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Allochthonous Terranes in the Tethyan Middle East: Anatolia and the Surrounding Regions [and Discussion]

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Allochthonous terranes in the Tethyan Middle East: Anatolia and the surrounding regions

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Turkey consists of a number of tectono-stratigraphic entities corresponding with specific former plate tectonic environments such as island arcs, submarine continental platforms with Atlantic-type and Pacific-type margins. These were successively accreted to Eurasia since the late Palaeozoic resulting in N to S development of the Turkish orogen.

Tethyan evolution of the Anatolia and surrounding regions is the result of demise of the oceanic environments that correspond to the Palaeo-Tethys and Neo-Tethys oceans. The former was totally consumed by Dogger while the latter opened during the Trias-Lias interval and survived into the Cenozoic.

Introduction

The Tethyan evolution of Anatolia is reviewed in terms of two main phases of activity which partly overlap in time: the Palaeo-Tethyan and the Neo-Tethyan. The Palaeo-Tethyan events occurred mainly during the Permian-Lias interval and were most prominent in Northern Anatolia. On the other hand, the Neo-Tethyan phase of activity affected almost the entire Anatolian region from the Triassic through to the Miocene, and its effects linger on to the present day.

The Turkish orogen may be divided into a number of E–W trending belts which are separated from each other by ophiolitic sutures (figure 1). The ages for suturing (Şengör & Yılmaz 1981) suggest that the Anatolian orogen evolved progressively through time from the northern regions to the south.

The purpose of this paper is to review the Mesozoic–Cenozoic tectonic evolution of the Anatolian orogenic belt by emphasizing the geological history of three regions, complementary in nature, which are critical in the evaluation of the consecutive stages of the orogeny through time. These are (1) the Sakarya continent in the west, (2) the Central Pontides in the north, and (3) the southeast Anatolian region in the south (figure 1). These areas have been selected for two main reasons. They have been studied in considerable detail in recent years (Yılmaz 1981; Yılmaz *et al.* 1984, 1987*a*; Tüysüz 1990) and they are located in regions where both the Palaeo- and the Neo-Tethyan systems are well exposed and can be reconstructed with some confidence. In the central Pontides the Palaeo–Tethyan and the Neo-Tethyan ophiolitic fragments are observed. In the Sakarya continent remnants of the Karakaya marginal sea and Neo-Tethyan ophiolitic fragments are exposed. In southeast Anatolia Neo-Tethyan ophiolitic fragments, metamorphic massifs, and the later stages in the orogenic evolution can all be evaluated (figure 1).

The Sakarya continent

The sequence in the Sakarya continent is shown in figures 2 and 3. Two different sectors may be distinguished within the region. In the north and the south metamorphic rocks and

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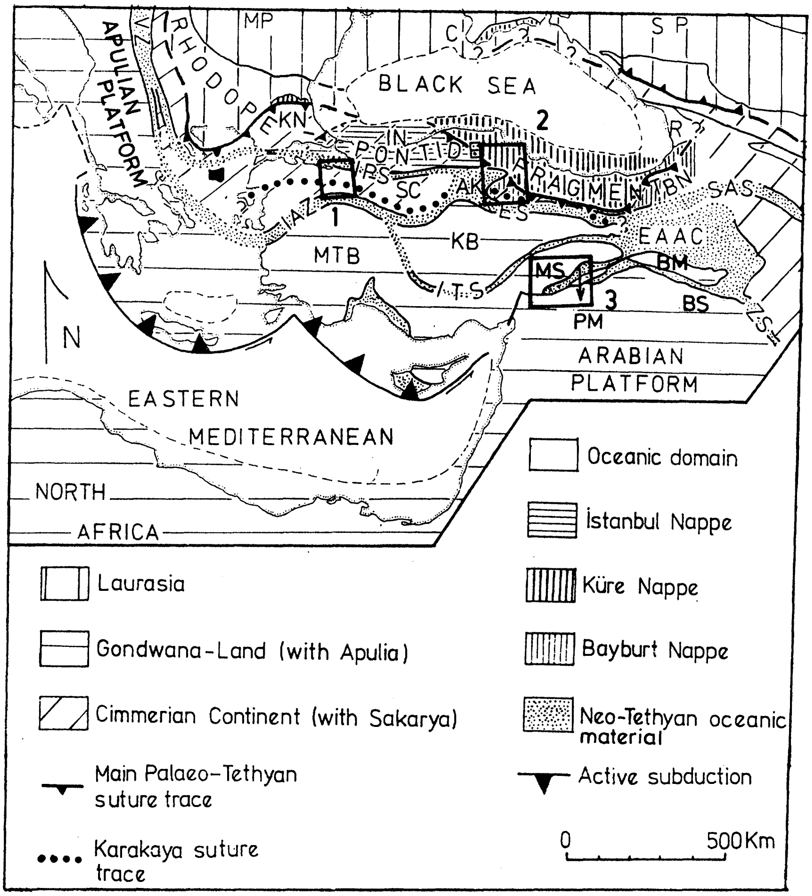

FIGURE 1. Tectonic map showing the Tethyan palaeotectonic elements in Anatolia and the surrounding regions. (Modified after Şengör *et al.* 1984). SP, Schythian platform; C, Crimea; MP, Moesian platform; Sc, Sakarya continent; MTB, Menderes-Taurus block; KB, Kirşehir block (MTB+KB, Anatolide-Tauride platform); PM, Pötürge massif; BM, Bitlis Massif; Vz, Vardar zone; IPS, Intra-Pontide suture; IAZ, Izmir-Ankara suture; AK, Ankara knot; ES, Erzincan suture; ITS, Intra-Tauride suture; SAS, Sevan-Akera suture; EAAC, East Anatolian accretionary complex; BS, Bitlis suture; MS, Maden suture; ZS, Zagros suture; KN, IN and BN are the Kirklareli, Istanbul and Bayburt nappes respectively; R, Riou depression. 1, 2 and 3 are the regions that are described in detail in the text under the headings of the Sakarya Continent, the Central Pontides, and southeast Anatolia respectively.

sedimentary rocks dominate, respectively. Between the two a metamorphosed ophiolitic assemblage and associated *mélange* occur. In the sediment-dominated southern sector there are also some metamorphic rocks occurring at the base of the sequence (figure 3), but these do not resemble the metamorphic rocks of the northern sector in terms of lithology, age, or metamorphic facies.

