GEOSCIENCE FRONTIERS 2(1) (2011) 49–56

available at www.sciencedirect.com

China University of Geosciences (Beijing)

GEOSCIENCE FRONTIERS

journal homepage: www.elsevier.com/locate/gsf

ORIGINAL ARTICLE

Arc magmatism as a window to plate kinematics and subduction polarity: Example from the eastern Pontides belt, NE Turkey

Yener Eyuboglu [a,*], M. Santosh [b], Osman Bektas [c], Seda Ayhan [c]

[a] *Department of Geological Engineering, Gumushane University, 29000 Gumushane, Turkey*
[b] *Faculty of Science, Kochi University, Kochi 780-8520, Japan*
[c] *Department of Geological Engineering, Karadeniz Technical University, 61030 Trabzon, Turkey*

Received 19 November 2010; accepted 13 December 2010
Available online 13 January 2011

KEYWORDS
Turkey;
Eastern Pontides belt;
Subduction polarity;
Arc magmatism;
Paleomagnetism

Abstract The Eastern Pontides orogenic belt in the Black Sea region of Turkey offers a critical window to plate kinematics and subduction polarity during the closure of the Paleotethys. Here we provide a brief synthesis on recent information from this belt. We infer a southward subduction for the origin of the Eastern Pontides orogenic belt and its associated late Mesozoic–Cenozoic magmatism based on clear spatial and temporal variations in Late Cretaceous and Cenozoic arc magmatism, together with the existence of a prominent south-dipping reverse fault system along the entire southern coast of the Black Sea. Our model is at variance with some recent proposals favoring a northward subduction polarity, and illustrates the importance of arc magmatism in evaluating the geodynamic milieu associated with convergent margin processes.

1. Introduction

The subduction polarity and geotectonic evolution associated with ocean closure and arc-continent suturing are topics of considerable interest, which have been addressed from the standpoints of geological milieu, geochemical signatures and geophysical perspectives from Precambrian and Phanerozoic terranes (e.g., Santosh et al., 2009; Whattam, 2009; Santosh, 2010; Xiao et al., 2010; Zhang et al., 2010). The geodynamic evolution of the eastern Pontides orogenic belt in Turkey has been much debated, primarily due to the scarcity of structural, geochemical and geochronological data. In general, models proposed for the subduction polarity in the eastern Pontides fall into three groups. Some authors, who consider the ultramafic rocks exposed in the

* Corresponding author.
E-mail address: y_eyuboglu@hotmail.com (Y. Eyuboglu).

Peer-review under responsibility of China University of Geosciences (Beijing).
doi:10.1016/j.gsf.2010.12.004

Production and hosting by Elsevier

south of the Pontides Arc as a remnant of the Paleotethys Ocean (e.g. Adamia et al., 1977; Ustaömer and Robertson, 1996) suggest that the eastern Pontides developed by northward subduction of Paleotethys from the Paleozoic until the end of Eocene. In contrast, Şengör and Yılmaz (1981) proposed that the Paleotethys was situated north of the Pontides, hence requiring southward subduction from the Paleozoic until the Mid-Jurassic, followed by northward subduction from the Upper Cretaceous until the end of the Eocene. According to their model, the eastern Pontides represent the southern active continental margin of Eurasia, along which Upper Cretaceous arc volcanism developed above the northward subducting Neotethys. The Neotethys was interpreted as a back-arc basin to the eastern Pontides magmatic arc that had originally opened in the Lower Jurassic. In a third model, Dewey et al. (1973), Chorowicz et al. (1998), Bektaş et al. (1999), Eyuboglu et al. (2006, 2007) and Eyuboglu (2010) consider that the region experienced uninterrupted southward subduction from the Paleozoic until the end of the Eocene. In this model, the Black Sea is considered as a remnant of the Tethys Ocean and the ophiolitic belt in the Axial zone represents a back-arc basin environment. In this work, we synthesize some of the recent results that provide robust evidence in support of a southward subduction model for the origin of the eastern Pontides during late Mesozoic–Cenozoic.

2. Geological framework

The ~500 km-long and 200 km-wide Eastern Pontides belt in the Black Sea region of Turkey is part of the Alpine metallogenic belt and has been subdivided into Northern, Southern and Axial zones that are separated by E-W-, NE-SW- and NW-SE-trending, vertical faults (Fig. 1; Bektaş et al., 1995; Eyuboglu et al., 2006). The Northern zone is characterized by Mesozoic–Cenozoic volcanic rocks and granitic intrusions. In this zone, the Mesozoic sequence begins with early to mid-Jurassic basalt-andesite and associated pyroclastic rocks. These volcanic units are covered by Late Jurassic to Early Cretaceous thick- to massive-bedded platform limestones (Berdiga Limestone). The Late Cretaceous is characterized by intense bimodal volcanism (Fig. 2A). This volcanism occurred in two different cycles (Eyuboglu, 2010), and is especially significant as it hosts several volcanogenic massive sulfide deposits such as those of Harkköy, Eseli, Kutlular, Köprübaşı, Murgul, Lahanos and Israildere (Akçay et al., 1998). The first cycle begins with basalt-andesite lavas and associated pyroclastics (Çatak Formation) and grades upward into hematitic dacite-rhyodacite and associated pyroclastics interbedded with limestone and marl (Kızılkaya Formation). The second cycle also begins with basaltic-andesitic rocks (Cağlayan Formation) and continues with biotite-bearing rhyolite-rhyodacite (Çayırbağ Formation). This sequence is covered by Maastrichtian-Paleocene sandy limestone, biomicrite, and marl alternations (Bakırköy Formation). In the Northern zone, the Cenozoic is typically represented by Eocene mafic volcanic rocks and granitic intrusions, and Neogene alkaline volcanic rocks (Fig. 2A).

