Taylor & Francis
Taylor & Francis Group

International Geology Review

ISSN: 0020-6814 (Print) 1938-2839 (Online) Journal homepage: http://www.tandfonline.com/loi/tigr20

Mid-Cretaceous Olistostromal Ophiolitic Mélange Developed in the Back-arc Basin of the Eastern Pontide Magmatic Arc, Northeast Turkey

Yener Eyuboglu , Osman Bektas & Dilek Pul

To cite this article: Yener Eyuboglu , Osman Bektas & Dilek Pul (2007) Mid-Cretaceous Olistostromal Ophiolitic Mélange Developed in the Back-arc Basin of the Eastern Pontide Magmatic Arc, Northeast Turkey, International Geology Review, 49:12, 1103-1126, DOI: 10.2747/0020-6814.49.12.1103

To link to this article: http://dx.doi.org/10.2747/0020-6814.49.12.1103

International Geology Review, Vol. 49, 2007, p. 1103–1126.

Mid-Cretaceous Olistostromal Ophiolitic Mélange Developed in the Back-arc Basin of the Eastern Pontide Magmatic Arc, Northeast Turkey

YENER EYUBOGLU,[1] OSMAN BEKTAS,

Karadeniz Technical University, Gümüşhane Engineering Faculty, Department of Geology, 29000 Gümüşhane, Turkey

AND DILEK PUL

The Ministry of Public Works and Settlement, 62100, Besirli, Trabzon, Turkey

Abstract

Geological and geochemical characteristics of the Mid-Cretaceous olistostromal ophiolitic mélange exposed in the southern part of the eastern Pontide magmatic arc indicates that it originally formed during the drifting stage of a back-arc basin (Neotethys). This view conflicts with the popular idea that this ophiolitic mélange represents a typical tectonic mélange or an accretionary prism developed in the fore-arc of the eastern Pontide magmatic arc by northward subduction of Neotethys or Paleotethys during the Cretaceous.

This Mid-Cretaceous ophiolitic mélange is composed of the three distinct lithological facies that may reflect a strike-slip cycle—from transtensional to transpressive tectonic regimes—in the deep spreading troughs of pull-apart basins. The lower part of the mélange is represented by redeposited carbonate rocks that occur as an upward thinning and fining sequence. The middle level of the mélange comprises basaltic pillow lavas, hyaloclastics, and intercalated pelagic sediments such as radiolarite, mudstone, and red pelagic limestone. The upper part of the mélange is represented by an olistolith-olistostromal facies that includes sandstone, siltstone, marl, and intervening olistoliths and olistostromes—mainly limestone, peridotite-gabbro, and metamorphic blocks derived from the continental shelf and a nearby peridotitic-metamorphic ridge.

Trace-element and REE contents of the basaltic rocks belonging to the Mid-Cretaceous ophiolitic mélange show distinct geotectonic settings (IA, WP, MOR) with various enrichment and depletion trends with respect to MORB and chondrite. Moreover, this ophiolitic mélange is overlain by analcime-bearing Upper Cretaceous-Paleocene(?) shoshonitic basalts in the Bayburt-Maden area. These geological and geochemical data imply that mélange formed in the back-arc basin of the eastern Pontide magmatic arc.

Introduction

OPHIOLITIC MÉLANGES—masses of mixed sedimentary and ophiolitic rocks—developed through processes of fragmentation and mixing (Hsü, 1968; Cloos, 1982; Raymond, 1984) occur at convergent (Raymond and Terranova, 1984; Tankut et al., 1998; Onen, 2003; Rojay et al., 2004), divergent (Dewey et al., 1973; Burchfiel, 1979; Marroni et al., 1998) and strike-slip (Reading, 1980; Einsele, 1992) plate boundaries. Ophiolitic mélanges are classified into two groups (tectonic and sedimentary mélanges) depending on the sedimentary or tectonic processes that gave rise to a particular deposit (Raymond and Terranova, 1984). Many mélange terranes are intensely deformed and include blocks of oceanic and continental material and high-P/low-T metamorphic rocks (Tankut et al., 1998). Therefore, recognition of ophiolitic mélange in orogenic belts is especially important for delineating ancient continental margins. Some ancient passive margins are eroded, such that deeper parts of the lithosphere are exposed. In the southern Alps, an entire section of the continental crust and several kilometers of its upper mantle are exposed (Burchfiel, 1980). Geological evidence indicates that this area was the site of a divergent plate boundary that evolved into a passive margin during the Mesozoic. Study of ancient passive margins permits the direct examina-

[1]Corresponding author; email: eyuboglu@ktu.edu.tr; obektas@ktu.edu.tr

0020-6814/07/967/1103-24 $25.00

tion of geological features produced at greater depths than those of modern plate margins. For example, Marroni et al. (1998) suggested that an Upper Cretaceous sedimentary mélange—including large slide-blocks of ophiolites and lower and upper continental crust rocks—are representative of a continent-ocean transition that reflects the opening of the Jurassic western Tethys. On the other hand, gulf-type pull-apart basins in the stage of early drifting include spreading centers (oceanic crust) and associated mass flow sediments (Einsele, 1992). The eastern Pontide ophiolitic mélange can be subdivided into: (1) a basement of redeposited carbonate rocks, including limestone breccia, calcarenite, and pelagic limestone; (2) submarine basalts intercalated with red pelagic limestone and radiolarites; (3) upper-level turbidite, including olistostromes with various types of blocks, derived from oceanic and continental lithosphere. The nature of the blocks gives important clues not only about the source of block material, but also about the processes of integration of this material into the depocentres of mélange formation. A sedimentary origin for the mélange units, for example, helps to constrain the nature of the environment of the deposition, evaluation of the source areas, and the magnitude of uplift of the mélange material, whereas a tectonic origin for the mélange units places significant constraints on the mechanics of growth and movement of accretionary wedges (Cloos, 1984).

In this paper, we suggest that the eastern Pontide olistostromal ophiolitic mélange is a typical strike-slip or divergent boundary mélange, in contrast to the popular collective suggestion that the eastern Pontide olistostromal ophiolitic mélange represents a typical accretionary wedge that developed at a south-facing convergent margin within the northern branch of Neotethys (Bailey and McCallien, 1953; Tankut et al., 1998). Instead, after Liassic rifting and formation of the Neotethys as a back-arc basin of the eastern Pontide magmatic arc, the first true deep-pelagic sediments (e.g., radiolarite and red pelagic limestone) and associated basaltic pillow lavas accumulated in the Mid-Cretaceous—corresponding to the drifting stage of Neotethys, but not the consuming stage. Similarly, our findings indicate that the WPB, MORB, and IA character of the Neotethyan oceanic crust during the Mid-Cretaceous developed by progressive partial melting of the supra-subduction mantle (from rifting to drifting stages), in contrast to the interpretation that the WPBs represent volcanic build-up and/or seamount-related volcanism on the Neotethyan oceanic floor (Tankut et al., 1998; Onen, 2003). On the other hand, ophiolitic mélange and ophiolites are found to be emplaced onto the Pontide and Anatolide/Tauride tectonic units by northward and southward thrusting, implying a positive flower structure (on a strike-slip fault zone) rather than a subduction zone.

Main Geological Features of the Eastern Pontides

Although the eastern Pontides coincide with a magmatic arc, the southern boundary is not precisely defined (Robinson et al., 1995). According to Bektaş et al. (1995), the eastern Pontides can be divided into three zones (northern, southern, and axial) based on characteristic lithological assemblages (Fig. 1) and gravity and magnetic data (Fig. 2). Each zone is separated by E-W–, NE-SW–, and NW-SE–trending fault zones that display the block-faulting tectonic style of the eastern Pontides (Bektaş and Çapkinoğlu, 1997; Eyuboglu et al., 2006). Insofar as these faults form boundaries along which the facies and thickness of the sediments change abruptly, relative uplift or subsidence may have occurred during Mesozoic sedimentation. These fault zones also control the alignment of Late Cretaceous calderas and intrusive rocks in the northern zone, and the extension of the Hercynian crystalline basement, the Pulur and Agvanis metamorphic massifs, and the Gümüşhane and Köse granites in the southern zone. (Fig. 1). The axial zone or back-arc basin of the eastern Pontides (Bektaş et al., 1984) or Anatolides (Ketin, 1966) is characterized by Alpine-type Cretaceous ophiolites and ophiolitic mélange.

The active, dextral North Anatolian fault and sinistral Northeast Anatolian fault—trending NW-SE and NE-SW, respectively—are parallel to the Mesozoic fault system, indicating that neotectonic activity was controlled by paleotectonics (Fig. 1). Moreover, Bouguer gravity, magnetic, and residual gravity anomalies also parallel paleo- and neo-fault systems, trending NW, E-W, and NE (Maden, 2005; Eyüboğlu et al., 2006).

Characteristic Magma Series of the Cretaceous in the Eastern Pontide Magmatic Arc

The eastern Pontide magmatic arc parallels the southeastern coast of the Black Sea. This arc

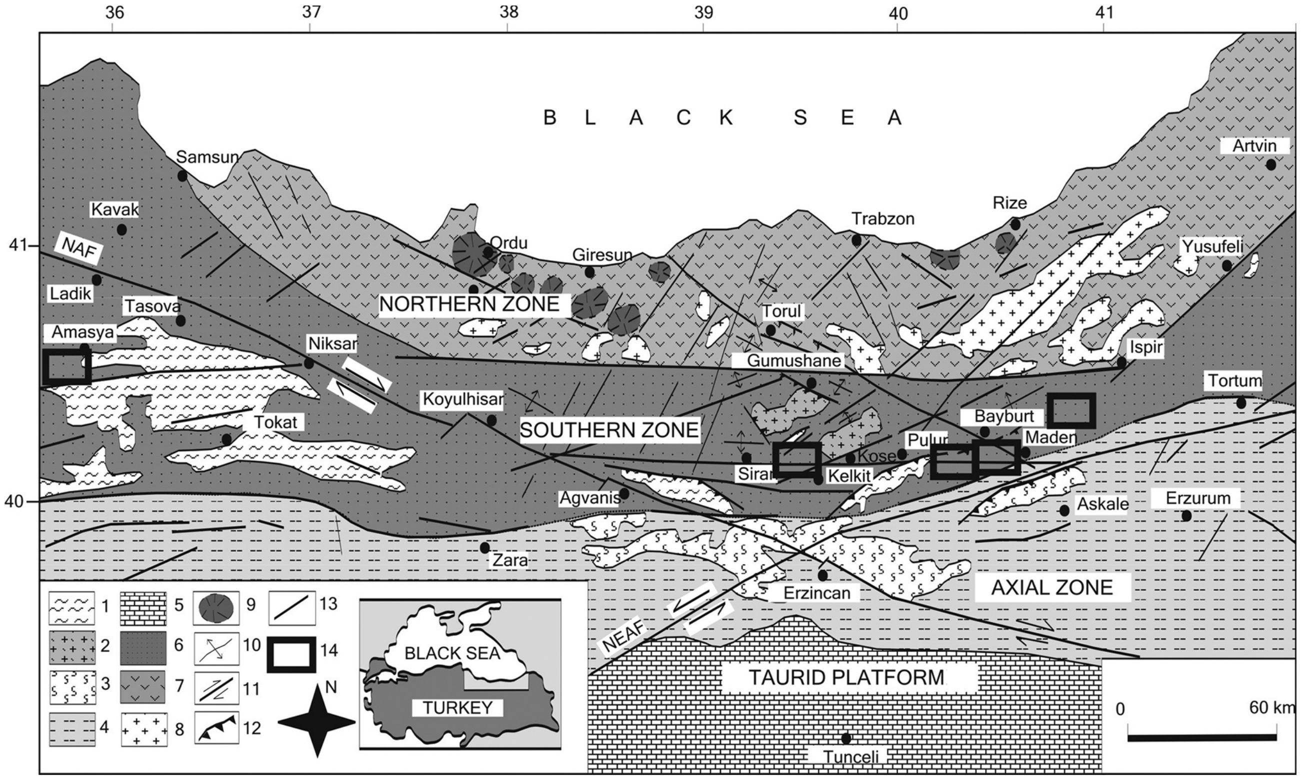

FIG. 1. Main tectonic features and tectonic zones of the eastern Pontides. Legend: 1 = Paleozoic metamorphic basement; 2 = Palaeozoic granites; 3 = serpentinite, 4 = undifferentiated Mesozoic and Cenozoic rocks; 5 = platform carbonate rocks; 6 = mainly Mesozoic sedimentary rocks; 7 = Cretaceous and Eocene arc volcanic rocks; 8 = Late Cretaceous and Eocene arc granites; 9 = caldera or dome; 10 = orthogonal drape and drag folds; 11 = fault; 12 = thrust fault; 13 = normal fault; 14 = study areas; NAF = North Anatolian fault; NEAF = Northeast Anatolian fault.

