

# Late Cretaceous–Cenozoic subduction–collision history of the Southern Neotethys: new evidence from the Çağlayancerit area, SE Turkey

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**Abstract** Evidence of the subduction–collision history of the S Neotethys is well exposed in the frontal part of the SE Anatolian thrust belt and the adjacent Arabian continental margin. The foreland succession in the study area begins with Eocene shelf carbonates, ranging from shallow marine to deeper marine, without sedimentary input from the Tauride continent to the north. After a regional hiatus (Oligocene), sedimentation resumed during the Early Miocene with terrigenous gravity-flow deposition in the north (Lice Formation) and shallow-marine carbonates further south. Clastic detritus was derived from the Tauride continent and oceanic accretionary material. The base of the overriding Tauride allochthon comprises ophiolite-derived debris flows, ophiolite-related mélangé and dismembered ophiolitic rocks. Above this, the regional-scale Bulgurkaya sedimentary mélangé (an olistostrome) includes blocks and dismembered thrust sheets of metamorphic rocks, limestone and sandstone, which include Late Cretaceous and Eocene foraminifera. The matrix is mainly strongly deformed Eocene–Oligocene mudrocks, hemipelagic marl and sandstone turbidites. The thrust stack is topped by a regionally extensive thrust sheet (Malatya metamorphic unit), which includes greenschist facies marble, calcschist, schist and phyllite, representing Tauride continental crust. Beginning during the Late Mesozoic, the S Neotethys subducted northwards beneath a backstop represented by the Tauride microcontinent (Malatya metamorphic unit).

Ophiolites formed within the S Neotethys and accreted to the Tauride active margin. Large-scale sedimentary mélangé developed along the Tauride active margin during Eocene–Oligocene. On the Arabian margin, a sedimentary hiatus and tilting (Oligocene) is interpreted to record initial continental collision. The Early Miocene terrigenous gravity flows represent a collision-related flexural foreland basin. Southward overthrusting of the Tauride allochthon took place during Early-Middle Miocene. Associated regional uplift triggered large-scale alluvial deposition. The foreland folded and faulted in response to suture zone tightening (Late Miocene). Left-lateral strike slip characterised the Plio-Pleistocene.

**Keywords** Tauride continent · Arabian foreland · Late Cretaceous · Cenozoic · Mélangé · Subduction · Collision

## Introduction

There is a consensus amongst geologists that the E–W belt of thrusting, folding and ophiolites (emplaced ocean crust) in SE Turkey records the suture zone of a regionally important Neotethyan ocean basin, generally known as the Southern Neotethys (Şengör and Yılmaz 1981; Robertson and Dixon 1984; Yılmaz 1993; Yılmaz et al. 1988, 1993a, b; Elmas and Yılmaz 2003; Robertson 2000, 2002; Robertson et al. 2004, 2006, 2012, 2015a, b). However, there have been few studies of the suture zone that link the geological development of the overriding plate, represented by the Tauride continent, with the foreland, represented by the Arabian continental margin. Palaeotectonic maps suggest that the Southern Neotethys subducted northwards, associated with the genesis and emplacement of ophiolites of supra-subduction zone type (e.g. Robertson et al. 2012).

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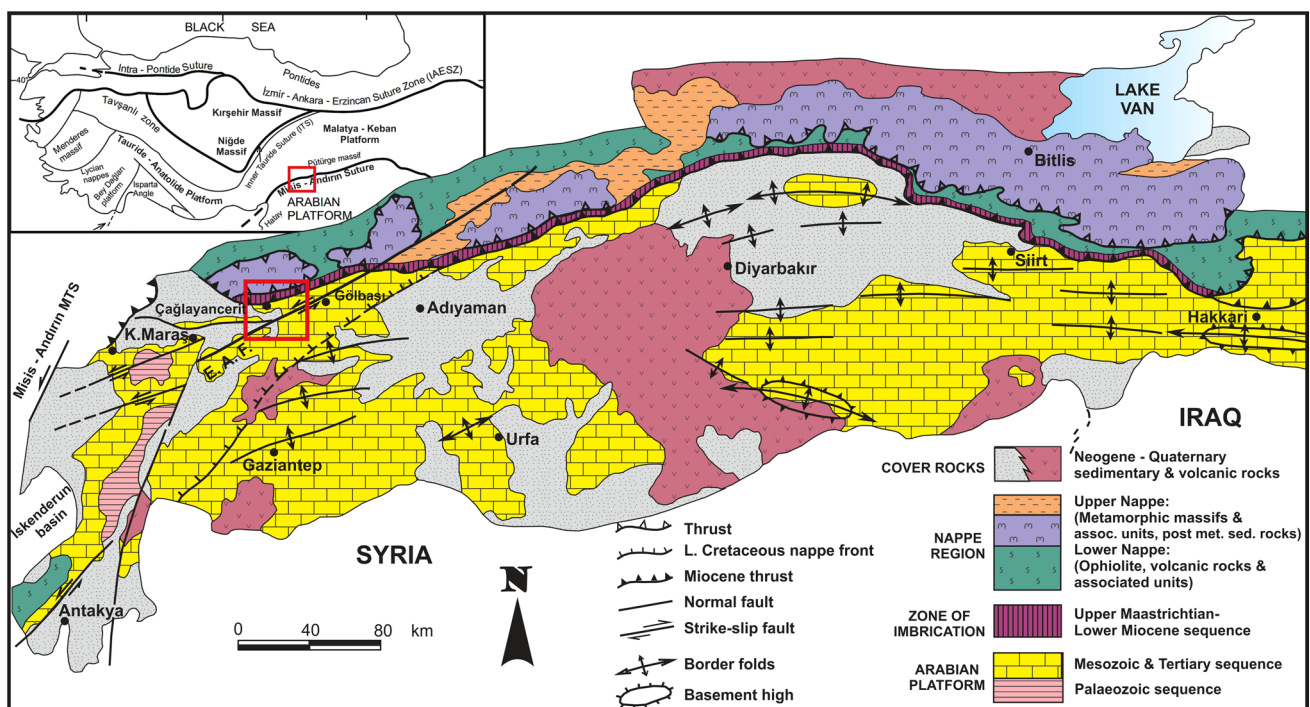
However, the processes and timing of ocean closure are debateable (Hall 1976; Aktaş and Robertson 1984; Yılmaz et al. 1993a, b; Beyarslan and Bingöl 2000; Okay et al. 2010; Robertson et al. 2015a).

The Southern Neotethyan suture zone extends eastwards throughout S Turkey and Cyprus, SE Turkey ('Bitlis suture') and Iran ('Zagros suture'). Three main alternatives have been proposed, which envisage collision during: (1) Late Cretaceous (Karig and Kozlu 1990; Kozlu 1997; Beyarslan and Bingöl 2000); (2) Late Eocene (Boulton et al. 2006; Boulton 2009); (3) Late Oligocene–Early Miocene (Aktaş and Robertson 1984; Yılmaz et al. 1993a, b; Robertson 2000; Robertson et al. 2004, 2006, 2012, 2015a; Okay et al. 2010). There is a comparable debate in Iran, where a wide range of ages for the closure of the eastward extension of the Southern Neotethys into this region have been proposed (e.g. McQuarrie and Hinsbergen 2013). A Late Oligocene–Early Miocene timing of collision is supported by sedimentary evidence from the Arabian foreland in Iran, northern Iraq and south-eastern Turkey (see Robertson et al. 2015a for a literature review).

The Arabian foreland near the suture zone and also the toe of the overriding Tauride allochthon are excellent locations to study the subduction–collision history of the Southern Neotethys. There have been several attempts to link the tectonic–sedimentary development of the Arabian foreland to the emplacement of the Tauride allochthon (Yılmaz

1993; Yılmaz et al. 1993a, b; Robertson et al. 2004, 2006, 2015a; Boulton et al. 2006; Boulton 2009). However, there are some practical difficulties. Near the suture zone, the Late Cretaceous–Neogene foreland succession is commonly obscured by Plio-Quaternary sediments or volcanics or disrupted by Plio-Quaternary strike-slip faulting. Also, in many places, the leading edge of the Tauride allochthon is poorly exposed, disrupted by landslipping or largely restricted to older rift/passive margin-related units (Robertson et al. 2015b). The area discussed here, around the town of Çağlayancerit in northern Kahramanmaraş Region (Fig. 1), is exceptional because the Arabian foreland succession and the overriding Tauride allochthon are both well exposed and their mutual relationships are clearly displayed. This allows a detailed interpretation of the processes and timing of subduction and collision, with implications for the suture zone as whole. The Çağlayancerit area was previously overlooked because it was incorrectly mapped, as discussed below.

Our work builds on previous knowledge concerning the Southern Neotethyan suture zone and the Arabian foreland in the northern Kahramanmaraş region. During the 1970s–1990s, regional mapping was coupled with stratigraphical, palaeontological and structural studies (Rigo de Righi and Cortesini 1964; Polat 1970; Sungurlu 1974; Perinçek 1979, 1980; Gözübol and Gürpınar 1980; Önalan 1985/1986, 1988; Derman et al. 1996). During the



**Fig. 1** Regional geological map of south-eastern Anatolia (modified after Yılmaz 1993). Note the study area marked by the red box. Inset left location of the study area relative to the tectonic zonation of Turkey (from Robertson et al. 2012)

early 2000s, the northern Kahramanmaraş region began to be interpreted in terms of geotectonic processes as currently understood. The sedimentology of the foreland basin around Kahramanmaraş, to the west of our main study area, was studied in detail and a tectonic-sedimentary model was proposed related to closure of the Southern Neotethys (Gül 2000; Gül et al. 2003a, b, 2011, 2012). The Kahramanmaraş region, together with the Andırın Range and the Misis Range further west, was included in a regional study leading to an interpretation involving northward subduction and suturing of the Southern Neotethys (Robertson et al. 2014). In addition, the Late Cretaceous to Pliocene sedimentary-tectonic development of the Arabian foreland has recently been investigated in the Adıyaman area and used to support an interpretation involving Late Cretaceous to Oligocene northward subduction and Late Oligocene–Early Miocene continental collision (Robertson et al. 2015a).

## Regional setting

The Tethyan orogenic belt in southeast Anatolian is traditionally divided into three main segments: (1) the nappe zone, (2) the imbricate zone and (3) the Arabian foreland (Yılmaz et al. 1993a, b; Fig. 1). The imbricate zone represents the leading edge of the Tauride allochthon and, as such, is a key to an understanding of the subduction–collision history of the Southern Neotethys. The imbricate zone is exposed approximately E–W, forming the southern margin of the allochthon, including the present study area (MTA 2002), easternmost Turkey as a whole and also Iran. The imbricate zone is widely interpreted as the result of Late Mesozoic–Cenozoic northward subduction and closure of the Southern Neotethys (Aktaş and Robertson 1984; Yılmaz 1993; Yılmaz et al. 1993a, b; Robertson and Ünlügenç 2001; Robertson et al. 2004, 2006, 2007, 2015a).

One of the most important units exposed within the imbricate zone in many areas is a chaotic unit of inferred Eocene–Oligocene age, which was first termed the Bulgurkaya Formation (Kozlu 1987) and later renamed the Bulgurkaya Olistrostroma (Kozlu 1997). This unit has been interpreted as a type of accretionary complex related to subduction or early-stage collision (Robertson et al. 2004) and is critical to an understanding of the convergence history.

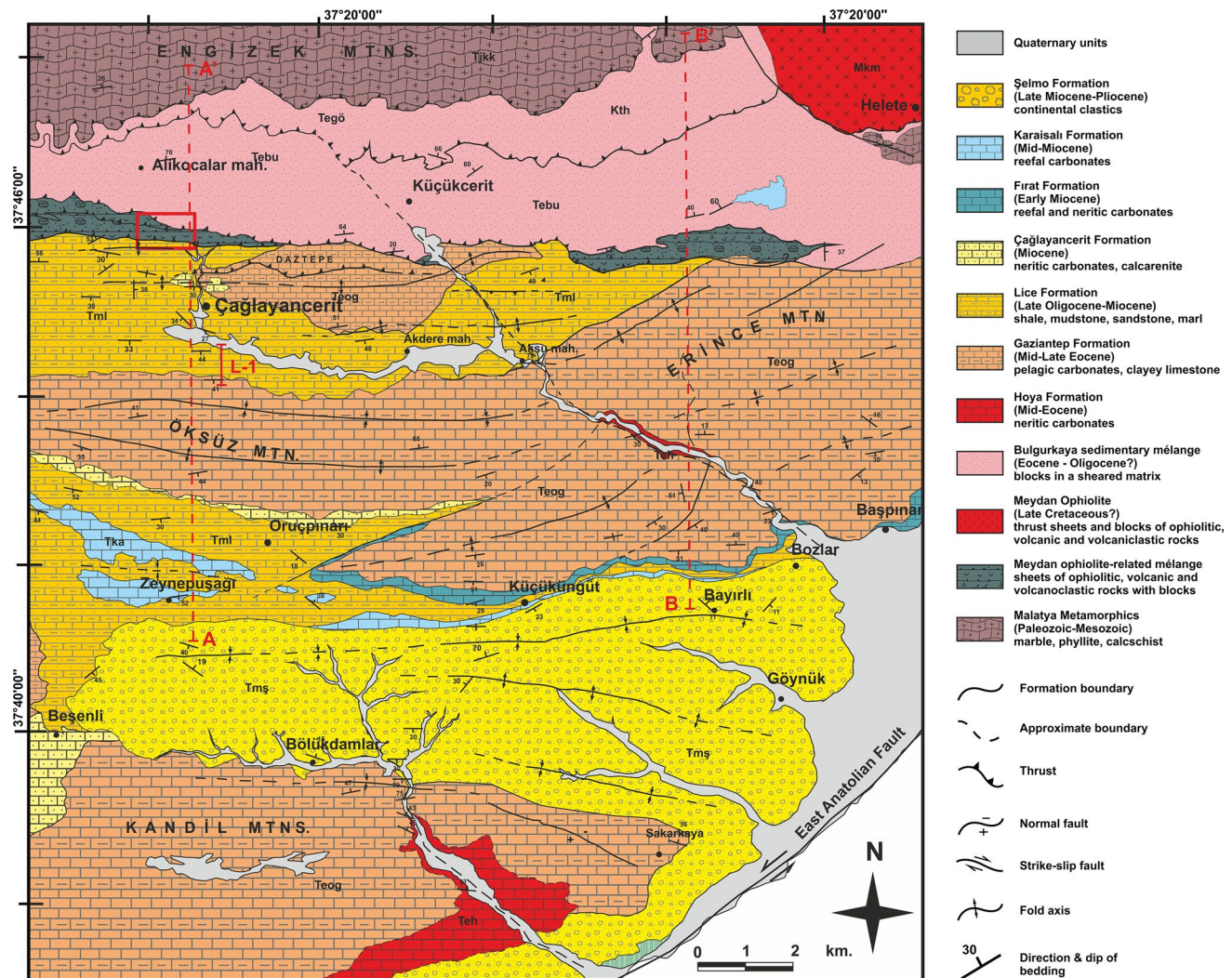
During the Pliocene to Pleistocene, the Arabian foreland and, in places, the adjacent Tauride allochthon were transected by left-lateral strike-slip faults related to the westward ‘tectonic escape’ of Anatolia towards the Aegean region (Şengör et al. 1985; Herece 2003; Duman et al. 2013). This deformation must be taken account of any interpretation of the region including the study area.

