International Geology Review, 2015
http://dx.doi.org/10.1080/00206814.2015.1010609

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Tectonic evolution of the southern margin of Laurasia in the Black Sea region

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(*Received 13 March 2014; accepted 19 January 2015*)

The Black Sea region comprises Gondwana-derived continental blocks and oceanic subduction complexes accreted to Laurasia. The core of Laurasia is made up of an Archaean–Palaeoproterozoic shield, whereas the Gondwana-derived blocks are characterized by a Neoproterozoic basement. In the early Palaeozoic, a Pontide terrane collided and amalgamated to the core of Laurasia, as part of the Avalonia–Laurasia collision. From the Silurian to Carboniferous, the southern margin of Laurasia was a passive margin. In the late Carboniferous, a magmatic arc, represented by part of the Pontides and the Caucasus, collided with this passive margin with the Carboniferous eclogites marking the zone of collision. This Variscan orogeny was followed by uplift and erosion during the Permian and subsequently by Early Triassic rifting. Northward subduction under Laurussia during the Late Triassic resulted in the accretion of an oceanic plateau, whose remnants are preserved in the Pontides and include Upper Triassic eclogites. The Cimmeride orogeny ended in the Early Jurassic, and in the Middle Jurassic the subduction jumped south of the accreted complexes, and a magmatic arc was established along the southern margin of Laurasia. There is little evidence for subduction during the latest Jurassic–Early Cretaceous in the eastern part of the Black Sea region, which was an area of carbonate sedimentation. In contrast, in the Balkans there was continental collision during this period. Subduction erosion in the Early Cretaceous removed a large crustal slice south of the Jurassic magmatic arc. Subduction in the second half of the Early Cretaceous is evidenced by eclogites and blueschists in the Central Pontides and by a now buried magmatic arc. A continuous extensional arc was established only in the Late Cretaceous, coeval with the opening of the Black Sea as a back-arc basin.

Keywords: Laurasia; Laurussia; Pontides; Caucasus; Black Sea; subduction; accretion; magmatic arcs

Introduction

The geological evolution of the Black Sea region is charted here from the early Palaeozoic to Tertiary in terms of major tectonic events. This review incorporates data which have become available from the region over the last ten years. The geological data are shown through outcrop distribution maps of the Black Sea region for the critical periods. There is a large body of geological literature on the Black Sea region in Russian and Turkish; however, for ease of access, the references here are restricted to those in English. Other reviews of the geology of the region (e.g. Nikishin *et al.* 1996, 2001, 2012; Okay and Şahintürk 1997; Adamia *et al.* 2011; Somin 2011) have citations to references in these languages.

The Pontides were adjacent to Laurasia before the Late Cretaceous opening of the Black Sea, and constituted its southern continental margin during much of the Phanerozoic. They consist of several continental and oceanic blocks, which were accreted to Laurasia over the last 500 million years. A significant feature of the Pontides is the presence of extensive outcrops with a wide range of ages and rock types, which contrasts with the almost complete lack of pre-Tertiary outcrops north of the Black Sea (Figure 1). The geological evolution of the Black Sea region is, therefore, based to a very large extent on data from Crimea, Caucasus, Pontides, Balkans, and Dobrugea, which were exhumed during the late Tertiary (e.g. Vincent *et al.* 2011; Albino *et al.* 2014). Especially, the Pontides and the Caucasus with their widely exposed and varied Precambrian to Mesozoic sequences are critical for deciphering the geological history of the southern margin of Laurasia.

The interaction of two megacontinents, Gondwana and Laurasia, and the intervening oceans, forms the dominant motif in the geological evolution of the Black Sea region. The general pattern is the separation of continental slivers from Gondwana and their accretion to Laurasia (e.g. Şengör 1984; Stampfli and Borel 2002). One additional process, which is emphasized here, is the growth of Laurasia by addition of oceanic subduction complexes during the Mesozoic.

The collision of Gondwana and Laurussia in the late Carboniferous led to the Variscan orogeny in southern Europe, southeastern North America, and northwest Africa and resulted in the creation of the supercontinent Pangea (e.g. Ziegler 1989). In contrast, most of Asia escaped the collision and continued to face a Palaeo-Tethyan ocean in the south (e.g. Dercourt *et al.* 2000;

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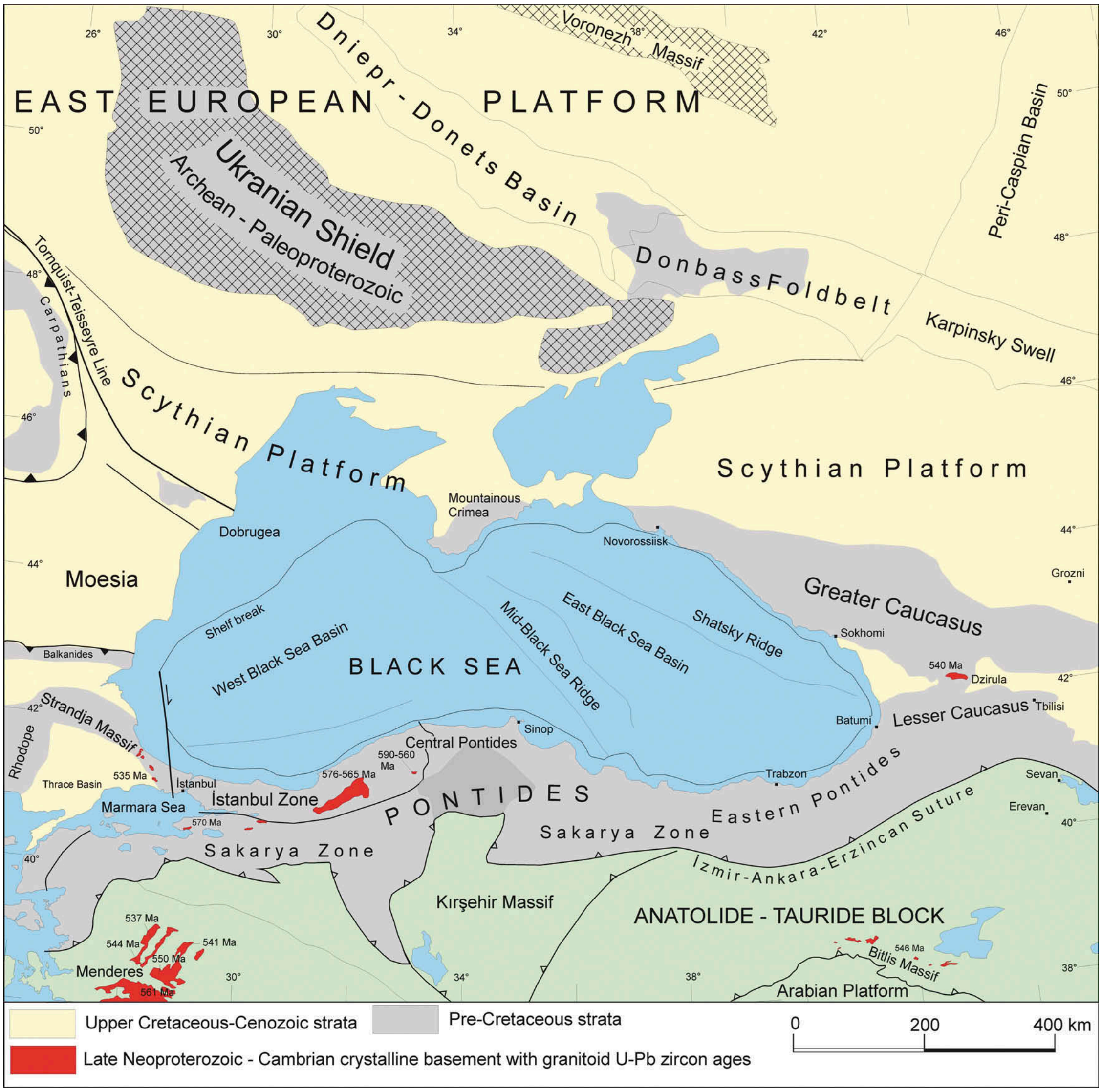

Figure 1. The main tectonic units in the Black Sea region. In this and subsequent maps, grey areas are predominantly made up of pre-Tertiary rocks, whereas yellow areas have extensive Tertiary cover. Note the lack of pre-Tertiary outcrops in the Scythian Platform. The map also shows outcrops of late Neoproterozoic crystalline basement. In this and subsequent maps, the limitations of geological information due to younger cover should be noted. The darker grey area in the Central Pontides shows the region accreted during the Jurassic and Cretaceous. The U–Pb zircon ages from the granitoids are from Chen *et al.* (2002), Ustaömer *et al.* (2005), Okay *et al.* (2008), Mayringer *et al.* (2011), Ustaömer *et al.* (2012b), and Şahin *et al.* (2014). For the source of ages in the Menderes Massif, see Koralay *et al.* (2011). The map is based on Anonymous (1972), MTA (2002), and Adamia (2010).

Barrier and Vrielynck 2008). The Black Sea region is located in this transitional region between Carboniferous continental collision in the west and continuing oceanic subduction in the east.

Laurasia, Laurussia, and Baltica are the names used for the same continent north of the Black Sea over geological time (cf. Cocks and Torsvik 2006). However, as there has been no change in the configuration of the stable shield north of the Black Sea since the Neoproterozoic (e.g. Gorbatchev and Bogdanova 1993), the northern continent is referred to here as Laurasia. The East European Platform refers to the Archaean–Palaeoproterozoic basement and its Proterozoic and younger sedimentary cover.

Geological setting

A major distinction in the Black Sea region is between the East European Platform with its Archaean and Palaeoproterozoic basement, and the Gondwana-derived blocks in the south (Figure 1). The Black Sea is a Late Cretaceous back-arc basin with oceanic crust (e.g. Okay *et al.* 1994; Robinson *et al.* 1996; Nikishin *et al.* 2015a),

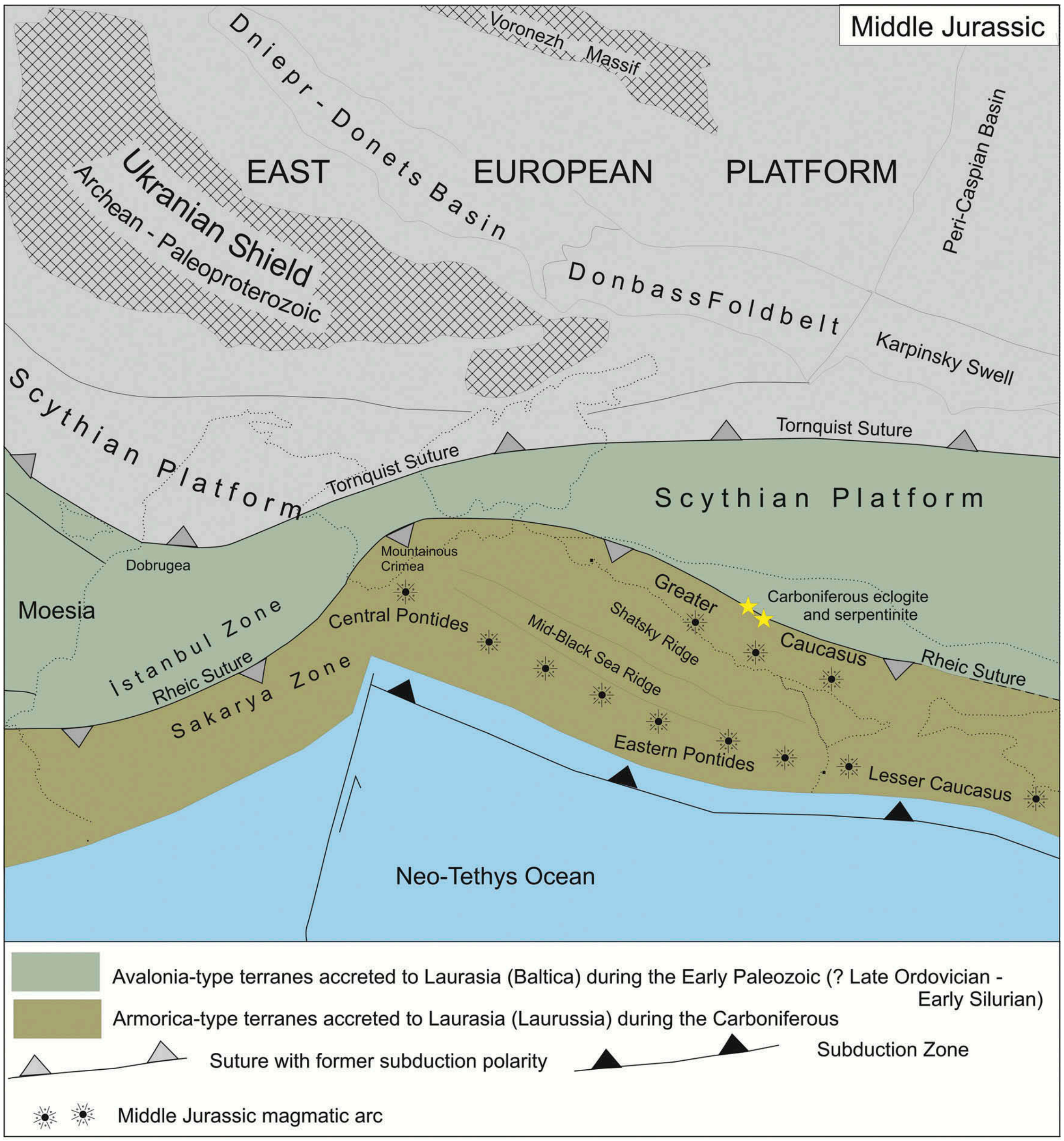

Figure 2. A possible configuration of the Laurasia margin during the Middle Jurassic before the opening of the Black Sea basin. The location of the Tornquist suture is highly uncertain.

and prior to its opening, the Pontides were located directly south of the East European Platform between Moesia and the Greater Caucasus (Figure 2). The Pontides consist of three terranes, which were amalgamated before the Tertiary. From west to east, these are the Strandja Massif and Istanbul and Sakarya zones (Figure 1). The Lesser Caucasus forms the eastward extension of the Sakarya Zone, separated only by the national border between Turkey and Georgia (e.g. Yılmaz *et al.* 2000). The Greater Caucasus is a predominantly Variscan orogen and was the site of a Jurassic–Cretaceous basin, which was inverted in the Miocene due to the Arabia–Eurasia collision (e.g. Vincent *et al.* 2011; Adamia *et al.* 2011). The Kırşehir Massif is a Cretaceous ensialic magmatic arc accreted to Laurasia in the early Tertiary (e.g. Whitney and Hamilton 2004; Lefebvre *et al.* 2013).

The Anatolide–Tauride Block forms the latest Gondwana-derived block accreted to the Laurasia margin during the Palaeocene–Eocene. Early palaeogeographic reconstructions show the Pontides and the Anatolide–Tauride Block as a single continental unit prior to early Mesozoic rifting (e.g. Şengör and Yılmaz 1981). However, data obtained subsequently showed that although both were located on the margins of Gondwana during the Neoproterozoic, they did not form conjugate margins (Figure 3; e.g. Dean *et al.* 2000; Okay *et al.* 2006a). The

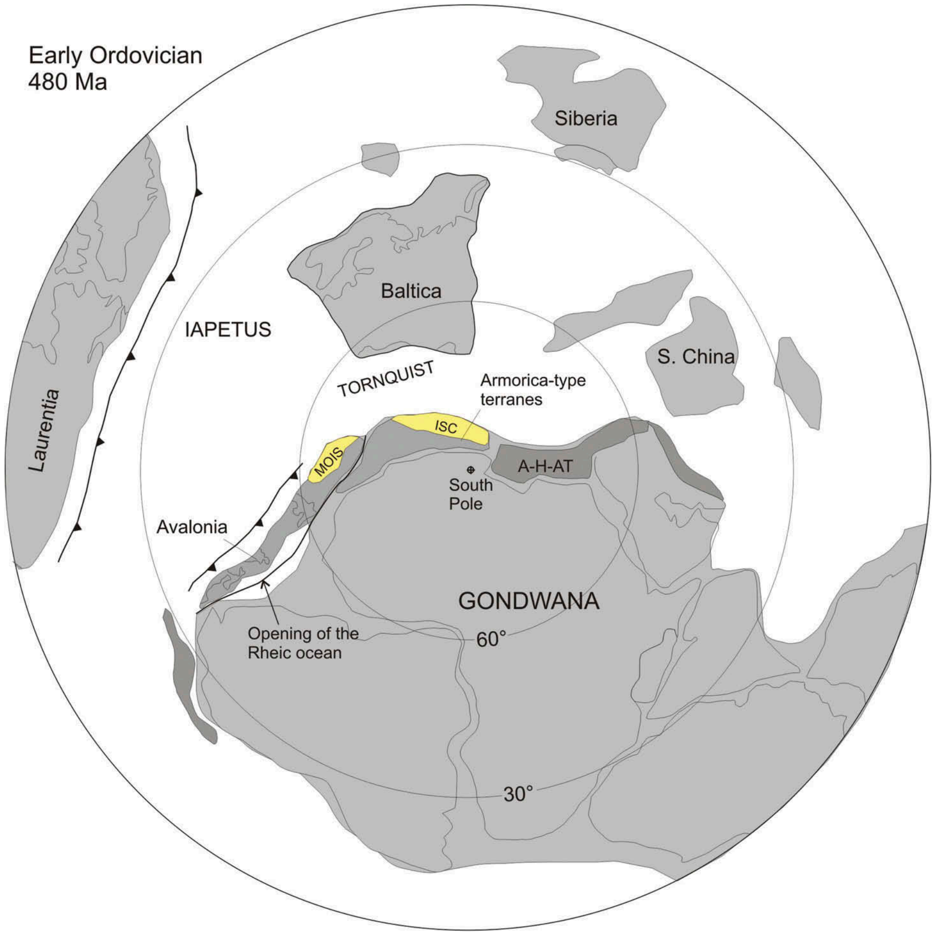

Figure 3. Palaeogeography of the southern hemisphere for the Early Ordovician (modified from Cocks and Torsvik 2002) showing probable locations of the Black Sea terranes. MOIS, Moesia, Istanbul and part of Scythian Platform; ISC, Strandja, Sakarya, and Caucasus; AHAT, Apulia, Hellenides, Anatolide–Tauride.

location of the Anatolide–Tauride Block is relatively well constrained on the northeast margin of Africa – north of Egypt, Syria, and Iraq (cf. Figure 3; e.g. Schattner and Ben-Avraham 2007). In the classical view, the Pontides were rifted from the northern margin of the Anatolide–Tauride Block during the Triassic or Early Jurassic (e.g. Şengör and Yılmaz 1981). However, the Pontide terranes and the Anatolide–Tauride Block have very different pre-Jurassic geological histories. For example, Variscan and Cimmeride deformation and metamorphism, prominent in the Pontides, are not observed in the Anatolide–Tauride Block, which has a thick, well-developed Palaeozoic sedimentary succession, similar to that of the Arabian Plate. Furthermore, recent discovery of Carboniferous and Permian pelagic sedimentary deposits in the ophiolitic melanges in the Taurides (Moix *et al.* 2011) suggests that the Anatolide–Tauride Block was facing a Palaeozoic Tethyan ocean in the north, in other words, it was part of the passive margin of Gondwana during the Palaeozoic (Figure 3). The Triassic rift deposits in the Anatolide–Tauride Block are related to its separation from the Africa–Arabia, to its southern rather than to its northern margin. The Istanbul and Sakarya zones of the Pontides were part of Avalonia and Armorica, respectively, and were located on the northwestern margin of Africa in the early Palaeozoic (Figure 3). The Palaeozoic–Mesozoic history of the Anatolide–Tauride Block is hence unrelated to that of the Laurasia and will not be considered here.