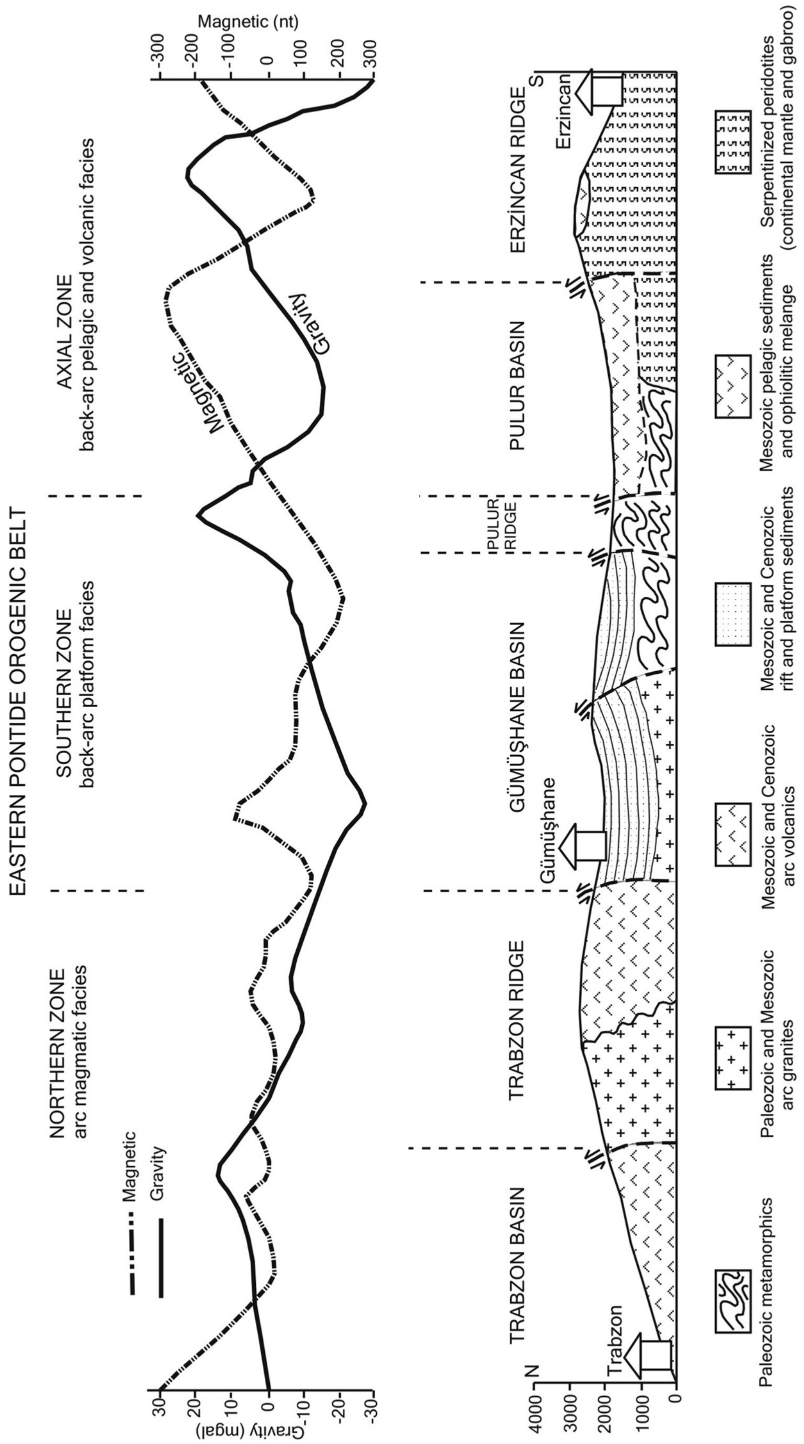

FIG. 2. Subtectonic units of the eastern Pontides (northern, southern, and axial zones), deduced from gravity and magnetic data (Maden, 2005).

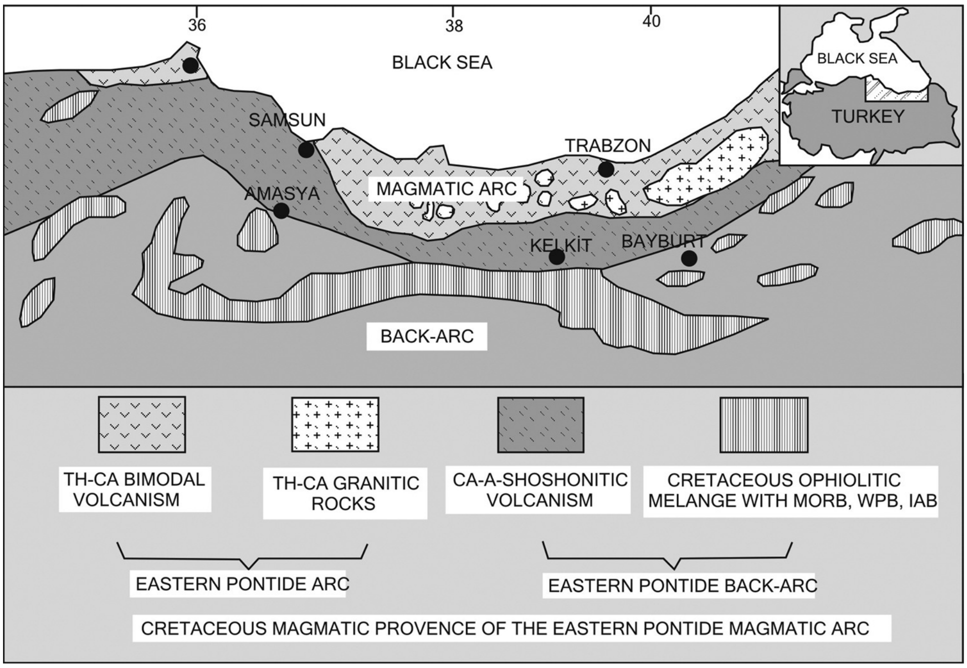

FIG. 3. Characteristic Cretaceous magma series in the eastern Pontide magmatic arc.

comprises three distinct Cretaceous magmatic provinces—TH, CA, and A, from north to south—reflecting the southward subduction polarity of the arc. Bimodal arc volcanism and associated Kuruko-type ore deposits and granitic rocks of the TH-CA provinces are widespread in the northern zone of the magmatic arc (Fig. 3). Farther south, the intensity of Cretaceous arc volcanism decreases, and volcanism changes from bimodal (basalts and dacites) to monogenic CA andesites in the southern zone. In addition to these, Cretaceous volcanism began before Campanian sedimentation of the red pelagic limestones, in the northern zone and post-Campanian in the southern zone. This temporal change in magmatism implies the migration of Late Cretaceous arc magmatism from north to south and from TH to CA along the south-facing subduction zone. The back-arc side of the eastern Pontide magmatic arc is characterized by shoshonitic volcanism (CA-A)—exposed in the southern and axial zones during the Cretaceous—in which two belts of Cretaceous ophiolitic mélange extend E-W (Fig. 3). Cretaceous basaltic lavas belong to the ophiolitic mélanges, with geochemical characteristics of MOR, WP, and IA basalts. These distinct geochemical characteristics imply a back-arc basin geotectonic environment (Smedley, 1986; Bektaş et al., 1987).

Geologic and Geotectonic Position of the Eastern Pontide Ophiolitic Mélanges

The Cretaceous ophiolitic mélange, extending E-W, is composed of two distinct parallel belts surrounding the eastern Pontide magmatic arc to the south. The Mid-Cretaceous ophiolitic mélange extends from the city of Amasya, through Kelkit, to the city of Bayburt, on the back-arc side of the eastern Pontide magmatic arc (Bektaş et al., 1984). The Upper Cretaceous ophiolitic mélange is the other parallel belt lying farther south, near the cities of Erzincan and Sivas, in the same geotectonic environment. Although the Mid- and Upper Cretaceous ophiolitic mélanges have many similar properties, herein we will only treat the Mid-Cretaceous ophiolitic mélange.

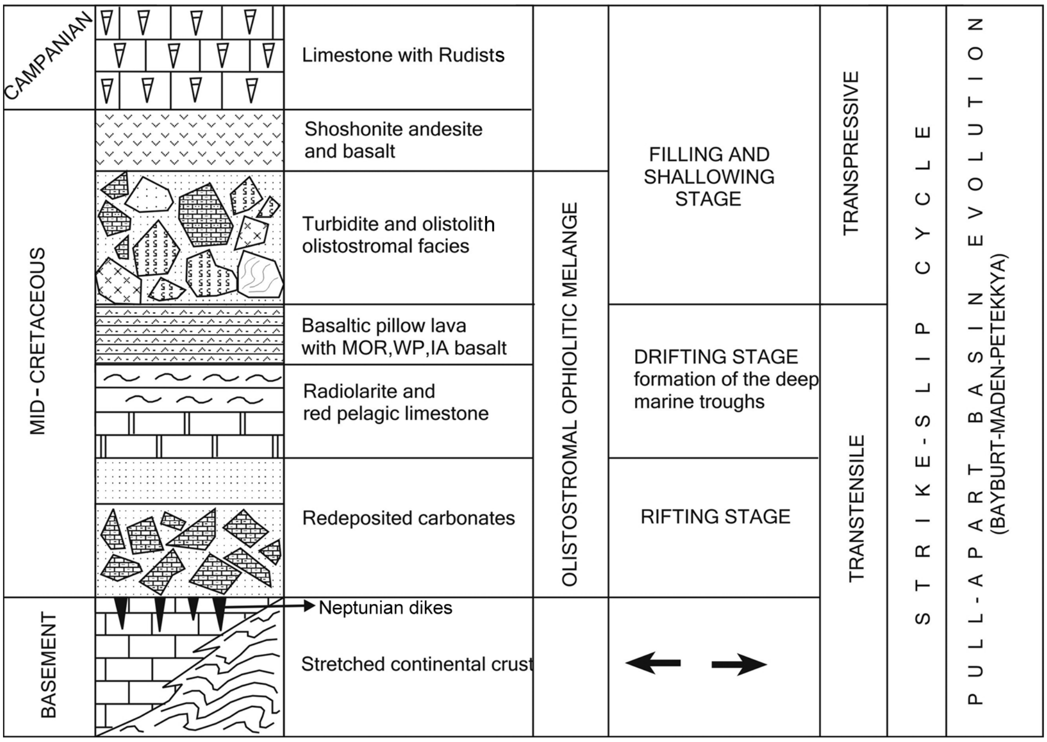

FIG. 4. Internal stratigraphy of the Mid-Cretaceous ophiolitic mélange.

Main Geological Features of the Mid-Cretaceous Ophiolitic Mélange

In addition to its internal stratigraphy and lithofacies, its sedimentary contact with basement (Fig. 4) suggests that the Mid-Cretaceous ophiolitic mélange is not a typical accretionary prism developed in the fore-arc of the eastern Pontide magmatic arc by northward subduction. The chaotic structure of the mélange developed via sedimentary processes, such as gravity sliding and slumping, rather than through tectonic events. Accordingly, this mélange is classified as olistostromal ophiolitic mélange (Raymond and Terranova, 1984).

Nature of the basement rocks of the mélange

The Mid-Cretaceous ophiolitic mélange is exposed, along with its basement, and displays a typical intact section, reflecting its internal structure and stratigraphy in places where these were preserved from subsequent tectonic events (Fig. 4). Basement rocks of the mélange comprise uplifted and eroded platform carbonate rocks, pelagic carbonate rocks of the Malm Lower Cretaceous, and metamorphic-peridotite assemblages that were exposed on the seafloor prior to Mid-Cretaceous time in the areas of the present-day cities of Amasya and Bayburt (Fig. 4). Different members of the redeposited Mid-Cretaceous carbonate rocks—limestone breccia to calcarenite and red pelagic limestone-radiolarite— overlap the different types of basement rocks in these asymmetric basins.

