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The Berit transect of the Tauride thrust belt, S Turkey: Late Cretaceous–Early Cenozoic accretionary/collisional processes related to closure of the Southern Neotethys

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Abstract

We report on an integrated study of a critical segment of the Tauride thrust belt in SE Turkey (Berit area). Units related to two sutures are exposed in the northerly and southerly parts of the area studied. In the north the Upper Cretaceous Binboğa Melange reflects the closure of a northerly Mesozoic oceanic basin. In the south, contrasting units document the closure of the Southern Neotethys.

In the south, the Berit (or Göksun) ophiolite formed as an incipient oceanic arc within the Southern Neotethys during the Late Cretaceous (c.90 Ma). Intercalated amphibolite–granulite facies rocks may record a dismembered metamorphic sole. An underlying meta-sedimentary/meta-volcanic unit is interpreted as accreted continental rift and oceanic seamount lithologies. The Berit ophiolite was accreted to the Tauride active continental margin to the north around 85 Ma and was then intruded by calc-alkaline granites (c.70–85 Ma). Northerly margin units were exhumed and covered by shelf-carbonate sediments during latest Cretaceous–Early Cenozoic time. Northward subduction during the mid-Cenozoic (c.45 Ma) resulted in back-arc extension along the Tauride active margin and subduction-influenced volcanism, possibly controlled by slab roll-back. During Oligocene–Early Miocene time the Southern Neotethys closed and the Tauride active margin was telescoped to create the present south-vergent thrust stack. This was accompanied by mass wasting of the advancing allochthon to form sub-aqueous frontal olistostromes. The Arabian platform was over-ridden by Mid-Miocene time, followed by left-lateral strike-slip along the East Anatolian Fault zone, as Anatolia began to escape westwards towards the Aegean Sea.

Keywords: SE Turkey; Neotethys; Ophiolite; Suture zone; Thrusting; Palaeogeography

1. Introduction

During recent years, it has become accepted that the SE Turkish Suture (Fig. 1) represents the remains of a southerly Neotethyan ocean (Fig. 2). Closure of this oceanic basin is believed to have been accomplished by northward subduction (Hall, 1976; Aktaş and Robertson, 1984; Dewey et al., 1986; Yılmaz, 1993; Yılmaz et al., 1993). The northern margin of this ocean, known as the Tauride Carbonate Platform, is envisaged as one, or several, microcontinents that rifted from Gondwana during Early Mesozoic time (Robertson and Woodcock, 1980; Şengör and Yılmaz, 1981; Garfunkel and Derin, 1984). The crustal fragments were re-amalgamated to the Arabian margin by mid-Cenozoic time, possibly with some strike-slip offset of units, following tectonic accretion and suturing (Dercourt et al., 1986, 1993, 2000; Robertson, 1998; Stampfli, 2001). There is, however, little consensus on the tectonic evolution of the Southern Neotethys ocean, especially during Late Cretaceous–Early Cenozoic time.

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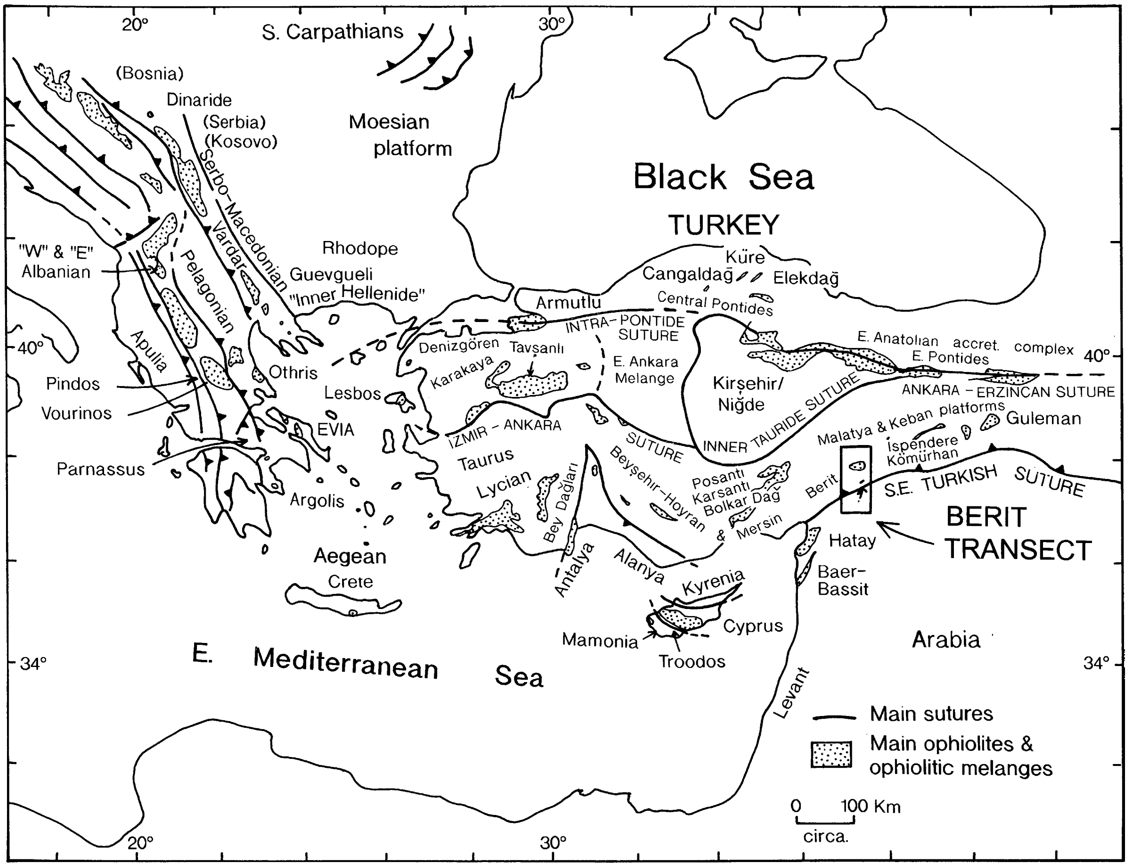

Fig. 1. The main tectonic zones of Turkey in the Eastern Mediterranean region showing the study area (Box 1). Modified from Robertson (2002).

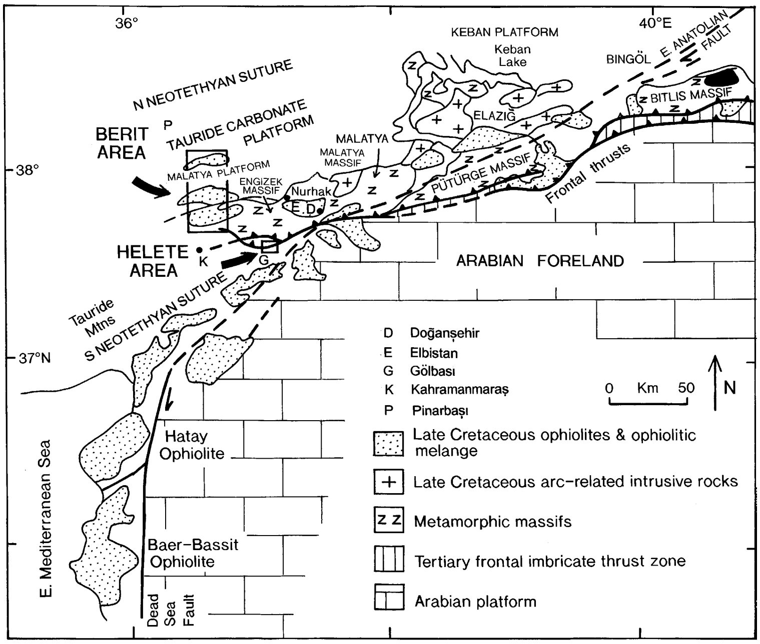

Fig. 2. Outline tectonic map of the Tauride allochthon in SE Turkey, showing the location of the areas discussed here. Based on the 1:1,000,000 scale map of Turkey (MTA). Note the location of the basal thrust with the Arabian foreland to the south.

Several alternative interpretations of the SE Anatolian Thrust Belt (SE Turkish Suture in Fig. 1) extending for c.500 km along strike have been published. These tectonic models are based mostly on extrapolations from relatively local field areas and large areas remain poorly known (Hall, 1976; Aktaş and Robertson, 1984, 1990; Yazgan, 1984; Yazgan and Chessex, 1991; Yılmaz, 1993; Yılmaz et al., 1993; Dilek et al., 1999). Two of the main alternatives are:

1. The Southern Neotethyan suture was located in a relatively northerly location (Fourcade et al., 1991; Dercourt et al., 1986). The Southern Neotethys was closed by latest Cretaceous time, followed by post-collisional shortening, related magmatism, and crustal scale imbrication of the foreland. All of the ophiolites in SE Turkey, including those within the suture zone, and those located on the Arabian foreland (e.g. Hatay, Baer–Bassit and Koçali ophiolites) represent remnants of a single huge thrust sheet of Late Cretaceous oceanic lithosphere emplaced southwards from a single Neotethyan oceanic basin in latest Cretaceous time.
2. The Neotethys accommodated two oceanic basins, with the ophiolites and related units in SE Turkey being rooted in a Southern Neotethys, distinct from a northern Neotethys, rooted near the southern margin of Eurasia (Şengör and Yılmaz, 1981; Robertson and Dixon, 1984). Some authors believe the Southern Neotethys was completely closed during latest Cretaceous time (Beyarslan and Bingöl, 2000), followed by thick-skinned re-thrusting of the suture zone during Eocene–Miocene time (Yazgan and Chessex, 1991). Others argue that the Southern Neotethys was only partially closed in latest Cretaceous time, associated with southward emplacement of ophiolites onto the Arabian foreland, and that final closure did not take place until Mid-Cenozoic time. The thrust belt in SE Turkey was then assembled by a combination of accretionary and collisional processes (Aktaş and Robertson, 1990; Yılmaz, 1993; Robertson et al., under review).

Several early interpretations also envisaged southward subduction beneath the Arabian margin in latest Cretaceous time (Perinçek, 1979, 1980; Şengör and Yılmaz, 1981), although this has received little support in recent years, mainly because the thrust stack is clearly south vergent.

In this paper, we will synthesise existing information and present new data concerning the critical Berit segment of the Southern Neotethyan suture zone (Fig. 2). The main aim is to test the existing tectonic models and to present a new tectonic interpretation. The Berit area is located in a critical position adjacent to a syntaxial bend, where the Tauride strike changes from approximately E–W in the east to more NE–SW as it approaches the Mediterranean Sea. This linking area (Misis–Andırın) was recently discussed elsewhere (Robertson et al., 2004).

In the following account, we will discuss and interpret each of the main components of the suture zone and then restore the thrust belt in time slices.

2. Tectonic units

The Berit region is dominated by the relatively autochthonous Tauride Carbonate Platform in the north, overlain by a stack of gently inclined thrust sheets (Figs. 3 and 4). Eight main tectono-stratigraphic units are exposed in general upward structural order, as follows:

1. Tauride Carbonate Platform (Mesozoic; relatively autochthonous).
2. Binboğa Formation (Mesozoic) and Binboğa Melange (Late Cretaceous).
3. Malatya Metamorphic Unit (Late Palaeozoic–Mesozoic).
4. Berit (or Göksun) Ophiolite (Late Cretaceous), with associated slices of high-grade metamorphic rocks.
5. Berit Sedimentary-Volcanic Unit, unconformably overlain by:
6. Volcanic-Sedimentary Maden Formation (Mid-Late Eocene).
7. Frontal imbricates, including the Mid-Late Eocene Volcanic-Sedimentary Helete Formation (east of the main study area).
8. Engizek Melange, a frontal olistostrome unit in the south (Late Oligocene–Early Miocene).

The thrust sheets were finally emplaced southwards onto a foreland basin overlying the Arabian continental margin during Late Oligocene–Early Miocene time.

We now consider each of the above tectonic units in turn.

2.1. Mesozoic Tauride Carbonate Platform

The Tauride Carbonate Platform is exposed in the far north of the area (Figs. 3 and 4) and is interpreted as part of a larger Tauride microcontinent. Intact successions in the wider region range from Late Precambrian to Early Cenozoic and are best exposed further west, in areas north of the easternmost Mediterranean Sea (Demirtaşlı, 1984).

Within the study area only the upper part of the regional Tauride Carbonate Platform succession of Cretaceous-Eocene age is exposed (Figs. 3 and 4). At several locations (Figs. 3, 5(a) and 6(a)) (e.g. Akdere; 15 km N of Fig. 3) the succession begins with Lower Cretaceous platform carbonates, overlain by deeper water pelagic and hemipelagic carbonate rocks of Maastrichtian-Early Eocene age (Akdere Formation). A disconformity exists between Cenomanian neritic carbonates (Yüceyurt Formation) and Upper Campanian-Lower Eocene pelagic carbonates. The Turonian,

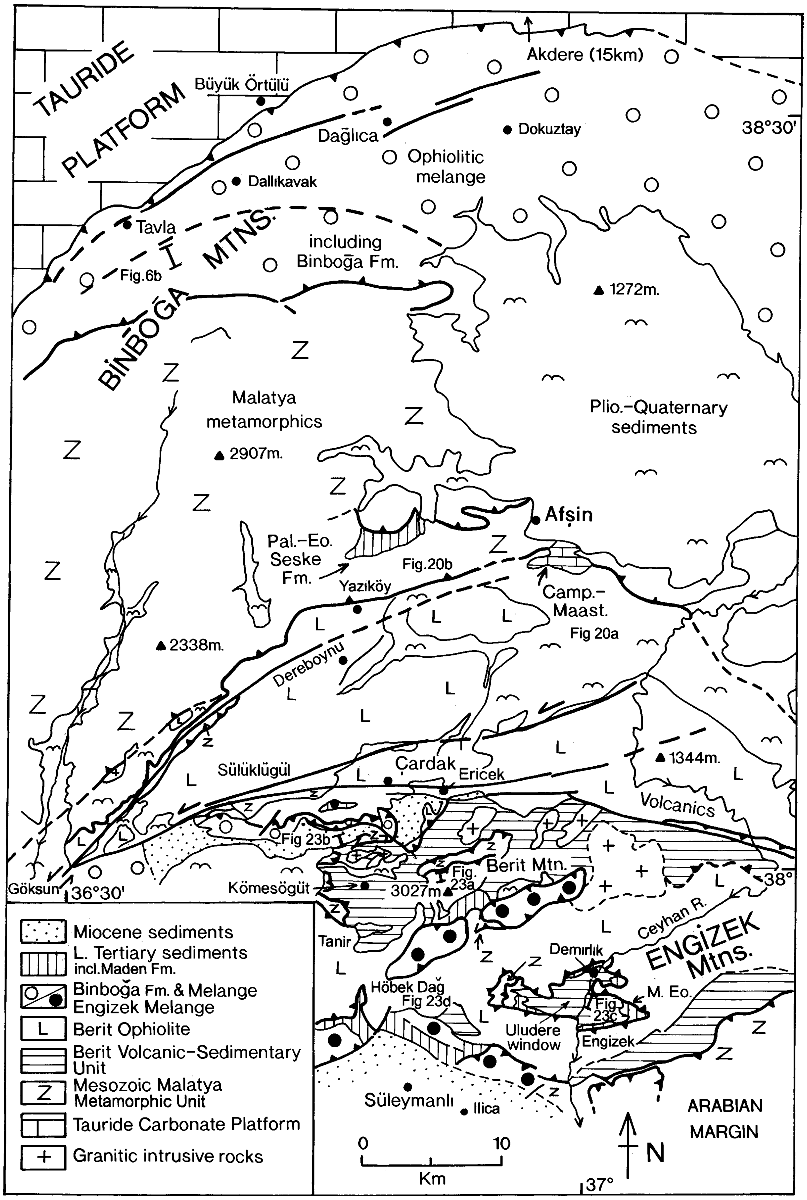

Fig. 3. Simplified geological map of the Berit area studied, based on regional mapping for the Turkish Petroleum Company (Perinçek and Kozlu, 1984). The main place names mentioned in the text are indicated.

Coniacian and Santonian stages retain little preserved sedimentary record (Kozlu et al., 1990). Overlying Upper Campanian–Maastrichtian limestones (Akdere Formation) include calcirudites suggestive of a tectonically unstable setting (Perinçek and Kozlu, 1984; Kozlu et al., 1990). One succession in the southwest (Büyükoluk Yaylası; see Perinçek and Kozlu, 1984) includes channelised calcarenites and calcirudites, and minor replacement chert in the Palaeocene interval. Further northeast (Akdere) finer grained pelagic and hemipelagic carbonates predominate. Several successions (e.g. Gürün, 25 km NE of Akdere) contain clastic sediment of ophiolitic origin (e.g. serpentinite pebbles) within the Maastrichtian interval. The Palaeogene succession is unconformably overlain by conglomerates, sandstones and shales, of Middle Eocene age (Perinçek and Kozlu, 1984) (Figs. 5(a) and 6(a)). Further east (e.g. north of Nurhak; Fig. 2) the carbonate platform succession extends down to the Late Permian and is punctuated by several hiatuses.

The existence of a structurally unbroken Late Cretaceous–Early Cenozoic succession, without intervening emplaced ophiolitic units, opposes the hypothesis that the South Neotethyan ophiolites were emplaced from a single Neotethyan ocean to the north of the Tauride Carbonate Platform (cf. Fourcade et al., 1991). Minor amounts of ophiolite-derived sediment were eroded from ophiolitic units that were emplaced onto the Tauride Carbonate Platform in latest Cretaceous, either from the south or north, but there is no evidence that ophiolites were thrust over the entire Tauride Carbonate Platform.

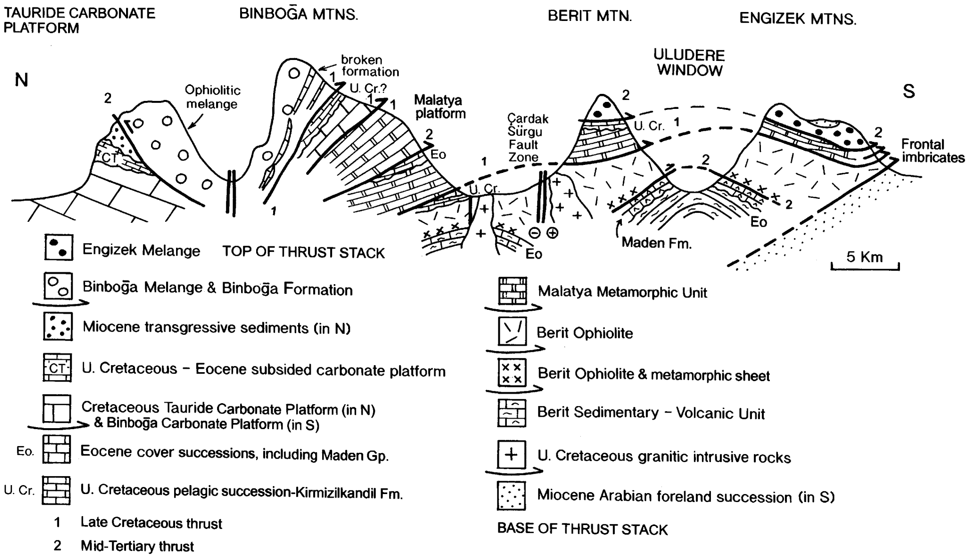

Fig. 4. Generalised N–S cross-section of the area studied (see Fig. 2). Modified from Perinçek and Kozlu (1984).

2.2. Upper Cretaceous deformed Mesozoic carbonate platform and melange

The area to the south of the Tauride Carbonate Platform is dominated by an E–W trending zone of broken formations (Binboğa and Kırmızıkandil Formations) and melange (Binboğa Melange; Figs. 3 and 4). In the north (e.g. near Büyük Örtülü; Fig. 3) coarse bioclastic limestones of the Tauride Carbonate Platform are overthrust northwards by the Binboğa Melange. The contact dips southwards at c.40° (Fig. 4). The Binboğa Formation (also known as the Andırın Limestone) comprises Mesozoic neritic carbonates, capped by an Upper Cretaceous deepening-upward succession (Kırmızıkandil Formation), as summarised below.

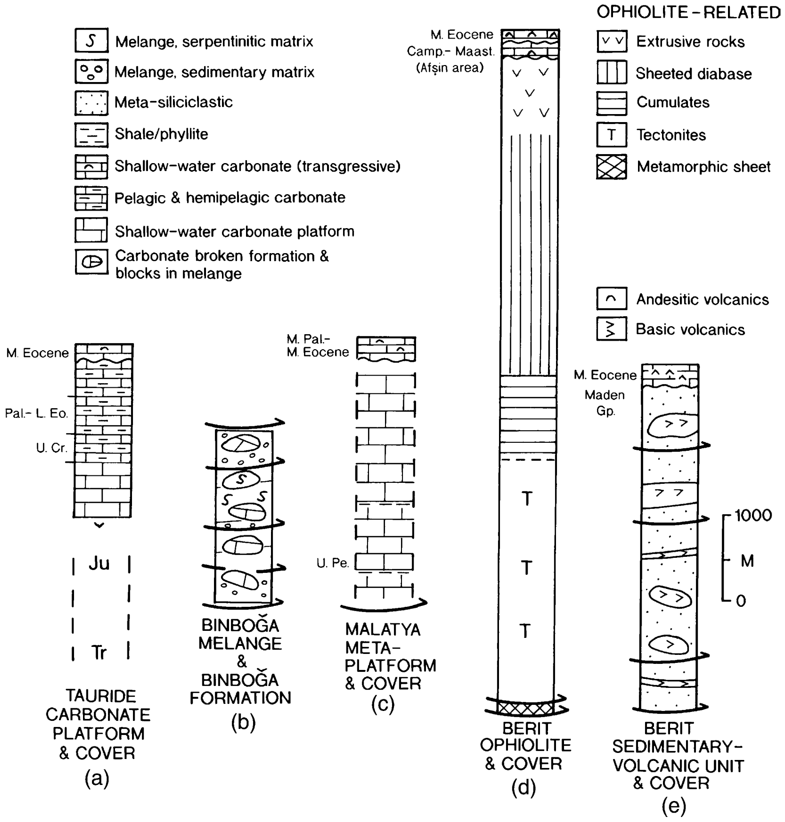

Fig. 5. Generalised stratigraphic successions of the main tectonic units exposed from north to south in the Berit area. Additional information on the poorly exposed thrust front was obtained from another area further east (Helete area).