The pre-Jurassic basement is exposed in the Southern Zone, and consists of the Pulur-Ağvanis-Tokat metamorphic massif, the Gümüşhane-Köse granites, and phlogopite- and hornblende-bearing, Alaskan-type, mafic-ultramafic rocks which cut the metamorphic massifs as small-scale elliptical intrusions (Eyuboglu et al., 2010). Sedimentary rocks overlying the basement consist of Jurassic, Cretaceous, and Eocene sequences. In the Gümüshane area, which is one of the best locations exposing the southern part of the eastern Pontides orogenic belt, Late Cretaceous formations are characterized by a thick sedimentary sequence known as the Kermutdere Formation (Fig. 2B). This unit starts with yellowish colored sandy limestones on the Late Jurassic to Early Cretaceous carbonate platform, grades upward into red pelagic limestones, and continues with sandstone, siltstone, claystone, marl and limestone alternations with some locally interbedded calc-alkaline tuffs (Fig. 2B). On the other hand, Late Cretaceous time is represented by bimodal volcanic rocks and arc-related I-type calc-alkaline granitic intrusions about 25 km north of the Gümüshane city center (Kaygusuz et al., 2008, 2009). These autochthonous Mesozoic units are intruded by early Eocene adakitic porphyritic andesites and dacites (Eyuboglu et al., 2010b, 2010c and 2010d), and are covered by early to middle Eocene Alibaba Formation, which is comprises a basal conglomerate grading upwards into Nummulites-bearing limestone and a thick volcanic sequence including basalt-andesite and associated pyroclastic rocks. All of the units exposed in the Southern zone are cut by the mid-late Eocene granitic intrusions and basaltic dikes of unknown age (Eyuboglu et al. 2010b and 2010d; Arslan and Aliyazıcıoglu, 2001; Arslan and Aslan, 2006). In the Southern-Axial transition zone, the late Mesozoic sequence is floored by an olistostromal ophiolitic mélange lying top platform carbonates. The Late Cretaceous magmatism in this part of the eastern Pontides orogenic belt is characterized by two different cycles (Eyuboglu, 2010). The first cycle is represented by shoshonitic trachyandesites and associated pyroclastic rocks (Fig. 2C). These high-K volcanic rocks cover the Mid-Cretaceous ophiolitic olistrostromal mélange and are in turn covered by late Campanian-Maastrichtian reefal limestones with rudists. $^{40}Ar/^{39}Ar$ dating of biotites separated from a trachyandesite within the formation indicates that it is Campanian in age (Eyuboglu, 2010). The second cycle of Late Cretaceous magmatism is represented by analcimized leucite-rich Maastrichtian ultrapotassic rocks in the southern part of the eastern Pontides belt (Eyuboglu et al., 2010a). These ultrapotassic rocks cut late Campanian-early Maastrichtian, rudist-bearing, reef limestones and are truncated by the late Paleocene-early Eocene adakitic rocks. All of these lithological units are unconformably overlain by Eocene sedimentary sequences (Fig. 2C). Upper mantle peridotites and an extensive Middle to Upper Cretaceous olistostromal mélange occur farther south in the Axial Zone (Eyuboglu et al., 2007; Eyuboglu et al., 2010).

3. Geodynamic implications

It has been widely considered that the eastern Pontides orogenic belt was shaped by northward subduction of the Tethys oceanic lithosphere during the late Mesozoic–Cenozoic time (Adamia et al., 1977; Şengör and Yılmaz, 1981; Ustaömer and Robertson, 1996; Okay and Sahintürk, 1997; Robertson and Ustaömer, 2004; Tüysüz and Tekin, 2007; Rice et al., 2009; Dilek et al., 2010). However, our recent studies negate this long held concept, and we summarize below the salient aspects from our detailed geological, geochemical and geochronological studies that suggest a southward subduction during the late Mesozoic–Cenozoic evolution of the eastern Pontides.

3.1. Evidence from magmatism

In a recent study, Cinku et al. (2010) suggested that southward migration of Late Cretaceous magmatism is related to the steepening (roll back) of oceanic lithosphere that was subducted

