The MORB-normalized multielement diagram (Fig. 10a) shows a progressively enriched pattern for basalts. Samples show relatively steep, but variable light REE fractionation patterns. Dereköy, Eldivan and Karacakaya samples show most primitive characteristics. The ratio of $(Ce/Yb)_N$ for the samples E of Kalecik (K40) and Dereköy (DK43) are 0.7 and 1.1, respectively, and for Eldivan: 2.6, İskilip: 2.8, for the others the ratio have higher values between 5.2 and 29.4 (Table II). The Chondrite-normalized REE pattern (Fig. 10b) shows a mainly enriched character together with few relatively flat patterns for the samples KC43, KC40, C78 similar to N-MORB which have tholeiitic character demonstrating little REE fractionation (with $(La/Yb)_N$ ratios between 2.4-3.3 to 4.6-54.6) (Table II) rather than the depleted light REE patterns of N-MORB (with $(La/Yb)_N$ ratios of about 0.6) [27]. $(La/Yb)_N$ ratios for Dereköy (only DK43) and Kalecik (only KC40 from E of Kalecik) are similar to N-MORB.

Pillow basalt samples show an enriched chemistry similar to oceanic island basalts (OIB) erupted in within-plate tectonic settings and also same types of MORB (Fig. 11a, b). In Fig. 11c, WP alkali and tholeiitic basalt fields are separated from E-MORB (C69 and C71 (Eldivan), C78 (İskilip)) and N-MORB (K40 (E of Kalecik), DK43 (Dereköy)). The majority of the volcanic rocks of mélanges are incompatible element enriched alkaline basalts similar to those found in OIB, although a few of them have a enriched mid-ocean-ridge (MORB) source. Similar results are obtained from several studies done on the Cretaceous

