Jurassic accretionary complex and ophiolite from northeast Turkey: No evidence for the Cimmerian continental ribbon

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ABSTRACT

Permian-Triassic and Late Cretaceous accretionary complexes, ascribed to the consumption of two distinct oceans, the Paleo- and Neo-Tethys, are exposed over extensive areas in the Eastern Mediterranean region. However, a separating continental ribbon, the so-called Cimmeride continent, between the Paleo- and Neo-Tethys during early Mesozoic time cannot be defined. Here we report a previously unknown Early Jurassic metamorphic oceanic accretionary complex and ophiolite from northeast Turkey, bounded by oceanic accretionary complexes of Permian-Triassic and Late Cretaceous age to the north and the south, respectively, without a continental domain in between. This special tectonic position and widespread coexistence of Permian-Triassic and Late Cretaceous accretionary complexes alongside the Izmir-Ankara-Erzincan suture imply that (1) the southern margin of Laurasia in the eastern Mediterranean region grew by episodic accretionary processes from late Paleozoic to end-Mesozoic time without involvement of a Cimmerian continental ribbon, and (2) the Paleo-Tethys and northern branch of the Neo-Tethys were not distinct oceans in the Eastern Mediterranean region.

INTRODUCTION

Paleogeographic reconstructions indicate the presence of a large oceanic domain, called Tethys, between Laurasia to the north and Gondwana to the south, from Late Paleozoic to early Tertiary time (e.g., Şengör, 1984; Stampfli and Borel, 2002). At the end of the Variscan orogeny, this oceanic domain formed an eastward-widening embayment due to the continental collision between Laurasia and Gondwana in the west (present-day Europe). Essentially, the existence of two temporally and spatially distinct Tethyan oceans has been deduced: (1) late Paleozoic to early Mesozoic Paleo-Tethys, and (2) Mesozoic to early Cenozoic Neo-Tethys. Both oceans are proposed to be coeval during the early Mesozoic, and separated by a continental strip, known as Cimmeride, extending from the present-day eastern Mediterranean region through Iran and Afghanistan to further east (e.g., Şengör, 1984; Stampfli and Borel, 2002).

Carboniferous to Triassic and Late Cretaceous accretionary complexes, ascribed to the Paleo- and Neo-Tethyan subductions, respectively, cover large areas in Greece, Turkey, and Iran (Fig. 1A; Pickett and Robertson, 1996; Okay, 2000; Zanchi et al., 2003, 2009; Robertson and Ustaömer, 2009; Rolland et al. 2009; Göncüoğlu et al., 2010). However, the relationship between the Paleo- and Neo-Tethys and the continental block(s) defined as the so-called Cimmerian continent are highly contentious. Proposed models include (1) southward subduction of Paleo-Tethys beneath Gondwana, and the backarc rifting leading to the opening of the southern Neo-Tethys concomitant with the formation of a Cimmerian ribbon continent (Sakarya-Rhodope-Strandja) during the Triassic (Şengör, 1984); (2) northward subduction of Paleo-Tethys beneath the Laurasian margin and the rifting of the Cimmerian continental ribbon (Apulia-Tauride) from Gondwana during the Late Permian due to the slab-pull effect, followed by the collision of the Cimmerian continental ribbon with Laurasia during the latest Triassic (Stampfli and Borel, 2002); and (3) accretion of seamounts and at least one continental fragment (Pickett and Robertson, 1996) or a large oceanic plateau (Okay, 2000) to the southern margin of Laurasia during the Late Triassic.