Internal stratigraphy of the mélange

The Mid-Cretaceous ophiolitic mélange is composed of the three distinct lithological facies that may reflect a strike-slip cycle, from transtensional to transpressive tectonic regimes, in the deep spreading troughs of pull-apart basins (Reading, 1980; Einsele, 1992). The lower part of the mélange is represented by redeposited carbonate rocks that show a thinning and fining upward sequence—from monogenic limestone breccia, through calcarenite, to red pelagic limestone-radiolarite (Fig. 4). The thickness and mode of distribution of the redeposited carbonate rocks on the basement rocks suggest basin asymmetry in the half graben.

The middle levels of the mélange comprise basaltic pillow lavas and hyaloclastics, and intercalated pelagic sediments—such as radiolarite, mudstone, and red pelagic limestone—in Bayburt province (Lipana-Kelkit-Petekkaya) and the city of Amasya (Fig. 5). The upper level of the mélange is represented by an olistolith-olistostromal facies, comprising sandstone, siltstone, marls, and intervening olistoliths and olistostromes—mainly limestone, peridotite-gabbro, and metamorphic rock (Fig. 5) derived from a continental shelf and nearby peridotitic-metamorphic ridge.

Cover of the mélange

The Mid-Cretaceous ophiolitic mélange is overlain by shoshonitic andesite, pyroclastic rocks, and succeeding reefal limestone with Campanian rudists in the cities of Bayburt and Amasya (Figs. 4 and 5). The Paleocene is represented by a lagoonal facies and associated analcime-bearing shoshonitic basalts as mélange cover in the Bayburt-Maden and Amasya areas.

City of Amasya

The nature of the basement rocks and lower contacts of the ophiolitic mélange are well displayed near the Amasya city center and in Karasenir village, 10 km south of Amasya. The Mid-Cretaceous ophiolitic mélange has depositional lower contacts with the underlying extended continental and transitional crusts in the Amasya area (Fig. 5). The continental and transitional crusts are represented by the platform and pelagic carbonate rocks of the Malm–Lower Cretaceous system and a peridotite-gabbro-parametamorphite association, respectively. The extension of the carbonate platform and the formation of a half graben during the Mid-Cretaceous are manifested by the presence of neptunian dikes in the platform carbonate rocks and rift-related redeposited carbonate rocks, which constitute a thinning and fining upward sequence that accumulated above the basement rocks, with neptunian dikes in the Amasya city center. The dikes in the platform carbonate rocks occur in vertical crack zones that are filled and overlain by Albian red pelagic limestones of the mélange (Bektaş et al., 2001; Eyüboğlu et al., 2006). These relationships imply that the contact between the platform carbonate rocks and the ophiolitic mélange was originally sedimentary, not tectonic. However, in many places, these types of contacts became tectonic through the post-Cretaceous inversion of the basins. On the other hand, near Karasenir village, 10 km south of Amasya, the pelagic facies of the mélange—comprising radiolarites and alternating red pelagic limesones—has a transitional lower contact with platform carbonates rocks and Malm–Lower Cretaceous pelagic carbonate rocks. These two distinct sedimentary lower contacts of the mélange imply that the sedimentary mélange formed by break-up of the carbonate platform, on the hanging walls and footwalls of listric faults that were active during the Mid-Cretaceous.

City of Bayburt

The Mid-Cretaceous ophiolitic mélange exposed near Bayburt has similar lower sedimentary contacts with the underlying extended continental and transitional crust. Redeposited carbonate rocks derived from the platform accumulated on eroded Malm–Lower Cretaceous platform carbonate rocks (Bayburt-Maden and Lipana villages, Kelkit) or on metamorphic rocks (Bayburt-Petekkaya village), and pass into the pelagic facies of the mélange, such as radiolarites and Mid-Cretaceous red pelagic limestone (Figs. 4 and 5).

Geochemistry and Geotectonic Classification of Basalts in the Mélange

Representative samples of basaltic lava were collected from six different locations (Petekkaya, Kelkit, Maden, Lipana, Karasenir, and the Amasya city center) for geochemical studies, and were analyzed at ACME Analytical Laboratories (Canada) by inductively coupled plasma/mass spectrometry (ICP/MS). The results of major-, trace-, and rare-earth element analyses of the samples are given in Tables 1 and 2. Basalts in the mélange are altered and spilitized. However, many studies have shown that high-field-strength elements (HFSE) and rare-earth elements (REE) in magmatic rocks are not affected during alteration (Pearce and Norry, 1979). Therefore, we have used trace and REE elements, immobile during alteration, for elucidating the magma genesis and geotectonic settings of the basalts. Geochemistry of the back-arc basin basalts vary widely because of different water content provided by subducting slab (Taylor and Martinez, 2003; Wiens et al., 2006). The basaltic lavas of the Middle Cretaceous ophiolitic olistostromal mélange

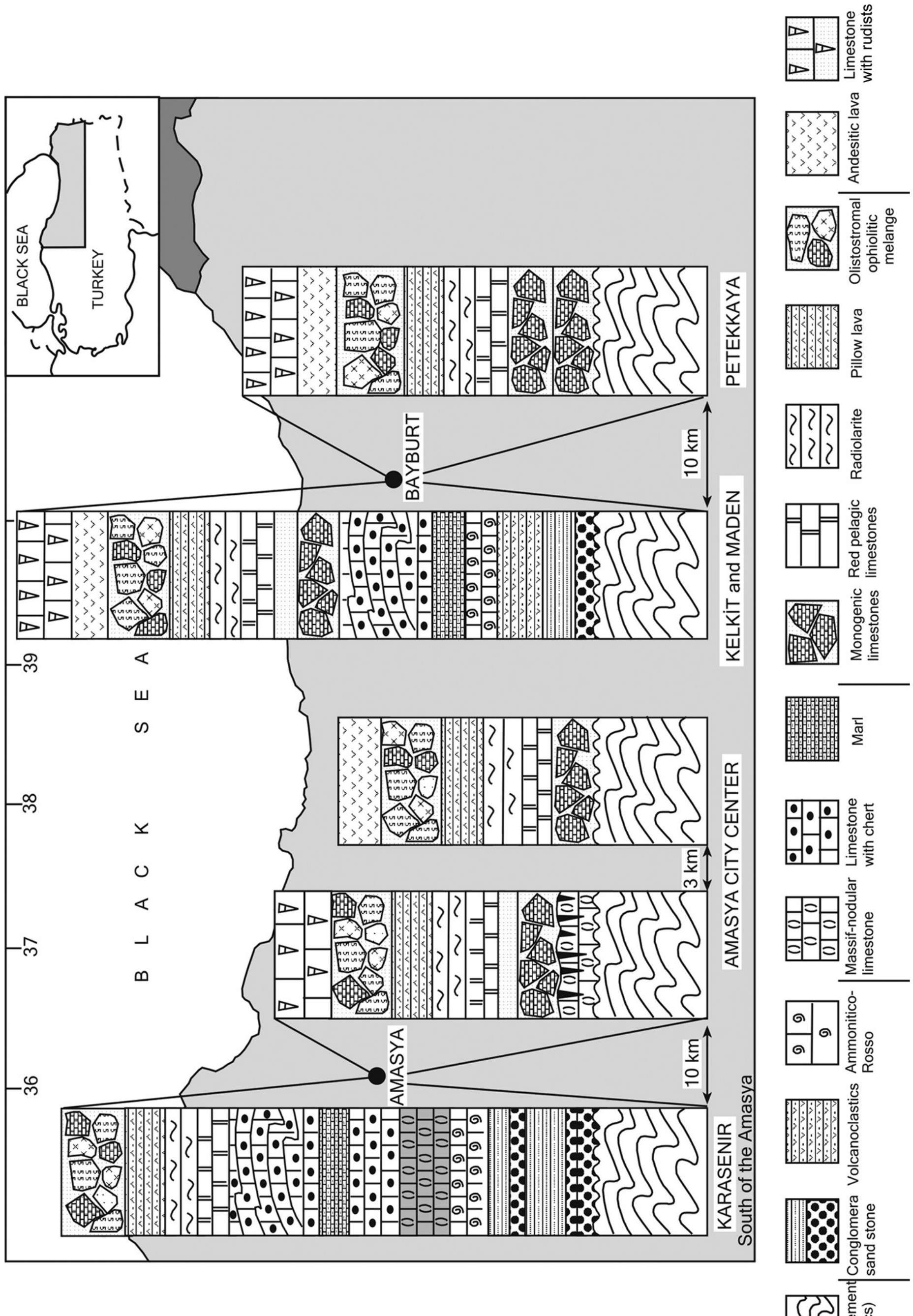

FIG. 5. Stratigraphic relations of the Mid-Cretaceous ophiolitic mélange in the Bayburt and Amasya areas.

TABLE 1. Results of Major- and Trace-Element Analyses of Basalts of the Ophiolitic Mélange

	Bayburt area											Amasya area				
	Lipana			Petekkaya			Maden			Kelkit		Moramil			Karasenir	
Sample:	Li-2	Li-3	Li-10	PT-5	PT-9	PT-6	M-14	M-2	M-3	K-4	K-2	M-5	M-9	M-10	M-15	KA-4
SiO_2	45.25	51.46	49.86	45.37	48.23	45.37	51.93	46.57	49.26	40.54	49.27	46.53	54.5	45.11	43.99	52.36
TiO_2	1.05	1.11	1.13	1.34	1.31	1.31	2.44	0.89	0.89	2.75	0.94	1.00	0.25	1.13	1.02	1.04
Al_2O	14.40	15.41	15.65	14.22	13.8	14.16	16.23	15.08	14.81	14.46	15.98	14.47	14.18	14.55	14.09	17.12
Cr_2O3	0.047	0.048	0.05	0.014	0.017	0.018	0.013	0.048	0.047	0.026	0.045	0.03	0.04	0.035	0.028	0.002
Fe_2O_3*	9.09	9.18	9.18	8.42	9.26	7.35	11.43	8.50	8.46	12.7	9.95	9.81	8.88	10.69	10.64	7.78
MgO	5.05	4.47	4.69	5.97	6.73	5.87	2.82	5.93	6.24	7.41	3.71	4.75	7.53	5.23	5.56	2.79
MnO	0.27	0.24	0.24	0.13	0.13	0.14	0.17	0.16	0.16	0.17	0.23	0.12	0.13	0.15	0.15	0.16
CaO	13.64	11.03	11.44	9.30	9.97	12.22	3.37	10.96	9.49	7.79	6.87	11.77	6.63	11.59	12.60	9.05
Na_2O	3.26	3.25	3.14	5.05	4.08	4.15	7.33	4.21	4.56	4.48	6.20	4.28	2.73	3.69	3.75	4.22
K_2O	0.27	0.17	0.15	0.79	0.59	0.55	n.d.	0.31	0.33	0.09	0.10	0.03	0.59	0.26	0.08	2.44
P_2O_5	0.15	0.15	0.14	0.17	0.16	0.14	0.95	0.08	0.09	0.59	0.13	0.11	0.03	0.14	0.11	0.43
LOI	7.60	3.40	4.30	8.70	5.70	8.90	3.20	7.00	5.60	10.20	6.90	7.00	4.40	7.40	8.90	2.10
Total	100.11	99.97	100.00	99.51	100.01	100.21	99.92	99.76	99.95	99.24	99.64	99.93	99.92	99.99	100.00	99.39
Cs	n.d.	n.d.	n.d.	0.3	n.d.	n.d.	n.d.	0.2	n.d.	1	n.d.	n.d.	0.2	n.d.	n.d.	2.4
Rb	3.7	1.7	1.4	0.9	4.2	4.9	n.d.	7.8	8.0	2.1	1.3	0.7	6.5	5.2	1.3	62.6
Ba	155.0	212.0	151.0	128.0	201.0	189.0	132	36.0	28.0	221.0	211.0	123.0	44.0	104.0	76.0	888.0
Sr	229.7	194.6	190.7	276.1	366.5	352.4	316.2	331.2	489.6	186.5	711.5	98.9	173.6	123.8	113.6	859.6
Y	24.8	26.8	27.4	28.5	26.1	25.0	38.3	23.4	24.1	27.0	27.3	30.4	6.6	43.4	32.9	26.0
Zr	56.0	63.0	66.2	81.4	78.6	81.4	240.0	44.7	47.5	230.1	47.6	44.9	20.5	52.1	49.3	151.7
Hf	1.6	2.1	2.4	2.5	1.8	2.3	6.2	1.5	1.5	6.1	1.2	1.7	n.d.	1.7	1.8	4.1
Pb	0.8	0.8	0.6	2.2	1.7	1.4	5.8	0.4	0.3	4.1	34.2	0.5	0.7	0.4	0.4	68.0
Zn	53.0	61.0	57.0	65.0	61.0	67.0	66.0	49.0	46.0	101.0	138.0	61.0	58.0	79.0	68.0	67.0
Ni	95.4	117.5	123.0	64.0	48.7	67.2	61.6	94.1	79.2	50.5	110.0	70.2	74.3	69.2	78.8	2.4
V	228.0	265.0	273.0	234.0	223.0	222.0	178.0	205.0	216.0	275.0	209.0	247.0	225.0	267.0	268.8	199.0
Cr	470.0	480.0	500.0	140.0	170.0	180.0	130.0	480.0	470.0	260.0	450.0	300.0	420.0	350.0	280.0	20.0
Sc	36.0	36.0	37.0	35.0	34.0	35.0	21.0	33.0	34.0	21.0	35.0	32.0	41.0	36.0	33.0	15.0
Nb	8.7	10.4	10.1	9.8	8.9	10.0	81.0	1.4	1.4	68.1	1.3	0.6	n.d.	0.70	0.8	13.1
Ta	0.5	0.6	0.5	0.6	0.4	0.5	4.8	n.d.	1.7	3.8	n.d.	n.d.	n.d.	n.d.	n.d.	0.8
U	0.2	0.2	0.2	1.8	1.0	1.6	1.3	n.d.	n.d.	1.8	n.d.	0.3	0.2	0.3	0.1	3.6
Th	0.9	1.3	0.8	0.7	0.9	1.1	10.3	n.d.	n.d.	5.8	0.2	0.1	0.1	n.d.	0.4	14.1