East European platform

Archaean and Palaeoproterozoic gneisses and granites locally overlain by a thin veneer of sedimentary rocks constitute the basement of the East European Platform north of the Black Sea; they form two vast massifs – the Ukranian shield and the Voronezh Massif (Figure 1; Claesson *et al.* 2006; Bogdanova *et al.* 2008). The Archaean and Palaeoproterozoic basement is a characteristic feature of the East European Platform and distinguishes it from the Gondwana-derived terranes farther south. Gondwana margins were shaped by the late

Neoproterozoic Pan-African orogeny, characterized by the dominance of granitoids of 590–560 Ma ages (e.g. Stern 1994). The distinctive basement ages, Archaean–Palaeoproterozoic *versus* late Neoproterozoic, allow recognition of Gondwana-derived fragments in the Alpine–Himalayan chain (e.g. Neubauer 2002).

The Ukranian Shield and the Voronezh Massif are separated by a large Upper Devonian–Carboniferous intra-cratonic rift, the Dniepr–Donets basin (Figure 1) with up to 22 km-thick upper Palaeozoic–Mesozoic sedimentary rocks (Stovba and Stephenson 1999). The basin was inverted during the latest Cretaceous–early Tertiary forming the Donbass Foldbelt. Stovba and Stephenson (1999) also describe a strong Late Triassic folding in the eastern part of the Donbass Foldbelt. The Tornquist–Teisseyre Line forms the western edge of the East European Platform. It is a major tectonic lineament separating the East European Platform from Gondwana-derived blocks in central Europe, which were deformed during the Palaeozoic (e.g. Guterch *et al.* 1999).

The Ukranian Shield is bordered in the south by a wide belt known as the Scythian Platform. Information on the stratigraphy and structure of the Scythian Platform is very limited as it is covered by Tertiary sedimentary rocks (Figure 1). It is generally considered as a Variscan belt (e.g. Zonenshain *et al.* 1990); however, its locations north of the Variscan core of the Greater Caucasus with Carboniferous eclogites and serpentinites, and stratigraphic data from the Pontides suggest that at least part of the Scythian Platform could have been accreted to the East European Platform during the early Palaeozoic and part of it could represent an even older continental margin (Figure 2; Stephenson *et al.* 2004; Saintot *et al.* 2006).

Gondwana-derived blocks

Gondwana-derived blocks in the Black Sea region can be broadly divided into two types: the Avalonia and Armorica. The first were accreted to the East European Platform during the early Palaeozoic, whereas the accretion of the Armorica-type blocks to the East European Platform occurred during the Carboniferous (Figure 2).

Avalonia-type blocks

The Avalonia-type blocks include Moesia, Dobrugea, Istanbul Zone, and probably part of the Scythian Platform. They are characterized by a late Neoproterozoic granitic basement (590–560 Ma, Seghedi 2001, 2011; Chen *et al.* 2002; Ustaömer *et al.* 2005; Okay *et al.* 2008) overlain by a Palaeozoic sedimentary sequence of Ordovician to Carboniferous age (Görür *et al.* 1997; Tari *et al.* 1997; Dean *et al.* 2000; Kalvoda and Bábek 2010; Özgül 2012; Sayar and Cocks 2013). The sedimentary sequence has a transgressive character and ranges from Ordovician red continental clastics to Upper Devonian–lower Carboniferous deep marine sedimentary rocks with marked lateral facies differences, and ends with lower Carboniferous turbidites or upper Carboniferous coal measures (Figure 4).

Armorica-type blocks

The Armorica-type blocks include the Greater and Lesser Caucasus, Strandja Massif and the Sakarya Zone. The lower Palaeozoic sequences in these blocks are metamorphosed or not present. Another distinguishing feature of these blocks is the extensive Carboniferous plutonism and high-temperature metamorphism.

Early Ordovician: separation of the Avalonian Moesia–Istanbul Block from Gondwana

Early in the Ordovician, the Istanbul Zone and Moesia and probably part of the Scythian Platform were separated from the margins of Gondwana and drifted north, opening the Rheic Ocean in their wake. These blocks were part of a much larger microplate, termed Avalonia, a major component of the early Palaeozoic palaeogeography in Europe (e.g. Cocks and Torsvik 2002).

Palaeozoic rocks are now buried under the Tertiary sediments of the Scythian Platform; therefore, most of the information on the Palaeozoic history of the region comes from the Pontides. The crystalline basement of the Istanbul Zone with widespread late Neoproterozoic granitoids (Figure 1) attests to its location on the northern margin of Gondwana at this period. The basement is overlain by a Lower–Middle Ordovician red sandstone and conglomerate, over 3000 m thick (Figure 4). This continental sequence probably marks the rifting of the Istanbul Zone from the northern Gondwana margin.

The thick and well-developed Palaeozoic succession of the Istanbul Zone indicates that it was not an isolated continental sliver but was part of a much larger lithospheric plate. Its early Palaeozoic history and trilobite and brachiopod faunas are similar to Avalonia in northwest Europe (e.g. Dean *et al.* 2000), and the Istanbul Zone has been considered as the eastward extension of Avalonia (Stampfli and Borel 2002; Stampfli *et al.* 2002; Winchester 2002; Kalvoda *et al.* 2003; Okay *et al.* 2006a, 2008; Bozkurt *et al.* 2008; Sunal *et al.* 2008; Franke 2014). This is also supported by the detrital zircons from the Ordovician and Silurian sandstones (Ustaömer *et al.* 2011), which show an absence of 2400–2050 Ma detrital zircons, a characteristic Avalonian feature (Samson *et al.* 2005). In northwest Europe, Avalonia was separated from Gondwana during the Early–Middle Ordovician with the opening of Rheic Ocean to its south and was accreted to the southwestern margin of Baltica during latest

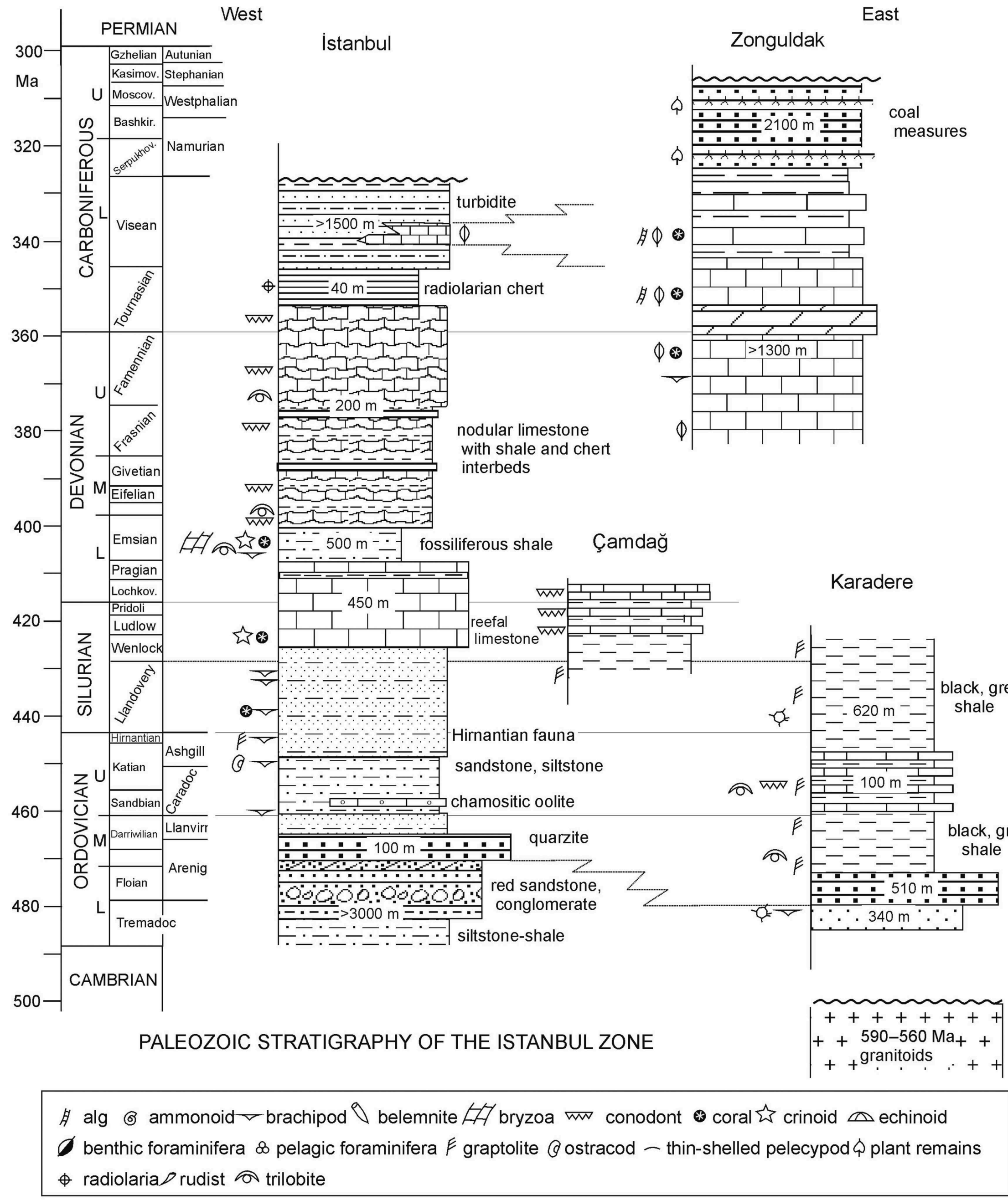

Figure 4. Palaeozoic stratigraphic sections of the Istanbul Zone. The stratigraphic and palaeontological data are from Dill *et al.* (1976), Görür *et al.* (1997), Dean *et al.* (2000), Özgül (2012), Sachanski *et al.* (2012), and Sayar and Cocks (2013). The geological time scale is after Gradstein *et al.* (2004).

Ordovician (Ashgill, 445 Ma, Cocks and Torsvik 2002, 2006).

Before the Late Cretaceous opening of the western Black Sea, the Istanbul Zone was adjacent to Moesia (Figure 2; Okay *et al.* 1994). Although Moesia is largely covered by Cretaceous and younger sedimentary rocks, well data indicate that it has a Palaeozoic stratigraphy similar to that of the Istanbul Zone, including Carboniferous coal measures in southeast Moesia, which correlate with those in the Zonguldak region of the Istanbul Zone (Tari *et al.* 1997; Kalvoda and Bábek 2010). The eastward extension of the Avalonian Moesia-Istanbul (MOIS) terrane is difficult to trace since the region between the Ukranian Shield and mountainous Crimea–Caucasus is covered by Neogene deposits. The presence of Carboniferous eclogites on the northern margin of the Caucasus (Philippot *et al.* 2001) indicates that the Avalonia-type terranes, if present, must lie north of the Crimea and Greater Caucasus (Figure 2).

Late Ordovician–early Silurian: amalgamation of Moesia–Istanbul Block with Laurasia

Data from northwest Europe suggest that during the latest Ordovician (Ashgill) Avalonia collided with Laurasia (e.g. Cocks and Torsvik 2002, 2006). The accretion of the Istanbul and Moesian blocks to Laurasia, on the other hand, is poorly constrained. Palaeomagnetic studies suggest that after the middle Silurian the Istanbul Zone was located on the southern margin of Laurasia and constituted part of the northern passive margin of the Rheic Ocean (Evans *et al.* 1991). The Devonian and Carboniferous foraminiferal assemblages in the Istanbul Zone are also typically Laurasian (Kalvoda *et al.* 2003). The northern margin of the Istanbul terrane, where there might be stratigraphic evidence for collision, lies under the Black Sea or is covered by Tertiary sediments (Figure 1). The Upper Ordovician interbedded sandstone–siltstone–shale sequence, interpreted by Sayar and Cocks (2013) as turbidites, may have been deposited during the accretion of the Istanbul terrane to Laurasia. The collision of the MOIS Block to Laurasia must have been soft, which is also the case for the Avalonia–Laurasia collision in northwest Europe. The thick and well-developed Ordovician–Silurian sequence of the Istanbul Zone, Moesia and Dobrugea are devoid of volcanic rocks (Tari *et al.* 1997; Seghedi 2011; Özgül 2012), which implies that the subduction was dipping under Laurasia, unlike the case for the western parts of Avalonia (Figures 2 and 3).

From Silurian onwards, the Istanbul Zone and Moesia formed part of the passive margin of Laurasia characterized by a deepening upward sedimentary sequence (Figure 4) facing the Rheic Ocean in the south (Stampfli and Borel 2002). The eastern part of the Istanbul Zone was in a shallower and more proximal position closer to the continent.

Carboniferous: Variscan orogeny – collision of a continental magmatic arc with Laurasia

During the Carboniferous, a continental magmatic arc collided with the southern margin of Laurasia. In the Black Sea region, this arc is represented by a zone of Permo-Carboniferous metamorphism and magmatism south of the Avalonian blocks (Figure 5); they include the Rhodope and Strandja massifs in the Balkans, the Sakarya Zone in the Pontides and the Caucasus, which can be correlated with the Armorican terranes in central Europe. Their location south of the Avalonian blocks and local presence of late Neoproterozoic granitoids indicate that they were also derived from Gondwana. However, data on the age of separation of the Black Sea Armorican terranes from Gondwana are virtually non-existent since their lower Palaeozoic sequences are either metamorphosed or are not present. Stampfli and Borel (2002) favour a late Silurian (Ludlow) age of rifting for the Armorican terranes.

The best evidence for a suture between the Avalonia and Armorican-type terranes in the Black Sea region comes from the northern margin of the Caucasus, where Perchuk and Philippot (1997) and Philippot *et al.* (2001) describe a tectonic belt of ultramafic rocks and kyanite-eclogites (Figure 5) with late Carboniferous (316–300 Ma) Sm–Nd, Lu–Hf garnet, and Ar–Ar phengite ages. Carboniferous granitoids with 330–300 Ma ages and with subduction geochemical signatures are widespread in the Greater Caucasus and in the Eastern Pontides–Lesser Caucasus region (Figure 5). In both regions, they are associated with granulite to high amphibolite facies metamorphic rocks and migmatites. The peak of the high-temperature metamorphism is estimated to have taken place at 330 Ma both in the Eastern Pontides and in the Lesser Caucasus (Topuz *et al.* 2004a; Mayringer *et al.* 2011). The plutonism and high-temperature metamorphism most likely occurred in the core of a magmatic arc.

As both the Istanbul Zone and Moesia are free of Devonian or Carboniferous magmatism and have characteristics of a passive continental margin, the Rheic Ocean must have been consumed by southward subduction. The collision occurred between a magmatic arc, represented by the Armorica-type terranes, and the passive margin of Laurasia. The latest Carboniferous (Kasimovian and Gzelian) molasse-type shallow marine to continental sedimentary rocks in the Eastern Pontides and Caucasus (Okay and Leven 1996; Çapkınoğlu 2003; Somin 2011) provide an upper age limit for the collision, which probably occurred at 320–310 Ma (Bashkirian–Moscovian) in the east in the Caucasus–Eastern Pontide region. In the west in the Istanbul Zone and in the Balkans, the collision was probably earlier. In the western part of the Istanbul Zone, siliciclastic turbidites, over 2000 m thick, were deposited during the early Carboniferous (Figure 4). The source of the turbidites was in the south from an approaching Armorican arc-terrane, as indicated by detrital zircon and rutile ages from the turbiditic sandstones, which are dominated by Late Devonian–early Carboniferous ages and do not comprise zircons of 700–1700 Ma age interval (Okay *et al.* 2011b). These are typical features of the Armorican terranes. The detrital zircon-rutile data and the abrupt termination of lower Carboniferous turbidite sedimentation followed by folding and thrusting with a NE vergence suggest that the collision of the Armorican terrane, possibly the Sakarya Zone, with Istanbul segment of the Laurasia margin started in the early Carboniferous (Visean, 340–330 Ma) in the west.

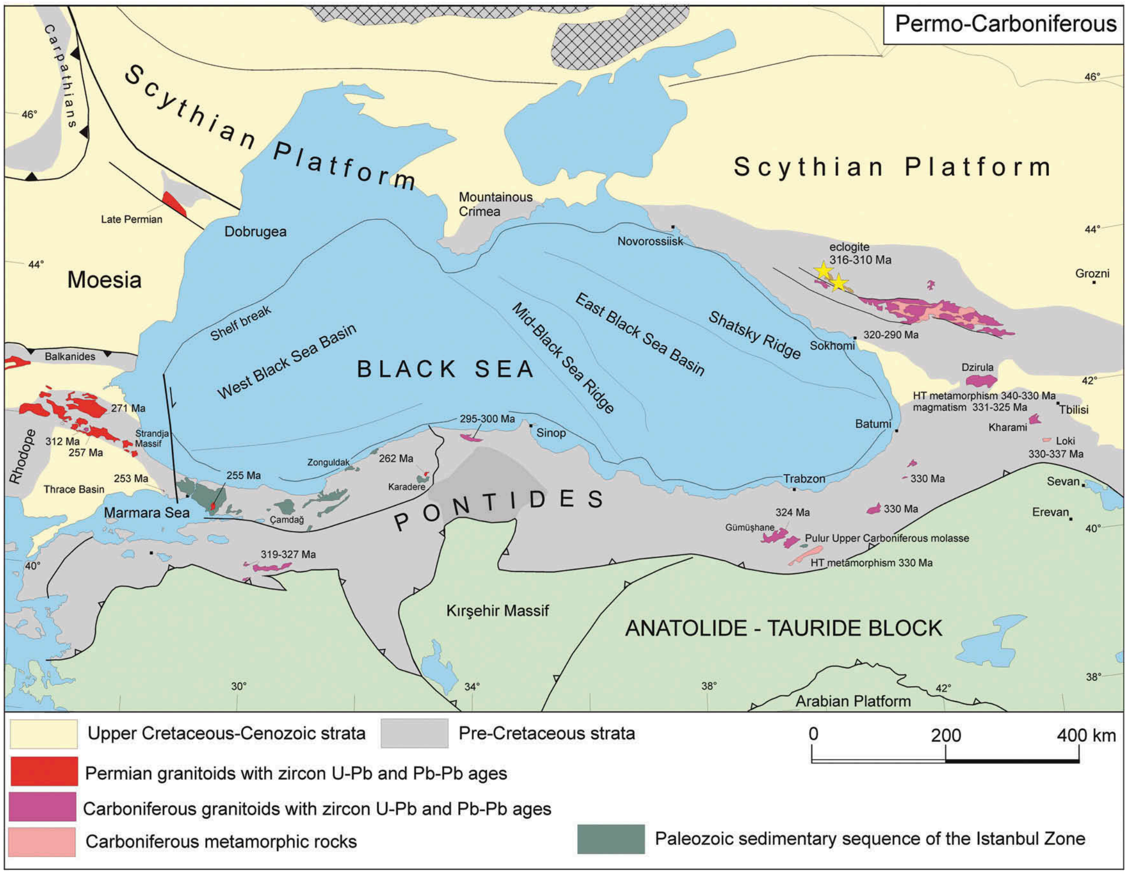

Figure 5. Outcrops of Permo-Carboniferous magmatic and metamorphic rocks in the Black Sea region. Also shown are the outcrops of the Palaeozoic series in the Istanbul Zone. Isotopic ages are from Yılmaz (1975), Hanel *et al.* (1992), Perchuk and Philippot (1997), Phillippot *et al.* (2001), Topuz *et al.* (2004a, 2010), Nzegge *et al.* (2006), Sunal *et al.* (2006), Somin (2011), Mayringer *et al.* (2011), Rolland *et al.* (2011), Natal'in *et al.* (2012), Ustaömer *et al.* (2012a), Ustaömer *et al.* (2013), and Okay *et al.* (2001, 2013, 2015). The map is based on Anonymous (1972), MTA (2002), and Adamia (2010).

