Geological Society, London, Special Publications

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Geological Society, London, Special Publications 2000; v. 173; p. 25-41
doi:10.1144/GSL.SP.2000.173.01.02

Notes

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Abstract: A belt of Late Triassic deformation and metamorphism (Cimmeride Orogeny) extends east–west for 1100 km in northern Turkey. It is proposed that this was caused by the collision and partial accretion of an Early–Middle Triassic oceanic plateau with the southern continental margin of Laurasia. The upper part of this oceanic plateau is recognized as a thick Lower–Middle Triassic metabasite–marble–phyllite complex, named the Nilüfer Unit, which covers an area of 120 000 km^2 with an estimated volume of mafic rocks of 2×10^5 km^3. The mafic sequence, which has thin stratigraphic intercalations of hemipelagic limestone and shale, shows consistent within-plate geochemical signatures. The Nilüfer Unit has undergone a high-pressure greenschist facies metamorphism, but also includes tectonic slices of eclogite and blueschist with latest Triassic isotopic ages, produced during the attempted subduction of the plateau. The short period for the orogeny (< 15 Ma; Norian–Hettangian) is further evidence for the oceanic plateau origin of the Cimmeride Orogeny. The accretion of the Nilüfer Plateau produced strong uplift and compressional deformation in the hanging wall. A large and thick clastic wedge, fed from the granitic basement of the Laurasia, represented by a thick Upper Triassic arkosic sandstone sequence in northwest Turkey, engulfed the subduction zone and the Nilüfer Plateau.

An east–west trending belt of latest Triassic deformation and regional metamorphism extends for over 1100 km in northern Turkey. The Early Mesozoic deformation (but not the regional metamorphism) was known previously (Şengör 1979; Bergougnan & Fourquin 1982) and was referred to as the Cimmeride deformation (Şengör *et al.* 1984). The Cimmeride deformation was ascribed to the closure of the Palaeotethys ocean following the collision of a Cimmerian continental sliver with the southern margin of Laurasia (Şengör 1979; Şengör *et al.* 1984). Here, an alternative explanation, involving the collision and partial accretion of an oceanic plateau to the southern margin of Laurasia, is proposed for the origin of the latest Triassic deformation and metamorphism in northern Turkey.

A tectonic map of Turkey and the surrounding region is shown in Fig. 1. During the Palaeozoic and Mesozoic, the various continental blocks that make up present-day Turkey were situated on the continental margins of the Tethys Ocean. The Pontides, which comprise the Strandja, İstanbul and Sakarya Zones, show Laurasian stratigraphic affinities, while the Anatolide–Tauride Block and the Kırşehir Massif are tectonically and stratigraphically related to Gondwana (Şengör & Yılmaz 1981; Okay *et al.* 1996; Okay & Tüysüz 2000). The İstanbul Zone is a continental fragment, which was translated south from the Odessa Shelf with the Cretaceous opening of the oceanic West Black Sea Basin (Fig. 1; Okay *et al.* 1994). Its stratigraphy is similar to that of the Scythian and Moesian platforms, with a fully developed Palaeozoic sedimentary sequence unconformably overlain by Triassic and younger sedimentary rocks (Haas 1968; Dean *et al.* 1997; Görür *et al.* 1997). In the İstanbul Zone, a weak latest Triassic deformation is marked by an unconformity between the Norian siliciclastic turbidites and the overlying Upper Cretaceous carbonates. The Strandja Zone consists of a Late Hercynian metamorphic and granitic basement unconformably overlain by Lower Triassic–Middle Jurassic sedimentary rocks (Chatalov 1988; Okay *et al.* 1996). The Anatolide–Tauride Block and the Kırşehir Massif are also devoid of Triassic metamorphism, and of any significant Triassic deformation. Several well studied Lower Mesozoic stratigraphic sections in the Taurides, including those in the Bornova Flysch Zone (Erdoğan *et al.* 1990) and in the central Taurides (Gutnic *et al.* 1979; Özgül 1997), show a continuous transition between Triassic and Jurassic with no evidence of an intervening deformation phase. The pre-Jurassic thrusting, described by Monod & Akay (1984) from a small locality in the central Taurides, is as yet of unknown significance. Late Triassic deformation and regional metamorphism in Turkey are predominantly found in the Sakarya Zone, which will form the main subject of this paper.

From: BOZKURT, E., WINCHESTER, J. A. & PIPER, J. D. A. (eds) *Tectonics and Magmatism in Turkey and the Surrounding Area.* Geological Society, London, Special Publications, **173**, 25–41. 1-86239-064-9/00/$15.00

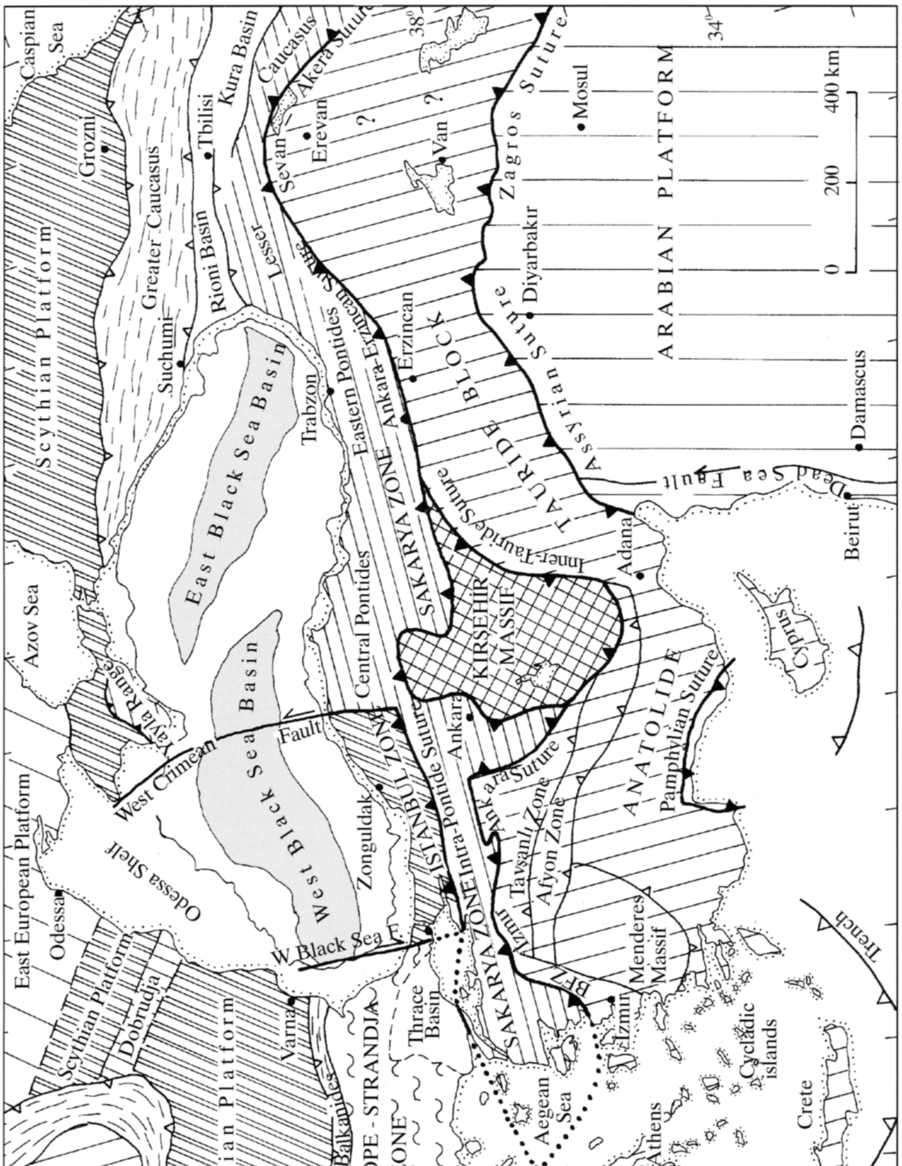

Fig. 1. Tectonic map of Turkey and the surrounding region [after Okay & Tüysüz (1999)].

The Sakarya Zone – a Hercynian unit with Palaeotethyan assemblages

The Sakarya Zone is an elongate continental fragment, 1500 km long and *c.* 90 km wide, which extends from the Biga Peninsula in the west to the Lesser Caucasus in the east (Figs 1 and 2). The İzmir-Ankara Suture forms its southern contact with the Anatolide–Tauride Block. The Sakarya Zone and the Anatolide–Tauride Block exhibit different Palaeozoic and Mesozoic stratigraphies and were amalgamated into a single continental unit during the latest Cretaceous–Palaeocene continental collision (Şengör & Yılmaz 1981; Okay & Tüysüz 1999). The Sakarya Zone is in contact with the İstanbul Zone in the northwest along the Intra-Pontide Suture of Early Eocene age (Okay *et al.* 1994), while in the northeast it is bounded by the oceanic East Black Sea Basin (Fig. 1).

A distinctive stratigraphic feature of the Sakarya Zone is a regional earliest Jurassic unconformity. Strongly deformed sedimentary, metamorphic and magmatic rocks of Devonian–Late Triassic age are unconformably overlain by the Lower–Middle Jurassic conglomerates and sandstones. The pre-Jurassic rocks, which are intermittently exposed along the 1500 km length of the Sakarya Zone (Figs 2 and 3), can be grouped into two categories: Hercynian continental units and Palaeotethyan subduction–accretion–collision complexes. As discussed below, there is still some controversy on the tectonic setting and correlation of the pre-Jurassic subduction–accretion complexes in the Sakarya Zone.

