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Structural correlation of the southern Transcaucasus (Georgia)–eastern Pontides (Turkey)

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Abstract: The eastern Pontides (northeastern Turkey) and Transcaucasus (Georgia) belong to the same geological belt representing an active margin of the Eurasian continent. According to palaeotectonic–palaeogeographic reconstructions, based on regional geological, palaeomagnetic, palaeobiogeographical and petrological data, the eastern Pontides and the major part of the Transcaucasus, situated to the north of the North Anatolian–Lesser Caucasian ophiolitic suture, comprise island arc, forearc, back and interarc basins. The eastern Pontide segment of the belt consists of three structural units which, from north to south, are the northern, central and southern units. The northern unit, the southeastern Black Sea coast–Adjara–Trialeti Unit, represents a juvenile back arc basin formed during the Late Cretaceous (pre-Maastrichtian). This unit separates the southern and northern Transcaucasus zones. The central Artvin–Bolinisi Unit is also known as the northern part of the southern Transcaucasus and is characterized by Hercynian basement, unconformably overlying the Upper Carboniferous–Lower Permian molasse and Upper Jurassic–Cretaceous arc association. The southern unit is the imbricated Bayburt–Karabakh Unit and is known as the southern part of the southern Transcaucasus. This unit has a similar basement to the Artvin–Bolinisi Unit and also includes a chaotic assemblage; it unconformably overlies the Upper Jurassic–Cretaceous forearc association. The eastern Pontide system is interpreted as the product of interference between a spreading ridge and subduction zone during Late Jurassic–Cretaceous times. The North Anatolian–Lesser Caucasus Suture, comprising ophiolites, mélanges and an ensimatic arc association, separates the overlying system from the Anatolian–Iranian Platform in the south. Maastrichtian–Lower Eocene cover rocks in the region unconformably overlie all the other units. Middle Eocene rifting resulted in the formation of new basins, some of which closed during an Oligocene–Early Miocene regression. Others, such as the Black Sea and Caspian Basins, have survived to the present day as relict basins.

The Caucasus and Turkey have been divided into different tectonic units and investigated by many authors. It is generally accepted that the eastern Pontides of Ketin (1966; Fig. 1a) are equivalent to the southern Transcaucasus (International Geological Congress XXVII Session, Moscow 1984). This belt (Fig. 1) is bordered to the north by the Adjara–Trialeti Unit and to the south by the North Anatolian–Lesser Caucasus ophiolitic belt; the latter is a product of the final closure of the Neotethys Ocean (Şengör & Yılmaz 1981) during the Oligocene (Koçyiğit 1991).

Although complete correlative studies are rare, it is suggested that the Adjara–Trialeti

Unit continues along the southeastern Black Sea coast in Turkey (A. Yılmaz 1989a; Adamia *et al.* 1995). After a joint geological compilation project in the border area, carried out between 1994 and 1996 (A. Yılmaz *et al.* 1996, 1997), it was concluded that the Adjara–Trialeti Unit can be traced along the Black Sea coast in Turkey as far west as the Sinop area. In the present study, tectonic division of the eastern Pontides and Transcaucasus is revised (Fig. 2) and characteristics of each unit, including the age, lithology and tectonic setting, are presented (Fig. 3). On the basis of this new division, the southeastern Black Sea coast–Adjara–Trialeti Unit represents the northern unit which is characterized

