Kinematic history of the opening of the Black Sea and its effect on the surrounding regions

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ABSTRACT

The Black Sea consists of two oceanic basins separated by the mid–Black Sea ridge. The east-west–oriented west Black Sea basin opened as a back-arc rift in the Cretaceous by tearing a Hercynian continental sliver, the Istanbul zone, from the present-day Odessa shelf. The Istanbul zone, which was initially contiguous with the Moesian platform in the west, moved south during the Late Cretaceous–Paleocene with respect to the Odessa shelf along two transform faults: the dextral west Black Sea and the sinistral west Crimean faults. It collided in the early Eocene with a Cimmeride zone in the south, thereby ending the extension in the western Black Sea and deactivating both the west Black Sea and the west Crimean faults as strike-slip faults. The east Black Sea basin opened as a result of the counterclockwise rotation of an east Black Sea block around a rotation pole located north of the Crimea. This block was bounded by the west Crimean fault, the southern margin of the eastern Black Sea, and the southern frontal thrusts of the Greater Caucasus. The rotation of the east Black Sea block was contemporaneous with the rifting of the west Black Sea basin but lasted until the Miocene, resulting in continuous compression along the Greater Caucasus.

INTRODUCTION

The Black Sea is a 423 000 km^2 elliptical basin, 70% of which lies below the shelf edge, with a maximum water depth of 2206 m (Ross et al., 1974). Multichannel deep seismic reflection and refraction, gravity, and magnetic data show that the western and eastern halves of the Black Sea have different structural features (e.g., Letouzey et al., 1977; Tugolesov et al., 1985; Finetti et al., 1988). The west Black Sea basin trends east-west and is floored by oceanic crust overlain by >14-km-thick, flat-lying, undisturbed probably Cretaceous to Holocene sediment, as inferred from the age of initial rifting of the Black Sea in the Aptian to Cenomanian interval (Görür, 1988). It is separated by the mid–Black Sea ridge, a region of thinned continental crust, from the northwest-trending east Black Sea basin, which has oceanic crust with <12 km of sediment cover (Fig. 1). Unlike the west Black Sea basin, the ridges and basins in the eastern Black Sea are intersected by a large number of faults (e.g., Finetti et al., 1988).

The Black Sea is generally believed to have opened during the Cretaceous as a back-arc basin behind the Rhodope-Pontide volcanic arc and in continuity with the now-closed Srednogorie zone in Bulgaria (e.g., Boccaletti et al., 1974; Robertson and Dixon, 1984; Zonenshain and Le Pichon, 1986; Görür, 1988). However, the detailed kinematics of the opening, and the origin of the different structural features in the two halves of the Black Sea, are not known. Here we propose a kinematic model for the opening of the Black Sea based on the geology and geophysics of the Black Sea region.

TECTONICS OF THE CIRCUM–BLACK SEA REGION

Tectonic zones with dominantly Hercynian, early (Late Triassic–Early Jurassic) and late Cimmeride (Jurassic–Early Cretaceous) deformations, separated by sutures or major faults, can be recognized in the western part of the circum–Black Sea area (Fig. 1). Those with relevance to the opening of the Black Sea are described below.

Hercynian Tectonic Zones

The Istanbul zone and the Moesian platform are characterized by a thick Ordovician to Carboniferous, transgressive sedimentary sequence of passive continental margin affinity (Fig. 2; Tokay, 1952; Haas, 1968; Sandulescu, 1978; Dachev et al., 1988). This Paleozoic sequence was deformed during the Permian-Carboniferous and was unconformably overlain by a Triassic sedimentary sequence that is especially well developed east of Istanbul (e.g., Özdemir, 1981) and in the eastern part of the Moesian platform.