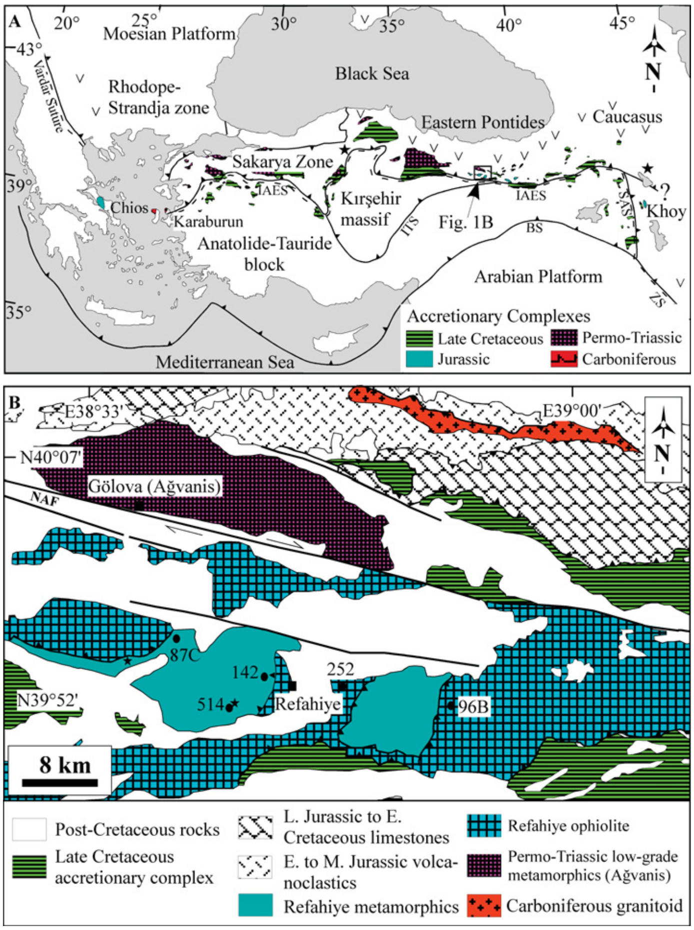

Figure 1. A: The main Neo-Tethyan sutures and continental blocks in the Eastern Mediterranean region, together with the locations of Paleo-Tethyan accretionary complexes. For clarity, Late Cretaceous accretionary complexes are shown only alongside the Izmir-Ankara-Erzincan suture (IAES) and South Azerbaijan suture (SAS). ITS—Intra-Tauride suture; BS—Bitlis suture; ZS—Zagros suture; v—Jurassic magmatism. Stars represent locations of Early-Middle Jurassic amphibolites and mica schist blocks. B: Geologic map of the Refahiye region of Turkey, together with locations of dated samples (black dots). Stars represent locations of eclogites. NAF—North Anatolian fault.

Our alternative model critically hinges on a previously unknown Early to Middle Jurassic low-grade oceanic accretionary complex and ophiolite from the Refahiye area (northeast Turkey), located between a Permian-Triassic and a Late Cretaceous oceanic accretionary complex with no intervening continental sliver in-between. This field relationship

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and the common coexistence of the Permian-Triassic and Late Cretaceous oceanic accretionary complexes indicate episodic accretionary growth of the southern margin of Laurasia from late Paleozoic to end-Mesozoic time in the Eastern Mediterranean region.

GEOLOGICAL FRAMEWORK

In the Eastern Mediterranean region, traces of the Neo-Tethyan oceans are represented by a number of sutures (Fig. 1A; e.g., Şengör and Yılmaz, 1981). The Izmir-Ankara-Erzincan suture (IAES), also known as the northern branch of Neo-Tethys, separates continental blocks: the Sakarya zone in the north, and the Anatolide-Tauride block and the Kırşehir massif in the south. The so-called Paleo-Tethyan accretionary complexes are represented by Carboniferous and Permian-Triassic rocks, cropping out mostly to the north of the IAES. The Carboniferous accretionary complexes are well documented in the Chios and Karaburun areas (e.g., Zanchi et al., 2003; Robertson and Ustaömer, 2009), and represent the westernmost exposure of the known Paleo-Tethyan accretionary complexes. The Permian-Triassic accretionary complexes are exposed within the pre-Jurassic basement of the Sakarya zone.

The Sakarya zone has a pre-Jurassic composite basement, consisting of (1) a Carboniferous domain with high temperature/low pressure metamorphism and magmatism (e.g., Topuz et al., 2010), and (2) Permian-Triassic low-grade oceanic accretionary complexes (e.g., Okay, 2000) (Fig. 2). Both rock associations may occur in tectonic contact, and are unconformably overlain by a Lower to Middle Jurassic transgressive sedimentary and volcaniclastic series. This pronounced unconformity suggests the presence of a major tectonic event. The volcanoclastic series is conformably overlain by Upper Jurassic to Lower Cretaceous platform carbonates with sporadic magmatism.