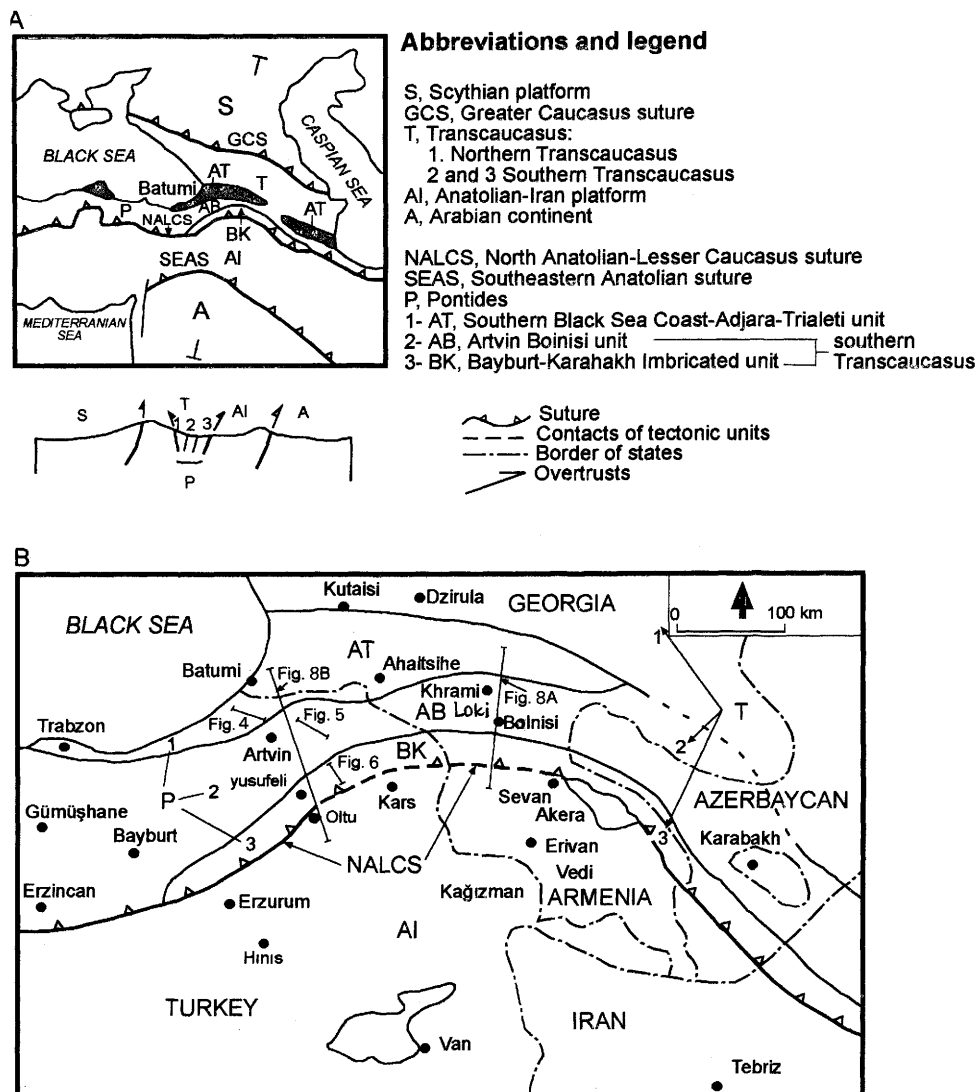


Fig. 1. Location-cross section (a) and sketch (b) maps of the study area [after A. Yılmaz *et al.* (1997) and new data].

by a juvenile back-arc association formed mainly during the Santonian–Campanian interval. The Artvin–Bolinisi Unit represents the central unit, which is characterized by an arc association formed mainly during the Liassic–Campanian interval. The Imbricated Bayburt–Karakahk Unit represents the southern unit and is characterized by a forearc association formed mainly during the Malm–Campanian interval. To the south the tectonic units are bordered by the North Anatolian–Lesser Caucasus Suture (Fig. 1). Maastrichtian–Tertiary sequences of

the tectonic units can be correlated from north to south and mainly represent a terrigenous to continental unity. Although no adequate data are presented, this unity is also considered to be a post-collision sequence.

This paper deals with the palaeotectonic evolution of the border area and has been undertaken in conjunction with a joint project between Turkey and Georgia. It aims to: (1) introduce a new tectonic subdivision of the border area (Fig. 1); (2) describe Upper Cretaceous–Tertiary units and facies in detail; (3)

TURKISH SIDE			GEORGIAN SIDE		
Gedikoğlu <i>et al.</i> 1979 Özsayar <i>et al.</i> 1981 Okay & Şahintürk 1997			Present Study	International Geological Congress XXVII Session (1984)	
Eastern Pontides	Outer/ Northern part	Southeastern Black Sea Coast-Adjara-Trialeti unit (northern part)		Adjara-Trialeti zone	
	inner Southern part	Artvin-Bolsini unit (central part)	Artvin-Bolsini zone		
		Imbricated Bayburt Karabakh unit (southern part)	Bayburt-Karabakh zone		
North Anatolian-Lesser Caucasus ophiolitic belt					

Fig 2. Tectonic division of the study area.

evaluate the interference between a spreading ridge and subduction during closure of Neotethys; (4) present this group's views on the polarity of the eastern Pontide-southern Transcaucasus active continental margin; and (5) evaluate the geological evolution of the region.

This paper presents three measured sections studied during 1996–1997 (Figs 4–6), including lithological and faunal data from critical local-

ities and a correlative table (Fig. 7) comparing generalized stratigraphic sections of each tectonic unit. Although there is no common formal lithostratigraphic nomenclature along the border area, some of the formations named by Adamia *et al.* (1995) and A. Yılmaz *et al.* (1997) have been used to facilitate correlations of the Turkish and Georgian sides in Figs 4–6. Samples have been collected at each location for

GEOLOGICAL AGE		Southern Black Sea coast - Adjara - Trialeti unit (northern part)		Artvin - Bolnisi unit (central part)		Imbricated - Bayburt - Karabakh unit (southern part)	
		Lithology	Setting	Lithology	Setting	Lithology	Setting
TERTIARY	QUATERNARY	Alluvial and marine deposits	POST COLLISION ?	Alluvial deposits	POST COLLISION ?	Alluvial deposits	POST COLLISION ?
	Pliocene	Continental volcanoclastic rocks		Continental deposits		Continental deposits	
	Miocene	Shallow marine to continental deposits with coal levels		Shallow marine to continental deposits		Shallow marine to continental deposits with coal levels	
	Oligocene	Shoshonitic lava and clastic rocks		Gabbro - Diorites		Andesitic volcanoclastic rocks	
	Eocene	Basaltic volcanics with delenites		Basaltic volcanoclastic rocks, in places delenites		Terrigenous clastic rocks	
		Basaltic volcanoclastic rocks		Terrigenous clastic rocks		Shallow marine limestones	
	Palaeocene	Terrigenous clastic rocks		Shallow marine limestones		Turbiditic clastic rocks, in places, epi and/or pyroclastic intercalations, hemipelagic shales	
	Maastrichtian	Hemipelagic turbiditic limestones		Granitoides		Turbiditic limestone and clastic rocks	
	Campanian	Basaltic lava, hemipelagic to pelagic limestone intercalations		Andesite, dacite, rhyolite and basalt with volcanoclastic rocks, in places, shallow marine to subaerial pyroclastic rocks.		Volcanic rocks and intrusive rocks. Black slates and diabase	
	Santonian	Dacite and in places andesite		Shallow marine reefal limestone with volcanic rocks		Black slates and sandstones	
CRETACEOUS	Cenomanian	Volcanoclastic sequence	ARC	Volcanoclastic rocks	ARC	Black slates and sandstones	ARC
	Albian			Shallow marine reefal limestone with volcanic rocks		Black slates and sandstones	
	Aptian			Volcanoclastic rocks		Black slates and sandstones	
	MALM			Shallow marine reefal limestone with volcanic rocks		Black slates and sandstones	
JURASSIC	DOGGER		ARC	Shallow marine reefal limestone with volcanic rocks	ARC	Black slates and sandstones	ARC
	LIASSIC			Shallow marine reefal limestone with volcanic rocks		Black slates and sandstones	
TRIASSIC			POST COLLISION	Shallow marine reefal limestone with volcanic rocks	POST COLLISION	Black slates and sandstones	POST COLLISION
PERMIAN				Shallow marine reefal limestone with volcanic rocks		Black slates and sandstones	
CARBONIFEROUS			ARC	Shallow marine reefal limestone with volcanic rocks	ARC	Black slates and sandstones	ARC
DEVONIAN				Shallow marine reefal limestone with volcanic rocks		Black slates and sandstones	
CAMBRIAN			ARC	Shallow marine reefal limestone with volcanic rocks	ARC	Black slates and sandstones	ARC
PRECAMBRIAN				Shallow marine reefal limestone with volcanic rocks		Black slates and sandstones	