TABLE 2. Results of Rare-Earth Element Analyses of Basalts of the Ophiolitic Mélange

	Bayburt area											Amasya area				
	Lipana			Petekkaya			Maden			Kelkit		Moramil			Karasenir	
Sample:	Li-2	Li-3	Li-10	PT-5	PT-9	PT-6	M-14	M-2	M-13	K-4	K-2	M-5	M-9	M-10	M-15	KA-4
La	7.70	7.70	7.20	8.20	7.50	8.10	61.90	2.00	2.00	50.80	2.90	1.60	1.70	2.000	2.00	46.90
Ce	16.5	16.40	17.60	21.30	19.50	19.40	117.30	6.10	6.10	101.10	6.50	5.30	2.70	6.80	6.00	94.60
Pr	2.09	2.28	2.14	2.73	2.36	2.50	12.64	1.10	1.06	11.67	1.27	0.97	0.42	1.20	1.11	10.35
Nd	10.8	11.90	11.00	13.1	10.40	11.50	49.90	5.00	6.90	50.70	6.40	6.50	1.80	8.80	7.90	46.60
Sm	2.90	2.90	2.80	3.70	3.10	3.30	8.80	2.30	2.30	8.50	2.10	2.30	0.70	2.90	2.80	9.10
Eu	0.82	0.91	0.95	1.20	1.16	1.13	2.62	0.82	0.77	2.71	0.90	0.83	0.22	1.34	0.95	2.39
Gd	3.63	3.39	2.96	4.26	3.61	3.69	7.90	2.85	3.11	6.83	3.56	3.37	0.83	4.75	3.73	7.05
Tb	0.74	0.63	0.69	0.87	0.78	0.87	1.19	0.60	0.69	1.12	0.73	0.69	0.17	1.00	0.81	0.95
Dy	3.80	4.04	4.01	4.84	4.35	4.20	6.57	3.57	3.95	5.35	4.06	4.03	1.04	5.59	4.58	5.05
Ho	0.84	1.00	0.89	1.01	0.96	0.89	1.24	0.84	0.87	1.03	0.91	1.05	0.27	1.41	1.07	0.87
Er	2.23	2.61	2.65	2.99	2.54	2.70	3.58	2.55	2.77	1.03	0.91	2.95	0.77	3.93	3.15	2.35
Tm	0.34	0.41	0.40	0.44	0.41	0.33	0.50	0.37	0.39	0.38	0.43	0.40	0.13	0.57	0.49	0.33
Yb	2.25	2.56	2.55	2.52	2.50	2.47	3.04	2.60	2.23	2.13	2.56	2.90	0.82	3.38	2.62	1.89
Lu	0.33	0.44	0.37	0.36	0.34	0.41	0.47	0.37	0.39	0.31	0.40	0.41	0.15	0.59	0.43	0.28
(La/Yb)n	2.31	2.03	1.90	2.19	2.02	2.21	13.73	0.52	0.60	16.08	0.76	0.37	1.40	0.40	0.51	16.73
Eu/Eu*	0.77	0.89	1.01	0.92	1.06	0.99	0.96	0.98	0.88	1.08	1.01	0.91	0.88	1.10	0.90	0.91

are of tholeiitic character except for two samples, as shown in the Nb/Y versus Zr/P_2O_5 diagram (Fig. 6).

Spider diagrams of MORB-normalized trace-element values for basaltic pillow lavas (Fig. 7) from the Amasya and Bayburt areas show apparent deflections in Ti, Zr, Y, and Nb from those of normal MORB, suggesting that synchronous basalts are of polygenetic origin, namely the IAB, MORB, and WPB associations of back-arc basins (Bektaş et al., 1984; Smedley, 1986; Farahat, 2004). A chondrite-normalized REE diagram for the same basaltic pillow lavas of the mélange (Fig. 8) also suggests a polygenetic origin, yielding trends characteristic of the MORB, WPB, and IAB associations of back-arc basins. At the very least, the IA affinities of the basalts (Fig. 7) imply that they formed in a geotectonic environment related to subduction (Shervais, 2001).

Moreover, most basalts from the eastern Pontide ophiolitic mélange plot in the within-plate, mid-ocean ridge and island-arc fields on the Zr-Ti, Zr-Zr/Y, and TiO_2-MnO-P_2O_5*10 diagrams (Fig. 9). The association of basaltic rocks from these distinctive geotectonic settings may be explained using a back-arc basin model.

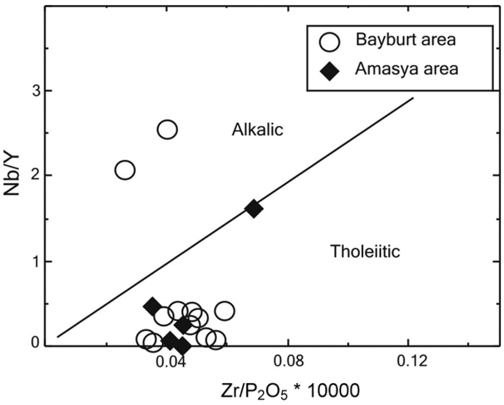

FIG. 6. Nb/Y versus Zr/P_2O_5 diagram for the analyzed basaltic rocks (Winchester and Floyd, 1976).

Classification of the Mélange

Most researchers have considered that the Mid-Cretaceous ophiolitic mélange represents a tectonic mélange that developed at the southern active margin of the eastern Pontides (Tankut et al., 1998; Onen, 2003; Rojay et al., 2004). However, our field and geochemical evidence suggest that the mélange formed along the southern passive margin of the eastern Pontides during the sea-floor spreading stage of Neotethys. The matrix of the mélange comprises pelagic and fine-grained detrital sediments that do not show widespread, intensive shearing. The chaotic internal structure of the ophiolitic mélange was mainly produced by gravity sliding and the formation of ophiolitic olistoliths and olistostromes. Thus, we classify the Mid-Cretaceous ophiolitic mélange with its sedimentary fabric not as a tectonic ophiolitic mélange, but rather as a sedimentary olistostromal ophiolitic mélange.

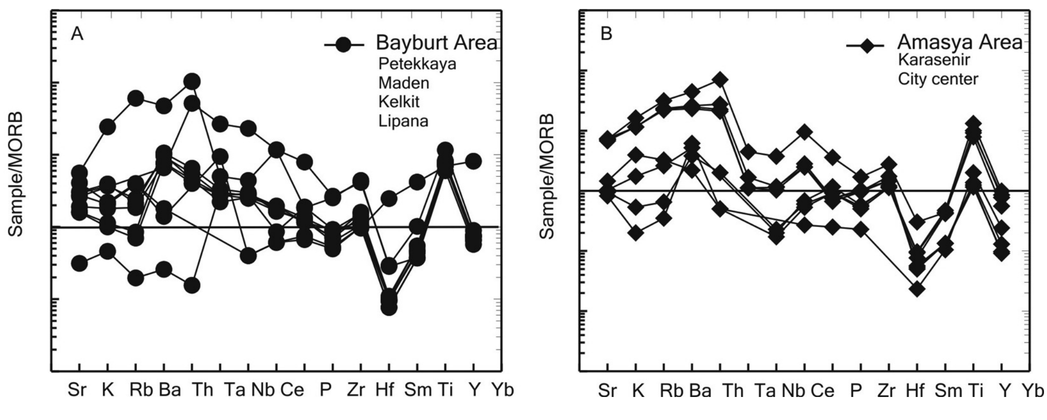

FIG. 7. MORB-normalized trace-element spider diagrams for the analyzed basaltic rocks. A. Bayburt area. B. Amasya area. Normalization values from Sun and McDonough (1989).

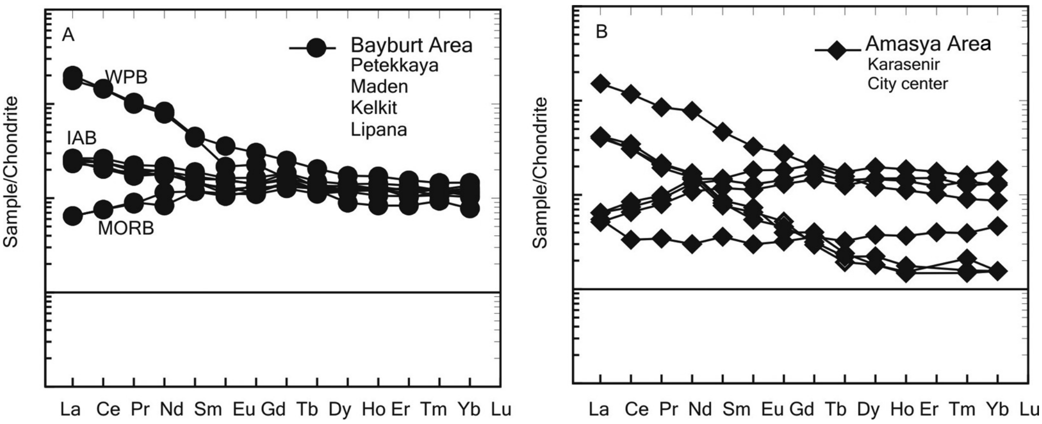

FIG. 8. Chondrite-normalized rare-earth element variation diagrams of the basaltic rocks. A. Bayburt area. B. Amasya area. Chondrite data from Taylor and McLennan (1985).

Formation of Mélange in Strike-Slip Cycles

In the eastern Pontides, after the break-up of the Malm–Lower Cretaceous carbonate platform during the transtensional tectonic regime, the deep Cretaceous basins—with radiolarite and associated basalts—formed diachronously in the Mid- and Late Cretaceous (Figs. 10 and 11). These deep Cretaceous basins are interpreted as deep spreading troughs that developed in the drifting stage of Neotethys, which opened via Liassic rifting as a back-arc basin in the southern zone of the Pontide magmatic arc. On the other hand, opening and closing of the deep basins at a coeval Cretaceous spreading center characterized the strike-slip tectonic regime. As the Middle Cretaceous deep troughs were filled and deformed during the Campanian in the Amasya, Kelkit, and Bayburt areas, new spreading centers with similar orientations developed farther south along a line extending from Erzincan to Sivas. In addition to the "duality" of the deep Cretaceous basins, the internal stratigraphy and lithofacies of the basins support the idea of a strike-slip tectonic regime in the eastern Pontides. Therefore, we suggest that three distinct lithological facies of the mélange can be explained by strike-slip cycles, without subduction of a large ocean, such as the Atlantic or Pacific.

Strike-slip cycles of the Mid-Cretaceous basins included two main phases: (1) transtension and formation of the deep spreading troughs; and (2) transpression and basin filling.