The Anatolide-Tauride block has a Neoproterozoic to early Cambrian crystalline basement, overlain by Paleozoic to Tertiary sedimentary successions of Gondwanian affinity (e.g., Özgül and Turşucu, 1984). Unlike the Sakarya zone, well-studied sections in the Anatolide-Tauride block lack any Late Triassic–Early Jurassic unconformity. The pre-Jurassic unconformity and thrusting described by Monod and Akay (1984) from the central Anatolide-Tauride block is only of local nature. The Carboniferous accretionary complexes of Chios and Karaburun are unconformably overlain by Early Triassic pelagic carbonates grading into Middle Triassic to Jurassic neritic carbonates of Gondwanian affinity, and interpreted to have formed at western terminus of the Carboniferous Paleo-Tethys (Zanchi et al., 2003), or as the accretionary products of the Paleo-Tethyan subduction beneath the Gondwana (Robertson and Ustaömer, 2009).

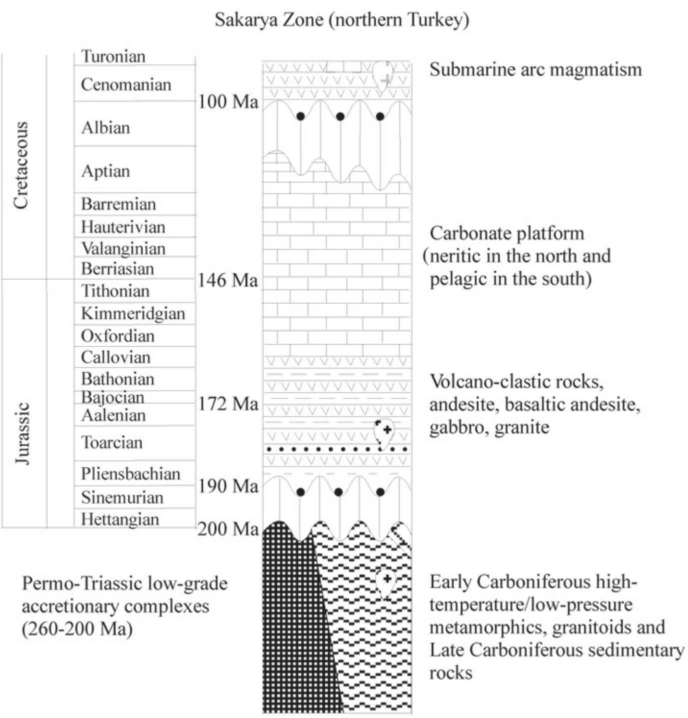

Figure 2. Regional stratigraphic columnar section of the Sakarya zone (northern Turkey).

THE REFAHIYE AREA

The Refahiye metamorphics and ophiolite are tectonically underlain by a Late Cretaceous accretionary complex to the south, and bounded by the North Anatolian fault (NAF) to the north (Fig. 1B). The Late Cretaceous oceanic accretionary complex is essentially unmetamorphosed, and includes blocks of basalt, radiolarian chert, pelagic and neritic limestone, shale, peridotite, amphibolite, greenschist, blueschist, and mica schist. The right lateral offset along the NAF is estimated to be 60–85 km (Şengör et al., 2005). Located immediately to the north of the NAF is the Ağvanis massif, which is made up of Late Triassic low-grade metabasite, phyllite, and marble, and subordinately metachert and serpentinite. In addition to the Late Cretaceous accretionary complex tectonically underlying the Refahiye ophiolite, there is another Late Cretaceous oceanic accretionary complex to the north of the NAF, tectonically sitting on top of Early to Middle Jurassic volcanoclastics. It is part of a larger Late Cretaceous accretionary complex overthrust northward onto the magmatic arc units (Bergougnan, 1975; Şengör and Yılmaz, 1981).