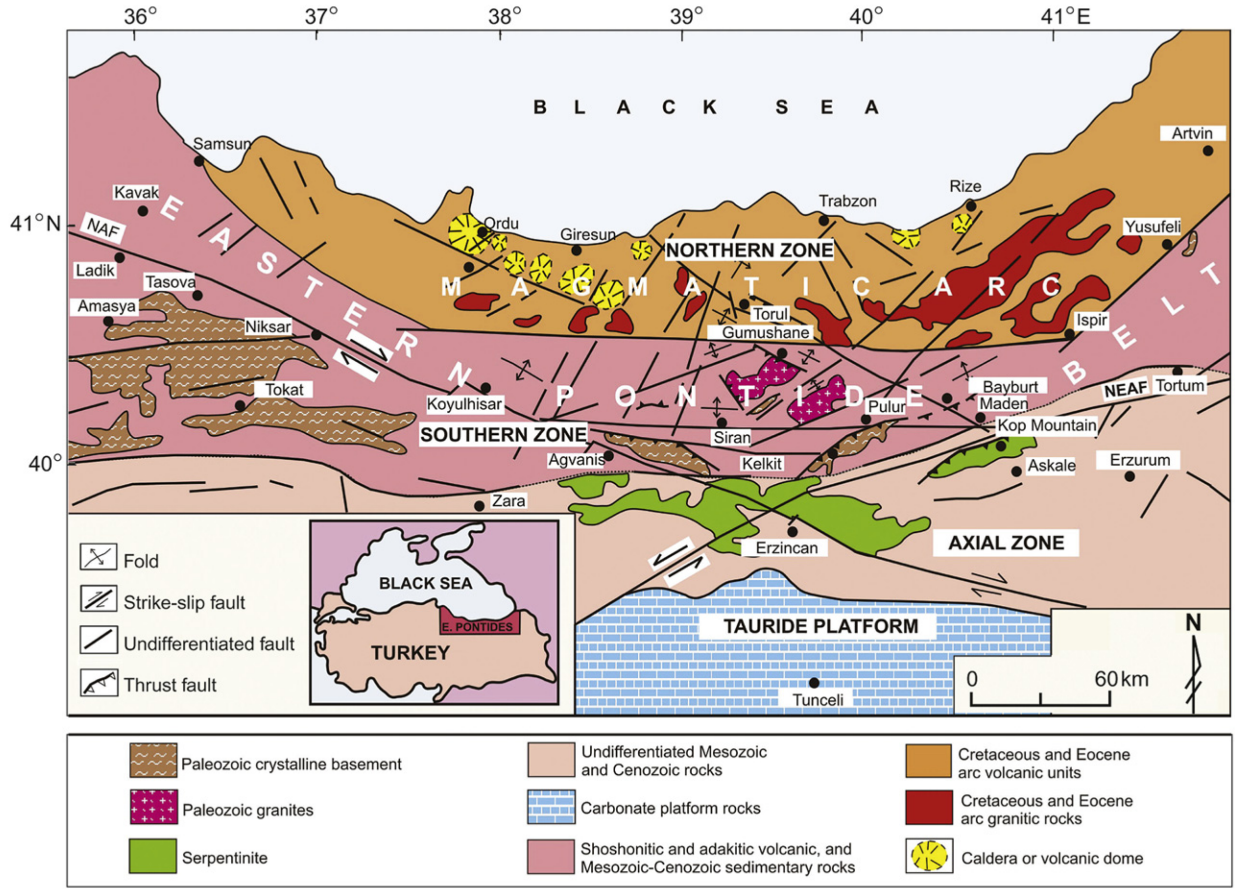

Figure 1 Major geological features and tectonic zones of the eastern Pontide orogenic belt. NAF = North Anatolian Fault; NEAF = Northeast Anatolian Fault (after Eyuboglu et al., 2006).

northwards during the Late Cretaceous. One of the geochemical criteria employed to identify the depth of magma generation in arc settings is the relationship with potassium content (Kuno, 1959; Hatherton and Dickinson, 1969; Arculus and Johnson, 1978; Gill, 1981). In general, low-K tholeiitic magmas are considered to form close to the trench and high-K magmas (shoshonitic and ultrapotassic) are generated progressively from the trench in subduction settings. It has been clearly demonstrated that the eastern Pontides orogenic belt represents a continental arc (Bektaş et al., 1999; Eyuboglu, 2010). The Late Cretaceous magmatism in this region started along the northern margin of the arc with intense TH-CA (thoeliitic − calc-alkaline) bimodal volcanism during the Turonian–Coniacian. The intensity of this magmatism decreased toward the south, and shows a southward transition to CA-A (calc-alkaline − alkaline) magmatism in the Coniacian–Campanian. Farther south, the igneous activity transitioned into Campanian shoshonitic volcanism (Bektaş et al., 1999; Eyuboglu, 2010; Fig. 3A). During Maastrichtian-early Paleocene time, magmatism was characterized by TH-CA to CA affinities in the north to shoshonitic to ultrapotassic affinities in the south (Eyuboglu et al., 2010a, c). These spatial and temporal variations of Late Cretaceous arc magmatism in this region clearly indicate southward subduction during the Late Mesozoic (Fig. 3A).

In contrast, comprehensive geochronological and isotopic studies on Late Mesozoic and Cenozoic magmatism in the entire eastern Pontides orogenic belt (Eyuboglu et al., 2010a, b; unpublished data) conclusively demonstrate that Late Cretaceous magmatism became progressively younger from north to south, and conversely, Tertiary magmatism from south to north (Fig. 3A, B). These spatial and temporal variations of subduction-related late Mesozoic-Tertiary arc magmatism in the eastern Pontides can be best explained by a Tertiary roll back of the Tethys oceanic lithosphere, which had been subducting southwards during the late Mesozoic (Eyuboglu et al., 2010a, b, c).

3.2. Geological evidence

When an oceanic lithospheric plate approaches continental lithosphere in convergent plate settings, the denser oceanic lithosphere sinks beneath the continental lithosphere. The overriding plate moves toward the trench and produces a regional-scale reverse fault that is crucial to interpreting subduction orientation in old and complex convergent plate settings such as the eastern Pontides orogenic belt. The most prominent structural feature of the southern coast of the Black Sea, north of Turkey (Fig. 4), is an east–west trending and south-dipping reverse fault (e.g., Şengör and Yılmaz, 1981; Okay et al., 1994; Spadini et al., 1996; Nikishin et al., 2003). Focal mechanism solutions for recent, low-magnitude earthquakes offshore in the eastern Black Sea and for the 1968 Bartın earthquake (M_s = 6.6) indicate reverse motion along the fault. The large-scaled thrust faults that formed after the Late Cretaceous and onshore from the southeastern Black Sea (eastern Pontides), show a NE strike and SE dip (e.g., Okay et al., 1997; Eyuboglu et al., 2006). In addition, recent geological, geophysical