During this work, a new geological map was made of the northernmost part of the Arabian foreland and the adjacent southernmost part of the Tauride allochthon (Figs. 1, 2) in the vicinity of the town of Çağlayancerit. Previously, important outcrops of ophiolites and ophiolite-related mélangé in this area were incorrectly shown as a granitoid body (Herece 2008). During this work, detailed sedimentary logs were measured of representative successions within the foreland, coupled with sedimentological and petrographic analysis. Lithological and structural data were also obtained from the overriding allochthonous units. The sedimentary units were also studied palaeontologically wherever possible.

## Tectono-stratigraphy

The following main tectono-stratigraphical units are present in the area studied from the base upwards:

1. *Arabian foreland succession* The succession (Fig. 3) begins with Eocene shelf carbonate rocks, represented by the Hoya Formation and the Gaziantep Formation in different areas (Durkee 1961; Rigo de Righi and Cortesini 1964). The overlying formations differ between the north and the south of the area (Fig. 3). In the north, shallow-marine carbonates, termed the Çağlayancerit Formation, pass upwards into siliciclastic sediments and marls of Miocene age. The formations pass southwards into shallow-water carbonate rocks (Figs. 3, 4), represented by the Fırat Formation and the Karaisalı Formation (Tuna 1973; Perinçek 1978). The Miocene formations as a whole are unconformably overlain by Late Miocene to Pliocene alluvial, fluvial-deltaic and lagoonal deposits that area variously known as the Şelmo Formation (Önem 1966) or the Lahti Formation (Duran et al. 1988, 1989).
2. *Tauride allochthon* The following units are recognised in the study area from the base upwards:
  - (i) *Igneous-derived clastic sedimentary rocks* The lowest structural unit of the Tauride allochthon is a discontinuous sequence of coarse conglomerates and sandstones including abundant ophiolite-derived detritus.
  - (ii) *Ophiolite-related Meydan mélangé* This is an assemblage of dismembered thrust sheets and blocks of ophiolitic rocks, limestones, volcanogenic rocks and matrix-supported conglomerates. The term ophiolite-related mélangé, rather than ophiolitic mélangé, is preferred here because the unit includes lithologies (e.g. marble), which are not part of an ophiolite pseudostratigraphy. The ophiolite-related mélangé is named after Meydan town, 17 km northeast of the inset map (Fig. 1), where similar rocks are more widely exposed.



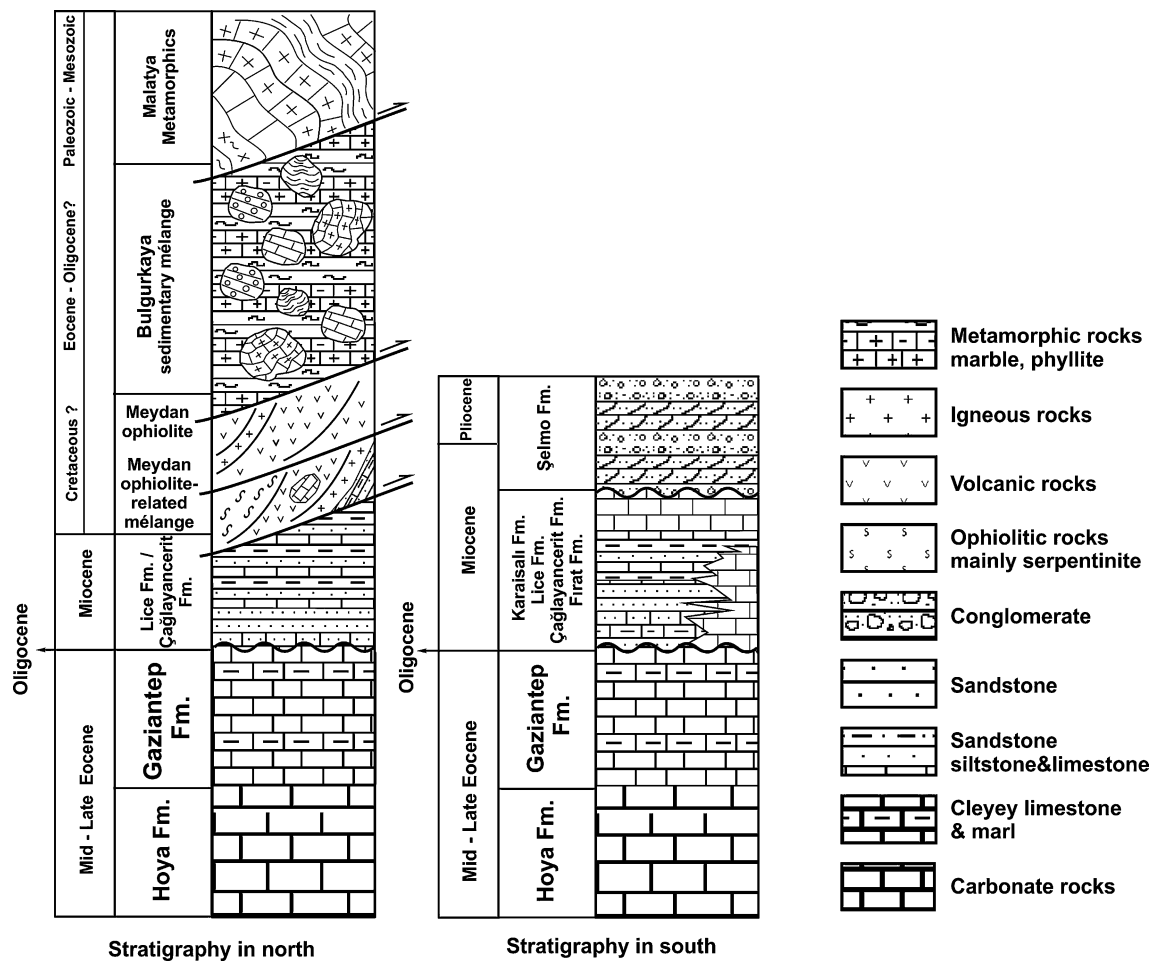
**Fig. 2** Geological map of the area studied; extensively modified following previous mapping by MTA, as compiled by Herece (2008)

The ophiolite-related rocks are undated in our study area but are inferred to be of Late Cretaceous age in the type area (Nurlu et al. 2015).

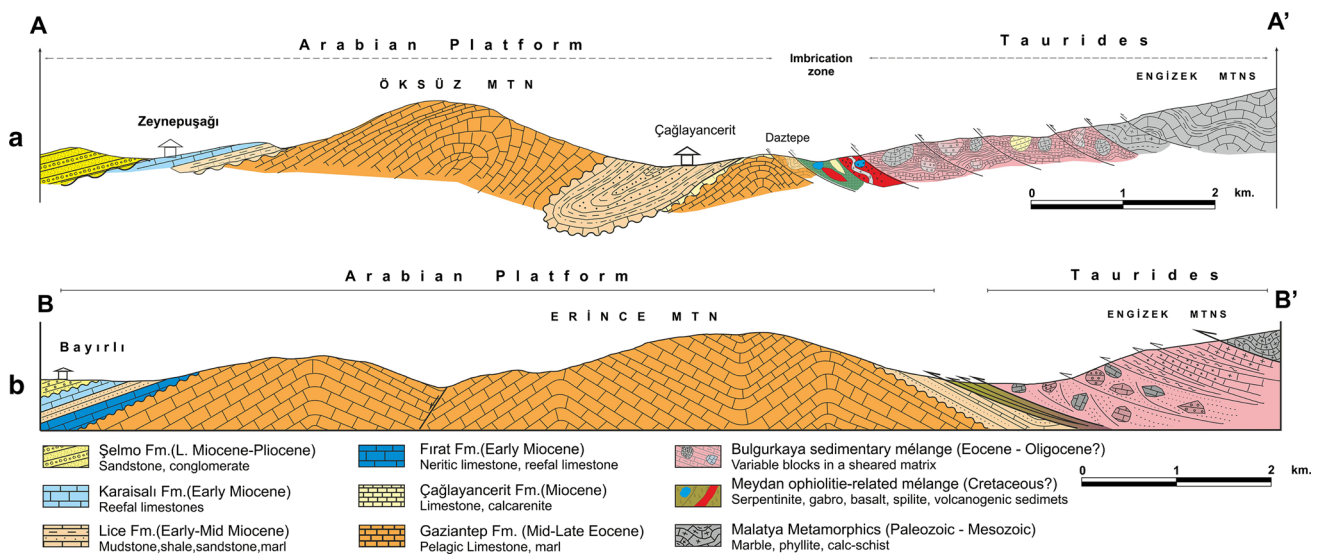
- (iii) *Meydan ophiolite* Ophiolitic rocks, which are exposed c. 2 km north of Çağlayancerit (Fig. 2), are named after a much larger exposure of ophiolite rocks further east, near Meydan Village. The Meydan ophiolite is correlated with the Koçali ophiolite, which is widely exposed throughout SE Turkey (Sungurlu 1974; Sungurlu and Arpat 1978; Yıldırım 1989; Uzunçimen et al. 2011; Yıldırım et al. 2012; Robertson et al. 2015b).
- (iv) *Bulgurkaya sedimentary mélangé* This unit includes blocks and dismembered slices of shallow-marine carbonates, conglomerates and metamorphic rocks, set in a matrix of terrigenous shales, marls and low-metamorphic-grade phyllite (Fig. 4). We use the term *Bulgurkaya sedimentary mélangé* because this unit has a recognisably sedimentary origin (equivalent to a traditional

olistostrome), although it is strongly deformed (Fig. 5). The type area, Bulgurkaya, is located c. 60 SW km of our study area, near Bulgurkaya village (Kahramanmaraş Region). Local sequences within this unit have been compared with Late Maastrichtian shallow-marine carbonates of the Harami Formation (Erdoğan 1975; Herece 2008) and with Eocene clastic sediments of the Gözülü Formation (Yılmaz et al. 1987), elsewhere in eastern Turkey. The Bulgurkaya unit was previously described as a flysch-like body of rocks, intercalated with volcanic rocks (Güzelbeyli volcanics) (Yılmaz and Gürer 1996) although this relationship was not observed within our study area.

The Bulgurkaya sedimentary mélangé occurs elsewhere in the Engizek Mountains and in the Andırın Range to the southwest (as the Alacık Formation of Erdoğan 1975, part of the Andırın Formation of Bilgin et al. (1981) and the Demirogluk Formation

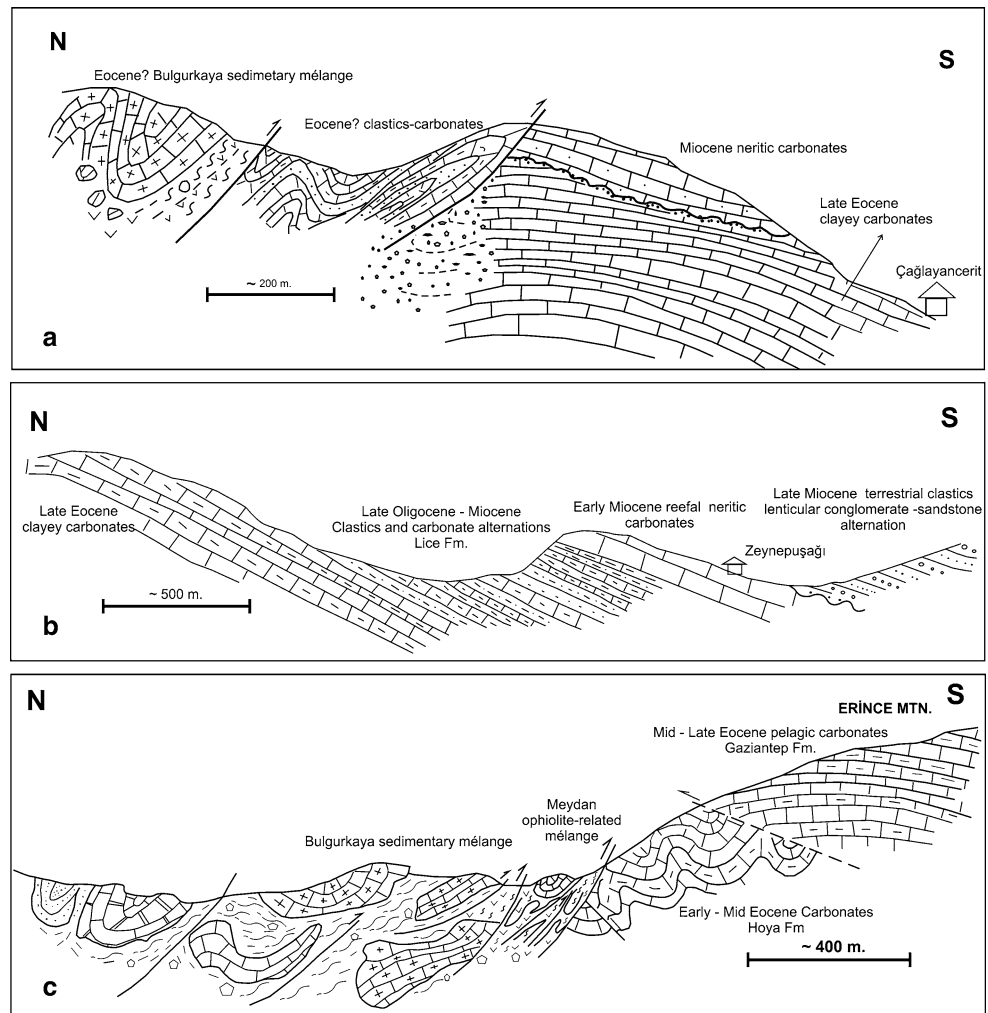


**Fig. 3** Columnar stratigraphic sections (not to scale) of the region studied. **a** Northern part of the area. **b** Southern part of the area. See text for data sources



**Fig. 4** Geological cross section of the investigated area. See Fig. 3 for lines of section

**Fig. 5** Local cross sections: **a** tectono-stratigraphic relations at Daztepe, north of Çağlayancerit town. Note the deformation in the allochthon and the unconformity between Eocene–Early Oligocene (?) and Early Miocene units; **b** stratigraphic relations of the Miocene foreland succession, as well exposed from Öksüz Dağ to Zeynepuşağı; **c** N–S section showing the local relation of the allochthon to the foreland



of Perinçek and Kozlu (1984)). A similar sedimentary mélangé has been described from the Misis Mountains further west (İsalı Catastrophic Facies of Schmidt 1961). An Eocene–Oligocene to possibly Early Miocene age was suggested for the sedimentary melange throughout the region as a whole (Gökçen et al. 1988; Kozlu 1997; Robertson et al. 2004). However, dating is difficult, especially as many microfossils may be reworked.