Fig 3. Correlation of tectonic units in the framework of age, lithology and tectonic setting. E, Early; M, Middle; L, Late.

stratigraphic analysis, dating and environmental interpretation. Approximate locations of the columnar sections are shown in Fig. 1.

The cross-sections (Fig. 8a and b) have been compiled from the Georgian and Turkish sides, respectively, based on new field observations and those of A. Yılmaz *et al.* (1997). Based on these sections, consecutive stages of the geological evolution of the region have been presented in terms of the Tethyan evolution.

The study area

The study area in the eastern Pontide and Transcaucasus belt represents the active margin of the Eurasian continent. Based on the tectonic division of the Caucasus, the Adjara–Trialeti Unit is a tectonic unit between the northern and southern Transcaucasus zones which extends along the southeastern Black Sea coast in Turkey (Fig. 1). The southern Transcaucasus zone comprises two tectonic units; the Artvin–Bolnisi Unit in the north and the Imbricated Bayburt–Karabakh Unit in the south. Hence, the study area comprises three tectonic subunits (Fig. 7). To the south, the Pontides–southern Transcaucasus zone is bordered by the North Anatolian–Lesser Caucasus ophiolitic belt.

The southeastern Black Sea coast–Adjara–Trialeti Unit

This unit represents the northern part of the eastern Pontides (Fig. 7) situated between northern Transcaucasus (the Georgian Dzirula Block) to the north and southern Transcaucasus (Artvin–Bolnisi Unit) to the south. It is a north-east–southwest trending structural unit and extends from the Lori River in the east to the southern Black Sea coast in the west (Fig. 1b). The northern and southern margins are defined by north and south facing overthrusts, respectively, delineated on the basis of dip angles of thrust planes (Fig. 8). Borehole data obtained in Georgia (Fig. 1b) show that Aptian–Cenomanian volcanoclastic rocks constitute the lowest level (Nadareishvili 1980, 1981), whereas the lowest level exposed in Turkey comprises acidic volcanic rocks conformably overlying an alternation of Santonian–Campanian basaltic lava and micritic limestone (A. Yılmaz *et al.* 1997). The alternation is named the Çağlayan Formation and the following pelagic forms (Fig. 4) have been determined from micritic limestones of the formation: *Globotruncana arca* (Cushman), *Globotruncana elevata* (Brotzen). Radiolaria are common in some levels of the limestone. Lithology and pelagic forms of the

unit indicate a comparatively deeper environment than that of the arc association to the south. In addition, there is no level which is characterized by oceanic crust along the tectonic unit. Hence, it is suggested that this association was formed in a pelagic to hemipelagic environment which probably indicates a juvenile back-arc setting (Fig. 4). Maastrichtian clastic rocks and hemipelagic limestones, and Palaeocene–Lower Eocene turbiditic terrigenous clastic rocks, overlie the juvenile back-arc association conformably and, in places, pass gradationally upwards into Eocene volcanic rocks. The Maastrichtian sequence is named the Cankurtaran Formation (Fig. 4). It starts with a clastic level, including *Siderolites* sp., *Cuvillerina* sp. and algae, and, in turn, passes upwards to, turbiditic limestone and reddish micritic limestone. These include mainly *Globotruncana stuartiformis* (Dalbiez), *G. stuarti* (de' Lapparent), *Globotruncana arca* (Cushman), *G. linneiana* (d'Orbigny), *Gansserina gansseri* (Bolli) and *Rosita contusa* (Cushman).

The Palaeocene–Lower Eocene sequence is named the Bakırköy Formation and is equivalent to the Borjomi Suite; it includes abundant nanno and foram fossils (Fig. 2). Dolerite dykes and sills are common in the Maastrichtian–Lower Eocene sequences but there are no volcanic interlayers in the Maastrichtian–Upper Eocene sequence (Fig. 4). Hence, it is concluded that the back-arc activity terminated during Maastrichtian–Early Eocene times. Middle Eocene volcanic rocks include, from bottom to top, an alternation of turbiditic rocks with basaltic volcanoclastic rocks up to 7 km in thickness and overlie the older sequences with a local unconformity mainly along the Black Sea coast on the Turkish side. Lordkipanidze *et al.* (1984) suggest that this sequence is a product of back-arc and/or interarc deposition, and is followed conformably by Upper Eocene shoshonitic volcanic rocks of a mature arc. However, similar volcanic rocks of the eastern Pontides with the same age and tectonic setting have been interpreted as the product of a post-collisional event (A. Yılmaz & Terzioğlu 1994; S. Yılmaz & Boztuğ 1996). Hence, the tectonic setting of the Eocene volcanic cycle is controversial and requires more study.