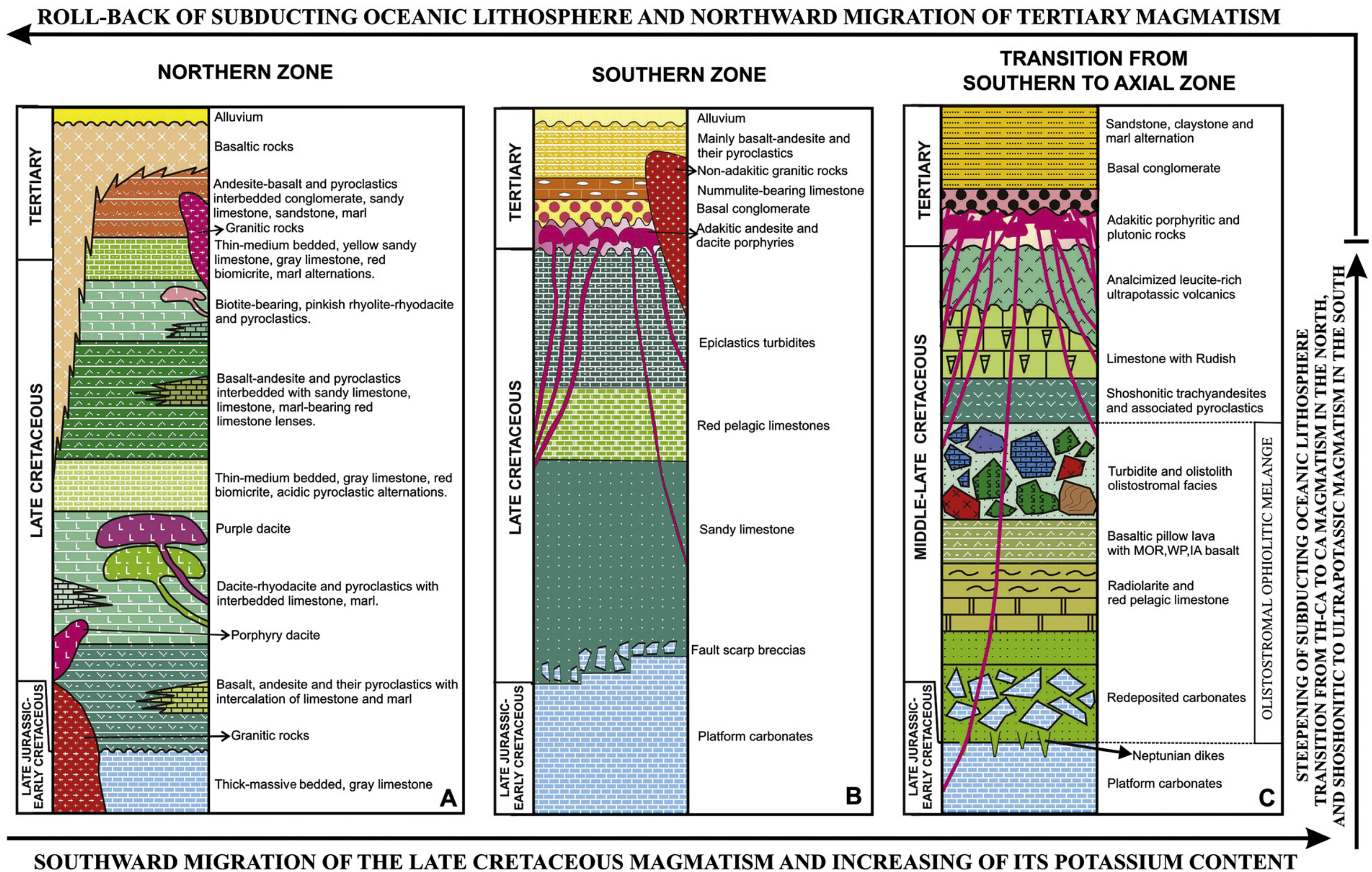

Figure 2 Stratigraphic columnar sections showing the relation of Mesozoic and Cenozoic lithological units of the eastern Pontides orogenic belt (after Eyuboglu et al., 2007; Eyuboglu, 2010; Eyuboglu et al., 2010a).