The Paleozoic sequence in the Moesian

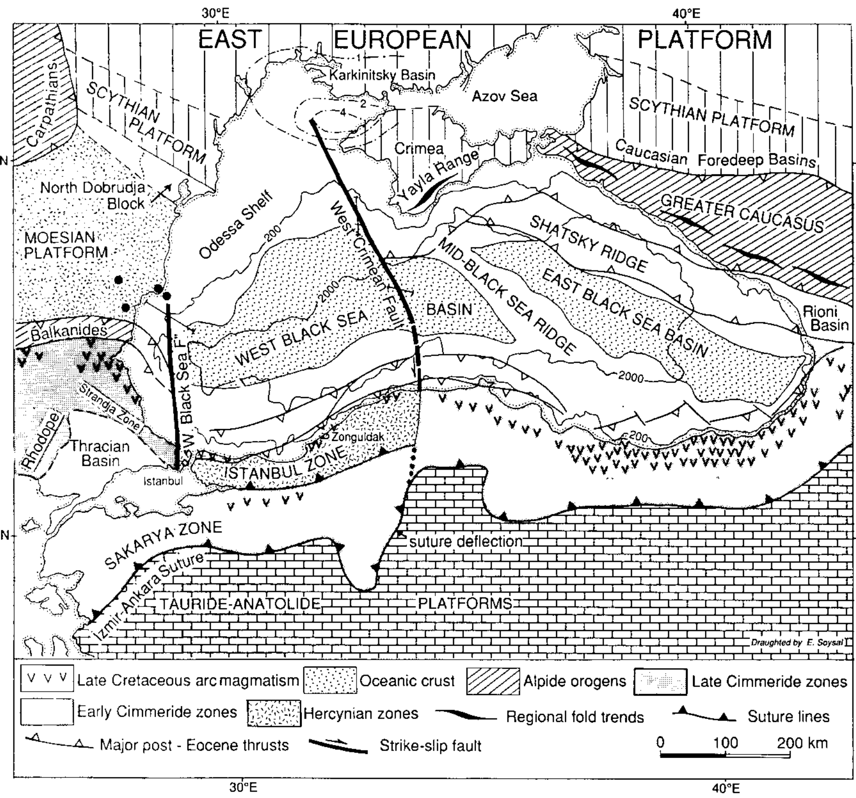

Figure 1. Tectonic map of Black Sea region (Şengör and Yılmaz, 1981; Tugolesov et al., 1985; Finetti et al., 1988; Okay, 1989). Bars across west Black Sea and west Crimean faults indicate locations of seismic sections in Dachev et al. (1988) and Finetti et al. (1988), respectively, which delineate these faults. Circles in southern part of Moesian platform indicate location of boreholes used for stratigraphy of Moesian platform (cf. Fig. 2). Contours north of Crimea give Upper Cretaceous–lower Miocene sediment thicknesses in Karkinitsky basin (Vinogradov, 1966, 1968). Depth contours in metres.

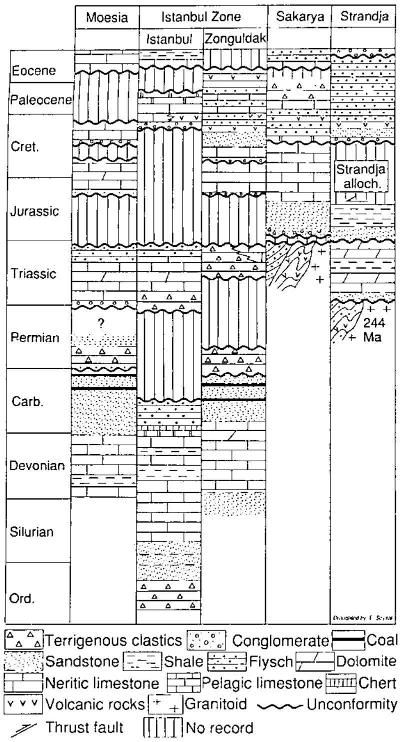

Figure 2. Simplified stratigraphic columns of southeastern Moesian platform (subsurface borehole data from Dachev et al., 1988; cf. Fig. 1), of Istanbul zone in Istanbul (Haas, 1968) and Zonguldak (Tokay, 1952) regions, of Sakarya zone (Saner, 1980) and of Strandja zone (Aydìn, 1974; Chatalov, 1988).