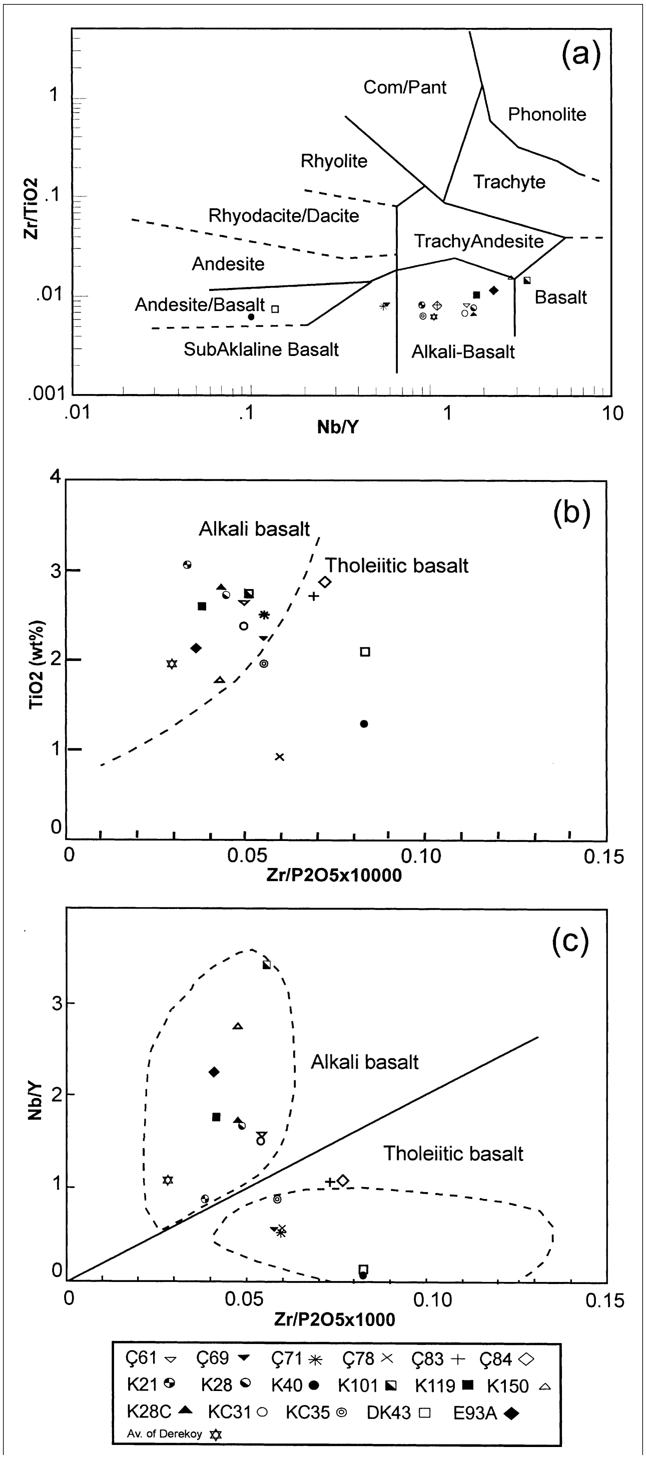


Fig. 8 Variation of *a*. Zr/TiO_2 *versus* Nb/Y [32]; *b*. TiO_2 *versus* Zr/P_2O_5; and *c*. Nb/Y *versus* Zr/P_2O_5 [32], for the basaltic pillow lavas.

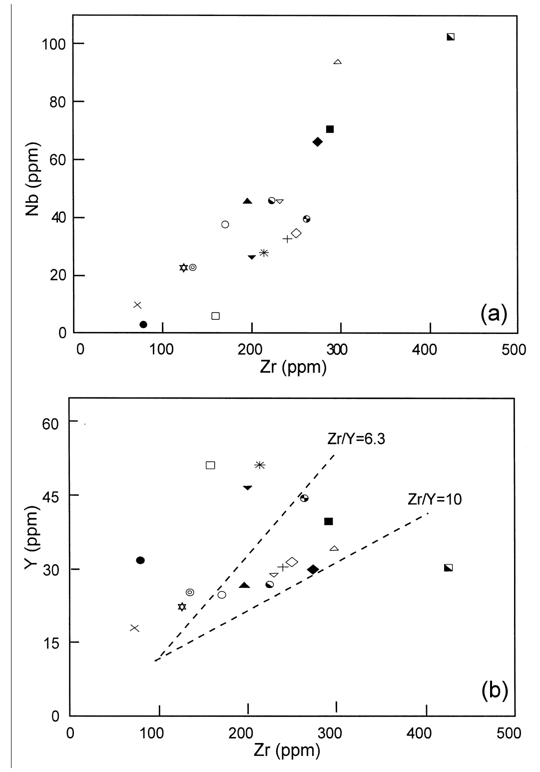


Fig. 9 Variation of *a*. Nb *versus* Zr; and *b*. Y *versus* Zr for the basaltic pillow lavas [5].

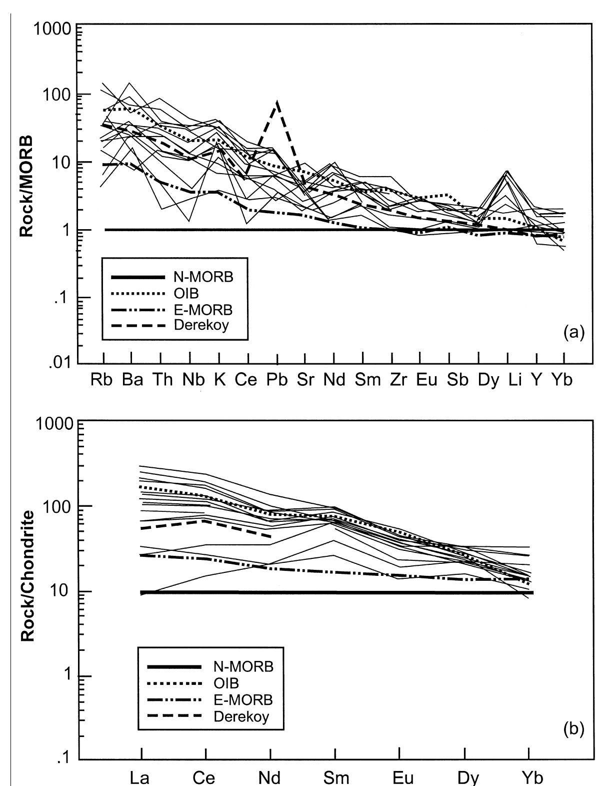


Fig. 10 *a*. Mantle normalized trace element variation diagram, and *b*. Chondrite normalized rare earth diagram for the basaltic pillow lavas. Normalization constants are from Sun and McDonough (1989) [26].