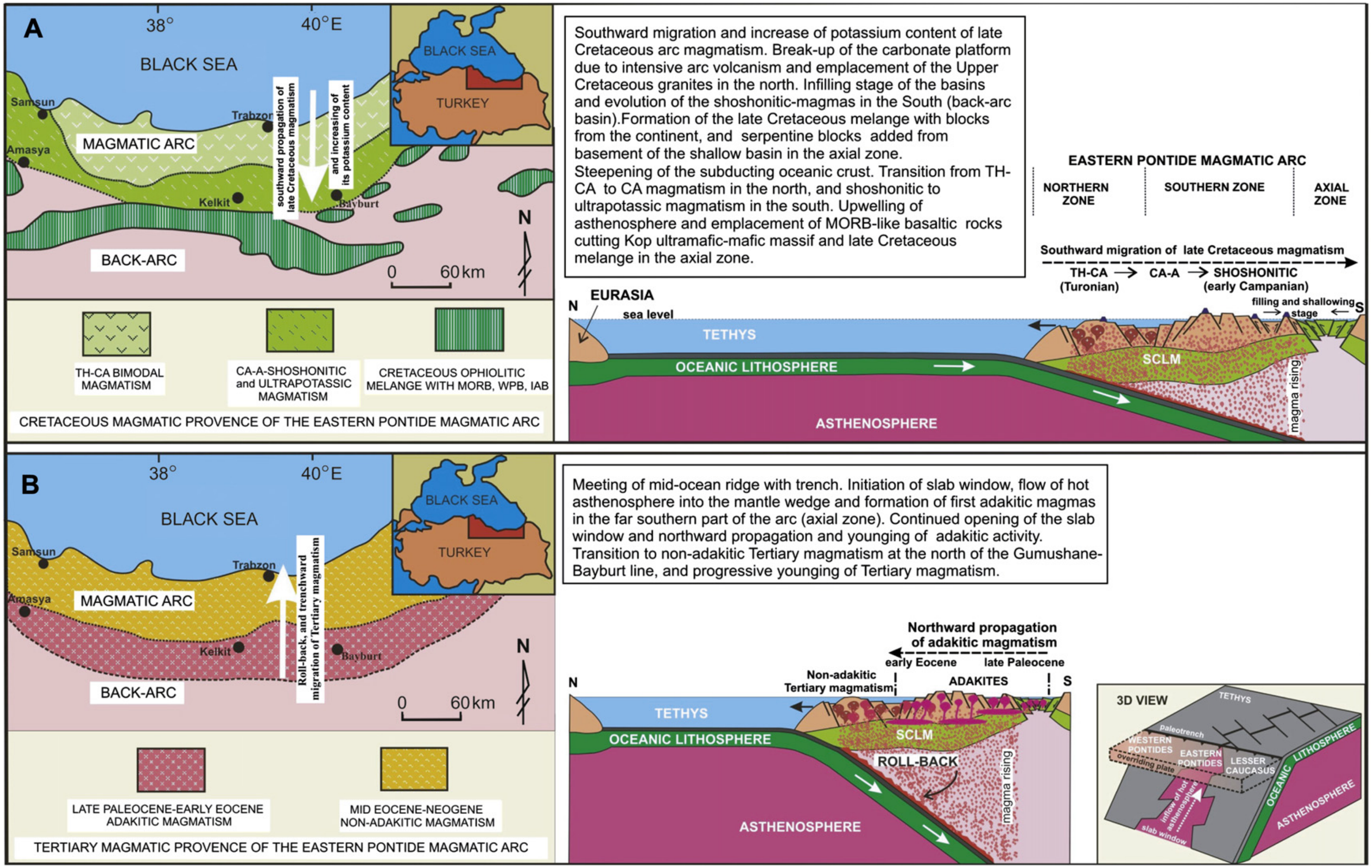

Figure 3 Characteristic magma series of the Cretaceous (A) and Tertiary (B) magmatic arcs in the eastern Pontide orogenic belt and their geodynamic settings (after Eyuboglu, 2010; Eyuboglu et al., 2010a).