platform is correlated in the west with similar sequences in the Krajstides in western Bulgaria (Sandulescu, 1978), in the Carnic Alps in Austria, and in the east with the Scythian platform and south Ural sequences (Zonenshain et al., 1984). They all form a belt along the southern margin of Laurasia. In contrast, the Istanbul zone is exotic with respect to its present surrounding tectonic units. In the west it is bordered by the Strandja zone, which has late Jurassic deformation and metamorphism. No rocks suggestive of a suture zone are present near the contact between the regionally metamorphosed Triassic clastic deposits of the Strandja zone and the unmetamorphosed Carboniferous flysch of the Istanbul zone; the actual contact between these two zones is covered by a 17-km-wide strip of undeformed middle Eocene limestone and marl (Fig. 1). The Istanbul zone is separated in the south along the Intra-Pontide suture from the Sakarya zone, which contains no in situ Paleozoic sedimentary rocks. It underwent strong deformation and metamorphism in the late Triassic (Şengör and Yılmaz, 1981; Okay, 1989). The east-west–oriented Intra-Pontide suture (thrust symbol south of the Istanbul zone, Fig. 1) is marked by slivers of serpentinite, blueschist, basic volcanic rock, and Upper Cretaceous to middle Paleocene pelagic limestone (Şengör and Yılmaz, 1981; Okay and Tansel, 1994), indicating that the Istanbul and Sakarya zones were juxtaposed after middle Paleocene time. The complex geology of the eastern contact of the Istanbul zone with the Sakarya zone is poorly known. However, the location of this contact on the scale shown in Figure 1 is tightly determined to be between the extreme eastern exposures of the Paleozoic rocks of the Istanbul zone and the deformed and partly metamorphosed Triassic flysch and volcanic rocks of the Sakarya zone.

The paleolatitudes from the Paleozoic (Evans et al., 1991) and Triassic rocks (Sarìbudak et al., 1989; Theveniaut, 1993) of the Istanbul zone are compatible with the apparent polar wander path for Laurasia and indicate that at least until the end of the Triassic the Istanbul zone was part of the southern margin of Laurasia in possible continuity with the Uralian sections in the east and the Hercynian sections in the west.

Early Cimmeride Tectonic Zones

The basement of the Sakarya zone in northern Turkey consists of strongly deformed and locally metamorphosed Permian-Triassic active margin units of the Paleo-Tethys, called the Karakaya complex (Şengör et al., 1984; Okay et al., 1991). The main deformation and metamorphism are of latest Triassic age and the Karakaya complex is unconformably overlain by Lower to Middle Jurassic molassic sandstone that grades into Upper Jurassic–Lower Cretaceous limestones and then into Upper Cretaceous flysch with volcanic intercalations (Fig. 2; Saner, 1980). Volcanic and volcaniclastic rocks become significant in Upper Cretaceous deposits in the northern parts of the Sakarya zone and signify the establishment of an Andean-type active margin above the northward-dipping Neo-Tethyan subduction zone. The Sakarya zone is separated in the south by the Izmir-Ankara suture from the Anatolide-Tauride platform (for the purposes of this paper including the Kìrşehir block) of Apulia-Gondwanaland affinity.

Two other circum–Black Sea regions with mid-Mesozoic deformation are the Yayla Range in the Crimea and the North Dobrudja block. In the North Dobrudja, complexly deformed Triassic and Jurassic sedimentary rocks and volcanics are unconformably overlain by Cenomanian sedimentary deposits (Sandulescu, 1978). The deformation in the North Dobrudja block may have been caused by transpressive movements along the faults that bound it (Gradinaru, 1984) and which are possibly related to the Tornquist-Tesseyre fault system. In the Yayla range in the Crimea, the deformed, thick Triassic to Lower Jurassic Tauridian flysch, which may tectonically overlie an Istanbul-type Paleozoic-Triassic sequence, is unconformably overlain by a Middle Jurassic to Paleocene sequence (Kotanski, 1978).