Permo-Triassic: restoration after the Variscan orogeny

The Carboniferous collision between Laurasia and Gondwana created the megacontinent Pangea, which during the Permian was predominantly a region of erosion or continental sedimentation (e.g. Ziegler 1989). Most of the Black Sea region was also undergoing uplift in the Permian, and Permian deposits are either not present or are represented by continental red beds, except for some shallow marine deposits in the Caucasus (e.g. Gaetani *et al.* 2005). Permian continental red beds are difficult to distinguish from those of the Lower Triassic; however, palynology and vertebrate palaeontology from the eastern part of the Istanbul Zone indicate that some of the red beds are truly Permian (Gand *et al.* 2011; Stolle 2015). Late Permian granitoids occur widely in the Strandja Massif and are also found in the Istanbul Zone and in Dobrugea (Figure 5). There is little evidence for subduction in the Permian in the Black Sea region, except for a small accretionary complex in the Eastern Pontides with MORB-type metabasalts with late Permian (~260 Ma) Rb–Sr and Ar–Ar ages (Figure 7; Topuz *et al.* 2004b). On the other hand, late Permian granitoids in the western part of the Black Sea region are probably related to rifting, which started over a wide area during the latest Permian to Early Triassic (e.g. Nikishin *et al.* 2002) with the deposition of uppermost Permian to Lower Triassic fluviatile red sandstones and conglomerates intercalated with basaltic lavas, best observed in the western part of the Istanbul Zone and in Dobrugea (Figure 6). The continental red beds pass up into an increasingly deeper marine sedimentary sequence, characterized by the deposition of pelagic nodular limestones in the Middle Triassic.

Latest Triassic: Cimmeride Orogeny – oceanic accretion

The Late Triassic in the Black Sea region is characterized by the deposition of siliciclastic turbidites followed by uplift and deformation, and emplacement of oceanic accretionary complexes (Figure 6; Nikishin *et al.* 2012).

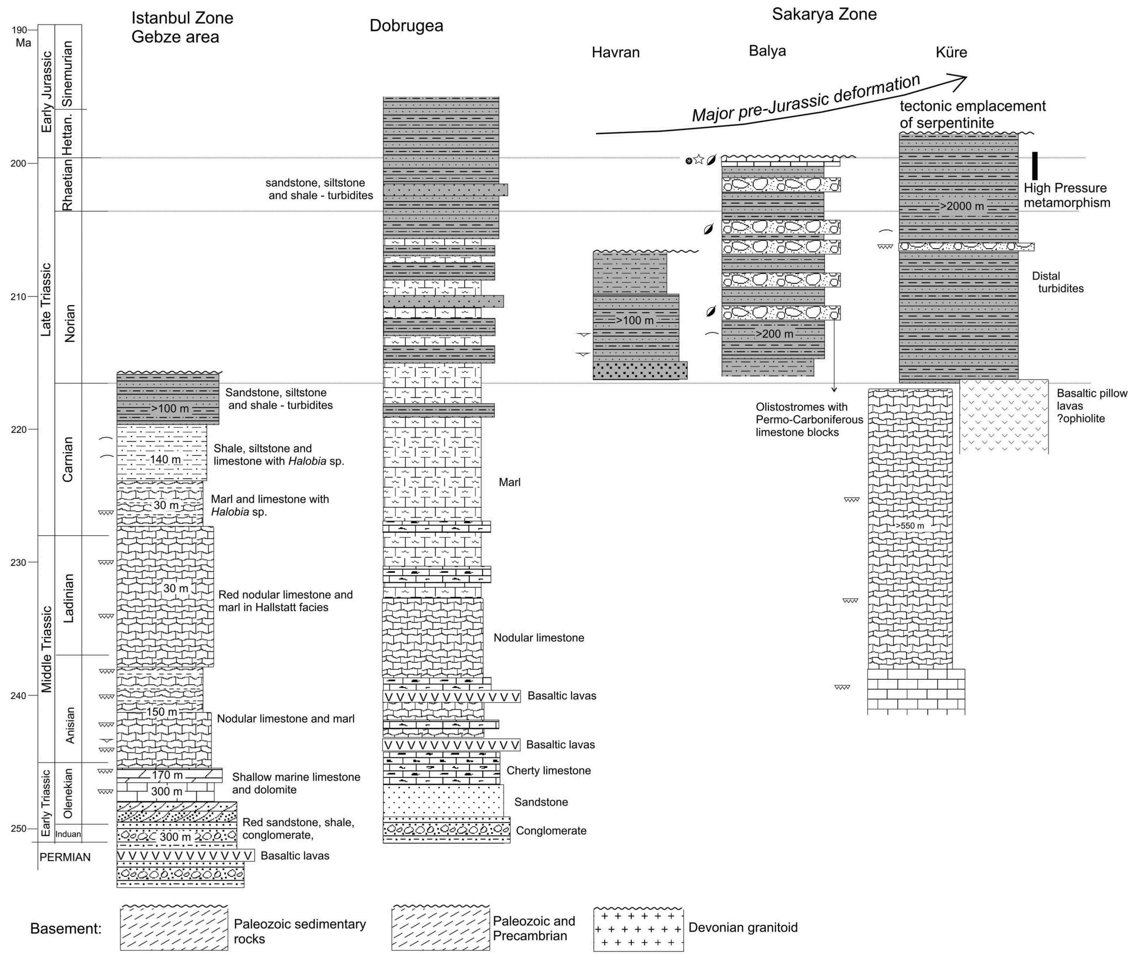

Figure 6. Triassic stratigraphic sections in the Black Sea region. The sections are based on Assereto (1972), Gedik (1975), Seghedi (2001), Okay and Göncüoğlu (2004), Okay and Altıner (2004), and Okay *et al.* (2015). The geological time scale is after Gradstein *et al.* (2004). For symbols, see Figure 4.

Deformation is even recorded in Moesia (Tari *et al.* 1997) and within the East European Platform in the Donbass fold belt (Stovba and Stephenson 1999). The cause of this Cimmeride orogeny is enigmatic. It has been related to the collision of a Cimmerian continent with the Laurasian margin (e.g. Şengör 1984); however, it has not been possible to define a coherent Cimmerian continent in the Pontides or anywhere else in the Black Sea region (e.g. Okay 2000; Topuz *et al.* 2013a). On the other hand, evidence for subduction and accretion during the Late Triassic is provided by large volumes of accreted oceanic complexes, including eclogites and blueschists, in the Pontides, which are commonly tectonically juxtaposed with the Late Cretaceous accretionary complexes (Figure 7; Bozkurt *et al.* 1997; Okay *et al.* 2002; Yılmaz and Yılmaz 2004). The Cimmeride deformation and metamorphism have a short duration and are largely restricted to the latest Triassic (Rhaetian) to the earliest Jurassic. The absence of a colliding continent, short time span of deformation, and great thicknesses of accreted oceanic crustal sequences suggest that the Cimmeride orogeny was caused by a collision and partial accretion of an oceanic plateau (Figure 8), thus it was an accretionary orogeny similar to those in the North American Cordillera (Okay 2000).

The accreted Permo-Triassic oceanic unit in the Sakarya Zone is represented by the Karakaya Complex (e.g. Okay and Göncüoğlu 2004; Robertson and Ustaömer 2012). A major component of the Karakaya Complex is a tectonically thickened pile of metabasite with minor marble and phyllite of Triassic age, called the Lower Karakaya Complex, which extends throughout the Sakarya Zone. The Lower Karakaya Complex is metamorphosed mainly in high-pressure greenschist facies but also includes Upper Triassic eclogites and blueschists (Okay *et al.* 2002). The geochemistry of the metabasites indicates predominantly an intra-plate setting (Pickett and Robertson 2004; Sayit *et al.* 2010; Catlos *et al.* 2013). With these features the Lower Karakaya Complex is interpreted as a Triassic oceanic plateau, which collided with

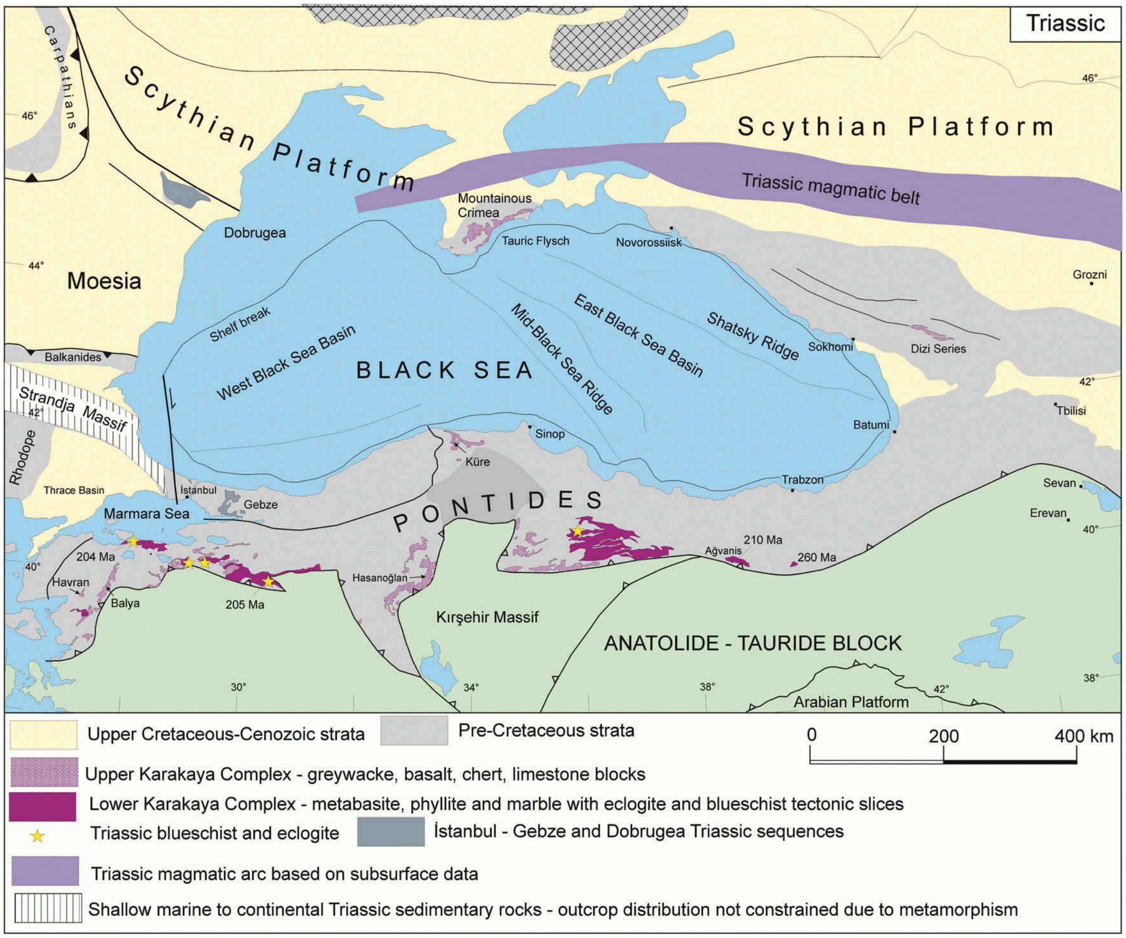

Figure 7. Outcrops of Triassic subduction-accretion complexes (Karakaya Complex), and the marine Triassic sequence in the Istanbul and Dobrugea regions. Also shown is the subsurface Triassic magmatic arc. The subsurface distribution of the Triassic subduction-accretion complex is much more continuous and larger than shown here. The isotopic ages and the outcrops of Triassic eclogites and blueschists are from Okay and Monié (1997), Okay *et al.* (2002), Catlos *et al.* (2013), and Topuz *et al.* (2014). The map is based on Anonymous (1972), MTA (2002), and Adamia (2010).

and partially accreted to the Laurasian margin during the latest Triassic (Okay 2000; Genç 2004).

The Lower Karakaya Complex is overlain by strongly deformed and locally metamorphosed Permo-Triassic clastic and volcanic rocks, representing trench and fore-arc deposits and accreted oceanic crustal rocks, over several thousand metres in structural thickness (Figure 8). This Upper Karakaya Complex includes olistostromes with Carboniferous and Permian shallow marine limestone blocks both in Turkey and in Crimea (Leven and Okay 1996) and smaller blocks of radiolarian cherts of Devonian, Carboniferous, Permian, and Triassic ages and tectonic slices of pre-Jurassic serpentinites (Kozur and Kaya 1994; Okay *et al.* 2011a, 2015; Sayit *et al.* 2011), suggesting subduction-accretion of a Devonian to Late Triassic oceanic crust, the Palaeo-Tethys. The Dizi series on the southern flank of the Greater Caucasus (Figure 7) shows similar features to the Upper Karakaya Complex including upper Palaeozoic limestone blocks, Late Triassic deformation and Lower Jurassic unconformity (Adamia *et al.* 2011; Somin 2011).

Although there is ample evidence for subduction in the Black Sea region during the Late Triassic, there are no outcrops of Triassic granitoids. Nevertheless, their presence is indicated by the Triassic zircons, which form the dominant population among clastic zircons in the Upper Triassic turbiditic sandstones in Turkey (Karslıoğlu *et al.* 2012; Ustaömer *et al.* 2014) and in Crimea (Nikishin and Khudoley, unpublished data). Further support for Triassic acidic to intermediate volcanic rocks is provided by well data, which shows a large belt of Triassic volcanic rocks in the Scythian Platform buried under the Tertiary cover (Figures 7 and 8; Alexandre *et al.* 2004; Tikhomirov *et al.* 2004) extending from the northern Crimea in the west (Nikishin *et al.* 2012) to Central Asia in the east (Natal'in and Şengör 2005).

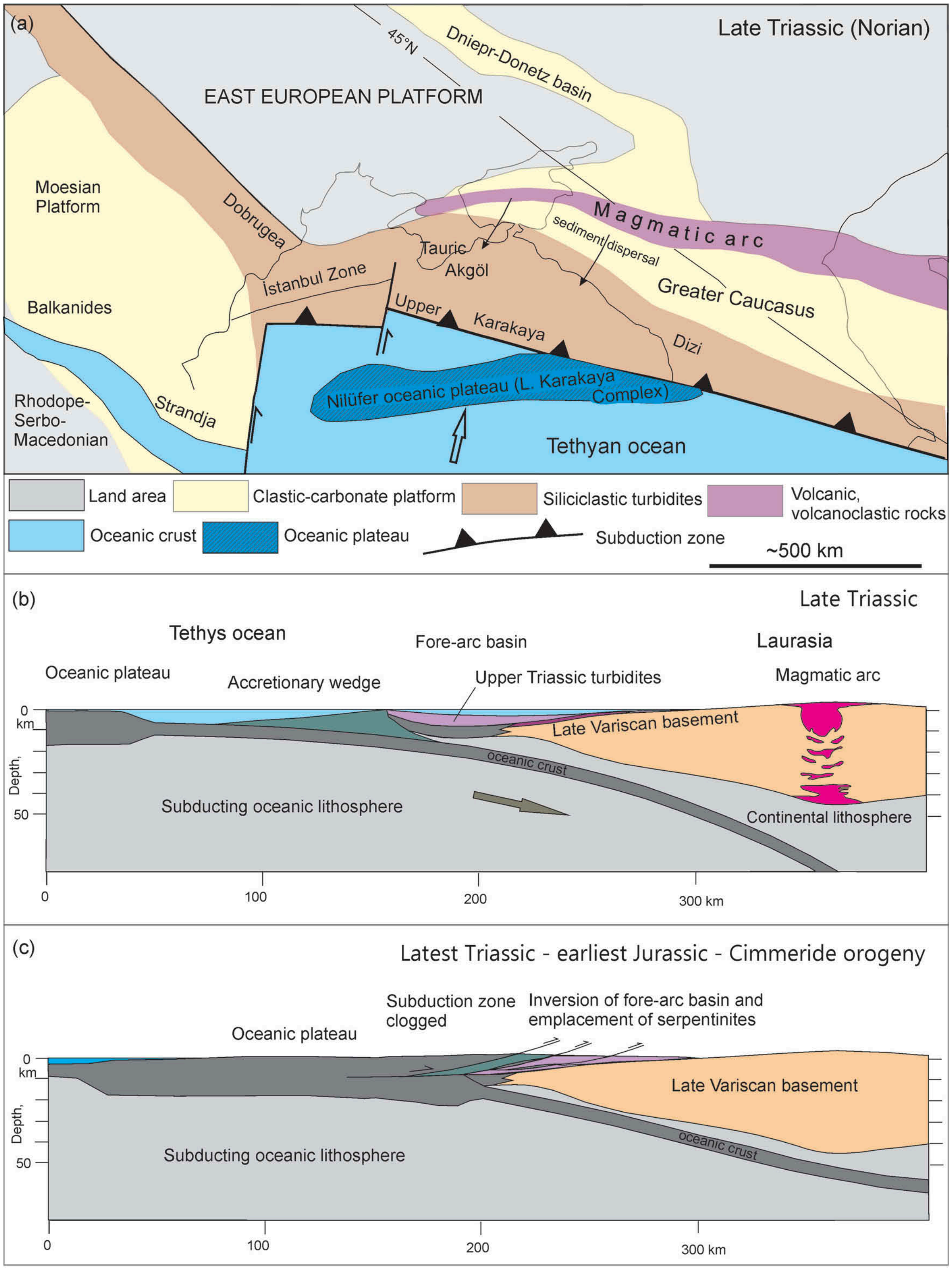

Figure 8. Palaeogeographic map and cross sections of the Black Sea region for the Late Triassic (modified from Okay *et al.* 2015).