Transtensional Phase and Formation of the Deep Spreading Troughs

After Liassic rifting of the eastern Pontide magmatic arc and following Malm–Early Cretaceous thermal subsidence, a second Mesozoic rifting episode began with the break-up of the carbonate platform (Figs. 10 and 11). Tectonic subsidence in the Mid-Cretaceous corresponds to the accumulation of redeposited carbonate rocks, derived from monogenic carbonate breccias and calcarenite to pelagic limestone. The asymmetric distribution of rift-related sediments suggests that further extension might have allowed true oceanic crust to form, giving rise to ophiolites and associated deep pelagic sedimentation in the deep troughs of the present-day Amasya-Bayburt area (seafloor stage of Neotethys). The Gulf of California is the best modern analogue of this type of setting (Einsele, 1992).

Transpressional Phase and Basin Filling

Mid-Cretaceous deep basins influenced sedimentation and volcanism in the Amasya-Bayburt area. These changes are apparent from the accumulation of clastic sediments rather than pelagic sediments, and the cessation of basaltic volcanism and the initiation of high-K CA andesitic volcanism, the products of which comprise cover of the mélange. Further filling and shallowing of the deep spreading troughs caused deposition of reefal limestones in the Campanian. The Palaeocene is represented by

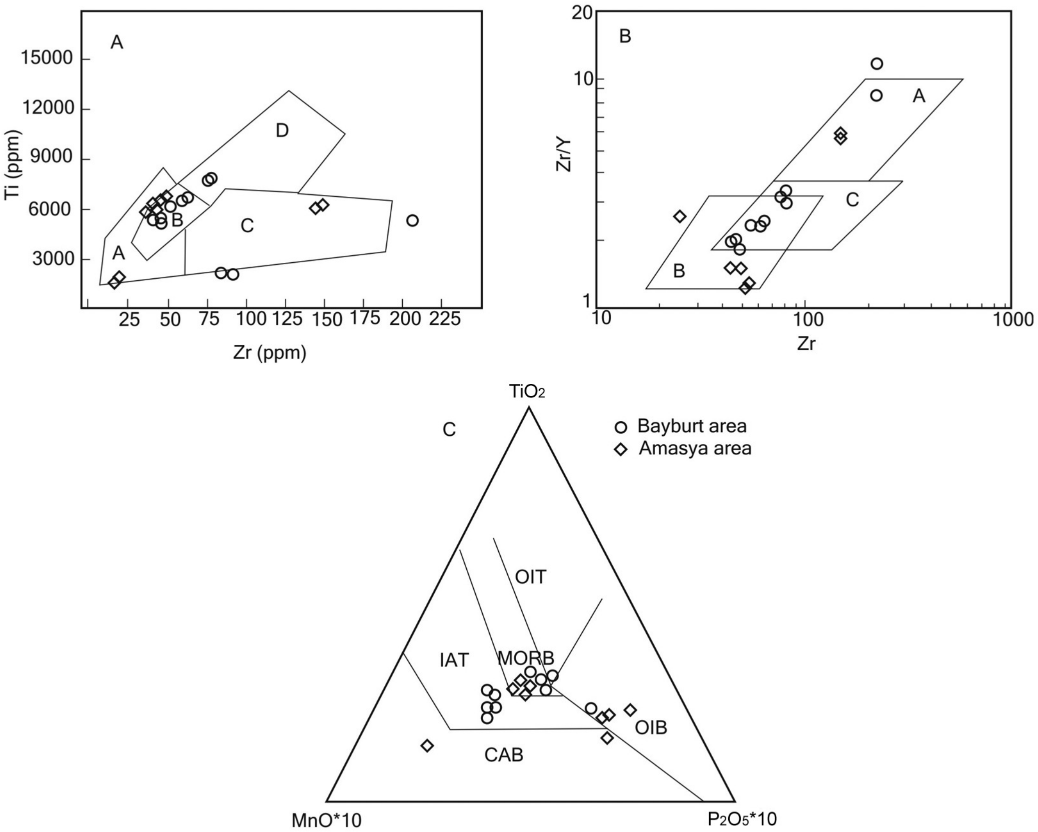

FIG. 9. Tectonic-setting discrimination diagrams for the basaltic rocks in the mélange. A. Ti versus Zr diagram (Pearce and Cann, 1973). Legend: A and B = IA basalts; B and C = CA basalts; B and D = MOR basalts; D = WP basalts. B. Zr/Y versus Zr diagram (Pearce and Norry, 1979). Legend: A = WP basalts; B = IA basalts; C = MOR basalts. C. TiO_2-MnO*10-P_2O_5*10 diagram (Mullen, 1983).

continental sedimentation and associated shoshonitic basaltic volcanism in the uppermost levels of the mélange in the Bayburt-Maden district. CA and shoshonitic volcanic products that cover the ophiolitic mélange imply that the mélange formed in the back-arc part of the eastern Pontide magmatic arc—in the deep pull-apart basins of southern zone. Mid-Cretaceous closing of the deep pull-apart basins in the Bayburt area was compensated for by the opening of the new (Campanian) deep spreading troughs farther south in Erzincan; this also suggests that deep spreading troughs of the pull-apart basins formed diachronously, depending upon the strike-slip tectonic regime in the back-arc basin of the eastern Pontide magmatic arc.

Fault Model for the Mesozoic Basins of the Eastern Pontide Orogenic Belt

In order to identify ancient basin boundary faults and their linked system, we generally use indirect geophysical methods (gravity, magnetic, and seismic) rather than direct geological observation insofar as all of the faults that constructed the basin were buried beneath/overlain by basin-filling sediments. However, since some faults may have been exhumed by late basement uplift and sediment erosion, the ages and senses of motion of the faults remain problematic due to inversion on the faults.

The fault model used to explain the formation of Mesozoic basins in the eastern Pontides was

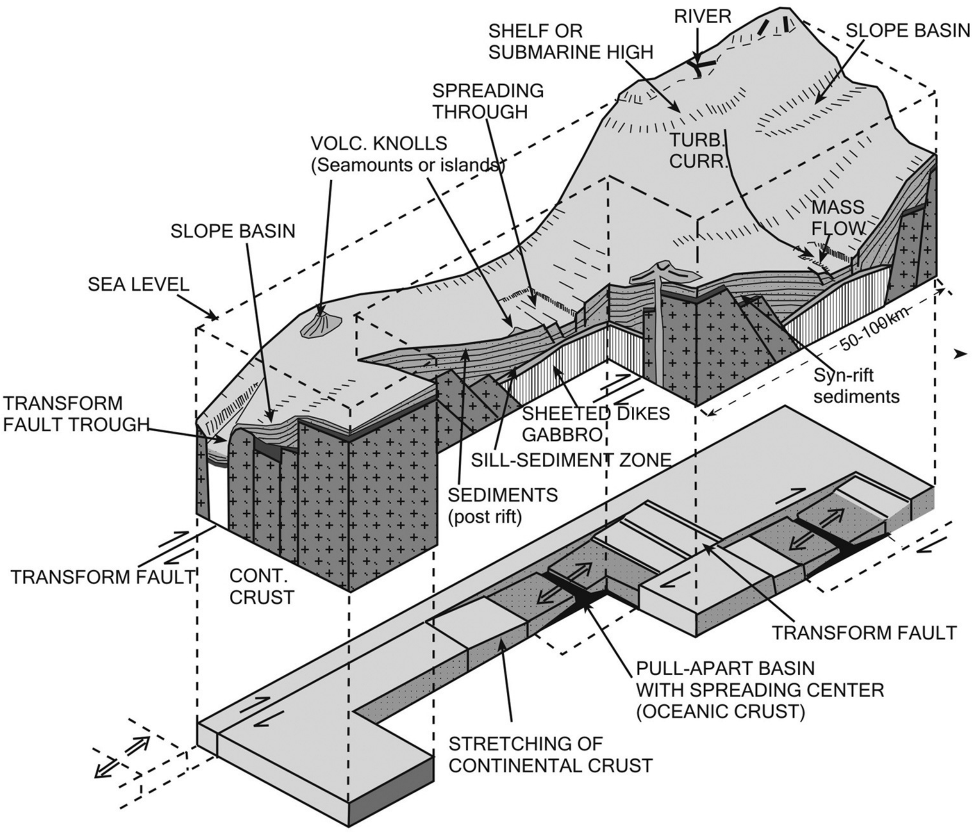

FIG. 10. Simplified plan view and block diagram of gulf-type pull-apart basins in the stage of early drifting, and formation of sill-sediment complexes in spreading troughs (Einsele, 1992).

deduced from the full horizontal gradient lineament map (Fig. 12) and gravity-anomaly profiles (A, B, C and D) that traverse the orogenic belt in a N-S direction, from Samsun in the west to Trabzon in the east (Fig. 13). Many separate deformation zones, corresponding to flower structures along strike-slip fault zones, are features common to all of the cross-sections. Upright, narrow master fault zones originated from the mantle and branch upward into lower and upper crust to form more extensive deformation zones—akin to strike-slip faults (flower structures) or pull-apart basins formed above these deformation zones. These main fault zones also coincide with individual block edges and boundaries of the different lithofacies in the Mesozoic basins (on the geological map), suggesting that each individual block formed separately during the Mesozoic. For example, in the C and D profiles from north to south (Fig. 13C and 13D), the Samsun-Artvin (mostly on the Black Sea shelf), Niksar-Ispir, Northeast Anatolian (NEAFZ), and North Anatolian (NAFZ) fault zones correspond to the boundaries of the subunits of the eastern Pontide orogenic belt, namely the northern, southern, and axial zones (see Fig. 1).

Modern seismicity is also controlled by these block-edge faults, implying that active faults are derived from paleofaults that constructed the Mesozoic basins of the eastern Pontides (Maden, 2005; Bektas et.al,. 2007). The closing of the Bayburt-Maden basin, which corresponded to the opening of the contemporaneous Gümüşhane basin in

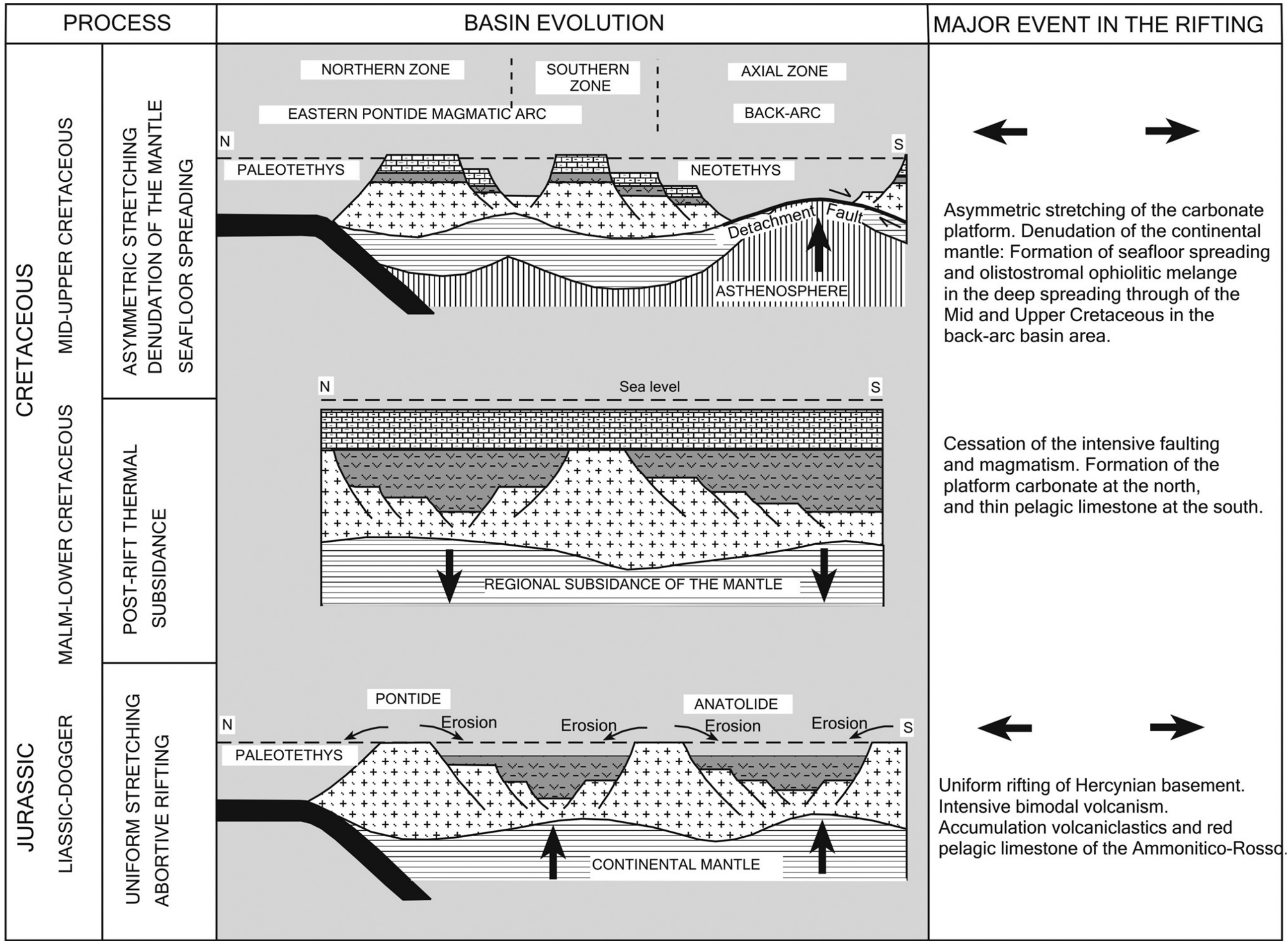

FIG. 11. Model of the geotectonic evolution of the Mid-Cretaceous olistostromal ophiolitic mélange in the eastern Pontide magmatic arc.

