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A new classification of the Turkish terranes and sutures and its implication for the paleotectonic history of the region

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Abstract

The Turkish part of the Tethyan realm is represented by a series of terranes juxtaposed through Alpine convergent movements and separated by complex suture zones. Different terranes can be defined and characterized by their dominant geological background. The Pontides domain represents a segment of the former active margin of Eurasia, where back-arc basins opened in the Triassic and separated the Sakarya terrane from neighbouring regions. Sakarya was re-accreted to Laurasia through the Balkanic mid-Cretaceous orogenic event that also affected the Rhodope and Strandja zones. The whole region from the Balkans to the Caucasus was then affected by a reversal of subduction and creation of a Late Cretaceous arc before collision with the Anatolian domain in the Eocene. If the Anatolian terrane underwent an evolution similar to Sakarya during the Late Paleozoic and Early Triassic times, both terranes had a diverging history during and after the Eo-Cimmerian collision. North of Sakarya, the Küre back-arc was closed during the Jurassic, whereas north of the Anatolian domain, the back-arc type oceans did not close before the Late Cretaceous. During the Cretaceous, both domains were affected by ophiolite obduction, but in very different ways: north directed diachronous Middle to Late Cretaceous mélange obduction on the Jurassic Sakarya passive margin; Senonian synchronous southward obduction on the Triassic passive margin of Anatolia. From this, it appears that the Izmir-Ankara suture, currently separating both terranes, is composite, and that the passive margin of Sakarya is not the conjugate margin of Anatolia. To the south, the Cimmerian Taurus domain together with the Beydağları domain (part of the larger Greater Apulian terrane), were detached from north Gondwana in the Permian during the opening of the Neotethys (East-Mediterranean basin). The drifting Cimmerian blocks entered into a soft collision with the Anatolian and related terranes in the Eo-Cimmerian orogenic phase (Late Triassic), thus suturing the Paleotethys. At that time, the Taurus plate developed foreland-type basins, filled with flysch-molasse deposits that locally overstepped the lower plate Taurus terrane and were deposited in the opening Neotethys to the south. These olistostromal deposits are characterized by pelagic Carboniferous and Permian material from the Paleotethys suture zone found in the Mersin mélange. The latter, as well as the Antalya and Mamonia domains are represented by a series of exotic units now found south of the main Taurus range. Part of the Mersin exotic material was clearly derived from the former north Anatolian passive margin (Huğlu-type series) and re-displaced during the Paleogene. This led us to propose a plate tectonic model where the Anatolian ophiolitic front is linked up with the Samail/Baër-Bassit obduction front found along the Arabian margin. The obduction front was indented by the Anatolian promontory whose eastern end was partially subducted. Continued slab roll-back of the Neotethys allowed Anatolian exotics to continue their course southwestward until their emplacement along the Taurus southern margin (Mersin) and up to the Beydağları promontory (Antaya-Mamonia) in the latest Cretaceous–Paleocene. The supra-subduction ocean opening at the back of the obduction front (Troodos-type Ocean) was finally closed by Eocene north–south shortening between Africa and Eurasia. This brought close to each other Cretaceous ophiolites derived from the north of Anatolia and those obducted on the Arabian promontory. The latter were sealed by a Maastrichtian platform, and locally never affected by Alpine tectonism, whereas those located on the eastern Anatolian plate are strongly deformed and metamorphosed, and affected by Eocene arc magmatism. These observations help to reconstruct the larger frame of the central Tethyan realm geodynamic evolution.

Keywords: Asia; Turkey; Tethys; Mesozoic; Terranes; Sutures; Ophiolites

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1. Introduction

This paper proposes a new terrane subdivision of the Turkish Tethyan domain and its implications for the geological evolution of that region. This new scheme is based on recent field investigations carried out by a team of geologists from our university over the past 10 years. The new subdivision also incorporates previous concepts published in French language during the 1970–80's as PhD theses mainly done under the direction of Prof. Brunn by teams of scientists from Paris-Orsay. More recent input from Turkish geologists offers a series of well-constrained data on the ophiolites, with precise and modern dating of the magmatic and metamorphic events. Each structural/paleogeographic domain is described in order to precise their main geological characteristics. Unpublished new data related to the Mersin mélanges characterize the new South-Taurides exotic domain. The latter, integrated in a larger tectonic framework can explain synthetically the origin of the Turkish nappes, reconciling ideas on a northern versus southern origin of the nappes.

2. Terranes, sutures and paleo-oceanic domains of Turkey and adjacent areas

Ophiolitic bodies are widespread in Turkey. The eastern Mediterranean region as a whole exhibits a fascinating diversity of ophiolites and related oceanic magmatic units of mainly Triassic, Jurassic and Cretaceous ages (Fig. 1). Turkey is also made of several continental and oceanic fragments assembled during the Late Cretaceous–Early Tertiary period in consequence of the closure of different Tethyan oceanic basins. The first assembly of terranes was realized during the Variscan orogeny with an amalgamation of Gondwana and Laurasia-derived elements. In Late Triassic times, this was repeated during the Eo-Cimmerian orogenic event with the final closure of the Paleotethys Ocean. This paper is mainly centered on younger amalgamation events. For the Paleozoic dynamics and origin of the Turkish terranes, the reader is referred to recent publications on the Variscan (e.g. Stampfli and Borel, 2002) and Paleotethys sutures in the Tethyan realm (e.g. Stampfli et al., 2003; Stampfli and Kozur, 2006).

One of the outstanding challenges for the interpretation of the western Tethyan realm is to solve the problem of the origin of the Anatolian-Tauric nappes. Some authors assumed that the nappes (including the ophiolitic series) were derived from the closure of a single major ocean located to the north of the Tauric carbonate platform during the Late Cretaceous. Analogies of facies on both flanks of the Bolkar Mountains (i.e. “Taurus limestone axis”), and similarities between the para-autochthonous sequences in the Taurides and the Arabian platform were the starting point of the nappe/window interpretation of Ricou et al. (1974, 1975) and Brunn et al. (1976). Other authors assumed that several oceanic basins were separated by micro-continents (Robertson and Woodcock, 1981; Şengör and Yılmaz, 1981; Stampfli et al., 1991). Northerly units were derived from a northern oceanic basin, i.e. the Inner Taurides Ocean (Dilek et al., 1999; Özer et al., 2004) or northern branch of Neotethys (Robertson and Woodcock, 1981; Şengör and Yılmaz, 1981). Southerly units came from a southern oceanic basin, i.e. the southern branch of the Neotethys (Robertson and Woodcock, 1981; Şengör and Yılmaz, 1981; Dilek et al., 1999). More recently, some authors supported both a northern and a southern origin for these ophiolitic nappes (Göncüoğlu et al., 1997; Robertson, 1998, 2000; Stampfli et al., 2001). Considering several oceanic basins, the Lycian Nappes, the Beyşehir-Hoyran Nappes, the Hadım Nappes, the Pınarbaşı and Munzur domains are typical northerly-derived units. On the other hand, southerly-derived units are represented by the Antalya Nappes, the Baër-Bassit ophiolite (Syria), the Mamonia Complex (Cyprus) and the Mersin ophiolite and its related mélanges.

In our new plate tectonic approach of this problem, and with the exception of the peri-Arabian ophiolites, all Turkish ophiolites south of the Izmir-Ankara suture are regarded as originating from the north. At some stage, they formed a unified obduction front with the peri-Arabian ophiolites, the latter progressively indented by the Anatolian-Tauric promontory.

2.1. Previous subdivision

Anatolia (Turkey) was previously subdivided into four major orogenic belts, namely the Pontides (Laurasian realm), the Anatolides, the Taurides and the Border folds (Gondwana realm) (Ketin, 1966). Three distinct ophiolitic belts were recognized some three decades ago (Gansser, 1974; Brinkmann, 1976; Juteau, 1980): from north to south, there are (1) the North Anatolian or northern ophiolitic belt associated with HP-LT sediments (Okay et al., 1998; Önen, 2003), (2) the Tauric ophiolitic belt, divided into four sub-parallel zones along the orogenic belt (Dilek et al., 1999) and (3) the peri-Arabian or southern ophiolitic belt, outlining the border with the Arabian plate and continuing eastward through the Zagros Range in Iran (Kermanshah and Neyriz ophiolites) and the Samail Nappes in Oman.

2.2. New subdivision

Recent geologic subdivisions of Turkey based on paleogeography and plate tectonics were made by Okay and Tüysüz (1999) and Bozkurt and Mittwede (2001). Based on proper terranes definitions and geologic descriptions of the main sutures, microcontinental blocks, and oceanic domains, we develop this concept further. Presently, the Izmir-Ankara-Erzincan suture divides Turkey into two main tectonic units, the Pontides and the Anatolides-Taurides platform (Şengör and Yılmaz, 1981; Okay et al., 1996) (Fig. 1). In the north, the Pontides comprise the Sakarya, Istanbul, Zonguldak and Rhodope-Strandja zones. All of them belonged to Laurasia and, except the Zonguldak zone, were affected by the Variscan metamorphic–plutonic events. South of the suture, the Anatolides-Taurides platform belonged for its southern part (Taurus terrane) to Gondwana, at least until the Permian, whereas the Anatolian terrane has Eurasian affinities. To the southeast, the Tertiary SE Turkish suture (Robertson et al., 2006) separates the Taurides-Anatolides domain from the

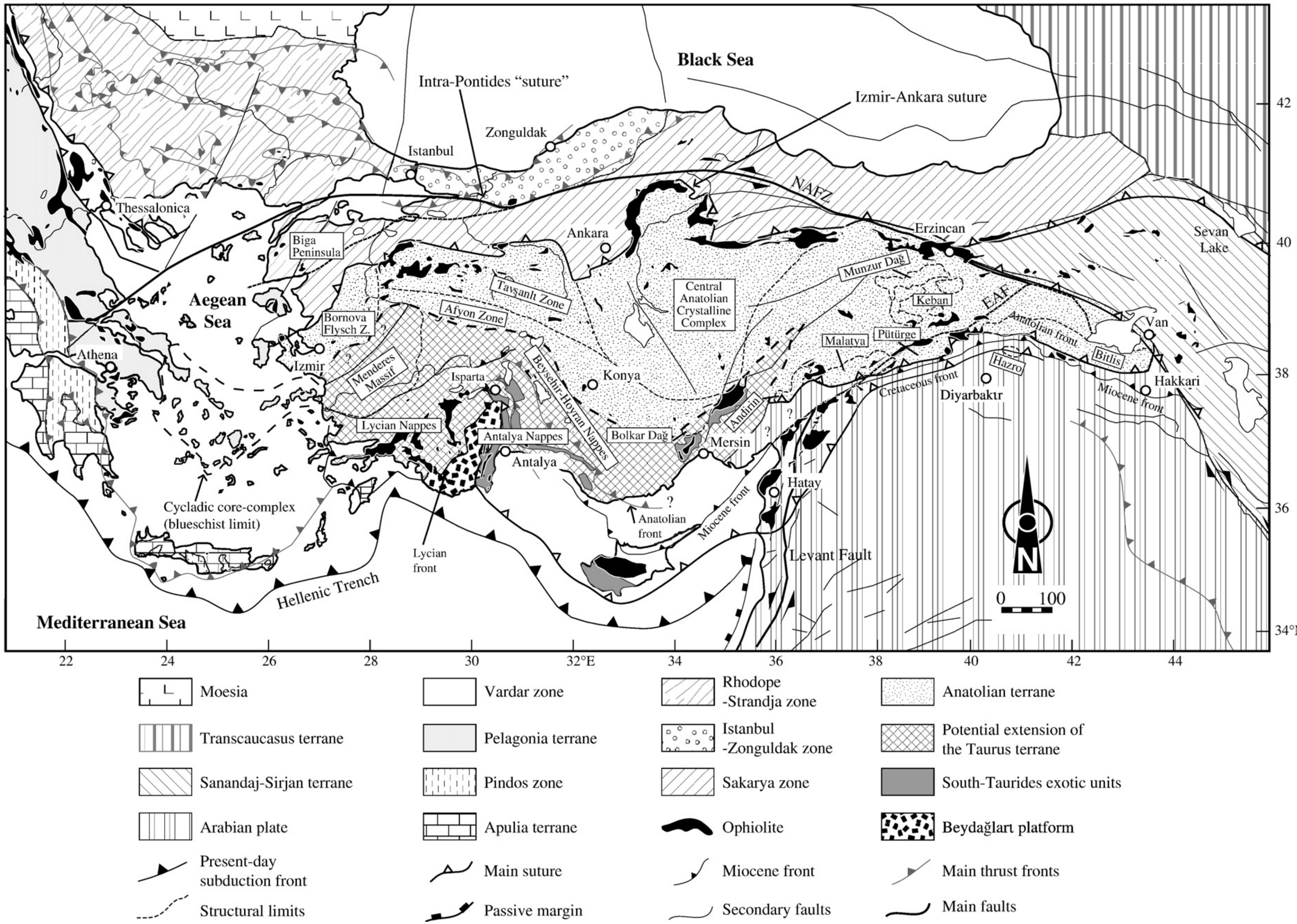


Fig. 1. Tectonic map of Turkey and surrounding regions. See the explanations in the text. NAFZ: North Anatolian Fault zone. EAF: East Anatolian Fault.

Arabian platform. Therefore, five main domains with contrasting geodynamic evolutions are differentiated: from north to south, there are (1) the Pontides domains. l. including the intra-Pontides and Izmir-Ankara-Erzincan sutures; (2) the Anatolian terrane and related ophiolitic nappes; (3) the Taurus Cimmerian terrane; (4) the South-Taurides exotic units and (5) the peri-Arabian domain. The composite Taurides-Anatolides domain is here subdivided into the Anatolian and Taurus terranes (Stampfli, 2000; Stampfli and Borel, 2002). These two terranes were not sealed by a common platform before the Late Triassic. Before that, the two blocks show a drastically different evolution and origin. All major domains are now reviewed in some detail (see Sections 3–7), presenting a summary of published and newly acquired field data.

3. The Pontides domain

The composite Pontides domain was affected by numerous terranes amalgations from the Variscan times until the Cretaceous–Paleocene opening of the Black Sea basins. Generally speaking, this domain was often located within a context of an active margin with widespread arc-related volcanic activity. This resulted in the formation and superposition of metamorphic–plutonic complexes. This zone is also linked on both ends with similar areas, such the Balkanic orogenic complex in the west and the Caucasus orogenic system eastward.

3.1. The Rhodope-Strandja zone (Fig. 2)

The Strandja zone of Turkey represents the eastern continuation of the Rhodope Massif of northeastern Greece and southeastern Bulgaria (Fig. 1). Stratigraphically, it consists of a Variscan (Eurasian) basement of highly deformed metamorphosed rocks in the amphibolite facies, intruded by Late Variscan extensional Permian granitoids (Okay et al., 2001) (Fig. 2). This basement is unconformably overlain by a Triassic transgressive sequence comprising continental to shallow marine metasediments, extending up to the Middle Jurassic in its Bulgarian part (Chatalov, 1988). The Late Jurassic–Early Cretaceous interval corresponds to an important deformational regime involving all the previous units (Austrian phase or Balkanic orogeny (Georgiev et al., 2001)). This deformation is characterized by northward thrusting and is sealed by Cenomanian conglomerates and shallow marine limestones, followed by Senonian arc-related magmatic rocks. The magmatic arc is related to the Late Cretaceous final closure and northward subduction of the Jurassic Vardar Ocean beneath the Rhodope margin. The related Vardar suture, located in Greece, separates the Rhodope and circum-Rhodope zones from the Pelagonian terrane.

The Rhodope area is also characterized by the occurrence of mélange-like units in the allochthonous nappes of northern Greece and eastern Bulgaria (e.g. Boyanov and Russeva, 1989; Bonev and Stampfli, 2003). These oceanic remnants are correlated with similar units found in the Biga peninsula of northwest Turkey, e.g. the Çetmi mélange of Albian age (Beccaletto et al., 2005). Before the Cenomanian, both were obducted northward onto the Rhodope margin during the Balkanic orogeny (Beccaletto, 2004). At a regional scale, this event may be related to a similar northward obduction process known in eastern Turkey and in the Caucasus (Sevan). There, accretionary complexes were obducted northward onto the Sakarya margin during the Cenomanian–Turonian interval (see Section 3.4). Finally, this implies a general northward obduction onto the Eurasian Rhodope-Sakarya margin, starting from the Albian in the west to the Turonian–Campanian in the east.

3.2. The Istanbul and Zonguldak zones (Fig. 3)

The Istanbul and Zonguldak zones are small continental fragments located southwest of the Black Sea. These zones are bounded to the east by the West Crimean Fault, and to the west by the West Black Sea Fault (Okay, 1989). They are separated from the southerly Sakarya zone by the Intra-Pontides “suture”/ North Anatolian Fault system (Fig. 1). The Istanbul and Zonguldak zones were generally regarded as a single unit. However, as shown by Demirtaşlı (1989), Göncüoğlu and Kozur (1998) and Kozur and Göncüoğlu (1999), both terranes have a very different Paleozoic and Mesozoic development.