Late Cimmeride Tectonic Zones

The Strandja zone in northwestern Turkey and southern Bulgaria, which forms the eastward prolongation of the Rhodope massif, comprises an autochthonous and an allochthonous succession (Aydìn, 1974; Chatalov, 1988). The autochthon consists of a basement largely made up of Hercynian granites (age of intrusion ~244 Ma) that are overlain by a shallow-water and relatively thin Lower Triassic to Middle Jurassic sequence, which is in turn tectonically overlain by Triassic flyschoid deposits with volcanic and carbonate intercalations making up the allochthon (Fig. 2). The whole sequence was metamorphosed and deformed semicontinuously during the Late Triassic to Early Cretaceous interval, as suggested by the progressively younger flysch sequences from the Lipacka in the Strandja nappes in the south to the Trojan-Luda-Kamçija zone flysches in the north (our own observations and, on the basis of these, our reinterpretation of data in Peybernès et al. [1989] and Tchoumatchenco et al. [1992]) and is unconformably overlain by a Cenomanian to Maastrichtian magmatic arc–related, volcanosedimentary sequence.

TECTONIC MODEL

We suggest that the Istanbul zone was, until the Cretaceous, located along the Odessa shelf between the Moesian platform and the Crimea (Fig. 3A) and was rifted during Aptian-Albian time (Görür, 1988) and moved south as a small continental fragment (or "terrane" in North American terms) bounded by two large transform faults and opening in its wake the west Black Sea basin. The evidence for this is the close stratigraphic similarity between the Istanbul zone and the Moesian platform (cf. Fig. 2), the morphological fit of the Istanbul zone to the Odessa shelf between Moesia and Crimea, and the presence on seismic sections of two major faults in the Black Sea, the southward projections of which form the western and eastern boundaries of the Istanbul zone (Finetti et al., 1988; Fig. 1). The northern section of the postulated 270-km-long dextral fault zone bounding the western margin of the Black Sea can be recognized in the seismic sections off the Bulgarian shelf (Dachev et al., 1988). This shelf margin shows abrupt changes in thickness between