Tectonic interpretation of the pre-Jurassic subduction–accretion complexes

Bingöl *et al.* (1975) defined the Karakaya Formation from the Biga Peninsula in northwest Turkey as a heterogeneous, slightly metamorphosed Triassic unit of feldspathic sandstone, quartzite, conglomerate, siltstone, basalt, mudstone and radiolarian chert. They pointed out its wide extent throughout the Pontides, from the Biga Peninsula to the Ankara region, and interpreted the depositional environment of the Karakaya Formation as an Early Triassic intracontinental basin (Bingöl *et al.* 1975). A completely new and revolutionary interpretation of the Karakaya Complex as a Carboniferous–Triassic subduction–accretion complex was proposed by Tekeli (1981). Şengör *et al.* (1984) followed this tectonic interpretation, but separated the pre-Jurassic subduction–accretion complexes in the central Pontides from the Karakaya Complex, ascribing the former to the subduction of the Palaeotethys and the latter to that of a small Permian–Triassic back-arc basin of the Palaeotethys. This led to an artificial subdivision of the Cimmeride Orogen into the Karakaya Orogen in northwest Turkey and the Palaeotethyan Orogen in the central Pontides. The discovery of Carboniferous and Permian radiolarian cherts (Kozur & Kaya 1994; Kozur 1997; Okay & Mostler 1994), Triassic eclogites (Okay & Monié 1997) and blueschists (Monod *et al.* 1996) in the Karakaya Complex, as well as more precise characterization of its deformational and stratigraphic features (Okay *et al.* 1991, 1996; Pickett & Robertson 1996), confirmed Tekeli's (1981) interpretation of the Karakaya Complex as a subduction–accretion complex, formed through the subduction of an ocean as old as Carboniferous. The pre-Jurassic subduction–accretion complexes in the central Pontides are lithologically and temporally similar to those further west and east in the Sakarya Zone. Furthermore, there is no continental unit that separates the pre-Jurassic subduction–accretion complexes of the central Pontides from those further west or east. The İstanbul Zone, which was claimed to separate the pre-Jurassic subduction–accretion complexes (Ustaömer & Robertson 1993), is now known to have reached its present position in the Cretaceous or even later (Okay *et al.* 1994). Therefore, in this paper, all the pre-Jurassic subduction–accretion complexes in the Sakarya Zone are regarded as having formed during the subduction of the Palaeotethys and are collectively referred to as the Karakaya Complex, as initially intended by Tekeli (1981).

Palaeotethyan subduction–accretion–collision complexes in the Sakarya Zone

Outcrops of the Palaeotethyan subduction–accretion–collision complexes occur throughout the Sakarya Zone beneath the Jurassic and younger cover rocks (Tekeli 1981; Figs 2 and 3). They comprise two main tectonostratigraphic units (Fig. 4). At the base there is a thick sequence of metabasite, marble and phyllite of Triassic age, which is overlain by strongly deformed, but generally unmetamorphosed, clastic and mafic volcanic sequences of Late Palaeozoic–Triassic age. The clastic and mafic volcanic sequences can be further subdivided into those which formed during the

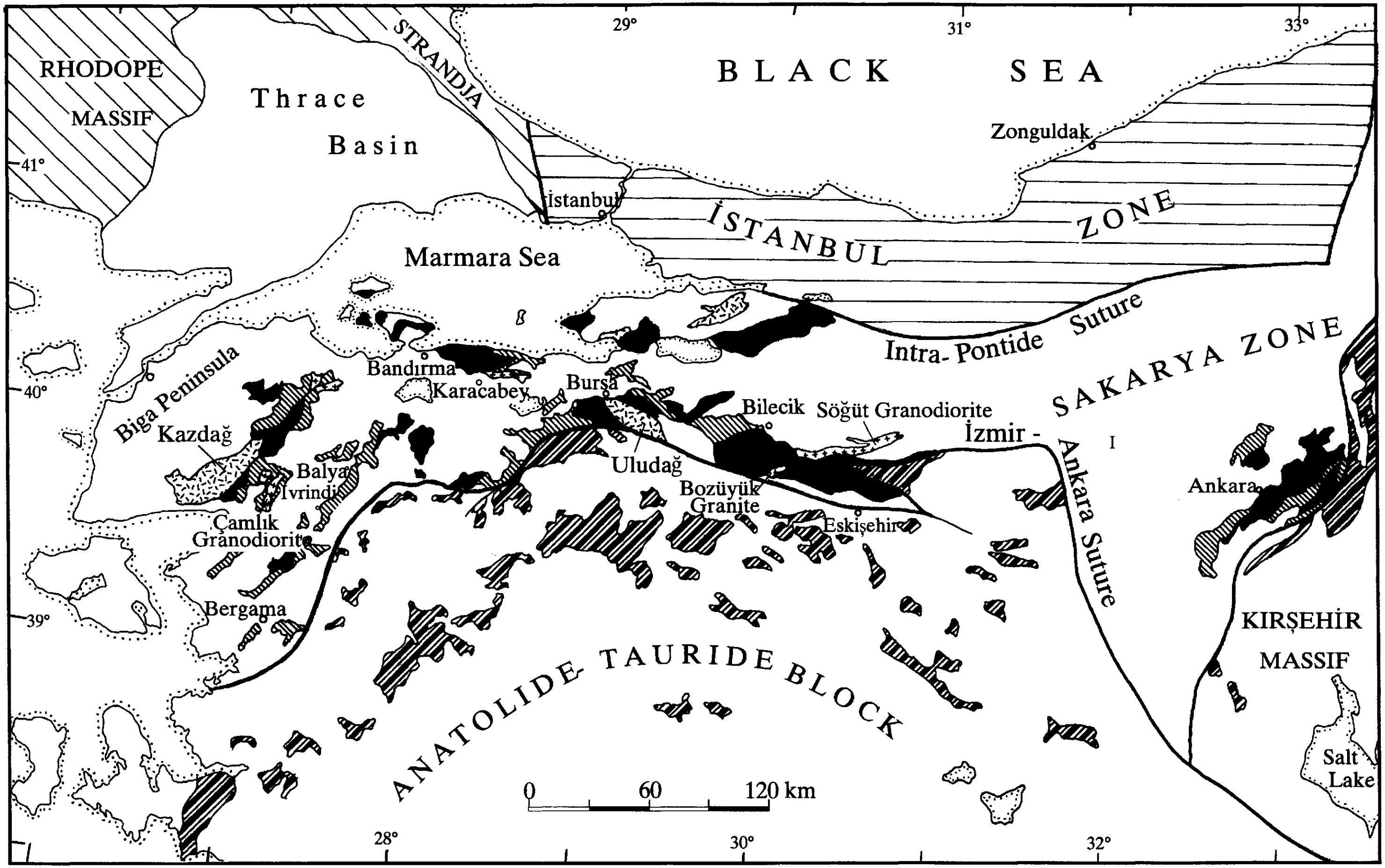

Fig. 2. Distribution of the pre-Jurassic outcrops in the western part of the Sakarya Zone and the Neotethyan subduction–accretion complexes and ophiolite in the Anatolide–Tauride Block. For key see Fig. 3.

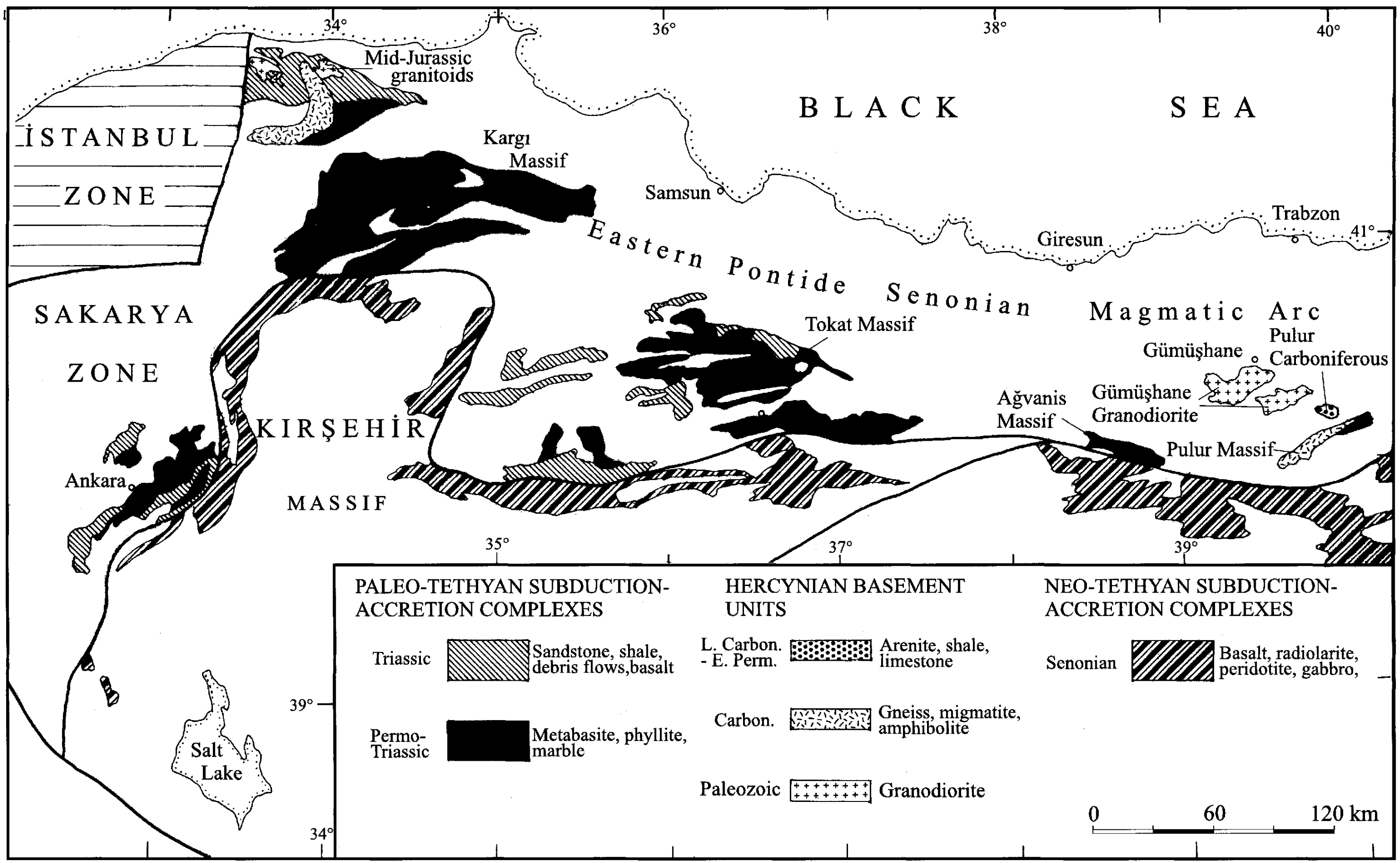

Fig. 3. Distribution of the pre-Jurassic outcrops in the eastern part of the Sakarya Zone, and the Neotethyan subduction–accretion complexes and ophiolite in the Anatolide–Tauride Block.