In the Zonguldak zone (Çamdağ, Zonguldak, Amasra and Safranbolu regions), a low-grade metamorphic Cadomian basement is present (Ustaömer and Robertson, 1997; Ustaömer et al., 2005) (Fig. 3A). One characteristic of the Zonguldak zone is the absence of Variscan overprint. The oldest rocks above the Cadomian basement are siliciclastic rocks of Tremadoc age (Dean et al., 2000). In the basal Arenig, a rapid deepening occurred and the Arenig to Ashgill consist of graptolite-bearing mudstones and siltstones with few limestones. The Baltic-type conodonts show a strong thermal alteration (CAI = 5–6). The Silurian consists of graptolite-bearing shales and mudstones, with few limestones in the upper part. The youngest Silurian rocks occur below an angular disconformity and belong to the Pridoli. The Pridoli and Ludlow rocks are often removed below this angular disconformity. Up to the uppermost Silurian, the conodonts show a strong thermal alteration (CAI = 5). In the Çamdağ Unit, the Ordovician consists of siliciclastic sediments and the Silurian is probably absent. Above the angular disconformity, the Devonian sequence begins with Pragian to Lower Emsian siliciclastic rocks, overlain by shallow water limestones and dolomites without Variscan alteration (CAI = 2). Shallow water limestones and dolomites continue throughout the Mississippian (until Namurian A). Conodonts show the absence of Variscan metamorphism (CAI = 1). Namurian B, C and Westphalian sequences consist of continental beds with coals and Euramerian flora. Continental beds without coals continued until the Stephanian. The Paleozoic development in the Zonguldak zone is similar to the Malopolski terrane in southeast Poland. The Triassic of the Zonguldak zone is continental (Görür et al., 1997). After a long gap, the Oxfordian transgression brought shallow marine sandstones and limestones. In the Cretaceous, shales, siltstones, and limestones prevail and Upper Cretaceous volcanics are present. In the Upper Maastrichtian, an unconformity is also present.

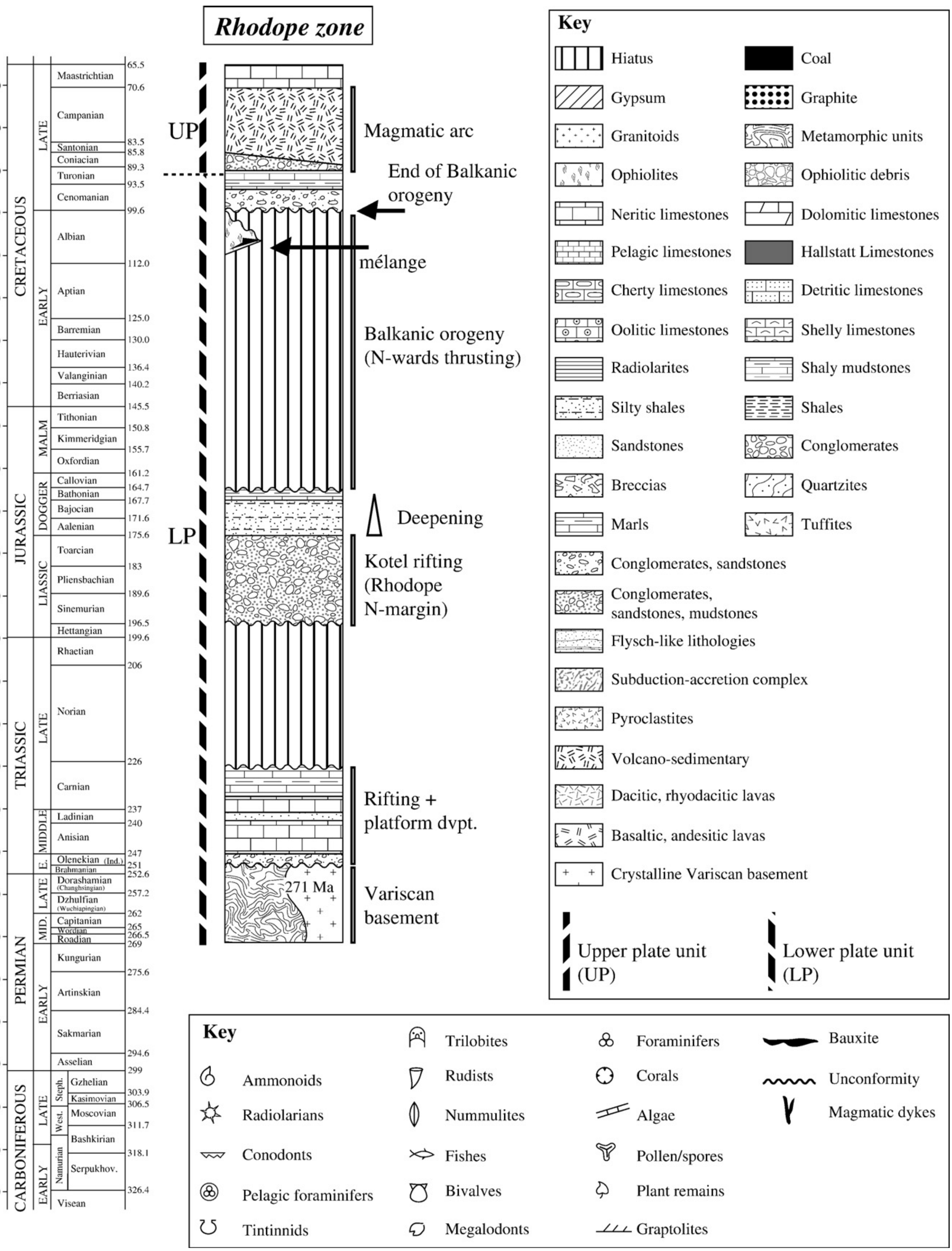


Fig. 2. Rhodope-Strandja zone: synthetic lithostratigraphic section and main geodynamic events. Section compiled from Georgiev et al. (2001) and Okay et al. (2001). The key refers to Figs. 2, 3, 4, 6, 7, 8, 9, 10, 11 and 12. For the Carboniferous, Lower Permian, Jurassic and Cretaceous, the geologic time scale is after Gradstein et al. (2004); for the Middle and Late Permian, and the Triassic, the geologic time scale is after Kozur (2003a,b). The same geological time scale is used on Figs. 4, 6, 7, 11 and 12.

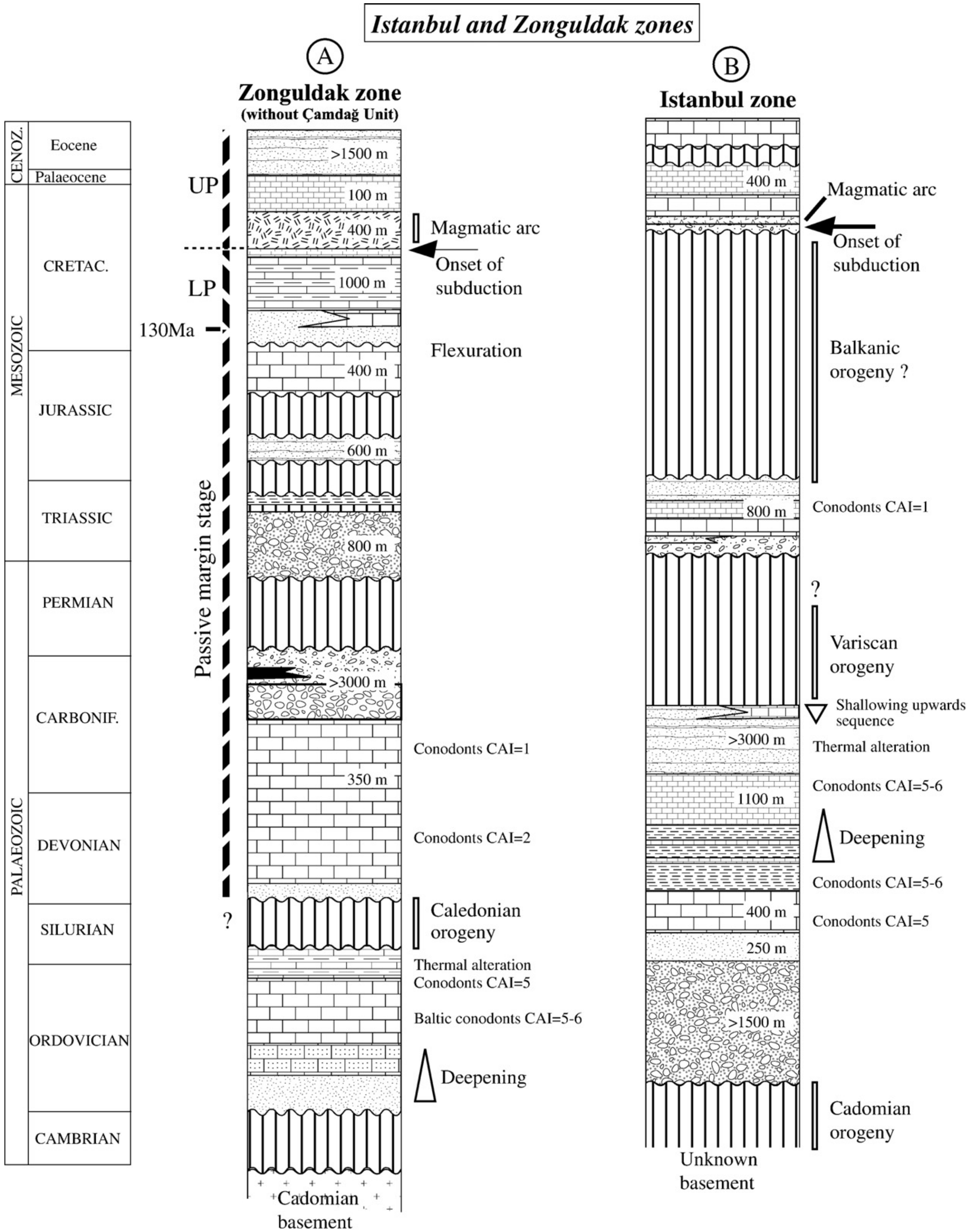


Fig. 3. Istanbul and Zonguldak zones: synthetic lithostratigraphic sections and main geodynamic events. Sections compiled from Okay and Tüysüz (1999) and Kozur (1999b). Key on Fig. 2.

The series in the Istanbul zone are different (Fig. 3B). The sedimentation began during the Arenig and the Ordovician and Llandovery rocks consist of shallow water clastics. The rocks ranging from the Wenlock to the Pridoli are represented by shallow water limestones. The thermal alteration of the conodonts (CAI = 5) in the Devonian was caused by Variscan metamorphism. Lochkovian to Lower Emsian rocks are represented by shallow water limestones, shales, greywackes and sandstones. A rapid deepening occurred within the Emsian. Pelagic nodular limestones and shales with paleopsychrosphaeric deep water

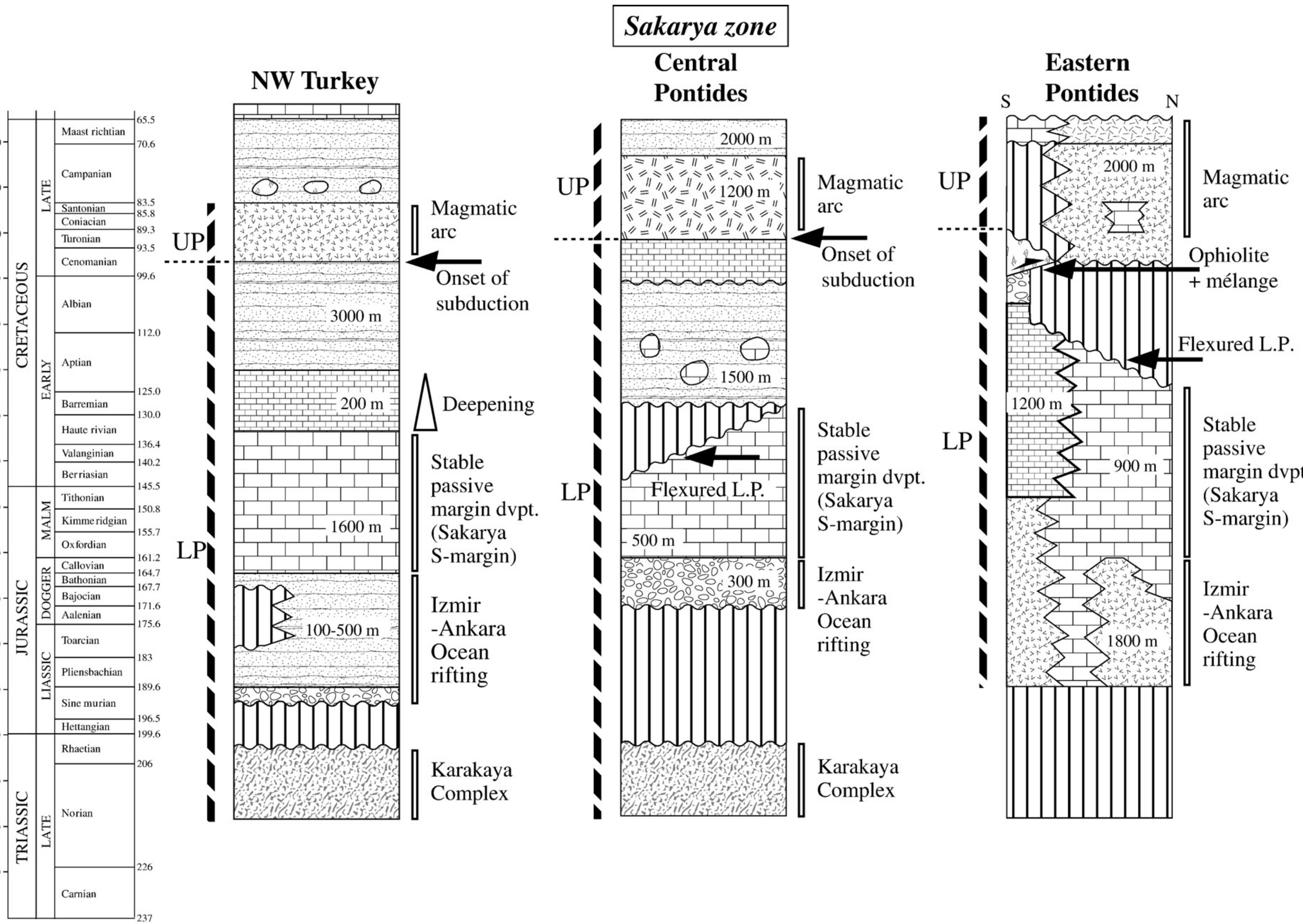


Fig. 4. Sakarya zone: synthetic lithostratigraphic sections and main geodynamic events. Sections modified from Okay and Tüysüz (1999). Key on Fig. 2.

ostracods and conodonts (CAI = 4–5) were deposited up to the top of the Devonian. The Tournaisian is characterized by radiolarites and shales followed by the Hercynian flysch (greywackes and shales), which age ranges up to the Namurian A. A rapid shallowing in the Namurian B and C results in the deposition of the Cebeciköy Limestones, followed by the Hercynian unconformity. Following a Lower Triassic transgression, shallow water conglomerates, sandstones, limestones, and marls were deposited. A strong deepening occurred in the Spathian. From this time to the end of the Middle Triassic, pelagic, partly nodular limestones, Ammonitico Rosso, and some shallow water carbonates were deposited. The conodonts are unaltered (CAI = 1). Carnian rocks are made of siliciclastic turbidites, which end in a shallowing upward sequence with Norian reefal limestones and sandstones. After a long gap, conglomerates, marls and rudist-bearing limestones mark the Campanian transgression. The absence of Jurassic and Lower Cretaceous rocks may be related to the influence of the Balkanic orogeny. Upper Cretaceous volcanics are also not present.

Both faunistic and paleomagnetic data demonstrate a Laurasian affinity for the Istanbul and Zonguldak zones during the Paleozoic (Görür et al., 1997) and the Early Triassic (Kerey et al., 1986; Saribudak et al., 1989). Senonian arc-related rocks, widespread in the northern part of the Zonguldak zone, are related to the closure of a southerly oceanic domain (Phrygian Ocean, see below), subducting northward beneath the Sakarya and Istanbul zones. This subduction also triggered the Late Cretaceous back-arc opening of the West Black Sea oceanic basin, leading to the southward translation of the Istanbul continental fragment away from the Odessa Shelf (Okay et al., 1994).

3.3. The Intra-Pontides "suture"

The Intra-Pontides "suture" (Şengör et al., 1980) separates the Istanbul and Zonguldak zones in the north from the Sakarya zone in the south (Fig. 1). The "suture" is a tectonic mixture of several units coming both from the Istanbul, Zonguldak and Sakarya zones, plus various metamorphic rocks and dismembered metaophiolitic bodies. However, the "suture" directly coincides with the major post-Miocene strike-slip North Anatolian Fault zone (Barka, 1992; Armijo et al., 1999). All the pre-Miocene structural relations between the Istanbul/Zonguldak and the Sakarya zones are thus disrupted. Besides this neotectonic problem, the lack of reliable field data (ages of metamorphic and ophiolitic rocks) prevents a clear understanding of the "suture" zone. For instance, there is still a debate on the age of the Almacık metaophiolite, considered either as Paleozoic (Abdüsselamoğlu, 1959; Gözübol, 1980; Yiğitbaş et al., 1999) or Late Cretaceous (Yılmaz et al., 1982, 1995; Robertson and Ustaömer, 2004).