The southern sector

Two distinct tectonostratigraphic units may be distinguished in the metamorphic rocks of the southern sector (figure 3). One of these is essentially composed of metapelitic rocks that range from a slate-phyllite association to schists and migmatitic gneisses. These are intruded by a post-tectonic granitic pluton (the Söğüt granite) dated isotopically at *ca.* 295 Ma (Çoğulu *et al.* 1965). This association is the oldest rock group of the region and is unconformably overlain by Permian sediments. The other metamorphic unit of the southern sector consists primarily of basic igneous rocks of Triassic age, with associated deep-sea sediments, which

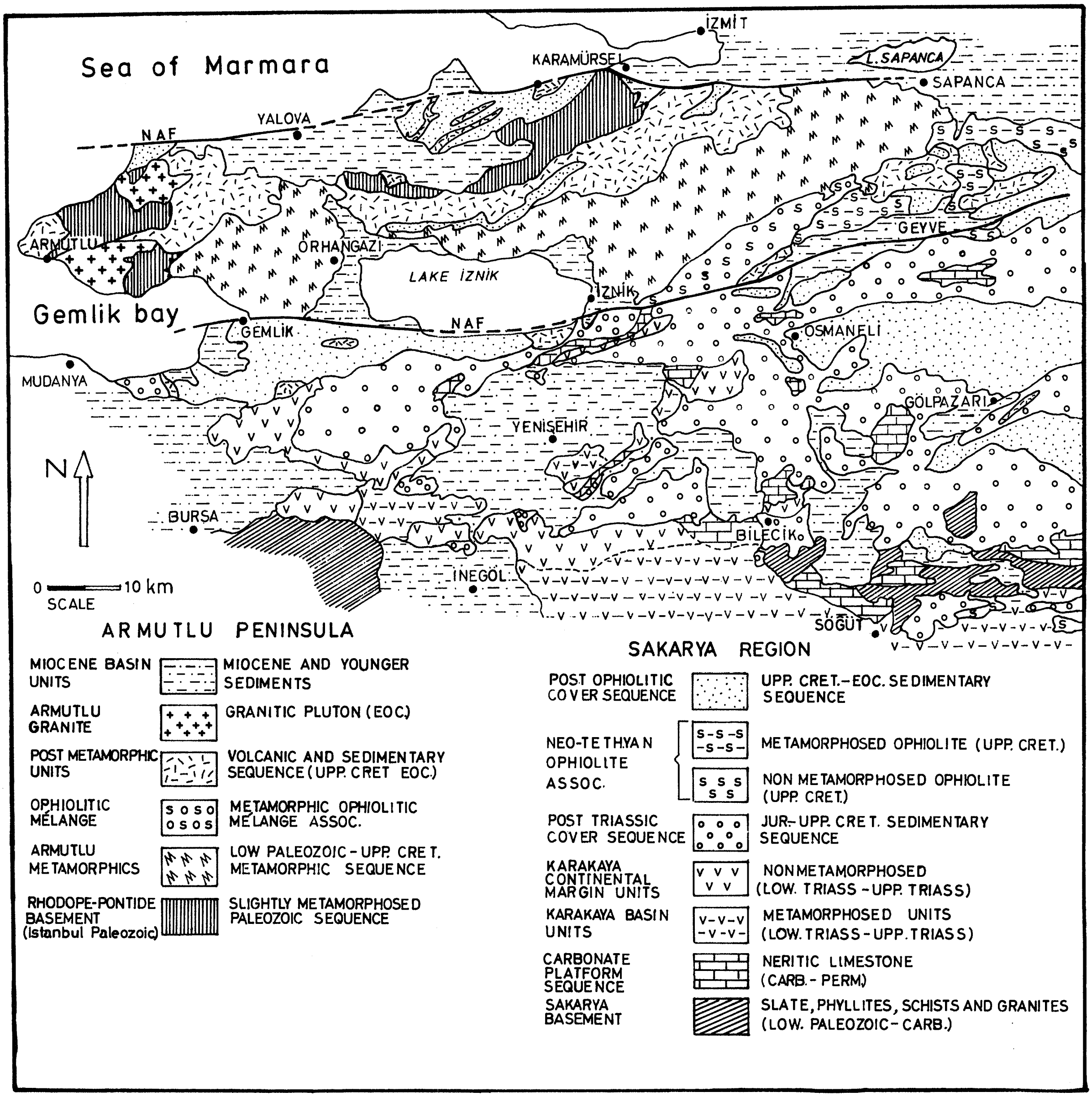

FIGURE 2. Geological map showing different tectono-stratigraphic units of the Sakarya Continent (the region that is shown as no. 1 in figure 1). NAF, branches of the North Anatolian Transform fault.

underwent high-pressure metamorphism. The Pre-Permian metamorphics overlie the Triassic metamorphics and the boundary between the two is a sharp mylonitized thrust contact.

The metamorphic rock units and their tectonic contact are overlain by a transgressive sedimentary sequence which begins with basal sandstones of Liassic age (figure 3). The following succession, as shown in figures 2 and 3 covers a period ranging from the late Jurassic to the Palaeocene.

The northern sector

The metamorphic assemblage of the northern sector forms a sequence (figure 3) more than 1000 m thick in which, despite the greenschist facies metamorphism, well-determined lithological units may be distinguished. In terms of its lithologies and faunas, the sequence may