The Artvin–Bolnisi Unit

The Artvin–Bolnisi Unit is located between the southeastern Black Sea–Adjara–Trialeti Unit to the north and the Imbricated Bayburt–Karabakh Unit to the south. It represents the northern part of the southern Transcaucasus and the

GEOLOGIC AGE			LITHOLOGY	THICKNESS (m)	FORMATIONS AND DESCRIPTIONS	FAUNAL CONTENT	Interpretation
TERTIARY	EOCENE	(M)		> 1000	Erenler and Kabaköy Formations, Likani and Peranga Suites Basaltic volcanoclastic sequence	<i>Sphenolithus radions</i> Deflandre <i>Ericsonia cava</i> (Hay and Mahler) <i>E. ovalis</i> Black <i>E. subpertusa</i> Hay and Mahler	ACTIVITY OF JUVENILE BACK ARC TERMINATED
	PALEOCENE	(E)		100	Bakırköy Formation–Barjomi Suite Turbiditic terrigenous clastic rocks Reddish to olive gray mudstone and claystone Diabasic dykes and sills	<i>Prinsius bisulcus</i> Hay and Mahler <i>Fasciculithus</i> sp. <i>Discoaster</i> sp. <i>Morozorella</i> cf. <i>uncinata</i> Bolli <i>Planorotalites</i> cf. <i>ehrenbergi</i> Bolli <i>Acarinia</i> sp.	
CRETACEOUS (LATE)	MAASTRICHTIAN			~ 2500	Cankurtaran formations Reddish micritic limestone Turbiditic limestone Yellowish sandy limestone Diabasic dykes and sills	<i>Globotruncanita stuartiformis</i> (Daubiez) <i>G. stuarti</i> (de'Lapparent) <i>Globotruncana arca</i> (Cushman) <i>G. linneiana</i> (d' Orbigny) <i>Gansserina gansseri</i> (Bolli) <i>Rosita contusa</i> (Cushman)	
					Clastic rocks	<i>Siderolites</i> sp. <i>Cuvilliferina</i> sp. Rotaliidae, Algae	
PRE-MAAST- RICHTIAN				> 1000	Çağlayan Formation: basaltic lavas and micritic limestone alternation	<i>Globotruncana arca</i> (Cushman) <i>Globotruncanita elevata</i> (Brotzen)	Juvenile back-arc

Fig. 4. Stratigraphic section in the Cankurtaran village area. (E, Early; M, Middle).

central part of the eastern Pontides (Figs 1 and 7). Its northern and southern margins are delineated by south facing overthrusts (Fig. 8).

The lowermost stratigraphic level is Precambrian(?) and/or Lower Palaeozoic, with metamorphic rocks and Variscan granites cropping out around the Khrami and Artvin Massifs. These massifs are mainly built up of granite-gneisses and S-type plagiogranites (Belov *et al.* 1978; Adamia *et al.* 1983, 1995). A Carboniferous continental volcanic-sedimentary sequence overlies the older rocks unconformably and is followed upwards unconformably by Lower-Middle Jurassic volcanoclastic rocks, an Upper Jurassic-Lower Cretaceous shallow-marine limestone and volcanoclastic alternation, and an Upper Cretaceous calc-alkaline arc association (Gediköğlu *et al.* 1979; Özsayar *et al.* 1981; Lordkipanidze *et al.* 1989). The latter association has been studied in detail along the Georgian side where it is divided into several suites and named the Varlık Group in the Artvin area (Fig. 5). It is made up of hemipelagic, shallow-marine to subaerial volcanoclastic rocks, andesite, dacite, rhyolite and basalt, and is intruded by granitoids. Coal levels and ignimbrite-type pyroclastic rocks can be seen mainly in the upper levels of the association. This sequence is followed by unconformably

overlying Maastrichtian-Palaeocene shallow-marine limestones and turbiditic terrigenous clastic rocks that pass upwards into Lower Eocene clastic rocks (Fig. 5). The Maastrichtian sequence is named the Ziyarettepe Formation and is equivalent to the Tetrtskaro Suite. It starts with cross-bedded conglomerate and shallow-marine to hemipelagic limestones, which include *Siderolites calcitrapoides* (Lamarck), *Orbitoides* sp., *Lepidorbitoides* sp. (and algae in the lower levels), *Globotruncana* gr. *linneiana* (d'Orbigny), *G. arca* (Cushman) and *G. stuarti* (de'Lapparent). The Palaeocene-Lower Eocene sequence is named the Kızılçık Formation and is made up of terrigenous clastic rocks, including abundant foraminifera (Fig. 5). The Maastrichtian-Lower Eocene sequence contains no volcanic rocks and it is concluded that arc activity had terminated by the Maastrichtian-Early Eocene. The Middle Eocene volcanic rocks show a similar succession to that in the Adjara-Trialeti Unit and appear to be 1.5–2 km or less in thickness. They overlie the older rocks unconformably and are themselves overlain conformably by Upper Eocene shallow-marine clastic rocks. The Eocene sequence is cut by the Karçal Intrusive Suite, which includes andesitic subvolcanics, diorite and gabbro. Similar intrusive rocks can be seen