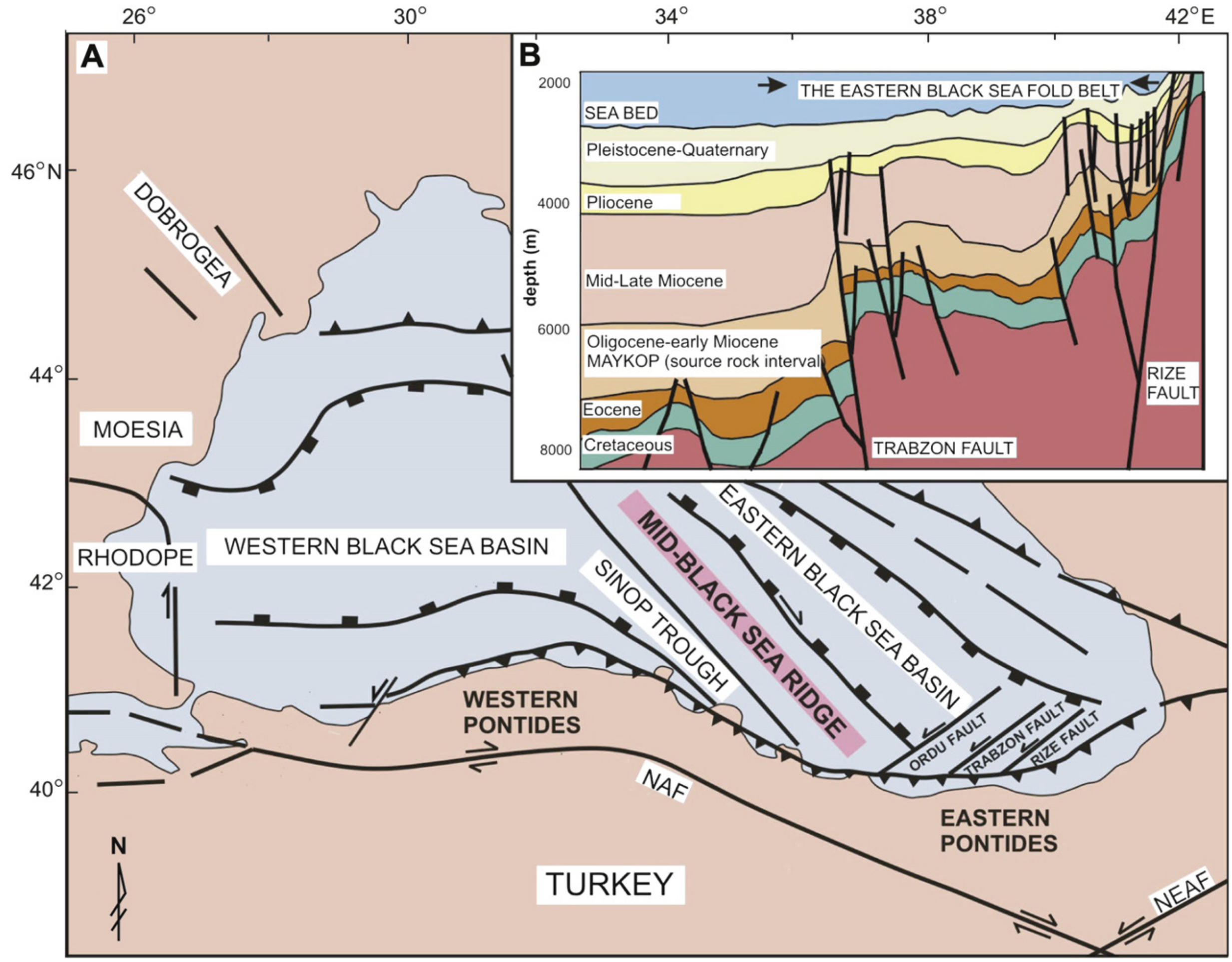

Figure 4 Tectonic map of the Black Sea and its vicinity (modified from Turkish Petroleum Corporation web page and Eyuboglu et al., 2010a).

and GPS data, as well as the launching of petroleum exploration offshore of Trabzon, Rize, and Hopa imply that an active collision system extends from Georgia into the eastern Black Sea shelf area along the Rize-Trabzon-Ordu line (Turkish Petroleum Corporation web page; Bektaş and Eyuboglu, 2003; Keskin et al., 2010). The existence of a south-dipping reverse fault system along the entire length of the southern coast of the Black Sea supports a southward subduction model for the origin of the eastern Pontides orogenic belt and late Mesozoic–Cenozoic magmatism.

Geological and geochemical characteristics of the Mid-Cretaceous ophiolitic olistostromal mélange, which is exposed along a belt in the southern part of the eastern Pontides orogenic belt and is covered by the products of first cycle high-K magmatic activity (the Fındıklı Formation), indicate that it originally formed during the drifting stage of a back-arc basin (Eyuboglu et al., 2007; Fig. 2). This mélange is composed of three distinct lithological facies that 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 within a thinning and fining upward 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 is represented by an olistolith-olistostromal facies that includes sandstone, siltstone, marl and intervening olistostromes and olistoliths, mainly limestone, peridotite-gabbro and metamorphic blocks derived from the continental shelf and the adjacent peridotitic-metamorphic ridge (Eyuboglu et al., 2007; Fig. 2C). The extension of the carbonate platform and the formation of a half graben during the Middle Cretaceous are indicated by the presence of neptunian dikes in the platform carbonate rocks and rift-related, redeposited carbonate rocks. This assemblage constitutes a thinning and fining upward sequence that accumulated above the basement rocks, with the neptunian dikes exposed around the Amasya city center. The dykes in the platform carbonate rocks occur in vertical crack zones that are filled and overlain by Albian red pelagic limestones of the mélange sequence (Bektas et al., 2001; Eyuboglu et al., 2006; Eyuboglu et al., 2007; Fig. 2C). These relationships imply that the contact between the platform carbonate rocks and the ophiolitic mélange was originally sedimentary, and not tectonic. However, at many places, the structural setting of these rocks was converted to a tectonic one during post-Cretaceous inversion of the basins. A different relationship is observed near Karasenir village, 10 km south of Amasya. Here, the pelagic facies of the mélange – comprising radiolarites and alternating red pelagic limestones – shows a transitional lower contact with platform carbonates rocks and Late Jurassic-Early Cretaceous pelagic carbonate rocks. These two different sedimentary assemblages in the lower parts of the sedimentary mélange may imply that it formed during break-up of the carbonate platform, across the hanging walls and footwalls of listric faults which were active during the Mid-Cretaceous (Eyuboglu et al., 2007).

3.3. Paleomagnetic evidence

Van der Voo (1968) was the first to perform a detailed paleomagnetic study in northeastern Turkey. Dewey et al. (1973) interpreted the ultramafic belt exposed in the southern part of the arc as the remnant of a back-arc basin to the eastern Pontide magmatic arc, based on the paleomagnetic data. Saribudak (1989) suggested that the entire Pontides might have undergone a northward drift of over 2000 km since the late Mesozoic. Moreoever, a study on Late Cretaceous red limestones yielded a paleolatitude of ∼25°N for the eastern Pontides (Channell et al., 1996). In a recent work, Cinku et al. (2010) inferred a southward migration of the Late Cretacaeous magmatism in this orogenic belt based on the paleomagnetic data that they obtained from one location in the eastern Pontides. According to their model, a subduction rollback process associated with a northward subducting oceanic lithosphere is envisaged to account for the southward migration of Late Cretaceous magmatism in the eastern Pontides. However, paleomagnetic studies have indicated that the eastern Pontides were situated at 27.8°N (+4.7°, −3.71°) in the Late Cretaceous, and at 31.8°N (+9.7°, −6.7°) in the Eocene (e.g., Cinku and Hisarli, 2009). Thus, it can be inferred that the eastern Pontides orogenic belt was located between 20° and 30° North latitudes during the Late Cretaceous. Because the present location of this belt is between 39° and 42° N latitudes, the paleomagnetic data suggest a northward displacement of 10°–15° since the Late Cretaceous. We, therefore, conclude that a northward drift of the eastern Pontides is most consistent with southward, rather than northward subduction.