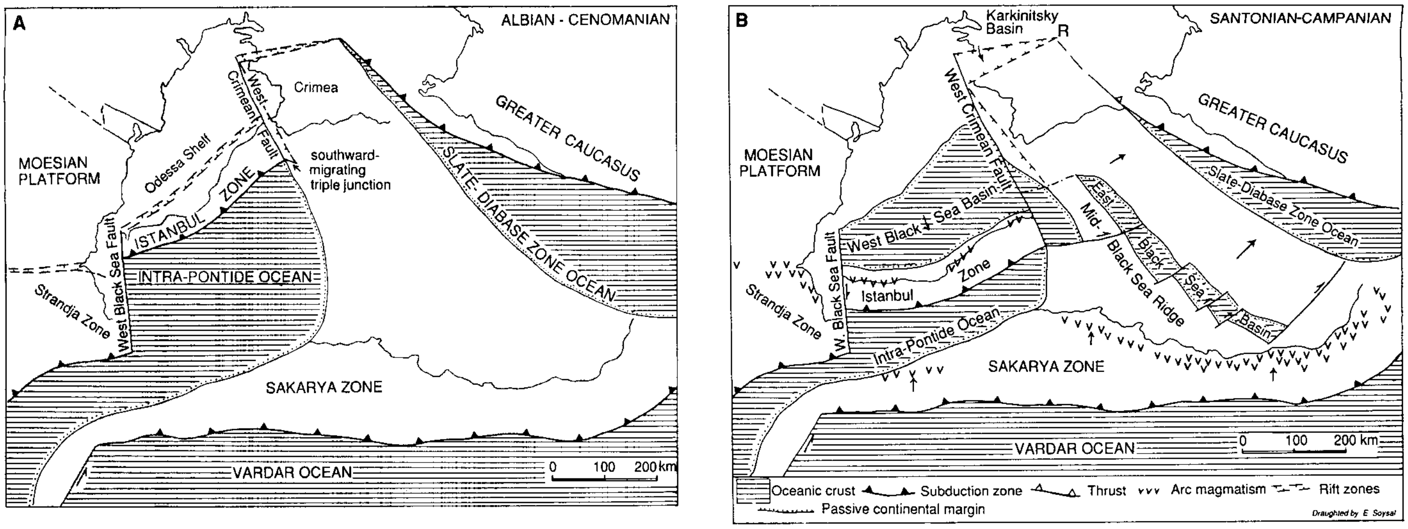

Figure 3. Paleogeographic reconstructions of Black Sea region for Albian-Cenomanian (A) and Santonian-Campanian (B). Arrows indicate movement of plates with respect to fixed Eurasia. R is rotation pole of east Black Sea block.

the Upper Triassic (Dachev et al., 1988, Fig. 11) and the top of the Upper Cretaceous (Dachev et al., 1988, Fig. 12), unlike that expected from a rifted and thermally subsiding margin. This transform fault, herein termed the west Black Sea fault, most likely comes ashore west of Istanbul and forms the tectonic boundary between the Strandja and Istanbul zones, now covered by undeformed middle Eocene sedimentary deposits (Fig. 1). We speculate that this marginal fault became active in the Early Cretaceous (Aptian-Albian) on the basis of the timing of rifting as constrained by stratigraphic data in the circum–Black Sea regions (Görür, 1988).

The eastern margin of the Istanbul zone was formed by the West Crimean fault, a major transform fault that on seismic-reflection lines can be traced from west of the Crimean shelf 300 km south into the oceanic west Black Sea basin where it deforms layers as young as Miocene (Fig. 1; Finetti et al., 1988). The southward continuation of the West Crimean fault into the Pontides is obliterated by the north-vergent post-Paleocene thrusts; however, its southward trace connects with the eastern margin of the Istanbul zone. Although Finetti et al. (1988) interpreted the movement along the west Crimean fault as dextral, on the basis of the apparent offset of the Crimean shelf, we suggest that the apparent offset is due to the removal of the Istanbul zone and the West Crimean fault is in reality a sinistral fault that railroaded the Istanbul zone during its southward drift.

Between the West Crimean fault and the mid–Black Sea ridge remains an oceanic area composing the eastern half of the west Black Sea basin (Fig. 1). This region and the east Black Sea basin most probably opened during the counterclockwise rotation of an east Black Sea block comprising Crimea and the eastern Black Sea around a pole located northeast of Crimea (Fig. 3). Counterclockwise rotation of Crimea is indicated by the paleomagnetic data (Westphal et al., 1986), and a rotation of about 20°–25° can be estimated from the present-day width of the west Black Sea basin east of the west Crimean fault. This counterclockwise rotation also provides an explanation for the present-day discordance between the trends of the Caucasus and the Yayla Range (Fig. 1) and for the opening of the wedge-shaped Karkinitsky basin north of Crimea, which has a >4 km thickness of Upper Cretaceous to Oligocene sedimentary deposits and Albian volcanic rocks (Vinogradov, 1966, 1968; Letouzey et al., 1977; Robertson Group and Geological Institute, undated, map 9.8; Fig. 1). The east Black Sea block was bounded by the Karkinitsky basin in the north, by the West Crimean fault in the west, and by a complex network of transform and extension faults in the southern margin of the Black Sea, as suggested by the segmented southeastern boundary of the east Black Sea basin (cf. Figs. 1 and 3B). The northeastern compressional boundary of the east Black Sea block consists of the south-vergent folds and thrusts that form the southern boundary of the Greater Caucasus. These folds and thrusts began forming in the late Eocene, when the Slate-Diabase ocean closed (Khain, 1975), and they have continued growing into the Quaternary (Zonenshain and Le Pichon, 1986, esp. Fig. 4A). The intensity of thrusting decreased toward the axis of rotation in the Crimea (Zonenshain and Le Pichon, 1986).