Published palaeogeographic reconstructions for the Triassic show a back-arc basin behind the northward subducting Palaeo-Tethys Ocean in the Black Sea region (e.g. Stampfli and Borel 2002; Barrier and Vrielynck 2008). This is based on the presence of Upper Triassic flysch in the Küre region (Figure 7), which is situated north of a magmatic arc and subduction-accretion complex, which were presumed to be of Triassic age (Ustaömer and

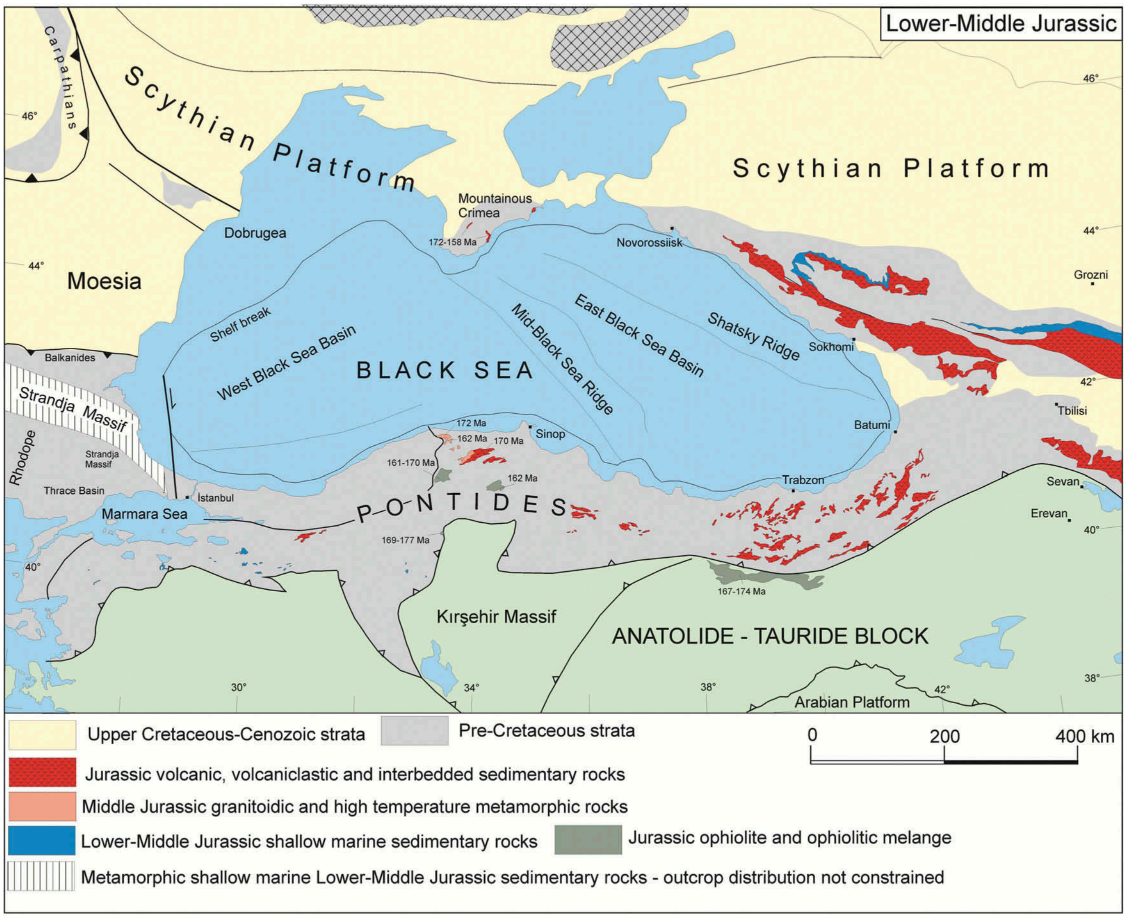

Figure 9. Outcrops of Lower–Middle Jurassic magmatic and sedimentary rocks, and Middle Jurassic ophiolites and related metamorphic rocks in the Black Sea region. The isotopic ages are from Dilek and Thy (2006), Meijers *et al.* (2010a), Çelik *et al.* (2011), Okay *et al.* (2013, 2014), and Topuz *et al.* (2013a, 2013b). The map is based on Anonymous (1972), MTA (2002), and Adamia (2010).

Robertson 1993, 1994). However, the magmatic arc is recently dated as Middle Jurassic (Figure 9; Okay *et al.* 2014) and the subduction-accretion complex as Early Cretaceous (Figure 10; Okay *et al.* 2006b, 2013); the actual Triassic magmatic arc lies north of the Upper Triassic flysch (Figure 7). Hence, the Upper Triassic flysch in the Central Pontides has a similar tectonic setting with the rest of the Upper Karakaya Complex and represents a deformed fore-arc basin sequence (Okay *et al.* 2015).

Jurassic: subduction and formation of a continental magmatic arc

By the Early Jurassic (Sinemurian), deformation related to the Cimmeride orogeny was largely over; the region underwent uplift and erosion followed by a major transgression, which is especially marked in the Sakarya Zone and in the Caucasus (e.g. Robinson *et al.* 1995; Okay and Tüysüz 1999; Gaetani *et al.* 2005; Ruban 2007; Adamia *et al.* 2011; Somin 2011). The Permo-Triassic subduction-accretion complex and the Variscan granitic and metamorphic basement are overlain with a pronounced unconformity by Lower Jurassic fluviatile to shallow marine conglomerates and sandstones, locally with coal seams, except in Crimea and the Central Pontides, where Cimmeride deformation lasted into the Early Jurassic.

During the Jurassic, there was differentiation between the eastern and western parts of the Black Sea region. In the east, a major extensional magmatic arc developed during the Middle–Late Jurassic (174–158 Ma, Toracian–Oxfordian) along the southern margin of Laurasia. Jurassic volcanic and plutonic rocks with subduction signatures extend from the Central Pontides through Eastern Pontides and Caucasus to Makran forming a linear belt, 2800 km long (Figure 9; McCann *et al.* 2010; Meijers *et al.* 2010a; Chiu *et al.* 2013; Okay *et al.* 2014). The magmatic arc is marked by a thick sequence of volcanoclastic and volcanic rocks, and minor acidic to intermediate intrusive rocks, which have subduction-related geochemical signatures (Yılmaz and Boztuğ 1986; Mengel *et al.* 1987; Şen 2007; Genç and Tüysüz 2010; Meijers *et al.* 2010a; Okay *et al.* 2014). In the Central

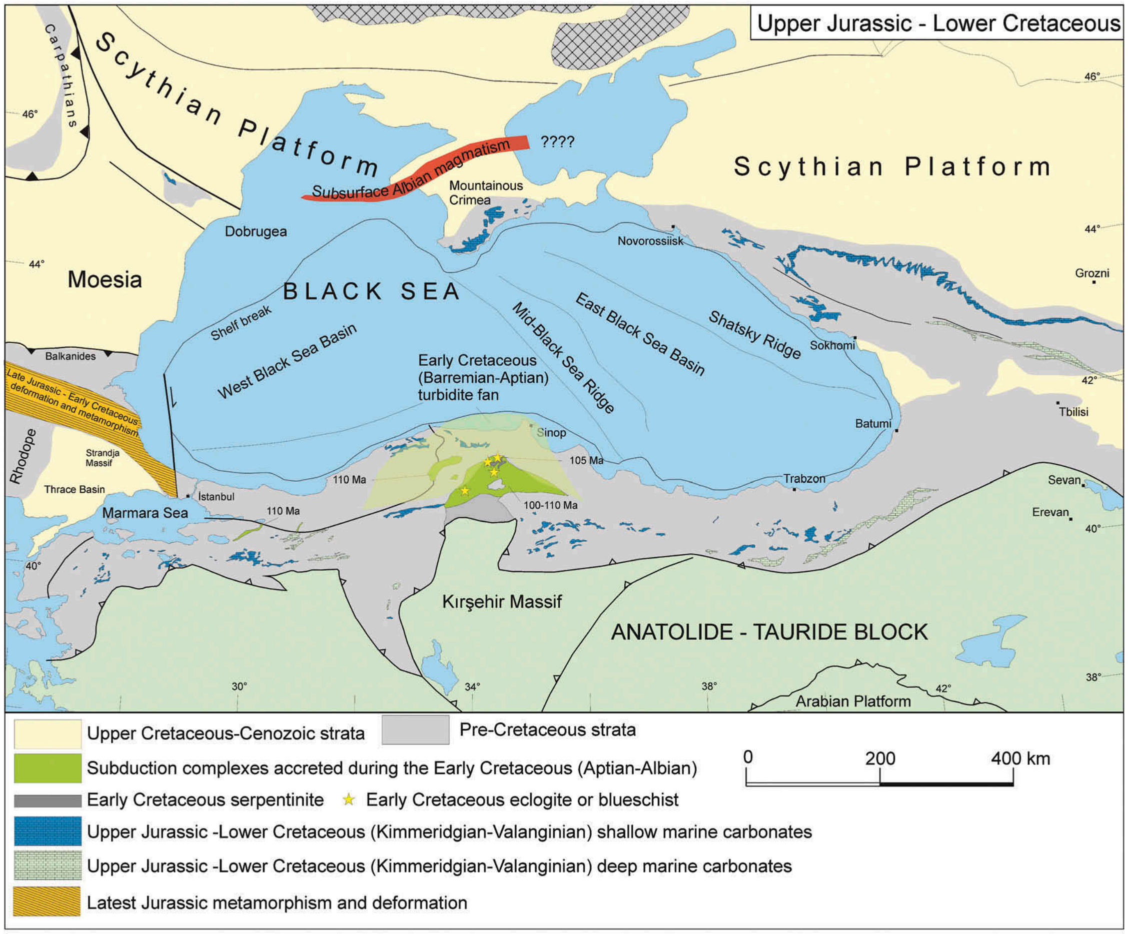

Figure 10. Outcrops of the Upper Jurassic–Lower Cretaceous (Kimmeridgian–Valanginian) carbonates, and Lower Cretaceous (Aptian–Albian) subduction-accretion complexes in the Black Sea region. The isotopic ages are from Okay *et al.* (2006b, 2013). The map is based on Anonymous (1972), MTA (2002), Adamia (2010), and Okay *et al.* (2013).

Pontides, high-temperature low-pressure metamorphic rocks, representing mid-crustal levels of a Middle Jurassic continental magmatic arc, are also exposed (Okay *et al.* 2014). The Jurassic arc granitoids intrude Triassic subduction-accretion complexes in the Pontides, indicating that the subduction zone jumped south of the accreted oceanic complexes. South of the Jurassic arc, there is a wide belt of ophiolite, ophiolitic mélange and related metamorphic rocks in the Central and Eastern Pontides (Figure 9), which were considered to be Cretaceous in age. However, recent isotopic data have shown that at least some of the ophiolites and related metamorphic rocks are Middle Jurassic in age (Figure 9; Dilek and Thy 2006; Çelik *et al.* 2011; Göncüoğlu *et al.* 2012; Okay *et al.* 2013, 2014; Topuz *et al.* 2013a, 2013b), providing further support for subduction during the Jurassic.

In the west, the Lower–Middle Jurassic sequences are either missing, as in the Istanbul Zone, or are represented by shallow marine sedimentary rocks with no trace of volcanism, as in the Strandja Massif (Figure 9).

Late Jurassic–Early Cretaceous (Kimmeridgian–Valanginian): continental collision in the west and carbonate deposition in the east

The differentiation between the western and eastern parts of the Black Sea region continued in the Late Jurassic and Early Cretaceous. In this period (Kimmeridgian to Valanginian), an extensive carbonate platform was established in the east in the Sakarya Zone, in Crimea, and in the Caucasus (Figure 10; Altıner *et al.* 1991; Kuznetsov 1993; Robinson *et al.* 1995; Ruban 2007; Krajewski and Olszewska 2007; Guo *et al.* 2011; Nikishin *et al.* 2015b). The shallow marine carbonates, locally with basal continental clastic rocks, unconformably cover the Lower–Middle Jurassic volcanic or granitoidic rocks (Okay *et al.* 2014). In the southern margins of the Eastern Pontides and Caucasus, they pass into pelagic limestones and calciturbidites, which suggest that the carbonate platform was facing an ocean in the south (Figure 10; Okay and Şahintürk 1997). There is no evidence for subduction during the Late Jurassic and early part of the Early

Cretaceous possibly because there was little convergence between Laurasia and Gondwana in this period, the plate motion being left-lateral transform (Smith 2006).

In contrast to the quiet carbonate deposition in the east, regional metamorphism associated with N-vergent contractional deformation took place in the west in the Strandja Massif and possibly in the Circum–Rhodope Belt during the Late Jurassic (Oxfordian, 160–150 Ma, Okay *et al.* 2001; Elmas *et al.* 2011; Sunal *et al.* 2011). The geological history of the Strandja Massif is linked to that of the Rhodope Massif in the west, which has a complicated poorly understood tectonic and metamorphic evolution (e.g. Burg 2012). Prior to the Late Jurassic deformation and metamorphism, the Strandja Massif was located on the continental shelf of Europe (Okay *et al.* 2001). The thick-skinned deformation of the continental shelf and its regional metamorphism, the scarcity of oceanic crustal rocks and the duration of the orogeny (160–140 Ma) suggest a continental collision, possibly between Rhodope and the Strandja massifs. The deformation in the Strandja Massif was over by the Cenomanian (ca. 99 Ma) when shallow marine sandstones and limestones were deposited on the metamorphic rocks (Okay *et al.* 2001).

Early Cretaceous (Hauterivian–Albian): subduction erosion

Subduction under Laurasia in the second half of the Early Cretaceous, in the Aptian–Albian, is evidenced by the eclogites and blueschists of this age in the Central Pontides (Figure 10; Okay *et al.* 2006b, 2013). They form part of a large oceanic subduction complex accreted to the southern margin of Laurasia during the Aptian–Albian. The Aptian–Albian subduction-accretion complexes, which crop out farther west between Istanbul and Sakarya zones (Figure 10; Akbayram *et al.* 2013), are either introduced later by strike-slip faulting (e.g. Elmas and Yiğitbaş 2001) or indicate the existence of a Mesozoic ocean between these blocks.

Although there is clear evidence for subduction, a contemporary magmatic arc is not exposed. Based on subsurface data, Nikishin *et al.* (2012, 2015b) show magmatism north of Crimea (Figure 10); this is also supported by the abundance of Albian zircons in the Cretaceous–Eocene sediments of southern Crimea (Nikishin and Khudoley, unpublished data). The Aptian–Albian subduction was preceded by a widespread uplift in the middle of the Early Cretaceous (Hauterivian–Barremian), which terminated the carbonate deposition in the Sakarya, Crimea, and the Caucasus. Most of the region stayed above sea level until the Late Cretaceous.

An exception to the general absence of late Lower Cretaceous sedimentary rocks is the Central Pontides where a large submarine turbidite fan fed partially from the East European Platform extended from the shelf down to the ocean (Figure 10; Okay *et al.* 2013). The distal parts of the turbidite fan were subducted and metamorphosed during the Aptian–Albian. The source to basin relation between the East European Platform and the Pontides indicates that the Black Sea, as a large basin, was not in existence in the Early Cretaceous.

Subduction erosion is common along the present-day convergent margins and is expected to have occurred widely in the past (e.g. Scholl and Von Huene 2010). It is characterized by the erosion of the upper plate, which is marked by landward migration of the magmatic arc. The magmatic arcs form at 100–125 km above the subducting slab and generally 200 km inland of the trench (e.g. Hamilton 1995; Stern 2002; Heuret *et al.* 2011). The Middle Jurassic magmatic-arc front in the Pontides is located south of the Cretaceous one and very close the İzmir–Ankara suture (Figure 11), indicating that a large crustal section south of the magmatic arc is missing, most likely through subduction erosion (Topuz *et al.* 2013b). The subduction erosion is constrained between the Late Jurassic (Oxfordian) and Early Cretaceous (Albian), and most probably occurred in the Early Cretaceous (Hautevian–Barremian), when there was widespread uplift through the Black Sea region.

Late Cretaceous: subduction in extensional mode, development of a major magmatic arc and opening of the Black Sea

The arc magmatism in the Black Sea region started in the early Late Cretaceous (Turonian) and continued for at least 20 million years, until the end of the Campanian (Okay and Şahintürk 1997). It formed a continuous Upper Cretaceous volcanic belt extending from the Lesser Caucasus to the Balkans (Figure 12). South of the volcanic belt there was a fore-arc basin, with several thousand metre thick siliciclastic turbidites. Shallow marine sedimentation prevailed in northern part of the Black Sea, except in the Greater Caucasus, where there was a basin with turbidite deposition (Nikishin *et al.* 2008). The magmatism waned in the Maastrichtian, when white marly limestones (chalk) were deposited over large areas.

The Late Cretaceous volcanism was all submarine; this feature and the large accumulated thickness of volcanoclastic and volcanic rocks, locally over 2000 m, indicate an extensional magmatic arc. The volcanic centres are probably now located offshore in the Black Sea (Nikishin *et al.* 2015a, 2015b). The opening of the Western and Eastern Black Sea basins occurred during the arc magmatism, predominantly in the Coniacian–Santonian (Tüysüz 1999; Okay *et al.* 2013). Late Cretaceous magmatic rocks in the Eastern Pontides are predominantly extrusive; the volumetrically minor

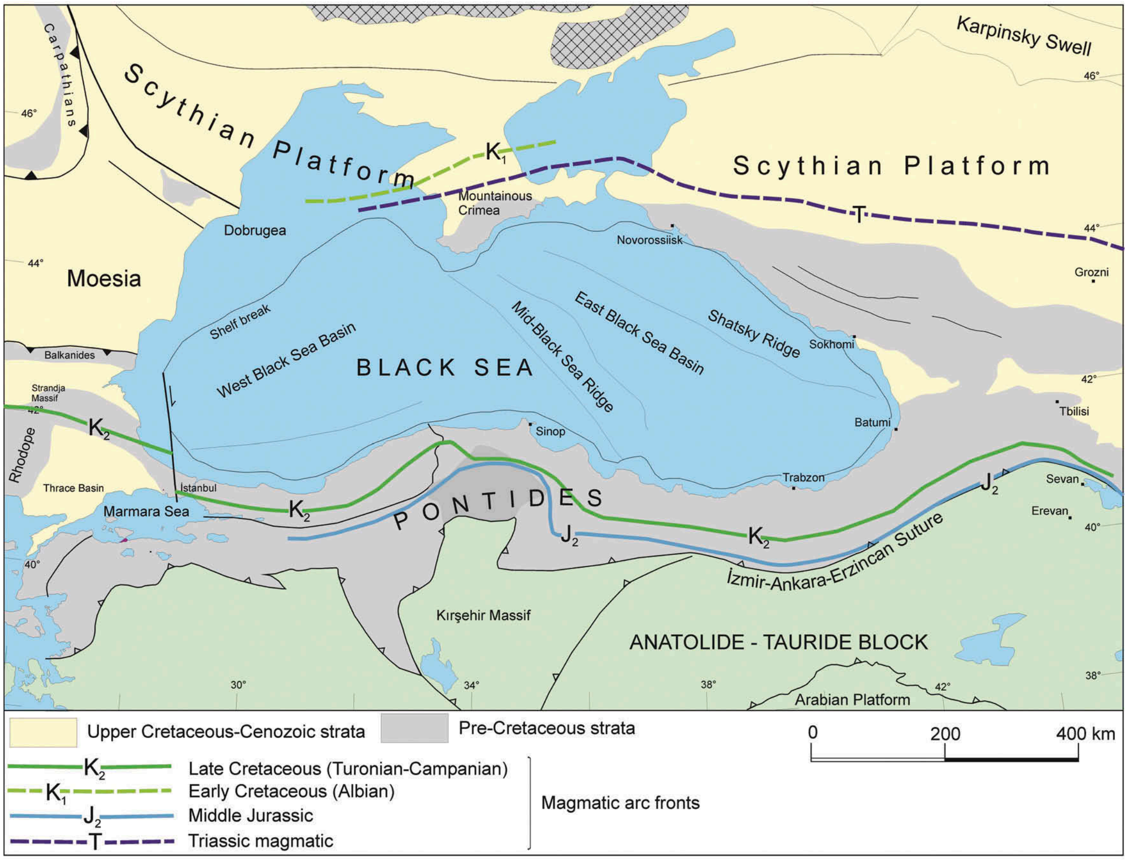

Figure 11. Magmatic fronts for the Triassic, Middle Jurassic, and Early and Late Cretaceous arcs. The location of the Triassic and Early Cretaceous magmatic arcs is approximate.

plutonic rocks are restricted to the west, mainly to the Balkans (Figure 12).