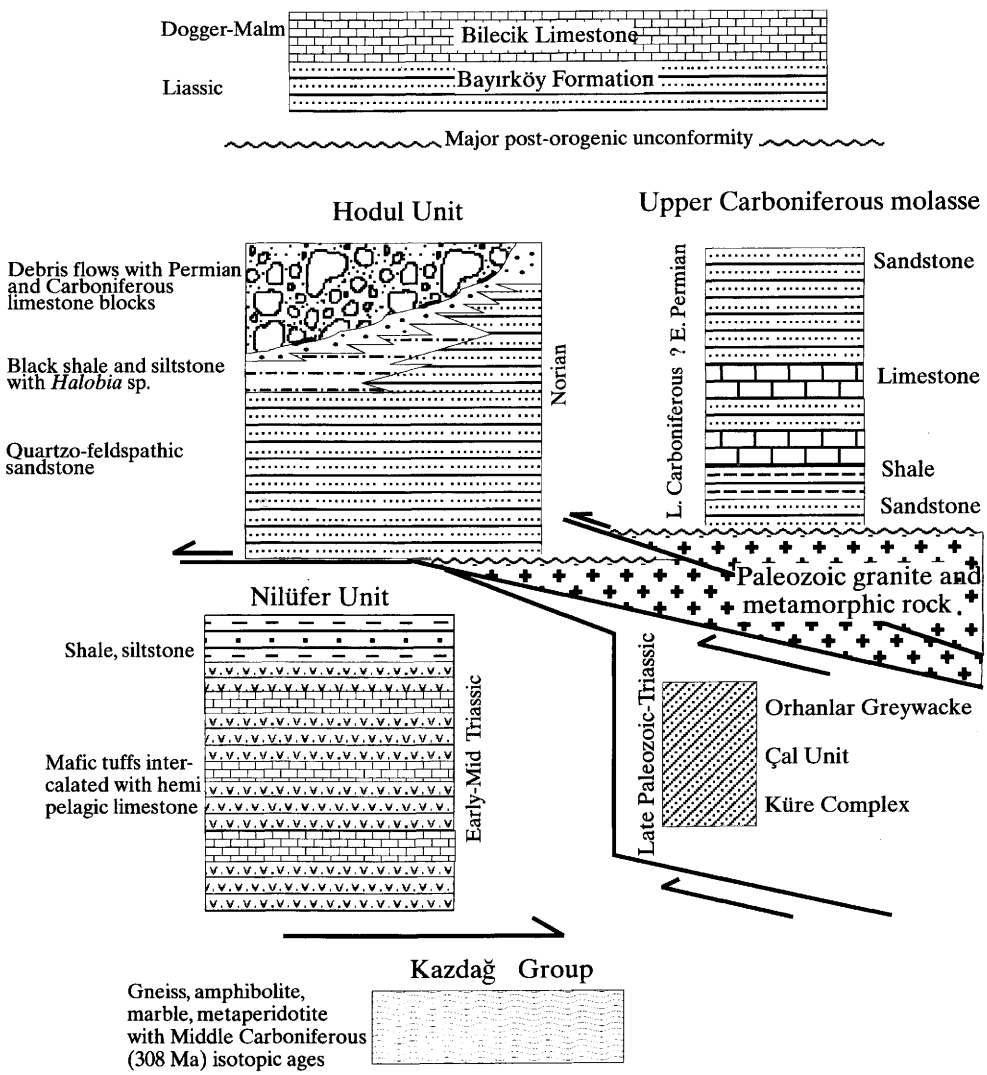

Fig. 4. Tectonostratigraphy of the pre-Jurassic units in the Sakarya Zone.

subduction–accretion of the Palaeotethys and those which formed during the collision of the oceanic plateau.

The Nilüfer Unit – a Triassic oceanic plateau?

At the base of the Karakaya Complex there is a strongly deformed metabasite–marble–phyllite unit of Triassic age, over 7 km in structural thickness. In the western part of the Sakarya Zone, between the Biga Peninsula and Bursa, this assemblage was mapped as the Nilüfer Unit (Okay *et al.* 1991, 1996; Leven & Okay 1996; Pickett & Robertson 1996). In northwest Turkey, the Nilüfer Unit is found wherever the base of the Triassic and older clastic and volcanic rocks are exposed (Fig. 2), suggesting that it forms a continuous layer at depth. Further east, the Nilüfer Unit is described under different names east of Bursa (Genç & Yılmaz 1995), north of Eskişehir (Monod *et al.* 1996; Monod & Okay 1999), around Ankara (Koçyiğit 1987, 1991; Akyürek *et al.* 1988), in the central Pontides (Tüysüz 1990; Ustaömer & Robertson 1994), in the Tokat (Yılmaz *et al.* 1997) and in the Agvanis massifs (Okay 1984)

(Figs 2 and 3). In all these localities the Nilüfer Unit forms the lowermost stratigraphic unit, suggesting stratal continuity at depth. The correlation of this metabasite–marble–phyllite unit across 1100 km in the Sakarya Zone is based on the present author's geological work in northwest Turkey (Okay *et al.* 1991, 1996; Leven & Okay 1996), north of Eskişehir (Monod *et al.* 1996; Monod & Okay 1999), in the Agvanis (Okay 1984) and in the Pulur massifs (Okay 1996; Okay & Şahintürk 1997), as well as on field reconnaissance in the Ankara region, in the central Pontides and in the Tokat Massif.

The Nilüfer Unit consists dominantly of metabasites, representing metamorphosed fine-grained mafic tuffs with rare pyroclastic flows and pillow lavas. These mafic rocks, which constitute about *c.* 80% of the sequence, are intercalated with carbonate layers, 0.5–200 m thick. The fine lamination, devoid of bioturbation, observed in many carbonate horizons, as well as the thin to medium bedding, suggests a pelagic environment of deposition. In the metabasites there are also phyllite horizons, up to several tens of metres thick. Apart from these rock types, the Nilüfer Unit also comprises minor (< 2%) metacherts, lenses of ultramafic rock and gabbro < 1 km long. Coarse-grained, continent-derived sediments, such as sandstones or conglomerates, are conspicuously absent in the Nilüfer Unit. In some regions, such as northeast of Kazdağ, the metabasites are overlain by phyllites and intercalated marbles, several hundred metres thick.

The uppermost part of the mafic volcanic sequence north of Bergama has been dated by conodonts in the intercalated limestones as Middle Triassic (Anisian–Ladinian boundary; Kaya & Mostler 1992), while conodonts from the lower parts of the Nilüfer Unit in the type section south of Bursa indicate an Early Triassic age (Kozur, pers. comm.). Thus, the mafic volcanic rocks of the Nilüfer Unit appear to have been generated in a relatively short period between 245 and 240 Ma. The trace element geochemistry of the mafic volcanic rocks of the Nilüfer Unit, from various regions in northwest Turkey, was studied by Pickett (1994), who showed that they are non-alkalic and non-orogenic in character and exhibit remarkably consistent geochemical characteristics. On basalt discrimination diagrams and multi-element plots they indicate a within-plate setting, which is supported by the analysis of relict igneous clinopyroxenes from the metabasites (Pickett 1994; Pickett & Robertson 1996). Triassic metabasites from the Ankara region (Çapan & Floyd 1985; Floyd 1993) and those from the Kargı Massif in the central Pontides (Doğan 1990) also exhibit trace element contents and ratios typical of within-plate oceanic island basalts.

The Nilüfer Unit is strongly deformed and in many areas shows the features of a broken formation. The early deformation is characterized by layer-parallel stretching, which resulted in the boudinage of the carbonate horizons. The stretching was followed by folding and shearing at high angles to the layering. Foliation is well marked in the mafic tuffs and phyllites, while the coarse-grained pyroclastic flows retain most of the igneous texture. Structural thicknesses > 7 km, as measured south of Bursa, are due to internal thrusting, as well as folding, although, because of the absence of marker horizons in the Nilüfer Unit, these internal thrusts are difficult to map. An exception occurs north of Eskişehir, where a tectonic slice of the Nilüfer Unit, 4 km thick and 25 km long, differentiated because of its blueschist facies metamorphism, tectonically underlies another slice of the Nilüfer Unit showing only greenschist facies metamorphism (Monod & Okay 1999).

The Nilüfer Unit commonly shows high-pressure greenschist facies metamorphism with the common mineral paragenesis of albite + chlorite + actinolite/barroisite + epidote in the metabasites. Rare, iron-rich metacherts in the Nilüfer Unit contain a sodic amphibole + quartz + epidote assemblage (Okay *et al.* 1996). Blueschist and eclogite facies rocks occur as exotic tectonic blocks and slices within the greenschist facies sequence. A small eclogite lens of garnet + glaucophane + omphacite + epidote + phengite occurs east of Bandırma on the southern coast of the Marmara Sea (Fig. 2; Okay & Monié 1997). A larger slice of the Nilüfer Unit, showing blueschist to eclogite facies metamorphism, is found north of Eskişehir (Monod *et al.* 1996; Monod & Okay 1999). Ar–Ar dating of phengites from both regions of high-pressure rocks, separated by 230 km, has given similar latest Triassic–earliest Jurassic ages [208–201 Ma in Bandırma and 214–192 Ma in Eskişehir; Monod *et al.* (1996) and Okay & Monié (1997)]. The greenschist facies metamorphism in the Nilüfer Unit postdates the high pressure–low temperature (HP–LT) metamorphism, and hence must also be of latest Triassic age. The regional metamorphism is further constrained stratigraphically as Late Triassic by the Middle Triassic depositional age of the Nilüfer Unit and the unconformable cover of the Liassic sandstones.