GEOLOGIC AGE			LITHOLOGY	THICKNESS (m)	FORMATIONS AND DESCRIPTIONS	FAUNAL CONTENT	Interpretation
TERTIARY	EOCENE	(L)		100	Karçal Intrusive rocks: subvolcanics diorite and gabbro (undivided) Kabaköy and Taşköprü Formation-Peranga and Nagrevi Suites: Basaltic to dacitic volcaniclastic sequence	<i>Planorotalites cf. pseudomenardii</i> Bolli <i>Morozovella cf. uncinata</i> Bolli <i>M. cf. pseudobulloides</i> (Plummer)	Debated Volcanic Cycle
		(M)					
	PALAEOCENE	(E)		50	Kızılıçık Formation: terrigenous clastic rocks Parallel bedded marl and sandstone	<i>Globigerina cf. trioculinoidea</i> (Plummer) <i>Acarinina</i> sp. Ostracoda	ACTIVITY OF THE ARC TERMINATED
CRETACEOUS (LATE)	MAASTRICHTIAN			75	Ziyarettepe Formation-Tetritskaro Suite Hemipelagic limestone Shallow-marine limestone	<i>Globotruncana gr. linneiana</i> (d'Orbigny) <i>G. arca</i> (Cushman) <i>G. stuarti</i> (de Lapparent)	
				25	Conglomerate, cross-bedded and tabular cross-stratification	<i>Siderolites calcitrapoides</i> Lamarck <i>Orbitoides</i> sp. <i>Lepidorbitoides</i> sp. Algae	
PRE-MAASTRICHTIAN				100	Varlık group-Shorsholeti Suite; granitoides Gasandami Suite Tandzla Suite Mashaveri Suite Didgverdi Suite		Arc

Fig. 5. Stratigraphic section in the Adagül-Karçal Dagħ area (E, Early; M, Middle; L, Late).

along the southeastern Black Sea coast at the Adjara-Trialeti Unit and in the Imbricated Bayburt-Karabakh Unit as outcrops of variable size.

The Imbricated Bayburt-Karabakh Unit

This unit crops out between the Artvin-Bolnisi Unit to the north and the North Anatolian-Lesser Caucasus ophiolitic belt to the south. It represents the southern part of both the southern Transcaucasus and the eastern Pontides (Fig. 7). Its northern and, in places, southern margins are delineated by south facing overthrusts (Fig. 8).

Hercynian metamorphic rocks (Robinson *et al.* 1995) and associated granitic rocks (Y. Yılmaz 1976), and an unconformably overlying Upper Carboniferous-Lower Permian continental sequence (Akdeniz 1988), are also located along the southern margin of Laurasia; the latter contains distinct Euro-American fauna and flora assemblages (Okay & Leven 1996). In addition, it is suggested that there is a pre-Liassic chaotic association of oceanic products such as a pre-Liassic sheeted dyke complex in the Yusufeli area (Şengör *et al.* 1980; Y. Yılmaz *et al.* 1997a, b). However, there is no direct relationship between the dyke complex and lower or upper levels of the ophiolitic

sequences in the Yusufeli area. In addition, the geochemical signature of the complex has not yet been determined. It is difficult to interpret the complex as the product of a relict ocean and it is concluded that there is no convincing data indicating Pre-Liassic ocean crust along the Imbricated Bayburt-Karabakh Unit.

Okay & Leven (1996) propose that the tectonic juxtaposition of these rock units occurred during the latest Triassic Cimmeride orogeny. Because Liassic volcaniclastic rocks overlie the older rocks unconformably and pass upwards into Upper Jurassic-Cretaceous forearc deposits with a local unconformity to the northeast of the Oltu area. Forearc deposits are represented by turbiditic limestones and clastics in the lower levels, turbiditic clastic rocks, and epi- and/or pyroclastic rock intercalations and hemipelagic shales in the upper levels; these are isoclinally folded and imbricated (Konak *et al.* 1995). Maastrichtian-Palaeocene turbiditic terrigenous clastics and limestone alternations overlie the forearc deposits unconformably; this sequence is named as the Atlılar Formation. It starts with a basal transgressive conglomerate and passes upwards into terrigenous clastic rocks and limestones with local turbiditic characteristics. In the lower levels of the sequence, corals and bivalves are common (Fig. 6). In the middle

GEOLOGIC AGE	LITHOLOGY	THICKNESS (m)	FORMATIONS AND DESCRIPTIONS	FAUNAL CONTENT	Interpretation
PALAEOCENE		50	Atilar Formation: terrigenous clastic rocks Claystone and siltstone alternation	<i>Missisipina binehorsti</i> (Reus) <i>Epinoidea</i> sp., <i>Planorbolina</i> sp. <i>Anomalina</i> sp.	ACTIVITY OF FOREARC TERMINATED
CRETACEOUS (LATE)	MAASTRICHTIAN	70	Green claystone with thin calciturbidite beds, and turbiditic terrigenous clastic rocks	<i>Globotruncana ventricosa</i> White <i>Stomiosphera sphaerica</i> (Kaufmann) <i>Pithonella ovalis</i> (Kaufmann) <i>Calcisphaerula innominate</i> Bonet <i>Globotruncana</i> gr. <i>linneiana</i> (d' Orbigny)	
			Turbiditic limestone		
		100	Sandstone interbedded siltstone and claystone		
			Thin to thick bedded limestone		
			Cross bedded sandstone and claystone		
PRE-MAAST- RICHTIAN		100	Cross-bedded clastic rocks	CORALS: <i>Cunolites sororius</i> (Quensted) <i>Diploctenium simplex</i> Alloiteau <i>Placcocoenia</i> sp., <i>Favia</i> sp. BIVALVES: <i>Inoceramus</i> sp., <i>Gryphaea</i> sp. Rotallidae, Echinoderm	Forearc
			Terrigenous clastic rocks		
			Basal transgressive conglomerate		
			Turbiditic clastic rocks and limestone, in places, epiclastic and/or pyroclastic rocks alternation		

Fig. 6. Stratigraphic section in the Olur–Atilar village area.