- (v) *Malatya metamorphic unit* This forms a regionally extensive overlying thrust sheet made up of greenschist facies metamorphic rocks, including marble, phyllite, calcschist and micaschist (Fig. 3). These units are undated locally but are likely to range from Late Palaeozoic through Mesozoic (e.g. Çayderesi and Yoncayolu formations) based on correlations with other areas (Perinçek and Kozlu 1984; Yazgan 1984; Bedi et al. 2012). A detailed study of the Malatya metamorphic unit is, however, outside the scope of this work.

## Arabian foreland succession

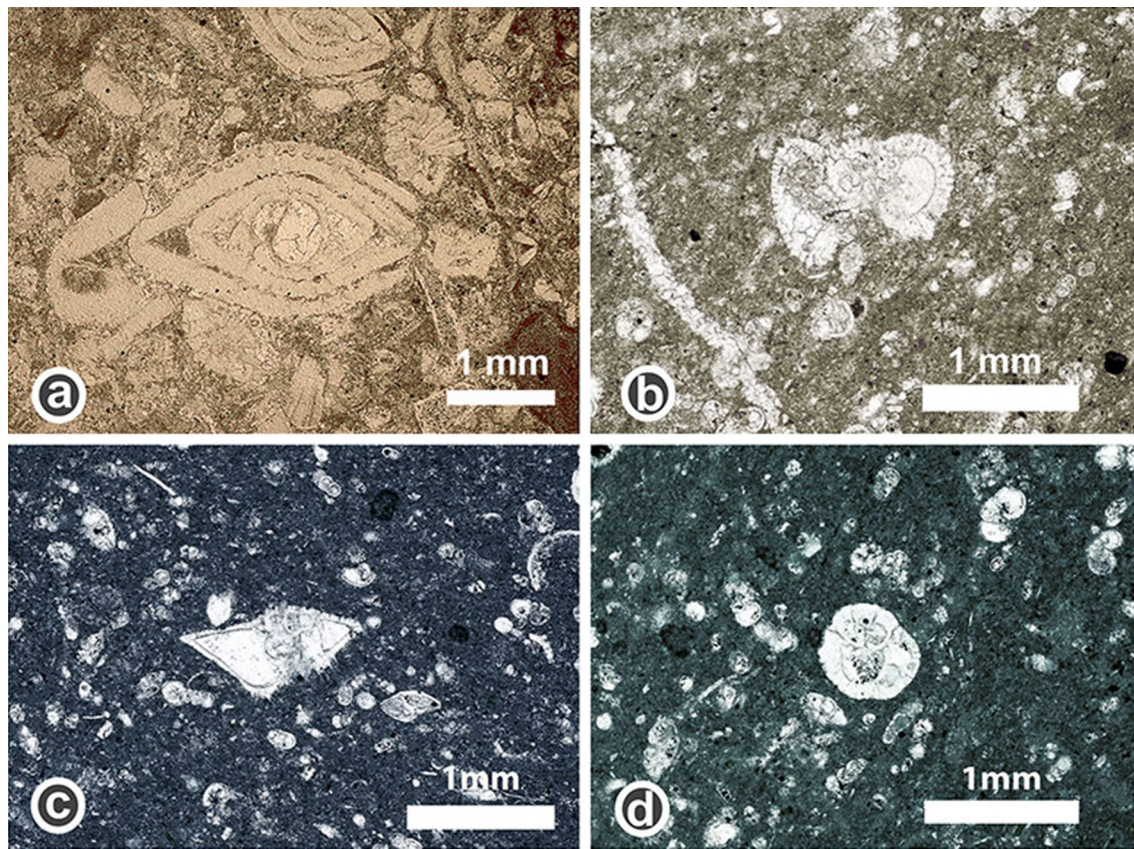
We now focus on the sedimentary facies, provenance, age and structure of each one of the formations of the Arabian foreland, with particular reference to the processes and timing of emplacement of the Tauride allochthon.

### Eocene Hoya Formation

The stratigraphically lowest unit exposed in the area studied is made up of shallow-water carbonates (Fig. 3), rich in Middle Eocene (Lutetian) large foraminifera, e.g. *Nummulites* sp. (Fig. 6a). Outcrops are restricted to the lower levels of deep valleys and canyons. These sedimentary rocks are strongly deformed, including spectacular chevron folds.

### Mid-Late Eocene Gaziantep Formation

The Hoya Formation is depositionally overlain by fine-grained carbonate rocks of the Gaziantep Formation



**Fig. 6** Photomicrographs of microfossils in the Mid-Eocene Hoya Formation (**a**) and the Mid-Late Eocene Gaziantep Formation (**b–d**): **a** *Nummulites* sp., **b** *Acarinina bullbrooki*, **c** *Morozovella crassatus*, **d** *Globigerinatheka* sp.

(Fig. 7a). This formation (>100 m thick) is dominated by thin- to medium-bedded micritic limestones. Several thin (tens of cm) layers of brownish yellowish claystone occur spasmodically throughout the succession. There are also numerous variably persistent layers and nodules of diagenetically formed chert, individually up to several metres thick.

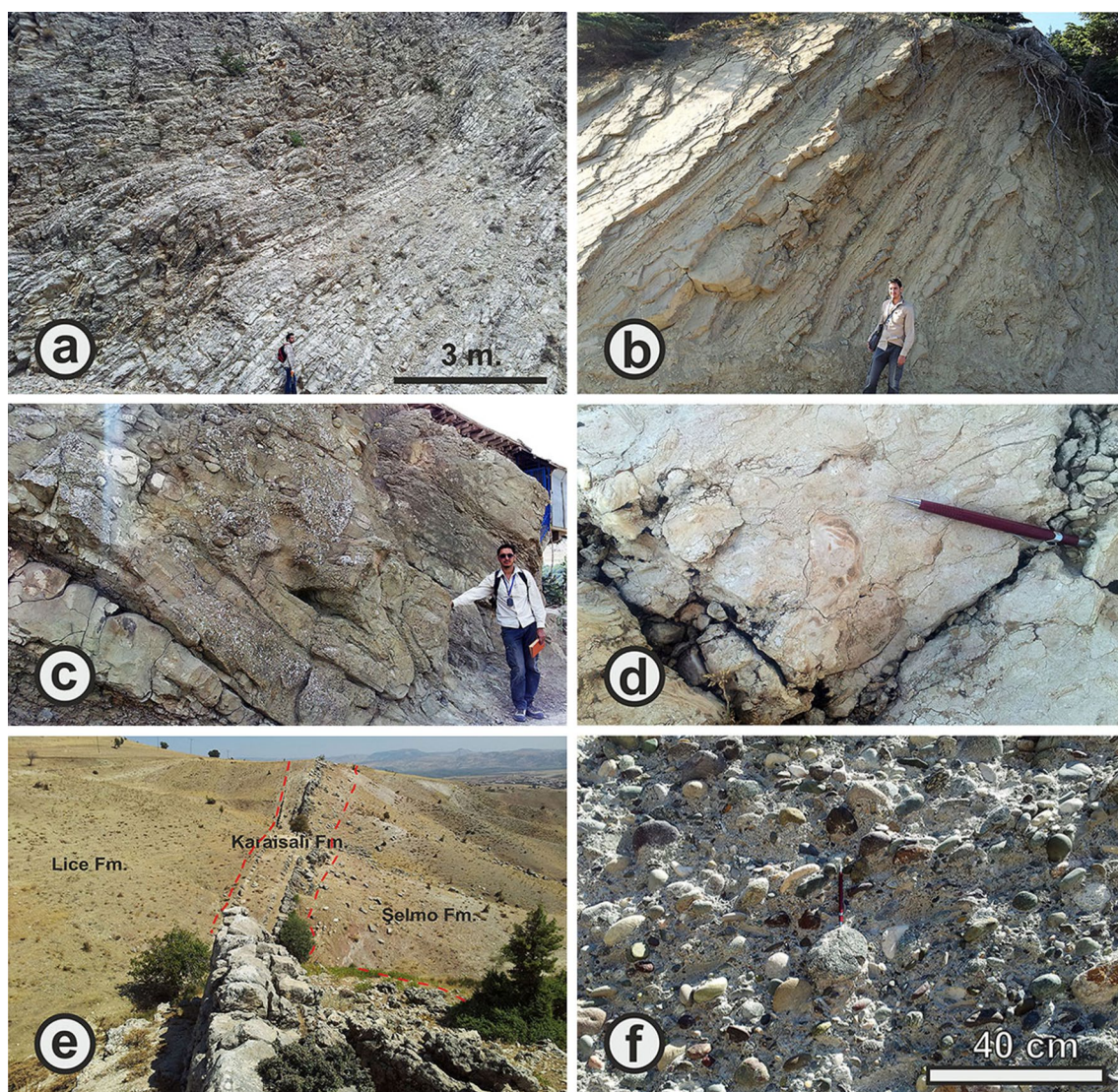
During this work, fine-grained hemipelagic limestones and clayey carbonates of the Gaziantep Formation yielded planktic and benthic foraminifera of Mid-Late Eocene age. The taxa include Globigerinidae, *Nummulites* cf. *N. gallensis* Heim, *Subbotina* sp., *Globigerinatheka* sp., *Acarinina praetopilensis* (Blow) 1979, *Morozovelloides crassatus* (Cushman) 1925, *Globigerinatheka* sp., *Pseudohastigerina* sp., *Morozovelloides coronatus* (Blow) 1979, *Chiloguembelina* sp., *Acarinina* sp., *Subbotina* sp. and *Acarinina bullbrooki* (Fig. 6b–d).

The Gaziantep Formation is strongly folded on an outcrop to kilometric scale (Figs. 5a, 7a). The folding is interpreted as being related to a much larger-scale whale-back-type structure, namely the Ahırdağ, north of Kahramanmaraş (c. 15 km west of our study area).

### Early Miocene Çağlayancerit Formation

The Gaziantep Formation is depositionally overlain by coarser-grained carbonate rocks known as the Çağlayancerit Formation (Gül 2000). The base of the formation is characterised by a low-angle unconformity, as seen in the upper part of Daztepe valley (Fig. 2). The formation is dominated by 10–15 m of brownish to greenish brown fossiliferous calcarenite together with clayey to sandy limestone (Fig. 2). The Çağlayancerit Formation is best exposed on Daztepe, just north of Çağlayancerit and also west of Oruçpınarı Village, where it is relatively thin (5–8 m). In the south, the formation is depositionally overlain by the Lice formation, as seen from northwest of Boylu Village (Fig. 2).

No age-diagnostic fossils could be obtained from the Çağlayancerit Formation in the area studied. However, 10 km west of Adıyaman (Karagöl and Kartaltepe areas) the formation is reported to include planktic foraminifera representative of the *Globigerinoides altiapertura*–*Catapsydrax dissimilis* and the *Globigerinoides trilobus* biozones of Early Miocene (Late Aquitanian–Burdigalian) age



**Fig. 7** Field photographs of the Arabian foreland succession; **a** pelagic limestones of Mid-Late Eocene Gaziantep Formation; **b** turbiditic clastics of the Early Miocene Lice Formation; **c** slump structures in the lower part of the Lice Formation; **d** shelly fossils in the neritic carbonates of the Early Miocene Fırat Formation; **e** transgres-

sive contact between the Miocene Lice Formation and the later Miocene Karaisali Formation (Reef Limestone), with the Şelmo Formation unconformably above; near the Küçüküngüt village; **f** oligomitic matrix-supported conglomerates of the Şelmo Formation (Pliocene?)

(Işık and Hakyemez 2010). In addition, benthic foraminifera in these sections indicate an Early Miocene age (Işık and Hakyemez 2010). The *Globoquadrina dehiscens*–*Globigerinoides altiapertura* sub-zone of inferred Early Aquitanian age was also tentatively identified near Kahramanmaraş (i.e. Soğukpınar area).

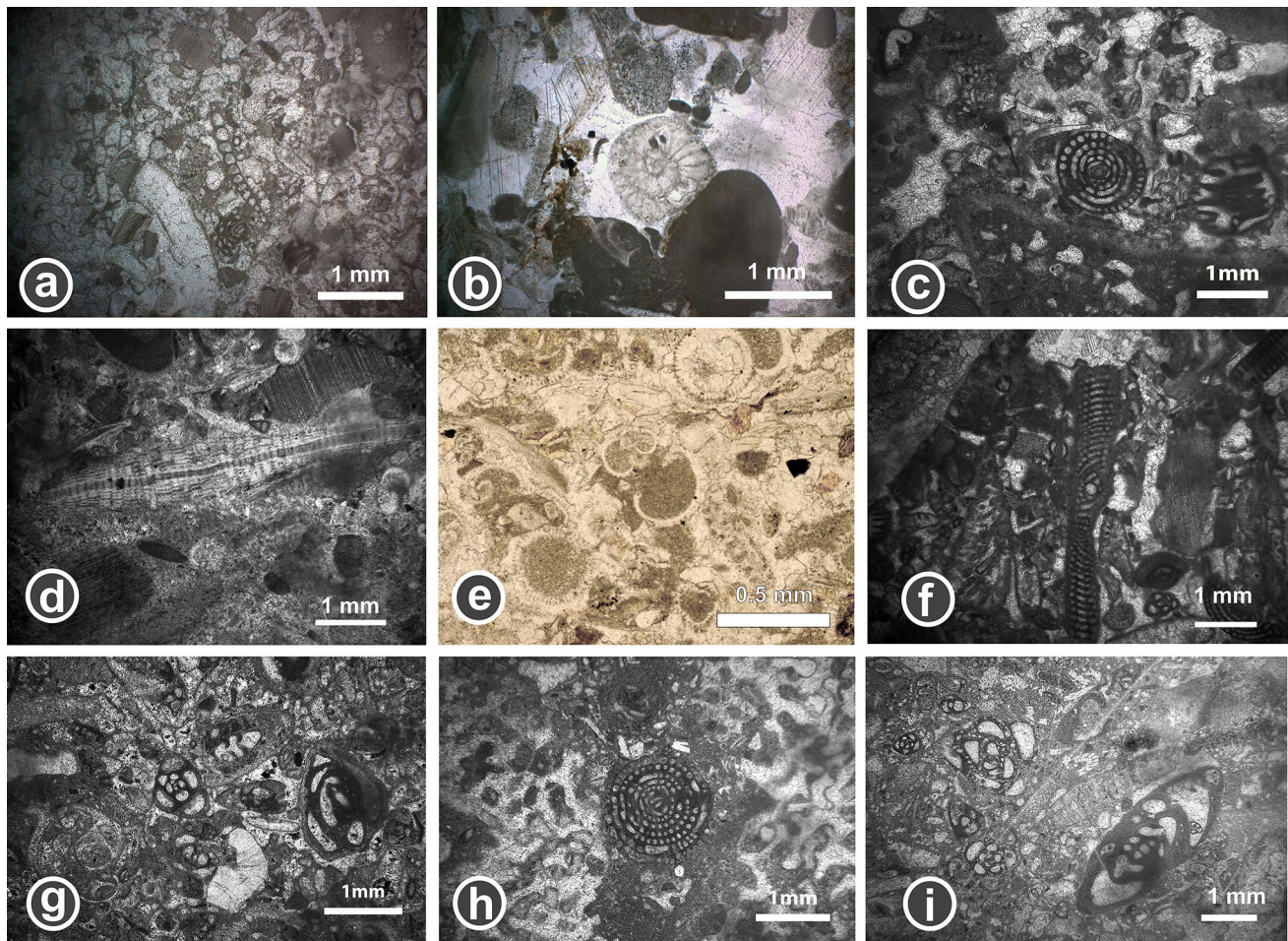
### Early Miocene Fırat Formation

In the south of the area, the Çağlayancerit Formation is transitionally overlain (over several metres) by shallow-water carbonates of the Fırat Formation (Fig. 3), as extensively exposed around the southern flanks of Öksüz Dağ

and near Küçüküngüt köy (Fig. 2). The Fırat Formation is dominated by medium- to thick-bedded bioclastic limestones, with abundant, variably reworked, pelecypods, gastropods, coral, echinoids, red algae and polyzoans (bryozoa).