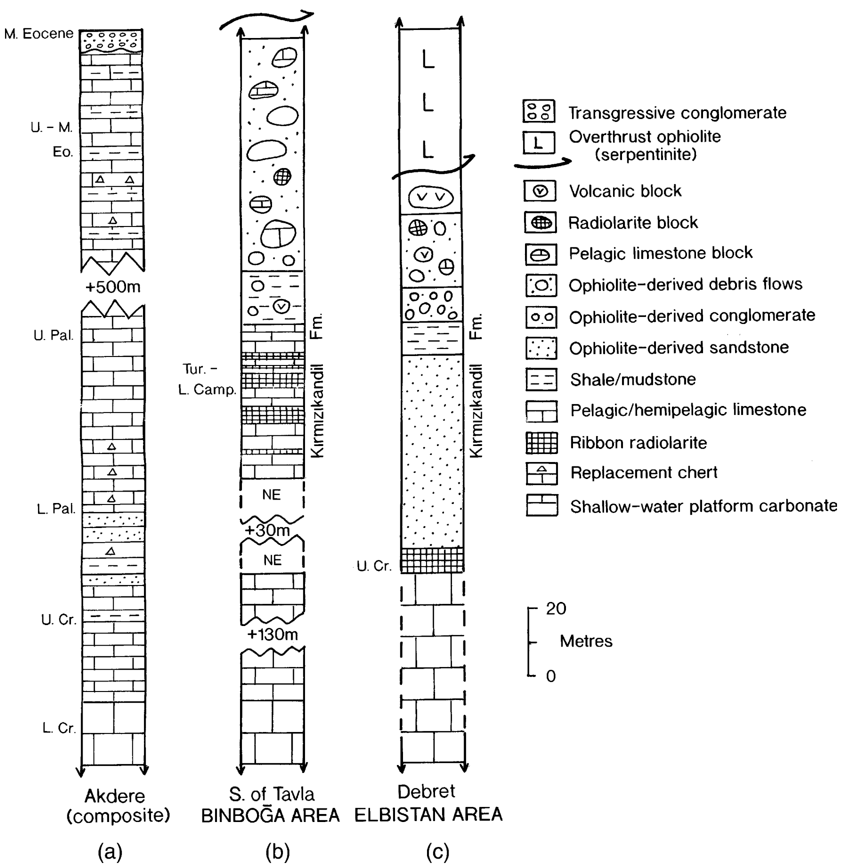

Fig. 6. Measured lithological logs of units associated with the latest Cretaceous Binboğa Mélange in the north of the area studied. (a) Unbroken Cretaceous to Middle Eocene succession typical of the Tauride Carbonate Platform in the north (Perinçek and Kozlu, 1984); (b) transition from carbonate platform to slope, then basinal melange sequence (Kırmızıkandil Fm.; near Tavla; (c) comparable transition east of the main area studied (Elbistan area). See text for explanation.

2.2.1. Binboğa formation: transition from Mesozoic platform to melange

In the area studied, locally intact successions of Turonian–Early Campanian age (Kırmızıkandil Formation of Perinçek and Kozlu, 1984) overlie a Middle Triassic–Lower Cretaceous shallow-marine succession (Binboğa Formation). This unit is preserved within the area studied as dismembered NW-dipping thrust sheets and large blocks that are exposed along the southern margin of the Binboğa Melange outcrop (e.g. Fig. 7; near Tavla). Similar lithologies are present as detached blocks within the structurally overlying melange. More coherent successions of the Binboğa Formation are exposed further east in the Nurhak area (Perinçek and Kozlu, 1984).

Where well exposed (near Tavla), thick-bedded, to massive, dark biomicrites, pass depositionally upwards into alternating thicker and thinner bedded calciturbidites, c.150 m thick (Fig. 7, No. 1). In thin section, slightly recrystallised dark biomicrites contain poorly preserved planktic foraminifera, but minimal terrigenous material. An overlying poorly exposed interval, c.60 m thick, is composed of grey-green shales and volcaniclastic sandstone, and is interpreted as the lowest part of the melange. One sandstone sample is very poorly sorted, with angular grains of basalt in a ferruginous mud matrix. Another sandstone is very quartz rich, with well-sorted, sub-equant grains of limestone, quartzite, polycrystalline quartz, micaschist, sandstone and rare zircon, cemented by sparry calcite.

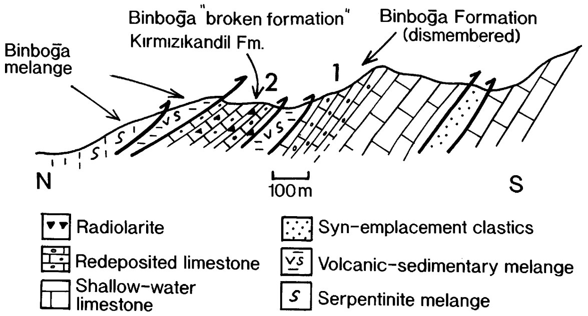

Fig. 7. Cross section of a locally preserved transition between the Binboğa carbonate platform unit (Binboğa Formation), Upper Cretaceous syn-tectonic sediments (Kırmızıkandil Formation) and the Upper Cretaceous Binboğa Mélange (near Tavla). Note the transition from a carbonate platform to a deeper-water, redeposited sequence, the imbrication, and the overlying mélange.

Above, a dismembered thrust sheet (c.80 m thick; Fig. 7, No. 2) is correlated with the Late Cretaceous Kırmızıkandil Formation. This begins with limestone debris flows, pink pelagic limestone and red radiolarite (10 m thick) and passes into medium- to thick-bedded calciturbidites (largely packstones), with abundant replacement chert and intercalations of red, or greenish ribbon radiolarite. Thin sections reveal oolitically coated grains, benthic foraminifera (including miliolines), algal-coated grains and shell fragments, set in calcite spar cement. This unit is overlain by the Binboğa Melange, beginning with reddish mudstones, followed by blocks of aphyric lava (up to 5 m in size) and brecciated gabbro set in a sedimentary matrix.

The dismembered sedimentary succession (Kırmızıkandil Formation) is restored as a Turonian–Early Campanian sedimentary transition from the Mesozoic Binboğa carbonate platform to the overlying Binboğa Mélange. A similar, but more intact, transition is reported further east in the Nurhak (Elbistan) area (Perinçek and Kozlu, 1984) (Fig. 6(c)).

2.2.2. Binboğa Mélange

The Binboğa Mélange (Dağlıca Complex of Kozlu et al., 1990) forms a major exposure area located between the dismembered Binboğa Platform in the south and the more intact Tauride Carbonate Platform in the north (Fig. 3). The mélange can be traced eastwards into the Elbistan–Nurhak area (Perinçek and Kozlu, 1984). However, further east, in the Malatya and Elazig regions, the Binboğa Mélange appears to be absent (Yazgan and Chessex, 1991).

The Binboğa Mélange in the area studied includes deep-marine radiolarian cherts, pelagic limestones, shale and sandstone turbidites, together with pelagic limestone, radiolarite and ophiolitic rocks, including sheared serpentinite, gabbro, diabase and lava. In general, two intergradational lithological associations are present: first, sedimentary-rock mélange and, secondly ophiolitic mélange. The ophiolitic mélange predominates at higher structural levels.

The sedimentary rock-dominated mélange is largely weakly lithified, matrix-supported conglomerates, interpreted as debris-flows, together with large (up to tens of metre-sized) blocks of neritic limestone (Fig. 8(a)). Most of the clasts in the debrites are angular, to sub-rounded (c.20 cm in diameter). The smaller blocks (mainly <1 m in size) include grey pelagic limestone, redeposited calcarenite, grey to black massive limestone and micaceous sandstone turbidites (with grains of black chert <3 mm in size) and radiolarian cherts. The fine-grained grey limestones are dominated by calcified radiolarians, with rare thin-walled *Posidonia*-type bivalves. The interbedded calcarenites contain abundant bioclastic debris, including echinoderm plates, large foraminifera (e.g. miliolines), calcareous algae and shell fragments, together with scattered fragments of micaschist and intraclasts of biomicrite. Some of the carbonate grains are partly silicified to microcrystalline quartz. Fossils of Late Permian, Jurassic and Early Cretaceous age were reported from several limestone blocks (Kozlu et al., 1990).

The ophiolitic mélange is dominated by ophiolitic rocks, which range from volcanic-sedimentary (lavas, pelagic

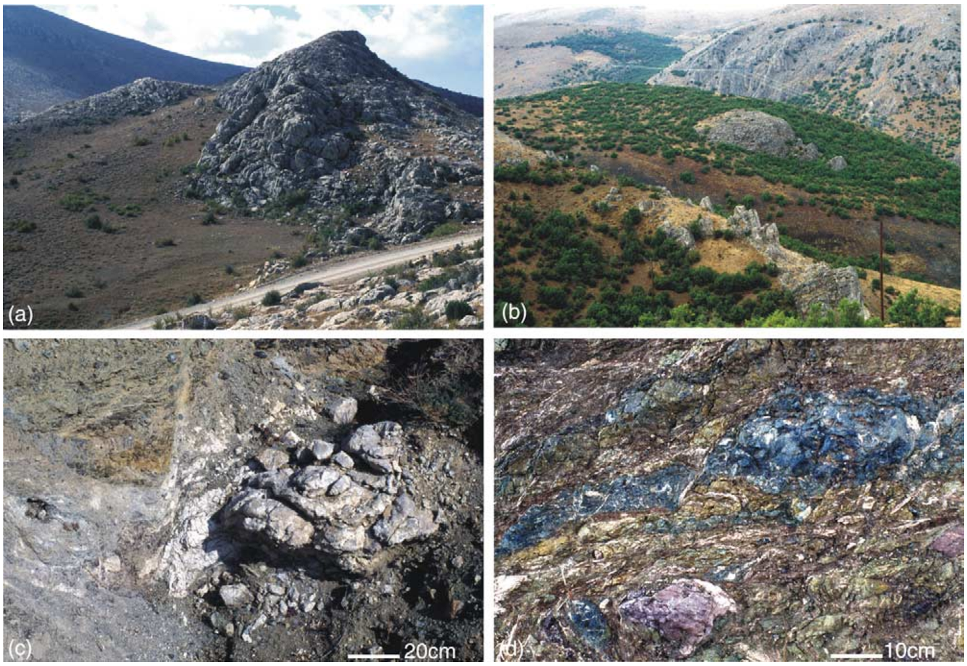

Fig. 8. Field photographs of the Binboğa Melange in the north of the area studied. (a) Limestone block in a matrix of volcaniclastic detritus (Tavla area); (b) upper part of the mélange, dominated by blocks of Mesozoic platform/slope carbonate (pale) in a matrix including, radiolarite, basalt and ophiolite-derived sandstone (dark) (Dağlıca area); (c) sheared mélange composed of brecciated limestone (right) in a matrix of sheared serpentinite (left) (near Tavla); (d) sheared debris flows mainly composed of basalt and pelagic carbonate; Dağlıca area.

limestones, chert), to intrusive ophiolitic rocks (serpentinite, gabbro, diabase). For example, the mélange is locally dominated by blocks of pillow lava and massive amygdaloidal basalt, together with siliceous pelagic limestone and ribbon radiolarite. Elsewhere, the ophiolitic mélange is dominated by pyroxenite, gabbro, diabase, basalt and serpentinite, set in a matrix that varies from shale to serpentinite (Fig. 8(c) and (d)).

The exotic components range from clasts (<1 m), to blocks, to dismembered thrust sheets up to several kilometres long. Some of the ophiolitic mélange shows clear sedimentary features. For example, blocks of serpentinised ultramafic rocks (commonly <2 m in size) and Mesozoic platform carbonates (mainly <10 m in size) locally occur in a matrix of sheared serpentinite, which includes sedimentary structures (e.g. bedding; grading). Stratified units of serpentinite-rich clastic sandstones and debris flow deposits include clasts of neritic limestone (mainly <1 m in size). In one area (e.g. near Dallıkavak), ophiolite-dominated mélange includes large tabular blocks (tens of metres in size) of sheared, dark, aphyric basalt (up to several 100 m long) (collected for analysis; see below), together with sheared ribbon radiolarite. Associated debrites are dominated by serpentinised ultramafic rocks, red chert, sheared basalt and radiolarite, with a well-defined phacoidal fabric. The volcanic blocks include pillow basalt, pillow disintegration breccia and green hyaloclastite, and are associated with volcanogenic debris-flow deposits including volcanic clasts set in a reworked volcaniclastic matrix.

Three samples of basalt were analysed from the ophiolitic mélange. They plot in the island arc tholeiitic fields on most discrimination diagrams, including V vs. Ti (Shervais, 1982) (Fig. 9(a)). In multi-element spidergrams (Pearce et al., 1984) these basalts show strongly depleted patterns with a marked negative Nb anomaly (Fig. 9(b)). The U-shaped patterns are suggestive of a high-Mg (i.e. boninite type) composition.

2.2.3. Interpretation of the Binboğa carbonate platform and mélange

The Binboğa carbonate platform (Binboğa Formation) in the south is interpreted as a Mid-Triassic to Cretaceous rift/passive succession including limestones, sandstones and shales. The resulting platform subsided during Turonian–Early Campanian time, marked by an upward passage to calciturbidites, red radiolarian cherts and shales (Kırmızıkandil Formation). This unit was then tectonically overlain by a mélange formed by mainly sedimentary processes (i.e. an olistostrome). The blocks of Mesozoic shallow-water carbonate and deeper water facies can be correlated with more intact successions to the south (Binboğa and Kırmızıkandil Formations). These successions were dismembered to form blocks and broken formations that dominate the lower part of the Binboğa Mélange.

The blocks and dismembered thrust sheets of basalt, ribbon radiolarite and pelagic sediments are interpreted as accreted Neotethyan oceanic crust and associated deep-sea sediments. The basalts were apparently erupted above a subduction zone. Thus, the oceanic basin that closed to form the melange was probably relatively wide (>250 km).

The Binboğa Mélange is interpreted to have originated in an oceanic basin to the north of the Binboğa carbonate platform. This basin was consumed by northward subduction in latest Cretaceous (Turonian–Campanian) time giving rise to accretionary mélange. When the advancing accretionary wedge collided with the Binboğa carbonate platform (Early Campanian) this unit collapsed to form a foredeep, shedding blocks that were incorporated into the over-riding mélange. The Binboğa Mélange was apparently juxtaposed with the Tauride Carbonate Platform in latest Cretaceous time, and was then finally emplaced (backthrust) northwards over the Tauride carbonate platform following the accumulation of Late Miocene sediments, locally exposed on the Tauride Carbonate Platform (Perinçek and Kozlu, 1984).

The Binboğa Mélange is similar in age and composition to another mélange, the Kireçlikyayla Mélange, that is located along the northern margin of the Tauride Carbonate

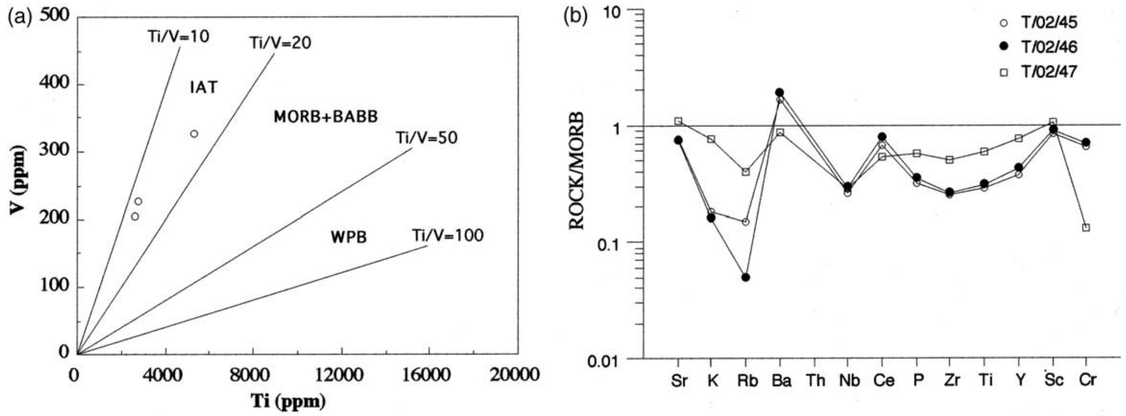

Fig. 9. Geochemical data for basaltic rocks from the Binboğa Mélange. (a) V vs. Ti; (b) MORB-normalised spider plot. MORB, Mid-ocean ridge basalt; WPB, within-plate basalt. See text for explanation.

Platform, to the northwest of the Berit transect (Pinarbaşı area; Fig. 2). This mélange includes blocks of mainly carbonate rocks of Middle Triassic-Cretaceous age, Triassic volcanics and subordinate radiolarian cherts, of various slope to basinal facies, set in a matrix of Upper Cretaceous shales and lithoclastic turbidites. The mélange is structurally overlain, by and interleaved with, more intact ophiolite thrust sheets, associated with a locally preserved metamorphic sole. The mélange and ophiolite were thrust southwards over the northern edge of the Tauride Carbonate Platform in latest Cretaceous time (Metin et al., 2004; and our unpublished field observations). The interior of the Tauride Carbonate Platform experienced a depositional hiatus during Early Campanian time which could mark the timing of mélange and ophiolite emplacement over the northern margin of the Tauride Carbonate Platform. However, deposition on the Tauride platform then resumed until Middle Eocene time, when there was a further disturbance in deposition. There is little evidence of any major thrusting or deformation affecting the northern margin of the Tauride Carbonate Platform after latest Cretaceous time (Y. Metin, personal communication, 2004). The Mid-Eocene disturbance affecting the Tauride platform interior could reflect a regional extensional event (see Section 12.4). The obvious possibility that the Binboğa Mélange was thrust southwards over the Tauride Carbonate Platform to its present position in either latest Cretaceous or mid-Cenozoic time, is thus unlikely.

Given the above constraints the Binboğa Mélange can be interpreted in two main ways (Fig. 10). First, it could have formed in a small oceanic basin between the Binboğa carbonate platform to the south and the Tauride Carbonate Platform to the north (Fig. 10(ai)–(aii)). Secondly, it might have originated as part of the northern margin of the Tauride microcontinent, but was then transported to its present position by strike-slip and terrane displacement, possibly after latest Cretaceous time (Fig. 10(bi)–(biii)). There is no obvious evidence of such strike-slip displacement in the area studied since the northern and southern contacts of the Binboğa Mélange are now thrusts rather than high-angle strike-slip faults. However, it is possible that Late Cretaceous strike-slip faults were rotated to a lower angle during mid-Cenozoic collisional deformation, and more work on this aspect is needed.

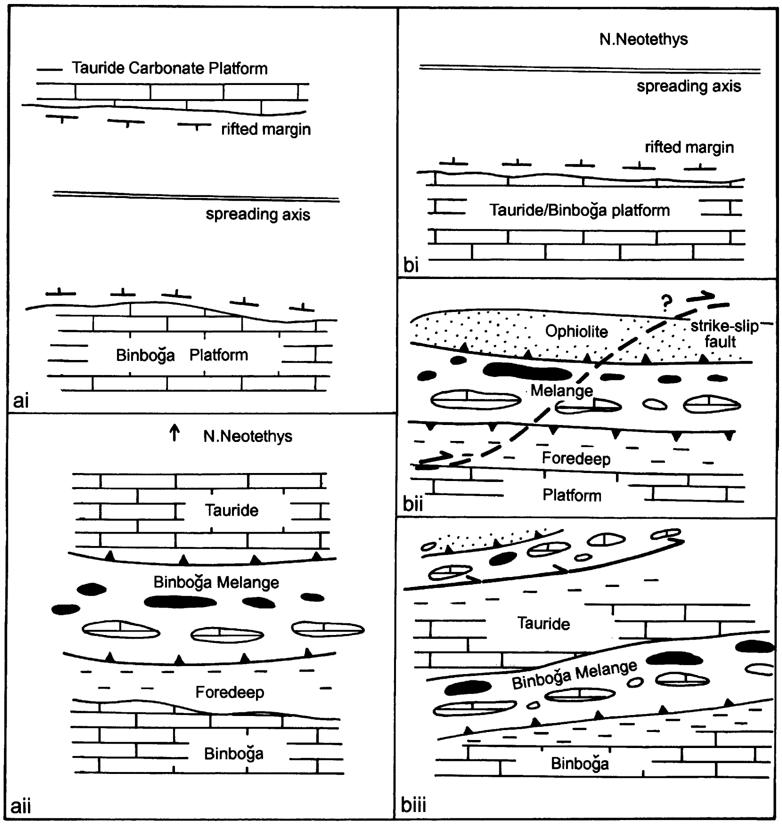

Fig. 10. Alternative tectonic settings of the Binboğa Melange with respect to the Binboğa carbonate platform and the Tauride Carbonate Platform. (a) Separate small ocean basin origin; (ai) opening of a small ocean basin between Binboğa and Tauride microcontinents; (aii) accretion and emplacement of the Binboğa Mélange onto the Binboğa carbonate platform to the south; (b) terrane displacement model; (bi) the Binboğa Mélange was accreted and emplaced southwards over a regional Tauride carbonate platform (including the Binboğa carbonate platform). This platform was then dissected into small terranes, interleaving the Binboğa Melange between two Mesozoic platform units. See text for discussion.

3. Malatya Metamorphic Unit

During the Mesozoic, the Binboğa carbonate platform probably passed southwards into the Malatya platform, although a palaeogeographic break (e.g. rift basin) between these two units could have existed. Some form of palaeogeographical or structural break is, indeed, suggested by the difference in metamorphic grade between the Binboğa platform: (unmetamorphosed) and the Malatya platform (greenschist facies). The Malatya Metamorphic Unit structurally underlies the Binboğa Mélange in the area studied (Figs. 3 and 4). Similar relations are mapped further east in the Nurhak area, NE of Doğanşehir (Perinçek and Kozlu, 1984; Kozlu et al., 1990).

The Malatya Metamorphic Unit is exposed both to the north and to the south of an array of NE–SW-trending Plio-Quaternary faults, known as the Göksun Fault Zone (Arpat and Şaroğlu, 1975). The most important of these is the Çardak-Sürgü Fault in the south (Perinçek and Kozlu, 1984) (Fig. 4). The Göksun Fault Zone (Fig. 11(b)) is assumed to have been active related to the Plio-Quaternary left-lateral westward tectonic escape of Anatolia (e.g. Şengör et al., 1985; Westaway and Arger, 1996; Reilinger et al., 1997).