ophiolitic mélange in the region [4-5, 25]. On the V *vs.* Ti/1,000 diagram (Fig. 11d), OIB and MORB characters of the samples are seen with the Ti/V ratios of between 50-100 and 20-50, respectively. Basaltic pillow lavas have Zr/Nb ratio ranges between 4 and 8 more similar to E-MORB except KC43 (Zr/Nb = 23) and KC40 (Zr/Nb = 11) (E of

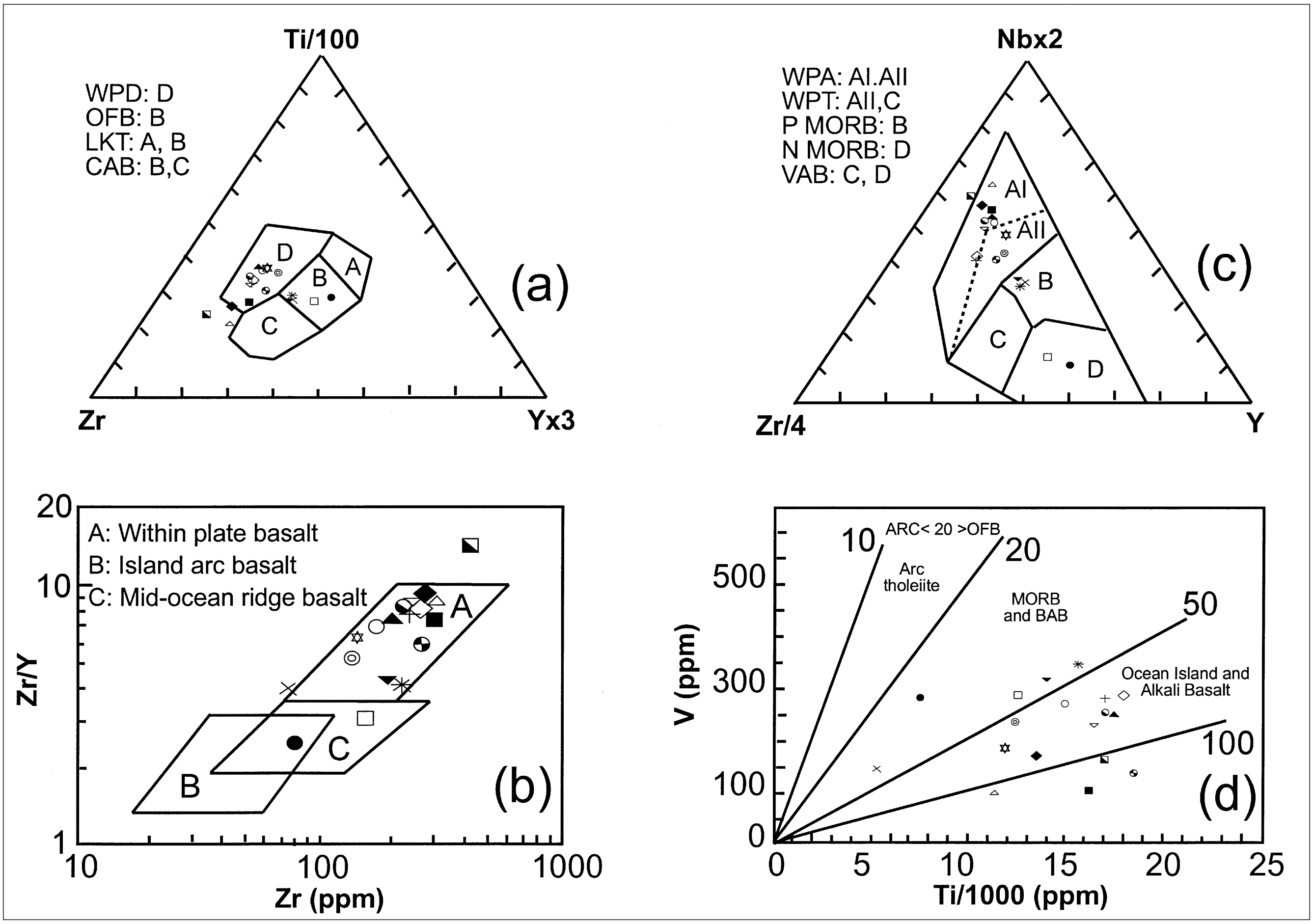


Fig. 11 Variation of *a*. Ti/100-Zr-Yx3 [39]; *b*. Zr/Y *versus* Zr [40]; *c*. Nbx2-Zr/4-Y [41]; and *d*. V *versus* Ti/1000 [42] for the basaltic pillow lavas.