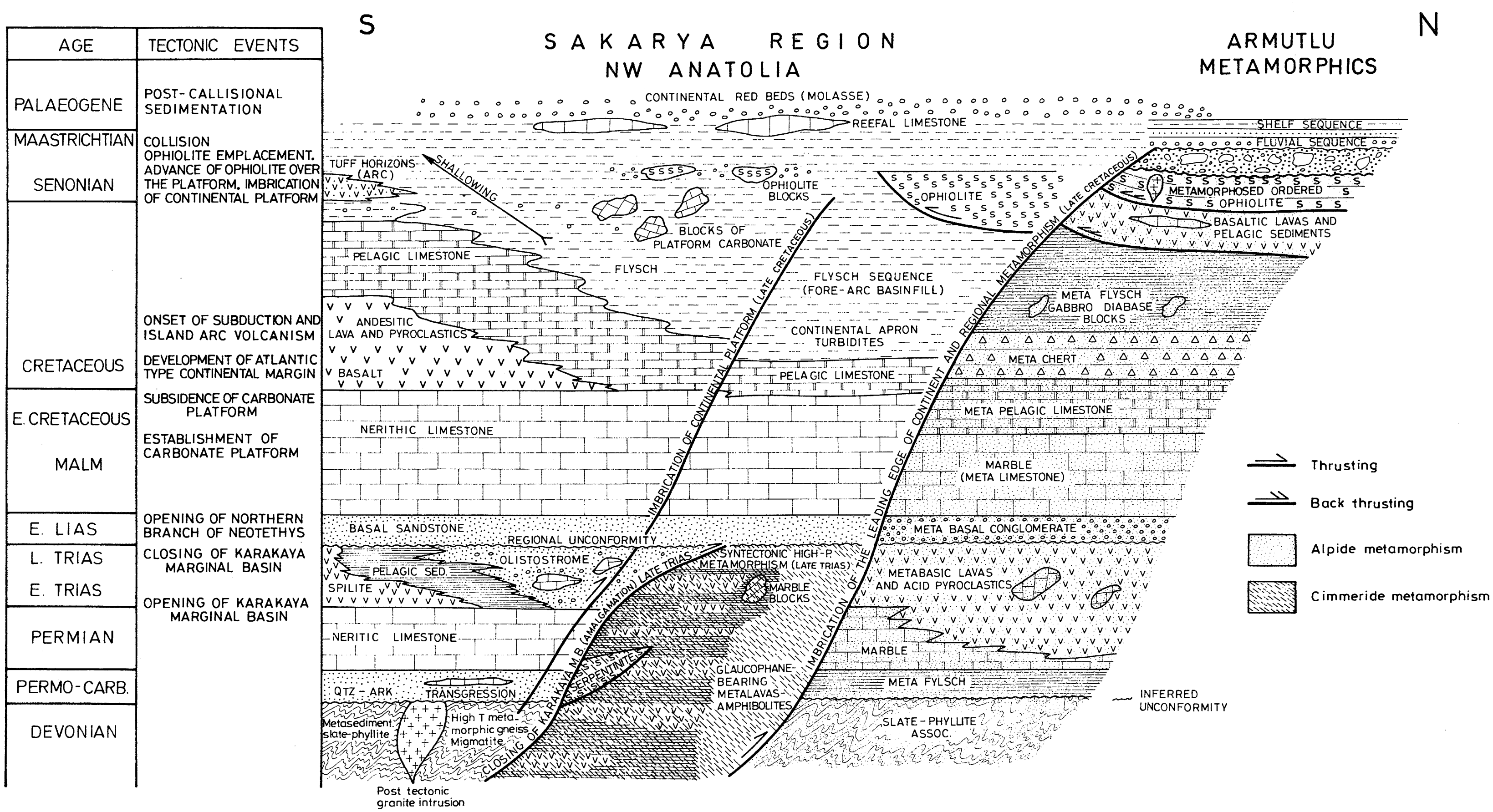

FIGURE 3. Generalized stratigraphic sections across the Sakarya Continent in N–S direction showing the major tectonic elements and tectonic events in time-space reference. The Cimmeride (Triassic) and Alpide (late Cretaceous) stages of metamorphisms are indicated by different symbols that are super-imposed on the lithological symbols.

be closely correlated with the non-metamorphic sequence of the southern sector (figure 3). The metamorphic units appear to represent the lateral, but more basinal, equivalents of the southern sedimentary sequence. Together they were deposited in a continental shelf and slope environment. The oldest sediments that were deposited on top of the northern sector metamorphics and the neighbouring meta-ophiolites are Maastichtian in age, placing a late Cretaceous time limit on the age of metamorphism.

The geological data indicate that the first important tectonic event in the Sakarya continent occurred during the Triassic (figure 3). At the end of the Permian, a carbonate platform was ruptured leading to the opening of a short-lived basin, known as the Karakaya marginal sea (Şengör & Yılmaz 1981). Its remnants can now be traced along the Pontides, in the Taurus mountains, and within the southeast Anatolian metamorphic massifs (figure 1) extending into Iran (Yılmaz *et al.* 1987*b*). Accompanying this event, a typical ocean floor, represented by an almost complete ophiolite sequence, was formed. At the end of the Triassic the basin was closed (figure 3), resulting in the northwards thrusting of the allochthons. The ophiolites were metamorphosed to glaucophane-bearing greenschists facies.

Following the late Triassic closure of the Karakaya marginal basin a new rifting phase began during the Liassic (Yılmaz 1981; Şengör & Yılmaz 1981). The rift-related sequence formed at that time can be traced throughout the Pontides (Görür *et al.* 1983) as far as Iran. During the Jurassic and early Cretaceous the region was covered by platform carbonates (figure 3). This platform was bordered by the oceanic environments in the north and south (Şengör & Yılmaz 1981). During the early late Cretaceous, platform subsidence occurred, as is evidenced by deposition of the pelagic limestones and cherts (figure 3). In the late Cretaceous, not long after the regional subsidence of the continental platform, a new phase of tectonism was initiated. The onset of tectonism is shown by the flysch deposition over units of variable age, thrusts, transportation of blocks of the older rock units into the flysch trough, and the influx of ophiolitic detritus (figure 3). All of these associated events may be regarded as linked with the emplacement of the ophiolite onto the continental platform (figure 3). At the same time the leading edge of the Sakarya continent was initially internally imbricated (figure 3), and was then buried and metamorphosed together with an obducted slab of the ophiolite to form the metamorphic assemblage of the northern sector.

These related events correspond to the demise of the northern branch of the Neo-Tethyan ocean floor and thus to the continental collision which occurred between the Sakarya continent and the Pontides during the late Cretaceous (Şengör & Yılmaz 1981).

The central Pontides

The central Pontides form a geological mosaic (figure 4) that is composed of amalgamation of various, roughly E–W trending accreted tectonstratigraphic units (figures 1 and 4). Among them the Ankara–Erzincan ophiolitic suture, the Karakaya suture, the eastern Pontide units (the Bayburt nappe), the western Pontide units (the Istanbul nappe) and the eastern extension of the Sakarya continent may be mentioned (Tüysüz 1990) (figure 1).