Two paleogeographic maps (Fig. 3) show the tectonic evolution of the Black Sea region. The first extensive calc-alkaline volcanism in the Istanbul zone is of Turonian age (e.g., Tokay, 1952), suggesting that the subduction of the Intra-Pontide ocean and probable rifting of the west Black Sea basin started in the Aptian-Cenomanian, as suggested by the Çağlayan rift-fill clastic and volcanic rocks of this age (the age may in places be as old as Berriasian; cf. Görür, 1988). The Karkinitsky rift basin also began to form during this time (Vinogradov, 1968; Robertson Group and Geological Institute, undated), suggesting that the counterclockwise rotation of the east Black Sea block was contemporaneous with the rifting of the west Black Sea basin. The rotation of this block might have been triggered by the onset of northward subduction of its oceanic appendage, the Slate-Diabase zone ocean (Khain, 1975; Şengör, 1990) and was coeval with the northward movement of the Sakarya zone because of the start of subduction of the Intra-Pontide ocean (Fig. 3A). The tectonic reconstruction at the onset of rifting (Fig. 3A) shows the east Black Sea block in its prerotational position and the Istanbul zone adjacent to the Odessa shelf. Judging from the present-day width of the west Black Sea basin and the minimum 150-km-wide oceanic crust required to generate a magmatic arc, the Intra-Pontide ocean was at least 300 km wide during Albian-Cenomanian time. In the Campanian, the Istanbul zone was moving south relative to the Odessa shelf, opening in its wake the west Black Sea basin (Fig. 3B). At the same time the east Black Sea block was rotating counterclockwise and opening the Karkinitsky, the eastern half of the west Black Sea and east Black Sea basins, and closing the Slate-Diabase zone ocean. In fact, the opening of the Black Sea can be viewed as the southward migration of an unstable transform-transform-trench–type triple junction along the West Crimean fault, which in time became a ridge-transform-trench–type junction.

The collision of the Istanbul and Sakarya zone, which heralded the end of extension in the west Black Sea basin and the deactivation of the west Black Sea fault, occurred in the early Eocene. The marine sedimentation in the Istanbul zone was continuous throughout the Late Cretaceous and Paleocene (Dizer and Meriç, 1983), and the zone was first uplifted in the early Eocene (Fig. 2) when the Black Sea changed from extensional to compressional faulting (Finetti et al., 1988). The indentation of the Istanbul zone produced the major southward deflection of the western part of the Sakarya zone and the Izmir-Ankara suture west of Ankara (Fig. 1). The north-trending suture in this region is marked by a sinistral strike-slip fault (O. Tüysüz, 1993, personal commun.). After the collision, widespread thrusting occurred around the margins of the Black Sea with the exception of the Odessa shelf area west of the West Crimean fault (Fig. 1). This, together with the continuing sediment accumulation in the Karkinitsky basin and thrusting along the southern margin of the Greater Caucasus well into the Miocene, suggests that the counterclockwise rotation in the eastern Black Sea continued into the Neogene, this time probably because of the indentation of the Arabian promontory.

CONCLUSIONS

The west and east Black Sea basins have separate origins. The major part of the west Black Sea basin opened during the Late Cretaceous by back-arc rifting of a Hercynian continental sliver from what is now the Odessa shelf. The opening of the west Black Sea basin came to an end when the Hercynian continental sliver collided with a Cimmeride zone during the early Eocene. In contrast, the east Black Sea basin, which has a more complicated structure, opened as a result of the counterclockwise rotation of the east Black Sea block that started in the mid-Cretaceous.

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REFERENCES CITED

Aydin, Y., 1974, Etude petrographique et géochimique de la partie centrale du Massif d'Istranca (Turquie) [Ph.D thesis]: Nancy, France, Université de Nancy, 131 p.

Boccaletti, M., Gocev, P., and Manetti, P., 1974, Mesozoic isotopic zones in the Black Sea region: Società Geologica Italiana, Bollettino, v. 93, p. 547–565.

Chatalov, G.A., 1988, Recent developments in the geology of the Strandzha Zone in Bulgaria: Technical University of Istanbul, Bulletin, v. 41, p. 433–465.

Dachev, C., Stanev, V., and Bokov, P., 1988, Structure of the Bulgarian Black Sea area: Bollettino di Geofisica Teorica ed Applicata, v. 30, p. 79–107.