Kalecik) that have higher ratios (N-MORB: Zr/Nb = 32) [26].

Most of the analyzed pillow lavas have an alkaline character in the Cretaceous ophiolitic mélange and come from a relatively enriched mantle source. Alkali basalts would be generated by low degrees of melting, and have high amounts of Zr, Nb, La and relatively high Zr/Y ratios compared to tholeiites (Table II), especially if garnet was present in the source. They have characteristically high incompatible element contents. The tholeiitic basalts have some features similar to MORB with low TiO_2, Nb, La and moderately high Zr/Nb. In this study, some basalts can be comparable to MOR type, whereas the majority are alkali basalts and similar to E-MORB with the enrichment of the more incompatible elements. E-MORB may be found in ridge segments or where there is a spreading axis under the influence of a nearby plume [28-29]. The chemical association between basalt types (MORB and OIB) from the region may indicate that some part of oceanic crust had developed at the earlier stage, whereas the dominant alkaline ocean island basalts developed subsequently.

5. Paleontology

The paleontologic surveys are carried out basically on foraminifers in intrafills between pillow basalt lobes (Fig. 3), bedded biodetrital carbonates and coralline carbonates with radiolarite and pillow basalt detritus. The best resolution is obtained from the pillow intrafills sampled in Dereköy area (SW of Ankara), and the biodetrital limestones and detrital coralline carbonates in Karacakaya (N of Ankara), Kalecik and Çandır (E of Ankara) areas.

Thin-shelled protoglobigerinid foraminifera (*Globuligerina* sp.), *Spirillina* sp., *Lenticulina* sp., epistominid foraminifers, nodasarids, agglutinated foraminifers, miliolids, *Cadosina* sp., crinoids, ammonoids and echinoid plates are identified in the pink, biomicritic calcareous infillings between the lava lobes of pillow basalts (intrapillow calcareous sediments) and a maximum age spectrum from Callovian to Barremian age is assigned to the infillings. However, the presence of thin-shelled protoglobigerinids and *Cadosina* associated with miliolids and epistominid foraminifers, in the absence of calpionellids, which are common in such pelagic facies in northern Anatolia [30-31], may indicate two possible narrower intervals for the formation of infills, Callovian to pre-Late Tithonian or Late Valanginian to Barremian interval.

Biodetrital carbonates with radiolarite and pillow basalt detritus consist of orbitolinid foraminifera and *Baccinella* with detritus of corals and rudists. This fossil assemblage includes *Paleorbitolina* sp. (possibly *P. lenticularis*) and *Mesorbitolina* or *Praeorbitolina* sp., *Haplophragmoides* sp., miliolids, and *Baccinella irregularis*. A Late Barremian-Early Aptian age is assigned to volcanic and radiolarite detritus-bearing orbitolinid and *Baccinella* biodetrital limestones.

As a result, the age of the intrafills can be broadly given as Callovian-Barremian due to the low resolution of paleontological data. However, the absence of calpionellids in the studied samples suggests that the age of the intrafills may be assigned either to Callovian to pre-Late Tithonian or Late Valanginian to Barremian intervals. The age of the biodetrital limestones is, however, much younger and assigned to Late Barremian-Early Aptian age.

6. Discussion and Conclusions

The pillow basalt blocks within the ophiolitic mélanges are important elements in identifying age relationships between the ophiolitic units and depositional environments prior to the development of the ophiolitic mélanges (Fig. 12).

In general, the pillow basalts are geochemically well studied, and the presence of Cretaceous seamounts was proved in the region between Dereköy (S of Ankara) and Çankırı (NE of Ankara) during the Mesozoic period [4-7, 20].