The Fırat Formation is dated as Early Miocene (Aquitanian–Burdigalian) over large areas of SE Turkey (Duran et al. 1988, 1989). The following benthic foraminifera were identified from the study area: *Miogypsina* sp., *Europeritia* sp., *Lepidocyclina* sp., *Textularia* sp., *Miogypsinoides* sp., *Spherogypsina* sp., *Rotalidae* sp., *Sorites* sp., *Archeas* sp., *Austrorillina* sp., *Peneroplis* sp., *Miliolidae* sp., *Amphistegina* sp., *Hetereostegina* sp., *Operculina* sp., *Boralis* sp.





**Fig. 8** Photomicrographs of fossil content in the Firat Formation (a–b), the Early Miocene Lice Formation (c–f), and the Karaisalı Formation (g–i): **a** *Rhapidionina* sp., **b** *Heterostegina* sp., **c** *Borelis* sp.,

**d** *Lepidocyclina* sp., **e** *Globigerinoides* sp., **f** *Archeas* sp., **g** *Austrorillina* sp., **h** *Borelis* sp., **i** *Austrorillina* sp. (left) and *Peneroplis* sp. (right)

and *Rhapidionina* sp. (Fig. 8a, b). This assemblage encompasses Late Oligocene to Early Miocene ages, although it is assumed that the Oligocene taxa are reworked since the formation post-dates the underlying Çağlayancerit Formation.

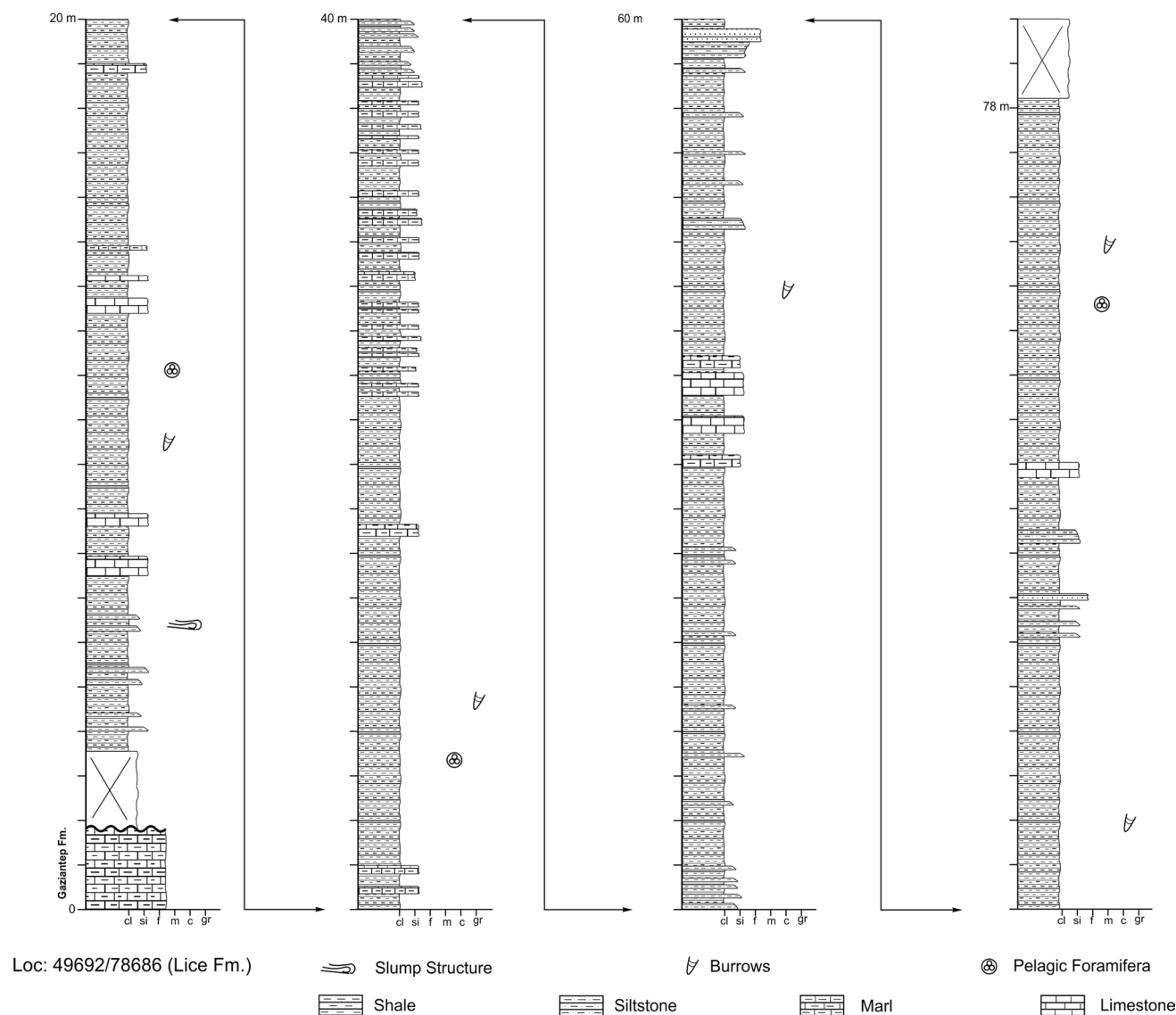
### Early Miocene Lice Formation

In the north of the area, the Gaziantep Formation is depositionally overlain by strongly contrasting terrigenous-carbonate sediments of the Lice Formation. The contact is a low-angle unconformity (3°–5°), as exposed near Çağlayancerit town centre and along the northern slope of Öksüz Dağ. The Lice Formation as a whole is well exposed in an E–W trending zone around Çağlayancerit town, along the Gölbaşı road and south of Öksüz Dağ (Figs. 1, 2).

The Lice Formation is a sequence of thin- to medium-bedded mudrocks (shale), siltstones, sandstones, marls and limestones (Fig. 7b). The maximum intact sequence in the study area is approximately 80 m (Fig. 9), although the

formation is very much thicker in adjacent areas (e.g. Gül et al. 2012). The sandstone beds are characterised by normal grading, bottom structures (e.g. groove and flute casts), bioturbation, microcross lamination and local convolute lamination. Bouma sequences (Bouma 1962) are rare, although B–D divisions occur within graded sandstones in the lower part of the succession. The tops of some beds are characterised by ripple marks, which are locally orientated approximately east–west. Marls and limestones containing planktic foraminifera are interbedded with the siliciclastic sediments in the lower to mid-parts of the sequence. Slump-deformed strata are present as 1- to 1.5 m-thick units near the base of succession, directly north of Çağlayancerit. The local slump-fold vergence is suggestive of southward sediment displacement.

Throughout SE Turkey the Lice Formation is dated as Early Miocene (Duran et al. 1988). During this work, the following benthic foraminifera were identified: *Peneroplis* sp., *Borelis* sp., *Archeas* sp., *Austrorillina* sp.,



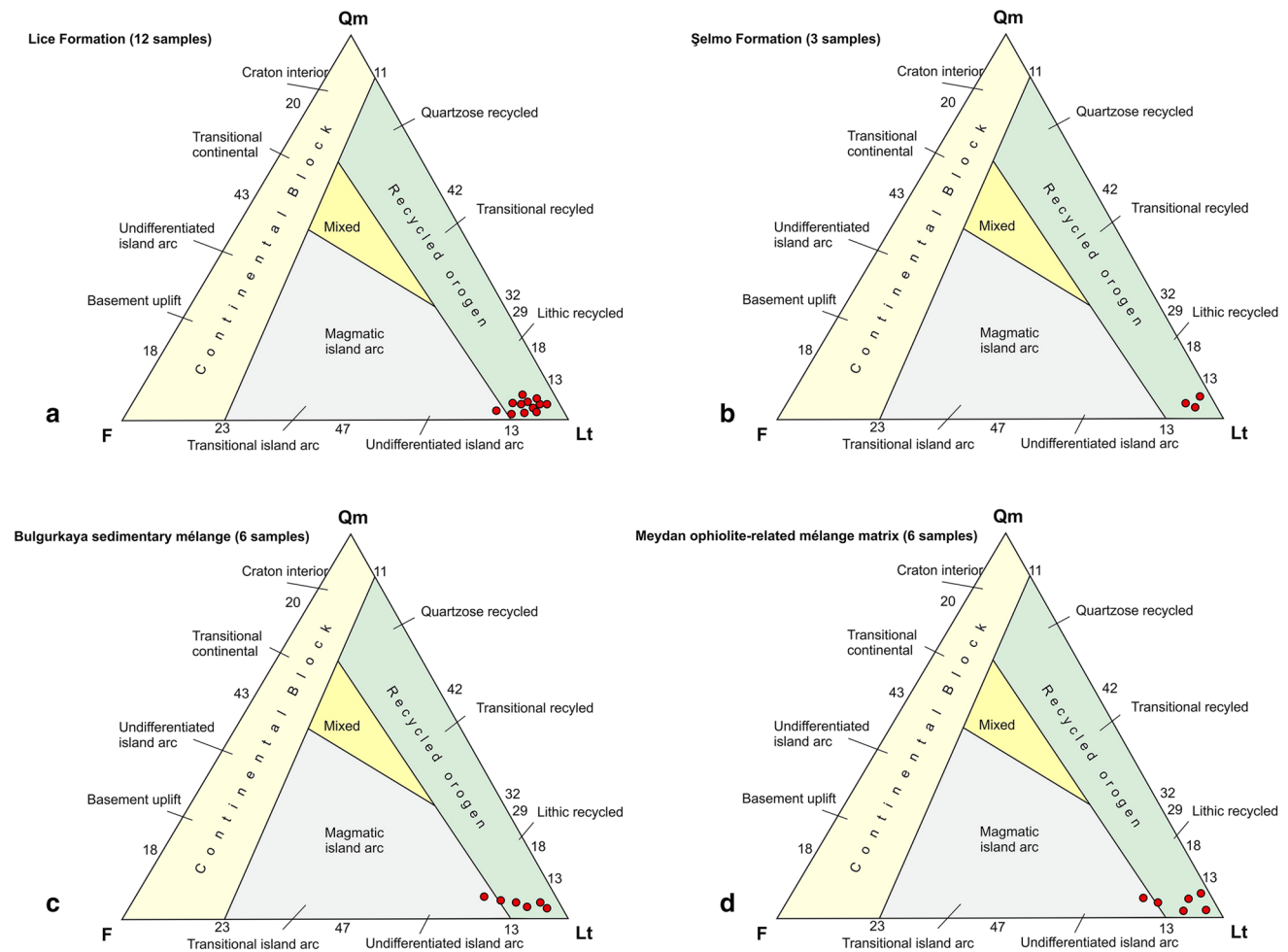
**Fig. 9** Sedimentological log of the Early Miocene Lice Formation; measured near Çağlayancerit town centre

*Miliolidae*, *Globigerinoides* sp., *Sphaerogypsina globulus* (Reuss), *Globigerina* sp., *Globorotalia* sp., *Rotaliidae* sp. In addition, a rich assemblage of planktic foraminifera was identified, including *Globigerina venezuelana* (Hedberg 1937), *Globigerina praebulloide* (Blow 1959), *Globigerina sellii* (Borsetti 1959), *Églobigerina binaiensis* (Koch 1935), *Catapsydrax dissimilis* (Cushman and Bermudez 1937), *Catapsydrax unicavus Bolli* (Loeblich and Tappan 1957), *Globorotaloides suteri* (Bolli 1957), *Paraggloborotalia nana* (Bolli 1957), *Ammonia* sp., *Amphistegina* sp., *Asterigerina* sp., *Lenticulina* sp. and *Gibicidoides* sp. The overall age range of the benthic and planktic foraminifera determined is Late Oligocene to Middle Miocene. However, several taxa indicate a specific Early Miocene age

(Fig. 8c–f); the Oligocene microfossils are assumed to be reworked.

Petrographic study of the sandstone revealed the following main grain types, in decreasing order of abundance: ophiolitic rock fragments (mostly serpentinite) (25–35 %), carbonate rock fragments (20–25 %), volcanic rock fragments (locally with plagioclase microlites) (15–20 %), intrusive igneous rock fragments (including large feldspar and quartz crystals) (10–15 %), feldspar grains (3–8 %), metamorphic-rock fragments (2–5 %) and quartz (1–3 %).

Representative samples of fine-grained sandstone (3 samples), medium-grained sandstone (7 samples) and coarse-grained sandstone (4 samples) were point counted using the method described by Dickinson et al. (1983). This



**Fig. 10** Petrographic point-count data for sandstones (using the methods of Dickinson et al. 1983 and Ingersoll et al. 1984). **a** Early Miocene Lice Formation; **b** Pliocene Şelmo Formation; **c** Bulgurkaya

sedimentary mélangé matrix (sandstone blocks); **d** Meydan ophiolite-related mélangé matrix (sandstone slices and blocks). See text for discussion

approach, known as the Gazzi–Dickinson method, maximises the source rock data while minimising the effects of grain-size variation (Ingersoll et al. 1984). This method considers quartz ( $Q$  = monocrystalline and polycrystalline), feldspar ( $F$  = plagioclase and alkaline feldspar) and lithic fragments ( $L$ ) as having sedimentary, metamorphic or igneous sources, respectively. The available data, when plotted on a  $Q$ – $F$ – $L$  diagram, indicate that the sandstones are strongly lithic, mostly plotting within the recycled orogen field (Fig. 10a).