Figure 5 shows a N–S geological section across the central Pontides. The section shows that in the south central part of the region Palaeozoic metamorphosed rocks occur at the base of the sequence. Onto this, different units, of ophiolitic rocks and associated assemblages, were emplaced initially from the north during the Middle Mesozoic, and then later from the south at the end of the Mesozoic. The older ophiolites, which outcrop in the northern part of the

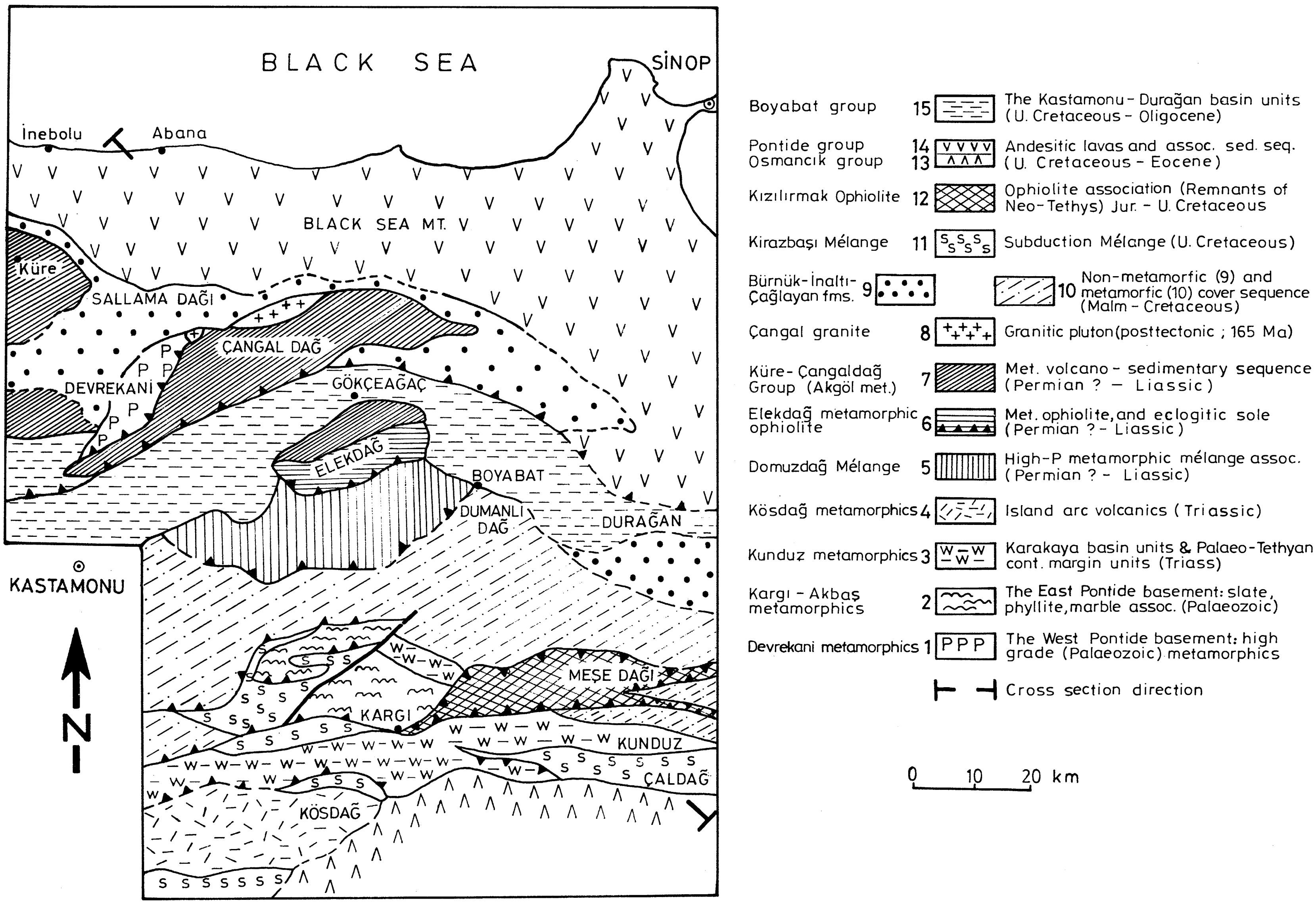

FIGURE 4. Geological map showing different tectono-stratigraphic units of the Central Pontides (the region that is shown as no. 2 in figure 1). The cross-section direction indicates the section shown in the figure 5, 9 and 10 are the identical units of which 9 is metamorphic, 10 is non-metamorphic.

region, are metamorphosed and are regarded to be remnants of the Palaeo-Tethyan ocean (Şengör *et al.* 1984).

The upper layers of these ophiolites, including the pillow lavas, occur in the Küre and Çangal Dağ areas (figure 4) where the epiophiolitic deep-sea sediments yielded ages ranging from Permian (?) to Liassic (Aydın *et al.* 1986). The lower layers outcrop in the Elekdağ area, where a thin eclogitic sole is seen to be attached to the ophiolitic base (figure 5). Together with this sliver of eclogite the ophiolites were thrust over a mélange association. The ophiolite was then emplaced southwards possibly as a backthrust onto the continental margin sequence as a nappe package.

At the base of the continental margin sequence there is a slate-phyllite association of possible lower Palaeozoic age. This is overlain by metamorphosed Permian carbonates followed by a basaltic metalava sequence that contains blocks of the underlying carbonates. The metalavas are intercalated with metapelitic rock units which include blocks of gabbro. Towards the upper levels of the sequence, metamorphosed pelagic sediments, intercalate with an upper unit of basaltic metalavas. At the top of the sequence metamorphosed olistostromes containing abundant ophiolitic fragments occur (figure 5). The units overlying the metamorphosed Permian carbonate succession are identical to the Triassic of the Sakarya continent.

The metamorphics are cut by a post-tectonic granitic intrusion (figure 5) which has been dated isotopically at 165 Ma (Yılmaz 1979). The granite, along with the underlying units, is overlain by a first common regional sedimentary cover sequence of Malm age (fiugre 5). However, post-deformation sedimentation commenced, locally earlier than this, in the Liassic. Deposition at first occurred only on the metamorphosed continental margin sequence, but it continued during the Malm. Sediment deposition was uninterrupted in areas which are unaffected by the Palaeo-Tethyan ophiolite obduction.