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 mantle plume source. As a result, the basalts that were sampled have an alkaline chemistry reflecting an

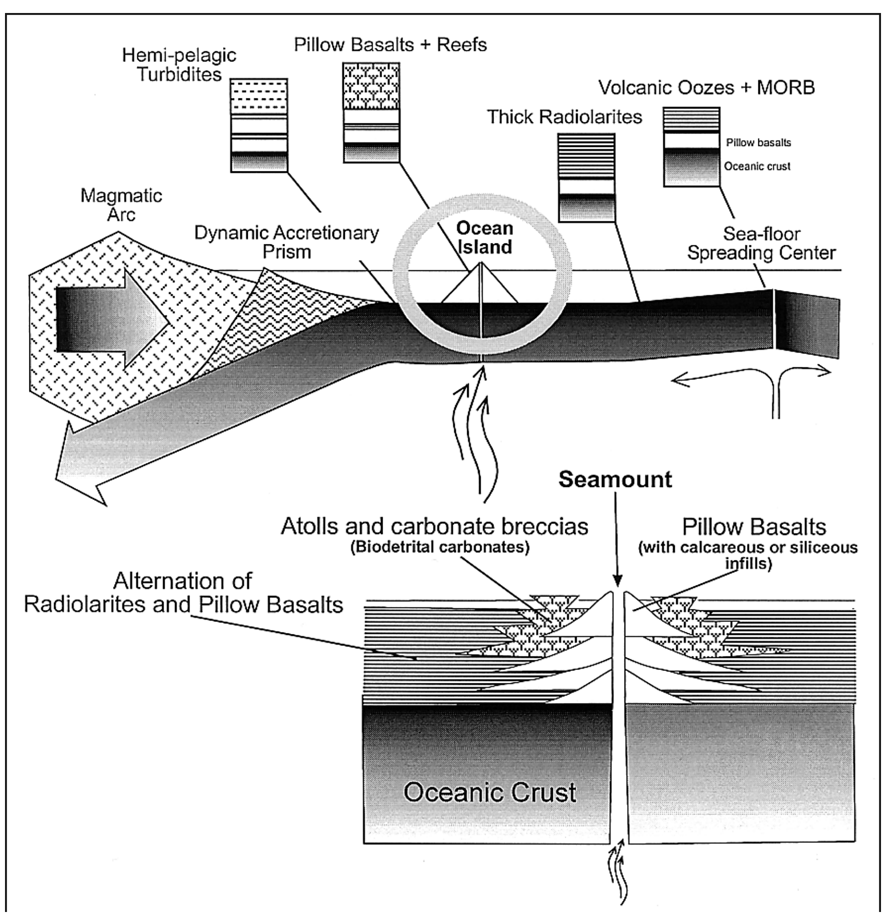


Fig. 12 Schematic cross-section showing possible cross-cutting relationship between Neotethyan oceanic crust and a seamount during the Cretaceous evolution of the northern branch of the Neotethys.

ocean-island basalt setting and may represent the products of an intra-plate hot spot on oceanic crust. Similar results are obtained from several researches carried out along IAES [4-6, 20, 25, 32] indicating the presence of OIB-type basalts within the Cretaceous ophiolitic mélange in Ankara region.

The chemical comparison of the various tectonic settings suggests an intraplate volcanic environment of an alkaline ocean-island environment and enriched MORB setting for the pillow basalts from Karacakaya to Haymana and to Çorum except the basalts from the east of Kalecik (Kızılırmak valley) that displays a MORB-like settings where the pillow basalts alternate with radiolarites along the eastern margin of Kızılırmak valley.