As field evidences for an Intra-Pontides "suture" are scarce, the evolution of the corresponding Intra-Pontides Ocean remains highly speculative and controversial (Robertson and Ustaömer, 2004; Elmas and Yiğitbaş, 2005; Ustaömer and Robertson, 2005). For instance, there are no data for the age of its opening, nor any recognized passive margin sequences. The age of its closure, generally based on the first transgressive sediments, is either placed in the Late Cretaceous (Yılmaz et al., 1995; Robertson and Ustaömer, 2004), the Paleocene–Eocene (Şengör and Yılmaz, 1981), the Early Eocene (Okay et al., 1994; Wong et al., 1995), or Early Eocene to Oligocene (Görür and Okay, 1996). Finally, data from Tüysüz (1999) favour a juxtaposition of the Istanbul and Sakarya zones during the Cenomanian, much earlier than previously suggested. Because of these discrepancies, and following the view of Elmas and Yiğitbaş (2001), we ignore the existence of a Mesozoic or Tertiary Intra-Pontides Ocean in the paleogeographic reconstructions.

3.4. The Sakarya zone (Fig. 4)

The Sakarya zone represents an east–west trending continental fragment. It is bordered to the northwest by the Rhodope-Strandja, Istanbul, and Zonguldak zones along the Intra-Pontides "suture"/North Anatolian Fault system and to the northeast by the Black Sea. To the south, the Sakarya zone is bounded by the composite Anatolian-Tauric block along the mélanges and ophiolites of the Izmir-Ankara-Erzincan zone (Fig. 1). The basement of the Sakarya zone (Okay et al., 1996) consists of a widespread Triassic subduction–accretion series, called the Karakaya Complex in its western part (Bingöl et al., 1975; Tekeli, 1981; Okay et al., 1991; Okay and Göncüoğlu, 2004). The Karakaya Complex may be seen as a fore-arc/foreland basin related to the northward subduction of the Paleotethys along the southern margin of Eurasia (Stampfli and Kozur, 2006). The various units of the Karakaya Complex are unconformably overlain by Liassic terrigenous to shallow marine clastic sedimentary rocks (Altıner et al., 1991) (Fig. 4). These clastics are unconformably overlain by Middle-Upper Jurassic platform-type neritic limestones and Lower Cretaceous pelagic limestones. The whole series is interpreted as a syn- to post-rift sequence, related to the opening of the Izmir-Ankara Ocean along the southern margin of the Sakarya microcontinent (Görür et al., 1983). This ocean extended eastward to the Sevan south Caspian oceanic domain (Stampfli and Borel, 2002, 2004). It is regarded as a marginal ocean of the Neotethys, opening through the subduction of the latter since the latest Triassic.

During the Middle Cretaceous, this Jurassic–Cretaceous passive margin took all the characteristics of a flexural margin. Regional landward erosion and karstification, seaward deepening and local occurrence of accretion-related mélanges and ophiolites at the top of them are outstanding features (Altıner et al., 1991; Koçyiğit et al., 1991; Okay and Şahintürk, 1997; Rojay and Altıner, 1998; Okay and Tüysüz, 1999) (Fig. 4). In the Central Pontides, the flexuration is pre-Aptian. In the eastern Pontides, it is pre-Albian and even younger (Cenomanian) in the Sevan region (Bergougnan, 1987). In the eastern Pontides, an accretionary complex was emplaced at the top of the flexured margin during the Cenomanian–Turonian interval (Bergougnan, 1975; Okay and Şahintürk, 1997). As pointed out by Okay and Tüysüz (1999), this Middle Cretaceous northward obduction of accretionary complexes is a characteristic feature of the Sakarya zone, and therefore must be integrated in any geodynamic scenario. Following this event, the Sakarya continental fragment and the Istanbul/Zonguldak zones flipped from a lower plate to an upper plate position. The development of a widespread Senonian volcanic arc indicates that the southerly ocean responsible for the former ophiolite obduction started to subduct northward sometime after the obduction. Moreover, the Triassic sequences in Crimea are similar to those found in the basement of the Sakarya zone, thus indicating that the latter was appended to Laurasia during the Jurassic and Cretaceous periods (Okay et al., 1996). Paleomagnetic data also indicate that the Sakarya zone was close to the Laurasian margin, at least during Liassic and Late Cretaceous times (Channell et al., 1996).

Another important feature of the Sakarya zone is the Küre Unit located close to the boundary with the Zonguldak zone. This unit comprises thrust-imbricated siliciclastic sediments interleaved with tectonic slices of a dismembered ophiolite (Ustaömer and Robertson, 1994, 1997). It is interpreted as a remnant of a back-arc basin (Küre) opened in the Early Triassic in response to the northward subduction of the Paleotethys (Kozur et al., 2000; Stampfli, 2000; Stampfli and Kozur, 2006). The Küre Ocean was closed in the Late Jurassic (Ustaömer and Robertson, 1997) after its southward subduction beneath the Sakarya zone (Kozur et al., 2000). Its northward roll-back in the Jurassic is the triggering mechanism for the opening of the Izmir-Ankara Ocean.

3.5. The Izmir-Ankara-Erzincan suture (Fig. 5)

The 2000 km long east–west trending Izmir-Ankara-Erzincan suture separates the Sakarya zone in the north from the Anatolian-Tauric block in the south (Fig. 1). The suture zone is made of ophiolitic rocks associated with accretionary mélange units. The ophiolites occur mainly as peridotite massifs, lacking a complete ophiolitic sequence. Radiochronologic data from the sub-ophiolitic amphibolitic soles are rare and suggest Albian-Cenomanian ages for the intra-oceanic subduction (Önen and Hall, 1993; Harris et al., 1994) (Fig. 5). Striking similarities in the age of the metamorphic sole, at least for the ophiolites of southern Turkey, Cyprus, and Syria should be also noted.

The mélanges, (the Ankara mélange of Bailey and McCallien (1950)), show dissimilar ages, origin, facies and size, generally with strong tectonic imbrications. The age of the blocks ranges from Carboniferous to Eocene (Çapan and Buket, 1975; Norman, 1993; Tüysüz et al., 1995). As pointed out by Okay and Tüysüz (1999), some ophiolites and accretionary complexes were obducted directly onto the flexural Sakarya margin along north verging thrust contacts (Bergougnan, 1975; Okay and Şahintürk, 1997). Two complexes should therefore be distinguished: one marking the northward obduction and the other related to the northward subduction and closure of the obducted ocean (Phrygian Ocean) after a flip of subduction polarity. This closure juxtaposed the Anatolian ophiolitic root zone to the Sakarya block and its mélange (Karakaya and

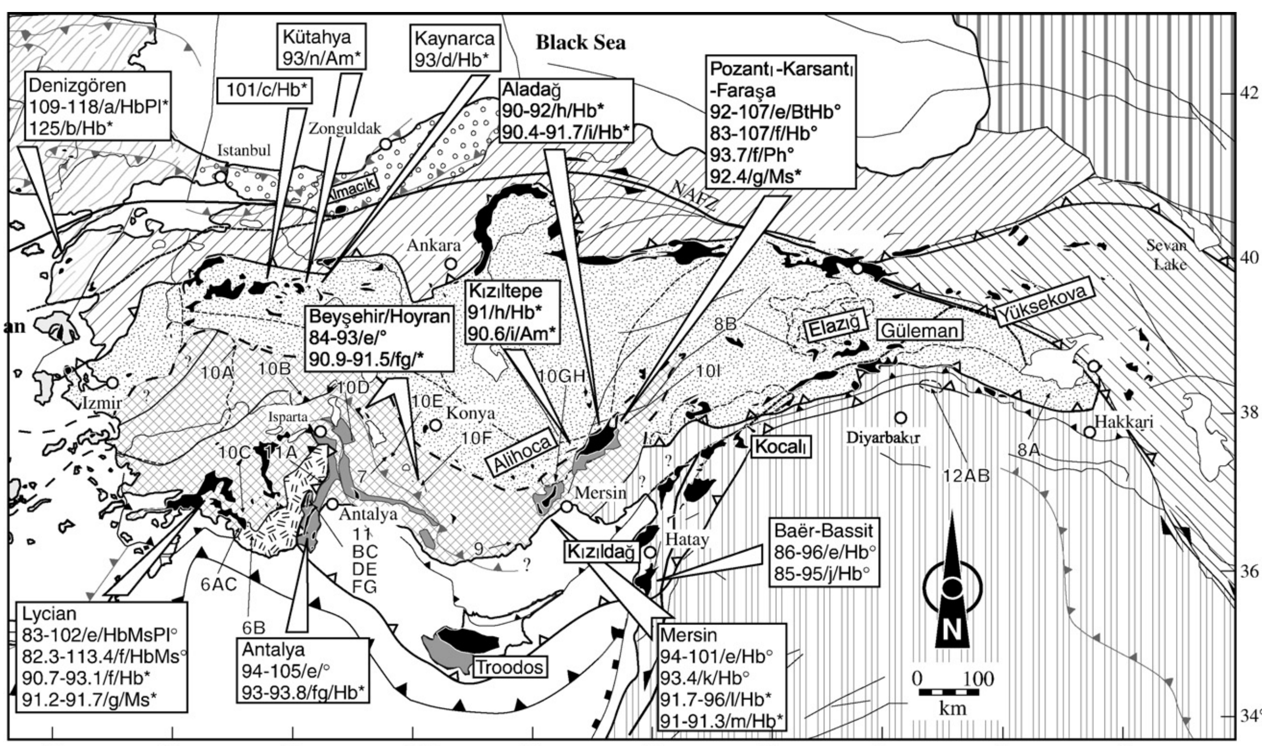
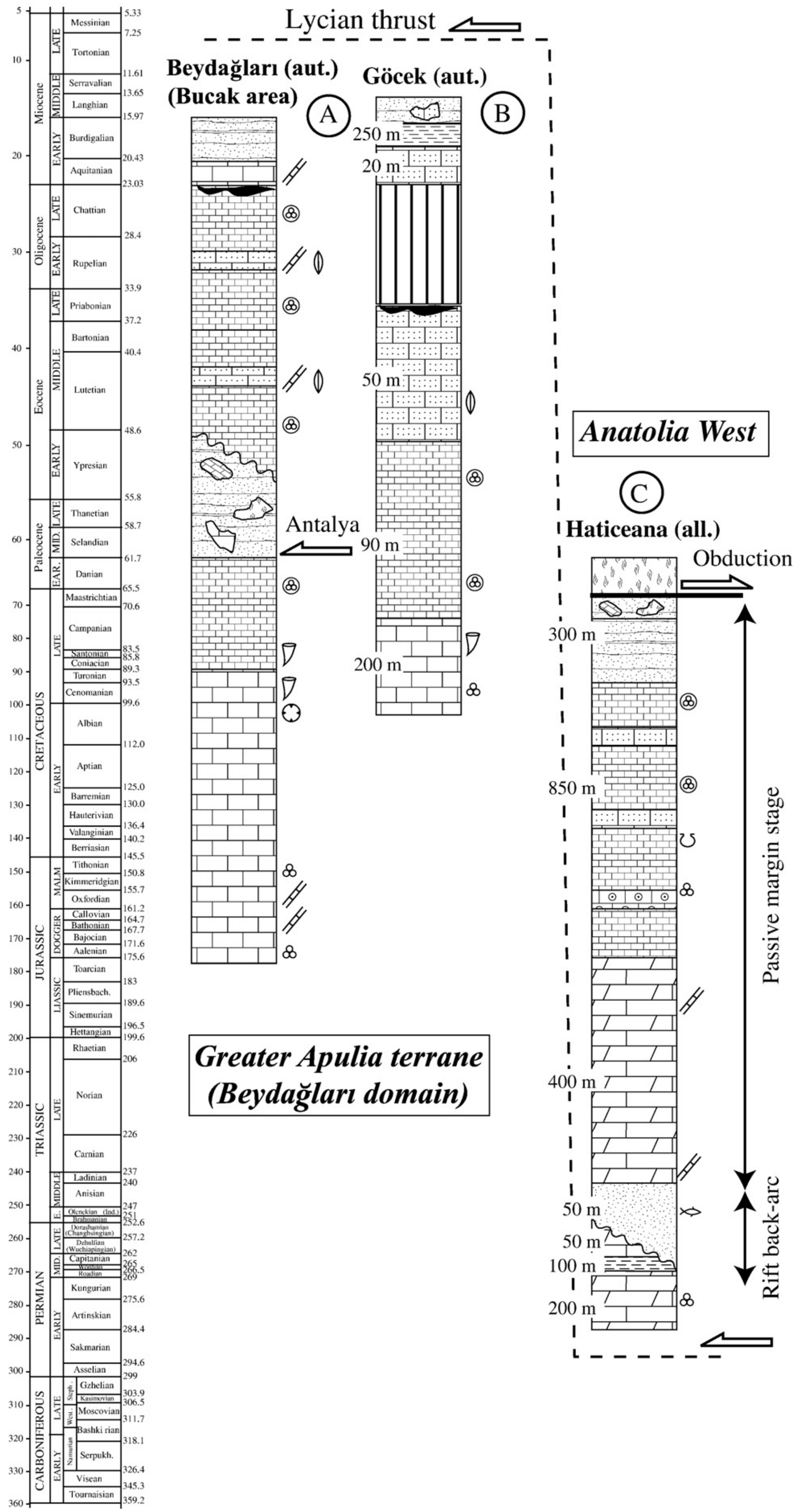


Fig. 5. Main ophiolitic massifs of Turkey, with the ages of their metamorphic soles, when published and location of the sections of Figs. 6, 7, 8, 9, 10, 11 and 12. Hb: hornblende; Bt: biotite; Pl: plagioclase; Ms: muscovite; Ph: phengite; Am: amphibole; °K–Ar method; *Ar–Ar method; (a) Okay et al. (1996); (b) Beccaletto and Jenny, 2004; (c) Önen and Hall, 2000; (d) Harris et al. (1994); (e) Thuizat et al. (1981); (f) Çelik, 2002; (g) Çelik et al. (2006); (h) Dilek and Whitney, 1997; (i) Dilek et al. (1999); (j) Delaloye and Wagner, 1984; (k) Parlak et al. (1995); (l) Parlak and Delaloye (1996); (m) Parlak and Delaloye (1999); (n) Önen, 2003. Same key as Fig. 1.


Lycian thrust
Beydağları (aut.)
(Bucak area)
A
Göcek (aut.)
B
Antalya
Anatolia West
C
Haticeana (all.)
Obduction
Passive margin stage
Rift back-arc
Greater Apulia terrane
(Beydağları domain)
250 m
20 m
50 m
90 m
200 m
300 m
850 m
400 m
50 m
50 m
100 m
200 m

Cretaceous ophiolitic mélange of Norman (1993)), both areas being imbricated until the Eocene.

The oceanic domain related to the Izmir-Ankara-Erzincan suture is generally known as the Izmir-Ankara Ocean. The latter opened in the Liassic as shown by the syn-rift sequences observed in the Sakarya zone (Şengör and Yılmaz, 1981; Görür et al., 1983). Upper Triassic radiolarian cherts locally associated with pillow-lavas are common in the Izmir-Ankara mélanges and were considered as an evidence for a Late Carnian opening of this ocean (Tekin et al., 2002; Göncüoğlu et al., 2003). In view of the merging of the two mélanges found on the Sakarya basement (Triassic Karakaya Complex and Upper Cretaceous ophiolitic mélange), lithologies older than Jurassic are likely derived from the Karakaya Complex (Norman, 1993). Therefore, the Anatolian block northern margin (characterized by Late Triassic volcanics) was not the southern conjugate margin of the Izmir-Ankara Ocean, both areas being juxtaposed only during the Late Cretaceous (Stampfli and Borel, 2004).