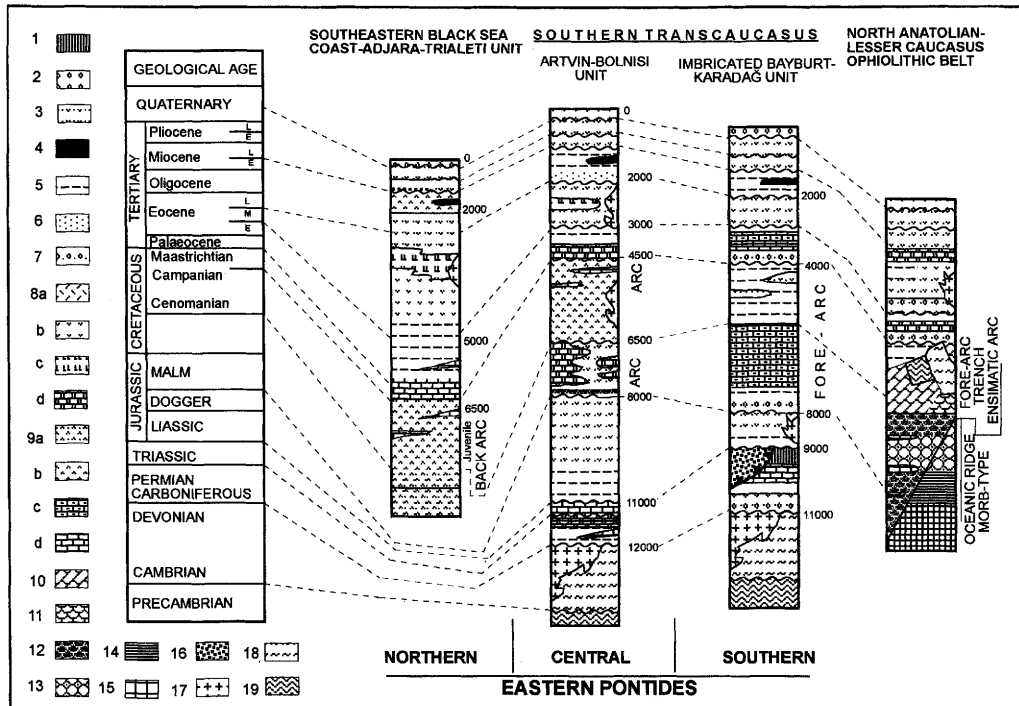


Fig. 7. Correlative table showing tectonic units of the study area. 1, Non-deposition; 2, alluvium and fluvial deposits; 3, continental volcanoclastic rocks; 4, coal levels; 5, siltstone; 6, sandstone; 7, conglomerate; 8, shallow marine – a, volcanoclastic rocks; b, lavas; c, delenites; d, limestone; 9, deep marine – a, volcanoclastic rocks; b, lavas; c, turbiditic limestone; d, limestone; 10, ophiolitic mélangé; 11, ensimatic arc lavas; 12, epiophiolitic lavas; 13, dyke complex; 14, gabbro; 15, serpentinite and peridotite; 16, pre-Liassic chaotic rocks; 17, intrusive rocks (undivided); 18, schist; 19, gneiss.

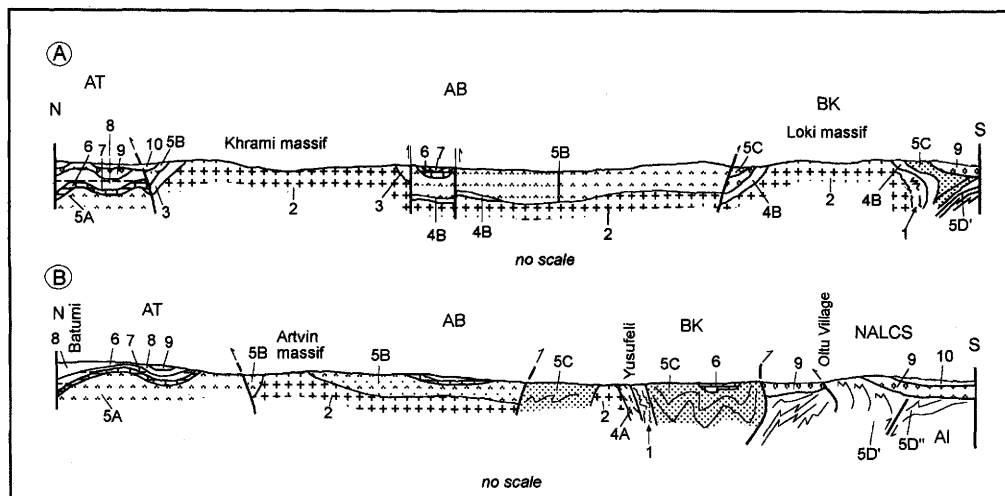


Fig. 8. Schematic cross-sections of the Georgian (a) and Turkish (b) sides. See Fig. 1 for abbreviations. 1, Precambrian–Cambrian metamorphic rocks; 2, Middle Palaeozoic granitoids; 3, Upper Carboniferous–Lower Permian molasse; 4A, Pre-Liassic dyke complex; 4B, Liassic–Dogger volcanoclastic and volcanic sequence; 5, Upper Jurassic–Cretaceous (Pre-Campanian) sequence – 5A, Juvenile back-arc volcanics; 5B, arc volcanoclastic rocks; 5C, forearc deposits; 5D, ophiolites, ophiolitic mélanges and ensimatic arc association – undivided; 5D', the Ankara–Erzincan/Sevan–Akera ophiolitic zone; 5D'', the Northern Taurus–Erzurum–Kağızman–Vedi ophiolitic zone; 6, Maastrichtian–Palaeocene limestone; 7, Palaeocene–Lower Eocene clastic rocks; 8, Middle Eocene volcanic rocks and volcanoclastic rocks; 9, Upper Eocene–Lower Miocene clastic rocks; 10, Upper Miocene–Quaternary continental deposits.