4. Summary

Models on past plate motions and subduction polarity in the eastern Mediterranean region, where complex petrogenetic and geodynamic processes have operated, should be able to account for the systematic spatial and temporal variations of magmatism in the eastern Pontides orogenic belt. Our synthesis of recent geological information from this belt, including the existence of a south-dipping reverse fault system along the entire southern coast of the Black Sea and the spatial-temporal features of late Mesozoic–Cenozoic magmatism provide robust evidence that the oceanic lithosphere of Paleotethys experienced prolonged southward subduction.

Acknowledgements

We gratefully acknowledge the research grant from The Scientific and Technological Research Council of Turkey (TUBITAK-Grant 108Y309).

References

Adamia, S.A., Lordkipanidze, M.B., Zakariadze, G.S., 1977. Evolution of an active continental margin as exemplified by the Alpine history of the Caucasus. Tectonophysics 40, 183–189.

Akçay, M., Lermi, A., Van, A., 1998. Biogeochemical exploration for massive sulphide deposits in areas of dense vegetation: an orientation survey around the Kankoy deposit (Trabzon, northeastern Turkey). Journal of Geochemical Exploration 63, 173–187.

Arslan, M., Aliyazıcıoglu, I., 2001. Geochemical and petrological characteristics of the Kale (Gümüşhane) volcanic rocks: implications for the Eocene evolution of eastern Pontide arc volcanism, northeast Turkey. International Geology Review 43, 595–610.

Arculus, R.J., Johnson, R.W., 1978. Criticism of generalized models for the magmatic evolution of arc-trench systems. Earth and Planetary Science Letters 39, 118–126.

Arslan, M., Aslan, Z., 2006. Mineralogy, petrography and whole-rock geochemistry of the Tertiary granitic intrusions in the eastern Pontides, Turkey. Journal of Asian Earth Sciences 27 (2), 177–193.

Bektaş, O., Eyuboglu, Y., 2003. Seismotectonics features and seismic hazard of the Eastern Turkish Black Sea coast. In: Symposium on the Geology and Mining Potential of Eastern Black Sea Region, Trabzon, Proceedings, pp. 6–11.

Bektaş, O., Şen, C., Atıcı, Y., Köprübaşı, 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 34, 95–106.

Bektaş, O., Yılmaz, C., Taslı, K., Akdağ, K., 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 57 (1–2), 233–244.

Bektas, O., Çapkınoğlu, Ş, 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 43 (9), 840–849.

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

Chorowicz, J., Dhont, D., Adıyaman, Ö, 1998. Black-Sea Pontid relationship: Interpretation in Terms of subduction. In: Third International Turkish Geology Symposium, Ankara, Turkey, p. 258.

Cinku, M.C., Hisarli, M., 2009. Palaeogeographic evidence for the Jurassic to Middle Eocene tectonic history of the Pontides: new palaeomagnetic data from the Sakarya continent and eastern Pontides. In: 62nd Geological Kurultai of Turkey, MTA Ankara, pp. 944–945.

Cinku, M.C., Ustaomer, T., Hirt, A.M., Hisarli, Z.M., Heller, F., Orbay, N., 2010. Southward migration of arc magmatism during latest Cretaceous associated with slab-steepening, East Pontides, N Turkey: new paleomagnetic data from the Amasya region. Physics of the Earth and Planetary Interiors 182 (1–2), 18–29. doi:10.1016/j.pepi.2010.06.003.

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

Dilek, Y., Imamverdiyev, N., Altunkaynak, Ş, 2010. Geochemistry and tectonics of Cenozoic volcanism in the Lesser Caucasus (Azerbaijan) and the peri-Arabian region: collision-induced mantle dynamics and its magmatic fingerprint. International Geology Review 52 (4–6), 536–578.

Eyuboglu, Y., 2010. Late Cretaceous high-K volcanism in the eastern Pontide orogenic belt, and its implications for the geodynamic evolution of NE Turkey. International Geology Review 52 (2–3), 142–186.

Eyuboglu, Y., Bektaş, O., Pul, D., 2007. Mid-Cretaceous olistostromal ophiolitic melange developed in the back-arc basin of the eastern Pontide magmatic arc (NE Turkey). International Geology Review 49 (12), 1103–1126.

Eyuboglu, Y., Bektas, O., Seren, A., Nafız, M., Jacoby, W.R., Özer, R., 2006. Three axial extensional deformation and formation of the Liassic rift basins in the eastern Pontides (NE Turkey). Geologica Carpathica 57 (5), 337–346.

Eyuboglu, Y., Chung, S.L., Santosh, M., Dudas, F.O., Akaryali, E., 2010a. Transition from shoshonitic to adakitic magmatism in the Eastern Pontides, NE Turkey: implications for slab window melting. Gondwana Research. doi:10.1016/j.gr.2010.07.006.

Eyuboglu, Y., Dilek, Y., Bozkurt, E., Bektaş, O., Rojay, B., Şen, C., 2010b. Structure and geochemistry of an Alaskan-type ultramafic–mafic complex in the Eastern Pontides, NE Turkey. In: Santosh, M., Maruyama, S. (Eds.), A Tribute to Akiho Miyashiro. Gondwana Research 18 (1), 230–252.