The region-wide transgressive Malm sequence (figure 5) began with basal sandstones and conglomerates. These were followed by neritic carbonates, which change laterally to shales, of Lower Cretaceous age. The Upper Cretaceous is represented by a flysch succession. In the northern parts of the region (the Central Black Sea Mountains) this is post-dated by calc-alkaline andesitic volcanism. In the south it is initially overlain by a wildflysch and then a flysch deposition of an ophiolitic nature, and these are then followed by the emplacement of a thick ophiolite nappe package consisting of slices of an internally ordered ophiolite sequence. In contrast to the northern ophiolites (the Palaeo-Tethyan ophiolites) that were emplaced during the Dogger, the southern ophiolites are not metamorphosed.

The geological evolution of the central Pontides shows some important similarities to the Sakarya region, especially where the Karakaya marginal basin events are recorded. The data indicate that the Karakaya basin closed at the end of the Triassic at a time when the Palaeo-Tethyan ocean was still present in the north. The demise of Palaeo-Tethys and the obduction of ophiolitic slabs took place in the Dogger (figure 5). Immediately after the closure of the Karakaya marginal basin a new rifting event started in the southern sector of the Pontides (Yılmaz 1981; Şengör & Yılmaz 1981) during the Liassic, and this eventually led to the opening of the Neo-Tethyan ocean in the southern part of the Pontides.

During the Malm, the Palaeo-Tethyan events ended completely, and a south-facing Atlantic-type continental margin became established by the beginning of the early Cretaceous. During the late Cretaceous, the Neo-Tethyan ocean began to be subducted along a north-dipping Benioff zone under the ophiolite-laden northern continent (Şengör & Yılmaz 1981).

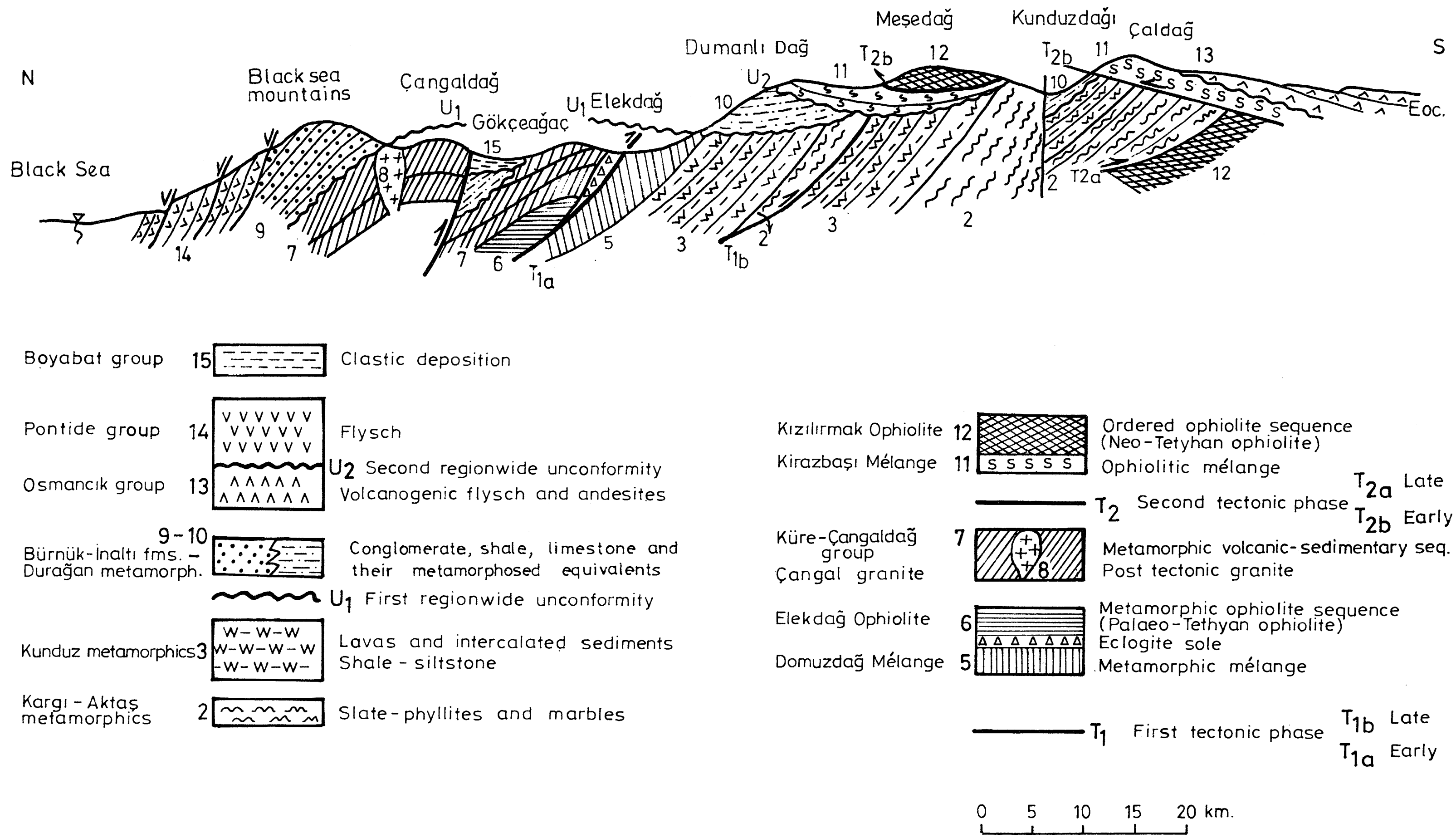

FIGURE 5. Geological section across the Central Pontides. Numbers refer to the rock units shown in figure 4. Abbreviations: Dağ, Mt, Mountain.

Subduction generated an Andean-type magmatic arc on the Upper Cretaceous units in the northern parts of the region, while in the south a subduction *mélange* was produced in front of the continent. At the end of the Cretaceous ophiolite slabs were obducted onto the continental margin sequence along the southern edge of the continent (figure 5), possibly by a *retrocharriage* mechanism (Yılmaz & Tüysüz 1984; Tüysüz 1990).

The southeast Anatolia

In the region of southeast Anatolia 3 geologically different zones may be distinguished. From south to north these are (1) the Arabian platform, (2) the zone of imbrication, and (3) the nappe region (figures 6 and 7).