The Refahiye metamorphics consist mainly of well- to poorly foliated greenschist, marble, serpentinite, phyllite, and subordinate metachert, mica schist, garnet amphibolite, and eclogite, and is sandwiched between the two large ophiolite bodies, represented by mantle peridotite. The mantle peridotite is locally intruded by stocks and/or dikes of variably foliated gabbro ranging in size from a few meters to several hundreds of meters. The eclogites crop out at two locations (N39°56′22.03” E38°34′18.36”, N39°53′29.60” E38°42′2.04”) (Fig. 1B) as blocks up to 10 m in size, surrounded by garnet amphibolite and garnet mica schist. The low-grade rocks commonly contain relics (e.g., garnet, hornblende, rutile, and chlorite pseudomorphs after garnet), suggesting that the entire unit was subjected to amphibolite and/or eclogite-facies metamorphism. Both the Refahiye and Ağvanis metamorphics are interpreted as metamorphosed oceanic accretionary complexes owing to the widespread presence of oceanic lithologies (metabasic rocks with mid-oceanic-ridge and ocean-island-basalt affinity, serpentinite, and metachert) and overall absence of granitic rocks.

GEOCHRONOLOGY

To constrain timing of metamorphism, stepwise $^{40}Ar/^{39}Ar$ dating on two phengite separates (87C and 142) and two hornblende separates (96B and 252), and high-resolution secondary ionization mass spectrometry U-Pb dating on rutile (514B), were performed at Geoazur (Nice, France) and at the University of California–Los Angeles (UCLA; United States), respectively. The analytical procedures and data are described in the GSA Data Repository[1].

Sample 87C is a phyllite; 142 and 514B are mica schists. They contain similar mineral assemblages (phengite, quartz, albite, chlorite, ± garnet, and accessory zircon, apatite, and rutile), but differ in grain size (phyllite ~75–200 μm; mica schists ~500–2000 μm). Late veins, up to 1 mm across, consisting of calcite, quartz and albite are present in 87C. 514B co-exists with eclogite on the outcrop scale. Samples 96B and 252 are foliated gabbros within the peridotite, comprising plagioclase, hornblende, ilmenite, titanite, and minor quartz.

[1]GSA Data Repository item 2013062, analytical procedure; Table DR1 (Ar-Ar data); Table DR2 (HR SIMS U-Pb data); Figure DR1 (Ar-Ar age spectra and U-Pb concordia), is available online at www.geosociety.org/pubs/ft2013.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Apart from the 87C phengite, all hornblende and phengite samples yielded well-defined age spectra with total fusion and weighted plateau ages (174 ± 4 Ma, 2σ) indistinguishable within error (Fig. DR1 in the Data Repository). Sample 87C, however, displays thermally disturbed, steadily increasing age spectra, with the latest age value corresponding to 167 ± 4 Ma (2σ). This age is regarded as a minimum age constraint for the metamorphism due to the thermally and/or fluid-disturbed nature of the spectra. Seventeen grains of rutile from 514B define a common-Pb corrected concordia age of 172 ± 4 Ma (2σ).

The $^{40}Ar/^{39}Ar$ phengite and U-Pb rutile ages are identical within analytical uncertainties. Isotopic closure of muscovite-phengite for Ar diffusion, and rutile for Pb diffusion, are ~430–500 °C and 500–650 °C, respectively (e.g., Harrison et al., 2009; Cherniak, 2010); therefore these ages should approximate the timing of metamorphism (peak temperature of ~500–600 °C). On the other hand, hornblende should date the cooling of the gabbroic bodies below 500–570 °C (Dahl 1996), providing a minimum age constraint on the genesis of the ophiolite body. All ages indicate that both the Refahiye metamorphics and ophiolite are of Early-Middle Jurassic age.