The Nilüfer Unit is overlain tectonically by two distinctive rock types. In many regions strongly deformed, but generally unmetamorphosed, Triassic clastic rocks of the Karakaya Complex lie over the Nilüfer Unit. These contacts have either been interpreted as tectonic (Okay *et al.* 1991, 1996) or as stratigraphic (Akyürek & Soysal 1983). In many localities, such as east of Bandırma and south of Bursa, the contacts are sheared and folded, although the consistent superposition of the Upper Triassic clastic rocks over the Nilüfer Unit suggests a sheared stratigraphic contact between the two units. In parts of northwest Turkey, such as in the Bilecik region, north of Karacabey, around Bozüyük (Fig. 2), the Nilüfer Unit is tectonically overlain by Palaeozoic granites (Yılmaz 1981; Genç & Yılmaz 1995).

The tectonic base of the Nilüfer Unit is exposed in two Miocene core complexes in the Kazdağ and Uludağ Ranges (Fig. 2). In both regions, Miocene and younger normal faults form the contact between the metabasites of the Nilüfer Unit and the underlying gneisses, amphibolites and marbles with Carboniferous zircon ages (Okay *et al.* 1996).

As discussed above, the scattered outcrops of the Nilüfer Unit are most probably connected at depth, and the Nilüfer Unit forms a blanket cover beneath Triassic and younger strata throughout most of the Sakarya Zone (Figs 2 and 3), and thus has an areal distribution of *c.* 120 000 km^2. Taking a minimum vertical thickness for the Nilüfer Unit as 2 km and considering that 80% of the sequence is made up of mafic magmatic rocks, the volume of basalt produced during the Early–Middle Triassic is estimated as 2×10^5 km^3. This is a large igneous province comparable in volume with the Columbia River basalts, the North Atlantic volcanic province, or the Deccan traps (Coffin & Eldholm 1994).

The Nilüfer Unit has been interpreted either as an ensimatic intra-arc to forearc sequence (Okay 1984; Okay *et al.* 1991, 1996), or as an oceanic seamount (Pickett & Robertson 1996). The thick and laterally extensive volcaniclastic sequences intercalated with sedimentary rocks, which form the bulk of the Nilüfer Unit, are characteristic of the sedimentary basins flanking active island arcs (e.g. Dickinson & Seely 1979). However, the geochemistry of the Nilüfer Unit does not indicate an arc affinity. On the other hand, a seamount origin for the Nilüfer Unit is unlikely as the seamounts have a maximum diameter of *c.* 35 km (e.g. Dominguez *et al.* 1998), while the Nilüfer Unit is more than 30 times this size. A third hypothesis for the origin of the Nilüfer Unit, suggested here, is that it represents the upper parts of a Triassic oceanic plateau, which was accreted to the Laurasian active continental margin during the Late Triassic.

Oceanic plateaux cover large areas of the present day oceanic basins (e.g. Ontong Java is 1.86×10^6 km^2, more than twice the size of Turkey), and are characterized by mafic crustal thicknesses > 10 km (Saunders *et al.* 1996; Gladczenko *et al.* 1997; Kerr *et al.* 1998). Because of their great crustal thicknesses and buoyancy, oceanic plateaux are less readily subducted than normal oceanic crust and are potentially preserved in the geological record (Burke *et al.* 1978; Ben-Avraham *et al.* 1981). Former oceanic plateaux have been described from Japan (e.g. Kimura *et al.* 1994), western North America (e.g. Ben-Avraham *et al.* 1981; Richards *et al.* 1991) and the Caribbean region (e.g. Kerr *et al.* 1998). During the subduction of the oceanic plateaus, it is usually the upper mafic volcanic layers that are detached from their plutonic substratum and accreted to the active continental margin (e.g. Tejada *et al.* 1996).

Evidence favouring an oceanic plateau origin of the Nilüfer Unit are as follows: (1) exclusive mafic magmatism associated with the absence of a known stratigraphic basement and lack of continent-derived detritus in the Nilüfer Unit suggest formation in an oceanic environment away from the continents; (2) intercalation of mafic rocks with hemipelagic limestone and shale is unusual for oceanic ridge magmatism, although it is to be expected in an off-axis intra-oceanic volcanism; (3) the areal distribution of the Nilüfer Unit and the volume of mafic magma produced is comparable with oceanic plateaux; (4) the geochemistry of the mafic rocks in the Nilüfer Unit show a consistent within-plate signature; (5) the presence of mafic eclogites and blueschists in the Nilüfer Unit implies association with an oceanic subduction zone.

The size of the Triassic oceanic plateau can be estimated from the outcrop distribution of the Nilüfer Unit. In the west outcrops of the Nilüfer Unit end abruptly in the Biga Peninsula; neither the equivalents of the Nilüfer Unit nor the Late Triassic deformation have been described from the mainland Greece. The easternmost extensive outcrop of the Nilüfer Unit is in the Agvanis Massif (Okay 1984); further east the Hercynian basement units are predominant, although small slivers of Nilüfer Unit have been described from the Pulur Massif (Fig. 3; Okay 1996). Between these two limits is an east–west length of *c.* 1100 km for the Nilüfer oceanic plateau. A minimum north–south length of *c.* 90 km for the

Nilüfer Plateau is indicated by the present-day width of the Sakarya Zone.

Subduction-related Palaeotethyan clastic and magmatic rocks

Subduction-related clastic and volcanic sequences include those accreted to the continental margin prior to the collision of the oceanic plateau, while the sequences deposited during the Late Triassic collision are designated as collision related. Differentiation of subduction- and collision-related Palaeotethyan sequences are often problematic, as subduction-related sequences are also involved in the collision. Nevertheless, such a distinction can be made in northwest Turkey, based on the age and lithology of the rocks. The subduction-related sequences are Late Palaeozoic–Triassic in age and are dominantly pelagic, while the collisional sequences are Late Triassic in age and also comprise shallow-marine series. The subduction-related sequences in northwest Turkey are the Orhanlar Greywacke and the Çal Unit, and in the central Pontides the Küre Complex. In addition to these formations there is a suite of Middle Jurassic granitoids in the northern part of the central Pontides, which may be related to the final phases of subduction of the Palaeotethys (Yılmaz & Boztuğ 1986).

The Orhanlar Greywacke. The Orhanlar Greywacke consists of homogeneous, grey siltstones and sandstones with a rich clay matrix (Brinkmann 1971; Okay *et al.* 1991, 1996). The greywackes are composed of very poorly sorted angular quartz, plagioclase, opaque, lydite, radiolarian chert, basalt and phyllite clasts in an argillaceous matrix. The Orhanlar Greywacke has undergone strong layer-parallel extension which has destroyed most of the bedding. In the type area north of Balya, the Orhanlar Greywacke contains small (< 1 m) olistoliths of dark Lower Carboniferous (Visean and Serpukhovian) limestone and is overlain by undeformed Liassic sandstones and siltstones (Leven & Okay 1996). South of Bursa, the Orhanlar Greywacke lies with a sheared stratigraphic contact over the Nilüfer Unit. It could represent trench fill clastics recycling material from the accretionary complex as well as from the arc.

The Çal Unit. Most of the Çal Unit consists of debris and grain flows with Upper Permian limestone and mafic clasts in a volcanic or volcano-clastic matrix (Okay *et al.* 1991, 1996; Leven & Okay 1996). There are also mafic pyroclastic flows, calciturbidites, pelagic limestones and radiolarian cherts in the sequence. Calciturbidites are made up of transported Upper Permian limestone grains. The radiolarian cherts, initially dated as Early Permian (Sakmarian–Artinskian) (Okay & Mostler 1994), are now redetermined as Late Permian (Dorashamian) (Kozur 1997). Associated with these rock types there are Anisian limestones, several hundred of metres thick. Like the other Karakaya units, the Çal Unit has been strongly deformed, largely destroying stratal continuity. It may represent an oceanic seamount, which was accreted to the Laurasian margin during the Middle Triassic (Leven & Okay 1996).

The Küre Complex. The Küre Complex, which crops out in the northern part of the central Pontides, consists mainly of dark shales intercalated with siltstones and fine-grained sandstones of pre-Middle Jurassic age. It includes tectonic slices of mafic pillow lava, gabbro and serpentinite (Ustaömer & Robertson 1994; Aydın *et al.* 1995), and represents a Franciscan-type subduction–accretion complex.

Kastamonu granitoids. These medium-sized plutons, < 20 km across, intrude the Upper Palaeozoic–Upper Triassic subduction–accretion complexes in the northern part of the central Pontides (Fig. 3), and are unconformably overlain by undated conglomerates and Upper Jurassic (Oxfordian) shallow-marine limestones (Yılmaz & Boztuğ 1986). They range from granodiorite to quartz–monzonite and show calc-alkaline geochemical features (Boztuğ *et al.* 1984). Yılmaz & Boztuğ (1986) related the formation of the granitoids to the northward subduction of the Palaeotethys.

Palaeotethyan clastic rocks formed during the collision of the oceanic plateau

The Hodul Unit

The Hodul Unit comprises collision-related clastic sequences in the western part of the Sakarya Zone, extending from the Biga Peninsula eastwards to the region north of Eskişehir (Okay *et al.* 1991, 1996). They form an easily recognizable unit with thick sequences of white arkosic sandstones, and extensive olistostromes with Permian and Carboniferous limestone blocks. The sequence is strongly deformed with anastomosing shear zones which have destroyed stratal continuity over distances as short as a few hundred metres. The clastic sequence ranges from coarse-grained and thickly bedded arkosic sandstones with pebbles of granite to distal turbidites with thinly bedded arkosic sandstones with shale intercalations (Okay *et al.* 1991). At several places in northwest Turkey the sequence is dated through macrofossils as Norian (Okay *et al.* 1991, 1996; Leven & Okay 1996). In regions near the İzmir–Ankara Suture, the arkosic sandstones pass up to greywackes and siltstones with exotic olistoliths of mafic volcanic rock and limestone (Okay *et al.* 1991, 1996; Fig. 2). The size of the limestone blocks in the Norian olistostromes ranges up to 1 km. A detailed palaeontological study of the foraminifera in the limestone blocks has shown the presence of almost all stages from Middle Carboniferous (Bashkirian) to uppermost Permian (Dorashamian) (Leven & Okay 1996). There are also rare blocks of pelagic limestone and radiolarite, which are dated by conodonts as Middle Carboniferous (Bashkirian) (Okay & Mostler 1994). The total thickness of the Hodul sequence is > 2 km: a more precise estimate is not possible because of the strong tectonism.