The Arabian platform

The Arabian platform represents the Arabian authochtonous and parauthochtonous sedimentary succession (figures 6, 7 and 8) that has accumulated, almost without interruption, since the early Palaeozoic on a stabilized craton (the Pan-African basement). The platform sequence is therefore relatively undeformed in its exterior parts. However, towards the north, where the region was affected by the southeast Anatolian orogen, the platform sequence gradually becomes more deformed into a foreland fold and thrust belt.

The Mesozoic sequence, and the associated geological evolution of southeast Anatolia until the ophiolite obduction onto the Arabian platform in the late Cretaceous appear similar in many ways to the other peripheral parts of the Arabian platform (see, for example, Robertson 1987).

However, the post-ophiolite geology of the Arabian platform in southeast Anatolia differs significantly from the other peri-Arabian regions as well as from the other regions of Anatolia. In this region, contrary to the other areas, the orogenic evolution had not ended with ophiolite obduction in the late Cretaceous, but extended into the late Cenozoic.

Figure 8 shows the post-ophiolite stratigraphy in the north of the Arabian platform and farther north where a marine environment was re-established over the continental platform at the end of Mesozoic (late Maastrichtian), and it survived until the end of the early Miocene with only one major phase of non-deposition during the late early Eocene (figure 8). Towards the north this platform joined an oceanic environment during the early–middle Tertiary as evidenced by co-eval units that occur in the zone of imbrication and along the Missis-Andırın Mountains (figures 6 and 8).

The zone of imbrication

The zone of imbrication is a narrow E–W trending belt which is seen to have been squeezed and sandwiched between the Arabian platform to the south and the nappe regions to the north (figures 6 and 7). It is separated from the other two regions by thrusts. The zone consists of a number of imbricated thrust slices which cover a succession comprising the late Cretaceous–early Miocene period. Between the thrust slices the stratigraphic sequences are reversed with older units overlying younger units (figures 7 and 8). The base of the section is represented by a flysch succession which appears to be laterally equivalent to the similar flysch at the top of the Arabian platform sequence. Although contacts between the units, described above, are tectonic in nature (thrusts), there is clear evidence within each slice to suggest that the slices are genetically related units which formed one continuous succession before imbrication.

Towards the west, the zone of imbrication extends to the Missis-Andırın Mountain range

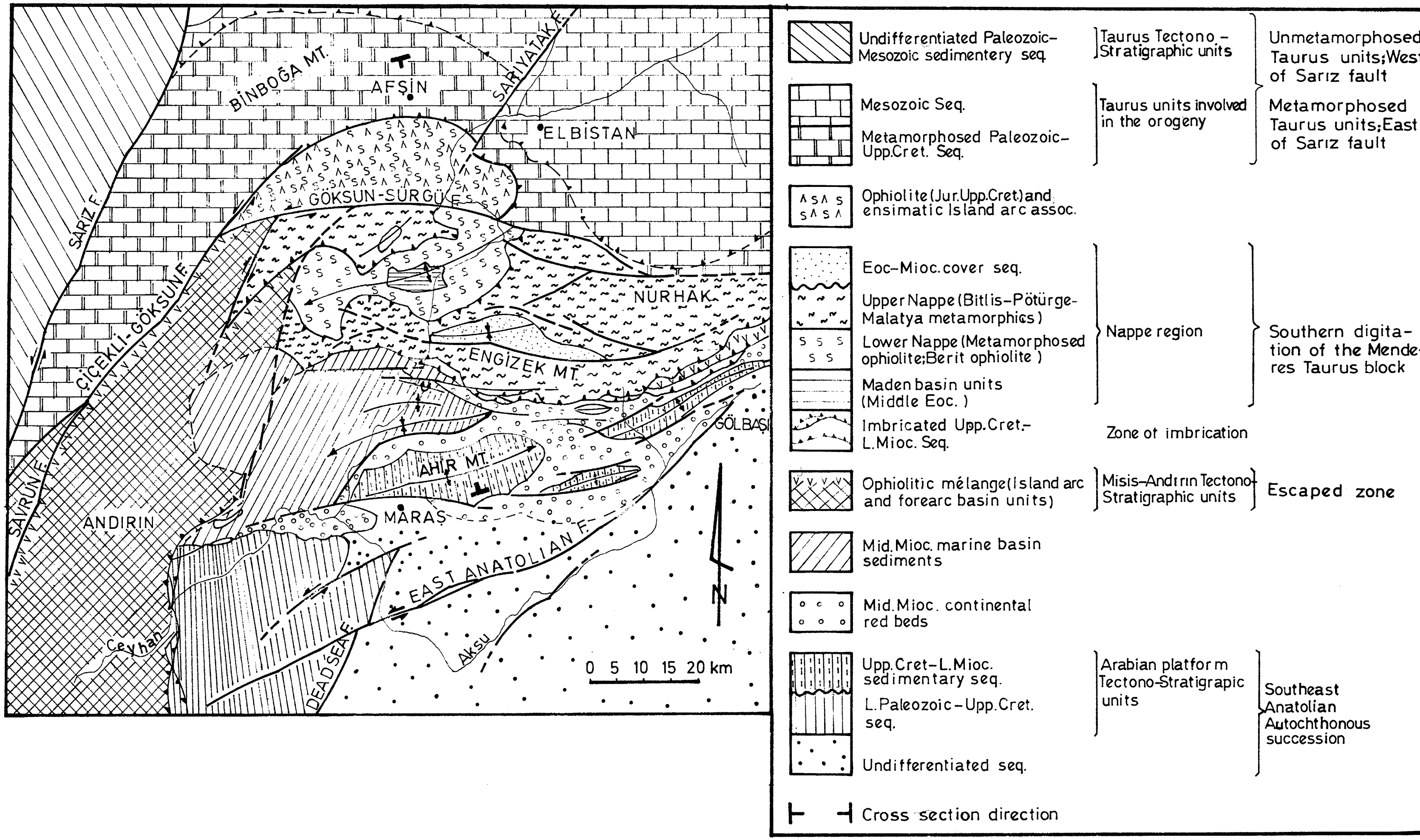

FIGURE 6. Geological map showing different tectono-stratigraphic units of the south-east Anatolia in the Maraş-Elbistan regions (the region that is shown as no. 3 in figure 1). The cross-section direction indicates the section shown in the figure 7.