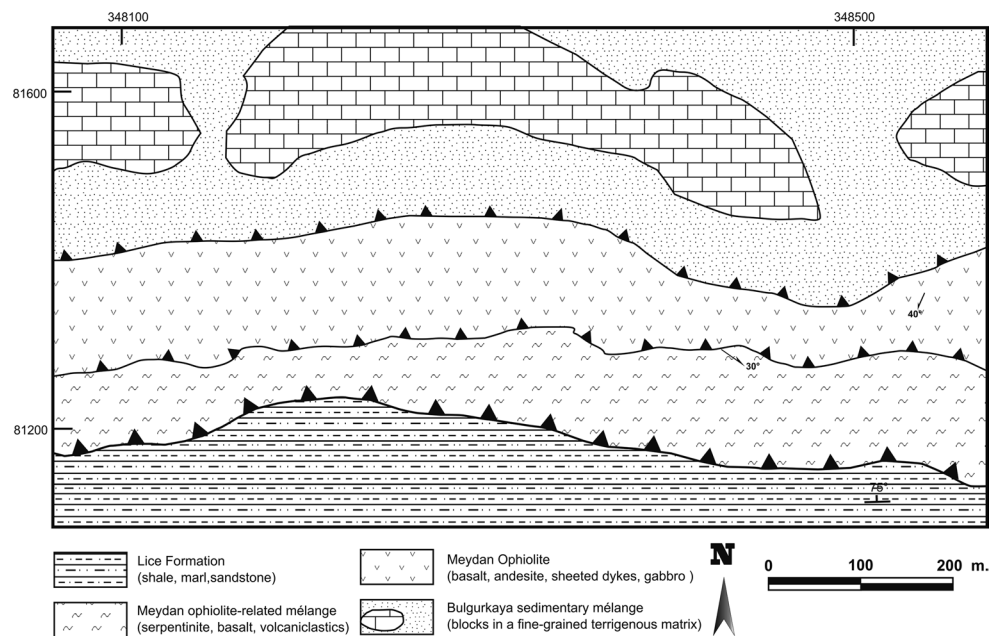
The Lice Formation as whole is folded on a large (up to kilometric) scale, together with the underlying succession. In addition, the formation is highly deformed in its upper part near the overlying allochthon, where low-angle thrusts, high-angle reverse faults, oblique-slip faults and both asymmetrical and overturned folds are present.

### Early Miocene Karaisalı Formation

Early Miocene shallow-water bioclastic carbonates, known as the Karaisalı Formation, conformably overlie the Çağlayanerit Formation. This formation is exposed in an E–W belt to the south of Öksüz Dağ. The underlying Lice Formation is unusually thin in this area, especially around Küçüküngüt (Fig. 7e). The Karaisalı Formation reaches an estimated maximum thickness of 25–30 m near Zeynepuşağı (Fig. 5b) and then thins eastwards over c. 10 km, until it disappears near Bayırlı (Fig. 2). The limestones are medium to thick bedded and include coral, pelceypods, calcareous algae and echinoderms, set in a sparry calcite cement. Reef limestones (patch reefs) are locally developed.

The Karaisalı Formation was previously dated as Burdigalian in other areas (e.g. Kahramanmaraş Basın) (Işık and

**Fig. 11** Large-scale geological map of a small part of the imbricate thrust zone (red box in Fig. 3)



Hakyemez 2010). During this work, the benthic foraminifera *Textularia* sp., *Asterigerina* sp., *Peneroplis* sp., *Austrotrillina* sp., *Boralis* sp., Miliolidae and Textularidae were identified from Fig. 8g–i, consistent with an Early Miocene age.

The Karaisalı Formation is deformed into a discontinuous broad (c. 1 km) syncline around Zeynepuşağı (Fig. 2). The fold limbs typically dip at 30–40° (e.g. around Zeynepuşağı) but are steeply dipping, vertical or even overturned in places (e.g. near Küçüküngüt).

### Şelmo Formation

The southern part of the area studied is dominated by poorly lithified, coarse-grained, terrigenous sediments of the Şelmo Formation (Fig. 3). This major depositional unit unconformably overlies Miocene units to the south of an imaginary line between Bozlar, Küçüküngüt and Zeynepuşağı (Fig. 2). A Late Miocene–Early Pliocene age has been inferred from plant spores and pollen (Çemen et al. 1990), although reworking is likely.

The Şelmo Formation is dominated by alternating conglomerates and sandstones, with an estimated total thickness of >130 m. Individual conglomerate packages are lenticular, typically several metres thick. The conglomerates are relatively massive, whereas cross-bedding is commonly well developed in the sandstones. The conglomerates are mostly clast supported, with a sandy matrix. The clasts are typically rounded to well rounded. Where observed, clast imbrication generally indicates southward palaeoflow. The clast composition is heterogeneous and includes limestone,

ophiolitic rocks (e.g. serpentinite, extrusive rocks) and metamorphic rocks (e.g. schist, marble, phyllite; Fig. 7f). Three samples of sandstone were point counted and these plot within the recycled orogen field (Fig. 10b).

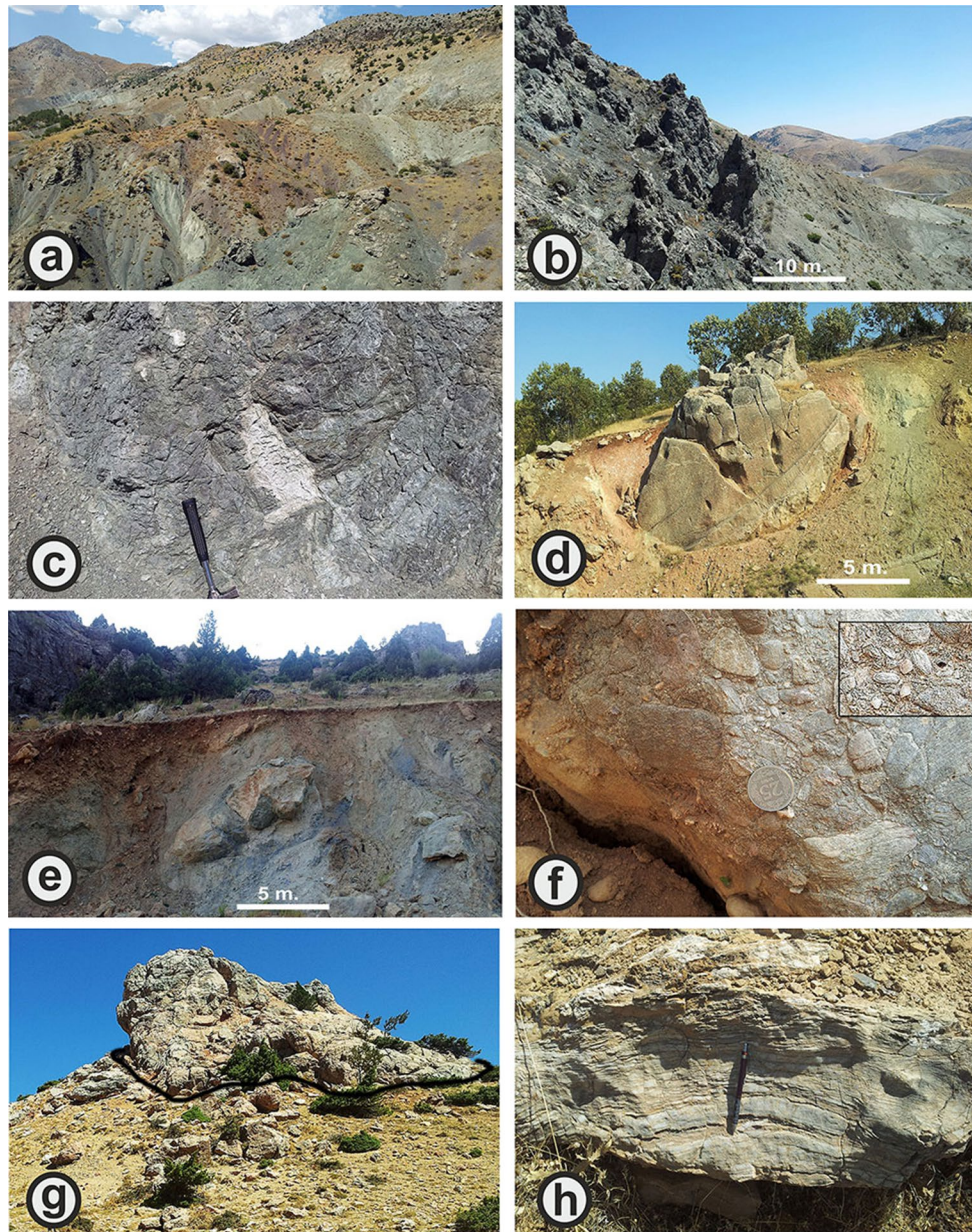
The Şelmo Formation is deformed into several large-scale (c. 1 km) symmetrical fold structures along E–W axes. In the west, the fold limbs dip at up to 30–40°. Eastwards, the folds become tighter with the fold limbs reaching dips of 80–85°, to overturned (e.g. around the Küçüküngüt village; Fig. 7e). Several E–W trending fault-bounded highs composed of reddish conglomerates and sandstones (e.g. Kandili Dağ) are covered by Plio-Quaternary alluvial deposits.

### Tauride allochthon

We now consider the individual units of the imbricate zone (Fig. 11) of the Tauride allochthon, moving structurally upwards.

### Igneous-sourced coarse clastic sedimentary rocks

The lowest allochthonous lithologies above the Miocene foreland succession (Lice Formation) are conglomerates and sandstones (up to 50 m thick), dominated by igneous rock detritus. A dismembered thrust sheet can be traced laterally for c. 600 m north of Çağlayancerit (Fig. 2). Additional very small outcrops occur north of Erince Dağ. The conglomerates are massive to very thick bedded and are matrix-supported, with mostly sub-rounded clasts set in a



**Fig. 12** Field photographs of the Tauride allochthon; **a** view of the Meydan ophiolite-related mélange, c. 2 km north of Çağlayancerit; **b** gabbroic rocks of the Meydan ophiolite, c. 2 km northwest of Çağlayancerit; **c** granitic intrusion within gabbroic rocks of the Meydan ophiolite; c. 2 km northwest of Çağlayancerit; **d** carbonate rock block in the Bulgurkaya sedimentary mélange; north of Erince Dağ; **e** block of recrystallised carbonate rock within a phyllitic matrix of the

Bulgurkaya sedimentary mélange; **c**. 1 km northeast of Küçükcerit village; **f** block of conglomerate with metamorphic-rock clasts and Eocene *Nummulites* (highlighted by box) within the Bulgurkaya sedimentary mélange, c. 1.5 km west of Küçükcerit; **g** pinkish–reddish coloured neritic carbonate block within the Bulgurkaya sedimentary mélange, c. 3.5 km northwest of the Helete; **h** foliated marble of the Malatya metamorphic unit; c. 2 km north of Engizek village

fine to medium-grained sandy-silty matrix. The detritus is mostly serpentinitised ultramafic rocks, mafic intrusive igneous rocks (e.g. diabase, gabbro, diorite) and altered extrusive igneous rocks (e.g. basalt, andesite). The sandstones include Eocene (Lutetian?) *Nummulites* sp., although these microfossils may be reworked.

### Eocene–Oligocene Bulgurkaya sedimentary mélange

The Bulgurkaya sedimentary mélange is dominated by blocks (typically up to tens of metres in size) and dismembered thrust sheets (up to hundreds of metres long by 10 s of metres thick), within a relatively fine-grained

sedimentary matrix (Fig. 12d, e). Both metamorphosed and unmetamorphosed rocks are present. The metamorphic rocks are mostly marble, calcschist, micaschist and phyllite, whereas the unmetamorphosed rocks are mostly limestone, marl, conglomerate, sandstone and shale (Fig. 12h).

Within the area mapped (Fig. 2), the sedimentary *mélange* differs in structure and composition from the north to the south of its outcrop. In the north, close to the overriding Malatya metamorphic thrust sheet, the unit has many of the characteristics of a broken formation (Fig. 5a, c). It is difficult to recognise any sedimentary matrix between what are effectively faulted and folded thrust sheets. In contrast, in the south, the exposure is characterised by isolated blocks and dismembered thrust sheets within a relatively fine-grained sedimentary matrix.

Local sedimentary sequences are recognisable within some of the larger blocks and dismembered thrust sheets. For example, reddish coloured, poorly stratified conglomerates with abundant metamorphic-rock pebbles (e.g. marble, calcschist, Fig. 12f) are present within the upper part of the *mélange*. These conglomerates are interbedded with reddish coloured limestone and marl.

In the east of the area, where well exposed (e.g. in quarries), some of the relatively fine-grained material in the *mélange* is seen to comprise well-bedded claystone–siltstone–fine sandstone alternations, up to tens of metres thick and traceable several hundred metres laterally. On the other hand, local outcrops, as little as 20 m apart, commonly dip at different angles without evidence of folding.

The *mélange* includes at least one large block/sheet of schist–psammite–marble, several hundred metres long by tens of metres thick, which directly underlies the Malatya metamorphic unit (near Küçükcerit; Fig. 2). This body of rocks lies within the uppermost part of the *mélange* in the west but is in direct fault contact with the Malatya metamorphics in the east. Within this unit, the metamorphic rocks are unconformably overlain by crudely stratified, unmetamorphosed conglomerates (c. 40 m thick). The conglomerates are composed of sub-angular to sub-rounded clasts (up to 0.4 m across) of metamorphic rocks, typical of the Malatya metamorphic unit. This local outcrop is important because it preserves a fragment of the original post-exhumation sedimentary cover of the Malatya metamorphic unit. Blocks of conglomerate of similar composition, but without preserved underlying metamorphic rocks are common within the *mélange* as a whole.

The Bulgurkaya sedimentary *mélange* has a relatively fine-grained matrix of shale, marl, phyllite and sandstone, which is abundant in the south, although rarely well exposed (Fig. 12e). The sandstones are normally-graded and are inferred to be gravity flows. Igneous-derived grains are abundant (>30 %), many of which are ophiolite derived (e.g. serpentinite, serpentinitised harzburgite, gabbro). Six sandstone

samples were point counted using the previously described method, indicating a Lithic recycled provenance (Fig. 10c).

Some of the limestone blocks were found to include the Foraminifera *Rugoglobigerina rugosa* (Plummer), *Globotruncanita* sp., *Contusotruncana fornicata* (Plummer), *Pseudotextularia elegans* (Rzehak) and *Pseudotextularia elegans* (Rzehak) fossils (Fig. 13c–f), indicative of a Maastriichtian age. In addition, some other carbonate units contain *Spherogypsina globula* and *Nummulites* sp. (Fig. 13a, b) of Eocene age. The reddish coloured matrix of the interbedded conglomerates also includes *Nummulites* sp.