The Malatya Metamorphic Unit is dominated by meta-carbonate rocks, mica schist, phyllite, meta-clastic rocks and meta-cherts (Perinçek and Kozlu, 1984). The highest metamorphic grade reported is greenschist facies. Based on limited available fossil data, the upper part of the Malatya metamorphic succession is dated as Late Permian to Early Triassic (Özgül et al., 1981). Near the southern boundary of the northern region (Fig. 3) the Malatya metamorphic rocks are mainly folded dark marbles with black chert of replacement origin. Near the contact (in the south), ophiolitic rocks or granitic intrusions dip northwards at c. 53°. On strike further east (near Yazıköy; Fig. 11(a)), well-bedded marble and dark schist alternate in beds up to 2 m thick. Further west again (at Dede Tepe) a well-developed lineation in the Malatya metamorphic rocks (locally marble) dips gently northwards (002°/06°) and is cut by a steeply dipping shear fabric (046°/80°E), parallel to the fault contact between the

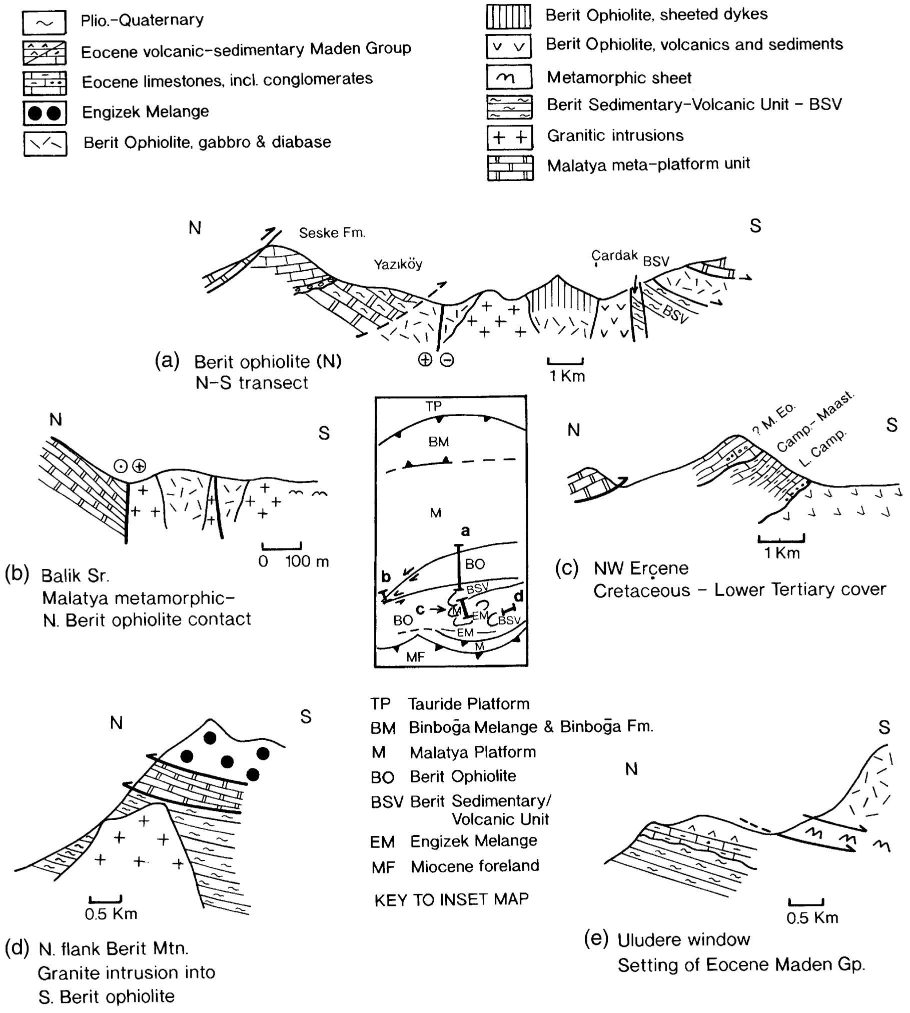

Fig. 11. Key structural relations in the central part of the area studied. The inset sketch map shows the main structural units (simplified from Fig. 3) and the location of the local cross-sections. See text for explanation (a)–(d).

Fig. 12. Field photographs of key structural relationships in the central and southern part of the area studied (from N to S). (a) Steeply S-dipping contact between the Berit (Göksun) ophiolite (North) and the overlying Malatya Metamorphic Unit along the south margin of the Göksun Fault Zone (east of section a in Fig. 11); (b) Berit Volcanic-sedimentary unit, cut by granitic plutons, structurally overlain by the Malatya Metamorphic Unit along south of the Göksun Fault Zone (near section d on Fig.11); (c) Berit Volcanic-sedimentary unit and the Middle Eocene volcanic-sedimentary Maden Group, structurally overlain by the Berit Ophiolite (South) (beneath the arrow), and then by the Malatya Metamorphic Unit (distant mountains above arrow); SW part of the Uludere window; (d) sharp thrust contact between the Mesozoic platform carbonates (Andırın Limestone) and dark schists and marbles of the Malatya Metamorphic Unit (N of Engizek village).

Malatya metamorphic rocks and the underlying Berit Ophiolite. A similar steep bedding fabric is seen along strike several kilometres further east (044°/80°S; near Karaömer). We interpret the contact between the Malatya Metamorphic Unit and the Berit Ophiolite as a north-dipping thrust, transected by left-lateral neotectonic strike-slip faults.

Near the southern boundary of the northern region, south of Çardak (Fig. 3), the Malatya metamorphic rocks alternate between well-bedded marble, black phyllite, calc-schist, finely laminated meta-carbonate and quartzite, in beds from 10 cm to several metres in thickness. The contact between the Malatya Metamorphic Unit to the south and the Berit Ophiolite to the north is variable in strike, but locally dips southwards at up to c.60° (Figs. 11(a) and 12(a)). Associated shear zones, up to 1 m thick, dip NW at c.58°. Elsewhere, a lower angle thrust contact ($<35°$) is exposed within a zone of intense shearing (c.5 m thick). Ophiolitic extrusive rocks become more intensely sheared southwards within this interval and contain phacoids of limestone or quartzite (up to 0.9 m long by 0.2 m wide), followed by steeply dipping marbles and black phyllites correlated with the Malatya Metamorphic Unit. Within 1 km southwards, the dip of well-bedded Malatya metamorphic rocks decreases to c.30–40° to the SE (Fig. 11(a)). Small folds and C/S fabrics indicate thrusting towards the SW.

South of the Göksun Fault Zone the Malatya Metamorphic Unit is extensively exposed on the steep slopes of Berit Mountain and elsewhere in the Engizek Mountains (Fig. 3). West-dipping folded marble and black schist alternate, with a locally well-developed cleavage-bedding intersection lineation, as exposed on the north flank of Berit Mountain (Fig. 11(d)). Elsewhere in the Engizek Mountains (e.g. Engizek village; Uludere window) Malatya metamorphic rocks (c.500 m thick) are dominated by gently dipping, well-bedded dark marble, alternating with black phyllite (Fig. 11(e)).

The Malatya Metamorphic Unit is interpreted as a Late Palaeozoic–Mesozoic carbonate platform succession that formed part of the Tauride Carbonate Platform to the north of the Southern Neotethys. The succession was metamorphosed to greenschist facies and then exhumed by latest Cretaceous time, as indicated by the presence of locally overlying detrital sediments (see Section 7.1). Two alternative causes of metamorphism can be considered. Metamorphism resulting from regional high heat flow related to magmatic intrusion is unlikely, especially as the Malatya Metamorpic Unit, as exposed north of the Göksun Fault Zone, lacks such intrusions. Alternatively, the metamorphism was caused by regional burial beneath higher thrust sheets, which were later removed by tectonic exhumation or erosion. The obvious candidates are the Binboğa carbonate platform and the Binboğa Mélange to the north, which together were several kilometres thick.

4. Berit Ophiolite

The Malatya Metamorphic Unit is underlain by ophiolitic rocks, exposed both to the north and to the south of the neotectonic Çardak–Sürgü Fault Zone (Fig. 4), the Göksun Fault of Arpat and Şaroğlu (1975). Yılmaz (1993) referred to the ophiolite as a whole as the Berit Ophiolite, a name we adopt here. The ophiolites to the south of the Çardak–Sürgü Fault Zone, although in places strongly sheared, have mainly experienced low-grade metamorphism and can be correlated with the northerly ophiolite. The northerly ophiolite exposure was termed the Göksun meta-ophiolite by Tarhan (1986, 1987) and the Göksun ophiolite by Parlak et al. (2001, 2004). Here, we use the terms: Berit Ophiolite (North) and Berit Ophiolite (South) for exposures to the north and the south of the Göksun Fault Zone, respectively.

Perinçek and Kozlu (1984) correlated the Berit Ophiolite with the Yüksekova Complex, a Late Cretaceous, inferred ensimatic arc, of which the type area is located c.500 km to the east, in the Lake Van area of SE Turkey. Lenticular intercalations of red mudstones and pelagic limestone within an extrusive succession of the ophiolite in the area studied include *Globotruncana arca*, of Late Cretaceous age (Tarhan, 1986). Mafic extrusive rocks exposed further east, in the Nurhak–Elbistan area, were reported to contain calpionnellids of Early Cretaceous (Valanginian) age (Tarhan, 1986; 1987). However, these volcanics may relate to associated mélange units rather than the intact Berit Ophiolite. Alternatively, ophiolites of different age may be present in the wider area. In addition, part of the volcanic exposure within the study area (southeast of the Çardak-Sürgü Fault) is shown as Lower Eocene on the new 1:500,000 map of Turkey (MTA, 1989). We interpret these extrusives to post-date the emplacement of the Berit Ophiolite against the Malatya Metamorphic Unit in latest Cretaceous time, rather than being part of the ophiolite.

4.1. Berit ophiolite (North)

An essentially intact, unmetamorphosed ophiolite is present, comprising, in ascending order, ultramafic–mafic cumulates, isotropic gabbro, a sheeted dyke complex, plagiogranite and volcanic units (Fig. 5(d)). No base to this northerly ophiolite is exposed.

The ultramafic cumulates are represented by wehrlite and lherzolite with mesocumulate and poikilitic textures. Mafic cumulate rocks include olivine gabbros that display *ortho*-cumulate and *meso*-cumulate textures (e.g. along the Çardak–Göksun road). The banding in the layered gabbros is mainly aligned NW–SW. Isotropic mafic intrusive rocks are mainly gabbro, diorite and quartz-diorite. Massive gabbros and, locally, pegmatitic gabbros are cut by isolated diabase dykes. The sheeted dyke complex begins with isolated dykes located at the contact with the isotropic gabbro and then passes upwards into an interval dominated by 100% dykes, individually ranging from 10 cm^{-1} m in the upper levels of the sheeted complex, as exposed to the north of Çardak (east of Tüllüce Tepe). The dykes are mostly diabase and microdiorite with well-developed chilled margins. These dykes are steeply dipping (60° W) and commonly NW–SE-trending. The diabase dykes are cut locally by several generations of minor intrusions. These

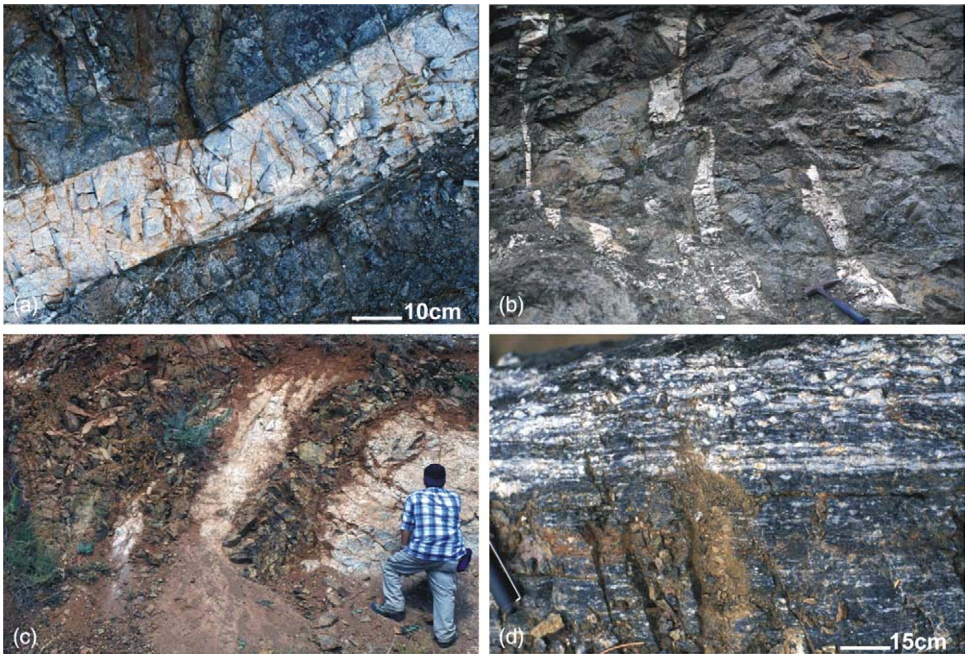

Fig. 13. Field photographs of the Berit Ophiolite. (a) Sheared gabbro cut by less deformed granitic veins, Berit Ophiolite (South), SW of Ericek; (b) disrupted felsic veins; (c) diabase dykes cut by plagiogranite, near Çardak (Berit Ophiolite, North); (d) Gneiss texture resulting from intense hot shearing (ductile shear zone) of Berit ophiolitic gabbros, S of Yazıköy (Berit Ophiolite, North) near the contact with the Malatya Metamorphic Unit.

include early plagiogranite dykes (Fig. 13(c)), cut by small felsic intrusions (<3 m wide) that are interpreted as feeders to the overlying extrusive sequence (which includes silicic extrusives). Granitic veins and dykes are also present (Fig. 13(a) and (b)). The ophiolite as a whole is intruded by granitic plutons, as discussed below.

In some areas, for example, near the Malatya Metamorphic Unit in the northwest, the ophiolitic diabase and gabbro are transected by ductile shear zones (typically tens of cm wide). The shear zones exhibit recrystallisation to gneiss or amphibolite, and some are mylonitic (Fig. 13(d)). Local anatexis in the form of small-scale migmatitic injections have been reported (Tarhan, 1986; 1987). The extrusive rocks are also cut by narrow (<10 m), high-angle brittle shear zones related to neotectonic faulting (e.g. in the Çardak area).

The ophiolitic extrusive rocks are represented by a wide spectrum of basalt, basaltic andesite, andesite, dacite and rhyolite. Several exposures show a transition from massive gabbros, to gabbros with isolated dykes, followed by basaltic extrusive rocks. Small fault-bounded exposures of mainly pillow basalt are interpreted as forming the lower levels of the extrusive succession. A large exposure area (east of Çardak; Fig. 3) is dominated by pillowed to massive, intermediate-composition lavas, interstratified with silicic, massive lava flows. Massive porphyritic andesite includes numerous zones of keratophyric alteration, locally rich in epidote. Intercalations of volcaniclastic sandstone, silicic tuff and sheared pelagic limestone are commonly present. These include occasional intercalations of thin- to medium-bedded volcaniclastic sandstones, interpreted as turbidites, together with lenses of pink pelagic carbonate and reddish-brown radiolarian chert.

4.2. Berit ophiolite (South)

To the south of the Göksun Fault Zone the ophiolite is more sheared, and is dissected into separate thrust sheets and fault blocks. The ophiolite is, however, relatively intact within a large antiformal structure in the south, known as the Uludere window (Fig. 3). In this area, the ophiolite is reported to comprise two main thrust sheets, of which the lower one is dominated by massive and sheeted metadiabase, overlain by gabbro, whereas the upper sheet begins with ultramafic tectonites, followed by meta-gabbros. The two thrust sheets have been interpreted as the upper and lower limbs, respectively, of a huge south-facing recumbent anticline (Genç et al., 1993). However, it is also possible that several different thrust sheets of mafic and ultramafic plutonic rocks exist in the area. Further north, along the northeast flank of the Engizek Mountains, the ophiolite is absent (or greatly reduced) and the Malatya Metamorphic Thrust Sheet rests directly on the Berit Sedimentary-Volcanic Unit.

The Uludere window exposes an intact succession (> 600 m thick), dominated by layered ultramafic and mafic cumulates (e.g. NE of Demirlik). The ophiolite is also well exposed as fault-bounded blocks, directly south of the Göksun Fault Zone (e.g. S of Ericek), where lithologies range from sheeted dykes, to massive gabbros (locally pegmatitic), cut by isolated basaltic dykes (individually up to several metres wide). In this area, small plagiogranite dykes cut massive gabbro and are, in turn, cut by a diabase dyke, then by granitic veins. As with the Berit Ophiolite (North), the ophiolitic rocks are cut by fault lineaments (e.g. strike 60, dip 38 S) exhibiting shearing, foliation and local recrystallisation.

4.2.1. Interpretation of the Berit Ophiolite

The Berit Ophiolite exposures, north and south of the Göksun Fault Zone, can be correlated as originally one regionally extensive thrust sheet (Fig. 14). The age of the

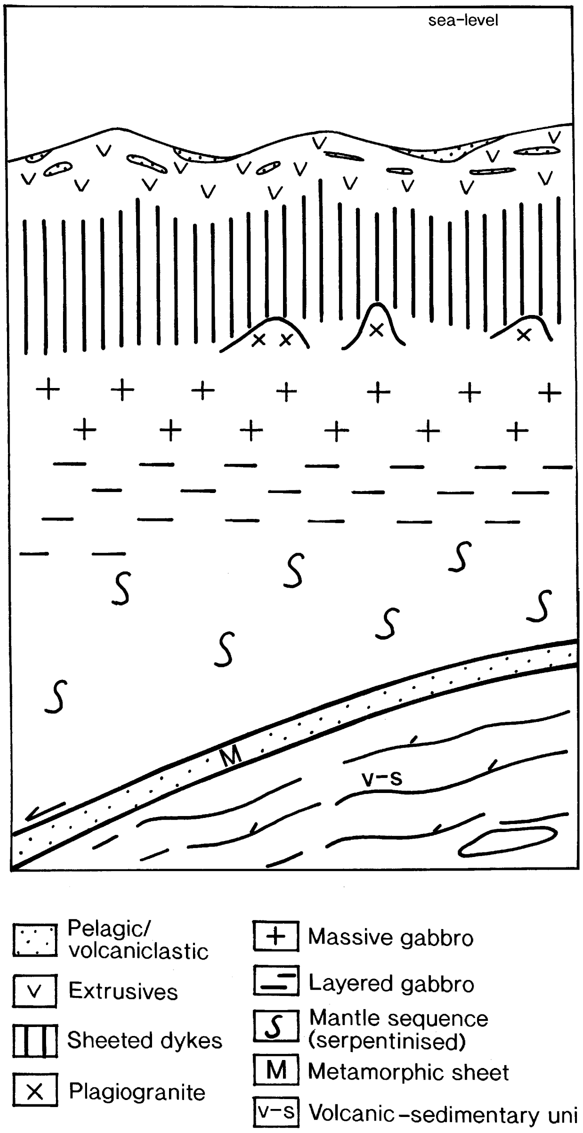

Fig. 14. Restored tectono-stratigraphy of both the northern and southern sectors of the Berit Ophiolite, together with the underlying metamorphic sheet and the Berit Sedimentary-Volcanic Unit. See text for explanation.

ophiolite is constrained as syn- or pre-c.85 Ma (Santonian), the oldest age determined for cross-cutting granitic intrusive rocks (see below). A Late Cretaceous (Campanian–Maastrichtian) age for the ophiolite-related extrusive rocks is inferred from pelagic microfossils within interbedded pelagic limestones (Tarhan, 1986).

Geochemical analyses of immobile major and trace elements suggest that the ophiolite formed in a supra-subduction zone setting (Parlak et al., 2001, 2004), similar to many other Upper Cretaceous Tethyan ophiolites (Pearce et al., 1984; Robertson, 2002). The presence of an extrusive succession including evolved intermediate, andesitic and silicic rocks, together with volcaniclastic and pelagic sediments points to a volcanic arc-related setting. However, there is little evidence that the volcanic pile was greatly thickened and rose above sea-level. The extrusive-sedimentary sequence is similar in field relations and geochemistry to that of Upper Cretaceous ophiolites exposed further east along the Tauride thrust belt in the Malatya and Elaziğ regions (i.e. İspendere, Kömürhan and Guleman ophiolites; e.g. Rızaoğlu et al., 2004), and also further east in the Van region (Yüksekova ophiolite; Beyarslan and Bingöl, 2000). In addition, similar lithologies are present as dismembered slices associated within the Misis Mélange, further west in the Misis Mountains, north of the easternmost Mediterranean Sea. These slices were interpreted as dismembered Upper Cretaceous oceanic crust formed in an incipient arc or back-arc setting (Robertson et al., 2004).

4.3. Ophiolite-related metamorphic sheet

High-grade metamorphic rocks are associated with the Berit Ophiolite (South) in several areas. In the south of the area (e.g. Uludere window), the metamorphic rocks are exposed, both within, and at the structural base of the ophiolite. A slice of metamorphic rocks showing a high-grade granulite-eclogitic assemblage is also reported from within the ophiolite (Genç et al., 1993). Metamorphic rocks at the base of the ophiolite are strongly sheared and mylonitised. For example, we observed banded gneiss and mylonite in the northeast part of the Uludere window (on the Engizek–Kandil road, near Demirlik village; Fig. 15(a)). A moderately dipping (c. 38°) metamorphic thrust sheet, c. 150 m thick, is exposed there beneath layered ultramafic rocks (including dunites). Similar metamorphic rocks are present in the southeast of the window. Elsewhere, to the west of Berit Mountain, the metamorphic sheet includes schist, amphibolite and garnet gneiss (with garnets up to 1 cm in size). In this area, high-grade gneiss, amphibolite and mylonite are folded (Fig. 15(c)) and locally structurally intercalated with greenschist facies rocks of the Berit Sedimentary-Volcanic Unit (e.g. along the road SE of Sülüklügöl, towards Kahramanmaraş; Figs. 15(c) and 16(a)).

The Berit Ophiolite (South) extends c.50 km eastwards into the Doğansehir area (Fig. 2), where ultramafic ophiolitic rocks are intercalated with similar high-grade metamorphic rocks. These lithologies include amphibolite facies rocks (amphibolite, plagioclase-amphibole schist, epidote-amphibole schist, garnet- and amphibole-bearing meta-gabbros), and probable meta-ultramafic rocks, together with granulite facies rocks (e.g. pyroxene-granulite). These lithologies are structurally imbricated with sheared mantle tectonites (harzburgite). They are folded, show polyphase deformation and are cut by a granite pluton. Geochemical analysis shows that amphibolites of the metamorphic sheet in the Doğanşehir area fall into two geochemical groups, corresponding to subduction-influenced tholeiites and N-MORB-type tholeiites (Parlak et al., 2002).

4.3.1. Interpretation of the metamorphic sheet

The high-grade metamorphic sheet can be generally compared with the sub-ophiolite metamorphic soles beneath ophiolites elsewhere (Williams and Smythe, 1973; Woodcock and Robertson, 1977; Spray et al., 1984) (Fig. 14). However, the Berit metamorphic sheet is unusual in several respects. First, it is structurally interleaved with plutonic ophiolitic rocks and locally underlies layered ultramafic rocks (e.g. dunite) rather than mantle tectonite (e.g. in the Uludere window). Secondly, unusually coarse-grained granulite–eclogite facies metamorphic rocks are present. Thirdly, the unit has commonly undergone intense mylonitic deformation, as seen at the base of the ophiolite in the Uludere Window.

The presence of amphibolite facies to granulite facies rocks implies the juxtaposition of mafic oceanic crust with hot peridotite (c.1000 °C), possibly combined with the effects of shear heating (Williams and Smythe, 1973; Woodcock and Robertson, 1977; Spray et al., 1984). The existence of ultramafic protoliths is supported by very low Rare Earth Element contents in some of the metamorphic rocks (Parlak et al., 2002). Some of the granulitic rocks could also be of continental origin. In Northern Oman (Dibba Zone) local granulite facies rocks within the metamorphic sole are interpreted as the result of subduction, then exhumation, of continental lithologies. Subduction was accompanied by minor intrusion of granitic melts derived by melting of subducted sediments (Searle and Cox, 1999; Cox et al., 1999).

Petrographic studies suggest that an inverted metamorphic gradient may have originally existed, but was disrupted by rethrusting (Parlak et al., 2002). However, it is also possible that the high-grade metamorphism took place under essentially static conditions allowing the growth of very large garnets, for example following underplating beneath a hot ophiolite mantle wedge.