In the early part of the Late Cretaceous (Cenomanian–Turonian), just prior to the inception of arc magmatism, there was northward emplacement of ophiolitic mélange in the Eastern Pontides and Lesser Caucasus (Okay and Şahintürk 1997), possibly related to the steepening and back-thrusting of the oceanic accretionary complex.

A different Late Cretaceous magmatic arc crops out in the Kırşehir Massif south of the İzmir-Ankara suture. It consists predominantly of granitoidic rocks of Cenomanian–Campanian ages (95–75 Ma) intruding Late Cretaceous metamorphic rocks of continental crustal origin and the overlying ophiolites (Figure 12; Whitney and Hamilton 2004; Lefebvre *et al.* 2011, 2013). This Central Anatolian magmatic arc is unrelated to the Pontide arc and probably constituted an isolated island arc within the Neo-Tethyan Ocean (Figure 13), which collided with the Pontides in the Palaeocene (e.g. Lefebvre *et al.* 2013).

Ophiolite and ophiolitic mélange crop out over large areas in western Turkey south of the İzmir–Ankara suture (Figure 12). The ophiolites have formed during the early Late Cretaceous (Turonian–Cenomanian), which is based on the age of the sub-ophiolite metamorphic rocks (95–90 Ma), whereas the ophiolitic mélange includes radiolarian cherts of Triassic to Cretaceous ages (Tekin *et al.* 2002), indicating subduction of a Mesozoic oceanic crust (Okay and Whitney 2010; Plunder *et al.* 2013). Their emplacement is related to the subduction of the continental margin of the Anatolide–Tauride Block in an intra-oceanic subduction zone during the Campanian (Figure 13). Pontides were on a different lithospheric plate during the Late Cretaceous and were not affected by this major phase of high-pressure metamorphism and deformation.

Palaeocene–early Eocene: collision and amalgamation of the Anatolide–Tauride Block

In the Palaeocene and early Eocene, the Anatolide–Tauride Block and the Kırşehir Massif collided with the Laurasia margin and thereby closed the northern Neo-Tethys (Şengör and Yılmaz 1981; Okay and Şahintürk 1997; Kaymakçı *et al.* 2009; Sosson *et al.* 2010). The collision produced Palaeocene fore-land basins in the Eastern Pontides, and northward imbrication of the Eastern Pontides and the Lesser Caucasus. The arc-shaped

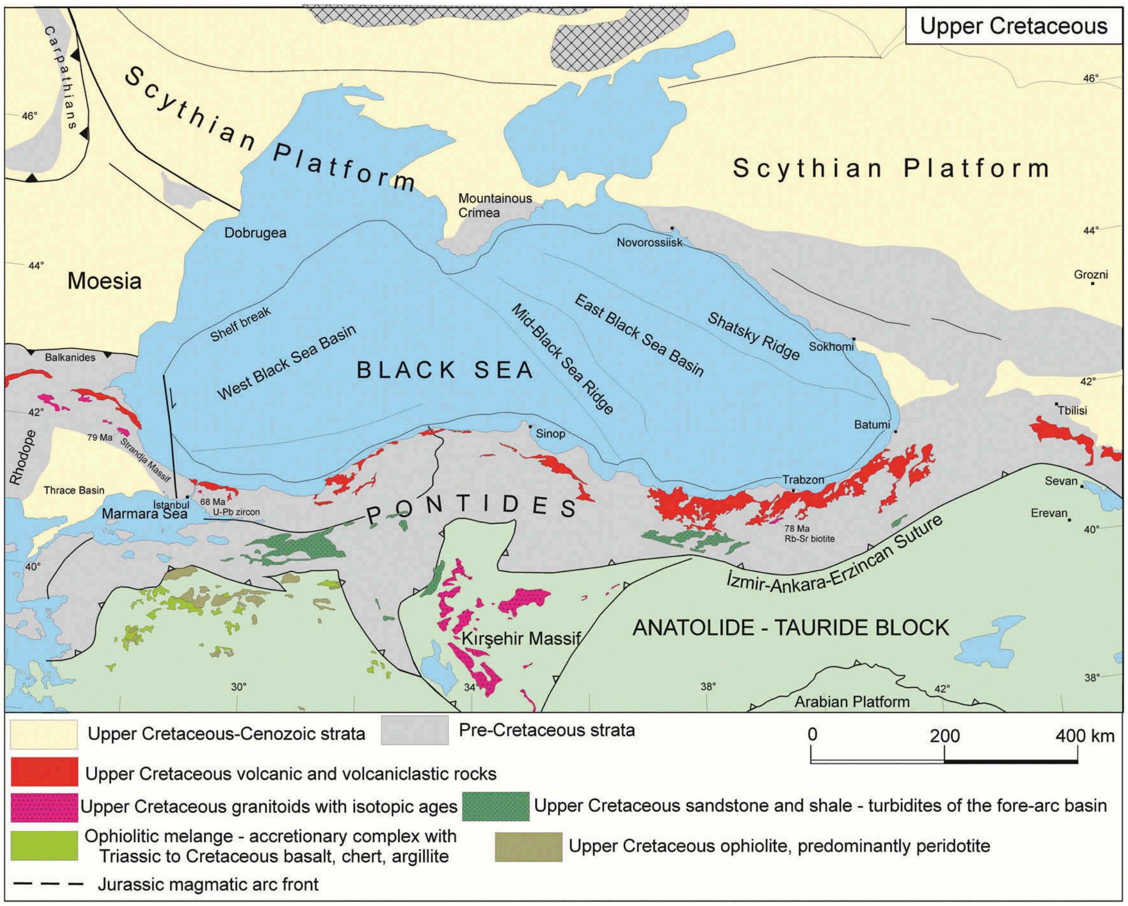

Figure 12. Outcrops of Upper Cretaceous magmatic rocks, fore-arc turbidites and ophiolites in the Black Sea region. The isotopic ages are from Moore *et al.* (1980) and Şahin *et al.* (2012). The map is based on Anonymous (1972), MTA (2002), and Adamia (2010).

geometry of the Central Pontides was also formed during the collision in the latest Cretaceous and Palaeocene (Meijers *et al.* 2010b). The final major event in the long history of the Gondwana–Laurasia convergence was the Miocene collision between Arabia and Laurasia (Okay *et al.* 2010).

Subduction episodes along the southern Laurasia margin

Oceanic subduction can be accretionary or erosive (e.g. Scholl and Von Huene 2010). Erosive subduction is characterized by landward migration of the trench and leaves little in the rock record. In contrast, accretionary subduction is marked through arc magmatism and by the growth of accretionary complexes, which may include rocks metamorphosed at high pressures. The duration of subduction is difficult to establish from a study of accretionary complexes since differentiation of the age of the matrix from the age of the blocks or tectonic slices in an accretionary complex is ambiguous. High-pressure metamorphic rocks provide primary evidence for subduction since no other tectonic environment on Earth can produce similar P-T conditions. However, their metamorphic ages provide an imprecise signature for the timing of subduction for two reasons. First, Ar–Ar phengite dating, the predominant dating method in high-pressure metamorphic rocks, gives inaccurate and imprecise results in eclogites and blueschists due to problems with excess argon or argon loss (e.g. Sherlock *et al.* 1999). Second, high-pressure metamorphism occurs at several tens of kilometres depth and not all blueschists and eclogites are necessarily returned to the surface. The best record for accretionary subduction is provided by arc magmatism, which is produced once the subducting slab reaches a depth of about 100–125 km (e.g. Stern 2002), which with average subduction rates can occur within two million years. Table 1 shows the palaeontological and isotopic ages for arc magmatism, that of subduction- and arc-related metamorphism, along with the primary data sources, for the five major accretionary subduction episodes in the Laurasian margin. The duration of accretionary subduction episodes ranges between 7 and 30 million years and they are interspersed with periods when the subduction was erosional, such as

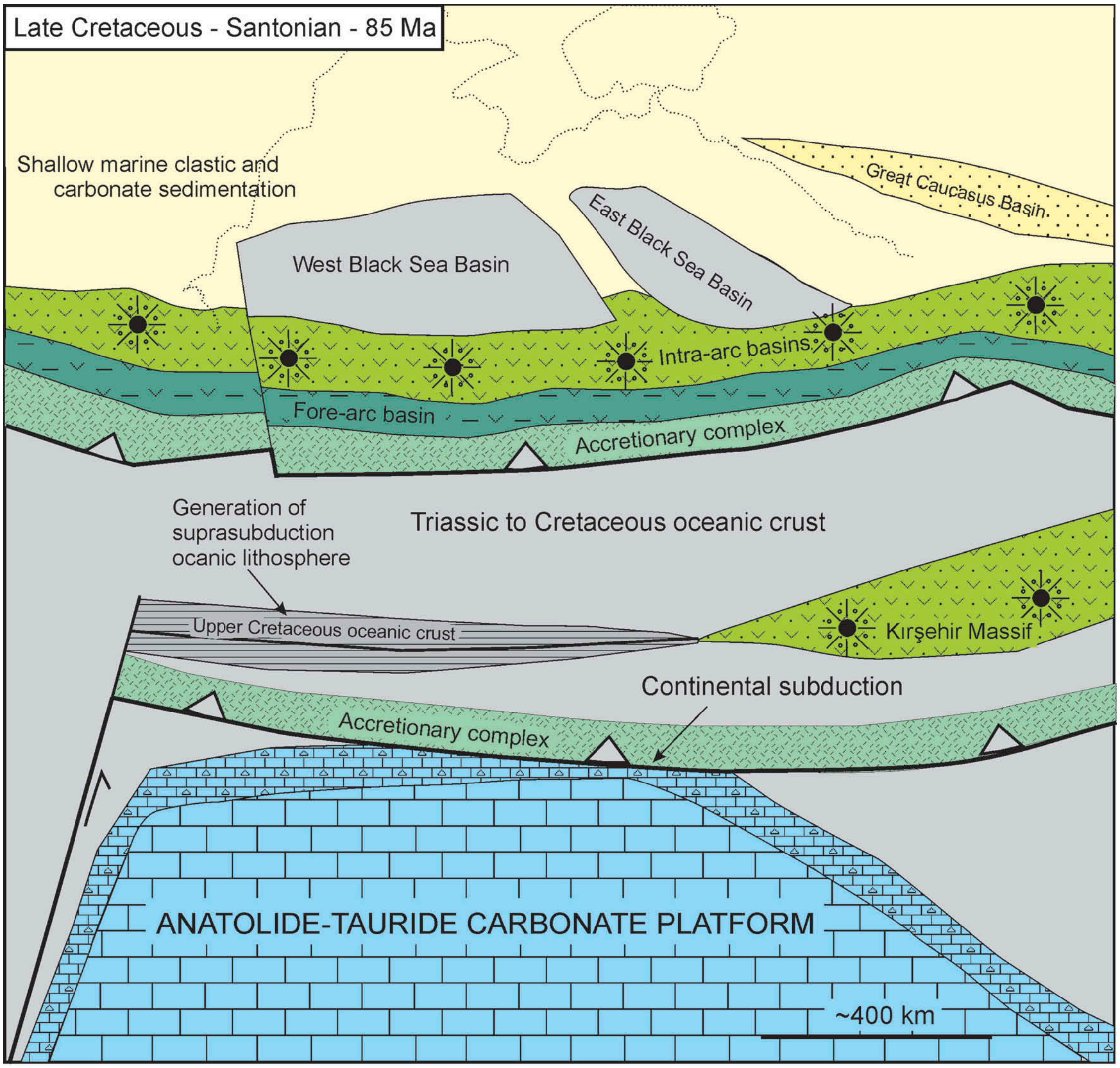

Figure 13. Palaeogeographic sketch for the Late Cretaceous in the Black Sea region.

during the Early Cretaceous (Hauterivian–Barremian), or when the margin was transform, such as during the latest Jurassic–earliest Cretaceous (Kimmeridgian–Valanginian).

Conclusions

The geological evolution of the southern margin of Laurasia can be viewed as the growth of the Archaean–Palaeoproterozoic core by addition of Gondwana-derived continental blocks and oceanic subduction complexes. The major geological events along the southern margin of Laurasia are summarized in Figure 14 and Table 1 and are listed below.

1. The Laurasian margin was generally a passive margin during the Palaeozoic and an active margin during most of the Mesozoic and Tertiary.

2. The first collision occurred in the early Palaeozoic, probably at around the Ordovician–Silurian boundary, when the Gondwana-derived Istanbul Block collided with the Laurasia margin. Data for this collision are very weak since the zone of collision is buried under younger sedimentary cover.

3. During the Carboniferous, a magmatic arc collided with the Laurasian margin resulting in the Variscan orogeny. The magmatic arc is represented by the Strandja Massif and the Sakarya Zone of the Pontides and by the Caucasus, which are characterized by Carboniferous plutonism and high-temperature metamorphism. The suture zone is marked by late Carboniferous eclogites and serpentinites on the northern margin of the Greater Caucasus.

4. There is little evidence for subduction during the Permian. However, in the Late Triassic, northward subduction under Laurasia is evidenced by eclogites and

Table 1. Palaeontological and isotopic data on arc magmatism and subduction-related metamorphism on the Laurasia margin.

Subduction episodes	Magmatism—palaeontological and isotopic ages	Facies and age of metamorphism in the subduction zone	Facies and age of metamorphism under the arc	Age of the subduction-accretion complex	Time and duration of documented subduction
Late Cretaceous	Turonian to Campanian[1,2,3] 93–74 Ma[4,5,6,7,8,9]	Eclogite to blueschist 90–80 Ma[10,11]	Not known	Late Cretaceous[29,30]	Turonian–Campanian 94–72 Ma 22 million years
Early Cretaceous	Albian[12] age poorly constrained	Eclogite to blueschist 112–104 Ma[2,13]	Not known	Poorly constrained	Albian 112–104 Ma 8 million years
Jurassic	Toarcian to Oxfordian[14–17] 172–158 Ma[18,19]	HP greenschist to amphibolite[13,20,21] 174–162 Ma[13,20,21]	HT amphibolite[19] ca. 172 Ma[19]	Poorly constrained	Toarcian–Oxfordian 174–158 Ma 16 million years
Late Triassic	Triassic[22,23] age poorly constrained	Eclogite to blueschist[24,25] HP greenschist[26] 210–203[24,25,26]	Not known	Late Triassic[27,28]	Norian–Rhaetian 210–203 7 million years
Carboniferous	330–295 Ma[31–36]	Eclogite[37,38] 316–300 Ma[38]	HT amphibolite to granulite[35,39] ca. 330 Ma[35,39]	Not known	Late Carboniferous 330–300 Ma 30 million years

Notes: [1]Taner and Zaninetti (1978), [2]Okay *et al.* (2006b), [3]Tüysüz *et al.* (2012), [4]Karsli *et al.* (2012), [5]Kaygusuz *et al.* (2014), [6]Asan *et al.* (2014), [7]Eyüpoğlu *et al.* (2014), [8]Aydın (2014), [9]Von Quadt *et al.* (2005), [10]Sherlock *et al.* (1999), [11]Mulcahy *et al.* (2014), [12]Nikishin *et al.* (2015b), [13]Okay *et al.* (2013), [14]Altıner *et al.* (1991), [15]Robinson *et al.* (1995), [16]Kandemir and Yılmaz (2009), [17]Bragin *et al.* (2002), [18]Meijers *et al.* (2010a), [19]Okay *et al.* (2014),[20]Marroni *et al.* (2014),[21]Topuz *et al.* (2013a), [22]Tikhomirov *et al.* (2004), [23]Alexandre *et al.* (2004), [24]Okay and Monié (1997), [25]Okay *et al.* (2002), [26]Topuz *et al.* (2014), [27]Okay *et al.* (2011a), [28]Sayit *et al.* (2011), [29]Rojay (2013),[30]Bragin and Tekin (1996), [31]Topuz *et al.* (2010), [32]Ustaömer *et al.* (2012b), [33]Okay *et al.* (2015), [34]Ustaömer *et al.* (2013), [35]Mayringer *et al.* (2011), [36]Rolland *et al.* (2011), [37]Perchuk and Philippot (1997), [38]Philippot *et al.* (2001), [39]Topuz *et al.* (2004a).