levels *Globotruncana ventricosa* (White), *Stomiosphera sphaerica* (Kaufmann), *Pithonella ovalis* (Kaufmann), *Calcisphaerula innominate* Banet and *Globotruncana gr linneiana* (d'Orbigny) occur, and *Missisipina binehorsti* (Reus), *Epinoides* sp., *Planorbulina* sp. and *Anomolina* sp. are found in the upper levels. Finally, Middle Eocene volcanoclastics and Upper Eocene clastics overlie the older rocks unconformably (Fig. 7). The lithology and stratigraphic setting is similar to the Middle–Upper Eocene sequence of the Artvin–Bolnisi Unit.

The North Anatolian–Lesser Caucasus ophiolitic belt

This belt is a suture zone between the Pontian–southern Transcaucasus arc to the north and the Anatolian–Iranian Platform to the south. It is divided into two subzones, which resemble each other in lithology. The Ankara–Erzincan/Sevan–Akera ophiolitic zone is located to the north, whereas the Northern Taurus–Erzurum–Kağızman/Vedi ophiolitic zone is located to the south. Both zones are believed to be allochthonous (Fig. 8b) and continuous beneath the

Cretaceous–Tertiary cover (Knipper 1980; Zakariadze *et al.* 1983).

Along this belt, ophiolites and ophiolitic mélanges of different ages crop out (Belov *et al.* 1978; Gasanov 1986; Tatar 1978; Koçyiğit 1990). The ophiolites comprise serpentinite, ultramafic rocks, layered gabbro, a sheeted dyke complex and volcano–sedimentary cover. Accretion and mixing of ophiolites of different ages occurred during Late Cretaceous tectonism. Jurassic–Lower Cretaceous volcanic rocks in the ophiolites are represented by mid-ocean ridge basalt (MORB)-type tholeiites, whereas Upper Cretaceous volcanic rocks in the ophiolites belong to the calc-alkaline island-arc basalt series (A. Yılmaz 1980, 1981; Buket 1982; Zakariadze *et al.* 1983). This arc may be regarded as ensimatic (Okay & Şahintürk 1997). Ophiolitic mélanges and olistostromes (Knipper 1980; Knipper *et al.* 1986), representing an accretionary prism (Koçyiğit 1991), formed during obduction of these ophiolites onto the southern Transcaucasus to the north and the Anatolian–Iranian Platform to the south. The formation and emplacement age of the mélange ranges from the Cenomanian to Early Coniacian in the Lesser Caucasus (Knipper & Khain 1980; Zakariadze *et al.* 1983) and is dated as pre-Late

Campanian in northeastern Anatolia (A. Yılmaz 1982). Therefore, the ophiolites in the region were all obducted before Late Coniacian–Campanian times.

Cover rocks

With the exception of the Adjara–Trialeti Unit, a Maastrichtian–Lower Eocene sequence overlies the older rock units unconformably and includes a great deal of terrigenous clastic rocks. It can be correlated from north to south along all tectonic units. No volcanic intercalations occur in this sequence. However, Middle Eocene volcanic rocks of the Adjara–Trialeti Unit have been interpreted as products of back-arc and/or interarc rifting (Lordkipanidze *et al.* 1984) with the Pontides as an arc (Tokel 1977). However, the A-type alkaline and M-type low-K tholeiitic characteristics have also been related to a post-collisional magmatic pulse in a tensional regime resulting from crustal thickening after collision (S. Yılmaz & Boztuğ 1996). Hence, the setting of the Middle Eocene volcanic rocks is controversial. In the study area, gabbro and diorite intrusions are common from north to south throughout all tectonic units and it can be concluded that Middle Eocene volcanic and intrusive rocks are products of a tensional event in a general sense. This may have led to the formation of the eastern Black Sea (Okay & Şahintürk 1997). The evolution of these basins differs greatly from the western part of the Black Sea basin (Görür *et al.* 1993; Ustaömer & Robertson 1997). Late Eocene volcanic activity ceased gradually from south to north. Oligocene–Lower Miocene regressive shallow marine to continental deposits overlie the tectonic units with local unconformity. After this regression the formation of some basins, such as the Ahaltısihe and Oltu, was terminated while others, such as the Black Sea and Caspian Sea, have survived to the present day. Upper Miocene–Lower Pliocene and Upper Pliocene–Quaternary continental deposits overlie the older rock units unconformably.