It is likely that the ophiolite-related metamorphic rocks originated from lithologies that were accreted from the down-going slab (e.g. N-MORB). The subduction-influenced basalts were either accreted from a subducting oceanic arc unit or detached from the front of the overriding Berit ophiolite and then underplated.

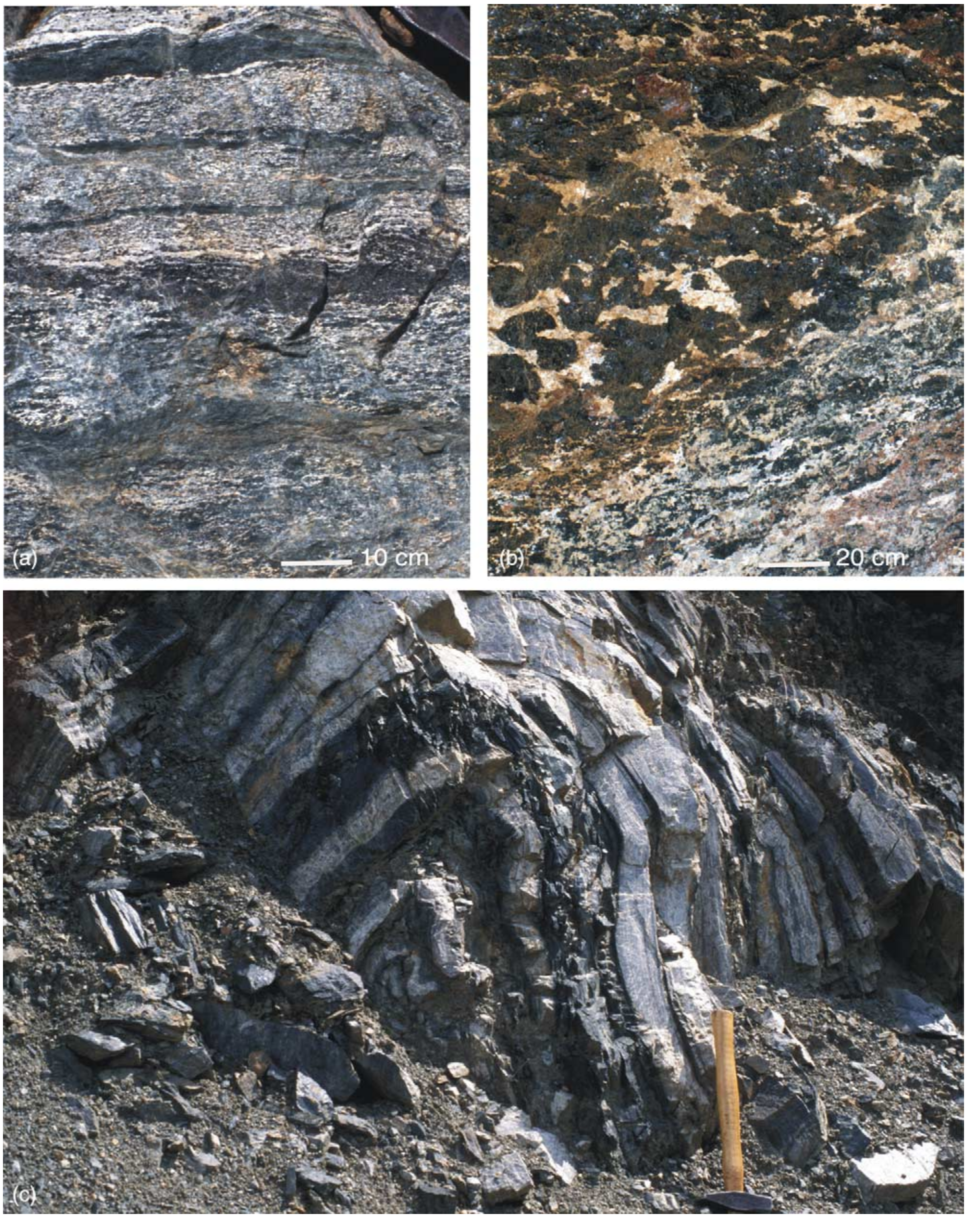

Fig. 15. Field photographs of metamorphic rocks associated with the Berit Ophiolite. (a) Foliated amphibolite from the metamorphic sheet underlying the Berit Ophiolite (South), NE part of the Uludere window; near Demirlik; (b) sheared (altered) granulite from the metamorphic sheet associated with the Berit Ophiolite (South), near Demirlik; (c) folded amphibolite from thrust slices within the Berit Volcanic-sedimentary unit, Sülüklügöl-Tanır road (W of Berit Mountain).

The ophiolite was affected by high-temperature ductile deformation and the metamorphic rocks were tectonically interleaved with the ophiolite in the south. This deformation might relate either to intra-oceanic slicing or to the docking of young, hot ophiolite with the Tauride active continental margin (Malatya platform) to the north during latest Cretaceous time (see Section 12.2). The basal mylonites in the Uludere window could reflect the effects of continuing northward underthrusting in a forearc setting after the Berit Ophiolite was accreted to the Tauride active margin. The ophiolite and the related metamorphic rocks were further disrupted by internal imbrication and faulting during their post-Eocene southward tectonic emplacement.

5. Berit sedimentary-Volcanic Unit

This regionally important greenschist facies unit structurally underlies the Berit Ophiolite (South) in many areas, and is best exposed in windows and fault blocks (e.g. in the Uludere window and south of Çardak; Figs. 3 and 4). Perinçek and Kozlu (1984) included this unit within the Berit Ophiolite (part of their Berit Group). However, this is clearly a separate tectono-stratigraphic unit (Fig. 5(e)). These authors reported the presence of quartz, muscovite and/or biotite schist with lenses of marble and calc-schist in more pelitic intervals. An origin was envisaged as slices of continental crust that were mixed with ophiolitic rocks

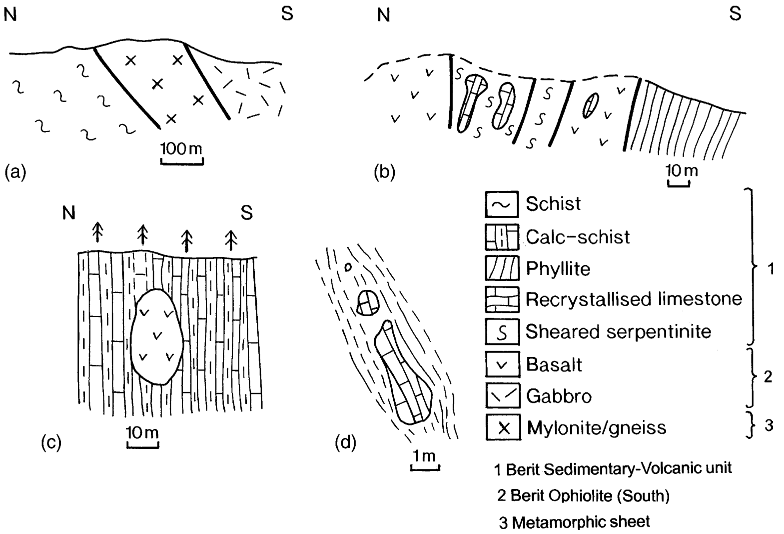

Fig. 16. Field sketches of the Berit Sedimentary-Volcanic Unit showing local relationships west of Berit Mountain (Sülüklügöl-Tanır road). (a) Typical greenschist facies meta-sedimentary rocks overlain by mylonite and gneiss of the Metamorphic Sheet, then by gabbro of the Berit Ophiolite (South); (b) high-angle fault zone marked by sheared serpentinite with entrained recrystallised limestone blocks (a possible strike-slip zone); (c) volcanic block in calc-schist; (d) Limestone block in sheared phyllite. See text for explanation.

during tectonic emplacement. Schists exposed in the Uludere window (Kızılkaya metamorphics of Genç et al., 1993) were correlated with the continentally related Pütürge metamorphic massif, exposed >100 km to the east. By contrast, the Berit unit, as exposed in the Uludere window was interpreted as the upper part of an ordered ophiolite, including local pillow lavas and overlying deep-sea sediments, of inferred Late Cretaceous–Early Eocene age (Kızılkaya metamorphic association; Yılmaz et al., 1993). The ophiolitic rocks were assumed to correlate with the Berit (North) (i.e. Yüksekova ophiolite).

The Berit Sedimentary-Volcanic Unit exhibits a complex internal structure, such that different exposure areas cannot readily be correlated. The unit was studied in four accessible exposures located to the north and the southwest of Berit Mountain. In general, the main lithologies are green, grey, black to reddish phyllites and mica schists, with local meta-carbonate interbeds, reddish meta-chert, metabasalt and meta-quartzitic sediments. There are significant differences between individual exposures areas, however, as summarised below.

5.1. Northerly area

North of Berit Mountain (along the road from Ericek to Sülüklügöl; Fig. 3), roadside exposures are dominated by grey psammite with several sheared lenses, or blocks, of feldspar-phyric and aphyric meta-basalt. Westwards, well-bedded dark marbles, with large rip-up clasts of dark phyllite (up to 0.6 m in size), are interbedded with minor dark chert, formed by replacement of carbonate. East of a shear zone, well-bedded buff-coloured marbles (ca. 20 m thick) alternate with intervals of pale to dark schist (<2 m thick). The marbles are isoclinally folded on an outcrop scale and cut by small normal faults. The pale schists mainly comprise quartz, muscovite, minor plagioclase and secondary carbonate, whereas the dark schist is rich in amphibole and quartz with minor plagioclase and ore minerals. This area is interpreted as a faulted succession of meta-sandstone turbidites and occasional debrites, together with siliceous calciturbidites, basic extrusive rocks and volcaniclastic sediments.

5.2. Northwesterly areas

Northwest of Berit Mountain (Sülüklügöl area), the Berit Sedimentary-Volcanic Unit is dominated by steeply dipping, foliated, dark pelitic schists and subordinate paler psammites. The schists are locally intercalated with dark grey, medium-bedded, partially silicified limestones. Nodular and bedded-replacement cherts, of inferred diagenetic origin are also present. Thin section study shows that the protoliths of the dark schists are basalts, mainly replaced by carbonate, quartz and chlorite. Reddish to greenish coloured phyllites are locally present, with subordinate intercalations of pale marble (up to several metres thick) (e.g. at Kömesüğüt; Fig. 17(a)). Folded marble intercalations (up to 20 m thick) can be traced laterally for up to several hundred metres. An intercalation (0.6 m thick) of silica-cemented quartzose sandstone was noted within dark schist. Area two thus records an imbricated succession of sandstones, mud rocks, siliceous carbonates and basaltic rocks.

The Berit Sedimentary-Volcanic Unit is again well-exposed 10–15 km further southeast on the road from Sülüklügöl (towards Tanır) within a forested area, where it is intercalated with steeply dipping thrust slices of sheared serpentinite (up to 80 m thick) and high-grade metamorphic rocks (Fig. 16(a) and (b)). Grey phyllites and psammites

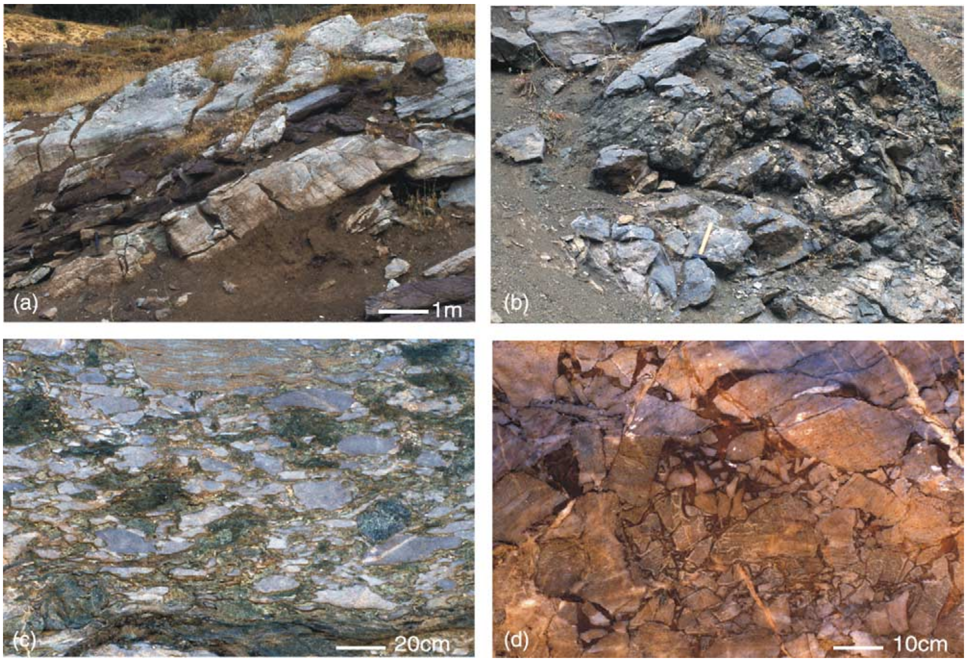

Fig. 17. Field photographs of the Berit Sedimentary-Volcanic Unit. (a) Lenses of marble within red non-calcareous shale, NW flank of Berit Mountain; (b) Sheared debris flow composed of marble clasts (pale) in a volcaniclastic matrix (dark); NW flank of Berit Mountain; (c) debris flows composed of volcanic and limestone clasts, eastern part of Uludere Window, near Demirlik; (d) Breccia composed of volcanic and limestone clasts affected by overpressuring, with jig-saw fit, eastern part of Uludere Window, near Demirlik.

alternate with subordinate marble, red ribbon radiolarite and quartzite. The main quartzite unit, ca. 60 m thick, is thin to medium-bedded, finely laminated and ranges in colour from white, pinkish, or greenish. The marble is composed of finely crystalline calcite, with silt-sized quartz. Further south, a slice of meta-basalt is associated with meta-limestone and red chert (Fig. 17(b)). Southwards again, phyllite and psammite are intercalated with meta-basalt (c.10 m thick), passing, with a depositional contact, into pale calc-schist (c. 60 m thick). The basalt includes a meta-volcanogenic debris-flow unit (1.5 m thick) with volcanic and marble clasts (Fig. 17(b)). The meta-basalt unit lenses out laterally in both directions over tens of metres. Nearby, large basalt blocks and basaltic debris are seen within phyllite (Fig. 16(c) and (d)). Southwards again, sheared phyllites include debris-flow deposits, up to 2.5 m thick, full of basalt clasts (<10 cm). Area three, therefore, includes mixed terrigenous-carbonate-pelagic-derived successions and primary associations of basalt–radiolarite–limestone.

5.3. Southerly area: Uludere window

The Berit Sedimentary-Volcanic Unit comprises several relatively coherent thrust sheets within the Uludere window. A lower thrust sheet is dominated by green fissile chloritic schist and pale micaceous schist, with subordinate intercalations of lenticular pale, silicic extrusive igneous rock (rhyolite), up to 60 m thick. Intercalations of medium-to-thick-bedded meta-sandstones contain quartz, plagioclase and ferromagnesian grains. Individual fine-grained meta-sandstone beds individually grade upwards through meta-siltstone/mudstone intervals on a tens-of-centimetre-, to several-metre scale. Well-bedded, graded meta-limestones (10–40 m thick) include rare intercalations of clast-supported meta-limestone breccias, with angular limestone clasts (up to 10 cm in size), set in a buff-coloured calcareous matrix (Fig. 17d). An overlying volcanic-sedimentary sheet, traceable >1 km along strike, begins with red/green phyllite interbedded with matrix-supported conglomerate (3 m thick), composed of basalt and limestone clasts (15 cm thick), and followed by altered basalt (c.20 m thick). The succession culminates in cleaved, matrix-supported conglomerates, dominated by flattened marble clasts (up to 20 cm long) set in a grey phyllite matrix (Fig. 17(c)). Both of the thrust sheets show evidence of isoclinal, folding on an outcrop scale (locally with S-vergence). Area four is, therefore, interpreted as two main thrust sheets of turbiditic sandstones interbedded with bimodal basic-silicic volcanics, volcaniclastic sedimentary rocks and carbonate/mud rock debris flows.

Five samples of metabasalt were analysed from the Berit Sedimentary-Volcanic Unit (Fig. 18). On the Zr/Ti vs. Nb/Y diagram they plot in the area of overlap between the sub-alkaline basalt, basaltic andesite and andesite fields (Fig. 18(a)). In the Ti/Zr diagram they plot in the area of overlap of the WPB, MORB and IAT fields (Fig. 18(b)). On MORB-normalised spider plots (Fig.18(c)) the basalts show a strong enrichment of LREE, typical of within-plate basalts.

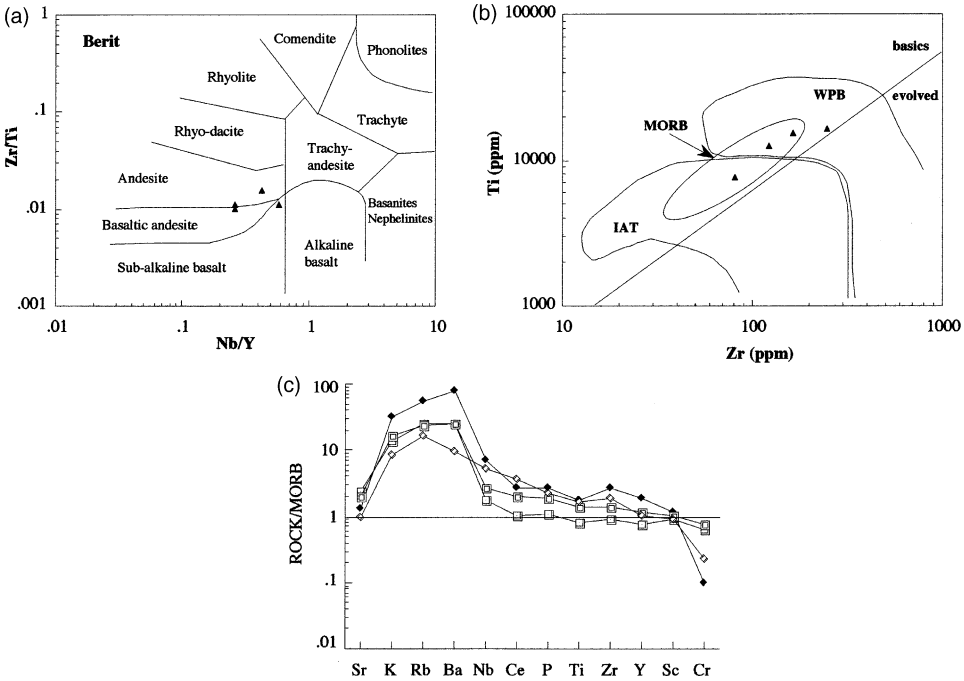

Fig. 18. Geochemical data for the Berit Sedimentary-Volcanic unit. (a)–(b) for the Sülüklügöl area: a. Zr/Ti vs. Nb/Y; (b) Ti vs. Zr; (c) MORB-normalised spider plots. See text for explanation.

5.4. Interpretation of the Berit Sedimentary-Volcanic Unit

The sedimentary protoliths of the Berit Sedimentary-Volcanic Unit include turbiditic sandstones, mudstones, radiolarian cherts, calciturbidites, slope carbonates and debris-flow deposits. The extrusive rocks include massive basalts, lava breccias, volcaniclastic sediments and minor tuffs, and range from basaltic to felsic in composition. The lavas were erupted in areas of considerable seafloor relief, marked by the emplacement of volcaniclastic and carbonate-rich debris flows. The volcanogenic units map out as lenses and blocks and could represent remnants of distal rift units or seamounts. On the other hand, laterally continuous (up to several km) volcanic-sedimentary intercalations include quartzitic sediments (e.g. in the Uludere window) and these could have originated as more proximal shallow-water deposits. The basalts are interpreted as E-type MORB, to enriched within-plate basalt, consistent with either rift- or seamount-type settings.

The Berit Sedimentary-Volcanic Unit lacks identifiable fossils and at present can only be dated with certainty as pre-Middle Eocene, the age of the unconformably overlying (Maden Group; Fig. 5(e)). However, mapping by Perinçek and Kozlu (1984) indicated that the Berit Sedimentary-Volcanic Unit is cut by granitic rocks in the north of the area (e.g. southeast of Çardak). This implies that the Berit unit lithologies are Late Cretaceous, or older.

Two tectonic settings can be considered: first, as rifted continental margin sediments and basic volcanics of Early Mesozoic age (possibly with older units); secondly, as volcanic seamounts, associated neritic carbonates and pelagic sediments (cherts). Similar lithologies are characteristic of South-Neotethyan rifted margins elsewhere in southern Turkey (e.g. Antalya Complex; Robertson and Woodcock, 1982; see Section 12.1).

6. Late Cretaceous granitic intrusions

The Berit Ophiolite (North and South) and the Berit Sedimentary-Volcanic Unit, as mapped by Perinçek and Kozlu (1984), are cut by granitic intrusions, of up to kilometre scale (Figs. 3 and 4). In the west, the granitic rocks cut the Berit Ophiolite (North), forming two main NE–SW trending lineaments that merge into a single zone, up to 4 km across in the east. The main lithologies are hornblende-biotite granodiorites and normal granites. The granodiorites include amphibole-bearing mafic inclusions, interpreted as assimilated ophiolitic rocks. In the northeast (near Dereboynu) undeformed exposures of massive pink granite are cut by finer grained aplitic dykes (up to 0. 5 m wide) (strike 130°/dip 60° SW). Near the northern margin of the Berit Ophiolite (North) (south of Yazıköy) sheared ophiolitic gabbro and gabbro pegmatite are cut by undeformed aplite dykelets and veinlets.

The Berit Ophiolite (South) and the Berit Sedimentary-Volcanic Unit are cut by large granitic intrusions. For example, a large granitic body is mapped as cutting the Berit Sedimentary-Volcanic Unit to the north of the Uludere Window (Perinçek and Kozlu, 1984). We examined a thermal aureole between granite and country rock, locally marble of the Berit Sedimentary-Volcanic Unit, on the northern slopes of Berit Mountain (Fig. 12(b)). Near its margin the granite is sheared, strongly altered and cut by aplitic veins, whereas the interior of the granite is relatively unaltered and undeformed. The aureole includes hematite ore that was formerly mined. The adjacent country rocks comprises sheared serpentinite with inclusions of marble (up to 1 m in size). Bedded marble lenses or blocks, up to tens of metres wide, are set in a matrix of micaceous mudstone, cut by haematitic veinlets. The Berit Sedimentary-Volcanic Unit is again cut by small granitic intrusions and dykes further west along the road to Ericek (Fig. 3). By contrast, granitic intrusions are largely absent further south (e.g. Uludere window; Fig. 3).

Small bodies of granitic rocks were previously mapped as cutting the contact between the Berit Ophiolite (North) and the overlying Malatya Metamorphic Unit in a poorly exposed area, 15 km north-east of Göksun (near Balık Sr.; Fig. 11(b)) (Perinçek and Kozlu, 1984; Parlak et al., 2001). This would be important, as it would confirm that the granites stitched the entire thrust stack as far up as the Malatya Metamorphic Unit. However, we observed that the Malatya metamorphic rocks (dipping northwards at c.50°) are separated from the underlying Berit Ophiolite (North) by a major thrust that dips northwards at c.30° (at Dede Tepe, just north of the Göksun–Afşin highway). The adjacent ophiolitic rocks include serpentinised cumulates, pegmatitic gabbro and massive gabbro. The granite crops out only to the south of this thrust contact, and can thus be considered to be intrusive into the Berit ophiolite, as elsewhere. On the other hand, further east (Doğanşehir, Nurhak, Malatya and Elazığ areas) the Malatya metamorphic rocks or equivalents (Keban Platform) are demonstrably cut by lithologically similar granitic plutons (e.g. Yazgan and Chessex, 1991).