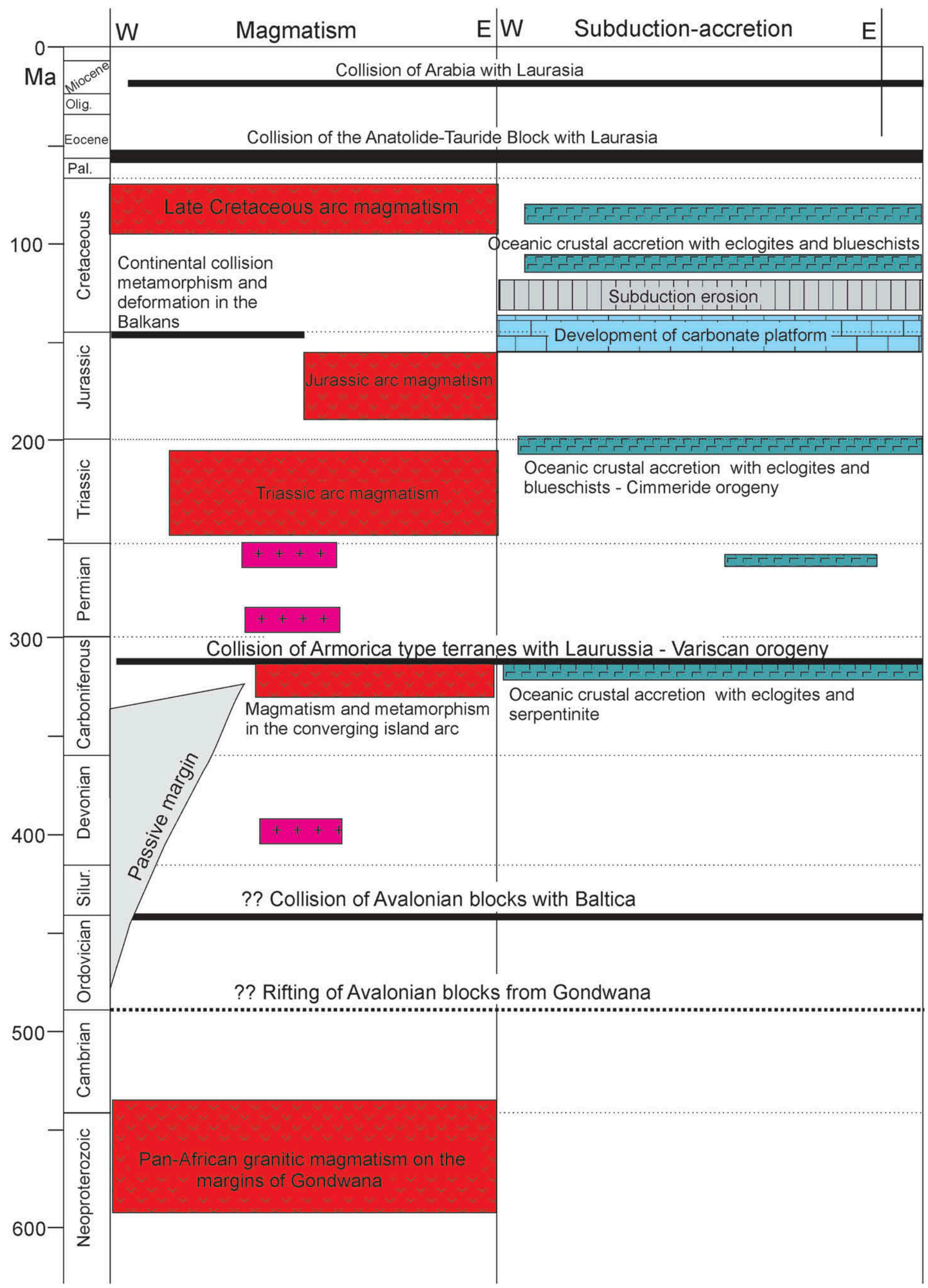

Figure 14. Summary of the orogenic events in the Black Sea region.

blueschists in the Pontides and by a buried magmatic arc north of the Caucasus (Figure 7). At around the Triassic–Jurassic boundary, there was widespread deformation throughout the Black Sea region, possibly caused by the collision and accretion of an oceanic plateau.

5. In the Middle Jurassic, northward subduction was established and resulted in the formation of an extensional magmatic arc, which can be traced for 2800 km from the Central Pontides to Makran (Figure 9).

6. Subduction was interrupted during the latest Jurassic–Early Cretaceous (Kimmeridgian–Berriasian) because of slowing down of the plate convergence, and a carbonate platform was established in the eastern part of the Black Sea region (Figure 10).

7. In the western part of the Black Sea region, in the Balkans, there was continent–continent collision during the latest Jurassic–Early Cretaceous (Kimmeridgian–Berriasian), possibly caused by the closing of an ocean between the Strandja and Rhodope massifs.

8. There was subduction erosion during the Early Cretaceous (Hauterivian–Barremian), when the crust south of the Middle Jurassic magmatic arc was

tectonically removed. The present Middle Jurassic arc-front lies south of the Cretaceous magmatic arc and very close to the İzmir–Ankara suture (Figure 11).

9. Subduction became accretionary in the second half of the Early Cretaceous (Aptian–Albian), as shown by blueschists and eclogites of oceanic crustal origin in the Central Pontides. There was arc volcanism north of Crimea and possibly in the Caucasus, as revealed by well and clastic zircon data (Figure 10).

10. The subduction was extensional in the Late Cretaceous and lead to the formation of a well-developed magmatic arc, predominantly of Turonian to Campanian age, which can be traced from the Lesser Caucasus through the Pontides to Iran (Figure 12).

11. The subduction was terminated in the Palaeocene–early Eocene by the collision of the Anatolide–Tauride Block, which closed the northern branch of the Neo-Tethys. The last ocean between Gondwana and Laurasia closed through the collision of Arabian Plate in the Miocene.

12. The major unknown in the history of subduction in the Black Sea region is the extent of strike-slip faulting. Orogen parallel transport along major strike-slip faults is common in active margins, where such faults take up the oblique motion of convergence. Strike-slip faulting was most likely important during the Mesozoic along the southern margin of Laurasia but is difficult to document since it was subparallel to the structural grain and left no palaeomagnetic record in the generally E–W-trending Tethyan subduction zones. One possible example is the Tornquist–Teisseyre line, which might have allowed eastward translation of the Istanbul Zone after the Carboniferous (Okay *et al.* 2011a), another is the possible strike-slip emplacement of Cretaceous ophiolitic mélanges between Istanbul and Sakarya zones (Elmas and Yiğitbaş 2001). It is also tempting to speculate large-scale sinistral strike-slip faulting between the Greater and Lesser Caucasus, based on the unusually wide Middle Jurassic magmatic belt (Figure 9), and the location of the Dizi series (Figure 7).

Acknowledgements

We thank Shota Adamia for geological field trips to the Lesser Caucasus, Gültekin Topuz for discussions and an internal review, and Douwe van Hinsbergen for a detailed review, which improved the text.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

Geological research in the Pontides over many years for Aral Okay was supported by MTA, TPAO; TÜBA and TÜBİTAK [grant number 109Y049], [grant number 101Y032]. Work of Anatoly Nikishin was supported by the Russian Foundation for Basic Research (RFBR grant 15-05-03004) and Darius project.

References

Adamia, S., 2010, Geological map of Caucasus 2010, 1/1 000 000 scale: M. Nodia Institute of Geophysics, Tbilisi State University, Georgia.

Adamia, S., Zakariadze, G., Chkhotua, T., Sadradze, N., Tsereteli, N., Chabukiani, A., and Gventsadze, A., 2011, Geology of the Caucasus: A review: Turkish Journal of Earth Sciences, v. 20, p. 489–544.

Akbayram, K., Okay, A.I., and Satır, M., 2013, Early Cretaceous closure of the Intra-Pontide Ocean in western Pontides (northwestern Turkey): Journal of Geodynamics, v. 65, p. 38–55. doi:10.1016/j.jog.2012.05.003

Albino, I., Cavazza, W., Zattin, M., Okay, A.I., Adamia, S., and Sadradze, N., 2014, Far-field tectonic effects of the Arabia-Eurasia collision and the inception of the North Anatolian fault system: Geological Magazine, v. 151, p. 372–379. doi:10.1017/S0016756813000952

Alexandre, P., Chalot-Prat, F., Saintot, A., Wijbrans, J., Stephenson, R., Wilson, M., Kitchka, A., and Stovba, S., 2004, The $^{40}Ar/^{39}Ar$ dating of magmatic activity in the Donbas Fold Belt and the Scythian Platform (Eastern European Craton): Tectonics, v. 23, p. TC5002. doi:10.1029/2003TC001582

Altıner, D., Koçyiğit, A., Farinacci, A., Nicosia, U., and Conti, M.A., 1991, Jurassic-lower Cretaceous stratigraphy and paleogeographic evolution of the southern part of north-western Anatolia: Geologica Romana, v. 28, p. 13–80.

Anonymous, 1972, Internationalen Geologischen Karte von Europa und der Mittelmeerlander, 1/5 000 000 scale: Bundesanstalt für Bodenforschung, Hannover.

Asan, K., Kurt, H., Francis, D., and Morgan, G., 2014, Petrogenesis of the late Cretaceous K-rich volcanic rocks from the Central Pontide orogenic belt, North Turkey: Island Arc, v. 23, p. 102–124. doi:10.1111/iar.12061

Assereto, R., 1972, Notes on the Anisian biostratigraphy of the Gebze area (Kocaeli Peninsula, Türkei): Zeitschrift der Deutschen Geologischen Gesellschaft, v. 123, p. 435–444.

Aydin, F., 2014, Geochronology, geochemistry, and petrogenesis of the Maçka subvolcanic intrusions: Implications for the late Cretaceous magmatic and geodynamic evolution of the eastern part of the Sakarya Zone, northeastern Turkey: International Geology Review, v. 56, p. 1246–1275. doi:10.1080/00206814.2014.933364

Barrier, E., and Vrielynck, B., 2008, MEBE Atlas of the Paleotectonic maps of the middle East. Commission for the Geological Map of the World, Paris, France.

Bogdanova, S.V., Bingen, B., Gorbatschev, R., Kheraskova, T. N., Kozlov, V.I., Puchkov, V.N., and Volozh, Y.A., 2008, The East European Craton (Baltica) before and during the assembly of Rodinia: Precambrian Research, v. 160, p. 23–45. doi:10.1016/j.precamres.2007.04.024

Bozkurt, E., Holdsworth, B.K., and Koçyiğit, A., 1997, Implications of Jurassic chert identified in the Tokat Complex, northern Turkey: Geological Magazine, v. 134, p. 91–97. doi:10.1017/S0016756897006419

Bozkurt, E., Winchester, J.A., Yiğitbaş, E., and Ottley, C.J., 2008, Proterozoic ophiolites and mafic-ultramafic complexes marginal to the Istanbul Block: An exotic terrane of Avalonian affinity in NW Turkey: Tectonophysics, v. 461, p. 240–251. doi:10.1016/j.tecto.2008.04.027

Bragin, N.Y., and Tekin, U.K., 1996, Age of radiolarian chert blocks from the Senonian ophiolitic melange (Ankara, Turkey): The Island Arc, v. 5, p. 114–122. doi:10.1111/j.1440-1738.1996.tb00018.x

Bragin, N.Y., Tekin, U.K., and Özçelik, Y., 2002, Middle Jurassic radiolarians from the Akgöl Formation, central Pontids, northern Turkey: Neues Jahrbuch, Geologische und Palaontologische Monatshefte, v. 2002, no. 10, p. 609–628.

Burg, J.-P., 2012, Rhodope: From Mesozoic convergence to Cenozoic extension. Review of petro-structural data in the geochronological frame: Journal of the Virtual Explorer, v. 42, paper 1. doi:10.3809/jvirtex.2011.00270

Çapkınoğlu, Ş., 2003, First records of conodonts from "the Permo-Carboniferous of Demirözü" (Bayburt), Eastern Pontides, NE Turkey: Turkish Journal of Earth Sciences, v. 12, p. 199–207.

Catlos, E., Hubert, K., and Shin, T.A., 2013, Geochemistry and geochronology of meta-igneous rocks from the Tokat Massif, north-central Turkey: Implications for Tethyan reconstructions: International Journal of Earth Sciences, v. 102, p. 2175–2198. doi:10.1007/s00531-013-0918-0

Çelik, Ö.F., Marzoli, A., Marschik, R., Chiaradia, M., Neubauer, F., and Öz, İ., 2011, Early–Middle Jurassic intra-oceanic subduction in the İzmir-Ankara-Erzincan Ocean, Northern Turkey: Tectonophysics, v. 509, p. 120–134. doi:10.1016/j.tecto.2011.06.007

Chen, F., Siebel, W., Satir, M., Terzioğlu, M.N., and Sak, K., 2002, Geochronology of the Karadere basement (NW Turkey) and implications for the geological evolution of the Istanbul Zone: International Journal of Earth Sciences, v. 91, p. 469–481. doi:10.1007/s00531-001-0239-6

Chiu, H.-Y., Chung, S.-L., Zarrinkoub, M.H., Mohammadi, S.S., Khatib, M.M., and Iizuka, Y., 2013, Zircon U–Pb age constraints from Iran on the magmatic evolution related to Neotethyan subduction and Zagros orogeny: Lithos, v. 162–163, p. 70–87. doi:10.1016/j.lithos.2013.01.006

Claesson, S., Bibikova, E., Bogdanova, S., and Skobelev, V., 2006, Archean terranes, Paleoproterozoic reworking and accretion in the Ukranian Shield, East European Craton, *in* Gee, D.G., and Stephenson, R.A., eds., European Lithosphere Dynamics: London, Geological Society, p. 645–654. Memoirs 32.

Cocks, L.R.M., and Torsvik, T.H., 2002, Earth geography from 500 to 400 million years ago: A faunal and palaeomagnetic review: Journal of the Geological Society, London, v. 159, p. 631–644. doi:10.1144/0016-764901-118

Cocks, L.R.M., and Torsvik, T.H., 2006, European geography in a global context from the Vendian to the end of the Palaeozoic, *in* Gee, D.G., and Stephenson, R.A., eds., European Lithosphere Dynamics: London, Geological Society, p. 83–95. Memoirs 32.

Dean, W.T., Monod, O., Rickards, R.B., Demir, O., and Bultynck, P., 2000, Lower Palaeozoic stratigraphy and palaeontology, Karadere-Zirze area, Pontus Mountains, northern Turkey: Geological Magazine, v. 137, p. 555–582. doi:10.1017/S0016756800004635

Dercourt, J., Gaetani, M., Vrielynk, B., Barrier, E., Biju-Duval, B., Brunet, M.F., Cadet, J.P., Crasquin, S., and Sandulescu, M., 2000, Peri-Tethys Palaeogeographical Atlas: Paris, Gauthier-Villars.

Dil, N., Termier, G., Termier, H., and Vachard, D., 1976, A l'étude stratigraphique et paléontologique du Viséen supérieur et du Namurien inférieur du bassin houiller de Zonguldak (nord-ouest de la Turquie): Annales De La Société Géologique De Belgique, v. 99, p. 401–449.

Dilek, Y., and Thy, P., 2006, Age and petrogenesis of plagiogranite intrusions in the Ankara melange, central Turkey: The Island Arc, v. 15, p. 44–57. doi:10.1111/j.1440-1738.2006.00522.x

Elmas, A., and Yiğitbaş, E., 2001, Ophiolite emplacement by strike-slip tectonics between the Pontide Zone and the Sakarya Zone in northwestern Anatolia, Turkey: International Journal of Earth Sciences, v. 90, p. 257–269. doi:10.1007/s005310000129

Elmas, A., Yılmaz, İ., Yiğitbaş, E., and Ullrich, T., 2011, A Late Jurassic–Early Cretaceous metamorphic core complex, Strandja Massif, NW Turkey: International Journal of Earth Sciences, v. 100, p. 1251–1263. doi:10.1007/s00531-010-0540-3

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

Eyuboglu, Y., Santosh, M., Yi, K., Tuysuz, N., Korkmaz, S., Akaryali, E., Dudas, F.O., and Bektas, O., 2014, The Eastern Black Sea-type volcanogenic massive sulfide deposits: Geochemistry, zircon U–Pb geochronology and an overview of the geodynamics of ore genesis: Ore Geology Reviews, v. 59, p. 29–54. doi:10.1016/j.oregeorev.2013.11.009

Franke, W., 2014, Topography of the Variscan orogen in Europe: Failed–not collapsed: International Journal of Earth Sciences, v. 103, p. 1471–1499. doi:10.1007/s00531-014-1014-9

Gaetani, M., Garzanti, E., Polino, R., Kiricko, Y., Korsakhov, S., Cirilli, S., Nicora, A., Rettori, R., Larghi, C., and Palliani, R. B., 2005, Stratigraphic evidence for Cimmerian events in NW Caucasus (Russia): Bulletin De La Société Géologique De France, v. 176, p. 283–299. doi:10.2113/176.3.283

Gand, G., Tüysüz, O., Steyer, S., Allain, R., Sakınç, M., Sanchez, S., Şengör, A.M.C., and Sen, S., 2011, New Permian tetrapod footprints and macroflora from Turkey (Çakraz Formation, northwestern Anatolia): Biostratigraphic and palaeoenvironmental implications: Comptes Rendus Palevol, v. 10, p. 617–625. doi:10.1016/j.crpv.2011.09.002

Gedik, I., 1975, Die Conodonten der Trias auf der Kocaeli-Halbinsel (Türkei): Palaeontographica, 150, 99–160.

Genç, S.C., 2004, A Triassic large igneous province in the Pontides, northern Turkey: Geochemical data for its tectonic setting: Journal of Asian Earth Sciences, v. 22, p. 503–516. doi:10.1016/S1367-9120(03)00090-7

Genç, Ş.C., and Tüysüz, O., 2010, Tectonic setting of the Jurassic bimodal magmatism in the Sakarya Zone (Central and Western Pontides), Northern Turkey: A geochemical and isotopic approach: Lithos, v. 118, p. 95–111. doi:10.1016/j.lithos.2010.03.017

Göncüoğlu, M.C., Marroni, M., Sayit, K., Tekin, U.K., Ottria, G., Pandolfi, L., and Ellero, A., 2012, The Ayli Dag ophiolite sequence (central-northern Turkey): A fragment of Middle Jurassic oceanic lithosphere within the Intra-Pontide suture zone: Ofioliti, v. 37, p. 77–92.

Gorbatschev, R., and Bogdanova, S., 1993, Frontiers in the Baltic Shield: Precambrian Research, v. 64, p. 3–21. doi:10.1016/0301-9268(93)90066-B

Görür, N., Monod, O., Okay, A.I., Şengör, A.M.C., Tüysüz, O., Yiğitbaş, E., Sakinç, M., and Akkök, R., 1997, Palaeogeographic and tectonic position of the Carboniferous rocks of the western Pontides (Turkey) in the frame of the Variscan belt: Bulletin De La Société Géologique De France, v. 168, p. 197–205.

Gradstein, F.M., Ogg, J.G., and Smith, A.G., 2004, A Geologic Time Scale 2004: Cambridge, Cambridge University Press.

Guo, L., Vincent, S.J., and Lavrishchev, V., 2011, Upper Jurassic reefs from the Russian western Caucasus: Implications for the eastern Black Sea: Turkish Journal of Earth Sciences, v. 20, p. 629–653.

Guterch, A., Grad, M., Thybo, H., and Keller, G.R., the POLONAISE Working Group, 1999, POLONAISE '97—An international seismic experiment between Precambrian and Variscan Europe in Poland: Tectonophysics, v. 314, p. 101–121. doi:10.1016/S0040-1951(99)00239-5

Hamilton, W.B., 1995, Subduction systems and magmatism, *in* Smellie, J.D., ed., Volcanisn associated with extension at consuming plate margins: Geological Society, p. 3–28. Special Publication 81.

Hanel, M., Gurbanov, A.G., and Lippolt, H.J., 1992, Age and genesis of granitoids from the Main-Range and Bechasyn zones of the western Great Caucasus: Neues Jahrbuch für Mineralogie Monatshefte, v. 12, p. 529–544.

Heuret, A., Lallemand, S., Funiciello, F., Piromallo, C., and Faccenna, C., 2011, Physical characteristics of subduction interface type seismogenic zones revisited: Geochemistry Geophysics Geosystems, v. 12, p. Q01004. doi:10.1029/2010GC003230

Kalvoda, J., and Bábek, O., 2010, The margins of Laurussia in central and southeast Europe and southwest Asia: Gondwana Research, v. 17, p. 526–545. doi:10.1016/j.gr.2009.09.012

Kalvoda, J., Leichmann, J., Babek, O., and Melichar, R., 2003, Brunovistulian Terrane (Central Europe) and Istanbul Zone (NW Turkey): Late Proterozoic and Paleozoic tectonostratigraphic development and paleogeography: Geologica Carpathica, v. 54, p. 139–152.