4. The Anatolian terrane (Figs. 6, 7, and 8)

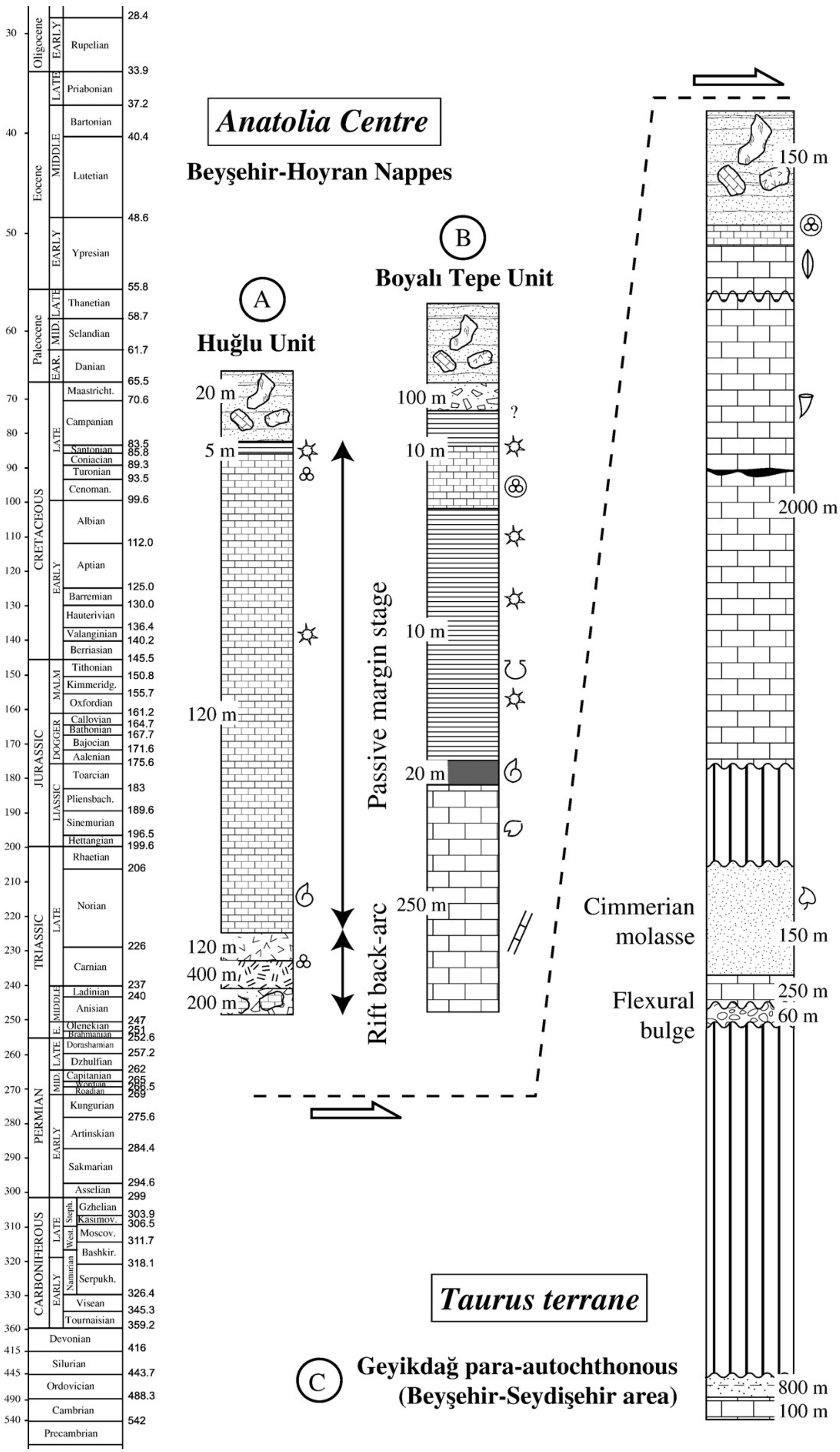
The Tavşanlı and Afyon zones of Okay (1984, 1986) correspond to the Anatolides of Ketin (1966) which include also the Menderes Massif (Fig. 1). The Tavşanlı zone is characterized by a Late Cretaceous blueschist metamorphism (Okay et al., 1998; Sherlock et al., 1999). It represents the northward subducted continental margin of the Anatolian platform. It is thrust over the Afyon zone, composed of Devonian to Paleocene metamorphosed sedimentary rocks in the greenschist facies (Okay, 1986; Okay et al., 1996). Eastward, the Central Anatolian Crystalline Complex (Nigde, Akdağ and Kirşehir massifs) may be seen pro parte as a core complex within the Anatolian zone (Whitney and Dilek, 1997, 1998, 2000). The CACC was formerly covered by ophiolitic nappes found in most areas of the Anatolian terrane. In that regard, the "Inner Taurides suture" does not exist, these ophiolites now surrounding the CACC being formerly located on top of it before the unroofing processes.

The Anatolian terrane is of Eurasian origin and joined the Taurus terrane during the Carnian–Early Norian closing of the Paleotethys (Stampfli et al., 2003). Before that, the slab roll-back of the Paleotethys detached the Anatolian terrane from Eurasia through the opening of a series of back-arc basins within the Eurasian active margin. The rapid collapse of the Variscan cordillera started in most places during the Permian. Active rifting leading to sea-floor spreading in the back-arc basins can be placed in Early to Middle Triassic times. This led to the formation of the northern Anatolian passive margin whose remnants are found as dismembered tectonic units (nappes) resting on the Taurus terrane. Characteristic deposits are open marine syn-rift sediments associated with widespread volcanic activity (Huğlu-type series). These events can be correlated with the Pietra Verde event of the Hellenides, Dinarides, and northern Italy (e.g. Ziegler and Stampfli, 2001).

The substratum of the Anatolian passive margin is observed only in very few places: the Karaburun area in western Turkey (e.g. Kozur, 1995a, 1998a,b, 1999a,b, 2000b; Stampfli et al., 2003), thrust sheets at the base of the Lycian Nappes (Kozur et al., 1998; Kozur and Şenel, 1999), the Konya region (Göncüoğlu et al., 2000; Eren et al., 2004), and the Bitlis Massif (Bergougnan, 1987). In these areas, the substratum of the Anatolian terrane is made of a series of pelagic, clastic, and volcanic rocks ranging from Silurian to Carboniferous. In the Lycian Nappes, we recently confirmed the presence of a Carnian wildflysch including Upper Carboniferous seamounts and a Lower Carboniferous mélange including MORBs, pelagic limestones, and radiolarites. Most of these sequences can be replaced in a context of a Carboniferous fore-arc basin evolving toward a Late Permian to Triassic arc. The Triassic arc is a characteristic feature of the sequences belonging to the Anatolian terrane and is totally absent from the Taurus terrane. The Anatolian terrane can be correlated westward to the Sitia-Arna terrane of the external Hellenides, representing the southern passive margin of the Triassic back-arc Pindos Ocean (Champod et al., 2003; Stampfli et al., 2003). Hence, the ocean bordering the northerly Anatolian-Sitia terrane will be referred to here as the Huğlu-Pindos Ocean. Eastward, in its former pre-Triassic position (Stampfli and Borel, 2004), the Anatolian terrane continued into the Sakarya terrane. The latter is also located to the south of another Triassic back-arc basin, the Küre Ocean, which opened in the region of the present Black Sea (Kozur et al., 2000).

Some of the nappe systems defined by Brunn et al. (1971) in southern Turkey represent allochthonous parts of the Anatolian terrane. These are the Lycian Nappes (Fig. 6A–C) lying on the Beydağları/Menderes autochthonous in the west (de Graciansky, 1972; Bernoulli et al., 1974; Poisson, 1977; Gutnic et al., 1979; Ricou et al., 1979); the Beyşehir-Hoyran Nappes (Fig. 7A–C) lying on the Geyikdağ autochthonous in the central part (Özgül, 1976, 1997; Monod, 1977; Gutnic et al., 1979; Andrew and Robertson, 2002; Andrew, 2003) and the Bitlis domain (Fig. 8A–B) in the east (Özgül, 1976; Özgül and Turşucu, 1984; Pampal and Kurtman, 1984; Perinçek and Kozlu, 1984; Yazgan, 1984; Bergougnan, 1987; Özer et al., 2004). There, the ophiolites and related imbricate structures are clearly sealed by Maastrichtian shallow water limestones. The underlying para-autochthonous (e.g. Beydağları, Geyikdağ) of all these nappes belongs generally to the Taurus terrane flexured in the Eocene. A flysch development preceded the emplacement of the Anatolian Nappes with their ophiolites, the latter corresponding to a synchronous Late Cretaceous obduction event generally sealed by a Maastrichtian carbonate platform (Fig. 5).

Fig. 6. Anatolia West: synthetic lithostratigraphic sections of the autochthonous (aut.) and one allochthonous (all.) series. (A) is compiled from Gutnic et al. (1979); (B) is modified from de Graciansky (1972); (C) is compiled from de Graciansky (1972) and Monod and Akay (1984). Key on Fig. 2 and location of the sections on Fig. 5.


Anatolia Centre
Beyşehir-Hoyran Nappes
A
Huğlu Unit
B
Boyalı Tepe Unit
20 m
5 m
120 m
120 m
400 m
200 m
100 m
?
10 m
10 m
20 m
250 m
Passive margin stage
Rift back-arc
150 m
2000 m
Cimmerian molasse
150 m
Flexural bulge
250 m
60 m
800 m
100 m
Taurus terrane
C
Geyikdağ para-autochthonous
(Beyşehir-Seydişehir area)
Oligocene
Eocene
Paleocene
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
EARLY
LATE
MIDDLE
MID.
EAR.
MALM
DOGGER
LIASSIC
E.
Steph.
West.
Namurian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanetian
Selandian
Danian
Maastricht.
Campanian
Santonian
Coniacian
Turonian
Cenoman.
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
Kimmeridg.
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbach.
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
Ladinian
Anisian
Olenekian
Brahmanian
Dorashamian
Dzhulfian
Capitanian
Wordian
Roadian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimov.
Moscov.
Bashkir.
Serpukh.
Visean
Tournaisian
Devonian
Silurian
Ordovician
Cambrian
Precambrian
28.4
33.9
37.2
40.4
48.6
55.8
58.7
61.7
65.5
70.6
83.5
85.8
89.3
93.5
99.6
112.0
125.0
130.0
136.4
140.2
145.5
150.8
155.7
161.2
164.7
167.7
171.6
175.6
183
189.6
196.5
199.6
206
226
237
240
247
251
252.6
257.2
262
265
268.5
269
275.6
284.4
294.6
299
303.9
306.5
311.7
318.1
326.4
345.3
359.2
416
443.7
488.3
542
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
360
415
445
490
540

5. The Taurus terrane (Figs. 9 and 10)

This terrane is a typical Cimmerian block (Şengör, 1979) recording the rifting/opening of the Paleotethys north of it in the Devonian and of the Neotethys south of it in the Permian (Fig. 1). Both periods correspond to locally large stratigraphic gaps and unconformities, but without major deformation or metamorphism. It shows an evolution similar to the Cimmerian–Iranian blocks located east of it. West of it, it corresponds to the most external part of the Hellenides. It comprises the Beydağları domain of southwest Turkey, forming altogether the Cimmerian Greater Apulian terrane (Stampfli et al., 1991, 2003) (Fig. 1). The Taurus terrane consists of a pre-Cambrian basement and a Paleozoic–Mesozoic cover mainly represented by carbonate platform-type sediments (Fig. 9). Together with the Pan-African Menderes Massif which is part of it (Şengör, 1984; Hetzel and Reischmann, 1996; Dannat and Reischmann, 1998, 1999), the Taurus terrane presents no Variscan deformations. On the contrary, it records the opening of the Neotethys south of it during its separation from the Gondwana in Permian times (Stampfli, 2000; Stampfli et al., 2001). This event and its related rift shoulder uplift created locally large-scale unconformities between the Permo-Triassic and older Paleozoic series. This is often regarded as "Variscan" unconformities, but no flysch, metamorphism or folding is observed.

The major event characterizing the Tauric sequence is the Eo-Cimmerian tectonic event (Fig. 10A–I) and associated sediments and deformation (Carnian–Early Norian closing of the Paleotethys). This Eo-Cimmerian phase of deformation is mainly recorded in the Taurus terrane (Monod and Akay, 1984), with major clastic input, unconformities, and flysch-like deposits (Gutnic et al., 1979). It is sealed by a Late Triassic widespread molassic sequence, and followed by the development of Upper Triassic–Liassic carbonate platforms, found both on the Taurus and Anatolian terranes. A similar evolution is also found in the adjacent Cimmerian domains of Greece and Iran (Krahl et al., 1983; Baud and Stampfli, 1989; Bagheri et al., 2003; Stampfli et al., 2003). In these two regions, the subduction of the Paleotethys was toward the north, the Eurasian margin being the active one and the Cimmerian margin being passive. The carbonate platform sealing this orogenic event usually started in the Late Triassic or locally not before the Middle Jurassic. In most places, the Tauric series would proceed with little interruption up to the Middle Eocene flysch deposits (Monod, 1977). At that time, it was overthrust by the Anatolian Nappes. In the Late Miocene, most of the Tauric sedimentary cover was detached from its basement and displaced to its present position. This was made following a subduction progradation into the East-Mediterranean realm and the Middle Miocene closure of the space between the Taurus-Menderes and the Beydağları domains (Gutnic et al., 1979). Before that, the southern border of the Taurus terrane was the site of emplacement of ophiolitic mélanges, from the latest Cretaceous through the Paleocene. These sequences define a South-Taurides exotic domain (see below), in which mélanges were juxtaposed to the Taurus or Greater Apulian terranes (i.e. Beydağları), as found in the Antalya Nappes.

The Taurus terrane presents several contrasting sequences. This is due to the Eo-Cimmerian deformation events which can be followed throughout the Taurus (Fig. 10A–I). The terrane being in lower plate position during its collision with the Anatolian terrane, it developed a flexural basin that was locally inverted in the Late Triassic. During the Late Cretaceous obduction of the ophiolites onto the Anatolian domain, the obducted nappes locally reached the Taurus terrane, and even went over it in its eastern segment. The ophiolites were then caught up in a westward slab retreat of the East-Mediterranean Ocean and redistributed along the southern margin of the Taurus domain mainly during the Paleocene. Typical Tauric sedimentary sequences are represented by the Geyikdağ Unit (Özgül, 1976) (Fig. 7C). The Tauric sedimentary sequences start usually in the Cambrian/Ordovician and end in the Late Cretaceous or later, depending on the proximity of the Anatolian ophiolitic front. The Taurus sequences closest to the Anatolian obduction front are found near Pınarbaşı (Altıner, 1981). There, the para-autochthonous sequence mainly presents a Devonian to Late Cretaceous neritic sedimentation. The sequence is interrupted during the Upper Triassic by the Eo-Cimmerian event accompanied by clastic input. This sequence is overthrust by allochthonous ophiolitic and sedimentary sequences. The neo-autochthonous cover is characterized by three successive sequences: the first one is composed of Upper Maastrichtian–Paleocene conglomerates derived from the allochthonous series; the second one is mainly made of Lutetian limestones and lays unconformably over the conglomerates; the third one is characterized by Upper Miocene conglomerates (Altıner, 1981).

On a more external position (between Silifke and Anamur), the autochthonous sequences of the Taurus terrane present a sedimentation ranging from the Cambrian to the Late Cretaceous/Paleocene (Demirtaşlı, 1984a,b), or even from the infra-Cambrian to the Middle Miocene (Koç et al., 1997). The Pınarbaşı sequence (Fig. 9) described by Demirtaşlı (1984a,b) can be closely compared with the Alborz series in northern Iran, recording the opening of both Paleo- and Neotethys. The Late Ordovician pebbly sandstone formation mark the Hirnantian glacial event (Monod et al., 2003). We associate it with the onset of the Paleotethys rifting, the rift shoulders being elevated and covered by temporary ice-sheets. A Lower Silurian black shale episode follows the glacial event and suggests a deposition in a restricted basin within the rift zone. This detrititic event can be related to the erosion of the Paleotethys rift shoulder, following thermal expansion uplift related to the onset of oceanic spreading. Subsequent thermal subsidence allowed the unconformable deposition of the Middle to Late Devonian series. This sequence marks the passive margin stage that lasted up to the Early Permian, when thermal uplift related to the opening of the

Fig. 7. Anatolia Centre: synthetic lithostratigraphic sections of a para-autochthonous and some allochthonous series. (A) compiled from Gökdeniz (1981), Monod (1977) and Özgül (1984); (B) modified from Monod (1977); (C) compiled from Özgül (1976, 1984). Key on Fig. 2 and location of the sections on Fig. 5.