Recent analytical studies, including Rare Earth Element (REE) patterns, ocean-ridge granite (ORG)-normalised spider plots and tectonic discrimination diagrams show that the granitic rocks intruding the Berit Ophiolite in the area studied are chemically of calc-alkaline type (Parlak and Rızaoğlu, 2004). K–Ar ages, determined for 13 biotite separates yielded ages ranging from 80.42 ± 2.0 to 70.05 ± 1.75 Ma. In addition, one hornblende separate yielded an age of 85.76 ± 3.17 Ma (Parlak, under review).

The field evidence indicates that the Berit Ophiolite was tectonically juxtaposed with the Malatya platform on a regional scale, followed by mutual granite intrusion (Fig. 19). The 85–70 Ma age range (Santonian–early Maastrichtian) is similar to the 87–76 Ma range reported for comparable granitic intrusions in the Elazığ area (Yazgan and Chessex, 1991). After the Eocene, the northerly part of the Berit Ophiolite (South), together with the underlying Berit Sedimentary-Volcanic Unit and cross-cutting granite intrusions were thrust southwards over part of the Berit Sedimentary-Volcanic Unit and its Mid-Upper Eocene transgressive cover (Maden Group; see below). This indicates that complex internal re-thrusting took place after the initial Late Cretaceous emplacement.

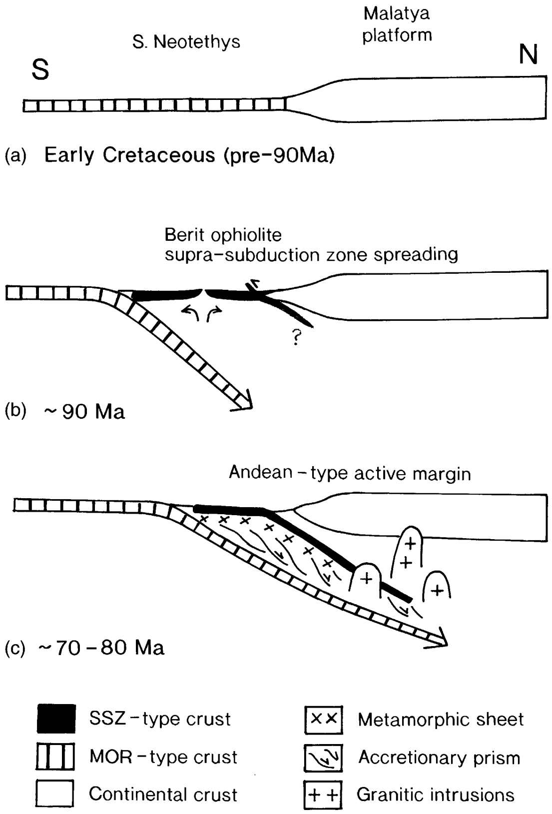

Fig. 19. Tectonic model for the evolution of the northern margin of the Southern-Neotethys ocean; see text for explanation. (a) Mesozoic passive margin phase; (b) genesis of the Berit ophiolite above an intra-oceanic subduction zone. Subsequent underthrusting or subduction beneath the Malatya platform carried the Berit ophiolite northwards until it docked with the Malatya platform; (c) the amalgamated Andean-type active margin was intruded and stitched by calc-alkaline granitic plutons.

7. Latest Cretaceous–Middle Eocene sedimentary cover

The Malatya Metamorphic Unit, the Berit Ophiolite, and the Berit Sedimentary-Volcanic Unit are depositionally overlain by a variety of sedimentary deposits of latest Cretaceous and Palaeogene age that shed light on the timing and assembly of the Tauride thrust belt in the area studied.

7.1. Syn-emplacement cover of the Malatya Metamorphic Unit

The Malatya Metamorphic Unit is mapped as being unconformably overlain by local exposures of unmetamorphosed clastic sedimentary rocks (Perinçek and Kozlu, 1984; Kozlu et al., 1990). This unit was termed the Kemaliye Formation by Özgül et al. (1981), although its type area is located in the Munzur Mountains, well to the northeast of the Berit area. Within our study area this unit was mapped as thin exposures between the Malatya Metamorphic Unit to the south and the Binboğa Formation/Binboğa Mélange to the north, as northeast of Afşin (Fig. 3). Small exposures were also mapped as overlying the Malatya Metamorphic Unit to the south of the Göksun Fault

Zone (SW of Çardak). The unit is also widely exposed beneath the over-riding Tauride carbonate platform further east, including the Nurhak area (Perinçek and Kozlu, 1984; Kozlu et al., 1990).

The clastic unit (Kemaliye Formation) begins with a basal conglomerate composed of limestone, chert, diabase and sandstone, mainly derived from basic rocks and carbonate rocks, and then passes laterally and vertically into redeposited carbonates and marls, with large clasts of neritic and pelagic carbonate rocks, also serpentinite (Perinçek and Kozlu, 1984). The limestone clasts are dated as Triassic to Lower Campanian and thus a Late Campanian–Maastrichtian age was inferred for deposition of this unit (Özgül et al., 1981).

7.2. Upper Cretaceous–Lower Cenozoic sedimentary cover of the Berit Ophiolite (N)

Ophiolitic extrusive rocks of the Berit Ophiolite (North) are overlain locally by latest Cretaceous sedimentary rocks (at Ercene, near Afşin; Fig. 3) that shed light on the timing and setting of ophiolite emplacement (Perinçek and Kozlu, 1984; their Un-named Unit) (Fig. 20(a)). During this study, we refined the dating of the lower part of this overlying succession (Fig. 20(a)) as Campanian, based on planktonic foraminifera (Sample 28—Appendix A) (Fig. 21(a)). In addition, a less specific Campanian–Maastrichtian age was determined for pelagic carbonates higher in this succession (Sample 31—Appendix A).

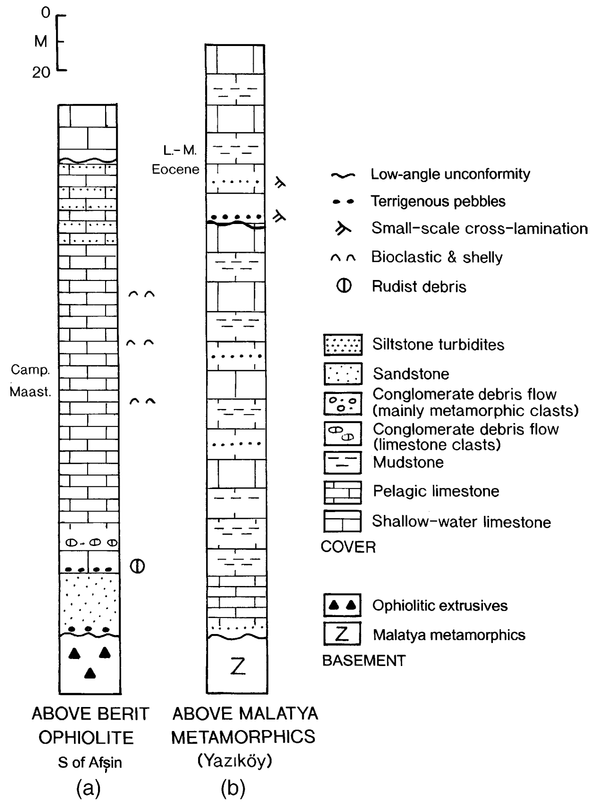

Fig. 20. Measured sedimentary logs of the latest Cretaceous and lower Cenozoic cover of: (a) the Berit Ophiolite (North) and (b) the Malatya metamorphic unit.

The uppermost levels of the ophiolite extrusives (Fig. 20(a)) comprise poorly exposed, undeformed, andesitic talus breccia, interbedded with coarse feldspathic sandstone and volcaniclastic conglomerate. The overlying sediments then exhibit an appearance of terrigenous sedimentary material (e.g. quartz; schist), and are thus interpreted to post-date the emplacement of the ophiolite.

The post-emplacement succession begins with volcaniclastic sandstone (in beds <0.8 m thick), intercalated with mudstone. The sandstone is rich in ophiolitic and metamorphic lithoclasts similar to lithologies of the adjacent Malatya Metamorphic Unit. Occasional microbreccias are dominated by metamorphic clasts.

Above, a thin (<1 m) lenticular conglomerate comprises well-rounded or elongate clasts (<10 cm in size), mainly marl, schist, quartzite, marble and crystalline limestone. This marks the base of a contrasting depositional unit dominated by coarse bioclastic limestones (bioclastic sparite), with rudist bivalve fragments and shell-rich layers, interbedded with bioturbated calcareous mudstones. Thin sections reveal abundant calcareous algae, benthic foraminifera (including miliolids), planktic foraminifera and shell fragments, together with scattered grains of micritic limestone, marble, siltstone and quartz (sub-rounded grains). The succession includes matrix-supported conglomerates (up to 0.9 m thick), with sub-rounded marble clasts, up to 15 cm long, set in an argillaceous matrix.

The succession continues upwards with a contrasting interval of thin-bedded (<3 cm), grey micritic limestone, with occasional large horizontal burrows and subordinate bioclastic interbeds. A prominent laterally continuous graded bed (1 m thick) is composed of bioclastic, calcareous sandstone, and exhibits large N–S trending flute casts (without observable azimuth). Hemipelagic carbonates include medium-to- fine grained, graded bioclastic sandstone beds every few tens of metres (Fig. 20(a)). These interbeds are rich in redeposited large foraminifera and moulds of large pelagic bivalves. Thin sections reveal densely packed, commonly fragmented, Nummulites, in a matrix of micrite with scattered detrital grains of quartz, pelagic carbonate, marble, biotite schist, and quartzite. The quartzose grains range from slightly to completely recrystallised. The uppermost 80 m of the succession is mainly hemipelagic carbonate with only a few clastic interbeds of partially recrystallised Nummulites, additional benthic foraminifera and scattered quartz grains.

The succession is then interrupted by a distinct, laterally persistent low-angle unconformity (<10°), overlain by strongly contrasting thick-bedded bioclastic limestones, c.50 m thick (Fig. 20(a)). Scouring and channelling into underlying thin-bedded micritic carbonates occurs along the unconformity surface. Thin, lenticular conglomerates above

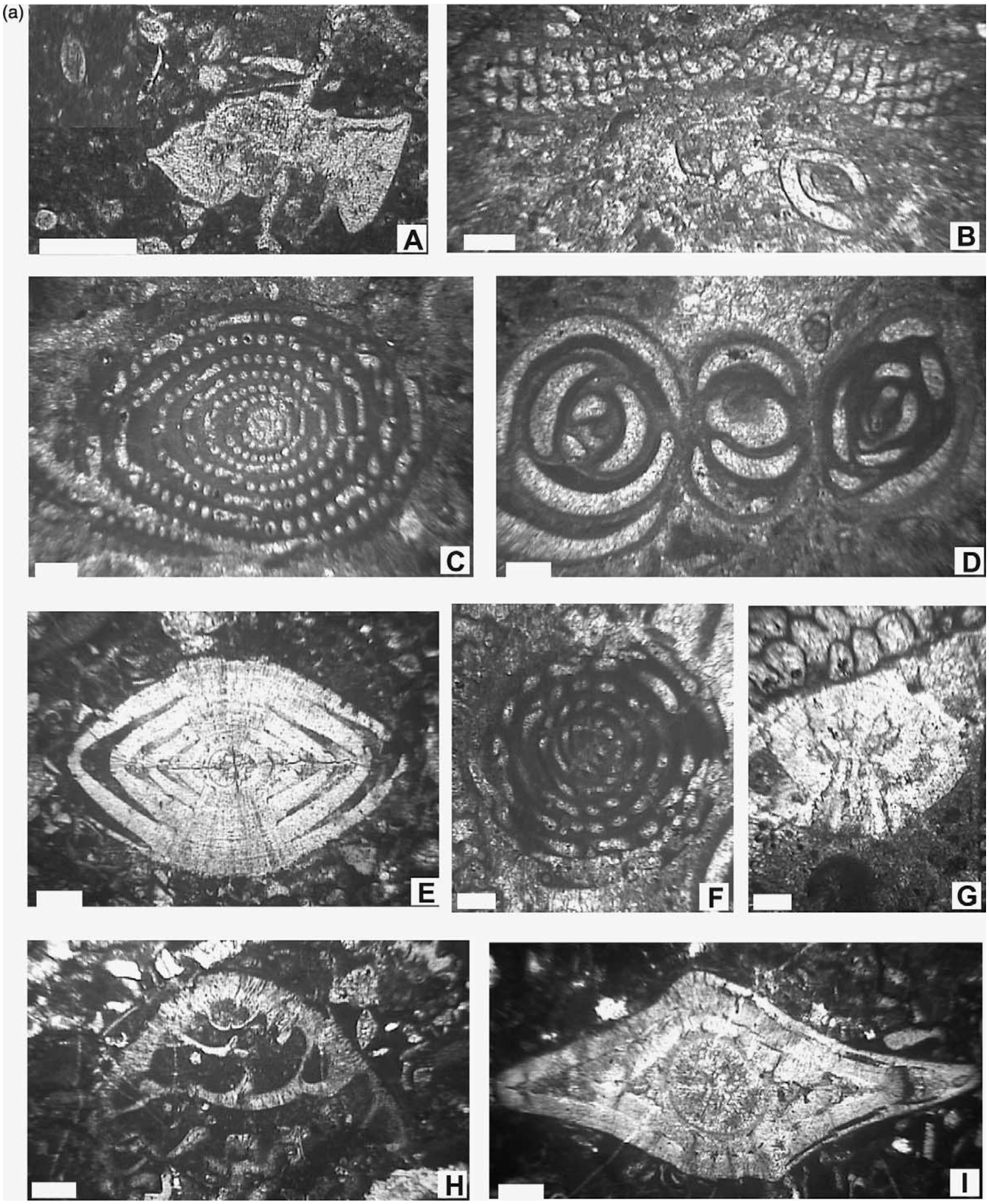

Fig. 21. Photomicrographs of selected microfossils from pelagic/hemipelagic limestones. (a) Microfossils from the main Berit area. Locations: (A) within volcaniclastic sediments overlying the Berit Ophiolite (North) at Ercene, near Afşin; (B–D, F–I), Helete Formation, E of Helete; (E) Fine-grained limestone above the Malatya Metamorphic unit; Yazıköy. See Appendix A for grid references. Taxa illustrated: (A) *Globotruncanita elevata* (BROTZEN) and *Pithonella ovalis* (KAUFMANN) (top left), lower Campanian; Sample 28; (B) *Opertorbitolites latimarginalis* LEHMANN, lower Ilerdian, Sample 82c; (C) *Alveolina (Glomalveolina) subtilis* HOTTINGER, lower Ilerdian, Sample 82c; (D) *Idalina sinjarica* GRIMSDALE, lower Ilerdian, Sample 82c; (E) *Nummulites* cf. *globosus* LEYMERIE, Lutetian, Sample 241b; (F) *Alveolina (Glomalveolina) lepidula* SCHWAGER, lower Ilerdian, sample 82c; (G) *Lockhartia haimei* (DAVIES), lower Ilerdian, Sample 82c; (H) *Lockhartia diversa* SMOUT, Ilerdian–Cuisian, Sample 83; (I) *Nummulites* cf. *pengaronensis* VERBEEK, Ilerdian–Cuisian, Sample 83. Bar scale 0.2 mm. (b) Microfossils from the eastern (Helete) area. Locations: Helete Formation, east of Savran. See Appendix A for grid references. Taxa illustrated: (A) *Sphaerogypsina globula* (REUSS) Lutetian, Sample 240a; (B) *Discocyclina scalaris* (SCHLUMBERGER), Lutetian, Sample 241b. (C) Sphaerogypsina anatolica INAN and OZGEN-ERDEM, Lutetian, Sample 240a; (D) *Sphaerogypsina carteri* SILVESTRI, Lutetian, Sample 240a; (E) *Asterocyclina stella taramelli* MUNIER-CHALMAS, Lutetian, Sample 241a; (F) *Discocyclina archiaci bartholomei* SCHLUMBERGER, Lutetian, Sample 240b; (G) *Asterocyclina* sp., Lutetian, Sample 240b; (H) (*Discocyclina seunesi*) DOUVILLE, Lutetian, ample 240a; (I) *Orbitoclypeus* cf. *ramaraoi* (SAMANTA), Lutetian, Sample 241a; (J) *Gypsina marianensis* HANZAWA, Eocene (Priabonian), Sample 95; (K) *Orbitoclypeus* sp., Lutetian, Sample 240a; (L) *Planorbulina* sp., Lutetian, Sample 240b; (M) *Acarinina* cf. *bullbrooki* (BOLLI), Middle Eocene, Sample 65; (N) *Mississippina binkhorsti* (REUSS), Lutetian, Sample 240b. Bar scale 0.2 mm.

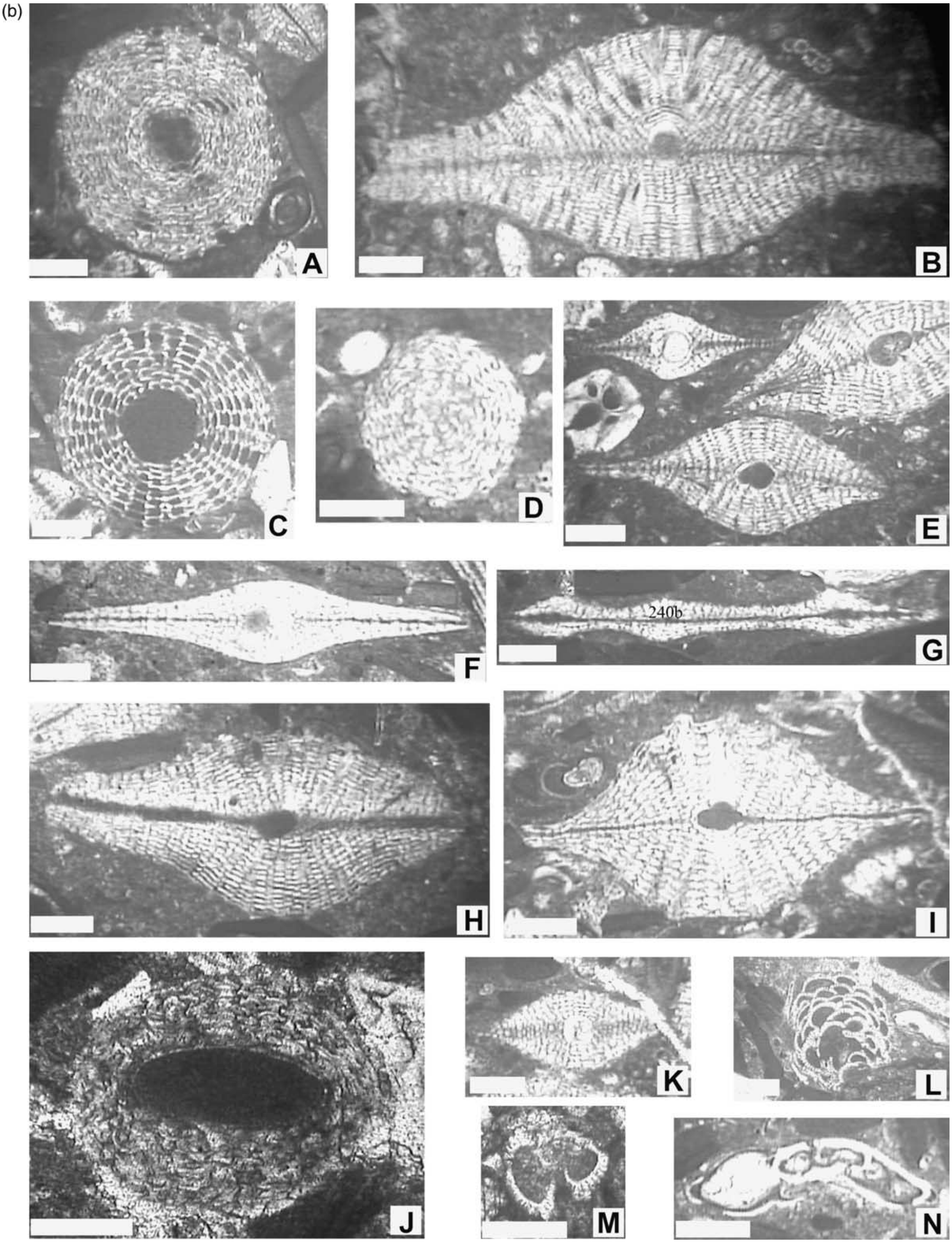

Fig. 21 (*continued*)

the unconformity include angular, to rounded, clasts ($<$ 3 cm in size) composed of marble, andesite, granite and carbonate bioclasts. Thin sections reveal biomicrite with debris of bivalves, calcareous algae, Nummulites, additional benthic foraminifera and echinoderm plates, together with abundant well-rounded grains of marble and scattered grains of basalt (with altered feldspar), reworked planktic foraminifera and rare quartz. These limestone are finally overthrust by the Malatya Metamorphic Unit with a north-dipping contact (Fig. 20(a)).