Kandemir, R., and Yılmaz, C., 2009, Lithostratigraphy, facies, and deposition environment of the lower Jurassic Ammonitico Rosso type sediments (ARTS) in the Gümüşhane area, NE Turkey: Implications for the opening of the northern branch of the Neo-Tethys Ocean: Journal of Asian Earth Sciences, v. 34, p. 586–598. doi:10.1016/j.jseaes.2008.08.006

Karsli, O., Caran, Ş., Dokuz, A., Çoban, H., Chen, B., and Kandemir, R., 2012, A-type granitoids from the Eastern Pontides, NE Turkey: Records for generation of hybrid A-type rocks in a subduction-related environment: Tectonophysics, v. 530–531, p. 208–224. doi:10.1016/j.tecto.2011.12.030

Karslıoğlu, Ö., Ustaömer, T., Robertson, A.H.F., and Peytcheva, I., 2012, Age and provenance of detrital zircons from a sandstone turbidite of the Triassic-Early Jurassic Küre Complex, Central Pontides. Abstracts, International Earth Science Colloquium on the Aegean Region, IAESCA-2012, p. 57.

Kaygusuz, A., Arslan, M., Siebel, W., Sipahi, F., İlbeyli, N., and Temizel, İ., 2014, LA-ICP MS zircon dating, whole-rock and Sr–Nd–Pb–O isotope geochemistry of the Camiboğazı pluton, Eastern Pontides, NE Turkey: Implications for lithospheric mantle and lower crustal sources in arc-related I-type magmatism: Lithos, v. 192–195, p. 271–290. doi:10.1016/j.lithos.2014.02.014

Kaymakçı, N., Özçelik, Y., White, S.H., and Van Dijk, P.M., 2009, Tectono-stratigraphy of the Çankırı Basin: Late Cretaceous to early Miocene evolution of the Neotethyan Suture Zone in Turkey, *in* Van Hinsbergen, D.J.J., Edwards, M.A., and Govers, R., eds., Collision and collapse at the Africa–Arabia–Eurasia subduction zone: London, Geological Society, p. 67–106. Special Publications, 311

Koralay, O.E., Candan, O., Akal, C., Dora, O.Ö., Chen, F., Satır, M., and Oberhansli, R., 2011, The geology and geochronology of the Pan-African and Triassic metagranitoids in the Menderes Massif, Western Anatolia, Turkey: Bulletin of the Mineral Research and Exploration, v. 142, p. 69–119.

Kozur, H., and Kaya, O., 1994, First evidence of pelagic Late Permian conodonts from NW Turkey: Neues Jahrbuch für Geologie und Palaontologie, Monatshefte, 339–347.

Krajewski, M., and Olszewska, B., 2007, Foraminifera from the Late Jurassic and Early Cretaceous carbonate platform facies of the southern part of the Crimea mountains, southern Ukraine: Annales Societatis Geologorum Poloniae, v. 77, p. 291–311.

Kuznetsov, V.G., 1993, Late Jurassic – Early Cretaceous carbonate platform in the Northern Caucasus and Precaucasus, *in* Simo, J.A., Scott, R.W., and Masse, J.-P., eds., Cretaceous Carbonate Platforms: American Association of Petroleum Geologists (AAPG), p. 455–463. Memoir 56.

Lefebvre, C., Barnhoorn, A., Van Hinsbergen, D.J.J., Kaymakci, N., and Vissers, R.L.M., 2011, Late Cretaceous extensional denudation along a marble detachment fault zone in the Kırşehir massif near Kaman, central Turkey: Journal of Structural Geology, v. 33, p. 1220–1236. doi:10.1016/j.jsg.2011.06.002

Lefebvre, C., Meijers, M.J.M., Kaymakci, N., Peynircioglu, A., Langereis, C.G., and Van Hinsbergen, D.J.J., 2013, Reconstructing the geometry of central Anatolia during the late Cretaceous: Large-scale Cenozoic rotations and deformation between the Pontides and Taurides: Earth and Planetary Science Letters, v. 366, p. 83–98. doi:10.1016/j.epsl.2013.01.003

Leven, E.J., and Okay, A.I., 1996, Foraminifera from the exotic Permo-Carboniferous limestone blocks in the Karakaya Complex, northwest Turkey: Rivista Italiana Paleontologia e Stratigrafia, v. 102, p. 139–174.

Marroni, M., Frassi, C., Göncüoğlu, M.C., Di Vincenzo, G., Pandolfi, L., Rebay, G., Ellero, A., and Ottria, G., 2014, Late Jurassic amphibolite facies metamorphism in the Intra-Pontide Suture Zone (Turkey): An eastward extension of the Vardar Ocean from the Balkans into Anatolia?: Journal of the Geological Society, London, v. 171, p. 605–608. doi:10.1144/jgs2013-104

Mayringer, F., Treloar, P.J., Gerdes, A., Finger, F., and Shengelia, D., 2011, New age data from the Dzirula Massif, Georgia: Implications for the evolution of the Caucasian Variscides: American Journal of Science, v. 311, p. 404–441. doi:10.2475/05.2011.02

McCann, T., Chalot-Prat, F., and Saintot, A., 2010, The Early Mesozoic evolution of the Western Greater Caucasus (Russia): Triassic -Jurassic sedimentary and magmatic history, *in* Sosson, M., Kaymakci, N., Stephenson, R.A., Bergerat, F., and Starostenko, V., eds., Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform: London, Geological Society, p. 181–238. Special Publication 340.

Meijers, M.J.M., Kaymakci, N., Van Hinsbergen, D.J.J., Langereis, C.G., Stephenson, R.A., and Hippolyte, J.-C., 2010b, Late Cretaceous to Paleocene oroclinal bending in the central Pontides (Turkey): Tectonics, v. 29, p. TC4016. doi:10.1029/2009TC002620

Meijers, M.J.M., Vrouwe, B., Van Hinsbergen, D.J.J., Kuiper, K. F., Wijbrans, J., Davies, G.R., Stephenson, R.A., Kaymakcı, N., Matenco, L., and Saintot, A., 2010a, Jurassic arc volcanism on Crimea (Ukraine): Implications for the paleo-subduction zone configuration of the Black Sea region: Lithos, v. 119, p. 412–426. doi:10.1016/j.lithos.2010.07.017

Mengel, K., Borsuk, A.M., Gurbanov, A.G., Wedepohl, K.H., Baumann, A., and Hoefs, J., 1987, Origin of spilitic rocks from the southern slope of the Greater Caucasus: Lithos, v. 20, p. 115–133. doi:10.1016/0024-4937(87)90002-8

Moix, P., Beccaletto, L., Masset, O., Kozur, H.W., Dumitrică, P., Vachard, D., Martini, R., and Stampfli, G.M., 2011, Geology and correlation of the Mersin Mélanges, Southern Turkey: Turkish Journal of Earth Sciences, v. 20, p. 57–98.

Moore, W.J., McKee, E.H., and Akıncı, Ö., 1980, Chemistry and chronology of plutonic rocks in the Pontid mountains, northern Turkey: Belgrade, European Copper Deposits Congress Book, p. 209–216.

MTA., 2002, Geological map series of Turkey, 1: 500 000 scale, 18 sheets: Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

Mulcahy, S.R., Vervoort, J.D., and Renne, P.R., 2014, Dating subduction-zone metamorphism with combined garnet and lawsonite Lu–Hf geochronology: Journal of Metamorphic Geology, v. 32, p. 515–533. doi:10.1111/jmg.12092

Natal'in, B.A., and Şengör, A.M.C., 2005, Late Palaeozoic to Triassic evolution of the Turan and Scythian platforms: The pre-history of the Palaeo-Tethyan closure: Tectonophysics, v. 404, p. 175–202. doi:10.1016/j.tecto.2005.04.011

Natal'in, B.A., Sunal, G., Satır, M., and Toraman, E., 2012, Tectonics of the Strandja Massif, NW Turkey: History of a long-lived arc at the northern margin of Palaeo-Tethys: Turkish Journal of Earth Sciences, v. 21, p. 755–798.

Neubauer, F., 2002, Evolution of late Neoproterozoic to early Paleozoic tectonic elements in Central and Southeast European Alpine mountain belts: Review and synthesis: Tectonophysics, v. 352, p. 87–103. doi:10.1016/S0040-1951(02)00190-7

Nikishin, A., Ziegler, P., Bolotov, S., and Fokin, P., 2012, Late Palaeozoic to Cenozoic Evolution of the Black Sea-Southern Eastern Europe Region: A view from the Russian Platform: Turkish Journal of Earth Sciences, v. 21, p. 571–634.

Nikishin, A.M., Alekseev, A.S., Baraboshkin, E.J., Kopaevich, L.F., Gabdullin, R.R., and Badulina, N.V., 2008, The Cretaceous history of the Bakhchisaray area, southen Crimea (Ukraine): Bulletin De L Institut Royal Des Sciences Naturelles De Belgique-Sciences De La Terre, v. 78, p. 75–85.

Nikishin, A.M., Okay, A., Tüysüz, O., Demirer, A., Wannier, M., Amelin, N., and Petrov, E., 2015a, The Black Sea basins structure and history: New model based on new deep penetration regional seismic data. Part 1: Basins structure and fill: Marine and Petroleum Geology, v. 59, p. 638–655. doi:10.1016/j.marpetgeo.2014.08.017

Nikishin, A.M., Okay, A., Tüysüz, O., Demirer, A., Wannier, M., Amelin, N., and Petrov, E., 2015b, The Black Sea basins structure and history: New model based on new deep penetration regional seismic data. Part 2: Tectonic history and paleogeography: Marine and Petroleum Geology, v. 59, p. 656–670. doi:10.1016/j.marpetgeo.2014.08.018

Nikishin, A.M., Ziegler, P.A., Abbott, D., Brunet, M.-F., and Cloetingh, S., 2002, Permo–Triassic intraplate magmatism and rifting in Eurasia: Implications for mantle plumes and mantle dynamics: Tectonophysics, v. 351, p. 3–39. doi:10.1016/S0040-1951(02)00123-3

Nikishin, A.M., Ziegler, P.A., Panov, D.I., Nazarevich, B.P., Brunet, M.F., Stephenson, R.A., Bolotov, S.N., Korotaev, M.V., and Tikhomirov, P.L., 2001, Mesozoic and Cenozoic evolution of the Scythian Platform-Black Sea-Caucasus domain, *in* Ziegler, P.A., Cavazza, W., Robertson, A.H.F., and Crasquin-Soleau, S., eds., Peri-Tethyan rift/wrench basins and passive margins: Memoires du Museum National d'Histoire Naturelle 186, p. 295–346.

Nikishin, A.M., Ziegler, P.A., Stephenson, R.A., Cloetingh, S.A. P.L., Furne, A.V., Fokin, P.A., Ershov, A.V., Bolotov, S.N., Korotaev, M.V., Alekseev, A.S., Gorbachev, V.I., Shipilov, E. V., Lankreijer, A., Bembinova, E.Y., and Shalimov, I.V., 1996, Late Precambrian to Triassic history of the East European Craton: Dynamics of sedimentary basin evolution: Tectonophysics, v. 268, p. 23–63. doi:10.1016/S0040-1951(96)00228-4

Nzegge, O.M., Satir, M., Siebel, W., and Taubald, H., 2006, Geochemical and isotopic constraints on the genesis of the Late Palaeozoic Deliktaş and Sivrikaya granites from the Kastamonu granitoid belt (Central Pontides, Turkey): Neues Jahrbuch für Mineralogie, Abhandlungen, v. 183, p. 27–40. doi:10.1127/0077-7757/2006/0057

Okay, A.I., 2000, Was the Late Triassic orogeny in Turkey caused by the collision of an oceanic plateau? *in* Bozkurt, E., Winchester, J.A., and Piper, J.A.D., eds., Tectonics and magmatism in Turkey and surrounding area, London, Geological Society, 25–41. Special Publication 173.

Okay, A.I., and Altıner, D., 2004, Uppermost Triassic limestone in the Karakaya Complex - stratigraphic and tectonic significance: Turkish Journal of Earth Sciences, v. 13, p. 187–199.

Okay, A.I., Altıner, D., and Kılıç, A.M., 2015, Triassic limestone, turbidite and serpentinite – Cimmeride orogeny in the Central Pontides: Geological Magazine. doi:10.1017/S0016756814000429

Okay, A.I., Bozkurt, E., Satır, M., Yiğitbaş, E., Crowley, Q.G., and Shang, C.K., 2008, Defining the southern margin of Avalonia in the Pontides: Geochronological data from the Late Proterozoic and Ordovician granitoids from NW Turkey: Tectonophysics, v. 461, p. 252–264. doi:10.1016/j.tecto.2008.02.004

Okay, A.I., and Göncüoğlu, M.C., 2004, Karakaya Complex: A review of data and concepts: Turkish Journal of Earth Sciences, v. 13, p. 77–95.

Okay, A.I., and Leven, E.J., 1996, Stratigraphy and paleontology of the Upper Paleozoic sequence in the Pulur (Bayburt) region, Eastern Pontides: Turkish Journal of Earth Sciences, v. 5, p. 145–155.

Okay, A.I., and Monié, P., 1997, Early Mesozoic subduction in the Eastern Mediterranean: Evidence from Triassic eclogite in northwest Turkey: Geology, v. 25, p. 595–598. doi:10.1130/0091-7613(1997)025<0595:EMSITE>2.3.CO;2

Okay, A.I., Monod, O., and Monié, P., 2002, Triassic blueschists and eclogites from northwest Turkey: Vestiges of the Paleo-Tethyan subduction: Lithos, v. 64, p. 155–178. doi:10.1016/S0024-4937(02)00200-1

Okay, A.I., Noble, P.J., and Tekin, U.K., 2011a, Devonian radiolarian ribbon cherts from the Karakaya Complex, northwest Turkey: Implications for the Paleo-Tethyan evolution: Comptes Rendus Palevol, v. 10, p. 1–10. doi:10.1016/j.crpv.2010.12.002

Okay, A.I., and Şahintürk, 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 (AAPG), p. 291–311. Memoir 68.

Okay, A.I., Satır, M., and Siebel, W., 2006a, Pre-Alpide orogenic events in the Eastern Mediterranean region, *in* Gee, D.G., and Stephenson, R.A., eds., European lithosphere dynamics: London, Geological Society, p. 389–405. Memoirs 32.

Okay, A.I., Satır, M., Tüysüz, O., Akyüz, S., and Chen, F., 2001, The tectonics of the Strandja Massif: Late-Variscan and mid-Mesozoic deformation and metamorphism in the northern Aegean: International Journal of Earth Sciences, v. 90, p. 217–233. doi:10.1007/s005310000104

Okay, A.I., Şengör, A.M.C., and Görür, N., 1994, Kinematic history of the opening of the Black Sea and its effect on the surrounding regions: Geology, v. 22, p. 267–270. doi:10.1130/0091-7613(1994)022<0267:KHOTOO>2.3.CO;2

Okay, A.I., Sunal, G., Sherlock, S., Altiner, D., Tüysüz, O., Kylander-Clark, A.R.C., and Aygül, M., 2013, Early Cretaceous sedimentation and orogeny on the southern active margin of Eurasia: Central Pontides, Turkey: Tectonics, v. 32, p. 1247–1271. doi:10.1002/tect.20077

Okay, A.I., Sunal, G., Tüysüz, O., Sherlock, S., Keskin, M., and Kylander-Clark, A.R.C., 2014, Low-pressure – high temperature metamorphism during extension in a Jurassic magmatic arc, Central Pontides, Turkey: Journal of Metamorphic Geology, v. 32, p. 49–69. doi:10.1111/jmg.12058

Okay, A.I., and Tüysüz, O., 1999, Tethyan sutures of northern Turkey, *in* Durand, B., Jolivet, L., Horváth, F., and Séranne, M., eds., The Mediterranean basins: Tertiary extension within the Alpine orogen: London, Geological Society, p. 475–515. Special Publication 156.

Okay, A.I., Tüysüz, O., Satir, M., Özkan-Altıner, S., Altiner, D., Sherlock, S., and Eren, R.H., 2006b, Cretaceous and Triassic subduction-accretion, high-pressure-low-temperature metamorphism, and continental growth in the Central Pontides, Turkey: Geological Society of America Bulletin, v. 118, p. 1247–1269. doi:10.1130/B25938.1

Okay, A.I., and Whitney, D.L., 2010, Blueschists, eclogites, ophiolites and suture zones in northwest Turkey: A review and a field excursion guide: Ofioliti, v. 35, p. 131–172.

Okay, A.I., Zattin, M., and Cavazza, W., 2010, Apatite fission-track data for the Miocene Arabia-Eurasia collision: Geology, v. 38, p. 35–38. doi:10.1130/G30234.1

Okay, N., Zack, T., Okay, A.I., and Barth, M., 2011b, Sinistral transport along the Trans-European Suture Zone: Detrital zircon-rutile geochronology and sandstone petrography from the Carboniferous flysch of the Pontides: Geological Magazine, v. 148, p. 380–403. doi:10.1017/S0016756810000804

Özgül, N., 2012, Stratigraphy and some structural features of the Istanbul Palaeozoic: Turkish Journal of Earth Sciences, v. 21, p. 817–866.

Perchuk, A., and Philippot, P., 1997, Rapid cooling and exhumation of eclogitic rocks from the Great Caucasus, Russia: Journal of Metamorphic Geology, v. 15, p. 299–310. doi:10.1111/j.1525-1314.1997.00022.x

Philippot, P., Blichert-Toft, J., Perchuk, A., Costa, S., and Gerasimov, V., 2001, Lu–Hf and Ar–Ar chronometry supports extreme rate of subduction zone metamorphism deduced from geospeedometry: Tectonophysics, v. 342, p. 23–38. doi:10.1016/S0040-1951(01)00155-X

Pickett, E.A., and Robertson, A.H.F., 2004, Significance of the volcanogenic Nilüfer Unit and related components of the Triassic Karakaya Complex for Tethyan subduction/accretion processes in NW Turkey: Turkish Journal of Earth Sciences, v. 13, p. 97–144.

Plunder, A., Agard, P., Chopin, C., and Okay, A.I., 2013, Geodynamics of the Tavşanlı zone, western Turkey: Insights into subduction/obduction processes: Tectonophysics, v. 608, p. 884–903. doi:10.1016/j.tecto.2013.07.028

Robertson, A.H.F., and Ustaömer, T., 2012, Testing alternative tectono-stratigraphic interpretations of the Late Palaeozoic-Early Mesozoic Karakaya complex in NW Turkey: Support for an accretionary origin related to northward subduction of Palaeotethys: Turkish Journal of Earth Sciences, v. 21, p. 961–1007.