The arkosic nature of the clastic rocks, as well as granitic pebbles in the sandstones, indicate a granitic source area for the Hodul Unit. In only one locality in the Sakarya Zone, in the area west of Ivrindi, the arkosic sandstones of the Hodul Unit can be observed to lie transgressively over the Palaeozoic Çamlık Granodiorite (Fig. 2). In other regions, e.g. east of Bandırma, the Hodul Unit lies with a shear zone contact over the Nilüfer Unit. The Hodul Unit is overlain unconformably by undeformed shallow-water Liassic sandstones and siltstones.

Hercynian continental units in the Sakarya Zone

The Hercynian continental units of the Sakarya Zone consist of three different rock assemblages: Carboniferous high-grade metamorphic rocks, Palaeozoic granites and a latest Carboniferous molasse sequence.

Carboniferous high-grade metamorphic rocks

These consist mainly of gneiss, migmatite, amphibolite and marble with rare meta-ultramafic rocks. They crop out mainly in the cores of two Tertiary core complexes in the Kazdağ and Uludağ Ranges (Fig. 2), and also in a Tertiary thrust slice in the Pulur Massif in the eastern Pontides (Fig. 3). The metamorphic grade is amphibolite to granulite facies with cordierite + sillimanite + garnet + biotite subassemblages in the Kazdağ and Pulur regions (Okay 1996; Okay *et al.* 1996). The high-grade metamorphism is of Late Carboniferous age. Gneisses from the Kazdağ region, dated by the single-zircon stepwise Pb-evaporation technique, have yielded an age of 308 ± 16 Ma (Moscovian; Okay *et al.* 1996), while those from the Pulur region gave Sm–Nd and Rb–Sr ages between 303 and 322 Ma (Moscovian–Bashkirian; Topuz *et al.* 1997).

In both the Kazdağ and Uludağ regions, the Carboniferous high-grade metamorphic rocks are tectonically overlain by the Palaeotethyan subduction–accretion complexes, while in the Pulur Massif the metamorphic rocks are unconformably overlain by Lower–Middle Jurassic limestones (Okay & Şahintürk 1997).

Palaeozoic granodiorites

These granitoid rocks form several isolated bodies, up to 30 km across, in the Sakarya Zone (Figs 3 and 4). They are generally hornblende–biotite granodiorites and are locally strongly deformed (Yılmaz 1976, 1981; Servais 1982; Bergougnan 1987; Okay *et al.* 1991). The few available isotopic ages range from Devonian to Permian. The Çamlık Granodiorite in the Biga Peninsula has yielded a zircon age of 399 ± 13 Ma (Devonian) using a single-zircon stepwise evaporation technique (Okay *et al.* 1996); the Söğüt Granodiorite gave a K–Ar biotite age of 272 ± 3 Ma (Early Permian; Çogulu & Krummenacher 1967) and a total Pb age of 290 Ma (latest Carboniferous; Çogulu *et al.* 1965); the Gümüşhane Granodiorite in the eastern Pontides has yielded a well-defined Rb–Sr isochron age of 360 ± 2 Ma (earliest Carboniferous; Bergougnan 1987).

Most of the Palaeozoic granodiorites are unconformably overlain by Lower Jurassic continental to shallow-marine clastic rocks. Only the Çamlık Granodiorite in the Biga Peninsula also has an unconformable cover of Upper Triassic (Norian) arkosic sandstones (Okay *et al.* 1991, 1996; Fig. 2). Some of the granodiorites, like the Bozüyük and Söğüt bodies, have narrow contact aureoles, although the country rock into which these plutons initially intruded are very poorly preserved. In the few localities, where the Palaeozoic granodiorites are in contact with the Palaeotethyan subduction–accretion complexes (Fig. 2), the granodiorites are seen to be thrust over the Nilüfer Unit. A mylonite belt > 1000 m thick separates the Söğüt Granodiorite from the underlying Triassic metabasite–phyllite–marble unit (Yılmaz 1981).

Latest Carboniferous molasse

This coherent shallow-marine to continental sequence crops out only in the eastern Pontides (Ketin 1951). The lower part of the sequence, > 1100 m in thickness, consists of an intercalation of pebbly sandstone, quartzite, shale with thin coal horizons and shallow-marine limestone with fusulinids; this is conformably overlain by continental arkosic red sandstones, > 1000 m in thickness. Sandstones throughout the sequence contain clasts of acidic plutonic and volcanic rocks. Fusulinids from the limestones indicate a latest Carboniferous age (Late Kasimovian–Early Gzelian) for the lower part of the sequence: the overlying continental series may possibly extend into the Early Permian (Okay & Leven 1996; Okay & Şahintürk 1997). Although the base of the Upper Carboniferous sequence is not exposed, it probably unconformably overlies the nearby Carboniferous granites and high-grade metamorphic rocks in the Pulur and Gümüşhane regions (Fig. 3). Similar Upper Carboniferous sequences overlying metamorphic and granitic rocks are exposed in the Lesser Caucasus (Khain 1975), and can be compared with the Rotliegende Formation of Hercynian Europe.

Timing of the Cimmeride Orogeny in the Sakarya Zone

The age of the Cimmeride deformation in the Sakarya Zone can be constrained between the age of the youngest deformed strata of the Karakaya Complex and the oldest unconformably overlying undeformed beds. The age of the deformed olistostromes in the Hodul Unit in northwest Turkey is established at several localities as Norian. This is based on macrofauna, such as *Halobia suessi* (Mojsisovics), *Pinacoceras postparma* (Mojsisovics) and *Pseudocardioceras acutum* (Mojsisovics) from the Balya region (Leven & Okay 1996), and *Halobia styriaca* (Mojsisovics) from north of Bursa (Erk 1942). A more precise Middle–Late Norian age has been obtained from the Hodul Unit south of Ivrindi, based on the forms *Zugmayerella* sp., *Anadontophora* cf. *griesbachi* (Bittner), *Amonotis*(?) sp. and *Gonionautilus securis* (Dittmar) (Leven & Okay 1996).

The age of the oldest unconformably overlying undeformed series in northwest Turkey (Bayırköy Formation) is firmly established as Sinemurian, based on ammonites, brachiopods and foraminifera (Alkaya 1982; Altıner *et al.* 1991). The Sinemurian sequence extends upwards semi-continuously to the Late Cretaceous, with no significant deformation until the Senonian. This brackets the age of the Cimmeride Orogeny between the latest Norian and Hettangian (215–200 Ma). Only in the central Pontides, where the undeformed sequence overlying the subduction–accretion units is of Middle Jurassic age, is the Cimmeride deformation probably slightly later (Tüysüz 1993).

Ar–Ar dating of phengites from the eclogite in the Nilüfer Unit east of Bandırma gave a narrow metamorphic age between 208 and 201 Ma (Okay & Monié 1997). A similar isotopic age range was obtained (214–192 Ma) from phengites from the blueschists north of Eskişehir (Monod *et al.* 1996). The eclogite was metamorphosed at a temperature of *c.* 480°C, which is close to the closure temperature for Ar in phengite [generally taken to be in the 350–400°C range (Okay & Monié 1997)]. Therefore, these isotopic ages, which correspond to the Late Norian–Early Liassic (Hettangian) (Gradstein *et al.* 1994), reflect an early stage of cooling and are compatible with the palaeontological ages of the deformation.

The Cimmeride Orogeny in northern Turkey is remarkable for its relatively brief deformation and metamorphism, and in this respect contrasts strongly with orogenies like the Alpide or the Himalayan, which have life spans > 50 Ma.

The duration of the Palaeotethyan subduction and the age of the subducting oceanic crust

The duration of subduction is best given by the age range of the magmatic arc and the forearc sequence: in the Sakarya Zone neither are recognized. In their absence, the Late Triassic age of the high pressure metamorphism provides a minimum duration for the subduction. The age range of the subducting oceanic crust can be deduced from the age of the pelagic sediments in the accretionary complexes. Middle Carboniferous (Bashkirian) and Upper Permian radiolaria are described from chert blocks in the Karakaya Complex (Kozur & Kaya 1994; Okay & Mostler 1994; Kozur 1997), suggesting subduction of an oceanic crust at least as old as Middle Carboniferous. This is compatible with palaeogeographic reconstructions which indicate the continued presence of a large oceanic area north of Gondwana in the Carboniferous and Permian (e.g. Smith *et al.* 1981; Stampfli 1996).

Origin of the Carboniferous and Permian limestone blocks in the Upper Triassic olistostromes

Voluminous olistostromes with Carboniferous and Permian neritic limestone blocks occur in the upper parts of the Upper Triassic arkosic clastic sequences in northwest Turkey (Okay *et al.* 1991, 1996; Leven & Okay 1996). The origin of these exotic blocks, e.g. whether they were initially deposited on the southern or northern margin of the Palaeotethys and how they were incorporated into the Hodul Unit, cannot be satisfactorily answered because of apparently conflicting evidence. Data which argue for a southerly origin of the Carboniferous and Permian limestone blocks are as follows. (1) The Triassic olistostromes form a belt, 15–25 km wide and 280 km long, immediately northwest of the İzmir–Ankara Suture (Fig. 2). The density and the size of the exotic limestone blocks decrease northward and westward away from the İzmir–Ankara Suture. These observations suggest that the blocks in the olistostromes were derived from a carbonate platform that lay in the present southeast, e.g. in the direction of the Anatolide–Tauride Block. (2) There is a general westward increase in the age of the limestone blocks from Midian–Dzhulfian immediately adjacent to the İzmir–Ankara Suture to Murgabian–Midian further northwest (Leven & Okay 1996). Assuming that the top of the carbonate platform was eroding first, this again argues for a southward derivation of the blocks. (3) No marine Permian deposits are known along the Laurasian margin in the western Palaeotethys. In Bulgaria, the Permian is represented by terrigenous clastic and volcanic rocks (e.g. Yanev 1992), and, in the İstanbul Zone, Permian deposits are largely absent and the Early Triassic and possibly latest Permian consist of red beds and basic lavas. In contrast, Permian and Carboniferous deposits in the Anatolide–Tauride Block are generally marine carbonates (e.g. Monod 1977; Argyriadis 1978; Altıner 1983). On the other hand, Permian fusulinid assemblages from the exotic limestone blocks in the Hodul Unit are faunistically different to those in the Anatolide–Tauride Block, and are similar to the fusulinid assemblages found in the northern margin of the eastern Palaeotethys in Afghanistan, the Pamirs and China (Leven & Okay 1996).