7.3. Palaeogene sedimentary cover of the Malatya Metamorphic Unit

Further west (near Yazıköy), the Malatya Metamorphic Unit is unconformably overlain by shallow-marine carbonates (Fig. 20(b)) that can be lithologically correlated with the Palaeogene Seske Formation in the Malatya and Elazığ regions (Aksoy et al., 1996). The Palaeogene succession, exposed south of Yazıköy (Fig. 22(a)), begins with pink, thin-bedded micritic limestones. Near the base thin calcarenite interbeds contain small angular marl clasts ($<$ 2 cm in size). The limestone fragments are micritic, within a matrix of pelagic carbonate with scattered planktic foraminifera, iron oxide and dolomite. The succession continues with well-bedded white limestone, alternating with soft-weathering, thinly bedded limestones (in 3–8 m thick intervals) and partly recrystallised, relatively massive limestone (4–9 m thick intervals). In thin section, the fine-grained limestone contains scattered planktic foraminifera

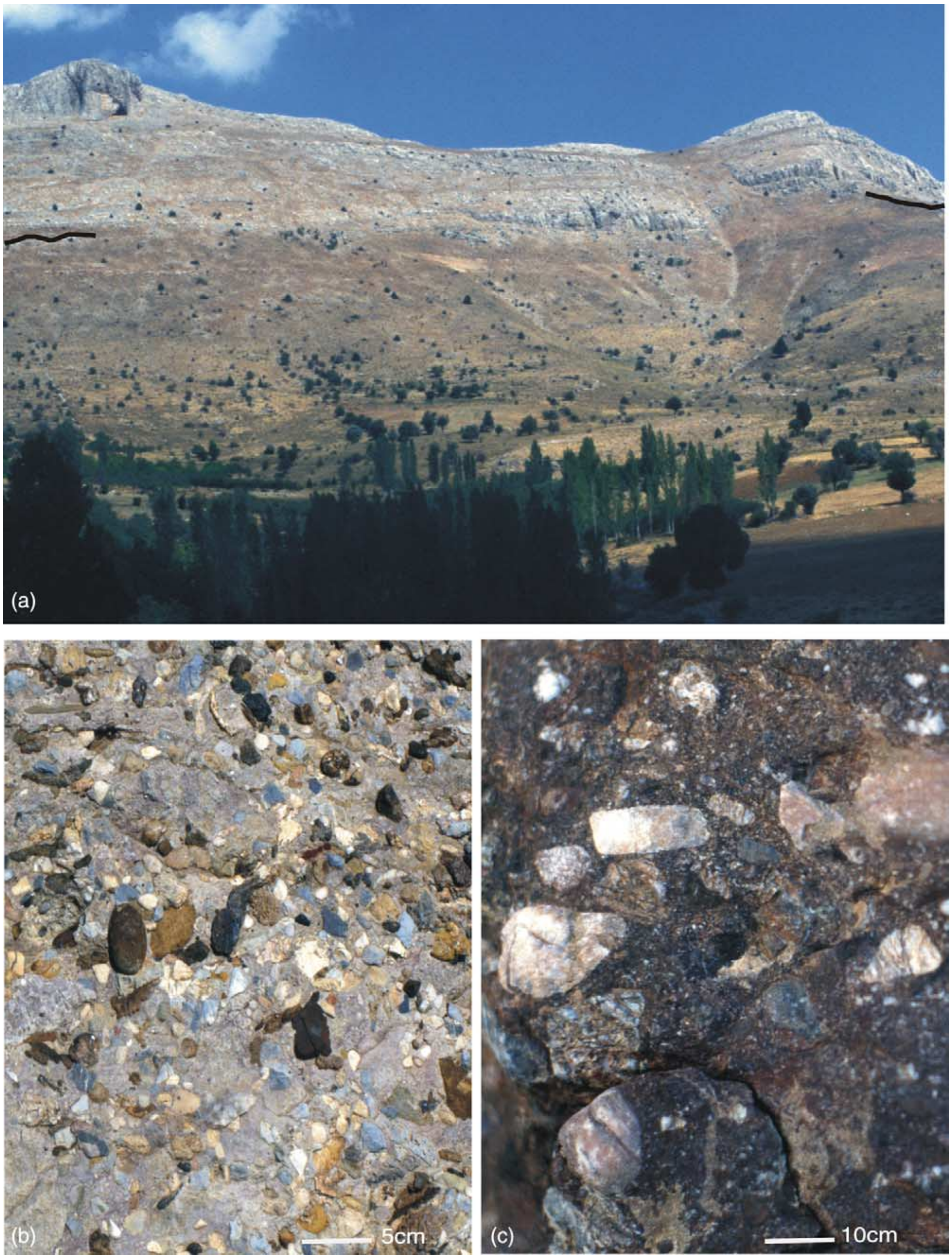

Fig. 22. Field photographs of the Lower Cenozoic cover sediments. (a) Lower-Middle Eocene succession (pale upper unit) unconformably overlying marbles and schists of the Malatya metamorphic unit (dark lower unit); (b) well-rounded detrital clasts within shallow-marine limestone, near the base of the Eocene succession; (c) matrix-supported conglomerate with well-rounded clasts in the upper part of the Eocene succession; (a)–(c) near Yazıköy (see Fig. 20; log b).

in a pelagic carbonate matrix, with only minor terrigenous input. Intercalations of well-sorted quartzose sandstone appear above this. Recessive weathering pinkish alternations contain abundant planktic foraminifera.

There is then a distinct, laterally continuous low-angle unconformity, followed by lenticular pebbly conglomerates with small metamorphic rock pebbles (Fig. 22(b)). Massive nodular limestones above this include lenticular conglomerates with angular, sub-rounded, to locally well-rounded clasts (<3 cm in size), composed of siltstone, quartzite, marble and cross-bedded calcarenite (Fig. 22(c)). Four measurements of transport directions from cross bedding range from WNW to NNW. This unit grades upwards into relatively massive and nodular bioclastic limestone, with stylolites developed around the margins of carbonate concretions. Thin sections reveal intact large foraminifera cemented by microspar, together with rare detrital grains of quartz, marble and altered basalt. During this study an Early-Middle Eocene age was determined for the Nummulitic limestones at this level in the succession (Samples 20–22—Appendix A). Pink flaggy limestones crop out above this to the crest of a ridge. The overall succession is deformed into a broad open syncline (footwall syncline), beneath a N-dipping thrust sheet of Malatya metamorphic rocks (Fig. 11(a)).

7.4. Interpretation of Upper Cretaceous–Lower Cenozoic cover

The latest Cretaceous clastic sediments that unconformably overlie the Malatya Metamorphic Unit accumulated in a tectonically active setting soon after regional metamorphism and exhumation of the Malatya platform. The presence of metamorphic detritus shows that the metamorphosed Malatya platform was exhumed and subaerially exposed as early as latest Cretaceous time.

The Late Cretaceous (Campanian–Maastrichtian) cover of the Berit Ophiolite (North), which is only very locally preserved (Fig. 20(a)), indicates shallowing and emergence soon after tectonic juxtaposition of the Berit Ophiolite with the Malatya Metamorphic Unit, but without any associated strong deformation, metamorphism, or deep erosion (Fig. 23). Initial shallow-water, mainly carbonate, deposition was followed by slight deepening and accumulation in an open-marine shelf setting, subject to continuing input of clastic sediment of both metamorphic and ophiolitic provenance. Water depths were then sufficient to allow hemipelagic deposition with minimal clastic input (i.e. several hundred metres). The interbedded coarser Nummulitic carbonates, as also seen above the Malatya Metamorphic Unit in the area (Fig. 20(b)), were introduced from neighbouring shallower water areas, perhaps related to storm activity (Fig. 2). Conditions became quieter and more uniform with time. Following tilting, resulting in a low-angle unconformity, higher energy shallow-water deposition ensued during the Eocene. Increased terrigenous clastic input above this unconformity could record tectonic rejuvenation of the source area in response to a regional extensional event related to rifting of the Maden basin (see Section 12.4).

The subsequent southward thrusting that affected the Malatya Unit and its Early Cenozoic cover is seen as relating to suturing of the Southern Neotethys during Oligo-Miocene time.

8. Eocene Maden Group cover

The Berit Ophiolite (South) is unconformably overlain by Eocene Nummulitic carbonates, interbedded with volcanic rocks in some areas. This unit was termed the Maden Complex (2–250 m thick) by Perinçek and Kozlu (1984) based on a comparison with the type area, c.120 km to the east (e.g. north of the Pütürge Massif; Fig. 2), where there are much thicker and more varied exposures (e.g. Yazgan and Chessex, 1991; Robertson et al., under review). An intact stratigraphical succession is present in the area studied and, therefore, we prefer the term Maden Group, rather than Maden Complex, which is more appropriate for a structurally dismembered unit.

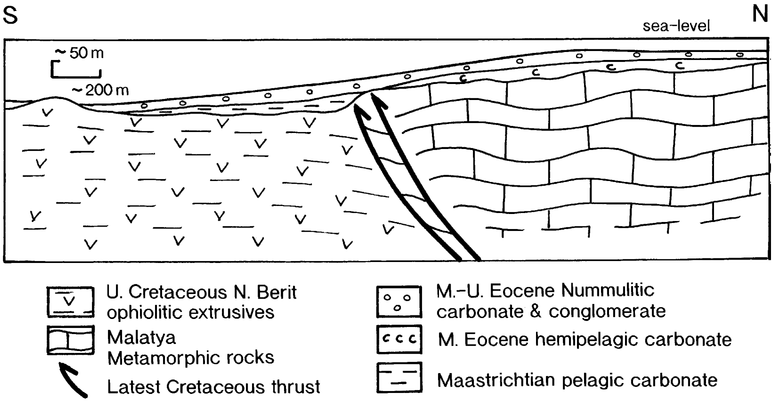

Fig. 23. Restored setting of the part of the Tauride margin after latest Cretaceous suturing of the Berit Ophiolite (North) and the Malatya Metamorphic Unit. Note the inferred Early Cenozoic transgressive cover.

The Maden Group is well exposed high on Berit Mountain and around its western periphery. Similar, but more sheared and recrystallised lithologies are exposed in the Uludere window (Fig. 3). Additional exposures occur widely to the east of the area studied, around Nurhak and south of Doğanşehir (Perinçek and Kozlu, 1984).

Limestones near the base of the succession, exposed to the west of Berit Mountain (near Sülüklügöl, Fig. 3), were assigned a Early Eocene (Ilerdian–Cuisian) age mainly based on Nummulites species present (Samples 82a–c and e, 83—Appendix A) (Fig. 21(a)). Nummulitic limestones interbedded with ophiolite-derived clastic sediment in the southwest of the area (Sülüklügöl road–Kahramanmaraş road) were dated as Middle to Late Eocene in age (Sample 95—Appendix A).

In general, the Maden Group begins with basal conglomerates and limestones rich in Nummulites, passing upwards into reddish and greenish pelagic limestones and shales, commonly with limestone clasts or blocks (Fig. 5). Green to purple extrusive rocks follow in some sections. Perinçek and Kozlu (1984) distinguished a facies variant in the southwest as a specific formation (Ballıkısık Formation); this is dominated by redeposited ophiolite-derived sediments, Nummulites-bearing limestones and clastic sediments, but without in situ volcanics. Exposures of the Maden Group (Fig. 24) show considerable facies variation, as summarised below.

8.1. Volcanogenic successions

In the southeast of the Uludere window (Fig. 3), schists of the Berit Sedimentary-Volcanic Unit are unconformably overlain by dark siliceous limestone (4–5 m thick), with lenses of dark chert of replacement origin (Fig. 24(b)). These sediments are overlain by reddish calcareous shale (c.4 m thick), then by intermediate-silicic volcanics (up to 60 m thick). Partly recrystallised planktic foraminiferal limestones include densely packed, redeposited foraminifera (including rare miliolines) and minor detrital quartz. The succession can be traced southwards (towards Engizek village), where it is deformed into south-facing, outcrop-scale folds. In the northeast part of the window (near Demirlik) an angular discordance (c.30–40°) is seen between the underlying Berit Sedimentary-Volcanic Unit and the Maden Group. Basal volcaniclastic sandstones there contain scattered small (< 5 cm) limestone clasts. Thin sections reveal sub-rounded grains of basalt, andesite, diabase, radiolarite, polycrystalline quartz, augite (originally phenocrysts), altered volcanic glass and rhyolite in a fine-grained, ferruginous matrix. Rhyolitic crystal tuffs include reworked feldspar and quartz phenocrysts in a fine siliceous matrix. This unit is overlain by greenish, to brownish, intermediate-siliceous lavas exhibiting keratophyric alteration. The succession then passes into medium-bedded volcaniclastic sandstones, shales, volcaniclastic debris flows (with volcanic clasts up to 0.2 m in size) and andesite. The volcaniclastic sandstones are dominated by sub-rounded, to rounded, quartz grains in a calcareous matrix.

Further west, in the Sülüklügöl area (Fig. 24(b)), the Berit Sedimentary-Volcanic Unit is overlain, with an irregular erosional unconformity, by locally variable successions of brownish-red bioclastic limestone, passing upwards into black foraminiferal limestones. These limestones are packed with well-preserved, intact Nummulites, additional large foraminifera (e.g. miliolines), and rare planktonic foraminifera, in a fine-grained ferruginous and calcareous matrix. A pebbly debris flow unit (4 m thick) follows, with well-rounded clasts of limestone, serpentinite,

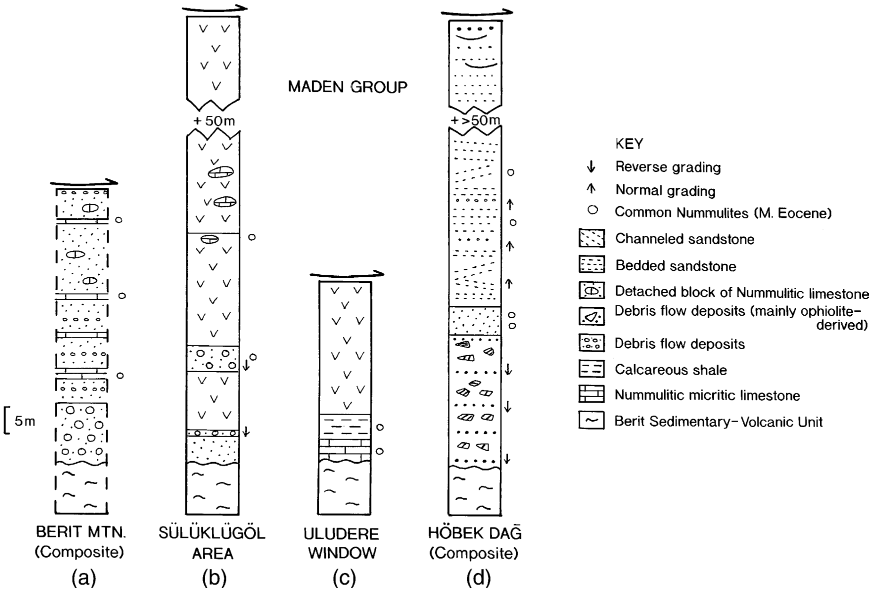

Fig. 24. Sedimentary logs of the Middle Eocene Maden Group. See text for explanation. See Fig. 3 for locations.

gabbro, chert and marble (up to 6 cm in diameter). The succession passes into pale, altered silicic lavas and then, after a short break, into andesitic lavas, up to several tens of metres thick, with thin micritic limestone intercalations. The silicic extrusive rocks are strongly altered, and contain plagioclase phenocrysts (strongly zoned) and microphenocrysts set in a quartz-bearing mesostasis. Associated volcaniclastic sandstones contain quartz and plagioclase phenocrysts (altered) rhyolite, quartz (former phenocrysts), and are interpreted as reworked silicic extrusive rocks. Perinçek and Kozlu (1984) mention the occurrence of additional intercalations of sandy and pebbly limestone with derived clasts of Nummulitic limestone and andesite in this area.

Non-evolved, basic extrusive rocks, suitable for chemical tectonic discrimination are rare. However, five suitable samples were analysed (Fig. 25). On the Zr/Y vs. Zr diagram (Pearce, 1980) (Fig. 25a), the samples plot in the IAT field. In the Ti/100 vs. Zr vs. Y.3 ternary diagram (Pearce and Cann, 1973) (Fig. 25(b)) four plot in the CAB field and one in the IAT+MORB field. On the V/Ti diagram (Shervais, 1982) the samples plot in the MORB + BABB field (Fig. 25(c)). On MORB-normalised multi-element spidergrams (Fig. 25(d)), large ion lithophile (LIL) elements are enriched: from Sr to Zr all elements are enriched relative to MORB, whereas Ti, Y, Sc and Cr are depleted. The samples show a distinctive Nb depletion relative to Ce; also, depletion in Ti relative to Zr and Y.

8.2. Non-volcanogenic successions

In the west (along the road southeast of Sülüklügöl towards Tanır), the Berit Sedimentary-Volcanic unit is unconformably overlain by a laterally discontinuous unit, correlated with the Ballıkısık Formation; this begins with serpentinite-derived conglomerates, up to 10 m thick. Overlying this, relatively steeply dipping (up to 45°) pebbly debris flows (individually up to 10 m thick), contain angular, to rounded, clasts including serpentinite, red chert, psammite, marble and limestone (< 1 m in size), set in a soft-weathering (unmetamorphosed), argillaceous matrix. A discrete intercalation of nearly monomict

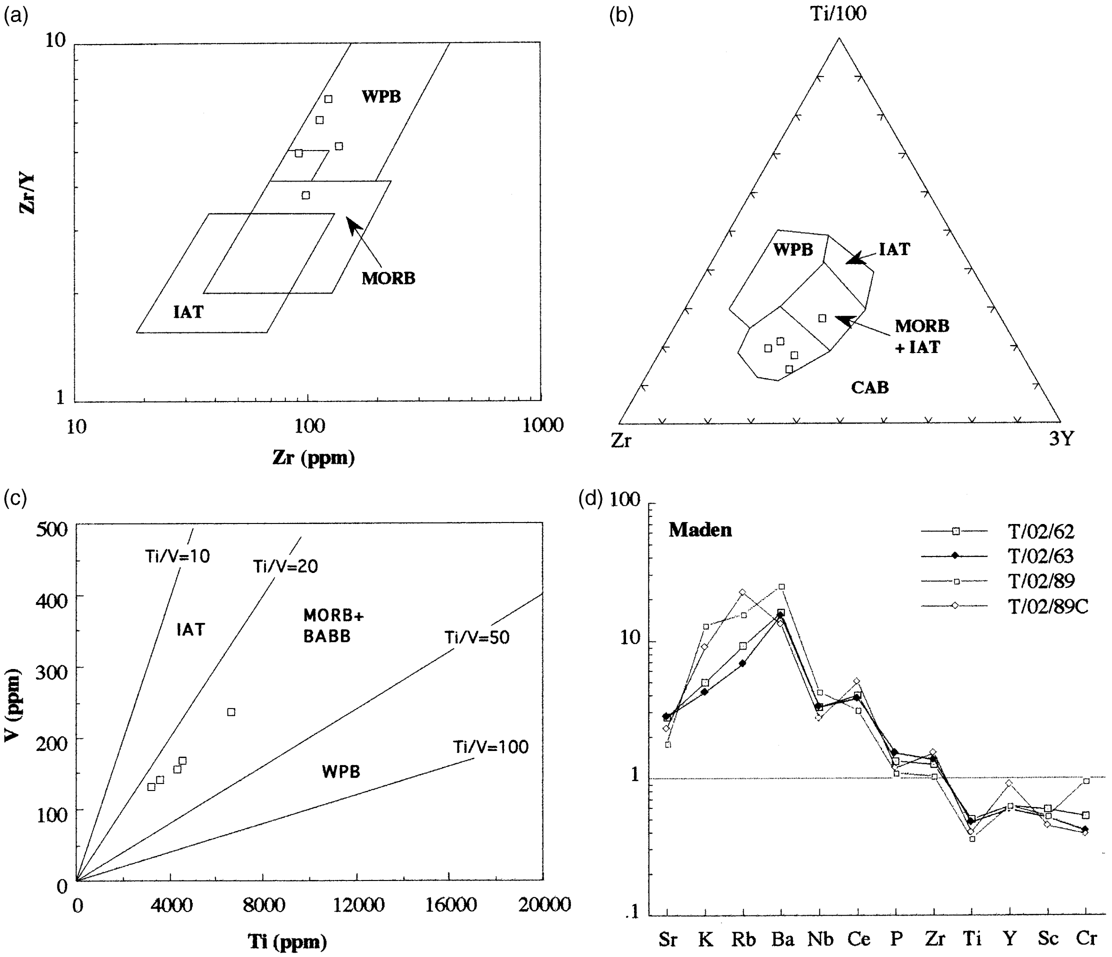

Fig. 25. Geochemical plots and inferred tectonic setting of extrusive rocks from the Middle Eocene Maden Group. (a) Zr/Y vs. Zr; (b) Ti/1000 vs. Zr vs. 3Y; (c) V vs. Ti; (d) MORB-normalised spider plot. See text for explanation.

serpentinite conglomerate (up to 2.5 m thick) contains well-rounded pebbles of serpentinite (up to 0.2 m in size). Higher levels include debris flows with blocks of Nummulitic limestone, serpentinite and polymict sandstone.

Similar, but thicker, facies (also correlated with the Ballıkısık Formation), reappear further south (approachable only from the SW). Where examined (SE of Höbek Dağ), sheared ophiolitic rocks are overlain by polymict ophiolite-derived debris-flow deposits, up to tens of metres thick (Fig. 24(d)). These sediments are depositionally overlain by relatively well-stratified Nummulites-rich terrigenous debrites and high-density turbidites. The debrites (c.10 m thick) include well-rounded limestone clasts, mainly nummulitic limestone, ophiolite and chert. In thin section, Nummulites are set in a micritic matrix, with grains of basalt, pelagic micrite, crystalline limestone, pelletal limestone, shells, microbial carbonate, miliolinids and radiolarian chert. Extrusive rock grains range from basalt, to lava (with biotite phenocrysts) and felsitic lavas (rhyolite). The nummulitic limestones pass upwards into coarse, thick-bedded sandstones and subordinate lenticular conglomerates and mudstones, up to ca.100 m thick. These sediments contain abundant metamorphic detritus, limestone, marble, pelagic carbonate, radiolarite, quartz, quartzite, rare basalt and sandstone clasts, chert, coral and oncolites. In addition, rare thick-bedded calcarenites (in units up to 8 m thick) are mainly composed of shell fragments, echinoderm debris, gastropods, micrite, miliolinids and large shells. Large foraminifera of Lutetian (Middle Eocene) age are present (Robertson et al., 2004). Limestone clasts within the debris flows include oolitic limestone, also minor echinoderm and shell debris.

According to Perinçek and Kozlu (1984) exposures high on Berit Mountain (Fig. 24(a); not accessible during this work) begin with conglomerates, passing upwards into what we infer to be debris-flow deposits (olistostromes), with clasts and blocks of serpentinite, pelagic limestone, radiolarite and recrystallised limestone. The succession includes sandstone, pebbly sandstone and pebbly limestone of Middle Eocene age.

8.3. Interpretation of the Eocene Maden Group

The Maden Group began to accumulate during Early–Middle Eocene time after exhumation and partial erosion of the underlying Berit Sedimentary-Volcanic Unit. The Maden Group records variable deposition and volcanism in a setting that ranged from marginal-marine to open-marine with hemipelagic carbonate accumulation. The presence of locally coarse clastic sediments, including turbidity current and mass-flow deposits indicates the existence of a topographically pronounced basin, induced by contemporaneous extensional faulting (Fig. 26; see also Section 12.4).