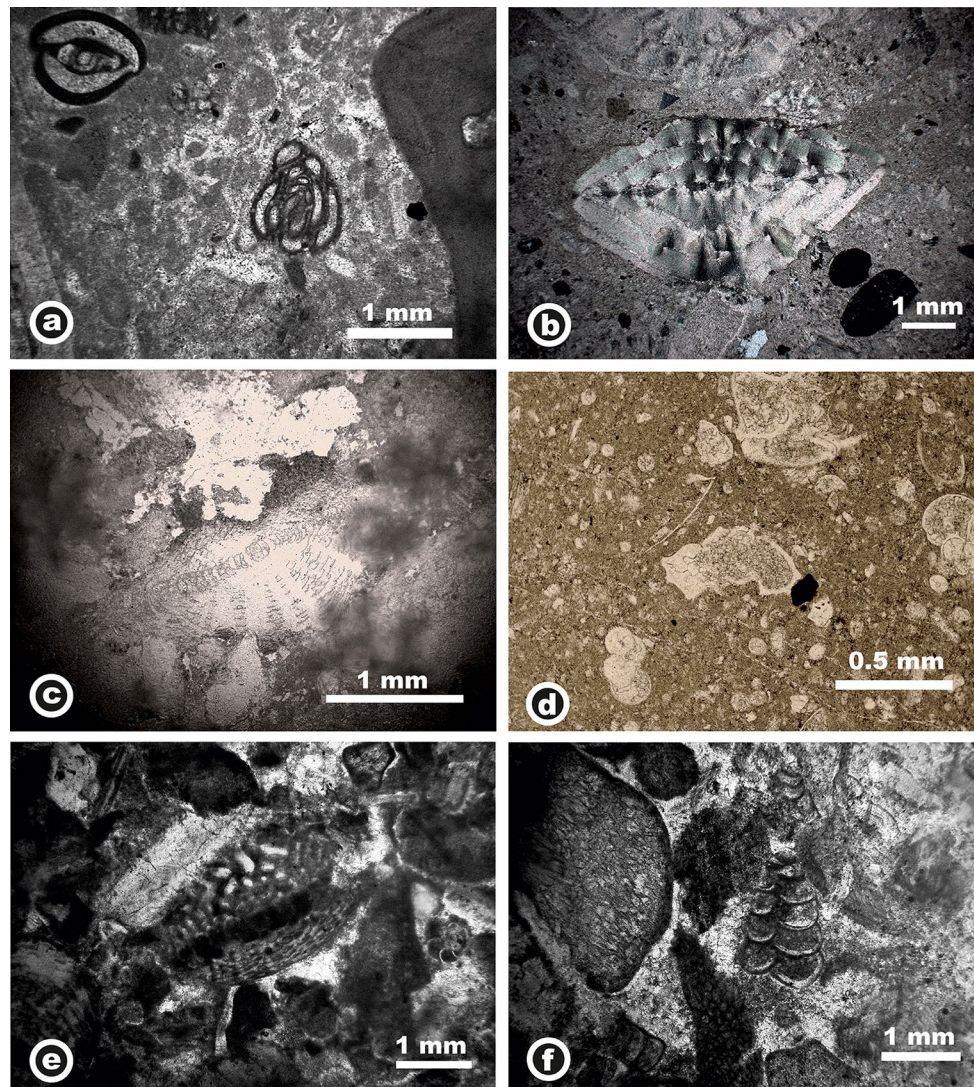
In previous studies, a key locality (Tülücüler) 40 km SE of Andırın/Kahramanmaraş yielded an Eocene foraminiferal assemblage: *Globigerina linaperta*, *Globorotalia centralis*, *G. cerroazulensis*, *G. pomeroli*, *G. cocaensis*, *G. increbescens*, *Hastegerina micra*, *Pseudohastegerina micra* (Kozlu 1997). In addition, an Oligocene foraminiferal assemblage is also present in the same area, based on: *Epidocyclina dilatata*, *Globigerina angulisytyralis*, *G. rohni*, *G. ciperoensis*, *G. ampliapertura*, *G. sellii*, *Globorotalia increbescens*, *G. opima* and *Globorotalia* sp.

In summary, the known age of deposition of the sedimentary blocks and dismembered thrust sheets of the Bulgurkaya sedimentary *mélange* is Late Cretaceous and Eocene. The matrix is likely to be Eocene–Oligocene.

### Late Cretaceous(?) Meydan ophiolite-related *mélange*

The structurally overlying ophiolitic *mélange* (Figs. 2, 3) is dominated by dismembered thrust sheets and blocks of extrusive igneous rocks (basalt, spilite, andesite), sheeted dykes and gabbroic rocks (e.g. troctolite) (Fig. 12a). The structurally lower part of the *mélange* in the south is dominated by serpentinitised harzburgite, whereas extrusive rocks are relatively more abundant at higher levels, further north. The igneous rocks represent a dismembered ophiolite, which is locally cut by tiny (0.5–2 m) granitic intrusions. Much larger granitic intrusions cut more intact ophiolitic rocks of inferred Late Cretaceous age directly east of the study area (Nurlu et al. 2015). There are also numerous blocks of pelagic limestone, redeposited limestone (calcarenite), neritic limestone, marble, volcanogenic sandstone and matrix-supported conglomerate.

Some of the conglomerates contain clasts of metamorphic rocks (e.g. marble, schist, phyllite), whereas others are rich in limestone clasts. The sandstones include the detritus of carbonate rocks, volcanic rocks, radiolarian chert and serpentinite, set in carbonate cement. These clastic sedimentary rocks include large Foraminifera of Eocene age (e.g. *Discocyclina* sp., *Asterigerina* sp., *Rotula* sp., *Textularia* sp., *Nummulidae*; Fig. 13c). Six sandstones were point counted, with the results indicating a Lithic recycled source area (Fig. 10d).



**Fig. 13** Photomicrographs of foraminifera from the Bulgurkaya sedimentary mélange. **a, b** From block of Eocene age (~Seske Formation); **c–f** from blocks of Maastrichtian age (~Harami Formation).

**a** *Spherogypsina globula*, **b** *Nummulites* sp., **c** *Orbitoides medius*, **d** *Contusotruncana fornicata* (Plummer) 1931, **e** *Orbitoides medius*, **f** *Pseudotextularia elegans* (Rzehak) 1891

The Meydan ophiolite-related mélange is variably sheared and commonly strongly altered. The blocks and dismembered thrust sheets, especially in the structurally higher part of the mélange, are separated by discontinuous, low-angle to high-angle thrusts and reverse faults (Fig. 11). A weak schistosity is developed along some tectonic contacts but otherwise brittle deformation dominates. Where present, the tiny granitic intrusions are sheared and faulted together with the surrounding mélange.

#### Late Cretaceous(?) Meydan ophiolite

The ophiolite-related mélange is overlain by the Meydan ophiolite, a unit of sheared and dismembered ophiolitic

rocks. In the type area of c. 15 km east of Çağlayancerit, similar ophiolitic rocks are inferred to be Late Cretaceous, based on the radiometrically determined ages of cross-cutting granitic intrusives (Nurlu et al. 2015). The Meydan ophiolite includes extrusive rocks (basaltic, andesite, silicic rocks), sheeted dykes, both massive and layered gabbro and serpentinised ultramafic rocks (Fig. 12b). In places, the volcanic rocks are cut by felsic dykes (Fig. 12c). In some areas (e.g. north of Çağlayancerit), the outcrop is dominated by sub-vertical slices of ophiolitic rocks, mostly less than 8 m wide. Elsewhere, larger intact exposures are present, e.g. serpentinite (2 km NW of Çağlayancerit). Many of the ophiolitic lithologies are strongly sheared, especially close to tectonic contacts.

## Discussion and interpretation

The tectono-stratigraphy was assembled from the structural top downwards, i.e. from the Malatya metamorphic sheet at the top to the Arabian foreland at the base, as discussed below.

### Tauride continental units

The Malatya metamorphic unit is interpreted as part of the Tauride continent, of Late Palaeozoic–Mesozoic age (Özgül 1981; Perinçek and Kozlu 1984; Yazgan 1984; Yılmaz and Yıldırım 1996; Yılmaz 1999; Robertson et al. 2004, 2006; Bedi et al. 2005, 2012). The Malatya metamorphic unit rifted from Gondwana during the Triassic to form a microcontinent within the Southern Neotethys (e.g. Yılmaz et al. 1993a, b; Robertson et al. 2012, 2015b). The Malatya continental rocks were metamorphosed to at least greenschist facies during the Late Cretaceous as the result of deep burial. Exhumation took place during latest Cretaceous–Palaeogene time based on the age of the oldest sedimentary cover in different areas. Details of the timing and processes of metamorphism and exhumation are, however, outside the scope of this work.

### Bulgurkaya sedimentary mélangé

The origin of the Eocene and Late Cretaceous sequences represented by the blocks and dismembered thrust sheets requires explanation, as does the setting of the formation of the melange matrix.

Many of the dismembered thrust sheets and blocks are composed of relatively fine-grained, mixed carbonate-siliciclastic sediments, which contain Middle Eocene *Nummulites*. These lithologies are similar to the Seske Formation, of which the type area is located further east in the Elazığ Region (Erdoğan 1975). The Seske Formation unconformably overlies the Malatya metamorphic rocks in many areas to the north of our study area (e.g. Robertson et al. 2006; Bedi et al. 2009). In addition, in the southern part of the Engizek Mountains, adjacent to our area, the lowest part of the Malatya metamorphic cover includes conglomerates known as the Gözülü Formation (Yılmaz et al. 1987). Recently, the Gözülü Formation was correlated with the lowest part of the Seske Formation and termed the Göllüpinar Yayla Member (Bedi 2009). This is important because in our area the locally observed, unit of Malatya metamorphic rocks at the highest level of the Bulgurkaya sedimentary melange includes transgressive metamorphic-rock-derived conglomerates. In our study area, the Malatya metamorphic rocks were transgressed by metamorphic-rock-derived conglomerates and are then likely to then

passed upwards into Eocene shelfal marls and limestones (~Seske Formation). The Eocene blocks and dismembered thrust sheets are therefore interpreted as the remnants of an upper-plate sedimentary sequence, which later underwent mass wasting and incorporation into the Bulgurkaya sedimentary mélangé.

The Late Cretaceous limestones and marls in the Bulgurkaya sedimentary mélangé can be correlated with a thrust sheet of similar rocks beneath the Malatya metamorphic unit, directly east of our study area (Erdoğan 1975; Nurlu et al. 2015). These Late Cretaceous carbonate rocks have been correlated with the Harami Formation, for which the type area is in the Elazığ area of SE Turkey, c. 200 km to the east of our study area. The Harami Formation is made up of Late Maastrichtian shallow-water marls and limestones that unconformably overlie Late Cretaceous ophiolitic rocks, comparable with the Meydan ophiolite (Yılmaz et al. 1992, 1993a, b; Robertson et al. 2006; Bedi et al. 2009). It is, therefore, possible that the Late Cretaceous shallow-water carbonates and marls of the Bulgurkaya sedimentary mélangé originated similarly as the sedimentary cover of an ophiolite. Such cover sediments would have accumulated after an ophiolite was accreted to the overriding plate and uplifted during latest Cretaceous time. Any such underlying ophiolite was, however, later structurally removed because intact ophiolitic rocks (as opposed to ophiolite-related detritus) are not exposed within the Bulgurkaya sedimentary mélangé in the area studied. In summary, whatever the local setting, the Eocene and Late Cretaceous mainly shallow-water carbonate rocks were derived from the overriding plate of the subduction zone.

The matrix of the sedimentary mélangé is mostly mudrock of inferred distal terrigenous origin, hemipelagic marl and relatively rare sandstone turbidites. The fine-grained calcareous sediments have been dated as Eocene–Oligocene in several areas (Yılmaz and Gürer 1996; Kozlu 1997; this study).

The Bulgurkaya sedimentary mélangé has been interpreted as a type of subduction complex related to the later stages of northward closure of the Southern Neotethys, with the Tauride continental unit (Malatya Metamorphics) as the backstop to the north (Robertson et al. 2004, 2006, 2007). However, the Bulgurkaya sedimentary mélangé is unusual for a subduction complex because most of the exotic material appears to have been derived from the overriding plate rather than the subducting plate (Robertson et al. 2004). On the other hand, the fine-grained matrix sediments (Eocene–Oligocene) accumulated in a relatively deep-water setting, probably a subduction trench, followed by accretion within the sedimentary mélangé. Where present, the low-grade phyllite could have resulted from intense shearing along décollement surfaces during the subduction process.



There are several possible explanations for the origin of the Bulgurkaya sedimentary melange. (1) The subduction décollement was located at a relatively high position in the subduction trench such that the oceanic crust and its deep-sea sedimentary cover entirely subducted. However, this by itself cannot explain the origin of the Bulgurkaya sedimentary melange; (2) oversteepening and collapse of the leading edge of the overriding plate as a result of a change in subduction wedge geometry (e.g. Platt 1986), for example, resulting from a change in the rate of subduction, the direction of convergence or the dip of the subducting slab, although such parameters are difficult to define in a suture zone; (3) subduction erosion is known from several modern active continental margins, notably the Middle America trench (e.g. von Huene et al. 2004; Clift and Vanucchi 2004). The locus of bending of the downgoing oceanic slab can migrate continentwards with time causing net removal of the overriding continental backstop. Subduction erosion could explain the apparent absence of the inferred continental or ophiolitic basement of the Eocene and Late Cretaceous sedimentary sequences. However, large-scale subduction erosion would be expected also to remove all accretionary material (including ophiolites), which is not observed. Also, rollback, rather than rollforward, of the subducting plate would be expected during late-stage subduction when cold, old oceanic crust is likely to have entered the trench; (4) collision—during early-stage collision, the Tauride backstop began to be dismembered and thrust southwards. The leading edge of the allochthon collapsed to form the sedimentary melange. However, collision was, at most, incipient during Eocene–Oligocene, whereas large-scale thrust emplacement over the Arabian foreland mainly was delayed until the Early-Mid-Miocene. In all of the above options, the sedimentary melange was dominated by upper-plate material, allowing little opportunity for underlying oceanic crust and pelagic sediments (e.g. Cenozoic oceanic sediments) to be accreted. This may explain why there is no known evidence of accretion of Neotethyan oceanic crust after Late Cretaceous time.

In the regional context, model 2, a change in the accretionary prism geometry, is a promising explanation for the Bulgurkaya sedimentary melange. A comparable sedimentary melange is located on strike to the west in the Kyrenia Range of northern Cyprus, known as the Kalograi-Ardana Formation (~Baçeli-Ardahan Formation), where it is well dated as Middle Eocene in age (Robertson et al. 2014). This sedimentary melange (~olistostrome) includes blocks of Late Palaeozoic–Mesozoic shelf carbonates, Palaeogene pelagic carbonates, mafic volcanics and also volumetrically minor ophiolitic rocks. Although the composition and age of the two sedimentary melanges are not identical, their origins may be similar. The north Cyprus sedimentary melange formed during or very soon after the suturing of the

İzmir–Ankara–Erzincan ocean in central Anatolia. As a result, the entire Africa–Eurasia plate convergence became focussed along the Southern Neotethyan active continental margin for the first time. In response to accelerated subduction and possible oceanic plate rollback, the northern continental margin oversteepened and repeatedly collapsed to form sedimentary melange (Robertson et al. 2014). A similar mode of formation may apply to the Bulgurkaya Formation, although its formation appears to have been more long-lived (Eocene–Oligocene).