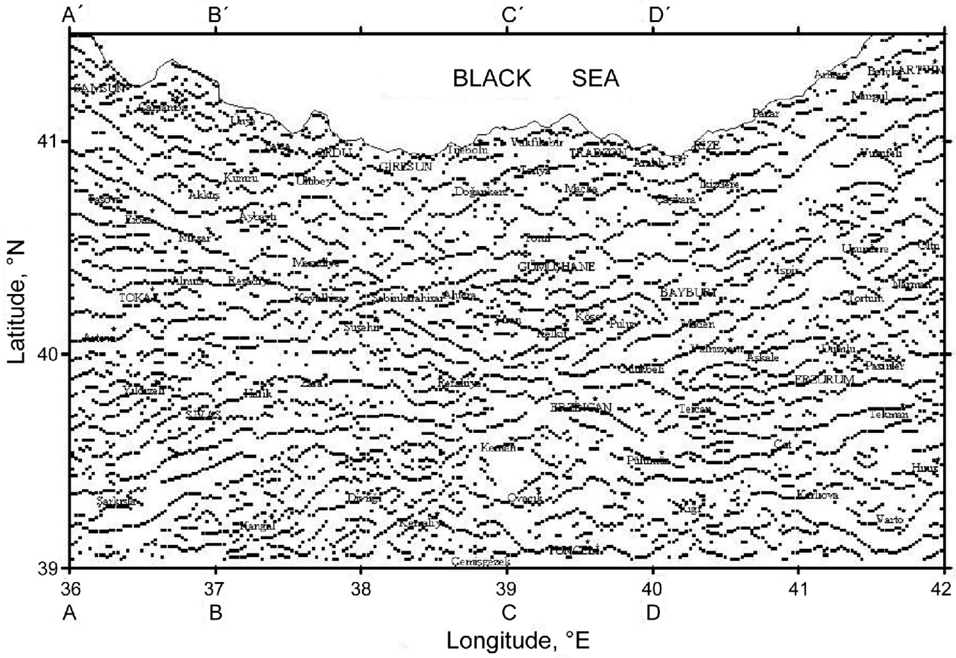

FIG. 12. Full horizontal gradient lineament map of the eastern Pontides, calculated from Bouguer gravity data using the finite differences method (Maden, 2005).

the southern zone, also provides supporting evidence for a different stress regime in the strike-slip fault zone during the Late Cretaceous. The duality of the two basins is characterized by the accumulation of reefal limestone and deep-red pelagic Campanian limestone in the Maden and Gümüşhane basins, respectively. A system of orthogonal (mutually perpen-dicular) folds, parallel to the block-edge faults, are interpreted as drag or wrench folds that formed in the conjugate strike-slip fault zones having NW-SE, E-W, and NE-SW orientations (see Fig. 1).

Consequently, the upright main faults originated from the mantle, and their flower structures in the lower and upper crusts may represent strike-slip fault zones that are responsible for the formation of the Mesozoic pull-apart basins of the eastern Pontides. Magmatic zonality in the eastern Pontide magmatic arc, from TH-CA to CA-A, suggests that Cretaceous subduction polarity was from north to south, and that a strike-slip fault system formed on this oblique subduction zone during the Cretaceous (Bektaş et al., 1999).

Late Cretaceous Subduction Polarity in the Eastern Pontide Magmatic Arc

Paleomagnetic evidence

Although debate is ongoing regarding the subduction polarity of the eastern Pontide magmatic arc during the Late Cretaceous, most researchers (e.g., Adamia et al., 1981; Şengör et al., 1981) have accepted northward subduction polarity, except for Dewey et al. (1973) and Bektaş (1986), who favored southward underflow.

The reason for the suggestion of northward subduction is that an ophiolitic suture zone, situated south of the magmatic arc, is a remnant of an open ocean (Paleotethys)—such as the Pacific—which was consumed by northward subduction during the Paleozoic and/or Mesozoic (Adamia et al., 1981; Şengör et al., 1981). On the other hand, on the basis of palaeomagnetic data (Van der Voo, 1968), the same suture zone was interpreted as the remnant of the back-arc basin to the eastern Pontide magmatic arc (Dewey et al., 1973). More recent paleomagnetic data suggest that the eastern Pontide magmatic arc was situated at 22° Lat. in the Late Cretaceous

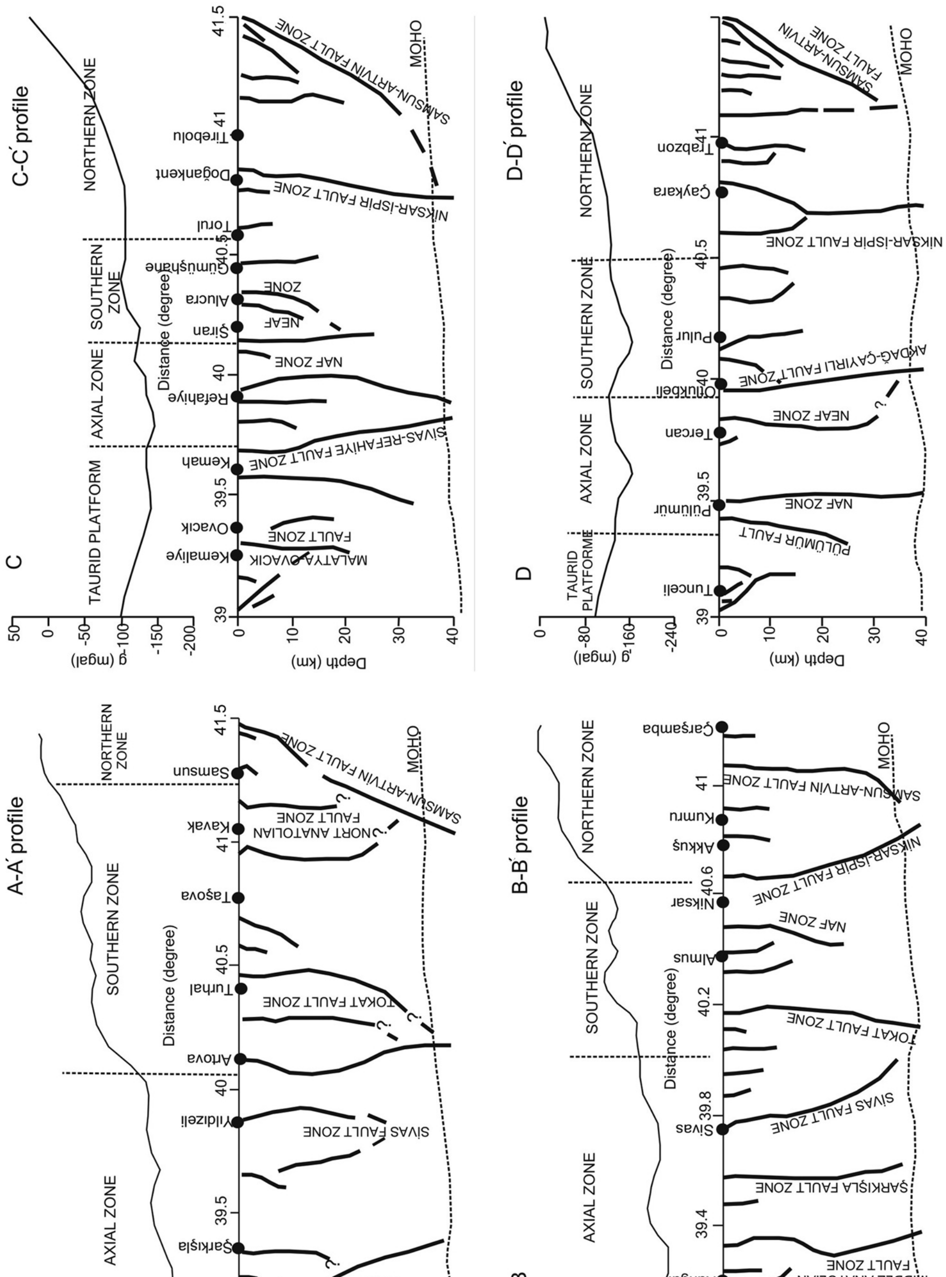

FIG. 13. Cross-sections (A, B, C, and D) that include the main fault orientations of the eastern Pontides, as deduced from Bouguer gravity data (Fig. 12) (Maden, 2005).

(Channel et al., 1996), and drifted to 42° during the Cenozoic as the leading edge of the Pontides, thus also supporting the southward subduction model.

Magmatic zonality of the eastern Pontide magmatic arc

The results of major-, trace-, and rare-earth element analyses of Upper Cretaceous volcanic rock samples collected from the northern, southern and axial zones are given in Tables 3 and 4. In the eastern Pontides, the zoning of Late Cretaceous arc magmatism (arranged TH-CA and CA-A, from north to south) also supports of the southward subduction model (Fig. 14). TH-CA bimodal (basalt-dacite) arc volcanism is widespread along the Black Sea coast, but monogenic andesitic volcanism is limited in the southern zone, near the cities of Gümüşhane and Bayburt. Campanian andesitic volcanism passes into Paleocene shoshonitic basalts in the Bayburt-Maden and Amasya–Merzifon areas (see Figs. 1 and 2). Moreover, Late Cretaceous volcanic rocks are enriched in LILE, HFS, and REE with respect to MORB and chondrite, respectively. These enrichments in trace- and rare-earth element values increase from north to south in the eastern Pontides (Fig. 15). Farther south, in the axial zone, Late Cretaceous basalts associated with ophiolite and ophiolitic mélange have MORB, IA, and WPB associations, reflecting a back-arc basin environment—also supportive of the southward subduction model. On the other hand, Late Cretaceous volcanism decreases volumetrically from north to south, suggesting a decrease in partial melting from arc to back-arc (Bektaş et al., 1999). The north-to-south migration of Late Cretaceous volcanism is another piece of evidence that supports the southward subduction model.

Discussion

As already noted, the subduction polarity of the eastern Pontide magmatic arc is a subject of debate. The ophiolitic mélange in the eastern Pontide orogenic belt is conventionally regarded as an accretionary prism that developed in the fore-arc area by northward subduction processes during the Cretaceous.

Thus, an evaluation of the ophiolitic mélange of the eastern Pontides throws light on the geotectonic evolution of the eastern Pontide orogenic belt, especially the subduction polarity of the eastern Pontide magmatic arc during the Cretaceous. According to northward subduction models, Late Cretaceous arc magmatism developed by northward subduction of Neotethys, which opened in the Liassic as a back-arc basin to the eastern Pontide magmatic arc (Şengör et al., 1981), or by northward subduction of Paleotethys, which was situated south of the magmatic arc since the Paleozoic (Adamia et al., 1981). Conversely, the southward subduction model suggests southward subduction of Paleotethys and formation of the Cretaceous ophiolitic mélange in a back-arc basin (Dewey et al., 1973; Bektaş et al., 1984; Bektaş, 1986). Magmatic zonation of the Late Cretaceous arc—from TH to CA-A—and palaeomagnetic data support the southward subduction model. The IA affinity of the basalts in the ophiolitic mélange is another piece of evidence in favor of southward subduction.

Northward underflow of Neotethys during the Cretaceous should be critiqued when viewed as the seafloor-spreading stage or consuming stage of Neotethys. After Liassic rifting, true deep pelagic sediments—such as radiolarite and red pelagic limestone—conventionally used as markers of seafloor spreading of Neotethys, first appeared in the Cretaceous section. Thus, the Cretaceous must coincide with the seafloor stage of Neotethys, but not with its subduction. In addition, the northward subduction of Neotethys or Paleotethys requires that the southern zone of the eastern Pontides be a fore-arc in which the products of volcanism should be absent. However, this zone is characterized by intense shoshonitic volcanism that constitutes the cover to the mélange in the back-arc of the eastern Pontide magmatic arc.