The Uludere window section (Area 1) records a relatively deep basinal setting with hemipelagic carbonates rich in diagenetic silica, overlain by andesitic extrusive rocks, with coarse detrital intercalations. Elsewhere (Sülüklügöl area; Area 2), the basal clastic sediments were mainly derived from unmetamorphosed ophiolite-related rocks including abundant red radiolarian chert, for which no local source is exposed. However, this can be assumed to be accreted Neotethyan oceanic crust and related pelagic sediments, possibly then exposed to the south. Deepening and andesitic volcanism ensued in this area, bordered by a marginal carbonate shelf, or highs, on which Nummulitic carbonates accumulated. This was followed by reworking of lithified clasts and blocks into the basin. The southerly

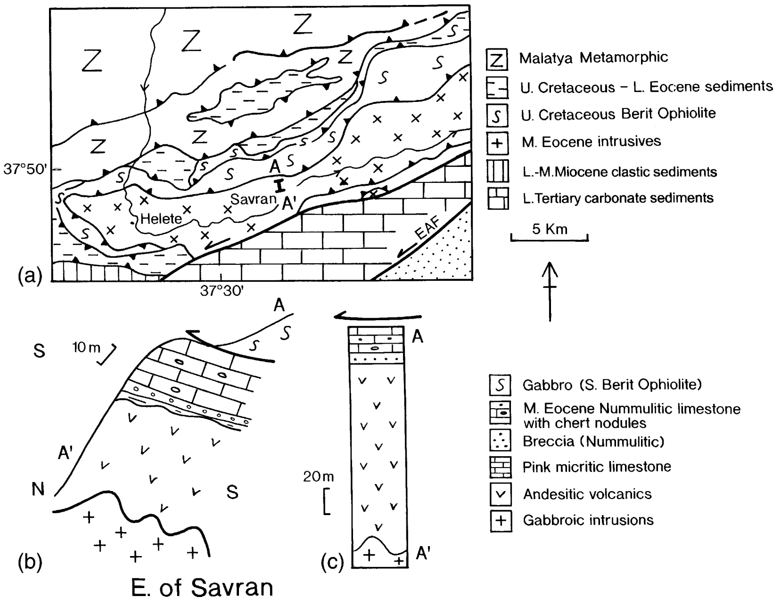

Fig. 26. Inferred setting of the Maden Group as a volcanically active extensional basin overlying units accreted in latest Cretaceous time. A supra-subduction situation is inferred from the regional tectonic setting.

locality (Höbek Dağ) records initial reworking of ophiolite-related lithologies, followed by accumulation in a proximal slope setting, characterised by coarse terrigenous and calcareous sediments (including Nummulites). Overall, a more marginal setting is recorded in the most southerly section (Höbek Dağ) compared to deeper water carbonates and volcanics further north.

The basalt chemistry suggests a within-plate influence, compatible with a rift setting. However, there is also a subduction influence, which was either contemporaneous, or could reflect crustal contamination related to the earlier (Late Cretaceous) subduction event.

9. Frontal imbricate thrust zone

A zone of imbricate thrusting characterises the southern front of the allochthon, beneath which are Miocene sediments of the Arabian foreland (Yılmaz et al., 1993; Derman et al., 1996). In the transect studied, dips of the imbricate thrust zone are variable, to steep, reflecting large-scale folding sub-parallel to the trend of the thrust belt; this took place during Late Miocene time after final emplacement of the Tauride allochthon. The frontal zone is locally truncated by the left-lateral neotectonic East Anatolian transform fault. The frontal area is also extensively mantled by Quaternary-Recent screes and affected by recent landslipping especially west of the Ceyhan River.

Within the main Berit area studied, the Imbricate Thrust Zone includes discontinuous thrust slices of serpentinite and pillow lava, best exposed to the east of the Ceyhan River gorge (Meydan ophiolite of Yılmaz et al., 1993; Helete Complex of Kozlu, 1997). Further east, Yılmaz et al. (1993) mention occurrences of ophiolitic melange (Dikenli Complex) and deep-sea sediments (Harami Formation), of inferred Late Cretaceous–Early Eocene age.

During this work, we observed that, directly east of the Ceyhan River gorge, north-dipping sheared Miocene mudstones of the underlying foreland succession are overlain by a slice of sheared pillow lava (c.100 m thick), in turn, structurally overlain by marbles correlated with the Malatya Metamorphic Unit (although the contact is largely concealed by landslipping). Just west of the Ceyhan River, units of undated dismembered plutonic rocks (e.g. serpentinite) and mafic extrusive rocks are exposed. We assume these units record a dismembered ophiolite, which remains undated in this area.

9.1. Eocene volcanic-sedimentary unit

An additional, better-exposed area was studied, c.90 km further east, to the northwest of Gölbaşı (from the villages of Helete to Savran; Fig. 27). In this area, the Göksu River runs sub-parallel to the mountain front for c.10 km, guided by lineaments associated with the East Anatolian Transform Fault, and as a result an excellent section is exposed.

In this area, Yıldırım and Yılmaz (1996) reported an imbricate stack of gently north-dipping thrust sheets. These are from the structural top downwards: (1) The Malatya Metamorphic Unit; (2) Late Cretaceous-Eocene, mixed carbonate-clastic deep-water sediments (Harami Formation); (3) Ophiolitic plutonic rocks (Maydan ophiolite), including microgabbros; (4) Eocene volcanic–sedimentary complex, including volcanic rocks and thrust imbricated olistostromes, with blocks of ophiolitic rocks and Nummulitic limestones (Fig. 27). Eocene, mainly volcanic rocks (Helete Formation) were reported to grade eastwards into olistostromes (Savran Formation). In addition, some geochemical evidence for the Helete volcanics, indicative

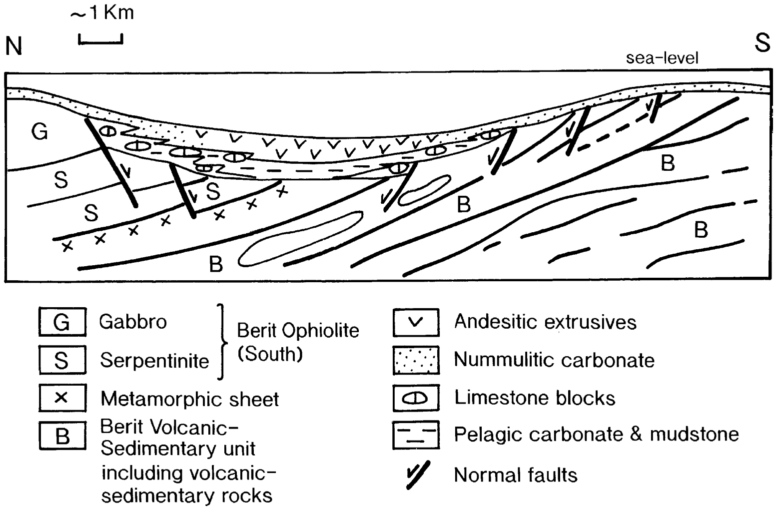

Fig. 27. Setting of Middle Eocene volcanic-sedimentary rocks within the Frontal Imbricate Thrust Zone, near Gölbaşı, east of the main area studied. (a) Geological map; (b) cross-section; (c) measured log. See Fig. 2 for location.

of a calc-alkaline/tholeiitic composition, was reported by Yiğitbaş and Yılmaz (1996a), and discussed by Elmas and Yılmaz (2003). These authors interpreted the Helete volcanics as a Mid-to Late Eocene oceanic island arc.

We confirmed the presence of thrust sheets numbers 1–3 but we interpret 4 differently. Thrust sheet 4 is dominated by a single stratigraphically intact succession of andesitic volcanic rocks, depositionally overlain by Nummulitic limestones (Fig. 27). We redefine this succession as the Helete Formation. The Savran Formation is redundant, as it is composed of landslipped tectonic slices of the Helete Formation. In agreement, Kozlu (1997) includes the Savran Formation within his Helete Complex, although we prefer the term Helete Formation, as this was originally an intact stratigraphical unit rather than mélange (Fig. 27). We date the typical pink limestone of our redefined Helete Formation as Eocene, based on benthic and planktic foraminifera (Samples 239a and b—Appendix A). In addition, grey limestone clasts from a basal breccia unit just above volcanic rocks yielded Middle Eocene (Lutetian) ages (Samples 240a and b; 242a and b—Appendix A) (Fig. 21(a) and (b))

The Helete Formation is dominated by brown, green and purple massive andesite, with coarser feldspar-phyric intervals (up to several metres thick). In places, traces of hydrothermal sulphide mineralisation are present, with tiny gossans. The volcanic rocks are cut by localised felsic intrusions forming small, dyke-like bodies, ranging from a narrow vein (5 cm wide), to units several metres wide (c.1 km east of Savran). The margins of the felsic rocks are locally sheared, reflecting a competency contrast between the felsic intrusions and the soft-weathering host andesite.

Andesitic extrusive rocks, c.3 km east of Savran, are overlain, with a clearly depositional contact, by pink micritic limestone (up to 4 m thick) containing *Nummulites* sp. (Fig. 27). This is followed by a thin breccia horizon rich in andesite clasts (up to 8 cm in size). An additional 10 m of Nummulitic limestone, with cherty intervals, occurs above this. Over a distance of several hundreds metres, laterally, these limestones are truncated by an overlying ophiolitic thrust sheet. Small thrust slices of similar limestone (affected by landslipping), are exposed for several kilometres on strike eastwards, giving the impression of blocks in a mélange (olistostromal unit of Yıldırım and Yılmaz, 1991).

The Helete Formation is locally underlain by gabbroic rocks, with a contact that ranges from a thrust to intrusive in places. The contact of the intrusive rocks is highly irregular and locally shows undeformed chilled margins against extrusive rocks of the Helete Formation. In thin section, the variably altered intrusive rocks are mainly composed of plagioclase, olivine, altered clinopyroxene and opaque minerals. We interpret these gabbroic rocks as intrusions into the Eocene volcanic rocks.

The Helete Formation and related intrusions are structurally underlain by debris flows (wildflysch) of Late Eocene–Oligocene age (Yıldırım and Yılmaz, 1991); these are in turn underlain by Cenozoic sediments (Midyat Group) related to the Arabian foreland (Fig. 27). In the south the Tauride allochthon is truncated and offset by the East Anatolian Transform Fault Zone (Fig. 27).

Nine samples of the Helete Formation volcanic rocks were chemically analysed (Table 1). Of these one is acidic, while the remainder are basic (48–57%), suitable for tectonic discrimination (Fig. 28). Seven samples with $<$ 2% loss on ignition (LOI) are relatively unaltered. The low K_2O content (0.26%) indicates a tholeiitic composition. Al_2O_3 contents (at similar SiO_2 values) range from 14 to 18%. Compared to the lavas of the Maden Group, discussed previously, the Helete volcanic rocks exhibit lower Nb/Y contents. Several samples can be classified as high-aluminum lavas. On the Zr/Y vs. Zr diagram (Pearce, 1980) the basalts plot in the IAT and MORB fields (Fig. 28(a)). On the 2Nb vs. Zr/4 vs. Y diagram (Meschede, 1986) the basalts plot in the N-MORB field (Fig. 28b); on the V vs. Ti diagram (Shervais, 1982) they mainly plot in the MORB + BABB field (Fig. 28(c)). On MORB-normalised multi-element spidergrams (Fig. 28(d)) there is a marked Nb depletion relative to Ce: from Ce to Sc, all the elements are close to MORB, but Cr is generally depleted. The most primitive sample is highly depleted relative to MORB in all elements except Sc and exhibits a marked Nb depletion.

9.2. Interpretation of the Middle Eocene Helete volcanic-sedimentary unit

The Helete Formation is interpreted as basic-silicic extrusive igneous rocks cut by contemporaneous intrusive rocks and overlain by open-marine Nummulitic carbonate sediments (Fig. 29). Clastic material was derived from the subjacent volcanic succession, without supply of e.g. ophiolitic material from the Berit Ophiolite, or metamorphic detritus from the Malatya Metamorphic Unit. The geochemical evidence is suggestive of an origin as relatively primitive volcanic arc tholeiites, possibly with back-arc basin chemical affinities. The well-developed negative Nb anomaly relative to MORB is indicative of a subduction influence. This was probably contemporaneous, but the presence of a subduction signal inherited from (Late Cretaceous) subduction-related events cannot be ruled out.

The Helete volcanic-Šedimentary unit was previously interpreted as a Middle–Late Eocene oceanic island arc, constructed on a basement of oceanic crust to the south of the Tauride active continental margin during the later stages of northward subduction of the Southern Neotethys ocean (Yıldırım and Yılmaz, 1991; Yılmaz, 1993; Yılmaz et al., 1993; Yiğitbaş and Yılmaz, 1996a; Elmas and Yılmaz, 2003). However, this interpretation is open to question for several reasons. First, the Helete volcanics are preserved as a thrust slice with no exposed basement. This basement in reality could have been oceanic crust, an accretionary complex, or even continental margin material similar to the Berit Sedimentary-Volcanic Unit. Secondly, the Helete unit

Table 1
Selected geochemical analyses of extrusive rocks from the transect studied; 1 to 4 from the Binboğa Mélange; 4 to 5 from the Maden Complex; 6 to 12 from the Berit Volcanic-sedimentary Unit; 13 to 15 from the Middle Eocene Helete Unit (frontal imbricate zone)

	1 T/02/45	2 T/02/46	3 T/02/47	4 T/02/62	5 T/02/63	6 T/02/79	7 T/02/70	8 T/02/72	9 T/02/73	10 T/02/98E	11 T/02/99A	12 T/02/99B	13 T/02/223	14 T/02/231	15 T/02/238
SiO_2	64.88	62.77	53.04	56.71	57.63	50.40	46.72	47.46	48.35	66.35	50.07	52.27	51.31	51.80	50.38
TiO_2	0.44	0.47	0.89	0.76	0.72	1.11	1.25	2.68	2.06	0.70	1.45	0.95	1.55	1.50	0.79
MnO	0.12	0.14	0.27	0.12	0.11	0.70	0.38	0.68	0.22	0.10	0.18	0.20	0.23	0.19	0.14
Al_2O_3	10.65	11.13	14.61	16.62	16.48	16.26	15.86	14.04	15.46	14.57	15.18	17.83	13.64	13.74	17.27
Fe_2O_3	6.31	6.83	11.13		5.45	9.83	10.07	15.71	13.49	6.19	11.79	9.46	10.92	12.35	7.25
MgO	4.85	5.02	6.13	4.76	5.02	7.72	8.18	3.57	7.14	2.81	6.96	6.21	3.69	5.78	6.58
CaO	4.54	4.88	4.84	4.80	4.62	7.03	8.84	7.13	5.60	1.65	7.72	3.31	9.23	7.30	11.74
Na_2O	4.27	4.42	5.15	5.34	5.21	4.84	3.65	2.52	4.06	3.46	4.34	5.98	4.33	4.65	3.30
K_2O	0.03	0.02	0.11	0.76	0.63	0.15	2.00	4.76	2.41	1.65	0.14	0.56	0.14	0.15	0.06
P_2O_5	0.04	0.04	0.07	0.16	0.18	0.22	0.13	0.33	0.23	0.19	0.14	0.12	0.13	0.10	0.04
LOI	4.15	4.57	3.64	4.12	3.99	1.16	2.90	0.62	1.24	2.09	2.31	3.21	4.95	2.66	2.69
Total	100.27	100.29	99.88	99.84	100.03	99.41	99.98	99.49	100.25	99.77	100.28	100.1	100.12	100.22	100.24
La	4	5	2	22	22	10	4	10	9	30	5	6	3	3	2
Ce	7	8	5	40	38	25	10	26	20	59	12	12	12	11	3
Nd	4	4	4	17	16	13	6	13	13	27	10	10	11	10	5
Nb	1	1	1	12	12	6	6	24	10	11	4	2	1	1	0
Zr	23	24	45	114	122	99	82	249	123	182	95	72	87	77	27
Y	11	13	23	19	18	26	23	55	35	32	37	22	34	35	17
Sr	92	90	131	332	339	185	286	160	242	168	83	123	164	135	211
Rb	0	0	1	19	14	2	49	107	46	62	1	7	2	1	1
Zn	52	59	86	55	53	991	182	41	183	87	99	103	84	59	44
Cu	27	50	275	28	29	9	10	8	7	23	73	43	53	12	56
Ni	70	71	34	42	36	89	130	37	108	40	47	43	15	37	56
Cr	164	172	33	132	102	336	162	25	189	107	62	158	9	61	191
V	205	226	326	168	156	238	196	402	297	127	323	302	403	362	243
Ba	33	38	18	323	304	49	499	1527	501	442	37	111	32	24	15
Sc	34	36	43	24	21	40	37	46	42	20	39	38	34	45	41

Analyses carried out by the X-ray Fluorescence technique at the Grant Institute of Earth Science, University of Edinburgh, as specified by Fitton et al. (1998). MORB values used (Pearce, 1980) Sr 120 ppm; K_2O 0.15%; Rb 2 ppm; Ba 20 ppm; Nb 3.5 ppm; Ce 10 ppm; P_2O_5 0.12%; Zr 90 ppm; TiO_2 1.5%; Y 30 ppm; Sc 40 ppm; Cr 250 ppm.

is thin (several hundred metres or less), relative to oceanic volcanic arc units, which are typically kilometres thick. Thirdly, the Helete unit is relatively unmetamorphosed and relatively undeformed (similar to the Maden Group), which is surprising if this unit was accreted from the down-doing oceanic plate. Fourthly, contrasting volcanics of the same age (Mid-Eocene) are exposed in a similar structural position c.200 km further east, in the Dıyarbakır region. In this area (Karadere area; near Lice), the volcanics are of chemically enriched type and include high-Ti and high-Al types (Aktaş and Robertson, 1984, 1990). Rather that recording an island arc, the Eocene volcanics in this area (Karadere Formation) were interpreted as a short-lived transtensional basin that opened during the later stages of subduction of the Southern Neotethys (Aktaş and Robertson, 1990).

We propose that the Helete Formation and the Maden Group formed coevally as parts of the over-riding Tauride plate, in response to regional extension that affected the Tauride margin during the later stages of northward subduction of the Southern Neotethys ocean. The extension was possibly related to roll-back of the oceanic plate during Eocene time (see Section 12.4). The subduction was probably oblique (Aktaş and Robertson, 1990; Elmas and Yılmaz, 2003), resulting in laterally variable volcanism in an active margin setting. The Maden volcanism formed in a relatively northerly back-arc setting within the hinterland of the Tauride active margin. In addition, the Helete volcanics were erupted further south along the southern distal edge of the Tauride active margin, possibly overlying previously accreted material. Such arc-type volcanic centres were interspersed with other areas along strike where alkaline volcanics were extruded in transtensional basins. Consistent with this interpretation, additional, somewhat younger, Eocene–Oligocene calc-alkaline volcanics (Gövelek volcanics) further east, in the Lake Van area, are reported to overlie the Eocene Maden Group (above the Bitlis metamorphic massif), and also accretionary mélange, rather than representing island arc volcanism founded on oceanic crust (Elmas and Yılmaz, 2003).

After the Eocene, the Helete–Maden supra-subduction zone basin collapsed and was then emplaced over the Arabian margin, near the base of the Tauride allochthon. There is abundant evidence from within the frontal imbricates of southward displacement, including large-scale thrusts, outcrop-scale duplexes, south-verging folds and small-scale C–S fabrics.

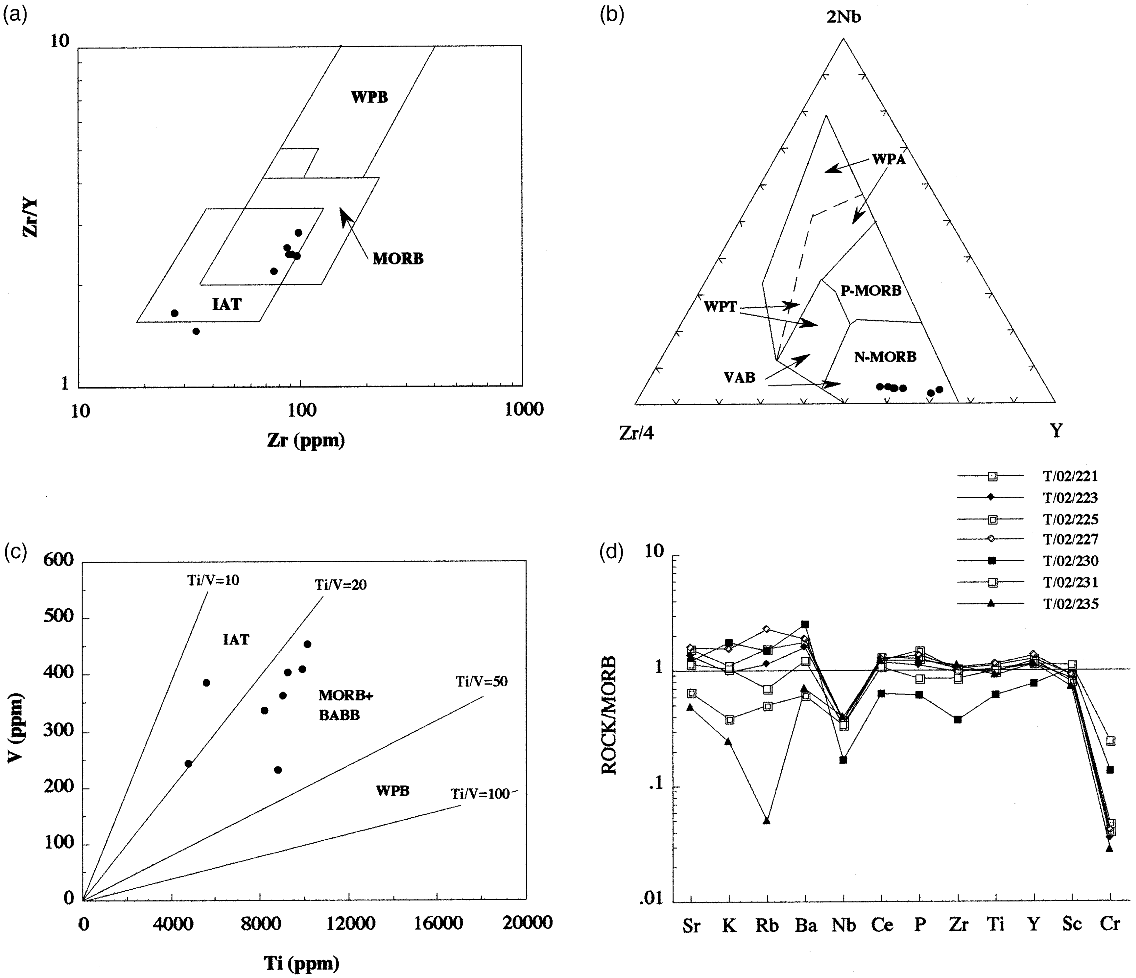

Fig. 28. Geochemical plots and inferred tectonic setting of extrusive rocks from the Middle Eocene Helete Formation near the thrust front in the eastern area studied. (a) Zr/Y vs. Zr; (b) 2Bb vs. Zr/4 vs. Y; (c) V vs. Ti; (d) MORB-normalised spider plot. See text for explanation.

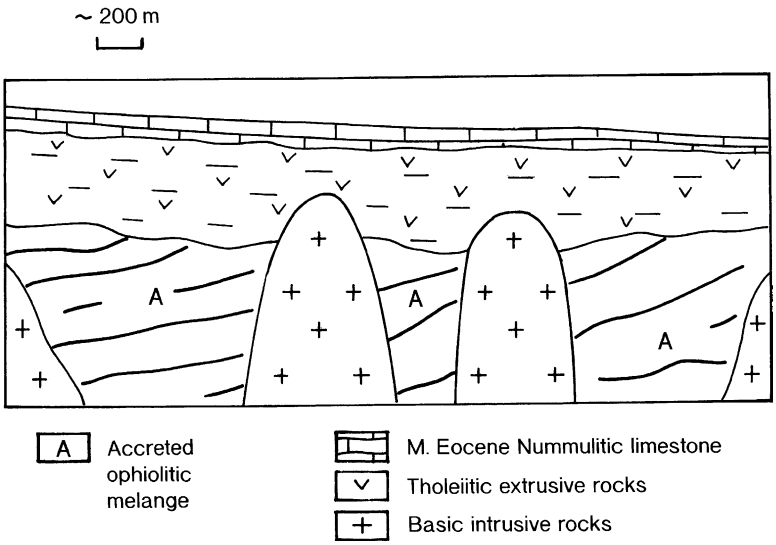

Fig. 29. Restored local setting of the Middle Eocene volcanic and sediments within the Frontal Imbricate Thrust Zone, near Gölbaşı (Fig. 27). The volcanic rocks are cut by mafic intrusions with chilled margins. The Eocene unit was possibly constructed on previously accreted material along the distal edge of the Tauride convergent margin.