DISCUSSION AND CONCLUSIONS

Early-Middle Jurassic accretionary complexes together with ophiolites, commonly related to the Neo-Tethys, are known only from Greece, Armenia, and Iran in the Eastern Mediterranean area (Fig. 1A): In Greece, Jurassic accretionary complexes are found beneath the Jurassic ophiolites obducted onto the passive continental margin (e.g., Danelian and Robertson, 2001). In Armenia and northwest Iran, Jurassic ophiolites and/or accretionary complexes are closely associated with Late Cretaceous ones (Khalatbari-Jafari et al., 2004; Rolland et al. 2009). Thus, the Refahiye accretionary complex and ophiolite of Early-Middle Jurassic age represents the missing link between Greece in the west and Armenia/Iran in the east. There are also sporadic reports of Jurassic plagiogranite and amphibolite-facies metamorphic blocks within a Late Cretaceous ophiolithic mélange in the Sakarya zone (Dilek and Thy, 2006; Çelik et al., 2011), and in a Late Cretaceous flysch in Armenia (Rolland et al., 2011). All these data imply that the Jurassic ophiolites and accretionary complexes must be more common in the Eastern Mediterranean region than previously recognized.

Jurassic magmatism was widespread in northern Turkey, the Caucasus, Iran, and Greece (Fig. 1A; Şen, 2007, and references therein). Its southern boundary is defined by the Vardar suture in Greece, the IAES in Turkey, and the Zagros suture in Iran. The presence of Jurassic accretionary complexes and suprasubduction ophiolites alongside the above-mentioned sutures suggests that the widespread Jurassic magmatism is subduction-related.

The main feature of the Refahiye region is the coexistence of oceanic accretionary complexes of Permian-Triassic, Early-Middle Jurassic, and Late Cretaceous ages without involvement of any continental block in between. Likewise, coexistence of the Permian-Triassic and Late Cretaceous oceanic accretionary complexes without any intervening continental domain is common alongside the IAES (Fig. 1A). This is suggestive of an episodic southward accretionary growth of the Sakarya zone from late Paleozoic to end-Mesozoic time, preceding the continental collision with the Anatolide-Tauride block during the Paleocene-Early Eocene (Figs. 3A and 3B), contrary to former suggestions (Fig. 3C; Şengör, 1984; Stampfli and Borel, 2002).

Dated deep-sea sedimentary blocks in the Carboniferous and Permian-Triassic accretionary complexes range from Devonian to Middle Triassic in age (Robertson and Ustaömer, 2009; Okay et al. 2011, and references therein), and are mostly Middle Triassic to Late Cretaceous in Late Cretaceous accretionary complexes (Bragin and Tekin, 1996). However, there are sporadic reports of Carboniferous and Permian pelagic blocks in Late Cretaceous accretionary complexes (Moix et al., 2011). The presence of Permian and Carboniferous pelagic blocks in the Late Cretaceous accretionary complexes also substantiate our inference that both Permian-Triassic and Late Cretaceous accretionary complexes are subduction and accretionary products of the same ocean. However, Moix et al. (2011) interpreted these blocks as reworked from a Paleo-Tethyan accretionary complex.