Assuming that the exotic Permo-Carboniferous limestone blocks in the Hodul Unit were deposited in the northern outer shelf of the Anatolide–Tauride Block, then a narrow sliver of this outer shelf must have rifted, possibly during the Early Triassic mafic magmatism, from the bulk of the Anatolide–Tauride Block. This Cimmerian continental sliver must have been translated northward and must have eventually been incorporated into the Upper Triassic olistostromes (Okay *et al.* 1996). However, a major problem with this tectonic scenario is that nowhere in the Sakarya Zone is there evidence for a Gondwanan continental basement, which must have underlain the Permo-Carboniferous limestones.

A model for the Cimmeride orogeny in Turkey

A basic tenet of the model presented here is that the Cimmeride deformation in Turkey is caused by the collision and partial accretion of an oceanic plateau with the Laurasian active continental margin during the Late Triassic. Accretion of an oceanic plateau to the Laurasian margin would imply a northward dipping subduction zone during the Late Triassic, as suggested by Robertson & Dixon (1984), Ricou (1994) and Stampfli *et al.* (1991) and others. The evidence in favour for the oceanic plateau origin of the Nilüfer Unit has been cited above. The alternative model for the Cimmeride deformation, involving the collision of a Cimmerian continent with the Laurasian margin (Şengör 1979; Şengör *et al.* 1984), is difficult to maintain as no coherent Cimmerian continent can be defined in northern Turkey. The pre-Jurassic rocks in the Sakarya Zone are either subduction–accretion complexes or fragments of a Hercynian continental sequence belonging to Laurasia. Furthermore, the comparatively short period of deformation and metamorphism in northern Turkey (< 15 Ma) would be incompatible with a continent–continent collision but would be explicable through the docking and partial accretion of a oceanic plateau to the Laurasian margin. It is also striking that neither the Late Triassic deformation nor the presence of the Nilüfer Unit have been documented from mainland Greece or from the Lesser Caucasus, illustrating a causal relation between the two.

Figure 5 shows two schematic cross-sections

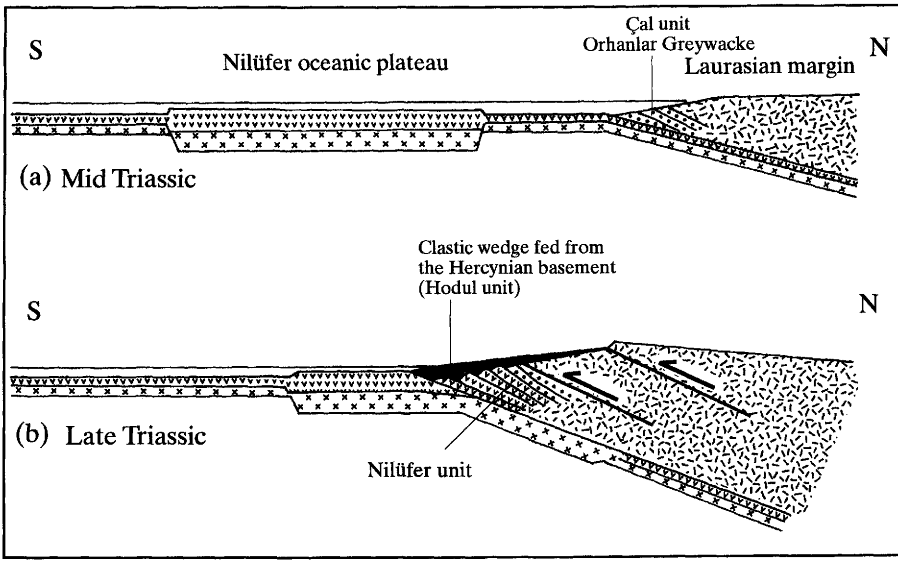

Fig. 5. Schematic cross-sections illustrating the tectonic evolution of the southern margin of Laurasia during: (**a**) Middle Triassic; and (**b**) Late Triassic.

illustrating the tectonic evolution of the Nilüfer oceanic Plateau. During the Early–Middle Triassic, the Nilüfer oceanic Plateau was generated during a voluminous intraplate mafic magmatism. This appears to have been part of a large Triassic mafic magmatic pulse in the Tethyan region. Triassic mafic tuffs, > 1000 m in thickness, are described from the allochthons in the Taurides (Huğlu Unit; Monod 1977; Gökdeniz 1981; Özgül 1997) and they are also widespread in the Triassic sections in Greece. The geochemistry of some Triassic mafic volcanic rocks in the eastern Mediterranean have a plume signature (Dixon & Robertson 1999) suggesting that the Triassic mafic magmatism was plume related. It is also possible, especially if a southerly origin is assumed for the exotic Permo-Carboniferous limestone blocks, that part of the outer shelf of the Anatolide–Tauride Block was also rifted during the Early Triassic magmatism.

In the Late Triassic, the northward movement of the Palaeotethyan plate brought the Nilüfer oceanic plateau near the Laurasian active margin. At this time the Laurasian margin was characterized by a Hercynian granitic and metamorphic basement with isolated molassic basins of Late Carboniferous–Permian age, and a thin cover of Triassic continental to shallow-marine sediments, e.g. as observed in Bulgaria or in the İstanbul Zone (e.g. Ganev 1974; Chatalov 1991). Subduction–accretion units of the Karakaya Complex, such as the Orhanlar Greywacke or the Çal Unit, were probably already part of the accretionary complex at the southern margin of the Laurasia (Fig. 5a). The collision of the Nilüfer oceanic Plateau with the active margin occurred during the Late Triassic (Norian), as indicated by the age of the syncollisional clastic sequences and the age of the HP–LT metamorphism. The volcanic edifice of the oceanic plateau was detached from its plutonic substratum and formed a thick accretionary wedge at the southern margin of Laurasia, represented by the Nilüfer Unit (Fig. 5b). The attempted subduction of a major oceanic plateau resulted in uplift and severe compressive deformation of the overlying active continental margin (e.g. Ben-Avraham *et al.* 1981; Cloos 1993). The arc and forearc sequences were probably largely eroded during the latest Triassic, and the Hercynian crystalline basement was internally sliced. A thick clastic wedge fed from the south vergent Hercynian thrust slices engulfed the subduction zone (Fig. 5b). This part of the model explains the unusual position of the arkosic sandstones of the Hodul Unit overlying the Nilüfer Unit, as well as the Carboniferous granites. The presence of Hercynian basement units both above and below the Nilüfer Unit suggests interdigitation of the two during the Late Triassic.

Conclusions

It is here proposed that the Late Triassic Cimmeride deformation and metamorphism in northern Turkey was caused by the collision and accretion of an Early–Middle Triassic oceanic plateau to the southern margin of Laurasia. The upper volcanic edifice of the oceanic plateau is preserved in northern Turkey as a very thick and extensive metabasite–marble–phyllite unit. Oceanic plateaux are common in the present-day Pacific Ocean and former examples have been described from Japan, western North America and the Caribbean region. This is apparently the first possible example of an ancient oceanic plateau from the Tethys Ocean.

An implication of the model presented here is that the İzmir–Ankara–Erzincan Suture represents both the Palaeo- and Neotethyan sutures. A suture can be defined as the site of a former ocean basin separating two continental plates (e.g. Moores 1981). It is expressed as a major tectonic line that forms a profound stratigraphic, structural, metamorphic and magmatic divide. The Araso Schuppen Zone, parts of the Insubric Line in the Western Alps (Trümpy 1975) and the Indus–Tsangpo Fault Zone in the Himalaya (e.g. Le Fort 1989) are examples of major sutures. The İzmir–Ankara–Erzincan Suture in Turkey is another example of a latest Cretaceous–Palaeocene suture across which stratigraphic, structural and metamorphic correlations are not possible (Şengör & Yılmaz 1981; Okay & Tüysüz 1999). However, as the Cimmeride Orogeny in Turkey was an accretionary rather than collisional orogeny, a Palaeotethyan suture as distinct from the Neotethyan suture does not exist. The Palaeotethyan suture shown on the maps (e.g. Şengör *et al.* 1984) does not correspond to a mappable tectonic line in the field, and does not form any stratigraphic, structural, metamorphic or magmatic boundary. Palaeotethyan subduction–accretion complexes, as well as the Hercynian continental units, occur on both sides of the supposed 'Palaeotethyan' suture line.

An important problem is the spatial and temporal relation between the Palaeo- and Neotethys. Accretionary complexes, consisting mainly of basalt, radiolarian chert, pelagic shale and serpentinite, occur widely to the south of the İzmir–Ankara Suture (Figs 2 and 3). Dating of radiolarian cherts from these accretionary complexes have yielded only Norian and younger ages, giving the duration of the İzmir–Ankara Neotethyan Ocean (Bragin & Tekin 1996; Bozkurt *et al.* 1997). The absence of Palaeozoic pelagic sedimentary rocks in the Neotethyan accretionary complexes reinforces the generally accepted view that the Neotethys opened as a separate ocean during the Triassic. It is possible that the narrow continental sliver with the Permo-Carboniferous limestone carapace, which may have rifted off from the northern margin of the Anatolide–Tauride Block during the Early Triassic, was responsible for the opening of the Neotethys and the closing of the Palaeotethys during its northward drift (Okay *et al.* 1996).

My fieldwork in northern Turkey over many years was generously supported by the Mineral Research and Exploration Institute of Turkey (MTA), the Turkish Petroleum Corporation (TPAO) and, in the last few years, by a grant from The Scientific and Research Council of Turkey (TÜBİTAK)-Glotek. Discussions with O. Monod, N. Okay, G. Stampfli and O. Tüysüz on various aspects of the Palaeotethyan problems are gratefully acknowledged. I also thank D. Altıner and G. Stampfli for critical reviews of this paper.