In the axial zone or back-arc basin (Bektaş et a1., 1984, 1999) or Anatolides (Ketin, 1966), Alpine-type peridotite and gabbro-diorites and overlying metamorphic units of continental affinity constitute the basement to Senonian ophiolitic basaltic rocks that have MORB and IAB affinities (Bektaş, 1981). This thin (<100 m) basaltic cover is not continuous laterally. Consequently, radiolarites and Senonian red pelagic limestones locally lie directly on the ultramafic basement.

Chondrite-normalized rare-earth element contents of the Kop (Bayburt) ultramafic rocks can be used to infer the origin of the subcontinental mantle (Aslaner and Kolayli, 1996). According to many researchers, the ultramafic-mafic and metamorphic rock association in the axial zone can be defined as ophiolite. This ophiolite has been interpreted as having formed as transitional crust (Bektaş et al.,

TABLE 3. Representative Major- and Trace-Element Analyses of the Upper Cretaceous Volcanic Rocks[1]

	Far South[2]							Southern zone[3]					Northern zone[4]			
	Maden					Amasya										
Sample:	A-1	M-30	M-33	M-82	M-102	G-27	G-51	SC13	ST1	SP6	SS18	M-136	159	C-29	209	C-17
SiO_2	61.14	58.84	50.61	49.94	52.57	48.11	50.73	57.84	51.73	54.60	57.32	56.40	69.16	54.40	78.31	56.13
TiO_2	0.60	0.78	0.86	0.88	0.69	0.92	0.70	0.56	0.65	0.68	0.57	0,62	0.44	0.87	0.18	0.72
Al_2O_3	17.27	18.16	16.11	16.50	19.01	14.10	16.07	17.67	19.49	18.14	17.71	18.02	14.77	18.43	10.69	16.93
Cr_2O_3	0.003	0.004	0.006	0.005	0.002	0.005	0.026	n.d.	n.d.	n.d.	n.d.	0.009	0.015	0.018	0.021	0.016
Fe_2O_3*	4.36	5.55	8.50	8.96	6.95	10.57	8.18	6.00	6.99	8.18	6.93	7.40	3.85	8.54	1.27	8.31
MgO	0.55	1.78	3.87	4.50	3.12	5.18	4.43	3.75	2.67	4.33	3.81	3.48	0.97	2.48	0.27	3.73
MnO	0.04	0.07	0.21	0.24	0.14	0.19	0.11	0.10	0.17	0.13	0.18	0.16	0.13	0.14	0.07	0.18
CaO	4.36	4.05	7.13	6.38	3.50	9.23	4.74	5.95	8.88	8.28	6.02	6.40	3.68	7.89	1.41	8.28
Na_2O	4.40	5.36	3.85	4.25	3.98	2.63	6.15	3.86	3.10	2.83	3.41	3.80	3.76	2.50	0.87	2.63
K_2O	4.27	4.11	4.30	4.19	6.05	4.48	3.29	0.82	0.73	0.95	1.28	0.87	1.38	0.81	1.26	0.45
P_2O_5	1.21	0.26	0.54	0.55	0.44	0.57	0.54	0.18	0.16	0.28	0.23	0.22	0.10	0.10	0.05	0.12
LOI	1.50	0.80	3.90	3.50	3.05	3.00	4.90	3.50	5.30	1.20	2.00	2.01	1.20	3.20	5.00	1.90
Total	99.70	99.76	99.88	99.89	99.95	99.64	99.86	100.23	99.87	99.60	99.46	99.38	99.45	99.37	99.40	99.39
Rb	142.3	82.1	39.5	45.6	76.4	127	189.8	29	17	18	27	34	35.15	42	47.31	32.06
Ba	820	1335	1181	1129	1137	1116	1575	493	89	350	416	312	481	287.2	278	287.1
Sr	734.1	857.3	1005	943.5	966.5	1037	327.3	253	324	407	460	405	234.2	229.8	152.7	224.6
Y	45.3	20.1	30.1	29.2	24.0	25.5	20.2	20	13	19	19	16	22.9	23.8	13.2	22.5
Zr	224	228	180.7	175.4	169.5	138.9	141.4	132	57	125	113	144	89.6	57.3	64.3	63.3
Hf	5.9	6.5	4.7	4.40	4.2	3.6	3.5	3.25	1.86	3.05	2.74	2.68	2,4	1.6	1.7	1.68
Pb	4.5	18.3	2.4	2.9	3.6	16.3	12.6	n.d	n.d	n.d	n.d	12	15	29	24	25
Zn	34	46	86	69	81	75	54	n.d	n.d	n.d	n.d	76	84	90	19	77
Ni	19	15	18	16	4.6	27	49	n.d	n.d	n.d	n.d	8	2	3	2	6
V	41	100	260	250	162	302	175	n.d	n.d	n.d	n.d	86	49	235	6	242
Sc	4	8	18	19	8	29	22	n.d	n.d	n.d	n.d	12	14	26	4	30
Nb	11.8	16.3	15.0	10.9	14.6	12.0	11.0	6.2	2.1	5.8	5.8	4.86	3.11	1.61	2.05	1.66
Ta	1.0	1.1	0.90	0.90	0.8	0.60	0.50	0.48	0.3	0.46	0.62	0.54	0.2	0.1	0.1	0.2
U	11.0	3.7	4.2	5.1	5.4	4.3	4.7	n.d	n.d	n.d	n.d	2.8	2.1	1.5	0.8	1.6
Th	16.2	19.0	15.4	15.3	14.8	11.1	15.3	7.26	2.89	2.36	2.78	3.01	5.1	3.0	4.7	3.4

[1]Analysis results are for southern zone samples, except M-136, taken from Bektas et al., 1999.
[2]Trachyandesites and analcime-bearing volcanics (Bayburt-Maden and Amasya areas).
[3]Gümüşhane area.
[4]Harsit Valley–Tirebolu

TABLE 4. Representative Rare-Earth Element Analyses of the Upper Cretaceous Volcanic Rocks[1]

	Far South[2]							Southern zone[3]					Northern zone[4]			
	Maden					Amasya										
Sample:	A-1	M-30	M-33	M-82	M-102	G-27	G-51	SC13	ST1	SP6	SS18	M-136	159	C-29	209	C-17
La	34.6	44.8	37.9	39.6	35.8	32.7	33.8	23.58	8.83	15.78	16.48	18.42	16.7	10.6	19.4	9.9
Ce	74.6	97.7	84.8	88.5	76.2	76.0	69.3	39.38	20.01	34.34	34.98	22.34	32.2	20.1	21.6	22.5
Pr	8.52	9.85	9.88	10.63	8.65	8.92	7.57	n.d.	n.d.	n.d.	n.d.	6.2	4.33	2.99	4.84	3.14
Nd	35.0	38.9	42.0	45.6	35.2	37.4	29.3	17.95	9.93	18.33	14.44	11.2	14.9	11.5	16.1	12.2
Sm	7.4	6.5	9.2	10.0	7.3	8.2	6.1	3.36	2.06	3.58	3.32	2.08	3.6	3.3	3.1	3.3
Eu	1.79	1.63	2.30	2.44	1.83	2.16	1.56	0.90	0.68	1.14	1.02	0.74	0.96	1.15	0.69	1.1
Gd	7.86	5.07	8.13	7.85	5.79	6.75	5.09	n.d.	n.d.	n.d.	n.d.	4.02	4.19	4.17	3.32	4.02
Tb	1.51	0.77	1.22	1.20	0.85	1.06	0.75	0.55	0.39	0.55	0.53	0.42	0.68	0.7	0.48	0.69
Dy	7.70	3.86	6.03	5.86	4.62	5.57	3.69	3.03	2.11	3.01	2.83	2.80	3.74	3.93	2.39	3.72
Ho	1.19	0.62	0.93	0.95	0.76	0.89	0.64	0.67	0.44	0.64	0.62	0.52	0.75	0.78	0.4	0.72
Er	3.07	1.53	2.57	2.61	2.10	2.46	1.73	1.93	1.18	1.80	1.85	1.34	2.56	2.56	1.3	2.44
Tm	0.39	0.23	0.31	0.31	0.28	0.37	0.24	0.36	0.24	0.33	0.31	0.20	0.43	0.41	0.23	0.38
Yb	2.00	1.45	2.29	2.28	2.02	2.21	1.64	1.76	1.00	1.64	1.79	1.30	2.58	2.32	1.37	2.31
Lu	0.32	0.22	0.34	0.32	0.32	0.30	0.25	0.31	0.22	0.30	0.29	0.28	0.51	0.46	0.24	0.42

[1]Analysis results are for southern zone samples, except M-136, taken from Bektas et al., 1999.
[2]Trachyandesites and analcime-bearing volcanics (Bayburt-Maden and Amasya areas).
[3]Gümüşhane area.
[4]Harsit Valley–Tirebolu

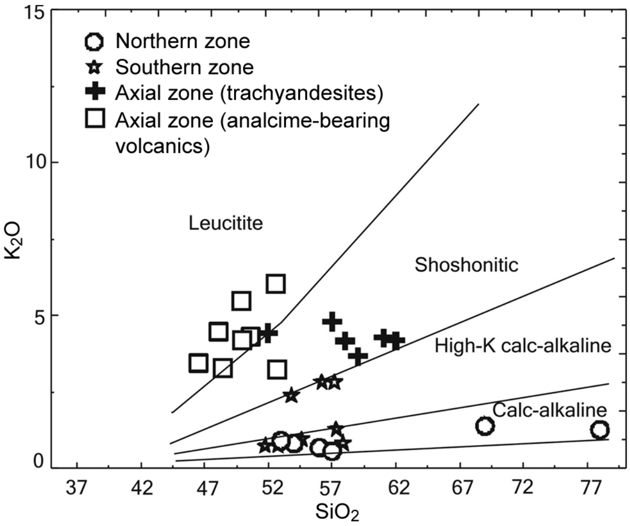

FIG. 14. K_2O-SiO_2 discrimination diagram for the Upper Cretaceous volcanic rocks exposed in the eastern Pontides.

1995, 1999) that existed during the late stages of rifting of the back-arc prior to emplacement of the oceanic lithosphere, an interpretation that has also been applied to the Red Sea (Bonatti and Seyler, 1987) and the Northern Apennines (Marroni et al., 1998). Thus, we can conclude that the Mid- and Upper Cretaceous ophiolitic mélange formed on transitional crust or on true oceanic crust restricted by deep spreading troughs of the pull-apart basins.

Conclusions

On the basis of field and geochemical evidence, we have reached several conclusions related to the formation, classification and geotectonic position of the ophiolitic mélange in the eastern Pontides.

1. Mid-Cretaceous olistostromal ophiolitic mélange does *not* represent a typical tectonic mélange or accretionary prism that developed in the fore-arc of the eastern Pontide magmatic arc by northward subduction of Neotethys (back-arc basin) or Paleotethys (open ocean, such as the Pacific).

2. Rather, we suggest that the mélange formed in pull-apart basins with deep spreading troughs during a transtensional tectonic regime in the back-arc area of the eastern Pontide magmatic arc.

3. Deformation of the deep-spreading troughs in which the mélange formed was initially extensional, but became increasingly compressional as the strike-slip cycle progressed.

4. Mid- and Upper Cretaceous olistostromal ophiolitic mélanges formed diachronously in the same strike-slip zone, parallel to the eastern Pontide magmatic arc.

5. Trace-element and REE contents of basalts in the Mid-Cretaceous mélange and of shoshonitic volcanites that cover the mélange both imply that the mélange formed in the back-arc of the eastern Pontide magmatic arc.

6. Along the southern part of the eastern Pontides, Cretaceous deep spreading troughs of the pull-apart basins have been essentially conserved as the ophiolitic mélange, which characterizes the strike-slip orogenic belt. If this interpretation is correct, neither an open ocean (such as the Atlantic or Pacific) nor northward subduction were necessary for the formation of the ophiolitic mélange in the eastern Pontides.