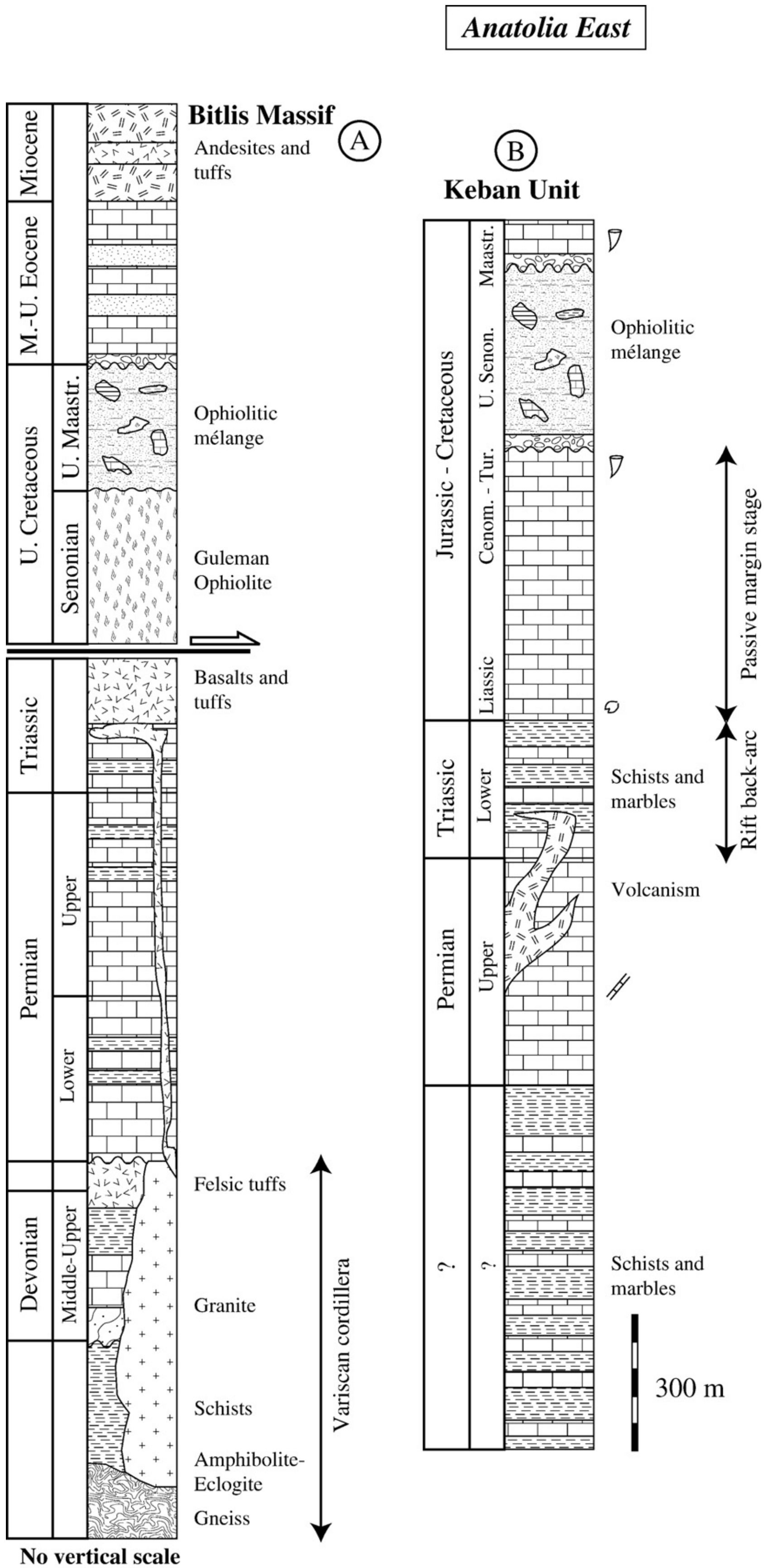


Fig. 8. Anatolia East: synthetic lithostratigraphic sections of the Bitlis Massif and the Keban Unit. (A) compiled from Bergougnan (1987) and Göncüoğlu and Turhan (1984); (B) compiled from Bergougnan (1987) and Özgül and Turşucu (1984). Key on Fig. 2 and location of the sections on Fig. 5.

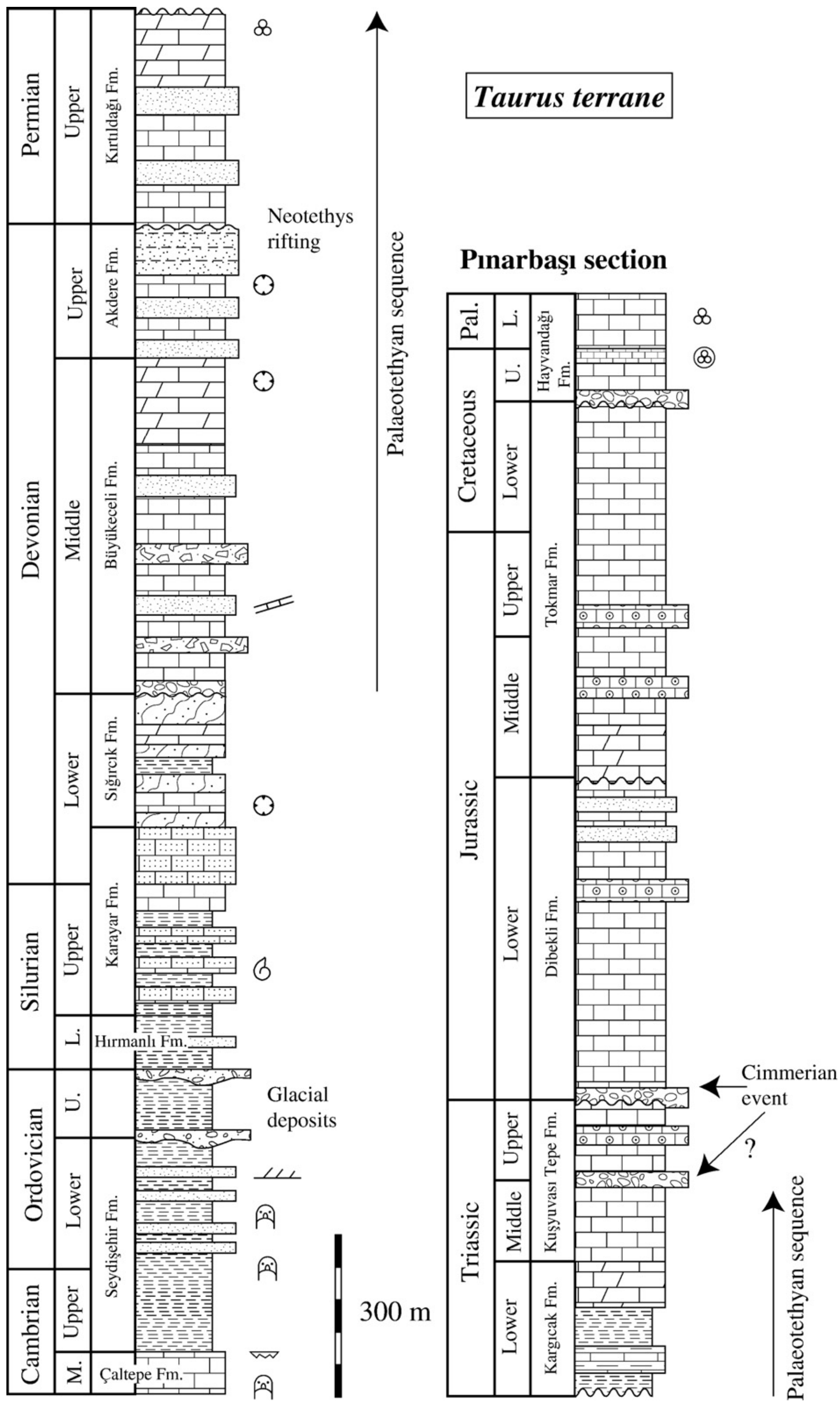


Fig. 9. Taurus terrane: synthetic lithostratigraphic section of a typical Tauric series between Silifke and Anamur (Pınarbaşı section). Compiled from Demirtaşlı (1984a,b). Key on Fig. 2 and location of the section on Fig. 5.

Neotethys created again major erosion and unconformities. The Carboniferous sequence is therefore often lacking. Locally, the Upper Permian made of limestones and quartzitic sandstones, overlies unconformably the Devonian. It corresponds to the flooding of the Neotethyan rift shoulder and to the onset of a new (Neotethyan) passive margin sequence. The subsequent Eo-Cimmerian event (Fig. 10A–I) is characterized by large-scale unconformities, flysch/molasse deposits during the Late

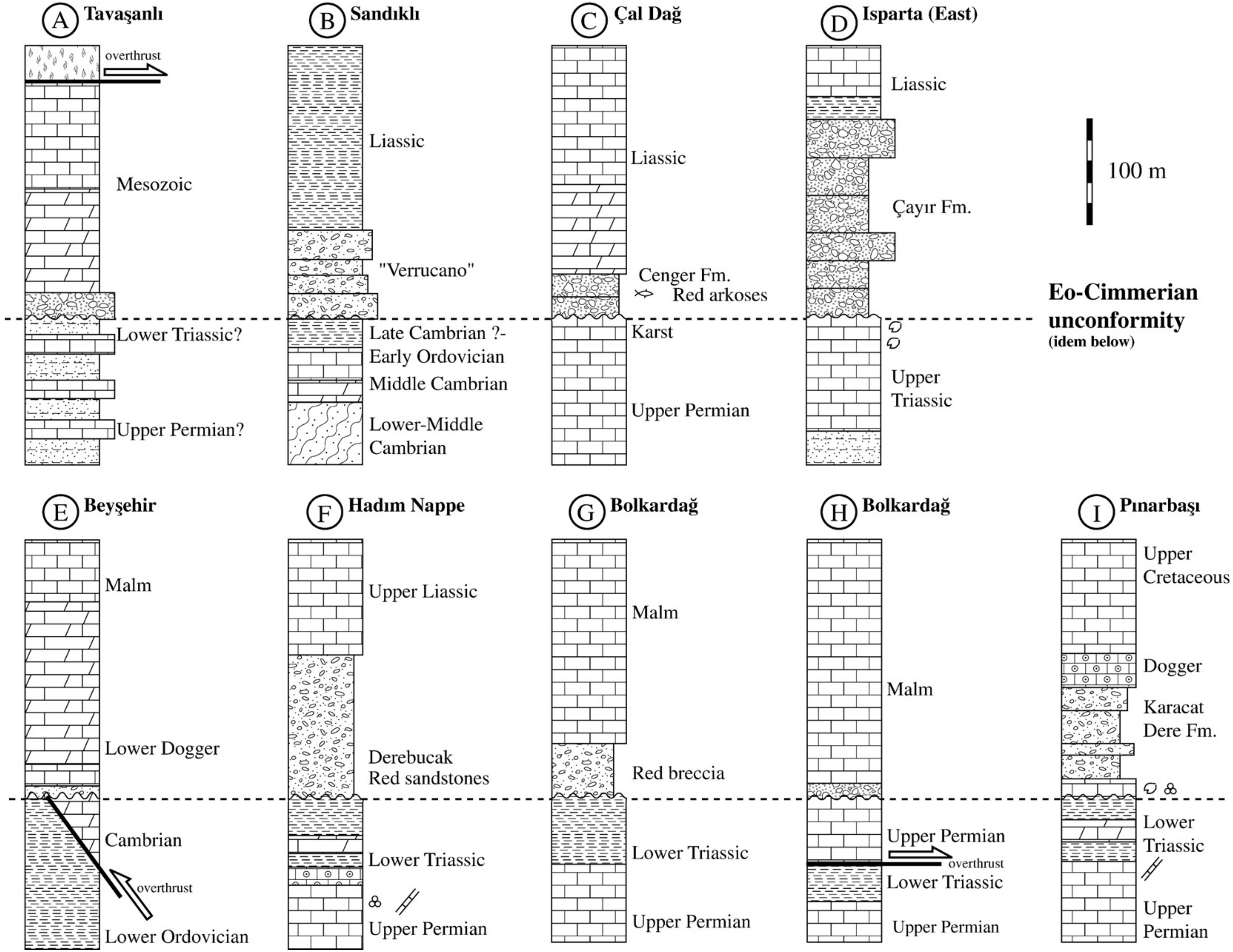


Fig. 10. The Eo-Cimmerian unconformities in the Taurus terrane. All sections are modified from Monod and Akay (1984), except (B) compiled also from Dean and Özgül (1994) and Erdoğan et al. (2004) and except (E) compiled also from Akay (1981). Key on Fig. 2 and location of the sections on Fig. 5.

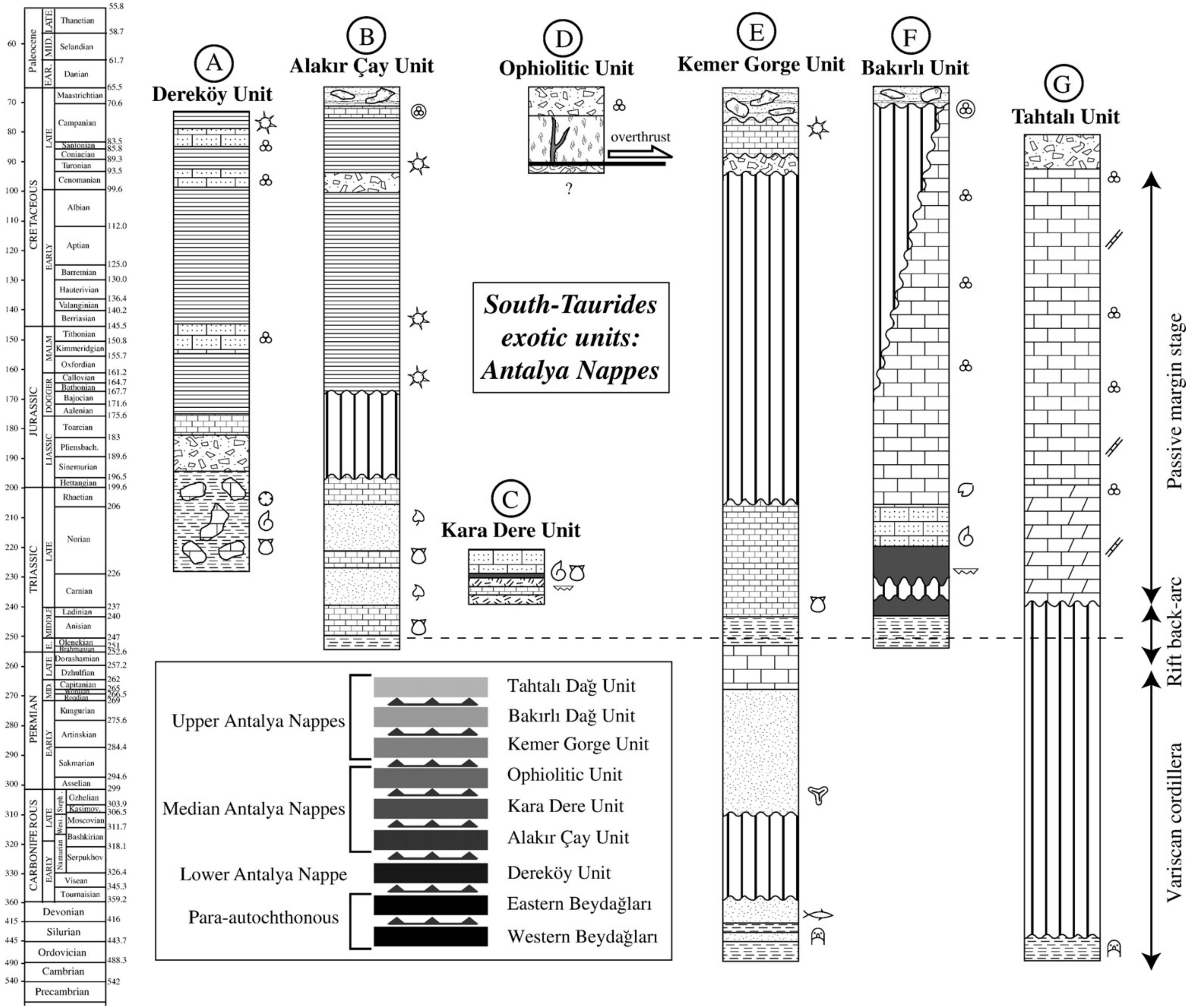


Fig. 11. South-Taurides exotic units: synthetic lithostratigraphic sections of the Antalya Nappes and the Beydağları para-autochthonous (see also Fig. 6), with their structural relationships. All sections are modified from Marcoux (1987a,b), except (D) from Whitechurch (1993). Key on Fig. 2 and location of the sections on Fig. 5.

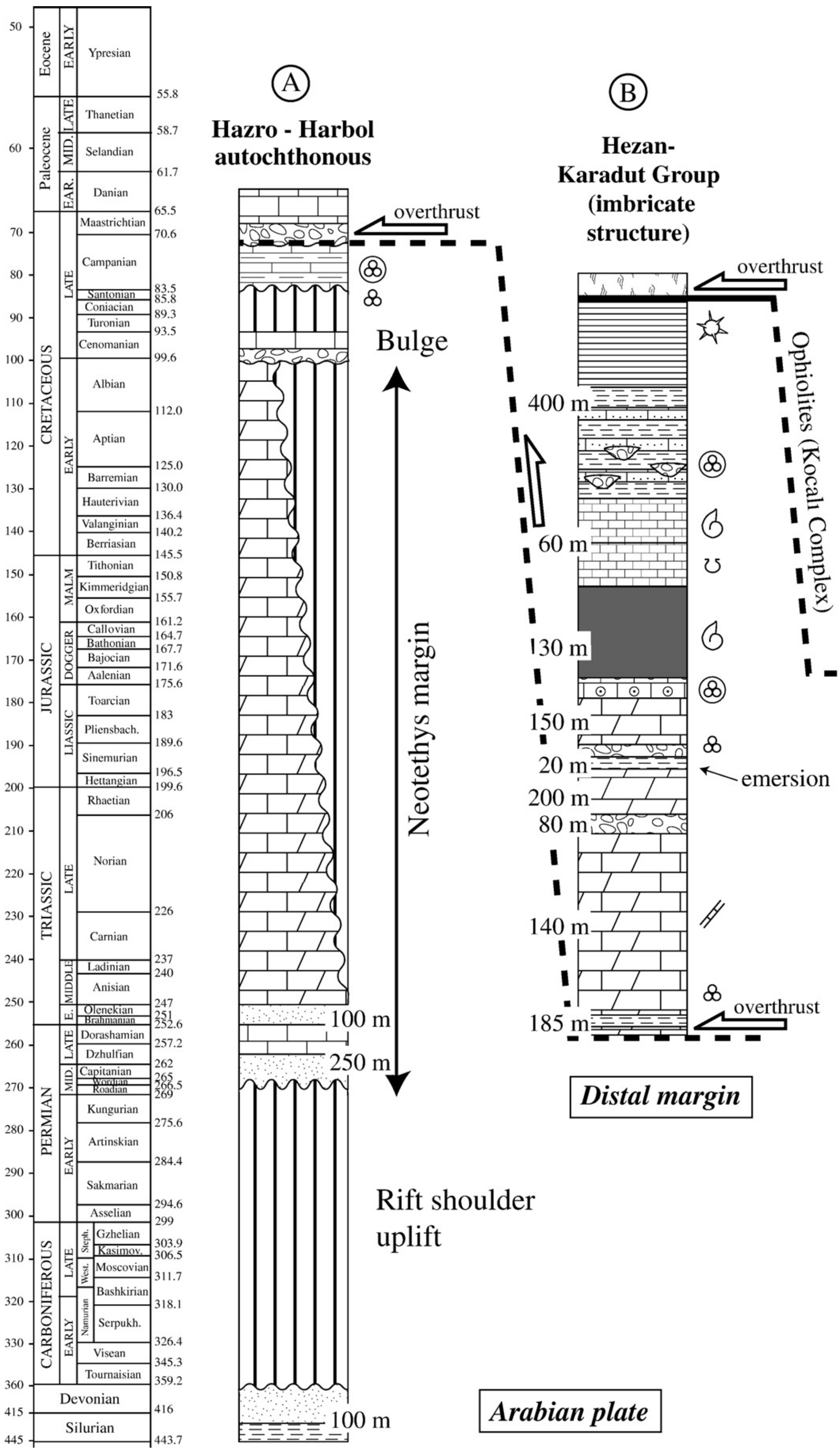


Fig. 12. Arabian plate: synthetic lithostratigraphic sections of the Hazro-Harbol autochthonous (A) and the Hezan-Karadut Group (B). Both sections modified from Fontaine (1981). Key on Fig. 2 and location of the sections on Fig. 5.