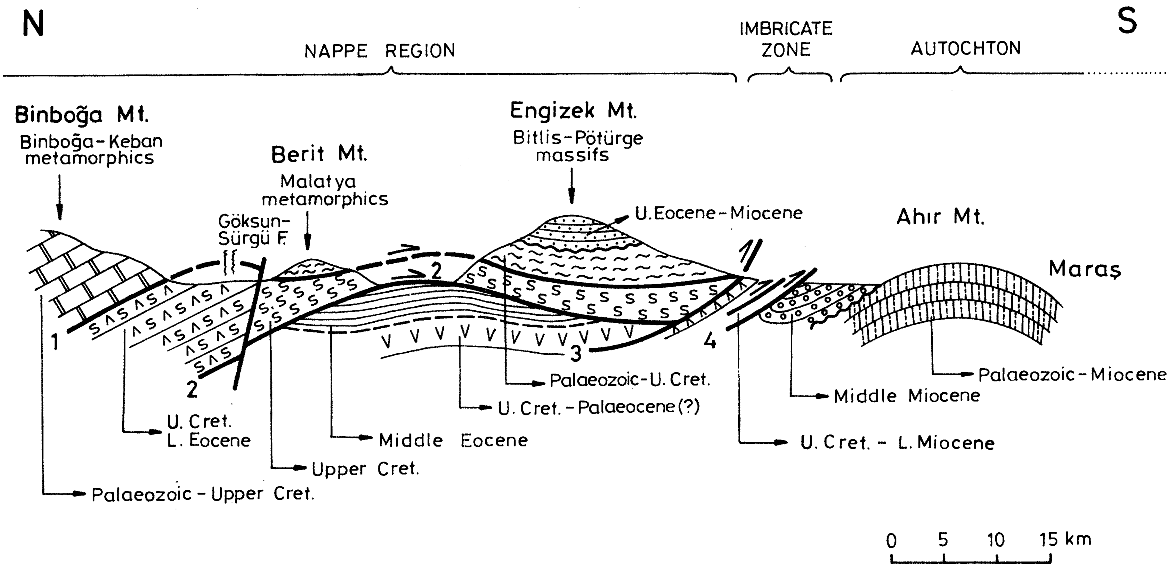

FIGURE 7. Geological section across the southeast Anatolian orogenic belt between Maraş and Afşin (see the map in figure 6). Numbers 1 to 4 indicate progressive southerly movement of the nappes. Main thrusting stages: 1, late early Ecocene; 2, late middle Ecocene; 3, early Miocene; 4, late early Miocene–middle Miocene. They correspond to numbers 2 to 5 respectively in Figure 8.

(figure 6), which forms a belt a few tens of kilometres wide. The rock units occurring along this mountain range are exposed as a 100 m belt within the imbricated zone. This observation suggests that the Missis-Andırın Mountains represent a region that has not been shortened to the same degree between the converging plates that formed the southeast Anatolian orogen. Therefore the Missis-Andırın Mountains may possibly be an escaped zone (figure 6). In fact the equivalent of the mélange units which form the basement of the Missis-Andırın belt is only barely present along the zone of imbrication where they are thought to have been totally subducted.

The Maastrichtian–Lower Eocene sedimentary units of the zone of imbrication appear to be the lateral, but more distal, equivalents of the Arabian platform units, distal either towards the northerly situated continental slope and the abyssal plain (Yılmaz *et al.* 1987*a*).

The Nappe region

To the north of the zone of imbrication is the Nappe region (figures 6, 7 and 8). The nappes are the structurally highest tectonic units of the southeast Anatolian orogenic belt (figures 7 and 8). They are composed of two large nappe packages: the lower nappes and the upper nappes. The lower nappe package consists primarily of ophiolitic rocks. In contrast, the upper nappe package is formed from the metamorphic massifs of southeast Anatolia, i.e. the Bitlis and Pötürge massifs (figures 1 and 7) or the Malatya, Keban and Engizek metamorphics. The upper nappe package rests on a gently folded thrust surface on top of the lower nappe package (figure 7).

The geological data indicate that the upper nappe package initially moved over the lower package at the end of the early Eocene after which the two packages were transported collectively (figures 7 and 8). The ophiolite nappe contains all of the layers of an ordered ophiolite sequence which has undergone polyphase metamorphism (Yılmaz *et al.* 1987*a*).

The upper nappe package is dominantly comprised of a regionally metamorphosed

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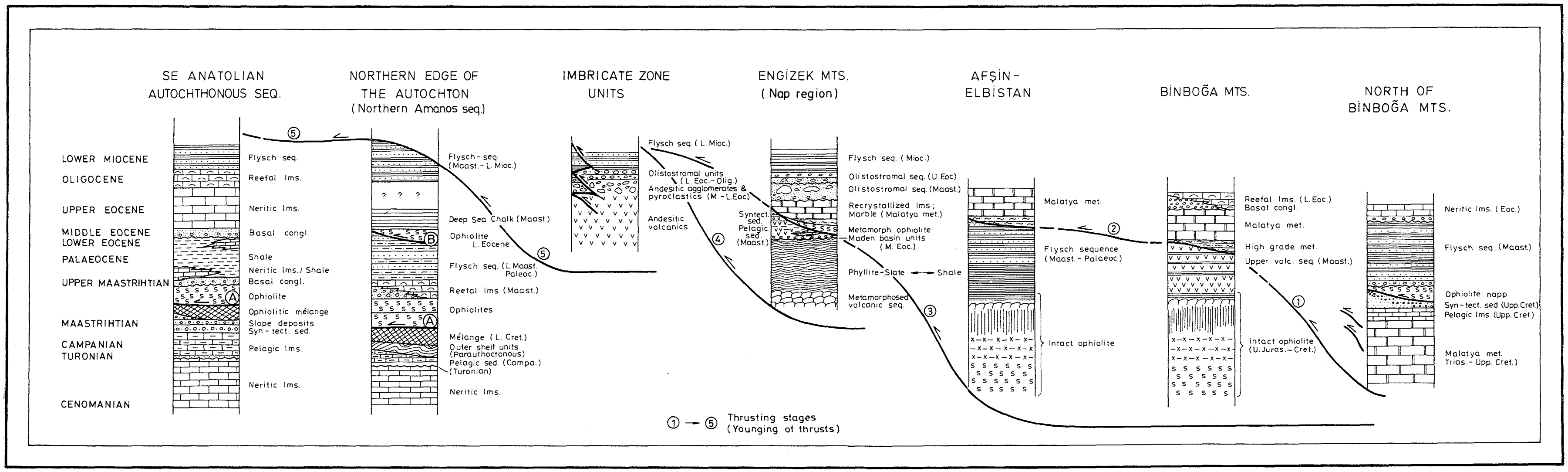