Discussion and conclusion

Within the Pontide–Transcaucasus system there are important lateral and vertical facies/lithology differences. Previous hypotheses explain these differences inadequately in the frame of regional geodynamic evolution of the region. For instance, during the Late Cretaceous the northern segment of the southeastern Black Sea coast–Adjara–Trialeti Unit represents a juvenile back-arc basin, whereas the western Pontides

have been interpreted as a juvenile ocean and/or mature back-arc basin (Görür *et al.* 1993). This indicates that the western and eastern Pontides experienced a different geodynamic evolution. However, a reddish hemipelagic limestone unit is Maastrichtian in the Artvin–Cankurtaran area (Fig. 5) but Palaeocene in age in the Sinop area. This reddish limestone represents a characteristic horizon in the Pontides and indicates a transition from shallow-marine to pelagic environment, expressing the deepening of the basin. Within this framework, it is concluded that this level indicates a transgression occurring from east to west in the Artvin–Cankurtaran and Sinop areas during Maastrichtian–Palaeocene times.

The eastern Pontides have been interpreted as an arc (Peccherillo & Taylor 1975; Eğin & Hirst 1979; Gedikoğlu *et al.* 1979; Manetti *et al.* 1983) which was either north facing (Tokel 1972, 1977; Adamia *et al.* 1981, 1977; Knipper *et al.* 1986) or south facing (Bektaş 1984; Bektaş *et al.* 1984) between Palaeozoic and Tertiary times. Şengör & Yılmaz (1981) suggest that the Tethyan evolution of Turkey can be divided into two main phases – Palaeotethyan and Neotethyan – which partly overlap in time. In addition, they interpret the Pontide–Transcaucasus–Sanandaj–Sirjan (Podataksasi) zone as a north facing Palaeotethyan magmatic arc during Early Triassic–Late Cretaceous times (Şengör 1987). In spite of these differences, the Pontide Arc is, in general, considered to have been a typical arc mainly during the Late Cretaceous. This view is also acceptable for the western part of the eastern Pontides. In the eastern part of the eastern Pontides, in the Artvin area, Jurassic–Cretaceous volcanic rocks as a whole are also products of an arc-related system (Konak *et al.* 1995).

In the present study, tectonic division of the region is revised and, on the basis of this division, it is concluded that only the southern segment of the easternmost Pontides represents a forearc. The central segment represents the arc and northern segment represents a juvenile back-arc. On the basis of this reconstruction and the dipping angles of the thrust planes developed along the suture zone, the arc is inferred to have had a south facing setting during Late Jurassic–Cretaceous times. In the southern segment of the eastern Pontides, the Imbricated Bayburt–Karabakh Unit represents the forearc basin of an active continental margin during Late Jurassic–Cretaceous time, whereas in the western part of the eastern Pontides the Jurassic–Lower Cretaceous sequence was formed during a rifting event and indicates a passive

continental margin (Görür *et al.* 1983; A. Yılmaz 1985). Thus, there is a progressive transition from east to west along the eastern Pontides. This may result from progressive interaction between a spreading ridge and a subduction zone, as suggested elsewhere by Dewey (1976); the consistent framework of this kinematic model includes a spreading ridge and a subduction zone together, as suggested by Cox & Hart (1986). Within this framework, the western part of the eastern Pontides was a passive continental margin during the Late Jurassic–Early Cretaceous, whilst during the Late Cretaceous (mainly pre-Maastrichtian) both western and eastern parts of the eastern Pontides became an active continental margin.

The Sevan Akera–Karadağ Suture of Şengör (1987) is a part of the North Anatolian (İzmir–Ankara–Erzincan) Lesser Caucasus Suture which separates the Anatolian–Iranian Platform from the eastern Pontide–Transcaucasus Arc. Ophiolites, mélanges and forearc deposits exposed in both sutures resemble each other in age and lithology. Due to the Tertiary cover, it is not possible to see outcrops of the Anatolian–Iranian Platform near the suture. However, the Akdağ metamorphic rocks of the Hınıs area and the Upper Palaeozoic–Lower Mesozoic carbonates of the Başkale (Van) and Nahçıvan areas are components of the Anatolian–Iranian Platform. They represent the continental crust in East Anatolia and crop out as tectonic windows beneath obducted ophiolite and the ophiolitic mélange association (A. Yılmaz *et al.* 1989a,b, 1997).

On the basis of facies and data presented above, it is suggested that the easternmost Pontide and southern Transcaucasus represent, from north to south, juvenile back-arc, arc and forearc environments active mainly during the Late Jurassic–Cretaceous (pre-Maastrichtian) interval. This clearly indicates a northward subduction polarity in the region where lithologic and structural data show an east to west transition from active to passive continental margin. The absence of structural elements between the facies of active and passive margins suggests that interference of the spreading ridge and the subduction zone was a progressive event.

Based on structural correlation of the eastern Pontides (Turkey) and the southern Transcaucasus (Georgia), the following conclusions are drawn:

- In setting, the eastern Pontides and southern Transcaucasus belong to the same geological belt and represent the subduction zone of the

Eurasian continent. They comprise, from north to south, juvenile back-arc, arc and forearc basins, formed mainly in the Late Jurassic–Campanian interval. In this context, the eastern Pontides are divided into three subzones, which, from north to south, are: the southeastern Black Sea coast–Adjara–Trialeti Unit, representing the juvenile back-arc; the Artvin–Bölnisi Unit, representing the arc; and the Imbricated Bayburt–Karabakh Unit, representing forearc environments. The region as a whole displays a clear northern polarity.

- On the basis of lateral facial distribution, a model comprising the interaction between a spreading ridge to the west and a subduction zone to the east of the region is preferable to other models.
- The activity of the system explained above ceased before the Maastrichtian and no evidence indicates volcanic activity in the Maastrichtian–Early Eocene interval. Debate continues on the setting of the Middle Eocene volcanism, which could have been erupted during a tensional period. This tensional event may be directly related to formation of the eastern Black Sea basin.

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