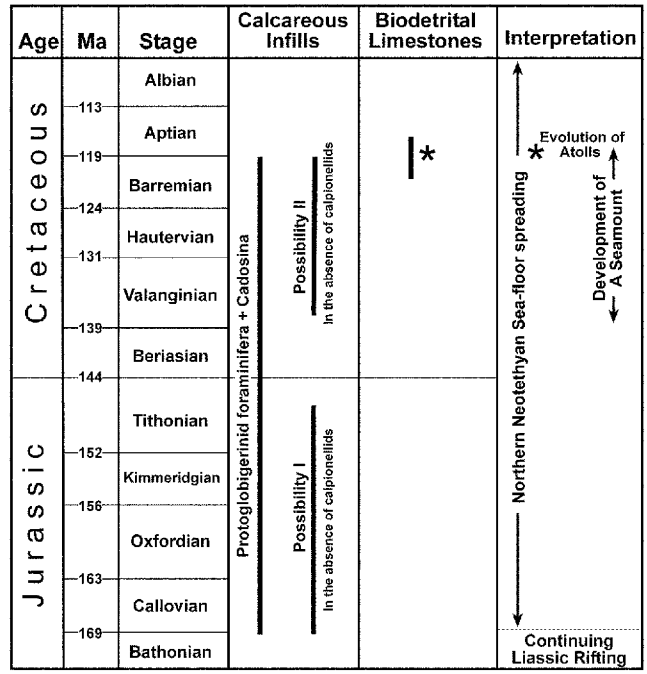
The only relative age dating of the pillow basaltic components of the ophiolitic mélange was presented by Boccaletti *et al.* (1966) on carbonates that are closely associated with pillow basalts (east of Kalecik, Ankara). The carbonates and radiolarites that alternate with pillow basalts are dated as Early to Late Jurassic, whereas the carbonates overlying the pillow basalt sequence are assigned to the Neocomian (?) to Aptian time span [3].

On the other hand, another age dating is carried out in dismembered blocks of radiolaria-bearing limestones and radiolarites. These are dated within a range of Late Norian to Late Albian—Turonian where Middle Jurassic radiolarites are missing in the region [18]. A composite dismembered section in south of Ankara supports this gap and a Late Oxfordian to Late Valanginian interval is documented with radiolarians [33]. However, the radiolaria-bearing limestone and radiolarite blocks dated in an age range of Late Norian to Late Albian—Turonian do 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 clearly interrelated. Without this, there might have been different oceanic basins in the Mesozoic Tethyan realm that diminished progressively over time.

In this study, the paleontologic dating is based on the carbonate fills between the pillow lobes and biodetrital carbonates closely associated with pillow basalts (Fig. 12). The carbonate fills between pillow lobes upon which we have concentrated our studies are not previously dated. The pillow basalts are dated as Callovian to Barremian age based on the presence of thin-shelled protoglobigerinid foraminifera and *Cadosina* within the intrapillow carbonate fills (Table III). However, the absence of calpionellids indicates two possible age intervals as Callovian to Early Tithonian or Late Valanginian to Barremian for the evolution of the seamount. The Callovian—Early Tithonian span is presumed to be too early for the evolution of a seamount in an evolving young oceanic crust in Mesozoic Tethys in Pontides due to the presence of a documented Triassic and Liassic regional discordances (e.g., [34-36]). Therefore, the Late Valanginian—Barremian age is preferred rather, to propose a coherent picture for the evolution of seamounts.

Table 3

Paleontological chart for the tectonic environmental interpretation of the OIB in central Anatolia.



In addition to the above age relations, the reefal carbonates closely associated with pillow basalts (Fig. 12) of the Late Valanginian—Barremian interval (representing atolls which could have developed around the seamount) were never detected in the study terrain. The presence of biodetrital limestones dated in an age range of Late Barremian—Early Aptian, are interpreted to be deposits around atolls present in north of Ankara region based on the presence of an orbitolinid and *Baccinella* fauna with volcanic detritus and corals [20] (Table III). Thus, the biodetrital reefal carbonates detected within pillow basalts reveal a younger age, Late Barremian to Early Aptian, indicating that seamounts evolved with atolls during that interval. Therefore, a Late Valanginian to Barremian interval is conformable with the Cretaceous geodynamics of the northern Neotethyan belt. The discussions above support the presence of a seamount with atolls in the Central Anatolian terrain during the Late Valanginian—Aptian interval.

Collectively, the sea-floor spreading in northern Anatolia should have started prior to the evolution of the seamount (dated as Late Valanginian—Barremian) and is younger than the Liassic rifting that is well-documented in the Pontides (the northern Neotethyan belt) (Table III).

Acknowledgements

The field surveys of this research are supported by the Scientific and Technical Research Council of Turkey's research project (TUBYTAK—YDABÇAG 392). The authors would like to thank Prof. Hall for his kind help in arranging trip to England and the laboratory facilities, Mrs. Diane Cameron, Miss Sue Hall and Mrs. Liz Whittaker for their kind assistance to Dr. Rojay in the geochemical analysis of rock samples in the Department of Geology, Royal Holloway, University of London, UK.

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