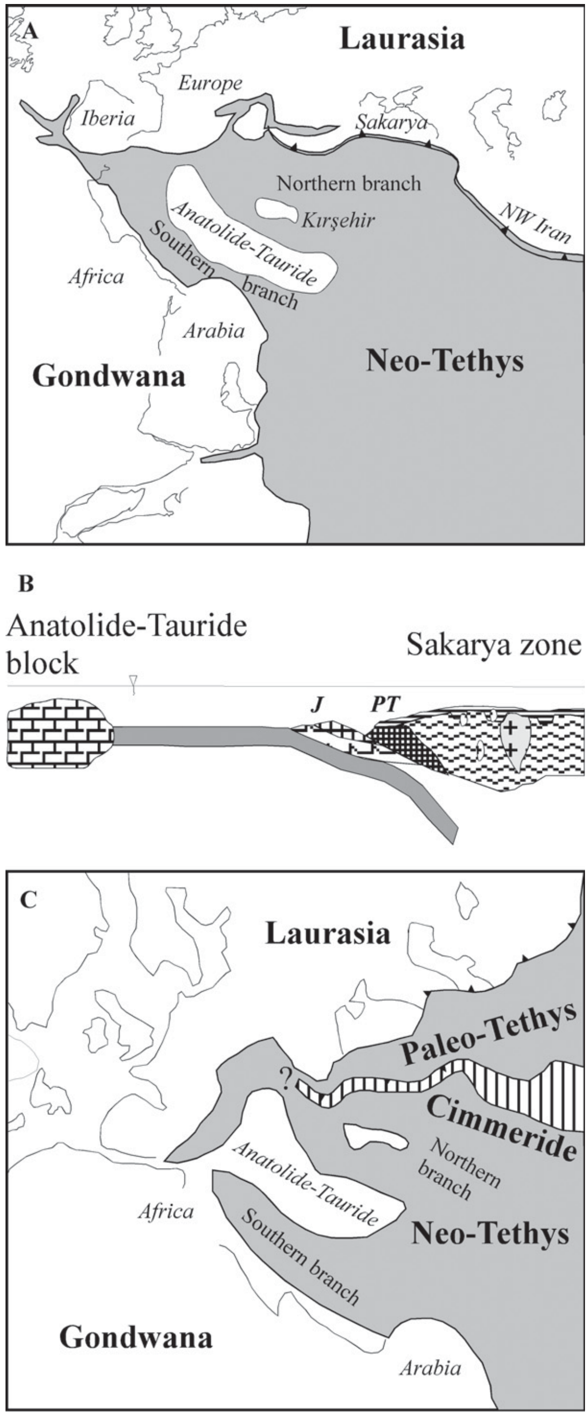

Figure 3. A: Paleogeographic reconstruction for the Early Jurassic time (modified after Barrier and Vrielynck, 2008). B: Schematic cross section from Anatolite-Tauride block to Sakarya zone for the Early-Middle Jurassic time. PT and J represent Permian-Triassic and Jurassic accretionary complexes, respectively. C: Şengör's (1984) paleogeographic reconstruction for Early Jurassic time. Note the Cimmerian ribbon between the Sakarya zone and Anatolide-Tauride block.

The latest Triassic-earliest Jurassic unconformity in the Sakarya zone, Caucasus, and northern Iran (Okay, 2000; Zanchi et al., 2009) marks a period of shortening followed by subsidence below sea level. A key unknown is the cause of this marked unconformity. There are three possibilities: (1) continental collision followed by displacement of the colliding "Cimmerian" continental ribbon by a strike-slip fault; (2) accretion of very large submarine topographic highs, e.g., oceanic aseismic ridges, oceanic plateaus, or seamount chains; and (3) the eastern Mediterranean region being located at the western end of the Cimmerian continental ribbon located to the east, and continental collision in the east leading to regional-scale compression and uplift in its western elongation. The first possibility is regarded as unlikely, because (1) the putative strike-slip fault would require an offset of ≥1200 km in ≤15 m.y., as deduced from the total length of the coexisting Permian-Triassic and Late Cretaceous accretionary complexes and the presence of Early to Middle Jurassic accretionary complex, and (2) no evidence for strike-slip activity apart from the active NAF has been documented in the accretionary complexes so far. Numeric calculations indicate that only subduction of very large oceanic topographic highs could jam the subduction zone, and cause orogenic collisions. Small (1–2 km in height) seamounts are expected to cause only local temporary dents (e.g., Cloos, 1993). The metabasaltic rocks in the Permian-Triassic accretionary complexes commonly display anorogenic alkaline and tholeiitic affinities similar to those in seamounts and aseismic ridges, suggesting a substantial amount of accreted seamounts (e.g., Pickett and Robertson, 1996). Due to the highly deformed and metamorphosed nature of the Permian-Triassic accretionary complexes, size and primary internal structure of the accreted seamounts cannot be reconstructed. In clear distinction to Turkey and Greece, there is a thick Norian to Middle Jurassic siliclastic succession in north Iran (Shemshak unit), interpreted as post-orogenic foreland molasse (Zanchi et al., 2009), and Jurassic magmatism is confined to the north of the Zagros suture in Iran, and to the north of the IAES in Turkey (Fig. 1A). Hence we cannot eliminate the second and third possibilities.

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