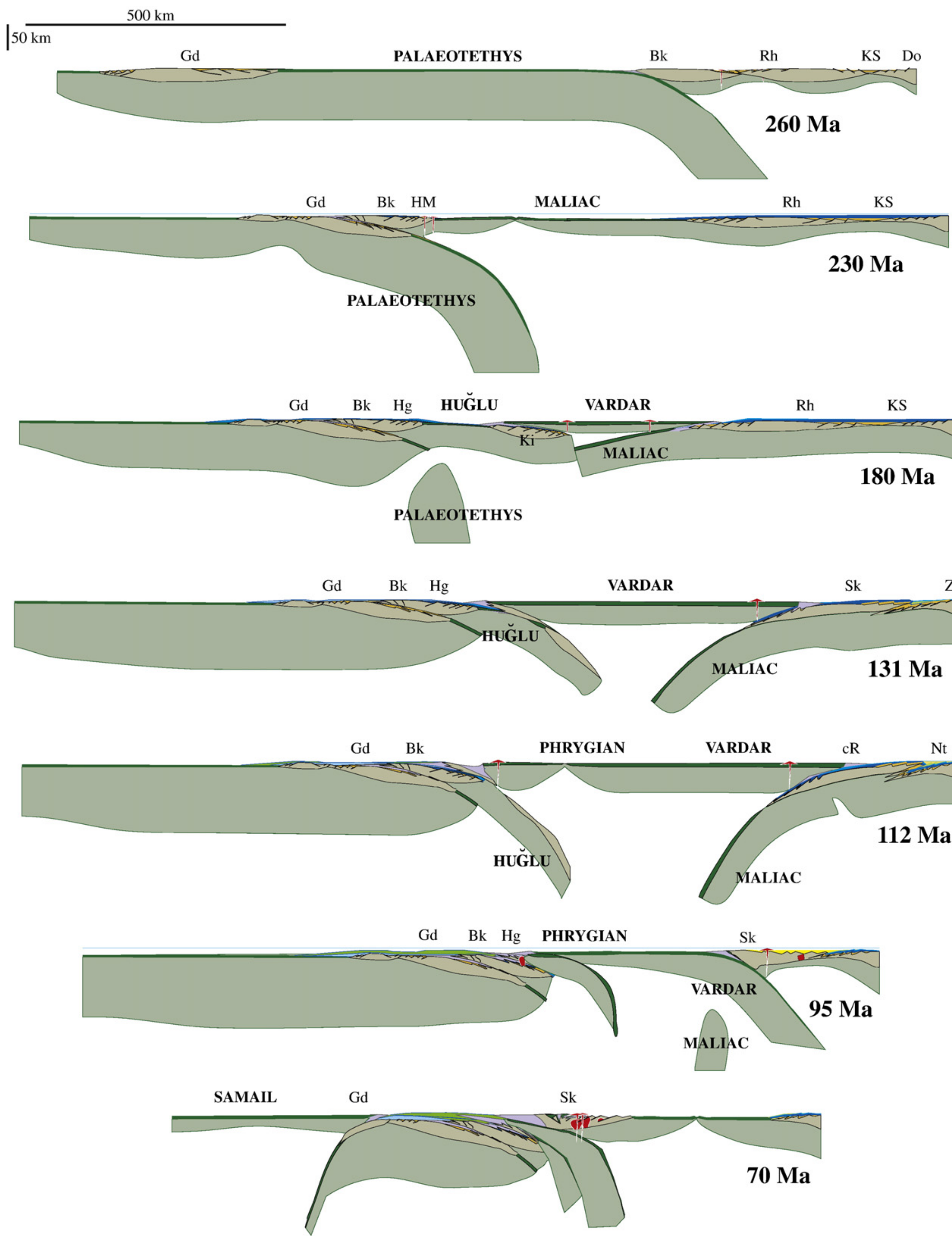
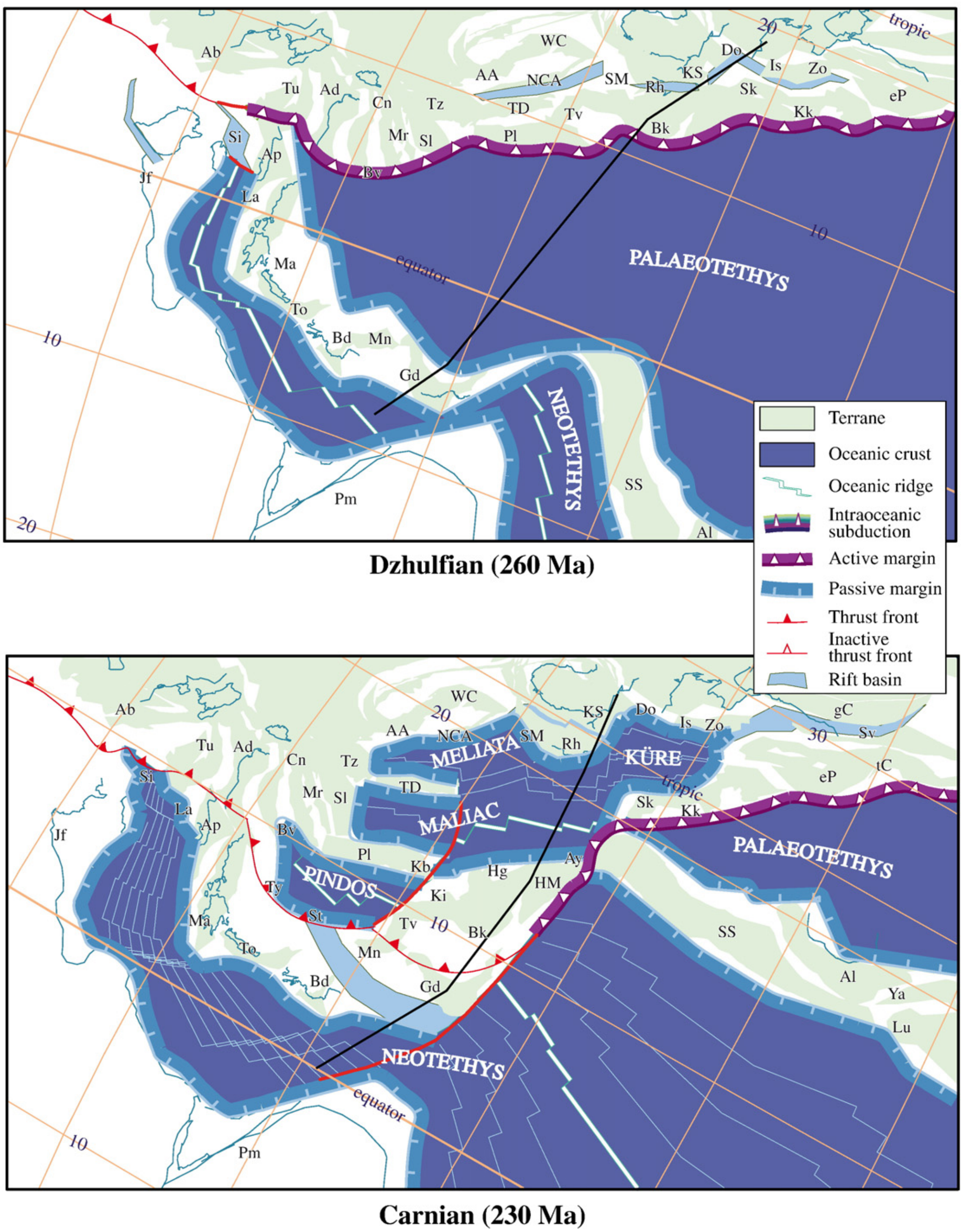


Fig. 13. Late Permian to Eocene palinspastic cross-sections through the East-Mediterranean realm. Traces of the palinspastic sections are on Figs. 14, 15, 16 and 17. Key on Fig. 14.

Triassic/Early Jurassic times, and pre-Jurassic thrusting (Gutnic et al., 1979; Akay, 1981; Monod and Akay, 1984). The Cimmerian molasse is mainly characterized by sandstones, locally associated with plant remains, and conglomerates with rhyolites, lydites, crystalline limestones, quartzites, schists, and quartz as main elements. Possible origins of the pebbles might be either one of the Paleozoic formations situated between Isparta and Seydişehir within the Taurus domain, their Pan-African basement, or the Anatolian domain, rich in lydites and volcanic formations. Some pelagic limestone and chert pebbles were recently dated and gave Paleozoic/Mesozoic ages, most likely derived from the Paleotethys oceanic series (Moix et al., 2007a).

In the sequence described by Demirtaşlı (1984a,b) (Fig. 9), the Eo-Cimmerian event is followed by the deposition of Lower Jurassic conglomerates and limestones. Locally, the Middle Jurassic seals major thrust faults. The Middle Jurassic to Upper Cretaceous sedimentation is characterized by the development of thick platform-type deposits in a stable environment. Finally, the Upper Cretaceous–Paleocene rests unconformably over the underlying sequences. It usually starts with a basal conglomerate with blocks ranging in age from the Cretaceous to the Lower Paleozoic. It is followed by shallow water limestones during the Upper Cretaceous passing upward to pelagic limestones during the uppermost Cretaceous. This erosion/deepening event is related to the flexure of the margin. The sedimentation became again neritic (benthic foraminifera) during the Paleocene. Thus, and despite its flexure, this continuous Cretaceous–Paleocene sequence precludes the passage of the ophiolitic nappes over that



part of the Tauric autochthon. A similar conclusion was drawn in the central Tauric series by Baudin et al. (1994).

5.1. The Pan-African Menderes metamorphic Massif

The Menderes Massif is a core complex exhumed in the Late Tertiary (e.g. Bozkurt and Oberhänsli, 2001; Gessner et al., 2001; Işik et al., 2004). The Izmir-Ankara-Erzincan suture bounds it to the north (including the Bornova flysch zone), the Lycian Nappes to the south, and the Afyon zone to the east (Fig. 1). In its southern region, the stratigraphy of the Menderes Massif was subdivided into two tectono-stratigraphic units: the core and the cover units (Şengör, 1984), which are themselves subdivided in more detail (Özgül, 1976; Dora et al., 2001; Özer et al., 2001; Rimmelé et al., 2003). The core series comprise Precambrian to Cambrian gneisses, schists, metagranites, migmatites and metagabbros belonging to the Pan-African basement, plus eclogite and granulite relics (Hetzel and Reischmann, 1996). The cover series comprise schists attributed to the Ordovician to Devonian period, with channels filled by metaconglomerates consisting mainly of quartzite and granite pebbles. They also comprise Permo-Carboniferous metaquartzites with metacarbonates alternation including graphite veins. The latter are followed by Upper Triassic metaconglomerates with quartzite pebbles and quartzite/schist intercalations. The cover series continues with Jurassic to Cretaceous platform-type marbles, including bauxite pockets around the Jurassic–Cretaceous boundary and rudists at the top. The Campanian/Maastrichtian interval is then represented by thin-bedded red pelagic marbles. An ophiolitic metaolistostrome and flysch, containing serpentinites, metagabbros, eclogites, and varied marble blocks embedded in a chlorite/albite schist matrix, was deposited during the Late Maastrichtian/Early Paleocene. Paleocene and Ypresian sediments including Nummulites (Gutnic et al., 1979) were found below the ophiolitic olistostrome (Boray et al., 1973). Both the core and the cover units are tectonically overlain by the Lycian Nappes and the stratigraphic sequence is cut by Early Triassic leucocratic metagranites and Miocene granitoid stocks (Dora et al., 2001).

In the Sandıklı-Afyon region, the Pan-African basement (Gutnic et al., 1979; Dean and Özgül, 1994; Gürsu and Göncüoğlu, 2001; Gürsu et al., 2004) of probable Menderes affinity yielded ages of 543±7 Ma (Kröner and Şengör, 1990) and 541.3±10.9 (M. Satır in Gürsu and Göncüoğlu, 2006) and is overlain by Cambro-Ordovician series. These series are unconformably covered by Liassic clastics grading to a Middle Jurassic carbonate platform. We interpret this contact as a typical Eo-Cimmerian unconformity, thus confirming the Tauric affinity of the Menderes Massif and suggesting that large areas of the massif may have been totally eroded during the Triassic period. Some "cover series" of the Menderes Massif (e.g. Çarak göl and Tekkeçal Tepe sections of Sarp, 1976) are quite different and are characterized by the Late Cretaceous ophiolite obduction. Other units also include Triassic magmatic events (Dora et al., 2001). Therefore, we do not regard these "cover series" as Menderes-Tauric "sedimentary cover" of the Pan-African basement, but as slivers of metamorphic Anatolian Nappes at the base of the Lycian Nappes.