Dizer, A., and Meriç, E., 1983, Late Cretaceous–Paleocene stratigraphy in northwest Anatolia: Maden Tetkik ve Arama Enstitüsü Dergisi, v. 95/96, p. 149–163.

Evans, I., Hall, S.A., Saribudak, M.A., and Aykol, A., 1991, Preliminary palaeomagnetic results from Palaeozoic rocks of the Istanbul-Zonguldak region, N.W. Turkey: Technical University of Istanbul, Bulletin, v. 44, p. 165–190.

Finetti, I., Bricchi, G., Del Ben, A., Pipan, M., and Xuan, Z., 1988, Geophysical study of the Black Sea: Bolletino di Geofisica Teorica ed Applicata, v. 30, p. 197–324.

Görür, N., 1988, Timing of opening of the Black Sea basin: Tectonophysics, v. 147, p. 247–262.

Gradinaru, E., 1984, Jurassic sedimentary rocks and bimodal volcanics of the Cirjelari-Camena outcrop belt: Evidence for a transtensile regime of the Peceneaga-Camena fault: Revue roumaine de Géologie, Géophysique et Géographie, v. 28, 96–121.

Haas, W., 1968, Das Alt-Palaozoikum von Bithynien (Nordwest Turkei): Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, v. 131, p. 178–242.

Khain, V.E., 1975, Structure and main stages in the tectono-magmatic development of the Caucasus: An attempt at geodynamic interpretation: American Journal of Science, v. 275-A, p. 131–156.

Kotanski, Z., 1978, The Caucasus, Crimea and their foreland (Scythian platform), Black Sea and the Caspian Sea, *in* Lemoine, M., ed., Geological atlas of Alpine Europe and adjoining Alpine areas: Amsterdam, Elsevier, p. 545–576.

Letouzey, J., Biju-Duval, B., Dorkel, A., Gonnard, R., Kristchev, K., Montadert, L., and Sungurlu, O., 1977, The Black Sea: A marginal basin; geophysical and geological data, *in* Biju-Duval, B., and Montadert, L., eds., International Symposium on the Structural History of the Mediterranean Basins: Paris, Editions Technip, p. 363–376.

Okay, A.I., 1989, Tectonic units and sutures in the Pontides, northern Turkey, *in* Şengör, A.M.C., ed., Tectonic evolution of the Tethyan region: NATO Advanced Science Institute (ASI) Series, C259, p. 109–116.

Okay, A.I., and Tansel, I., 1994, New data on the upper age of the Intra-Pontide ocean from north of Parköy (Thrace): Mineral Research Exploration Institute of Turkey, Bulletin (in press).

Okay, A.I., Siyako, M., and Bürkan, K.A., 1991, Geology and tectonic evolution of the Biga Peninsula, northwest Turkey: Technical University of Istanbul, Bulletin, v. 44, p. 191–256.

Özdemir, H., 1981, Microfauna and biostratigraphy of the Tepeköy Triassic in Kocaeli Peninsula: Mineral Research Exploration Institute of Turkey, Bulletin, v. 77, p. 57–98.

Peybernès, B., Tchoumatchenco, P., Dercourt, J., Ivanov, Z., Lachkar, G., Rolando, J.-P., Surmont, J., and Thierry, J., 1989, Données nouvelles sur les flyschs jurassiques de la zone de Luda Kamçija (Balkanides orientales, Bulgarie): Conséquences paléogéographiques: Académie des Sciences de Paris, Comptes Rendus, v. 309, sér. II, p. 115–124.

Robertson, A.H.F., and Dixon, J.E., 1984, Introduction: Aspects of the geological evolution of the Eastern Mediterranean, *in* Dixon, J.E., and Robertson, A.H.F., eds., The geological evolution of the eastern Mediterranean: Geological Society of London Special Publication 17, p. 1–74.

Robertson Group and Geological Institute, undated, Paleogeographic atlas of the shelf regions of Eurasia for the Mesozoic and Cenozoic, Volume 2 (maps): Llandudno, United Kingdom, Robertson Group.