Eyuboglu, Y., Santosh, M., Chung, S.L., 2010c. Crystal fractionation of adakitic magmas in the crust-mantle transition zone: petrology, geochemistry and U-Pb zircon chronology of the Seme adakites, eastern Pontides, NE Turkey. Lithos. doi:10.1016/j.lithos.2010.10.012.

Eyuboglu, Y., Santosh, M., Dudas, F.O., Chung, S.L., Akaryali, E., 2010d. Migrating magmatism in a continental arc: geodynamics of the eastern Mediterranean revisited. Journal of Geodynamics. doi:10.1016/j.jog.2010.11.006.

Gill, J.B., 1981. Orogenic Andesites and Plate Tectonics. Springer-Verlag, Berlin Heidelberg, New York, p. 390.

Hatherton, T., Dickinson, W.R., 1969. The relationship between andesitic volcanism and seismicity in Indonesia, the Lesser Antilles, and other island arcs. Journal of Geophysical Research 74, 5301—5310.

Kaygusuz, A., Siebel, W., Şen, C., Satir, M., 2008. Petrochemistry and petrology of I-type granitoids in an arc setting: the composite Torul pluton, eastern Pontides, NE Turkey. International Journal of Earth Sciences 97, 739—764.

Kaygusuz, A., Chen, B., Aslan, Z., Siebel, W., Şen, C., 2009. U-Pb zircon SHRIMP ages, geochemical and Sr-Nd isotopic compositions of the early Cretaceous I-type Sarıosman Pluton, eastern Pontides, NE Turkey. Turkish Journal of Earth Sciences 18, 549—581.

Keskin, S., Pedoja, K., Bektaş, O., 2010. Coastal uplift along the eastern Black Sea Coast: new marine tarrace data from eastern Pontides (Turkey) and a review. Journal of Coastal Research. doi: 10.2112/JCOASTRES-D-09-00058.1.

Kuno, H., 1959. Origin of Cenozoic petrographic provinces of Japan and surroundings areas. Bulletin of Volcanology 20, 37—76.

Nikishin, A.M., Korotaev, M.V., Ershov, A., Brunet, M.F., 2003. The Black Sea basin: tectonic history and Neogene-Quaternary rapid subsidence modeling. Sedimentary Geology 156, 149—168.

Okay, A.I., Şahintürk, Ö, Yakar, H., 1997. Stratigraphy and tectonics of the Pulur (Bayburt) region in the eastern Pontides. Bulletin of the Mineral Research and Exploration Institute (MTA) of Turkey 119, 1—24.

Okay, A.I., Sahintürk, Ö, 1997. Geology of the eastern Pontides. In: Robinson, A.G. (Ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Region. American Association of Petroleum Geologists Memoir, 68, pp. 291—311.

Okay, A.I., Şengör, A.M.C., Görür, N., 1994. Kinematic history of the opening of the Black Sea and its effect on the surrounding regions. Geology 22, 267—270.

Rice, S.P., Roberson, A.H.F., Ustaömer, T., İnan, T., Taslı, K., 2009. Late Cretaceous-early Eocene tectonic development of the Tethyan suture zone in the Erzincan area, eastern Pontides, Turkey. Geological Magazine 146 (4), 567—590.

Robertson, A.H.F., Ustaömer, T., 2004. Tectonic evolution of the intra-Pontide suture zone in the Armutlu Peninsula, NE Turkey. Tectonophysics 381 (1—4), 175—209.

Santosh, M., 2010. Assembling North China Craton within the Columbia supercontinent: the role of double-sided subduction. Precambrian Research 178, 149—167.

Santosh, M., Maruyama, S., Sato, K., 2009. Anatomy of a Cambrian suture in Gondwana: Pacific-type orogeny in southern India? Gondwana Research 16 (2), 321—341.

Saribudak, M., 1989. New results and a palaeomagnetic overview of the Pontides in northern Turkey. Geophysical Journal International 99 (3), 521—531.

Şengör, A.M.C., Yılmaz, Y., 1981. Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75, 181—241.

Spadini, G., Robinson, A., Cloetingh, S., 1996. Western versus eastern Black Sea tectonic evolution: pre-rift lithospheric controls on basin formation. Tectonophysics 266, 139—154.

Tüysüz, O., Tekin, U.K., 2007. Timing of imbrication of an active continental margin facing the northern branch of Neotethys, Kargı Massif, northern Turkey. Cretaceous Research 28 (3), 754—764.

Ustaömer, T., Robertson, A.H.F., 1996. Paleotethyan tectonic evolution of the north Tethyan margin in the central Pontides, N Turkey. In: Erler, A., Ercan, T., Bingöl, E., Örçen, S. (Eds.), Proceedings of the International Symposium on the Geology of the Black Sea Region. Ankara, pp. 24—33.

Van der Voo, R., 1968. Jurassic, Cretaceous and Eocene pole positions from northeastern Turkey. Tectonophysics 6 (3), 251—269.

Whattam, S.A., 2009. Arc-continent collisional orogenesis in the SW Pacific and the nature, source and correlation of emplaced ophiolitic nappe components. Lithos 113, 88—114.

Xiao, W.J., Huang, B., Han, C., Sun, S., Li, J., 2010. A review of the western part of the Altaids: a key to understanding the architecture of accretionary orogens. Gondwana Research 18 (2—3), 253—273.

Zhang, Z.M., Zhao, G.C., Santosh, M., Wang, J.L., Dong, X., Shen, K., 2010. Late Cretaceous charnockite with adakitic affinities from the Gangdese batholith, southeastern Tibet: evidence for Neo-Tethyan mid-ocean ridge subduction. Gondwana Research 17 (4), 615—631.