References

Akyürek, B. & Soysal, Y. 1983. Basic geological features of the region south of the Biga peninsula (Savaştepe–Kırkağaç–Bergama–Ayvalık). *Mineral Research and Exploration Institute of Turkey (MTA) Bulletin*, **95/96**, 1–13 [in Turkish with English abstract].

——, Akbaş, B. & Dager, Z. 1988. *Çankırı-E16 Quadrangle, 1:100 000 Scale Geological Map and Explanatory Text.* Mineral Research and Exploration Institute of Turkey (MTA) Publications [in Turkish with English abstract].

Alkaya, F. 1982. Taxonomic revision of the Lower Jurassic (Liassic) Phylloceratids of northern Turkey (Part I). *Geological Society of Turkey Bulletin*, **25**, 31–40 [in Turkish with English abstract].

Altiner D. 1983. Upper Permian foraminiferal biostratigraphy in some localities of the Taurus Belt. *In*: Tekeli, O. & Göncüoğlu, M. C. (eds) *Geology of the Taurus Belt.* Proceedings of the International Tauride Symposium. Mineral Research and Exploration Institute of Turkey (MTA) Publications, 255–268.

——, Koçyiğit, A., Farinacci, A., Nicosia, U. & Conti, M. A. 1991. Jurassic, Lower Cretaceous stratigraphy and palaeogeographic evolution of the southern part of north-western Anatolia. *Geologica Romana*, **28**, 13–80.

Argyriadis, I. 1978. *Le Permien Alpino–Méditerranéen à la charnière entre l'Hercynien et l'Alpin.* Thèse, l'Université de Paris Sud, Centre d'Orsay.

Aydin, M., Demir, O., Özçelik, Y., Terzioğlu, N. & Satir, M. 1995. A geological revision of İnebolu, Devrekani, Ağlı and Küre areas: new observations in Palaeotethys–Neotethys sedimentary successions. *In*: Erler, A., Ercan, T., Bingöl, E. & Örçen, S. (eds) *Geology of the Black Sea*

Region. Proceedings of the International Symposium on the Geology of the Black Sea Region, Mineral Research and Exploration Institute of Turkey (MTA) Publications, 33–38.

BEN-AVRAHAM, Z., NUR, A., JONES, D. & COX, A. 1981. Continental accretion: from oceanic plateaus to allochthonous terranes. *Science*, **213**, 47–54.

BERGOUGNAN, H. 1987. *Etudes géologiques dans l'est-Anatolien*. PhD Thesis, University Pierre et Marie Curie, Paris, France.

—— & FOURQUIN, C. 1982. Remnants of a pre-Late Jurassic ocean in northern Turkey: fragments of Permian–Triassic Neotethys? Discussion. *Geological Society of America Bulletin*, **93**, 929–936.

BİNGÖL, E., AKYÜREK, B. & KORKMAZER, B. 1975. Geology of the Biga peninsula and some characteristics of the Karakaya blocky series. *Proceedings of the 50th Anniversary of Turkish Republic Earth Sciences Congress*, Mineral Research and Exploration Institute of Turkey Publications, 70–75 [in Turkish with English abstract].

BOZKURT, E., HOLDSWORTH, B. K. & KOÇYİĞİT, A. 1997. Implications of Jurassic chert identified in the Tokat Complex, northern Turkey. *Geological Magazine*, **134**, 91–97.

BOZTUĞ, D., DEBON, F., LE FORT, P. & YILMAZ, O. 1984. Geochemical characteristics of some plutons from the Kastamonu granitoid belt (Northern Anatolia, Turkey). *Schweizerische Mineral-ogische und Petrographische Mitteilungen*, **64**, 389–404.

BRAGIN, N. Y. & TEKİN, U. K. 1996. Age of radiolarian chert blocks from the Senonian ophiolitic mélange (Ankara, Turkey). *Island Arc*, **5**, 114–122.

BRINKMANN, R. 1971. Jungpaläozoikum und alteres Mesozoikum in NW-Anatolien. *Mineral Research and Exploration Institute of Turkey (MTA) Bulletin*, **76**, 56–67.

BURKE, K., FOX, P. J. & ŞENGÖR, A. M. C. 1978. Buoyant ocean floor and the origin of the Caribbean. *Journal of Geophysical Research*, **83**, 3949–3954.

ÇAPAN, U. Z. & FLOYD, P. A. 1985. Geochemical and petrographic features of metabasalts within units of Ankara melange, Turkey. *Ofioliti*, **10**, 3–18.

CHATALOV, G. A. 1988. Recent developments in the geology of the Strandzha Zone in Bulgaria. *Bulletin of the Technical University of İstanbul*, **41**, 433–465.

—— 1991. Triassic in Bulgaria – a review. *Bulletin of the Technical University of İstanbul*, **44**, 103–135.

CLOOS, M. 1993. Lithospheric buoyancy and collisional orogenesis: subduction of oceanic plateaus, continental margins, island arcs, spreading ridges, and seamounts. *Geological Society of America Bulletin*, **105**, 715–737.

COFFIN, M. F. & ELDHOLM, O. 1994. Large igneous provinces: crustal structure, dimensions, and external consequences. *Reviews of Geophysics*, **32**, 1–36.

ÇOĞULU, E. & KRUMMENACHER, D. 1967. Problèmes géochronométriques dans le partie NW de l'Anatolie Centrale (Turquie). *Schweizerische Mineralogische und Petrographische Mitteilungen*, **47**, 825–831.

——, DELALOYE, M. & CHESSEX, R. 1965. Sur l'age de quelques roches plutoniques acides dans la région d'Eskişehir, Turquie. *Archives des Sciences, Genève*, **18**, 692–699.

DEAN, W. T., MARTIN, F., MONOD, O., DEMİR, O., RICKARDS, A. B., BOLTYNCK, P. & BOZDOĞAN, N. 1997. Lower Palaeozoic stratigraphy, Karadere–Zirze area, central Pontides, northern Turkey. *In*: GÖNCÜOĞLU, M. C. & DERMAN, A. S. (eds) *Early Palaeozoic Evolution in NW Gondwana*. Turkish Association of Petroleum Geologists, Special Publications, **3**, 32–38.

DICKINSON, W. R. & SEELY, D. R. 1979. Structure and stratigraphy of the fore-arc regions. *AAPG Bulletin*, **63**, 2–31.

DIXON, J. E. & ROBERTSON, A. H. F. 1999. Are multiple plumes implicated in the Triassic break-up of the Gondwanan margin in the Eastern Mediterranean region. *Journal of Conference Abstracts*, **4**, 314.

DOĞAN, M. 1990. *Petrologic, magmatic and tectonic modelling of the Palaeotethyan Ophiolites from the Pontides*. PhD Thesis, İstanbul University [in Turkish with English abstract].

DOMINGUEZ, S., LALLEMAND, S. E., MALAVIEILLE, J. & VON HUENE, R. 1998. Upper plate deformation associated with seamount subduction. *Tectonophysics*, **293**, 207–224.

ERDOĞAN, B., ALTINER, D., GÜNGÖR, T. & ÖZER, S. 1990. Stratigraphy of the Karaburun Peninsula. *Mineral Research and Exploration Institute of Turkey (MTA) Bulletin*, **111**, 1–24 [in Turkish with English abstract].

ERK, A. S. 1942. *Etude géologique de la région entre Gemlik et Bursa (Turquie)*. Mineral Research and Exploration Institute of Turkey (MTA), Special Publications, Seri B, **9**.

FLOYD, P. A. 1993. Geochemical discrimination and petrogenesis of alkalic basalt sequences in part of the Ankara mélange, central Turkey. *Journal of the Geological Society, London*, **150**, 541–550.

GANEV, M. 1974. Stand der Kenntnisse über die Stratigraphie der Trias Bulgariens. *In*: ZAPFE, H. (ed.) *Die Stratigraphie der alpin–mediterranean Trias*. Springer, 93–96.

GENÇ, S. C. & YILMAZ, Y. 1995. Evolution of the Triassic continental margin, northwest Anatolia. *Tectonophysics*, **243**, 193–207.

GLADCZENKO, T. Z., COFFIN, M. F. & ELDHOLM, O. 1997. Crustal structure of the Ontong Java Plateau: modelling of new gravity and existing seismic data. *Journal of Geophysical Research*, **102**, 22 711–22 729.

GÖKDENİZ, S. 1981. *Recherches géologiques dans les Taurus occidentales entre Karaman et Ermenek, Turquie. Le series a 'tuffites vertes' Triassiques*. Thèse, l'Université de Paris Sud, Centre d'Orsay.

GÖRÜR., N., MONOD, O., OKAY, A. İ *ET AL*. 1997. Palaeogeographic and tectonic position of the Carboniferous rocks of the western Pontides (Turkey) in the frame of the Variscan belt.

Bulletin de la Société Géologique de France, **168**, 197–205.

Gradstein, F. M., Agterberg, F. P., Ogg, J. G., Hardenbol, J., Van Veen, P., Thuerry, J. & Huang, Z. 1994. A Mesozoic time scale. *Journal of Geophysical Research*, **99**, 24 051–24 074.

Gutnic, M., Monod, O., Poisson, A. & Dumont, J. F. 1979. Géologie des Taurides Occidentales (Turquie). *Mémoires de la Société Géologique de France*, **137**, 1–112.

Haas, W. 1968. Das Alt-Paläozoikum von Bithynien (Nordwest Türkei). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **131**, 178–242.

Kaya, O. & Mostler, H. 1992. A Middle Triassic age for low-grade greenschist facies metamorphic sequence in Bergama (İzmir), western Turkey: the first palaeontological age assignment and structural–stratigraphic implications. *Newsletter for Stratigraphy*, **26**, 1–17.

Ketin, İ. 1951. Über die Geologie der Gegend von Bayburt in Nordost-Anatolien. *İstanbul University, Faculty of Science Bulletin, Seri B*, **16**, 113–127.