Figure 8. Generalized stratigraphic sections from the different regions of the south-east Anatolia across the orogenic belt (see the map in figure 6 for the locations). Thrusting stages indicate progressive southerly movement of the nappes towards the Arabian platform during the late Cretaceous–middle Miocene period. Main thrusting stages are; 1, late Cretaceous (early Maastrichtian); 2, early Eocene; 3, late middle Eocene; 4, early Miocene; 5, late early Miocene–middle Miocene. Abbreviations (in bracket); L, lower; M, middle; U, Upper; MS, limestone; Congl, Conglomerate; Agl, Agglomerate; Syn-tect sed, Syntectonic sediment deposition; slate shale, shale–slate transition; seq, sequence; met, metamorphic units. A and B indicate ophiolite emplacement on to the Arabian platform during the late Cretaceous and middle Eocene respectively. Repetitive arrows indicate imbrication.

sedimentary sequence which ranges in age from the Palaeozoic to the Upper Cretaceous. Within this sequence two parts may be clearly distinguished: (*a*) high-grade metamorphic schists and gneisses as core rocks, (*b*) low-grade metamorphic slate-phyllites and marbles as the envelope rocks. The oldest sedimentary rocks to be deposited on top of the metamorphic rocks of the upper nappe are clastic sediments of Upper Maastrichtian age. The age of metamorphism may therefore be well constrained as late Cretaceous, most probably late Campanian–early Maastrichtian, because the youngest metamorphic rocks are Campanian pelagic limestones (Yılmaz *et al.* 1987*a*).

Collectively the data (figure 8) suggest that the cause of the orogeny was the progressive elimination and eventual demise of an ocean which existed in the northern part of the Arabian plate. During closure of the ocean, convergence initially led to formation of a collision between an island arc and a continent (between the Yüksekova complex and the Taurides) at the end of early Eocene. This deformed package then collided with the Arabian platform when the remainder of the ocean had been entirely consumed during late middle Eocene–late Eocene (Yılmaz *et al.* 1987*a*). Thus the southeast Anatolian orogenic evolution may be summarized as the progressive relative (southerly) movement of the northerly situated allochthons (the nappes) towards the Arabian platform during the late Cretaceous–early Miocene interval (figure 8). During these events, new tectonic units (an island arc association: the Helete Volcanics and the Yüksekova complex); a back arc basin unit: the Maden Complex; a remnant sea infill: the Çüngüş Complex; and a syntectonic flysch deposition: the Lice Fm.) were progressively amalgamated. The allochthons, as a package, were thrust over the authochthonous sequence at a later stage in the orogeny, during the late early Miocene. The zone of imbrication which lies adjacent to the nappes may thus be regarded as a region which was bulldozed in front of the southwards moving nappe pile.

Post-collisional convergence after the middle Miocene began to be largely accommodated by E–W trending strike–slip faults leading to the reactivation of earlier thrusts and to their dissection by high-angle faults.

Conclusion

In the above paragraphs I reviewed, in as much detail as allowed by the available space, the tectonic evolution of three complicated regions from the Turkish orogenic collage. Throughout these paragraphs I placed interpretative labels on the tectono-stratigraphic units I defined. Nowhere in the analysis presented above did I follow the recommended 'terrane analysis' (see, for example, Jones *et al.* 1983). Before the advent of plate tectonics, the Turkish geology had reached a cul-de-sac. We had mapped many regions at a scale of 1:25000 and we had stopped dead in front of insurmountable difficulties of not being able to make sense out of the fragmentary and vastly complicated record. Şengör & Yılmaz (1981) was our first venture into the interpretation of the vast database in terms of plate tectonics. That paper suddenly lifted the mist and the progress since then in Turkish geology has been immense. Therefore I can see no advantage in a return to this tectonic taxonomy.

I thank Dr A. M. C. Şengör and Dr D. Latin for improving the text and giving useful comments.

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Discussion

P. D. Clift (*Grant Institute, University of Edinburgh, U.K.*). The proposed model for the tectonic evolution of Anatolia and the Tethyan Middle East envisages a progressive accretion of continental terranes to the active northern margin of the Neotethys, following rifting from Gonwana and a relatively straightforward south-to-north migration. This is in marked contrast to models of other orogenic belts, e.g. the North American Cordillera and the North Atlantic Caledonides. The structural evidence so far gathered indicates a simple strike–perpendicular thrust shortening, with little indication of large degrees of motion of accreted terranes along the active margin. The relatively small width of the Neotethys (*ca.* 100–1000 km) in this region makes the use of faunal provinces for tracking block motions impossible. In addition the east–west trend of the belt means palaeomagnetism cannot be used to follow margin parallel displacements. Some quantification of the amounts of along strike motion and potential sites of the 'home ports' of these continental terranes may be obtainable by application of isotopic ($^{87/86}$Sr or Sm/Nd T_{CR}) provenance studies to these regions. Pursuit of these methods, which has yielded so much information in the Caledonides may help us to be more certain whether the Neotethys really does provide us with an important exception to the Pacific-type terrane accretion model or not.

Y. Yilmaz. In its general frame I agree with Dr Clift's comment. However, the possibility of margin-parallel displacement in the Anatolian orogen should not completely be ruled out. I suspect it especially in the eastern Anatolia from facies arguments and, timing and nature of tectonic events of Trias–Lias and late Cretaceous–Eocene periods (see Yılmaz *et al.* 1987*a*, *b*), possibly similar to that as shown by A. M. C. Şengör on his recent accounts about Iran. In this paper I only presented data within the limit of the space allowed to me. Therefore I could not enter more detailed discussion on this topic.

It is my view, however, that the large, orogen-parallel strike–slip can be detected by field geological methods as long as detailed regional and relevant data are available. More sophisticated approaches of the kind Dr Clift points out can be used more effectively as additional supporting data in the regions which underwent multistages of orogenic deformation where earlier events were obscured by later events.