Ross, D.A., Uchupi, E., Prada, K.E., and MacIlvaine, J.C., 1974, Bathymetry and microtopography of Black Sea, *in* Degens, E.T., and Ross, D.D., eds., The Black Sea—Geology, chemistry and biology: American Association of Petroleum Geologists Memoir 20, p. 1–10.

Sandulescu, M., 1978, The Moesic platform and the north Dobrogean Orogene, the Balkans, *in* Lemoine, M., ed., Geological atlas of Alpine Europe and adjoining Alpine areas: Amsterdam, Elsevier, p. 427–460.

Saner, S., 1980, Paleogeography and the depositional characteristics of the Jurassic and post-Jurassic deposits in the Mudurnu-Göynük basin (in Turkish): Geological Society of Turkey, Bulletin, v. 23, p. 39–52.

Saribudak, M., Sanver, M., and Ponat, E., 1989, Location of western Pontides, NW Turkey, during Triassic time: Preliminary palaeomagnetic results: Geophysical Journal, v. 96, p. 43–50.

Şengör, A.M.C., 1990, A new model for the late Palaeozoic-Mesozoic tectonic evolution of Iran and implications for Oman, *in* Robertson, A.H.F., et al., eds., The geology and tectonics of the Oman region: Geological Society of London Special Publication 49, p. 797–834.

Şengör, A.M.C., and Yilmaz, Y., 1981, Tethyan evolution of Turkey: A plate tectonic approach: Tectonophysics, v. 75, p. 181–241.

Şengör, A.M.C., Yilmaz, Y., and Sungurlu, O., 1984, Tectonics of the Mediterranean Cimmerides: Nature and evolution of the western termination of Palaeo-Tethys, *in* Dixon, J.E., and Robertson, A.H.F., eds., The geological evolution of the eastern Mediterranean: Geological Society of London Special Publication 17, p. 77–112.

Tchoumatchenco, P., and nine others, 1992, Étude d'un domaine de transition balkan-Moésie: Evolutions paléogéographique et paléotectonique du sillon du flysch jurassique inférieur et moyen dans la Stara Planina orientale (Bulgarie orientale): Société Géologique de France, Bulletin, v. 163, p. 49–61.

Theveniaut, H., 1993, Evolution de la Téthys occidentale et de la Pangée au Trias [Ph.D. thesis]: Paris, Université de Paris VII.

Tokay, M., 1952, Géologie de la région de Bartin (Zonguldak, Turquie de Nord): Mineral Research Exploration Institute of Turkey, Bulletin, v. 46/47, p. 46–63.

Tugolesov, D.A., Gorshkov, A.S., Meysner, L.B., Solov'yev, V.V., and Khakhalev, Y.M., 1985, The tectonics of the Black Sea trough: Geotectonics, v. 19, p. 435–445.

Vinogradov, A.P., editor, 1966, Atlas of the lithological-paleogeographical maps of the USSR, Volume IV (Paleogene, Neogene, Quaternary): Moscow, USSR Ministry of Geology.

Vinogradov, A.P., editor, 1968, Atlas of lithological-paleogeographical maps of the USSR, Volume III (Triassic, Jurassic and Cretaceous): Moscow, USSR Ministry of Geology.

Westphal, M., Bashenov, M.L., Lauer, J.P., Pechersky, D.M., and Sibuet, J.C., 1986, Paleomagnetic implications on the evolution of the Tethys belt from the Atlantic Ocean to the Pamirs since the Triassic: Tectonophysics, v. 123, p. 37–82.

Zonenshain, L.P., and Le Pichon, X., 1986, Deep basins of the Black Sea and Caspian Sea as remnants of Mesozoic back-arc basins: Tectonophysics, v. 123, p. 181–212.

Zonenshain, L.P., Korinevsky, V.G., Kazmin, V.G., Pechersky, D.M., Khain, V.V., and Matveenkov, V.V., 1984, Plate tectonic model of the south Urals development: Tectonophysics, v. 109, p. 95–135.

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