Kerr, A. C., Tarney, J., Nivia, A., Marriner, G. & Saunders, A. D. 1998. The internal structure of oceanic plateaus: inferences from obducted Cretaceous terranes in western Columbia and the Caribbean. *Tectonophysics*, **292**, 173–188.

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

Kimura, G., Sakakibara, M. & Okamura, M. 1994. Plumes in central Panthalassa? Deductions from accreted oceanic fragments in Japan. *Tectonics*, **13**, 905–916.

Koçyiğit, A. 1987 Tectonostratigraphy of the region of Hasanoğlan (Ankara): evolution of the Karakaya orogenic belt (in Turkish). *Hacettepe University Earth Sciences*, **14**, 269–294 [in Turkish with English abstract].

—— 1991. An example of an accretionary forearc basin from northern Central Anatolia and its implications for the history of subduction of Neotethys in Turkey. *Geological Society of America Bulletin*, **103**, 22–36.

Kozur, H. 1997. Pelagic Permian and Triassic of the western Tethys and its palaeogeographic and stratigraphic significance. *Abstracts, XLVIII. Berg- und Hüttenmannischer Tag, Technische Universitat Bergakademie Freiberg*, 21–25.

—— & Kaya, O. 1994. First evidence of pelagic Late Permian conodonts from NW Turkey. *Neues Jahrbuch für Geologie und Paläontologie Monatshefte*, 339–347.

Leven, E. Ja. & Okay, A. İ. 1996. Foraminifera from the exotic Permo-Carboniferous limestone blocks in the Karakaya Complex, northwest Turkey. *Rivista Italiana Palaeontologia e Stratigrafia*, **102**, 139–174.

Le Fort, P. 1989. The Himalayan orogenic segment. *In*: Şengör, A. M. C. (ed.) *Tectonic Evolution of the Tethyan Region*. Kluwer, 289–386.

Monod, O. 1977. *Recherches géologiques dans le taurus occidental au sud de Beyşehir (Turquie)*. Thèse, l'Université de Paris Sud, Centre d'Orsay.

—— & Akay, E. 1984. Evidence for a Late Triassic–Early Jurassic orogenic event in the Taurides, *In*: Dixon, J. E. & Robertson, A. H. F. (eds) *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 113–122.

—— & Okay, A. İ. 1999. Late Triassic Palaeotethyan subduction: evidence from Triassic blueschists. *Journal of Conference Abstracts*, **4**, 315–316.

——, ——, Maluski, H., Monié, P. & Akkök, R. 1996. Schistes bleus du Trias supérieur en Turquie du NW: comment s'est fermée la Palaeo-Téthys? *16th Réunion des Sciences de la Terre*, 10–12 April 1996, Orléans, France, Abstracts, 43.

Moores, E. M. 1981. Ancient suture zones within continents. *Science*, **213**, 41–46.

Okay, A. İ. 1984. The geology of the Agvanis metamorphic rocks and neighbouring formations. *Mineral Research Exploration Institute of Turkey (MTA) Bulletin*, **99/100**, 16–36.

—— 1996. Granulite facies gneisses from the Pulur region, Eastern Pontides. *Turkish Journal of Earth Sciences*, **5**, 55–61.

—— & Leven, E. Ja. 1996. Stratigraphy and palaeontology of the Upper Palaeozoic sequence in the Pulur (Bayburt) region, Eastern Pontides. *Turkish Journal of Earth Sciences*, **5**, 145–155.

—— & Monié, P. 1997. Early Mesozoic subduction in the Eastern Mediterranean: evidence from Triassic eclogite in northwest Turkey. *Geology*, **25**, 595–598.

—— & Mostler, H. 1994. Carboniferous and Permian radiolarite blocks in the Karakaya Complex in northwest Turkey. *Turkish Journal of Earth Sciences*, **3**, 23–28.

—— & Şahintürk, Ö. 1997. Geology of the Eastern Pontides. *In*: Robinson, A. (ed.) *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. AAPG Memoir, **68**, 291–311.

—— & Tüysüz, O. 1999. Tethyan sutures of northern Turkey. *In*: Durand, B., Jolivet, L., Horváth, F & Séranne, M. (eds) *The Mediterranean Basin: Tertiary Extension within the Alpine Orogen*. Geological Society, London, Special Publications, **156**, 475–515.

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

——, Siyako, M. & Bürkan, K. A. 1991. Geology and tectonic evolution of the Biga peninsula, northwestern Turkey. *Bulletin of the Technical University of İstanbul*, **44**, 91–256.

——, Satir, M., Maluski, H., Siyako, M., Monié, P., Metzger, R. & Akyüz, S. 1996. Palaeo- and Neotethyan events in northwest Turkey: geological and geochronological constraints. *In*: Yin, A. & Harrison, M. (eds) *Tectonics of Asia*. Cambridge University Press, 420–441.

Özgül, N. 1997. Stratigraphy of the tectono–stratigraphic units in the region Bozkır–Hadım–

Takent (northern central Taurides). *Mineral Research and Exploration Institute of Turkey (MTA) Bulletin*, **119**, 113–174 [in Turkish with English abstract].

PICKETT, E. 1994. *Tectonic evolution of the Palaeotethys Ocean in northwest Turkey*. PhD Thesis, University of Edinburgh.

—— & ROBERTSON, A. H. F. 1996. Formation of the Late Palaeozoic–Early Mesozoic Karakaya Complex and related ophiolites in NW Turkey by Palaeotethyan subduction–accretion. *Journal of the Geological Society, London*, **153**, 995–1009.

RICHARDS, M. A., JONES, D. L., DUNCAN, R. A. & PAOLA, D. J. 1991. A mantle plume initiation model for the Wrangellia flood basalt and other ocean plateaus. *Science*, **254**, 263–267.

RICOU, L. E. 1994. Tethys reconstructed: plates, continental fragments and their boundaries since 260 Ma from Central America to south-eastern Asia. *Geodinamica Acta*, **7**, 169–218.

ROBERTSON, A. H. F. & DIXON, J. E. 1984. Introduction: aspects of the geological evolution of the Eastern Mediterranean. *In*: DIXON, J. E. & ROBERTSON, A. H. F. (eds) *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 1–74.

SAUNDERS, A. D., TARNEY, J., KERR, A. C. & KENT, R. W. 1996. The formation and fate of large oceanic igneous provinces. *Lithos*, **37**, 81–95.

ŞENGÖR, A. M. C. 1979. Mid-Mesozoic closure of Permo-Triassic Tethys and its implications. *Nature*, **279**, 590–593.

—— & YILMAZ, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics*, **75**, 181–241.

——, —— & SUNGURLU, O. 1984. Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Palaeo-Tethys. *In*: DIXON, J. E. & ROBERTSON, A. H. F. (eds) *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 77–112.

SERVAIS, M. 1982. *Collision et suture téthysienne en Anatolie Centrale, (tude structurale et métamorphique (HP-BT) de la zone nord Kütahya*. PhD Thesis, Université de Paris-Sud, Centre d'Orsay.

SMITH, A. G., HURLEY, A. M. & BRIDEN, J. C. 1981. *Phanerozoic Palaeocontinental World Maps*. Cambridge University Press.

STAMPFLI, G. 1996. The Intra-Alpine terrain: a Palaeotethyan remnant in the Alpine Variscides. *Eclogae Geologica Helvetica*, **89**, 13–42.

——, MARCOUX, J. & BAUD, A. 1991. Tethyan margins in space and time. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **87**, 373–409.

TEJADA, M. L. G., MAHONEY, J. J., DUNCAN, R. A. & HAWKINS, M. P. 1996. Age and geochemistry of basement and alkalic rocks of Malaita and Santa Isabel, Solomon Islands, southern margin of Ontong Java Plateau. *Journal of Petrology*, **37**, 361–394.

TEKELİ, O. 1981. Subduction complex of pre-Jurassic age, northern Anatolia, Turkey. *Geology*, **9**, 68–72.

TOPUZ, G., SATIR, M., ALTHERR, R. & SADIKLAR, M. B. 1997. Thermobarometrische und geochronologische Untersuchungen zur Metamorphosegeschichte Granat- und Cordieritführender Gneise des Pulur Massivs, NE Türkei. *Deutsche Mineralogische Vereinigung*, **Abstracts**, 45.

TRÜMPY, R. 1975. Penninic–Austroalpine boundary in the Swiss Alps: a presumed former continental margin and its problems. *American Journal of Science*, **275-A**, 209–238.

TÜYSÜZ, O. 1990. Tectonic evolution of a part of the Tethyside orogenic collage: the Kargı Massif, northern Turkey. *Tectonics*, **9**, 141–160.

—— 1993. A geo-traverse from the Black Sea to the central Anatolia: tectonic evolution of northern Neotethys. *Turkish Association of Petroleum Geologists Bulletin*, **5**, 1–33 [in Turkish with English abstract].

USTAÖMER, T. & ROBERTSON, A. H. F. 1993. A Late Palaeozoic–Early Mesozoic marginal basin along the active southern continental margin of Eurasia: evidence from the Central Pontides (Turkey) and adjacent regions. *Geological Journal*, **28**, 219–238.

—— & —— 1994. Late Palaeozoic marginal basin and subduction–accretion: the Palaeotethyan Küre Complex, Central Pontides, northern Turkey. *Journal of the Geological Society, London*, **151**, 291–305.

YANEV, S. N. 1992. The Permian in Northern Bulgaria. I. Formal lithostratigraphy related to the Lower Permian. *Geologica Balcanica*, **22**, 3–27.

YILMAZ, O. & BOZTUĞ, D. 1986. Kastamonu granitoid belt of northern Turkey: first arc plutonism product related to the subduction of the Palaeotethys. *Geology*, **14**, 179–183.

YILMAZ, Y. 1976. Geology of the Gümüşhane granite (petrography). *İstanbul University, Faculty of Science Bulletin, Seri B*, **39**, 157–172 [in Turkish with English abstract].

—— 1981. Tectonic evolution of the southern margin of the Sakarya continent. *İstanbul University Earth Sciences*, **1**, 33–52 [in Turkish with English abstract].

——, SERDAR, H. S., GENÇ, C. *ET AL.* 1997. The geology and evolution of the Tokat Massif, south-central Pontides, Turkey. *International Geological Review*, **39**, 365–382.