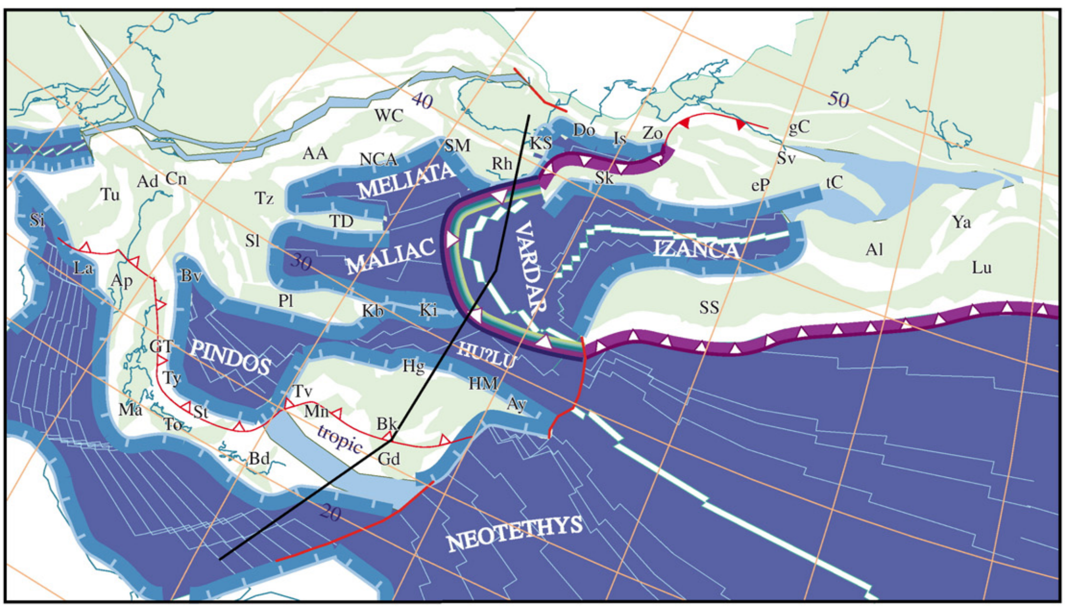
6. The South-Taurides exotic units (Fig. 11)

The Mersin Ophiolitic Complex (Demirtaşlı et al., 1984; Pampal, 1987; Parlak, 1996; Masset and Moix, 2004; Özer et al., 2004; Parlak and Robertson, 2004; Moix et al., 2007a,b) is a key point in the development of the new South-Taurides exotic units (Fig. 1). Other key units are found in the Pozantı−Karsantı−Faraşa Massif (Demirtaşlı et al., 1984; Tekeli et al., 1984; Dilek and Whitney, 1997; Dilek et al., 1999), the Antalya Nappes (Lefèvre, 1967; Gutnic et al., 1979; Marcoux, 1987a,b) (Fig. 11/A−G) and the Troodos-Mamonia Complex in Cyprus (Lapierre, 1975; Robertson, 1977; Robertson and Woodcock, 1979; Swarbrick and Robertson, 1980; Malpas et al., 1993; Urquhart and Banner, 1994). This new domain is made of exotic elements of the Anatolian terrane now found south of the Taurus terrane. They are

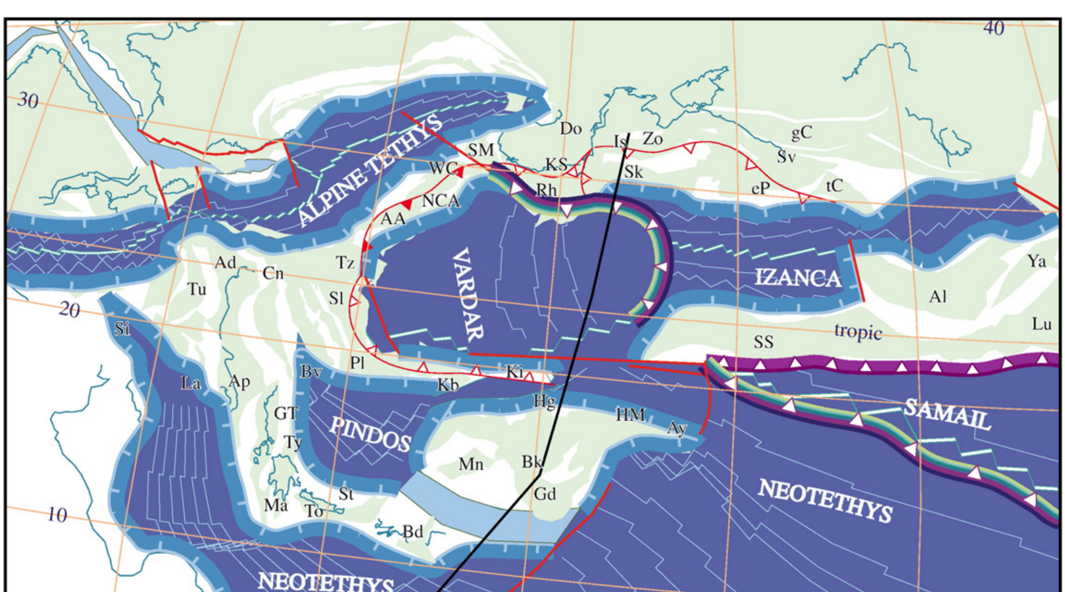
Fig. 14. Dzhulfian (260 Ma) and Carnian (230 Ma) paleotectonic reconstructions. As the Paleotethys subduction came to a final stage, slab roll-back along its northern margin accelerated and was marked by the opening of oceanic back-arc basins. There was still enough space available to open successive back-arc basins south of Meliata, the Maliac, then Pindos basin, before the final closure of Paleotethys in Carnian or Early Norian times. A detailed account of these opening is given in Stampfli and Kozur (2006). To the east, back-arc rifting was very active also in the Caucasus (Svanetia) and north Iran (Agh-Darband). The Nilüfer seamount was colliding with the Karakaya fore-arc basin, and both soon collided with the Cimmerian terranes. This induced soon after the closing of the Küre back-arc along a south-directed subduction. The East-Mediterranean part of the Neotethys was still spreading. A position around 10°N of the Taurus and Anatolian terranes is in agreement with Théveniaut et al. (1993) for the Bakırlı section. The Greater Apulia-Taurus Cimmerian block is being separated from the Beydağları. In the Late Triassic the Paleotethys was completely closed from Greece to the Himalayas. In Iran, this closing generated the development of a large molassic basin (Shemshak) followed by subduction progradation to the northern side of Neotethys, and the onset of subduction-related volcanism in the Sanandaj-Sirjan and Lut blocks, already in the Late Triassic. On an Anatolian-Tauric transect, there was no subduction progradation and the spreading in the Pindos back-arc stopped; the Eo-Cimmerian orogenic zone was rapidly eroded and covered by large carbonate platforms. Key areas: AA, Austro-Alpine; Ab, Alboran; Ad, Adria s. str.; Al, Alborz; Ap, Apulia s. str.; Ay, Antalya; Bd, Beydağları; Be, Betic; Bf, Baft ophiolite; BH, Baër-Bassit-Hatay ophiolites; Bk, Bozdağ-Konya fore-arc; Br, Briançonnais; Bu, Bucovinian; Bv, Budva; Ca, Calabria; cB, central Bosnia; Cn, Carnic; Da, Dacides; Db, Dent-Blanche; Do, Dobrogea; EBS, Eastern Black Sea; El, Elazığ-Guleman ophiolites and arc; eP, east Pontides; Er, Eratosthen; gC, great Caucasus; Gd, Geyikdağ-Anamas-Akseki; GT, Gavrovo-Tripolitza; Hg, Huğlu-Boyalı Tepe; hK, high Karst; HM, Huğlu-Mersin; Is, Istanbul; Jf, Jeffara rift; Kb, Karaburun; Ki, Kirşehir; Kk, Karakaya fore-arc; Ko, Korab; Kr, Kermanshah ophiolite; KS, Kotel-Strandja rift; Ky, Kabylies; La, Lagonegro; Li, Ligurian; Lu, Lut; Ma, Mani; Mk, Mangyshlak rift; Mm, Mamonia accretionary Complex; Mn, Menderes; MP, Mersin-Pozantı ophiolites; Mr, Mrzlevodice fore-arc; NC, North Caspian; NCA, North Calcareous Alps; Nn, Nain ophiolite; Ny, Neyriz ophiolite; Oz, Ötztal-Silvretta; Pa, Panormides; Pi, Piemontais; Pl, Pelagonian; Pm, Palmyra rift; Pn, Pienniny rift; Rh, Rhodope; Ri, Rif internal; sB, sub-Betic rim basin; sC, Scythian platform; SC, South Caspian; Si, Sicanian; Sl, Slavonian; Sk, Sakarya; SM, Serbo-Macedonian; SS, Sanandaj-Sirjan; St, Sitia E-Crete; Sv, Svanetia rift; Sz, Sabzevar ophiolite; tC, trans-Caucasus; TD, Transdanubian; Tk, Tuarkyr; To, Talea Ori; Tp, Troodos ophiolite; Tu, Tuscan; Tv, Tavas Nappe; Ty, Tyros fore-arc; Tz, Tizia; UM, Umbria-Marches; Va, Valais trough; WBS, Western Black Sea; WC, West Carpathian; Ya, Yazd; Zo, Zonguldak.

juxtaposed to elements derived from the Neotethys/Taurus terrane, and emplaced onto the Taurus southern margin (Mersin) or Beydağları domain (Antalya) in the Paleocene (Fig. 1). The main Anatolian elements are represented by sequences belonging to the northern margin of the Anatolian terrane, i.e. the Triassic syn-rift volcanic event (Huğlu-type series) and the Late Cretaceous obducted ophiolitic sequences (Fig. 5). Tauric elements are represented by Eo-Cimmerian flysch-like sequences including Paleotethyan material (Moix et al., 2007a) intercalated in Neotethyan series. This mixture of Anatolian and Tauric elements, emplaced onto more external platforms, is locally sealed by nummulitic limestones like in the Eğridir region (Gutnic et al., 1979).

Similar mélanges are found in Cyprus (Mamonia Complex) and Syria (Baër-Basit). Therefore, an arc-like accretionary front joined at some time the southern Taurus domain to the Arabian promontory, cutting across the Neotethyan East-Mediterranean Basin (see discussion below). As in the Anatolian domain, the peri-Arabian ophiolitic obduction is sealed by a Maastrichtian platform, whereas the Mersin-Antalya-Cyprus accretionary domain continued its westward migration at least until the Paleocene. Closing of the accretionary orocline on itself took



Toarcian (180 Ma)



Hauterivian (131 Ma)

place during the Eocene–Miocene interval, generating arc magmatism to the north (e.g. Maden Complex) (Aktaş and Robertson, 1984; Perinçek and Kozlu, 1984; Yazgan, 1984; Bergougnan, 1987; Robertson et al., 2006) and finally juxtaposing peri-Arabian elements to Anatolian elements around the Arabian promontory. As a consequence, the Tauric and South-Taurides elements have been nearly totally subducted or tectonically eroded during the collision processes in that region. The suture zone between these two domains is also found in Cyprus between the Kyrenia Range (Taurus terrane) and the Troodos-Mamonia Complex (Baroz, 1976, 1980; Robertson and Woodcock, 1986).

7. The peri-Arabian domain (Fig. 12)

In eastern Turkey, the peri-Arabian domain (Fig. 1) is represented by the Hazro-Harbol autochthonous overthrusted by the Hezan-Karadut imbricate structures (Fontaine, 1981; Bergougnan, 1987; Fontaine et al., 1989) (Fig. 12A–B) and by the Kızıldağ ophiolite in Hatay (Ricou, 1971; Pişkin et al., 1986; Robertson, 1986; Dilek and Delaloye, 1992; Dilek et al., 1999). Elsewhere, it is also represented by the Baër-Basit ophiolitic massif in Syria (Lapierre and Parrot, 1972; Delaune-Mayère et al., 1977; Parrot, 1980; Delaune-Mayère, 1984; Pişkin et al., 1986; Al-Riyami and Robertson, 2002; Al-Riyami et al., 2002) and the Samail ophiolite in Oman (Glennie et al., 1974; Béchennec, 1988; Béchennec et al., 1990; Le Métour et al., 1995; Pillevuit et al., 1997; Stampfli et al., 2001; Stampfli and Borel, 2002). Since the Permian, the peri-Arabian domain represents the northern Gondwana passive margin after the drifting of the Cimmerian blocks and concomitant opening of Neotethys (Al-Belushi et al., 1996; Angiolini et al., 2003a,b). This segment of the southern Neotethys Ocean passive margin is characterized by Lower Permian syn-rift sequences and volcanics. These series are found in Sicily, Greece, Iran, Oman, the Tethys Himalaya, and north of Australia (Catalano et al., 1991, 1992; Stampfli et al., 2001; Langhi and Borel, 2005; Kock et al., 2007), witnessing a simultaneous opening of the Neotethys all along the Gondwana border. A large rift shoulder uplift (up to 2 km of erosion) was followed by a Middle to Late Permian transgression onto Pan-African Paleozoic or even Neoproterozoic sequences (Gass et al., 1990; Béchennec et al., 1993). In Hazro-Harbol (Fig. 12A), the Middle Permian is transgressive onto the Early Carboniferous. Thereafter, a passive margin sequence, dominated by carbonates, lasted until the Late Cretaceous obduction of the Samail-type ophiolitic nappes, found in Oman, Iran, Iraq, Syria and Turkey (Fig. 5). These were sealed by a short lived Maastrichtian platform. In Oman, part of Turkey and Syria the nappes were never re-displaced during the Alpine collisional events. On the contrary, in the Iranian and Iraqian Zagros and southeast Turkey, the Cretaceous ophiolites and parts of their Gondwanan basement are included in the Tertiary Alpine Nappes.

8. Discussion

The Turkish segment of the Tethysides is subdivided into several terranes, separated by complex suture zones of different ages. Before the mainly north–south displacements marking the Late Cretaceous and Cenozoic period, the different terranes of Turkey underwent large lateral displacements in a roughly east–west direction since the Triassic. This resulted in the duplication of major suture zones (Stampfli and Borel, 2004). Major strike–slip movements during the Variscan orogenic cycle created the first juxtaposition of terranes. These were subsequently dispersed during the collapse of the Variscan cordillera and opening of Triassic back-arc basins (e.g. Küre back-arc in Stampfli and Kozur, 2006). In Late Triassic times, the southernmost Eurasia-derived block (Anatolian terrane) was assembled by the Cimmerian collage with Gondwana-derived terranes (Cimmerian terranes: Greater Apulia, Taurus terranes). Some terranes were finally emplaced only during the Late Cretaceous–Early Tertiary, such as the Antalya-Cyprus exotic domain derived from the Lycian-Anatolian-Samail obduction front, and the Apulia-derived Beydağları domain. The last juxtaposition was realized during the Alpine north–south shortening. The east–west shortening (2000 km) in the Tethyan region is in direct relation to the opening of the Central Atlantic Ocean. This can be measured

Fig. 15. Toarcian (180 Ma) and Hauterivian (131 Ma) paleotectonic reconstructions. Diverging slab roll-back, both in Küre and in the Neotethys, induced the opening of the Izmir-Ankara Ocean. This opening prograded eastward up to the south Caspian region in Middle Jurassic times. The Central Atlantic rift widened and spreading started in the Toarcian (Steiner et al., 1998), the Alpine Tethys rift started to spread in Bajocian times, finally breaking the Pangea super-continent. The opening of the Vardar corresponds to the subduction progradation from the Küre domain toward the Maliac domain. The roll-back of the Maliac sea-floor generated westward spreading of the Vardar Basin in a scenario of intra-oceanic subduction, the Vardar progressively replacing in situ the Maliac-Meliata Ocean. The closure of the Küre Ocean induced a collision in the Black Sea domain and around the Rhodope promontory. During the Oxfordian, spreading in the Alpine Tethys Ocean reached the Carpathian domain. In the process, Moesia was detached from Europe by only a few hundred kilometers. The Küre Ocean was closed and the collision of its arc–trench system with the Rhodope was causing the first phases of the Balkanic orogeny accompanied by inversion of former rift zones. The Vardar arc–trench system was soon to collide with the Pelagonian-Dinaric landmass. This east–west shortening in the Maliac-Vardar domain was due also to the anti-clockwise rotation of Gondwana with respect to Europe, inducing the inception of an intra-oceanic subduction zone in the Vardar. Differential movement between Africa and India reactivated a Neotethys former N–S transform, separating the future Indian plate from Africa. Along this feature, intra-oceanic subduction took place and was at the origin of the Samail Ocean. In the Valanginian–Hauterivian, accelerating anti-clockwise rotation of Gondwana was responsible for the obduction of part of the Vardar mid-ocean ridge system onto the Pelagonian, Dinaric and Tizia blocks. Simultaneously, the Vardar arc–trench system collided with the northern margin of Meliata, detaching the future North Calcareous Alps domain from its basement (internal Austroalpine). Collision of the Vardar arc–trench system continued also in the Balkans, where parts of the Rhodope cover and basement were transported northward and thrust onto the Nish-Troyan trough (Bonev and Stampfli, 2003, 2008). The major changes affecting the Neotethyan domain brought to an end the opening of the Izmir-Ankara Ocean (south Caspian) back-arc basin system. Then, the Izmir-Ankara slab started retreating eastward inducing the opening of a new supra-subduction spreading centre north of the Anatolian plate (Phrygian Ocean). This sytem was linked eastward with the opening supra-subduction Samail Ocean. Key on Fig. 14.

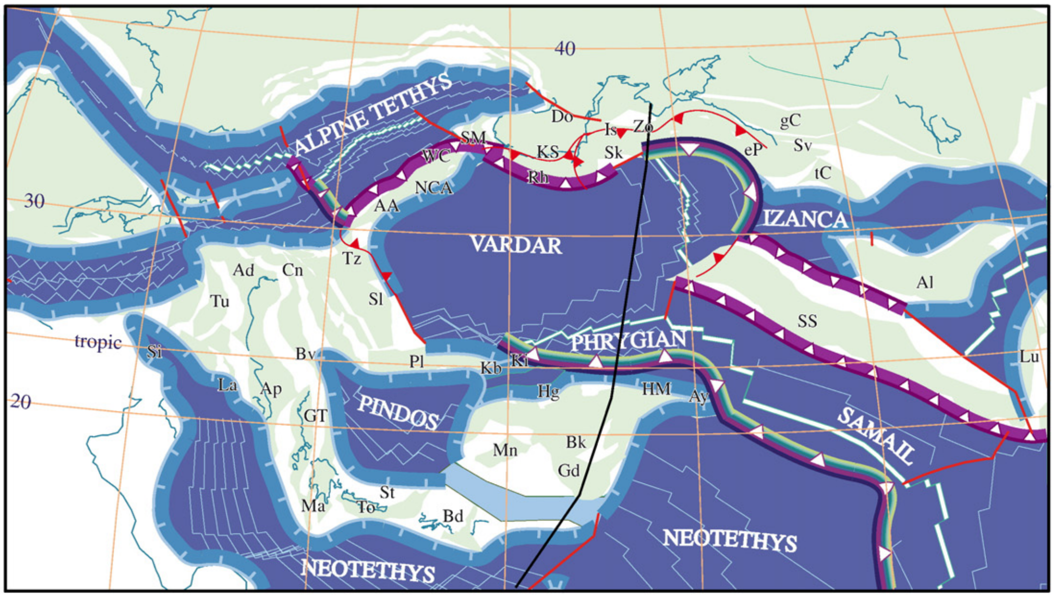
precisely through the magnetic anomalies of the Atlantic, and it is a key factor for any plate tectonic reconstruction of that area (e.g. Dewey et al., 1989).