### Oceanic-derived units

The Meydan ophiolitic rocks, which are exposed beneath the Bulgurkaya sedimentary melange, are interpreted as oceanic crust and mantle that formed by spreading above a subduction zone during the Late Cretaceous. This is based mostly on mineralogical and geochemical evidence from more widely exposed and intensively studied outcrops further east (Nurlu et al. 2015). Geochemical studies of the correlative Koçali ophiolite further east in the Adıyaman area indicate a supra-subduction zone origin (Yıldırım et al. 2012). Within our study area, the ophiolitic rocks are locally cut by small bodies of granitic rocks. In the more easterly outcrop, similar, but larger, granitic rocks were recently dated as Late Cretaceous ( $92.9 \pm 2.2$ – $83.1 \pm 1.5$  Ma; Cenomanian–Campanian) by the U–Pb isotopic method, using extracted zircons. The granites are interpreted as representing part of a Late Cretaceous magmatic arc (Nurlu et al. 2015).

The above age results imply a Late Cretaceous (or possibly older) age for the genesis of the Meydan ophiolite. The underlying Meydan ophiolite-related mélangé contains a similar range of ophiolitic rocks to the Meydan ophiolite and is, therefore, interpreted as highly deformed lithologies related to the same ophiolite.

The Eocene shallow-water limestones, sandstones and conglomerates of the Meydan ophiolite-related mélangé are interpreted as the remains of a cover unit, similar to that inferred for the Bulgurkaya sedimentary melange (see above). The source of the sandstones includes intrusive ophiolitic rocks, deep-sea sediments (radiolarites) and volcanic rocks of uncertain provenance. In addition, the marble blocks are likely to have been sourced from the Tauride continent, represented by the Malatya metamorphic unit. The larger outcrops of ophiolitic rocks and ophiolite-related mélangé that are exposed directly east of the study area include Middle Eocene transgressive volcanogenic sandstones and *Nummulites*-rich limestones (Robertson et al. 2006; Nurlu et al. 2015). Some of the *Nummulites*-bearing sandstones and limestones in the mélangé could have a similar origin.

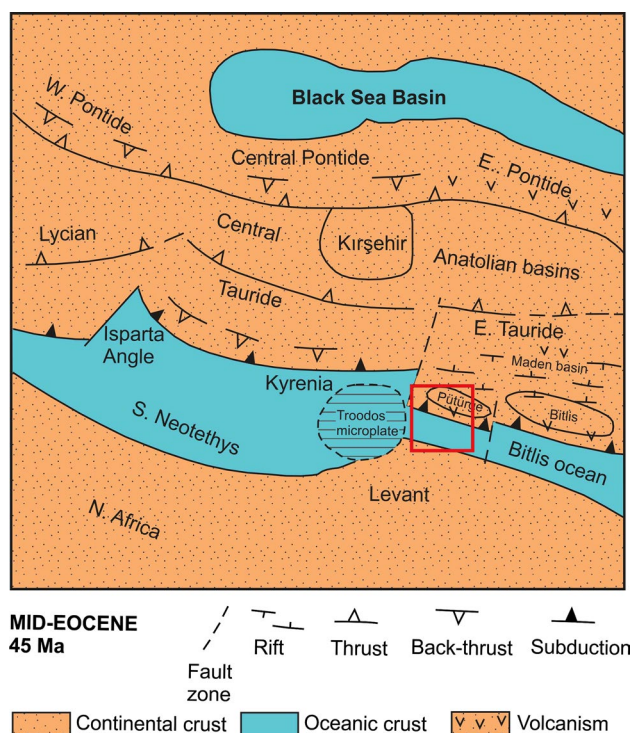
It is likely that the Meydan ophiolite-related mélangé has a composite origin, including fragments of a supra-subduction zone ophiolite, its Eocene cover and accretionary material. The presence of abundant metamorphic-rock debris in Eocene sediments suggests that the mélangé had accreted to the Tauride continental backstop by this time. The shearing and imbrication resulted from the combined effects of initial accretion along the Tauride active margin, incorporation into the Tauride thrust stack and final emplacement onto the Arabian foreland.

The coarse clastic sediments at the base of the allochthon could represent a fragment of the Early Miocene Çüngüş Formation, which is interpreted as a northerly (proximal) facies equivalent to the Miocene Lice Formation (Perinçek 1979). These deposits would have accumulated on the foreland before being accreted to the base of the overriding allochthon.

### Arabian Foreland succession

The Eocene *Nummulites*-bearing neritic limestones record shallow-water carbonate deposition throughout southeast Turkey (Perinçek 1978; Görür et al. 1981; Çemen 1986). The low-angle unconformity beneath the Mid-Late Eocene hemipelagic carbonates (Gaziantep Formation; Fig. 3) could reflect a change in regional convergence (e.g. accelerated subduction) that affected the southern margin of the Southern Neotethys (Robertson et al. 2015a) during the time when the Bulgurkaya sedimentary mélangé was forming along the northerly, active margin of the Southern Neotethys. The Gaziantep Formation records submergence and relatively deep-water carbonate accumulation in a setting of high organic productivity that favoured diagenetic chert formation. A major stratigraphic hiatus followed during the Oligocene. Low-angle tilting took place prior to the resumption of shallow-marine deposition, marked by the Early Miocene Çağlayançerit and Lice Formations.

The northern part of the foreland submerged strongly during the Early Miocene to form a relatively deep-water basin, which infilled with gravity flows, mostly thin- to medium-bedded turbidites and hemipelagic shales/mudstones (Lice Formation). Facies evidence is suggestive of a submarine fan setting sediments in a relatively sediment-starved part of the foreland basin. A very much thicker and more diversified submarine fan complex is present in the Kahramanmaraş Basin further west (Gül et al. 2003a, b). The petrographic evidence from our area indicates that the clastic material was derived from the overriding thrust sheets, including the ophiolite-related rocks and the Malatya metamorphic unit. In addition, sparitic carbonate intraclasts (<10 % by volume) could have been derived from uplifted foreland units (e.g. Gaziantep or Hoya



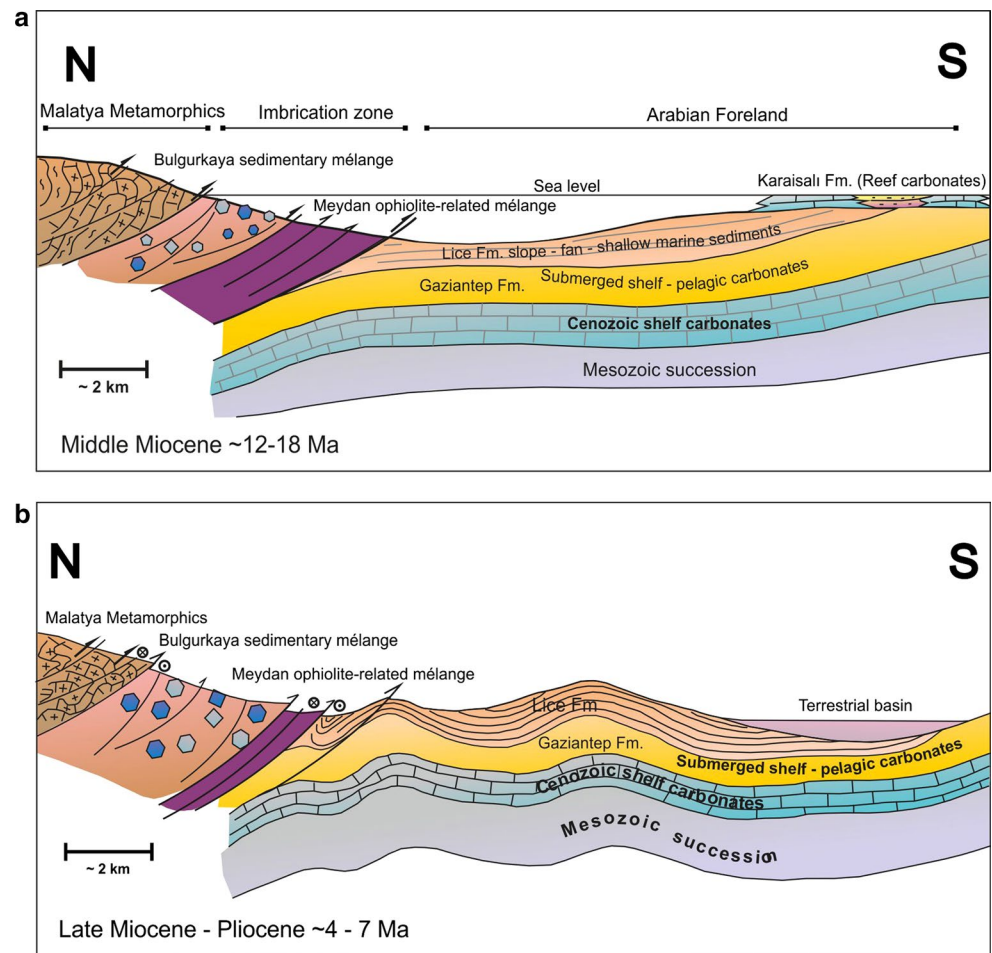
**Fig. 14** Palaeogeographical map for the Mid-Eocene. Note that the Southern Neotethys (~Bitlis ocean) is largely subducted but not yet sutured. Other ocean basins within Turkey are by then sutured causing all of the convergence of the Eurasian and African plates to be accommodated along the northern active continental margin of the Southern Neotethys. This was the regional setting for the development of the large-scale Bulgurkaya sedimentary mélangé (~olistostrome)

Formations). The Early Miocene basin was tectonically unstable resulting in slumping, mostly near the base of the succession. The basin shallowed upwards overall because the interbedded marls show an incoming of neritic biota towards the top of the succession. Further south, bioclastic carbonates accumulated contemporaneously, represented by the Early Miocene Karaisalı Formation.

During the Early Miocene, the northerly, leading of the Arabian foreland subsided strongly to become a peripheral foreland basin (Fig. 14a). In the north, bioclastic shallow-water carbonates initially accumulated (Çağlayançerit Formation). This was followed by the accumulation of terrigenous gravity flows derived from the overriding Tauride allochthon (Lice Formation).

Final suturing of the Southern Neotethys is interpreted to have occurred during the Early to Mid-Miocene when the Tauride continent (Malatya Metamorphic unit) overrode the Arabian foreland (Figs. 14b, 15a). The footwall, represented by the upper part of the Lice Formation, was strongly deformed. Faulting and folding extended downwards into the older foreland succession near the thrust front.

**Fig. 15** Development of the collision zone. **a** Mid-Miocene thrusting of the Tauride allochthon over the Early Miocene foreland basin (Lice Formation); **b** Late Miocene post-suture tightening of the foreland; thrusting had by then ended and was followed by regional-scale folding of the foreland and the allochthon together



After emplacement ended, the Miocene units were covered by the mainly fluvial sediments of the Late Miocene–Pliocene? Şelmo Formation. These sediments and their substratum were folded, faulted and uplifted along approximately east–west axes, probably during Late Miocene–Pliocene time (Fig. 15b). The resulting structures include large-scale Zagros-type whale-back-type folds in the north and smaller-scale more open folds, coupled with high-angle faults, further south (Fig. 2). The Plio-Quaternary was characterised by fluvial and lacustrine deposition in the south of the study area (e.g. near Gölbaşı; Fig. 1). The Late Miocene–Pliocene sediments were truncated and displaced by strike slip related the East Anatolian Transform Fault (Arpat and Şaroğlu 1972; Şengör et al. 1985; İmamoğlu 1993; Herece 2008; Duman et al. 2013).

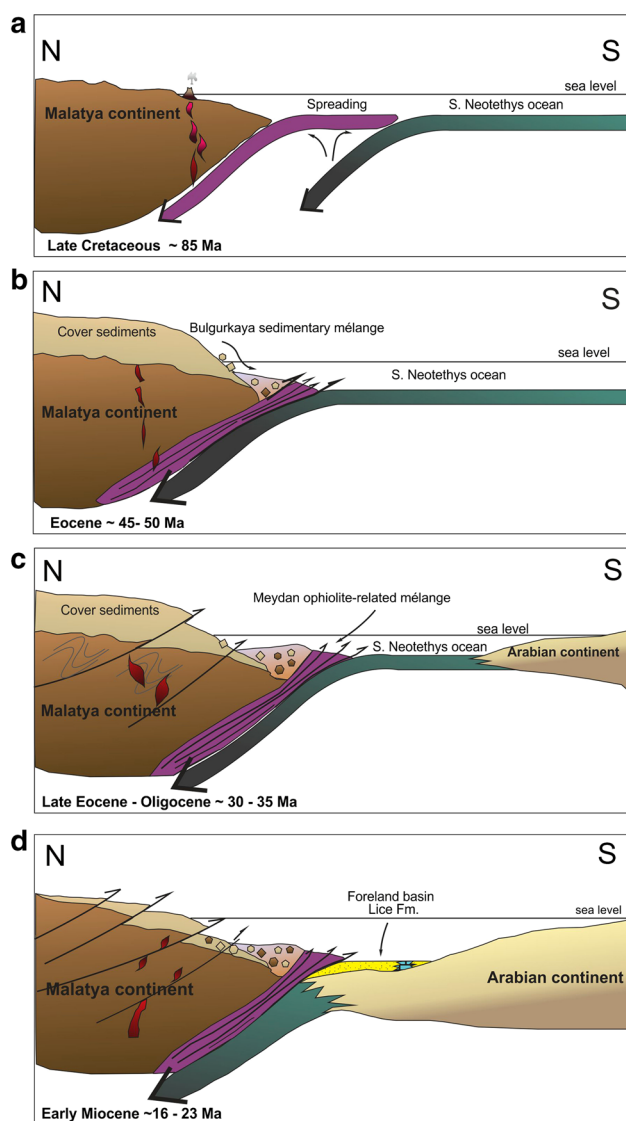
### Tectonic model

The assembled information and interpretations can be used to develop a tectonic model for the Late

Mesozoic–Cenozoic subduction and collision history of the Southern Neotethys in the area studied, which may be applicable to SE Turkey and beyond (Fig. 16).

Subduction is inferred to have taken place beneath the Tauride continental margin during the Late Cretaceous (Fig. 16a). The ophiolitic rocks are assumed to have formed by spreading above an intra-oceanic subduction zone, although the processes involved are outside the scope of this study (see Nurlu et al. 2015). The supra-subduction zone ophiolites are inferred to have accreted to the Tauride active margin during latest Cretaceous time, while the Southern Neotethys remained partially open to the south.

During the Eocene–Oligocene, further northward convergence lead to the development of the Bulgurkaya sedimentary mélangé as a type of subduction complex (Fig. 16b). The exotic material was mostly derived by the gravitational collapse of the backstop, represented by the already exhumed Malatya metamorphic rocks and their inferred Late Cretaceous–Eocene cover sediments. In addition, some of the exotic material (e.g. detrital radiolarian



**Fig. 16** Tectonic model for the development of the south-eastern Anatolian thrust belt, based on evidence from the study area and the adjacent region. **a** Late Cretaceous. Two subduction zones are active, one within the Southern Neotethys related to genesis of the Meydan ophiolite and one along the southern margin of the Tauride continent giving rise to arc magmatism, **b** Northerly oceanic crust accreted to the Malatya continent while southerly oceanic crust still subducted, **c** development of the Bulgurkaya sedimentary mélange above the melange and the ophiolitic units, **d** flexural subsidence of the Arabian foreland and formation of the Lice foreland basin

chert) was probably derived from subducting oceanic crust (Fig. 16c).