Acknowledgments

We thank Prof. Dr. Erdin Bozkurt, Osman Parlak, Yildirim Dilek, and Ismet Gedik for contributions and essential discussions. We also thank Steven Keith Mittwede for constructive comments and correcting the English of the manuscript. This work was

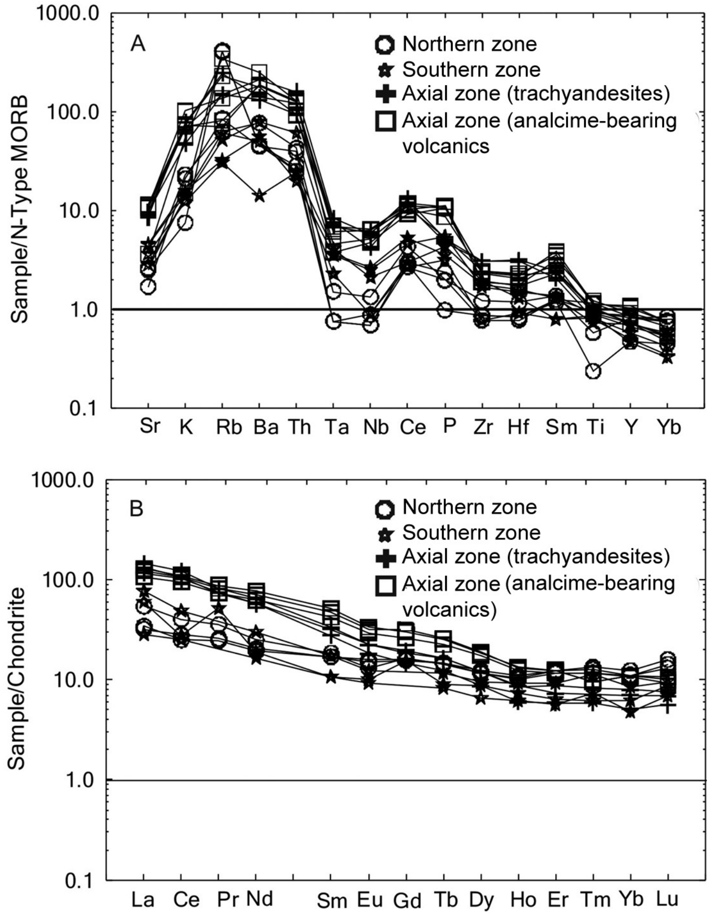

FIG. 15. A. N-type MORB-normalized trace-element patterns for the Upper Cretaceous volcanic rocks. B. Chondrite-normalized rare-earth element patterns for the Upper Cretaceous volcanic rocks (normalization values from Sun and McDonough, 1989).

supported by Karadeniz Technical University Foundation Grants 21.112.005.9.

REFERENCES

Adamia, S. A., Chkhotua, T., Kekelia, M., Lordkipanidze, M., Shavishvili, I., and Zakariadze, G., 1981, Tectonics of the Caucasus and adjoining regions: Implications for the evolution of the Tethys ocean: Journal of Structural Geology, v. 3, p. 437–447.

Aslaner, M., and Kolayli, H., 1996, An analytical approach to palaeogeotectonic position of ultramafics in the Kopdağlari (Erzincan-Erzurum): *in* Karadeniz Technical University, Trabzon, 30th-Year Symposium Book, p. 240–248.

Bailey, E. B., and McCallien, C., 1953, Serpentine lavas, the Ankara melange, and the Anatolian thrust: Transactions of the Royal Society of Edinburgh, v. 62, p. 403–442.

Bektaş, O., 1981, Geological characteristics between Erzincan-Tanyeri of the North Anatolian Fault and local ophiolite problems: Unpubl. Ph.D. thesis, Karadeniz Technical University, Trabzon, Turkey.

Bektaş, O., 1986, Paleostress trajectories and polyphase rifting in arc-back arc of the eastern Pontides: Bulletin of Mineral Research Exploration, p. 103–104.

Bektaş, O., and Çapkinoğlu, Ş., 1997, Neptunian dikes and block tectonics in the eastern Pontide magmatic arc, NE Turkey: Implications for the kinematics of the Mesozoic basins: Geosound, v. 30, p. 451–461.

Bektaş, O., Çapkinoğlu, Ş., and Akdağ, K., 2001, Successive extensional tectonic regimes during the Mesozoic as evidenced by neptunian dikes in the Pontide magmatic arc, northeast Turkey: International Geology Review, v. 43, p. 840–850.

Bektaş, O., Eyuboglu, Y., and Maden, N., 2007, Different modes of stress transfer in a strike-slip fault zone: An example from the North Anatolian fault system in Turkey: Turkish Journal of Earth Sciences, v. 16, p. 1–12.

Bektaş, O., Pelin, S., and Korkmaz, S., 1984, Mantle uprising and polygenetic ophiolite fact in the back-arc basin of the Eastern Pontides, *in* TJK Ketin Symposium: Ankara, Turkey, p. 175–188.

Bektaş, O., Şen, C., Atici, Y., and Köprübaşi, N., 1999, Migration of the Upper Cretaceous subduction-related volcanism toward the back-arc basin of the eastern Pontide magmatic arc (NE Turkey): Geological Journal, v. 34, p. 95–106.

Bektaş, O., Van, A., and Boynukalin, S., 1987, Jurassic volcanism and its geotectonics in the eastern Pontides (NE Turkey): Geological Bulletin of Turkey, v. 30, p. 9–18.

Bektaş, O., Yilmaz, C., Tasli, K., Akdağ, K., and Özgür, S., 1995, Cretaceous rifting of the eastern Pontide carbonate platform (NE Turkey): The formation of carbonates breccias and turbidites as evidences of a drowned platform: Geologia, v. 57, no. 1-2, p. 233–244.

Bonatti, E., and Seyler, M., 1987, Crustal underplating and evolution in the Red-Sea rift-uplifted gabbro-gneiss crustal complexes on Zabargad and Brothers islands: Journal of Geophysical Research–Solid Earth and Planets, v. 92 (B12), p. 12,803–12,821.

Burchfiel, B. C., 1979, Structural geology of the earth's exterior: Proceedings of the National Academy of Sciences, U.S.A., v. 76, no. 9, p. 4201–4207.

Burchfiel, B. C., 1980, East European Alpide system and the Carpathian orocline as an example of collision tectonics: Tectonophysics, v. 63, p. 31–66.

Channell, J. E. T., Tüysüz, O., Bektaş, O., and Şengör, A. M. C., 1996, Jurassic–Cretaceous paleomagmatism and paleogeography of the Pontides (Turkey): Tectonics, v. 15, p. 201–212.

Cloos, M., 1982, Flow mélanges: Numerical modeling and geologic constraints on their origin in the Franciscan subduction complex: Geological Society of American Bulletin, v. 93, p. 330–345.

Cloos, M., 1984, Flow mélanges and the structural evolution of accretionary wedges, *in* Raymond, L. A., ed., Melanges: Their nature, origin, and significance: Geological Society of America Spec. Publ., v. 198, p. 71–79.

Dewey, J. F., Pitman, W. C., Ryan, W. B. F., and Bonnin, J., 1973, Plate tectonics and evolution of the Alpine system: Geological Society of America Bulletin, v. 84, p. 3137–3180.

Einsele, G., 1992, Sedimentary basins: Evolution, facies, and sediment budget: New York, NY, Springer-Verlag, 628 p.

Eyüboğlu, Y., Bektas, O., Seren, A., Nafiz, M., Jacoby, W.R., and Özer, R., 2006, Three-directional extensional deformation and formation of the Liassic rift basins in the eastern Pontides (NE Turkey): Geologica Carpathica, v. 57, no. 5, p. 337–346.

Farahat, E. S., 2004, Continental back-arc basin origin of some ophiolites from the Eastern Desert of Egypt: Mineralogy and Petrology, v. 82, p. 81–104.

Hsü, K. J., 1968., Principles of mélange and their bearing on the Franciscan-Knoxville paradox: Geological Society of America Bulletin, v. 79, p. 1063–1074.

Ketin, I., 1966, Tectonic units of Anatolia: MTA Bulletin, v. 66, p. 861–872.

Maden, N., 2005, Investigation of the structural styles and crustal structure of the eastern Pontides orogenic belt with geophysical methods: Unpubl. Ph.D. thesis, Karadeniz Technical University, Trabzon, Turkey.

Marroni, M., Molli, G., Montanini, A., and Tribuzio, R., 1998, The association of continental crust rocks with ophiolites in the Northern Apennines (Italy): Implications for the continent-ocean transition in the western Tethys: Tectonophysics, v. 292, p. 43–66.

Mullen, S.B., 1983, $MnO/TiO_2/P_2O_5$: A minor element discriminant for basaltic rocks of oceanic environments and implications for petrogenesis: Earth and Planetary Science Letters, v. 62, p. 53–62.

Onen, P., 2003, Neotethyan ophiolitic rocks of the Anatolides of NW Turkey and comparison with Tauride ophiolites: Journal of Geological Society, London, v. 160 (Part 6), p. 947–962.

Pearce, J., and Cann, J., 1973, Tectonic settings of basic volcanic rocks using trace element analysis: Earth and Planetary Science Letters, v. 19, p. 290–300.

Pearce, J., and Norry, M. T., 1979, Petrogenetic implication of Ti, Zr, Y, and Nb variations in volcanic rocks: Contributions to Mineralogy and Petrology, v. 69, p. 33–47.

Reading, H. G. 1980, Characteristics and recognition of strike-slip fault systems: International Association of Sedimentologists, Special Publication, v. 4, p. 7–26.

Raymond, L. A. 1984, Classification of mélanges, *in* Raymond, L. A., ed., Mélanges: Their nature, origin, and significance: Geological Society of America Special Paper, v. 198, p. 7–20.

Raymond, L. A., and Terranova, T., 1984, Prologue: The melange problem—a review, *in* Raymond, L. A., ed., Mélanges: Their nature, origin, and significance: Geological Society of America Special Paper, v. 198, p. 1–5.

Robinson, A. G., Banks, C. J., Rutherford, M. M., and Hirst, J. P. P, 1995, Stratigraphic and structural development of the eastern Pontides, Turkey: Journal of the Geological Society, London, v. 152, no. 5, p. 861–872.

Rojay, B., Altiner, D., Altiner, S. O., Önen, P., James, S., and Thirlwall, M. F., 2004, Geodynamic significance of the Cretaceous pillow basalts from North Anatolian ophiolitic mélange belt (central Anatolia, Turkey): Geochemical and paleontological constraints: Geodinamica Acta, v. 17, no. 5, p. 349–361.

Şengör, A. M. C., Yilmaz, Y., and Ketin, I., 1981, Remnants of a pre-Late Jurassic ocean in northern Turkey: Fragments of a Permian-Triassic Paleotethys: Geological Society of America Bulletin, v. 91, p. 599–609.

Shervais, J. W., 2001, Birth, death, and resurrection: The life cycle of suprasubduction zone ophiolites: Geochemistry, Geophysics, Geosystems, v. 2 [No:2000GC000080].

Smedley, P. M., 1986, The relationship between calc-alkaline volcanism and within-plate continental rift volcanism: Evidence from Scottish Paleozoic lavas: Earth and Planetary Science Letters, v. 76, p. 13–128.

Sun, S. S., and McDonough, W. F., 1989, Chemical and isotopic systematic of ocean basalts: Implications for mantle composition and process, *in* Saunders, A. D., and Norry, M. J., eds.,) Magmatism in the ocean basins: Journal of the Geological Society, London, v. 42, p. 313–345.

Tankut, A., Dilek, Y., and Önen, P., 1998, Petrology and geochemistry of the Neo-Tethyan volcanism as revealed in the Ankara mélange, Turkey: Journal of Volcanology and Geothermal Research, v. 85, p. 265–284.

Taylor, B., and Martinez, F., 2003, Back-arc basin basalt systematics: Earth and Plenetary Science Letters, v. 210, p. 481–497.

Taylor, S. R., and McLennan, S. M., 1985, The continental crust: Its composition and evolution. Oxford, UK, Blackwell Scientific.

Van der Voo, R., 1968, Jurassic, Cretaceous, and Eocene pole positions from northeastern Turkey: Tectonophysics, v. 6, no. 3, p. 251–269.

Wiens, D. A., Kelley, K. A., and Plank, T., 2006, Mantle temperature variations beneath back-arc spreading centers inferred from seismology, petrology, and bathymetry: Earth and Planetary Science Letters, v. 248, p. 30–42.

Winchester, J. A., and Floyd, P. A., 1976, Geochemical magma type discrimination: Application to altered and metamorphosed basic igneous rocks: Earth and Planetary Science Letters, v. 28, p. 459–469.