10. Engizek mélange

The Engizek Mélange forms a discrete unit that is exposed along the front of the Tauride allochthon. Good outcrops are, for example, present along on both flanks of the Ceyhan River gorge (Robertson et al., 2004) (Figs. 3 and 4). The melange is mapped, in different areas, as overlying the Berit Sedimentary-Volcanic Unit, the Eocene Maden Group, and the Berit Ophiolite (South) (Perinçek and Kozlu, 1984), and can be seen as mantling the thrust front on a regional basis. In general, the lower levels of the mélange locally include blocks of schist, quartzite, amphibolite, marble and mica schist, whereas the higher levels are dominated by blocks of shallow-water carbonates.

The structurally higher levels of the Engizek Mélange are well exposed on the upper, eastern side of Ceyhan gorge (below the Ilıca-Engizek road (Robertson et al., 2004). The mélange there is dominated by north-dipping blocks and slabs of Mesozoic limestone (Andırın Limestone), set in an unmetamorphosed sedimentary matrix. Most of the limestone blocks are internally brecciated, but the cores of some large blocks are less disrupted. The mélange includes large disrupted slump folds with fold limbs up to tens of metres in size, as seen along the sub-vertical western side of Ceyhan gorge (again below the Ilıca-Engizek road).

Further northwest (SE of Höbek Dag), the mélange (ca. 200 m thick) overlies the Middle Eocene Maden Group and is, in turn, transgressed by Mid-Late Miocene shallow-marine clastic sediments. The mélange in this area includes well-stratified debris flows and high-density turbidites. Limestone blocks include oolitic limestone, with echinoderm and shell debris.

Further northwest again (towards the Delihöbek Fault, near Kapıkaya; see Robertson et al., 2004 for locality details), the mélange is dominated by pale brecciated crystalline limestone set in a matrix, mainly composed of debris-flow deposits, including clasts of well-bedded dark (locally folded) coralline limestone (up to 1 m in size), vesicular lava, limestone breccia and red chert. There are also interbeds of medium-bedded turbidity current deposits.

Equivalents of the Engizek Mélange are also known further east, including the Gölbaşı area, where the thrust front is reported to be mantled by a predominantly clastic unit of Late Oligocene–Early Miocene age that includes olistostromes and detached blocks (Alacık Formation of Erdoğan, 1975). The Engizek Mélange can also be viewed as a regional equivalent of the extensive Misis–Andırın Mélange, exposed in a comparable structural position further southwest, in the Andırın and Misis areas (Kelling et al., 1987; Robertson et al., 2004).

10.1. Interpretation of the Engizek Mélange

The Engizek Mélange is interpreted as composed of giant sub-aqueous debris flows (olistostromes), of mainly Oligocene-Early Miocene age, related to the latest stages of subduction of the Southern Neotethys and collision with the Arabian continent (Robertson et al., 2004).

Perinçek and Kozlu (1984) correlated the unit that we term the Engizek Mélange with the Binboğa Mélange in the far north of the area. These authors envisaged that both units represent parts of a vast over-riding thrust sheet located at the highest levels of the allochthon. However, it is unlikely that the mélange units can be correlated as a single over-riding thrust sheet as they differ in lithology and age. The Binboğa Mélange is dominated by carbonate platform, platform margin and ophiolite-related lithologies and was emplaced in latest Cretaceous time. By contrast, the Engizek Mélange includes lithologies representative of all of the presently assembled thrust sheets (i.e. the Malatya Metamorphic Unit, the Berit Ophiolite, the Berit Sedimentary-Volcanic Unit and the Maden Group) and was mainly formed during Late Oligocene–Early Miocene time.

11. Miocene units

Miocene sedimentary rocks overlie the allochthon in the both the north and the south of the area and form the highest levels of the underlying Arabian foreland succession to the south (Rigo de Righi and Cortesini, 1964).

In the north, the thrust stack is unconformably overlain by Miocene transgressive sediments, as exposed to the northeast of the area studied (north of Nurhak area; Perinçek and Kozlu, 1984). In the area we studied, south of the Göksun Fault Zone (e.g. W of Sülüklügöl; Fig. 3), the Tauride thrust sheets are unconformably overlain (or faulted against) Miocene shallow-marine clastic sedimentary rocks (e.g. sandstones, mudstones and minor conglomerates). The basal sandstones are rich in detrital neritic carbonate components (e.g. calcareous algae, benthic foraminifera), with, in addition, quartz, quartzite, radiolarite, and less common grains of basalt and marble.

Further south (in the Süleymanlı area; Fig. 3), the Tauride thrust sheets are unconformably overlain by shallow-marine argillaceous and clastic sediments of late Early to Middle Miocene age (see Robertson et al., 2004). The basal sandstones are rich in shallow-marine grains (e.g. micrite, shell fragments, calcareous algae), together with lithoclasts of bioclastic limestone, packstone and relatively unaltered basalt. The succession passes upwards into Middle–Late Miocene shallow-water carbonates (Atlık Member), in turn overlain by conglomerates of Late Miocene–Pliocene age (Kozlu, 1987, 1997).

Further south, the Tauride thrust sheets are structurally underlain by a well-documented foreland succession that culminates in Early Miocene proximal to distal sandstone turbidites (Lice and Çüngüş Formations; Perinçek, 1979; Perinçek and Özkaya, 1981; Yılmaz, 1993; Derman et al., 1996). The basal thrust of the Tauride thrust sheet is clearly exposed in the east along the Engizek mountain front but is largely obscured by Late Miocene folding and Quaternary landslipping further west (e.g. in the Ceyhan River–Süleymanlı area) (Robertson et al., 2004).

12. Discussion: restoration of the Tauride allochthon

In this section, we consider the implications of the individual units exposed in the Berit transect for the tectonic assembly of the Tauride thrust belt.

12.1. Pre-Cretaceous evolution

The Southern Neotethys rifted in the Triassic, bordered by the Malatya platform to the north and the Arabian continental margin to the south. The Malatya platform was either contiguous with the Binboğa platform to the north, or was separated from it by a palaeogeographical break or rift basin. The main uncertainties are the original setting of the Binboğa Mélange and the Berit Sedimentary-Volcanic Unit.

The Binboğa Mélange represents an accretionary prism composed of Mesozoic continental margin and oceanic units, emplaced southwards onto a Mesozoic carbonate platform (Binboğa Formation) in latest Cretaceous time in response to northward subduction. These units might have formed in a small oceanic basin located between a Binboğa/Malatya microcontinent to the south and a Tauride carbonate platform to the north. A correlation with the inferred Inner Tauride Ocean (Görür et al., 1984) would then be possible. This latter oceanic basin is thought by some authors to have rifted in Early Mesozoic time (see Monod, 1977; Özgül, 1984; Andrew and Robertson, 2002) and then closed by latest Cretaceous time (Clark and Robertson, 2002). A South-Neotethyan oceanic basin interspersed with several microcontinents and carbonate platforms of variable size and geometry could thus be envisaged, similar to the modern Caribbean region. Alternatively, the Binboğa Mélange could have originated along the northern margin of the Tauride carbonate platform, where similar melanges and ophiolitic rocks are exposed (Metin et al., 2004; and our unpublished data). It would then represent part of the southern margin of the separate Northern Neotethys ocean. As noted above (Section 2.2). It is conceivable that the Binboğa Mélange reached it present position, sandwiched between two Mesozoic carbonate platform units, in response to regional-scale strike slip after latest Cretaceous time. Significant post-Late Cretaceous strike-slip is inferred to have affected the Taurides elsewhere in southeast Turkey (Yiğitbaş and Yılmaz, 1996b).

The Berit Sedimentary-Volcanic Unit includes rift-related (Triassic and older) sediments and volcanics, and may also include more distal material (e.g. oceanic seamounts and cherts; see Section 5.1). In practice, the Berit unit could represent continental/oceanic crustal material located to the south that was subducted beneath the Tauride forearc and accreted to the base of the over-riding Berit ophiolite during Late Cretaceous time. The structural position of the Berit Sedimentary-Volcanic Unit beneath, and to the south, of the Berit Ophiolite appears to favour such a southerly origin. This is, however, unlikely to represent the leading edge of the Arabian continent, as this did not collide with the opposing Tauride active margin until mid-Cenozoic time (see below). The Berit Sedimentary-Volcanic Unit could also be interpreted as remnants of the rifted margin of the Malatya (Tauride) platform to the north. However, it is difficult to explain the low structural position beneath the Berit Ophiolite (e.g. in the Uludere window), although complex out-of-sequence thrusting (rethrusting) might have reversed the initial stacking order during Mid-Cenozoic suturing of the Southern Neotethys. On balance, it seems likely that the Berit Sedimentary-Volcanic Unit represents a rift block that was detached and isolated within oceanic crust following early Mesozoic rifting of the Arabian margin; this was then accreted to the opposing (northerly) Tauride margin during Late Cretaceous time, while the Southern Neotethys still remained partly open to the south.

12.2. Late Cretaceous subduction-related processes

Passive margin conditions persisted until Late Cretaceous time when regional convergence initiated northward subduction, as elsewhere in the southern Neotethys region (Robertson and Dixon, 1984; Dercourt et al., 1986; Yılmaz, 1993; Yılmaz et al., 1993; Robertson, 1998, 2000). The northward subduction triggered genesis of the Berit ophiolite in a supra-subduction zone setting. The intersliced high-grade amphibolite–granulite–eclogite facies rocks are seen as a disrupted metamorphic sole of oceanic crust and sediments that was accreted to the hot ophiolite within the hanging wall of the subduction trench. The underlying Berit Sedimentary-Volcanic Unit represents a subduction complex that was accreted beneath, under lower temperature conditions (greenschist facies).

To explain the genesis of the Berit ophiolite, its tectonic juxtaposition with the Tauride margin (Malatya platform) to the north, and the mutual granite intrusion, all during Late Cretaceous time, three main tectonic models can be considered.

12.2.1. Single subduction zone model

Both the Berit Ophiolite and the granitic intrusions formed above a single Late Cretaceous north-dipping subduction zone. The main difficulty here is that if the Berit Ophiolite formed by intra-oceanic spreading above a north-dipping subduction zone, as inferred for other south-Neotethys ophiolites (e.g. Cyprus, Oman), this subduction zone would then be to too far south of the Tauride continental margin (several hundred kilometres) to allow simultaneous granitic intrusion into both the Berit ophiolitic/accretionary units and the Tauride continental margin, as seen regionally (Robertson, 1998, 2000).

12.2.2. Double subduction zone model

The genesis of the Berit Ophiolite and intrusion of granites into the Malatya–Keban platform relate to the coeval activity of two separate north-dipping subduction zones, one to generate the Berit ophiolite above an intra-oceanic subduction zone and another located along the continental margin to the north, giving rise to Andean-type magmatism within the Malatya–Keban platform (Robertson, 1998, 2000). The main challenge here is to identify evidence for the activity of two contemporaneous northward-dipping subduction zones.

12.2.3. Multi-phase convergence model

The Berit Ophiolite formed above a northward-dipping intra-oceanic subduction zone possibly around 90 Ma (the age of the Troodos ophiolite; Mukasa and Ludden, 1987). Subduction was initiated not far outboard (south) of the Tauride continental margin (tens to several hundred kilometres) giving rise to the SSZ-type Berit Ophiolite and a metamorphic sole (c.90 Ma). Any intervening Early Mesozoic oceanic crust was then underthrust (subducted) along the Tauride continental margin (Fig. 30). The SSZ Berit ophiolite was then accreted and thrust beneath the Tauride active margin, where it was intruded by calc-alkaline granitic rocks.

The third model fits the field evidence obtained during this project and also new radiometric dating results (Parlak and Rızaoğlu, 2004; Parlak, under review). The main uncertainty is the location of the initial SSZ-spreading relative to the continental margin to the north. If this were located well south of the margin (hundreds of kilometres) a second subduction zone would be required to juxtapose the ophiolite with the margin. However, if the ophiolite formed close to the Tauride (Malatya) margin only less important underthrusting would be needed.

12.3. Latest Cretaceous–Early Cenozoic extension then quiescence

Latest Cretaceous time was marked by progressive suturing of the Northerly Neotethys while the Southern Neotethys remained partly open to the south. The Malatya platform was regionally metamorphosed, possibly a result of overthrusting of platform and melange units (Binboğa Formation and Binboğa Mélange) from the north. The Malatya platform was then exhumed and eroded by latest Cretaceous time. The Berit Sedimentary-Volcanic unit was also metamorphosed in latest Cretaceous time and then exhumed prior to formation of the Eocene volcanic-sedimentary Maden Group. The probable cause of the exhumation was tectonic extension related to roll-back of the subducting Southern Neotethyan oceanic plate after accretion of the Berit ophiolite to the Malatya–Keban margin to the north. Early Cenozoic time was then characterised by relative quiescence during which passive margin conditions resumed on the Arabian margin to the south and shelf-type carbonates accumulated on the exhumed Malatya platform and other Tauride units to the north.

12.4. Middle Eocene supra-subduction zone extension (c. 45 Ma)

During the Eocene, northward subduction either resumed or intensified and the entire northern margin of the remaining South-Neotethyan oceanic basin experienced pervasive extension. The probable cause was roll-back of old, dense marginal oceanic crust of early Mesozoic age (Fig. 30). An extensional setting fits the field observations and the chemical evidence for the Maden and Helete volcanics. The Middle Eocene basin was filled with conglomerates and redeposited shallow-marine carbonates in proximal areas, whereas depocentres experienced extensive volcanism and deeper water hemipelagic sedimentation. The coeval Helete volcanics are seen as small arc-type volcanic centres located along the southerly, distal edge of the Tauride convergent margin, rather than as island arc volcanoes constructed on undeformed Neotethyan oceanic crust.

The Maden and Helete units are unlikely to record rifting after latest Cretaceous continental collision, as suggested by Yazgan and Chessex (1991). By the Early Cenozoic, the Southern Neotethys was potentially the only remaining oceanic area where continuing convergence of the Arabian (African) and Eurasian plates could take place (c.10° of remaining separation; Livermore and Smith, 1984; Savostin et al., 1986). Also, further west, mélange of mainly Late Oligocene–Early Miocene age (Misis–Andırın Complex) is interpreted as an accretionary wedge of Late Oligocene–Early Miocene age, related to final closure of the southern Neotethys in this area (Robertson et al., 2004). Furthermore, the geo-history of the Arabian foreland, marked by strong subsidence in Early-Mid Miocene time, and can best be interpreted as the result of downflexure activated by overthrusting of the Tauride allochthon (Aktaş and Robertson, 1984; Dewey et al., 1986; Yılmaz, 1993; Derman et al., 1996).

12.5. Post-mid Eocene to mid-Miocene time

Subduction continued until the still loosely assembled Tauride allochthon began to collide with the Arabian continental margin to the south. The pre-existing Tauride active margin was reactivated and strongly shortened, driving the more northerly units southwards to form the present pile of thrust sheets (Fig. 4). For example, the Malatya Metamorphic Sheet, which originated in a northerly position, is now also exposed in the south near the Arabian foreland. The timing of this thrusting is currently constrained only as post-Eocene and pre-mid-Miocene. The absence of post-Eocene sedimentary successions within the thrust sheets (e.g. above the Maden Formation) suggests that

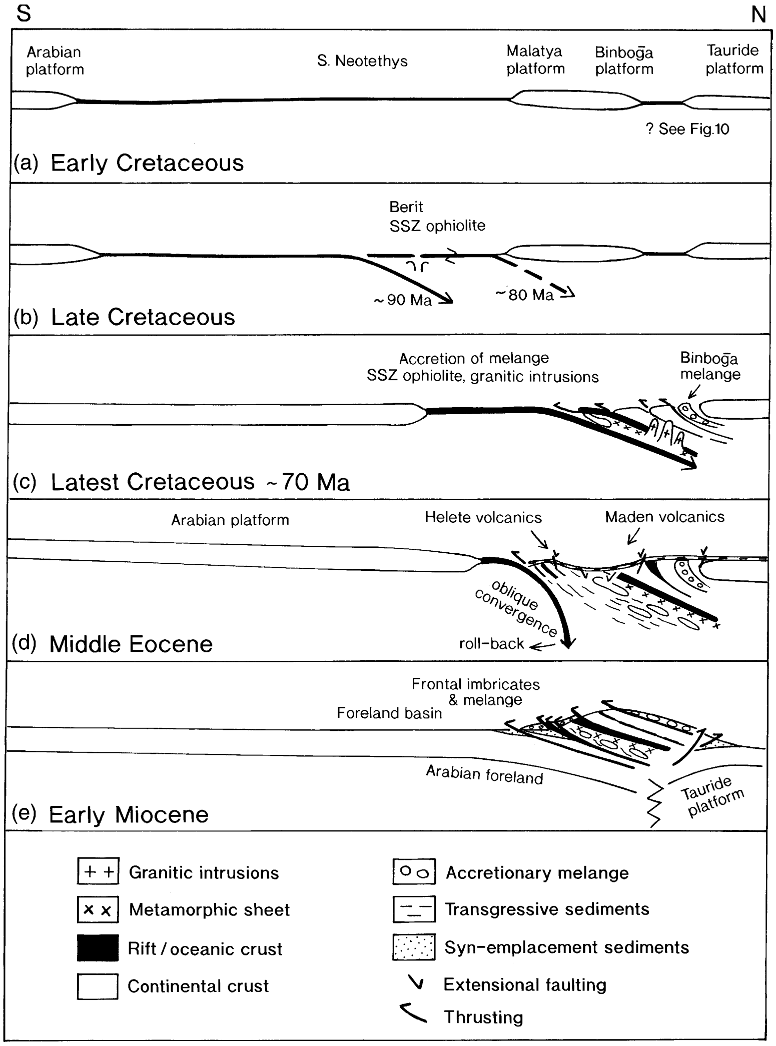

Fig. 30. Schematic tectonic evolution of the Southern Neotethys in the Berit area of the Tauride Mountains studied in E Turkey. See text for explanation. (a) representative of the Mesozoic passive margin phase; (b) genesis of the Berit ophiolite above an intra-oceanic subduction zone, followed by subduction/thrusting beneath the continental margin to the north; (c) accretion of the Berit ophiolite to the northerly continental margin, followed by intrusion of calc-alkaline granitic rocks; (d) later stage of subduction, marked by roll-back of old Neotethyan oceanic crust; (e) collision phase with telescoping of unit to form the present pile of thrust sheets, coupled with large-scale mass wasting of the thrust front to form a giant sub-aqueous olistostrome. See text for discussion.

over-thrusting may have begun soon after Eocene time (Yılmaz et al., 1993). However, it is also possible that any such younger sediments were cut out by the overthrusting. It is probable that the over-thrusting and the assembly of the present thrust pile took place progressively during Oligocene and Early Miocene time.

There is little evidence of a thick accretionary prism along the thrust front dating from this convergent phase, and it is likely that subduction erosion predominated. Instead, material was mainly derived from the over-riding plate. During southward thrusting the front of the advancing allochthon repeatedly collapsed to form the giant sub-aqueous olistostromes of the Engizek Mélange.

Collision was complete prior to Mid-Miocene time and this was followed by suture tightening, leading to large-scale folding during Late Miocene time, as seen along the southern front of the allochthon. This, in turn, was succeeded by a switch to left-lateral tectonic escape of much of the Tauride allochthon along the East Anatolian Fault Zone during Plio-Quaternary time (Şengör et al., 1985) (Fig. 30).

13. Conclusions

The following main stages in the tectonic evolution of the N–S Berit transect of the Tauride allochthon studied are inferred:

1. Early Mesozoic rifting and continental break-up gave rise to the Southern Neotethys, bordered by the Arabian continental margin to the south and the Malatya (Tauride) microcontinent to the north. The Malatya

platform and the main Tauride continent were either contiguous or separated by a rift/small oceanic basin.

2. The regionally extensive Berit (Göksun) Ophiolite formed in Late Cretaceous time above a northward-dipping intra-oceanic subduction zone. The presence of basic to silicic volcanism and volcaniclastic sedimentation points to the development of an incipient (ensimatic) intra-oceanic arc.
3. The Berit Ophiolite was accreted to the Malatya microcontinental margin (Tauride margin) to the north in latest Cretaceous time, associated with subduction of any intervening Mesozoic oceanic crust. Ultramafic ophiolitic rocks underwent ductile deformation, related to intra-oceanic thrusting, or docking with the Malatya (Tauride) microcontinent to the north.
4. Oceanic crust of MOR and subduction-influenced type was emplaced beneath the Berit Ophiolite and dismembered to form high-temperature amphibolite and granulite facies rocks (metamorphic sole).
5. A greenschist facies unit beneath the Berit Ophiolite (Berit Sedimentary-Volcanic Unit) is of continental margin and possibly oceanic (seamount) origin. This metamorphic unit may represent a detached rift block (surrounded by oceanic crust) that was accreted to the Tauride active margin during Late Cretaceous time.
6. Late Cretaceous calc-alkaline subduction-related granitic rocks were intruded into the Berit Ophiolite. Evidence from the Malatya–Elazığ area further east shows that the Malatya–Keban platform was also intruded by similar Late Cretaceous granitic rocks (c.85 Ma).
7. The Malatya Metamorphic Unit was metamorphosed to regional greenschist facies and then exhumed by latest Cretaceous time. The possible trigger was extensional roll-back of South-Neotethyan oceanic crust.
8. Shelf-type sedimentation resumed on the Malatya carbonate platform during Early Cenozoic time. Platform carbonate-type sedimentation also continued on the Tauride Carbonate Platform in the north.
9. The entire Tauride margin experienced N–S extension during Mid-Eocene time. Northward subduction (possibly oblique) is inferred to have resumed or intensified during the Eocene, possibly related to accelerated roll-back of old, marginal South-Neotethyan oceanic crust.
10. The extension resulted in rifting in hinterland areas (Maden Formation) and chemically enriched volcanism (with a subduction signal) near depocentres. In addition, localised arc volcanism occurred near the distal edge of the Tauride active margin (Helete Formation), with a clear subduction influence.
11. Middle Eocene subduction-influenced tholeiites located within frontal imbricates in the east (Helete Formation) are interpreted as localised, incipient arc-type volcanoes located along the distal, southerly edge of the Tauride accretionary margin.
12. Remaining Neotethyan oceanic crust was subducted during Oligocene-Early Miocene time. Progressive continental collision telescoped the former active margin to the north to produce the present thrust pile.
13. Mass wasting of the advancing thrust front took place during the latest stages of subduction/accretion and initial collision (Late Oligocene–Early Miocene), giving rise to a huge frontal sub-aqueous sedimentary olistostrome (Engizek Mélange).
14. Strike-slip processes probably played a significant role in the assembly of the Tauride thrust best in the area studied. This includes possible strike-slip and terrane displacement after latest Cretaceous time, and the effects of oblique convergence and diachronous collision during mid-Cenozoic time.

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