The following are some of the main points regarding the plate tectonic evolution of the region:

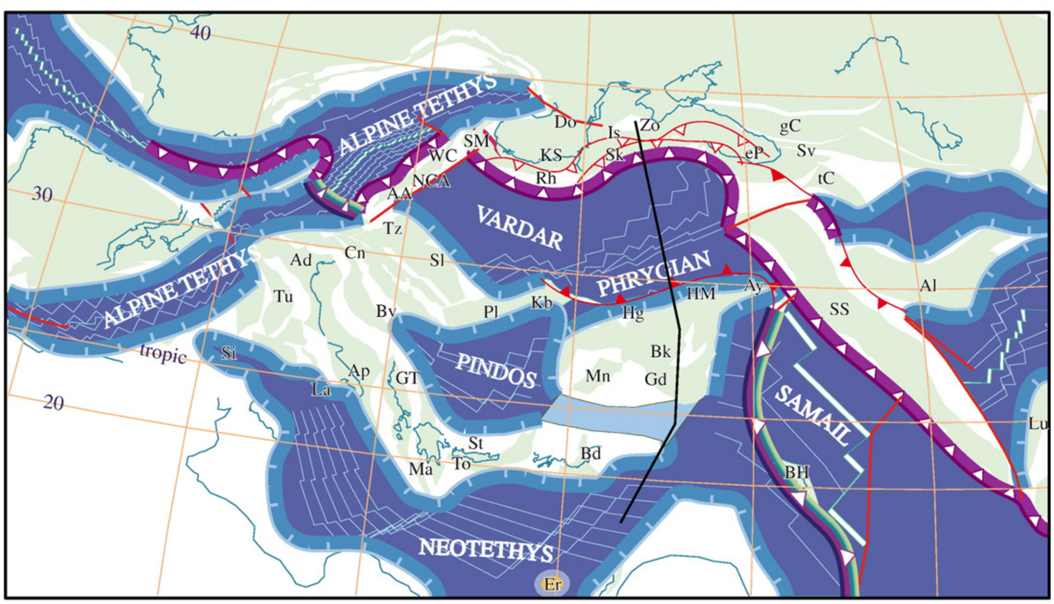
(1) The Taurus terrane was detached from Gondwana together with other Cimmerian blocks in Permian times during the opening of the Neotethys and the East-Mediterranean oceans. Permian pelagic material found in Sicily (Kozur, 1990, 1991, 1995b; Catalano et al., 1991, 1992) were also found as exotic blocks at the base of the Mersin mélanges. Other important geological and geophysical arguments for this Permian opening of the Neotethys/East-Mediterranean Basin have been recently published (Stampfli et al., 2001; Finetti, 2005; Kock et al., 2007);
(2) The Tauric block collided during the Middle Triassic with the Anatolian terrane, thus, sea-floor spreading in the East-Mediterranean Basin ended in the Middle Triassic or in the Carnian. From the Late Triassic onward, the Taurus domain and the Anatolian terrane were again part of the African plate. It is only since the Eocene–Miocene that these terranes were progressively detached, through subduction, from the African plate and accreted to Laurasia. It means that the wander path of the Tauric-Anatolian plate from the Triassic to the Miocene was the same as Africa;
(3) In the north, the Pontides domain was detached from Eurasia in latest Early Triassic through the opening of the Küre Ocean, the closure of which took place in Late Triassic–Middle Jurassic times (Stampfli and Kozur, 2006). From that time until the Late Cretaceous, the Pontides were part of Eurasia. During the Cenomanian, they were detached again from Laurasia through the opening of the Black Sea basins. This opening was short lived, and from the Paleocene onward, the Pontides wander path is similar to that of Eurasia;
(4) The southern margin of the Izmir-Ankara Ocean is not known in Turkey and is regarded as an element that may have left this region. The Anatolides northern margin is usually regarded as such, but, it was not due south of the Pontides when the Izmir-Ankara Ocean opened in the Liassic, the separation between the two domains being on the order of 2000 km in an east–west direction (Stampfli and Borel, 2002). Thus, the northern margin of Anatolia is not the conjugate margin of the southern Pontides margin. On the contrary, the Anatolian northern margin is a clear Triassic margin, not Jurassic, from which many segments are known in the Anatolian Nappes. Therefore, the southern margin of the Izmir-Ankara Ocean must have been either totally subducted or displaced laterally. We regard the Sanandaj-Sirjan domain of Iran and eastern Turkey as representing part of that margin, displaced eastward during the closing of the Izmir-Ankara Ocean and the opening of the peri-central Iranian microplate ocean in the Cretaceous;
(5) The Cyprus-Baër-Bassit domain and their ophiolites were mainly derived from an intra-oceanic subduction zone inside the large Neotethys Ocean, their supra-subduction geochemical character being quite clear (Pearce et al., 1984). This domain extends eastward to the peri-Arabian ophiolites up to Oman. Guyots of Triassic age are found at their sole in exotic mélanges, together with Permian to Cretaceous pelagic sequences derived from the Neotethys sea-floor (e.g. Pillevuit et al., 1997). These ophiolites were first obducted onto the Arabian plate, at that time quite far from the Tauric-Anatolian domain. Then, during the Late Tertiary, the Arabian promontory was brought in contact with this domain. This was done during the closing of a remnant Samail Ocean, inducing the development of a Cenozoic arc along its northern margin, found from Turkey (e.g. Maden-type sequence) to Iran, and creating the Zagros orogen;
(6) In the Eocene, the Tauric-Anatolian plate became a free moving plate, whereas the Greater Apulian domain (e.g. external zones of the Hellenides) was still moving with Africa. The last remnant of that, i.e. the Puglia-Adria part of Apulia in Italy, is still attached to Africa. An east to west diachronous transformation of the East-Mediterranean northern margin from passive to active is therefore demonstrated. The easternmost promontory of Greater Apulia is represented by the Beydağları domain of southwest Turkey. A collision of the Beydağları promontory with the Taurus domain was accompanied by a flysch basin found along the northern side of the Beydağları (Gutnic et al., 1979). This indicates a clear re-displacement of the ophiolitic Lycian Nappes onto the Beydağları platform in Miocene times. The presence of a migrating flexural bulge and development of a foreland basin show that the Tauric-Anatolian domain and Beydağları-Apulian domain were separated at least by a few hundred kilometers. We put this separation in the Middle Carnian (Kozur, 2000a);
(7) The Late Cretaceous partial closure of the remnant eastern Huğlu-Pindos Ocean is witnessed by the first Pindos flysch (Neumann and Zacher, 1996; Wagreich, 1996), in which chrome-spinels have been found (Faupl et al., 2006). The Pindos Basin in the Cretaceous was bordered by major carbonate platforms to the south (Ionian-Mani), to the west (Karst-Budva), and to the north (Pelagonia-Parnassos). Therefore, flysch deposits can only come from the east (Anatolian-Tauric domain), from an orogenic domain related to the emplacement of the Lycian ophiolites (Bernoulli et al., 1974). The Pindos s. str. basin was finally closed only in the Oligocene (Richter et al., 1993; Degnan and Robertson, 1998).

Elements being subducted in space and time along the Eurasian margin are of continental or oceanic types. In the Cenozoic, oceanic domains such as the Pindos basin or the remnant Samail Ocean and continental elements such as the Beydağları or Arabian promontories were subducted simultaneously. Oceanic elements accompanied by slab roll-back induced major extensional events and formation of core complexes in the upper plate (i.e. Anatolia, Aegean domain). At the same time, continental promontories generated re-displacement of Anatolian or Tauric tectonic elements as nappes.

In Fig. 13 we present palinspastic cross-sections together with a series of plate tectonic reconstructions (Figs. 14–17) derived from Stampfli and Borel (2002, 2004). The reconstructions are



Aptian-Albian boundary (112 Ma)



Cenomanian (95 Ma)

Fig. 16. Aptian–Albian boundary (112 Ma) and Cenomanian (95 Ma) paleotectonic reconstructions. Subduction progradation brought the exotic Austroalpine terrane and Vardar-Meliata suture zone onto the eastern Alpine Tethys, whereas the western segment of this ocean was being passively transported with the African plate. Orogenic processes were soon to come to an end in the Balkans (sealed by Albian molasses), whereas roll-back of the Izmir-Ankara Ocean continued eastward, generating diachronous ophiolitic mélanges emplacement onto its northern margin (Sakarya-Pontides-Sevan). Thereafter, the Phrygian Ocean fore-arc-trench collided with the Anatolian northern margin. Similarly, the Samail fore-arc block collided with the distal Arabian margin, forming a continuous tectonic front from western Turkey to Oman. Roll-back of the Neotethyan sea-floor south of the Lut block had detached the latter from Eurasia, together with the Sanandaj-Sirjan block. Eastward movement of these two Iranian blocks was accompanied by the expansion of the Vardar-Phrygian back-arc oceans, which totally replaced the Izmir-Ankara Ocean. Then, east-west shortening, due to the rotation of Africa, triggered the southward obduction of the Phrygian Ocean onto the Anatolian-Tauric block. The eastern Anatolian-Tauric plate was partly covered by ophiolitic-type mélange. The remnant Vardar Ocean subduction generated an active margin setting in the Balkans. Eastward, the northward subduction of the remnant Phrygian Ocean generated a similar active margin along the Pontides soon to be accompanied by the opening of the Black Sea back-arc basins. Key on Fig. 14.

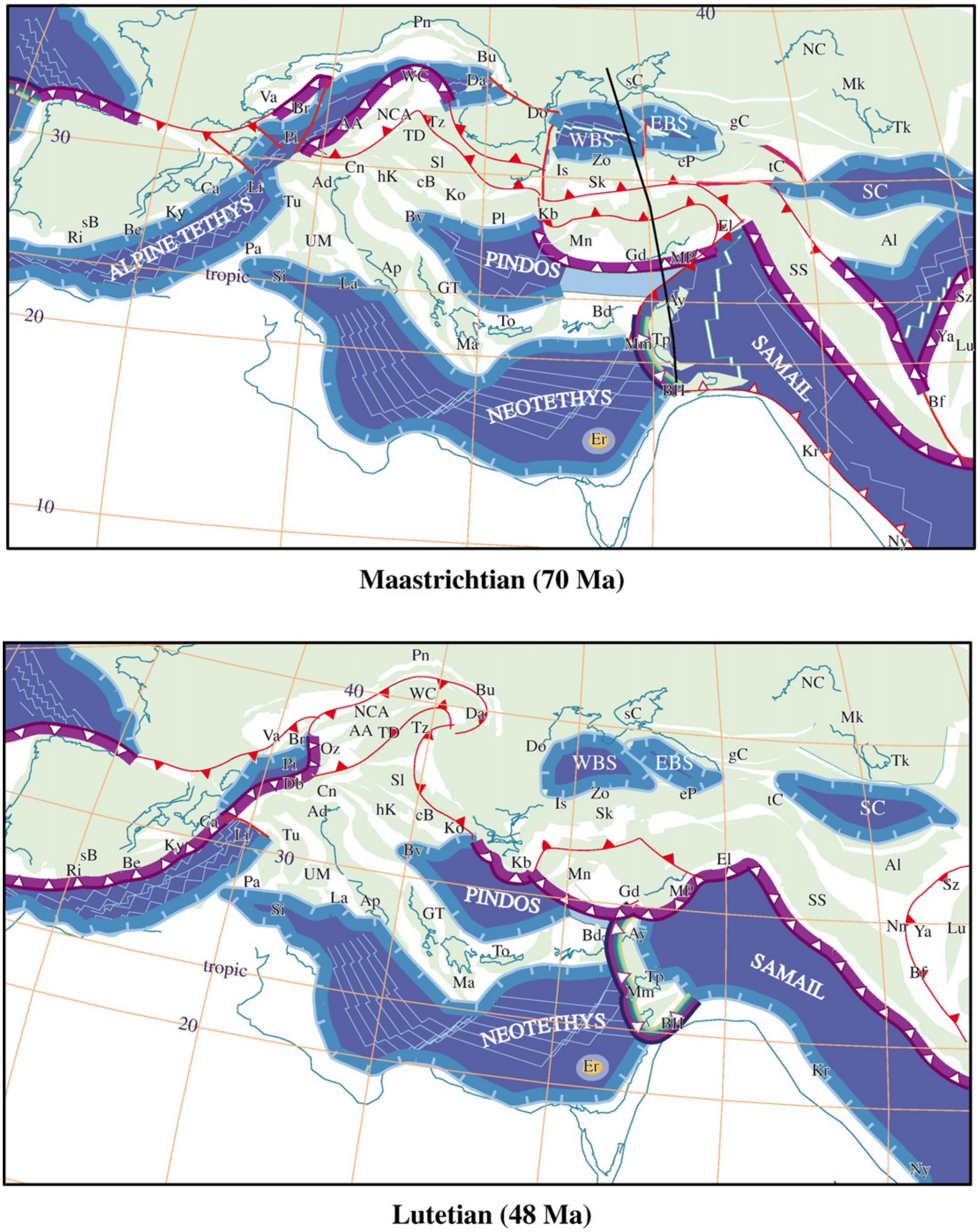


Fig. 17. Maastrichtian (70 Ma) and Lutetian (48 Ma) paleotectonic reconstructions. In the Maastrichtian, continued counterclockwise rotation of Africa was responsible for the obduction of the Samail Ocean onto Arabia (from Oman to Syria), and of the Phrygian Ocean onto the Anatolian block. A Maastrichtian platform seals the obduction in both areas; however, some ophiolitic massifs were re-displaced during the Paleocene and finally emplaced along the south-Tauric margin up to the eastern Beydağları. This resulted in the mixing of Neotethyan, Tauric and Anatolian elements as exotic material (e.g. Antalya, Mersin and Mamonia) at the base of the advancing Cyprus arc. In the eastern Taurus Mountains, the obduction passed over the Anatolian-Tauric plate before to reach the Neotethys. East-west shortening was still very active in the Alpine and Vardar domains. The latter is now totally closed, whereas roll-back of the remnant Phrygian slab allows the opening of the East Black Sea back-arc basin. By Eocene times, the Anatolian-Tauric plate was becoming a free moving entity, pulled westward by roll-back in the Pindos Ocean. Then most Turkish crustal elements were detached from their lithospheric root to form an orogenic complex. The Antalya (Pamphylian) suture zone is going to be the result of the closing of the Cyprus back-arc domain. This resulted in the juxtaposing of peri-Arabian ophiolites to Anatolian derived ophiolites in eastern Turkey. Key on Fig. 14.

centered on the Turkish area. For a larger picture, the reader is referred to the above-cited publications. These models differ from models that have been proposed so far, which are essentially continental drift models. These are constructed on the basis of field observations and compiled literature about the whole Tethyan realm and are inserted into plate tectonics frameworks in which plate movements are constrained in space and time at a global scale.

9. Conclusions

The detailed study of exotic material found associated to the Mersin ophiolite (Masset and Moix, 2004; Moix et al., 2007b) led to the discovery of mixed origins for this material. Some blocks or series are clearly part of a passive margin formerly located north of the Anatolian domain and whose remnants are also found in other places such as the Huğlu series in the Beyşehir-Hoyran Nappes. This margin is interpreted as emerging from the collapse of the former Variscan cordillera and opening of major back-arc type basins along the northern active margin of the Paleotethys during the Triassic and can be correlated with similar events in Greece and in Iran. Other types of exotic material clearly do not belong to this passive margin sequence, such as pelagic Carboniferous and Permian sediments, but to sequences related to the Paleotethys suture zone, and reworked as major olistostromes in the Neotethys basin during the Eo-Cimmerian orogenic event. From these observations, it became necessary to develop a coherent model of terrane definition and dispersion for the Turkish and surrounding areas between the Late Paleozoic and the Tertiary. Thus, we have re-defined several terranes/domains whose geological history is clearly different through space and time; they consist of: (1) the Pontides domain; (2) the Anatolian terrane; (3) the Taurus terrane; (4) the south Taurides exotic units and (5) the peri-Arabian domain. These terranes, characterized by contrasting stratigraphy and geodynamic evolution, can be easily replaced in the larger paleotectonic frame of the western Tethyan realm. The main point we tried to convey is that the present juxtaposition of these terranes is far from their original places. This is due to major east–west translation and shortening of the Tethyan space in the Mesozoic, where the Beydağları, Taurus and Arabian domains moved with Gondwana/Africa, whereas the wander path of the Pontides is similar to Eurasia. In between, the Anatolian terrane was detached from Eurasia to be accreted to the Taurus Cimmerian domain in the Late Triassic and then moved with Gondwana. The detailed studies of the passive/active margins of these terranes in space and time is the key element of this new geodynamic scheme, as well as a plate tectonic reconstruction model, departing from the continental drift models used so far.

Detailed field studies carried out since the 1960's are at the base of these new proposals. Although modern analytical techniques and mainly absolute dating methods play an important role in the deciphering of a complicated geological puzzle that Turkey and surrounding areas represent. Only further classical field studies will help ameliorate the proposed models. Vast areas in eastern Turkey, Iraq, and western Iran are still under-explored, and a better investigation of these regions is necessary to go further in the understanding of the central Tethyan realm.

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