Robinson, A.G., Banks, C.J., Rutherford, M.M., and Hirst, J.P.P., 1995, Stratigraphic and structural development of the Eastern Pontides, Turkey: Journal of the Geological Society, London, v. 152, p. 861–872. doi:10.1144/gsjgs.152.5.0861

Robinson, A.G., Rudat, J.H., Banks, C.J., and Wiles, R.L.F., 1996, Petroleum geology of the Black Sea: Marine and Petroleum Geology, v. 13, p. 195–223. doi:10.1016/0264-8172(95)00042-9

Rojay, B., 2013, Tectonic evolution of the Cretaceous Ankara Ophiolitic Mélange during the Late Cretaceous to pre-Miocene interval in Central Anatolia, Turkey: Journal of Geodynamics, v. 65, p. 66–81. doi:10.1016/j.jog.2012.06.006

Rojay, B., and Göncüoğlu, M.C., 1998, Tectonic setting of some pre-Liassic low grade metamorphics in northern Anatolia: Yerbilimleri, v. 19, p. 109–118. in Turkish.

Rolland, Y., Sosson, M., Adamia, S., and Sadradze, N., 2011, Prolonged Variscan to Alpine history of an active Eurasian margin (Georgia, Armenia) revealed by $^{40}Ar/^{39}Ar$ dating: Gondwana Research, v. 20, p. 798–815. doi:10.1016/j.gr.2011.05.007

Ruban, D.A., 2007, Jurassic transgressions and regressions in the Caucasus (northern Neotethys Ocean) and their influences on the marine biodiversity: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 251, p. 422–436. doi:10.1016/j.palaeo.2007.04.008

Sachanski, V., Göncüoğlu, M.C., Lakova, I., Boncheva, I., and Demiray, G.S., 2012, Silurian graptolite, conodont and cryptospore biostratigraphy of the Gülüç section in Ereğli, Zonguldak terrane, NW Anatolia, Turkey: Turkish Journal of Earth Sciences, v. 21, p. 867–903.

Şahin, S.Y., Aysal, N., and Güngör, Y., 2012, Petrogenesis of Late Cretaceous adakitic magmatism in the Istanbul Zone (Çavusbaşı Granodiorite, NW Turkey): Turkish Journal of Earth Sciences, v. 21, p. 1029–1045.

Şahin, S.Y., Aysal, N., Güngör, Y., Peytcheva, I., and Neubauer, F., 2014, Geochemistry and U-Pb zircon geochronology of metagranites in Istranca (Strandja) Zone, NW Pontides, Turkey: Implications for the geodynamic evolution of Cadomian orogeny: Gondwana Research (in press).

Saintot, A., Stephenson, R.A., Stovba, S., Brunet, M.F., Yegorova, T., and Starostenko, V., 2006, The evolution of the southern margin of Eastern Europe (Eastern European and Scythian platforms) from the latest Precambrian - Early Palaeozoic to the Early Cretaceous, *in* Gee, D.G., and Stephenson, R.A., eds., European lithosphere dynamics: London, Geological Society, p. 481–505. Memoirs 32.

Samson, S.D., D'Lemos, R.S., Miller, B.V., and Hamilton, M.A., 2005, Neoproterozoic palaeogeography of the Cadomia and Avalon terranes: Constraints from detrital zircon U-Pb ages: Journal of the Geological Society, London, v. 162, p. 65–71. doi:10.1144/0016-764904-003

Sayar, C., and Cocks, L.R.M., 2013, A new Late Ordovician Hirnantia brachiopod fauna from NW Turkey, its biostratigraphical relationships and palaeogeographical setting: Geological Magazine, v. 150, p. 479–496. doi:10.1017/S0016756812000520

Sayit, K., Göncüoglu, M.C., and Furman, T., 2010, Petrological reconstruction of Triassic seamounts/oceanic islands within the Palaeotethys: Geochemical implications from the Karakaya subduction/accretion Complex, Northern Turkey: Lithos, v. 119, p. 501–511. doi:10.1016/j.lithos.2010.08.004

Sayit, K., Tekin, U.K., and Göncüoglu, M.C., 2011, Early-middle Carnian radiolarian cherts within the Eymir Unit, Central

Turkey: Constraints for the age of the Palaeotethyan Karakaya Complex: Journal of Asian Earth Sciences, v. 42, p. 398–407. doi:10.1016/j.jseaes.2011.04.027

Schattner, U., and Ben-Avraham, Z., 2007, Transform margin of the northern Levant, eastern Mediterranean: From formation to reactivation: Tectonics, v. 26, p. TC5020. doi:10.1029/2007TC002112

Scholl, D.W., and Von Huene, R., 2010, Subduction zone recycling processes and the rock record of crustal suture zones: Canadian Journal of Earth Sciences, v. 47, p. 633–654.

Seghedi, A., 2001, The North Dobrogea orogenic belt (Romania): A review, *in* Ziegler, P.A., Cavazza, W., Robertson, A.H.F., and Crasquin-Soleau, S., eds., Peri-Tethyan rift/wrench basins and passive margins, Vol. 186: Memoires du Museum National d'Histoire Naturelle, p. 237–257.

Seghedi, A., 2011, Palaeozoic formations from Dobrugea and Pre-Dobrugea – an overview: Turkish Journal of Earth Sciences, v. 21, p. 669–721.

Şen, C., 2007, Jurassic volcanism in the Eastern Pontides: Is it rift related or subduction related?: Turkish Journal of Earth Sciences, v. 16, p. 523–539.

Şengör, A.M.C., 1984, The Cimmeride Orogenic System and the Tectonics of Eurasia. Geological Society of America, Special paper, 195, 82 pp.

Şengör, A.M.C., and Yılmaz, Y., 1981, Tethyan evolution of Turkey: A plate tectonic approach: Tectonophysics, v. 75, p. 181–241. doi:10.1016/0040-1951(81)90275-4

Sherlock, S., Kelley, S.P., Inger, S., Harris, N., and Okay, A.I., 1999, 40Ar-39Ar and Rb-Sr geochronology of high-pressure metamorphism and exhumation history of the Tavsanli Zone, NW Turkey: Contributions to Mineralogy and Petrology, v. 137, p. 46–58.

Smith, A.G., 2006, Tethyan ophiolite emplacement, Africa to Europe motions, and Atlantic spreading, *in* Robertson, A.H. F., and Mountrakis, D., eds., Tectonic development of the Eastern Mediterranean Region: London, Geological Society, p. 11–34. Special Publication 200.

Somin, M., 2011, Pre-Jurassic basement of the Greater Caucasus: Brief overview: Turkish Journal of Earth Sciences, v. 20, p. 545–610.

Sosson, M., Rolland, Y., Müller, C., Danelian, T., Melkonyan, R., Kekelia, S., Adamia, S., Babazadeh, V., Kangarli, T., Avagyan, A., Galoyan, G., and Mosar, J., 2010, Subductions, obduction and collision in the Lesser Caucasus (Armenia, Azerbaijan, Georgia), new insights, *in* Sosson, M., Kaymakci, N., Stephenson, R.A., Bergerat, F., and Starostenko, V., eds., Sedimentary basin tectonics from the Black Sea and Caucasus to the Arabian Platform: London, Geological Society, p. 329–352. Special Publications 340.

Stampfli, G.M., and Borel, G.D., 2002, A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons: Earth and Planetary Science Letters, v. 196, p. 17–33. doi:10.1016/S0012-821X(01)00588-X

Stampfli, G.M., Von Raumer, J.F., and Borel, G.D., 2002, Paleozoic evolution of pre-Variscan terranes: From Gondwana to the Variscan collision, *in* Martínez, C.J.R., Hatcher Jr., R.D., Arenas, R., and Díaz García, F., eds., Variscan-Appalachian dynamics: The building of the Late Palaeozoic basement: Geological Society of America, p. 263–280. Special Paper 364.

Stephenson, R., Mart, Y., Okay, A., Robertson, A., Saintot, A., Stovba, S., and Khriachtchevskaia, O., 2004, TRANSMED transect VIII: East European Craton, Crimea, Black Sea, Anatolia, Cyprus, levant Sea, Sinai, Red Sea, *in* Cavazza, W., Roure, F.M., Spakman, W., Stampfli, G.M., and Ziegler, P.A., eds., The TRANSMED Atlas - The Mediterranean region from crust to mantle: Berlin, Springer, 141 pp.

Stern, R.J., 1994, ARC assembly and continental collision in the Neoproterozoic East African Orogen: Implications for the Consolidation of Gondwanaland: Annual Review of Earth and Planetary Sciences, v. 22, p. 319–351. doi:10.1146/annurev.ea.22.050194.001535

Stern, R.J., 2002, Subduction zones: Reviews of Geophysics, v. 40, no. 4, p. 1012. doi:10.1029/2001RG000108

Stolle, E., 2015, Çakraz Formation, Çamdağ area, NW Turkey: Early/mid-Permian age, Rotliegend (Germany) and Southern Alps (Italy) equivalent—A stratigraphic re-assessment via palynological long-distance correlation: Geological Journal. doi:10.1002/gj.2620

Stovba, S.M., and Stephenson, R.A., 1999, The Donbas Foldbelt: İts relationships with the uninverted Donets segment of the Dniepr–Donets Basin, Ukraine: Tectonophysics, v. 313, p. 59–83. doi:10.1016/S0040-1951(99)00190-0

Sunal, G., Natal'in, B., Satir, M., and Toraman, E., 2006, Paleozoic magmatic events in the Strandja Massif, NW Turkey: Geodinamica Acta, v. 19, p. 283–300. doi:10.3166/ga.19.283-300

Sunal, G., Satır, M., Natal'in, B., Topuz, G., and Von Der Schmidt, O., 2011, Metamorphism and diachronous cooling in a contractional orogen: The Strandja Massif, NW Turkey: Geological Magazine, v. 148, p. 580–596. doi:10.1017/S0016756810001020

Sunal, G., Satir, M., Natal'in, B., and Toraman, E., 2008, Paleotectonic position of the Strandja Massif and surrounding continental blocks based on zircon Pb-Pb age studies: International Geology Review, v. 50, p. 519–545. doi:10.2747/0020-6814.50.6.519

Taner, M.F., and Zaninetti, L., 1978, Etude paléontologique dans le Crétace volcano-sédimentaire de Güneyce (Pontides orientales, Turquie): Rivista Italiana Di Paleontologia E Stratigrafia, v. 84, p. 187–198.

Tari, G., Dicea, O., Faulkerson, J., Georgiev, G., Popov, S., Stefanescu, M., and Weir, G., 1997, Cimmerian and Alpine stratigraphy and structural evolution of the Moesian Platform (Romania/Bulgaria), *in* Robinson, A.G., ed., Regional and petroleum geology of the Black Sea and surrounding region: American Association of Petroleum Geologists (AAPG), p. 63–90. Memoir 68.

Tekin, U.K., Göncüoğlu, M.C., and Turhan, N., 2002, First evidence of Late Carnian radiolarians from the Izmir-Ankara suture complex, central Sakarya, Turkey: Implications for the opening age of the Izmir-Ankara branch of Neo-Tethys: Geobios, v. 35, p. 127–135. doi:10.1016/S0016-6995(02)00015-3

Tikhomirov, P.L., Chalot-Prat, F., and Nazarevich, B.P., 2004, Triassic volcanism in the Eastern Fore-Caucasus: Evolution and geodynamic interpretation: Tectonophysics, v. 381, p. 119–142. doi:10.1016/j.tecto.2003.10.014

Topuz, G., Altherr, R., Kalt, A., Satır, M., Werner, O., and Schwartz, W.H., 2004a, Aluminous granulites from the Pulur Complex, NE Turkey: A case of partial melting, efficient melt extraction and crystallisation: Lithos, v. 72, p. 183–207. doi:10.1016/j.lithos.2003.10.002

Topuz, G., Altherr, R., Satir, M., and Schwarz, W.H., 2004b, Low-grade metamorphic rocks from the Pulur Complex, NE Turkey: Implications for the pre-Liassic evolution of the Eastern Pontides: International Journal of Earth Sciences, v. 93, p. 72–91. doi:10.1007/s00531-003-0372-5

Topuz, G., Altherr, R., Siebel, W., Schwarz, W.H., Zack, T., Hasözbek, A., Barth, M., Satır, M., and Şen, C., 2010, Carboniferous high-potassium I-type granitoid magmatism in the Eastern Pontides: The Gümüşhane pluton (NE Turkey): Lithos, v. 116, p. 92–110. doi:10.1016/j.lithos.2010.01.003

Topuz, G., Çelik, O.F., Şengör, A.M.C., Altıntaş, I.E., Zack, T., Rolland, Y., and Barth, M., 2013b, Jurassic ophiolite formation and emplacement as backstop to a subduction-accretion complex in northeast Turkey, the Refahiye ophiolite, and relation to the Balkan ophiolites: American Journal of Science, v. 313, p. 1054–1087. doi:10.2475/10.2013.04

Topuz, G., Göçmengil, G., Rolland, Y., Çelik, Ö.F., Zack, T., and Schmitt, A.K., 2013a, Jurassic accretionary complex and ophiolite from northeast Turkey: No evidence for the Cimmerian continental ribbon: Geology, v. 41, p. 255–258. doi:10.1130/G33577.1

Topuz, G., Okay, A.I., Altherr, R., Schwarz, W.H., Sunal, G., and Altınkaynak, L., 2014, Triassic warm subduction in northeast Turkey: Evidence from the Ağvanis metamorphic rocks: Island Arc, v. 23, p. 181–205. doi:10.1111/iar.12068

Tüysüz, O., 1999, Geology of the Cretaceous sedimentary basins of the Western Pontides: Geological Journal, v. 34, p. 75–93. doi:10.1002/(SICI)1099-1034(199901/06)34:1/2<75::AID-GJ815>3.0.CO;2-S

Tüysüz, O., Yılmaz, İ.Ö., Švábenická, L., and Kirici, S., 2012, The Unaz formation: A key unit in the western Black Sea Region, N Turkey: Turkish Journal of Earth Sciences, v. 21, p. 1009–1028.

Ustaömer, P.A., Mundil, R., and Renne, P.R., 2005, U/Pb and Pb/Pb zircon ages for arc-related intrusions of the Bolu Massif (W Pontides, NW Turkey): Evidence for Late Precambrian (Cadomian) age: Terra Nova, v. 17, p. 215–223. doi:10.1111/j.1365-3121.2005.00594.x

Ustaömer, P.A., Ustaömer, T., Gerdes, A., Robertson, A.H.F., and Collins, A.S., 2012a, Evidence of Precambrian sedimentation/magmatism and Cambrian metamorphism in the Bitlis Massif, SE Turkey utilising whole-rock geochemistry and U–Pb LA-ICP-MS zircon dating: Gondwana Research, v. 21, p. 1001–1018. doi:10.1016/j.gr.2011.07.012

Ustaömer, P.A., Ustaömer, T., Gerdes, A., Robertson, A.H.F., and Zulauf, G., 2014, Discovery of a Triassic magmatic arc source for the Permo-Triassic Karakaya subduction complex, NW Turkey: Geophysical Research Abstracts, v. 16, EGU2014-9548-2.

Ustaömer, P.A., Ustaömer, T., Gerdes, A., and Zulauf, G., 2011, Detrital zircon ages from a Lower Ordovician quartzite of the Istanbul exotic terrane (NW Turkey): Evidence for Amazonian affinity: International Journal of Earth Sciences, v. 100, p. 23–41. doi:10.1007/s00531-009-0498-1

Ustaömer, P.A., Ustaömer, T., and Robertson, A.H.F., 2012b, Ion Probe U-Pb Dating of the Central Sakarya Basement: A peri-Gondwana Terrane Intruded by late Lower Carboniferous Subduction/Collision-related Granitic Rocks: Turkish Journal of Earth Sciences, v. 21, p. 905–932.

Ustaömer, T., and Robertson, A.H.F., 1994, Late Palaeozoic marginal basin and subduction-accretion: The Palaeotethyan Küre Complex, Central Pontides, northern Turkey: Journal of the Geological Society, London, v. 151, p. 291–305. doi:10.1144/gsjgs.151.2.0291

Ustaömer, T., Robertson, A.H.F., Ustaömer, P.A., Gerdes, A., and Peytcheva, I., 2013, Constraints on Variscan and Cimmerian magmatism and metamorphism in the Pontides (Yusufeli -Artvin area), NE Turkey from U-Pb dating and granite geochemistry, *in* Robertson, A.H.F., Parlak, O., and Ünlügenç, U.C., eds., Geological development of Anatolia and the easternmost Mediterranean region: London, Geological Society, p. 49–74. Special Publication 372.

Ustaömer, T., and Robertson, A.H.F., 1993, A Late Palaeozoic-Early Mesozoic marginal basin along the actives sourthern continental margin of Eurasia: Evidence from the central Pontides (Turkey) and adjacent regions: Geological Journal, v. 28, p. 219–238. doi:10.1002/gj.3350280303

Vincent, S.J., Carter, A., Lavrishchev, V.A., Rice, S.P., Barabadze, T.G., and Hovius, N., 2011, The exhumation of the western Greater Caucasus: A thermochronometric study: Geological Magazine, v. 148, p. 1–21. doi:10.1017/S0016756810000257

Von Quadt, A., Moritz, R., Peytcheva, I., and Heinrich, C.A., 2005, 3: Geochronology and geodynamics of Late Cretaceous magmatism and Cu–Au mineralization in the Panagyurishte region of the Apuseni–Banat–Timok–Srednogorie belt, Bulgaria: Ore Geology Reviews, v. 27, p. 95–126. doi:10.1016/j.oregeorev.2005.07.024

Whitney, D.L., and Hamilton, M.A., 2004, Timing of high-grade metamorphism in central Turkey and the assembly of Anatolia: Journal of the Geological Society, London, v. 161, p. 823–828. doi:10.1144/0016-764903-081

Winchester, J.A., The PACE TMR Network Team, 2002, Palaeozoic amalgamation of Central Europe: New results from recent geological and geophysical investigations: Tectonophysics, v. 360, p. 5–21. doi:10.1016/S0040-1951(02)00344-X

Yılmaz, A., Adamia, S., Chabukiani, A., Chkhotua, T., Erdoğan, K., Tuzcu, S., and Karabıyıkoğlu, M., 2000, Structural correlation of the southern Transcaucasus (Georgia) - eastern Pontides (Turkey), *in* Bozkurt, E., Winchester, J.A., and Piper, J.A.D., eds., Tectonics and magmatism in Turkey and surrounding area: London, Geological Society, p. 171–182. Special Publication 173.

Yılmaz, A., and Yılmaz, H., 2004, Geology and structural evolution of the Tokat Massif (Eastern Pontides, Turkey): Turkish Journal of Earth Sciences, v. 13, p. 231–246.

Yılmaz, İ., 1975, Determination de l'age d'un granite de Sancaktepe, dans la presquile de Kocaeli (Nord de la Mer de Marmara): Comptes Rendus Académie des Sciences D, v. 281, p. 1563–1565.

Yılmaz, O., and Boztuğ, D., 1986, Kastamonu granitoid belt of northern Turkey: First arc plutonism product related to the subduction of the Paleo-Tethys: Geology, v. 14, p. 179–183. doi:10.1130/0091-7613(1986)14<179:KGBONT>2.0.CO;2

Ziegler, P., 1989, Evolution of Laurussia: Dordrecht, Kluwer Academic Publishers, p. 102 pp.

Zonenshain, L.P., Kuzmin, M.I., and Natapov, L.M., 1990, Geology of the USSR: A plate tectonic synthesis: Washington, DC, American Geophysical Union, 242 pp.