The Arabian foreland underwent shallow-water deposition during the Eocene (Hoya Formation), followed by gentle tilting, possibly in response to pre-collisional flexural deformation, then submergence and hemipelagic carbonate deposition (Gaziantep Formation). A period of non-deposition and gentle tilting followed, probably during

the Oligocene, resulting in emergence and non-deposition. The pre-Early Miocene low-angle unconformity can be explained by southward migration of a flexural forebulge (Robertson et al. 2004; 2015a). This was caused by the collision of the Arabian continent with the northerly, active (Tauride) continental margin of the Southern Neotethys (Robertson et al. 2015a, b; Fig. 16d). The Early Miocene foreland basin is, therefore, interpreted as the product of the collision of the Tauride and Arabian continental units (Robertson et al. 2015a; Fig. 15a, b).

During and after soon after collision, the Tauride allochthon was uplifted and subaerially exposed, giving rise to huge volumes of alluvial sediments. Further compression during Late Miocene–Pliocene resulted in large-scale E–W folding and faulting of the Arabian foreland and the adjacent Tauride allochthon. The compressional stress is assumed to have ceased prior to the left-lateral strike-slip, which accompanied the westward ‘tectonic escape’ of Anatolia along the East Anatolian Transform Fault Zone.

In summary, the new data and interpretations presented here for the Çağlayancerit area support and develop the interpretation of the Southern Neotethyan suture zone. However, no one area can supply all of the necessary information for the suture zone as a whole and additional evidence is needed from several areas including easternmost Turkey and NW Iran.

## Conclusions

The area studied in SE Turkey, around Çağlayancerit, provides excellent evidence of the later stages of the subduction, accretion and collision of the Southern Neotethys during Late Cretaceous–Cenozoic time.

- An imbricate stack of thrust sheets was finally emplaced southwards over the collapsed northern margin of the Arabian continent during the Early Miocene.
- The thrust stack is interpreted to have developed in response to northward subduction of the Southern Neotethys beneath a backstop represented by the Tauride microcontinent (Malatya metamorphic unit).
- The oceanic crust of the Southern Neotethys in the area studied is represented by a dismembered ophiolitic thrust sheet and an underlying ophiolite-related mélange.
- A sedimentary mélange (Bulgurkaya sedimentary mélange) developed along the Tauride active continental margin during Eocene–Oligocene time. The main process of formation was gravity collapse of the continental backstop and its sedimentary cover, while oceanic crust subducted.

- Tilting of the Arabian foreland during the Oligocene reflects early-stage collision of the Tauride and Arabian continents.
- As collision intensified, the Arabian shelf subsided to form an Early Miocene flexural foredeep (Lice Formation). Upflexed highs to the south were colonised by coral reefs.
- Final collision (Mid-Miocene) was followed by emergence and erosion of the Tauride thrust stack to form widespread alluvium. Post-suture shortening (Late Miocene–Pliocene) resulted in large-scale Zagros-type folding and faulting of the foreland.

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## References

- Aktaş G, Robertson AHF (1984) The Maden Complex, SE Turkey: Evolution of a Neotethyan continental margin. In: Dixon JE, Robertson AHF (eds) *The Geological Evolution of the Eastern Mediterranean*, vol 17. Geological Society, London, Special Publications, pp 375–402
- Arpat AE, Şaroğlu F (1972) Doğu Anadolu Fayı ile ilgili bazı gözlemler ve düşünceler. *MTA Dergisi* 78:44–50
- Bedi Y, Usta D, Özkan MK, Beyazpirinç M, Yıldız H, Yusufoglu H (2005) Doğu Toroslar'da (Göksun-Sarız-Elbistan) Allohton istiflerin tektonostratigrafik özellikleri. *TJK Bildiri Özleri* 58:262
- Bedi Y, Yusufoglu H, Beyazpirinç M, Özkan MK, Usta D, Yıldız H (2009) Doğu Torosların jeodinamik evrimi (Afşin-Elbistan-Göksun-Sarız dolayı). Maden Tetkik ve Arama Genel Müdürlüğü, Jeoloji Etütleri Dairesi, Rapor no. 11150, Ankara, 388 p
- Bedi Y, Yusufoglu H, Usta D, Okuyucu C (2012) The presence of the Aladağ and Yahyalı Nappes in the Eastern Taurides (Afşin-Malatya) and their tektonostratigraphic characteristics. In: Yalçın MN, Çorbacıoğlu H, Aksu Ö, Bozdoğan N (eds) *Paleozoic of Northern Gondwana and its Petroleum Potential*. Turk Assoc Petrol Geol Spec Publ, Vol 6. Ankara, pp 24–25 (**Extended Abstracts**)
- Beyarslan M, Bingöl AF (2000) Petrology of a Supra-Subduction Zone ophiolite (Kömürhan-Elazığ-Turkey). *Can J Earth Sci* 37:1411–1424
- Bilgin AZ, Elibol E, Bilgin ZR, Beğenilmiş S (1981) Ceyhan-Karataş Yumurtalık-Osmaniye-Haruniye-Kadirli dolayının Jeolojik Raporu. General directorate of mineral research and exploration, MTA Report No 7215 (unpublished)
- Boulton SJ (2009) Record of Cenozoic sedimentation from the Amanos Mountains, Southern Turkey: implications for the inception and evolution of the Arabia–Eurasia continental collision. *Sed Geol* 216:29–47
- Boulton SJ, Robertson AHF, Ünlügenç UC (2006) Tectonic and sedimentary evolution of the Cenozoic Hatay Graben, Southern Turkey: a two-phase, foreland basin then transtensional basin model. In: Robertson AHF, Mountrakis D (eds) *Tectonic evolution of the eastern mediterranean*, vol 260. Geol Soc, London, Spec Publ, pp 613–634
- Bouma A (1962) *Sedimentology of some flysch deposits: a graphical approach to facies interpretation*. Elsevier, Amsterdam
- Çemen İ (1986) Structural geology of the western part of the Arabian tectonic block: implications concerning petroleum potential of the region: TPAO Arama Grubu, Rapor No. 2239
- Çemen İ, Perinçek D, Ediger VŞ, Akça L (1990) Güneydoğu Anadolu'daki Bozova doğrultu atımlı fayı: üzerindeki ilk hareket ters faylanma olan faylara bir örnek. *Türkiye 8. Petrol Kongresi, Jeoloji Bildirileri*: 169–179
- Clift P, Vannucchi P (2004) Controls on tectonic accretion versus erosion in subduction zones: implications for the origin and recycling of the continental crust. *Rev Geophys* 42:2001. doi:10.1029/2003RG000127
- Derman AS, Akdağ K, Gül MA, Yeniay G (1996) Maraş Miyosen basenindeki sedimantasyon ile Tektonik arasındaki ilişki. *Türkiye Petrol Kongresi Bildiriler Kitabı* 11:91–102
- Dickinson WR, Beard IS, Brakenridge GR, Erjavec JL, Ferguson RC, Inman KF, Knepp RA, Lindber FA, Ryberg PT (1983) Provenance of North American Phanerozoic sandstones in relation to tectonic setting. *Geol Soc Am Bull* 93:222–235
- Duman TY, Emre Ö, Karakaya-Gülmez F, Özalp S, Elmacı H, Olgun Ş, Çörekçioglu Ş, Çan T, Şaroğlu F (2013) Türkiye Diri Fayları veri tabanı, TBBOB Coğrafi Bilgi Sistemleri Kongresi 2013
- Duran O, Şemşir D, Sezgin İ, Perinçek D (1988) Güneydoğu Anadolu'da Midyat ve Sivan gruplarının stratigrafisi, sedimentolojisi ve petrol potansiyeli (Stratigraphy, sedimentology of the Midyat and Silvan Groups and their hydrocarbon potentials, southeast Turkey). *Türkiye Petrol Jeologları Derneği Bülteni* 1(2):99–126
- Duran O, Şemşir D, Sezgin İ, Perinçek D (1989) Güneydoğu Anadolu'da Midyat ve Sivan gruplarının stratigrafisi, sedimentolojisi ve paleocoğrafyası, paleontolojisi, jeoloji tarihi, rezervuar ve diyajenez özellikleri ve olası petrol potansiyeli. TPAO Arama Grubu, Rapor No. 2563
- Durkee EF (1961) Proposed stratigraphic nomenclature, District VI, Southeast Turkey, vol 6. Petroleum Administration Publications, Ankara, pp 38–46
- Elmas A, Yılmaz Y (2003) Development of an oblique subduction zone—tectonic evolution of the tethys suture zone in southeast Turkey. *Int Geol Rev* 45:827–840
- Erdoğan T (1975) Gölbaşı yöresinin jeolojisi (Geology of the Gölbaşı Region). Turkish Petroleum Company Field Group Report, Ankara, 229
- Gökçen SL, Kelling G, Gökçen N, Floyd PA (1988) Sedimentology of a Late Cenozoic collisional sequence: the Misis Complex, Adana, southern Turkey. *Sed Geol* 59:205–235
- Görür N, Akkök R, Yöntem F, Sarıdaş B (1981) Sabunsuyu-II ölçülmüş kesiti. *Türkiye Petrolleri Anonim Ortaklığı Arama Grubu, Arşiv No: 9244*
- Gözübol AM, Gürpınar O (1980) Kahramanmaraş Kuzeyinin Jeolojisi ve Tektonik Evrimi. 5th Petroleum Congress of Turkey, pp 21–29
- Gül MA (2000) Kahramanmaraş yöresinin jeolojisi. Hacettepe Üniversitesi, Doktora Tezi
- Gül M, Gürbüz K, Cronin BT, Aiken E (2003a) Multiple deep water slope feeder channel evolution of submarine fan system in the Maraş Basını (Miocene, S Turkey). In: Hodgson D, Edwards C, Smith R (eds) *Submarine slope systems: processes, products and prediction*. Conference Abstract Volume, p 46

- Gül M, Gürbüz K, Cronin BT, Aiken E (2003b) Tektonik olarak aktif bir havzada (Miyosen, Kahramanmaraş) denizaltı yelpaze sisteminin (Tekir Sistemi) sedimentolojik özellikleri. Mersin Üniversitesi, Mühendislik Fakültesi, Jeoloji Mühendisliği Bölümü 10. Yıl sempozyumu:16
- Gül M, Gürbüz K, Cronin BT (2011) Provenance of the Northern Part of the Kahramanmaraş; Peripheral Foreland Basin (Miocene, S Turkey). *J Asian Earth Sci* 40(2):475–495
- Gül M, Cronin BT, Gürbüz K (2012) Confined deep water system development on the accretionary wedge (Miocene, Kahramanmaraş Foreland Basin, S Turkey). *Earth Sci Rev* 114(3–4):195–217
- Hall R (1976) Ophiolite emplacement and the evolution of the Taurus suture zone, South-east Turkey. *Geol Soc Am Bull* 87:1078–1088
- Herece E (2003) Doğu Anadolu Fayı. Türkiye Jeoloji Kurultayı Bildiri Özleri 56:309–312
- Herece E (2008) Doğu Anadolu Fayı Atlası MTA Özel Yayın Serisi No: 13
- İmamoğlu MŞ (1993) Gölbaşı (Adıyaman)-Pazarcık- Narlı (K.Maraş) arasındaki sahada Doğu Anadolu Fayı'nın neotektonik incelenmesi. Ankara Üniversitesi, Fen Bilimleri Enstitüsü, Jeoloji Mühendisliği Anabilim Dalı Doktora Tezi, (Unpublished), Ankara
- Ingersoll RV, Bullard TF, Ford RL, Grimm JP, Pickle JD, Sares SW (1984) The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point-counting method. *J Sediment Petrol* 54:103–116
- İşık U, Hakyemez A (2010) Integrated Oligocene-Lower Miocene Larger and planktonic Foraminiferal Biostratigraphy of the Kahramanmaraş Basin (Southern Anatolia, Turkey). *Turk J Earth Sci* 20:185–212
- Karig D, Kozlu H (1990) Late Palaeogene–Neogene evolution of the triple junction region Near Maraş, south-central Turkey. *J Geol Soc Lond* 147:1023–1034
- Kozlu H (1987) Misis-Adıranın dolaylarının stratigrafisi ve yapısal evrimi. *Türkiye Petrol Kongresi Dergisi* 7:104–116
- Kozlu H (1997) Doğu Akdeniz Bölgesinde yer alan Neojen Basenlerinin (İskenderun, Misis-Adıran) tektono-stratigrafi birimleri ve bunların tektonik gelişimi. Doktora Tezi
- McQuarrie N, van Hinsbergen DJJ (2013) Retrodeforming the Arabia-Eurasia collision zone: age of collision versus magnitude of continental subduction. *Geology* 41:315–318
- MTA (2002) Geological Map of Turkey, 1:500,000. Maden Tetkik ve Arama Genel Müdürlüğü (General Directorate of Mineral Research and Exploration) Ankara
- Nurlu N, Parlak O, Robertson AFH, Quadt A (2015) Implications of Late Cretaceous U–Pb zircon ages of granitoid intrusions cutting ophiolitic and volcanogenic rocks for the assembly of the Tauride allochthon in SE Anatolia (Helete area, Kahramanmaraş Region, Turkey). *Int J Earth Sci* (in this volume). doi:10.1007/s00531-015-1211-1
- Okay Aİ, Zattin M, Cavazza W (2010) Apatite fission-track data for the Miocene Arabia–Eurasia collision. *Geology* 38:35–38
- Önalın M (1985/1986) Kahramanmaraş Tersiyer istifinin sediment özellikleri ve çökme ortamları, İstanbul Üniversitesi Mühendislik Fakültesi Yayınları Yer Bilimleri Dergisi 5: 39–78
- Önalın M (1988) Kahramanmaraş Tersiyer kenar havzasının jeolojik evrimi. *Türkiye Jeoloji Bülteni* 31:1–10
- Önem Y (1966) Çelikli ile Gölüp Belaşa sahaları 1965 yazı saha çalışmalarına dair jeolojik rapor: TPAO Arama Grubu, Rapor 339: 20p
- Özgül N (1981) Munzur dağlarının jeolojisi. MTA Reports (unpublished), 6995 (In Turkish)
- Perinçek D (1978) V-VI-IX. bölge (Güneydoğu Anadolu otokton-allokton birimler) jeoloji sembolleri. TPAO, Rapor: 6657
- Perinçek D (1979) Hazro, Korudağ-Çüngüş, Maden, Hazar, Elazığ, Malatya dolayının jeolojisi (The geology of Hazro, Korudağ-Çüngüş, Maden, Hazar, Elazığ, Malatya Area) TPAO Arama Grubu. Rapor 1395:62
- Perinçek D (1980) Arabistan Kıtası Kuzeyindeki Tektonik Evrimin, Kıta Üzerinde Çökelen İstifteki Etkileri Türkiye Petrolleri Kongresi Tebliğler, 77–93
- Perinçek D, Kozlu H (1984) Stratigraphy and structural relations of the units in the Afşin-Elbistan-Doğanşehir region (Eastern Taurus). In: Tekeli O, Gönçüoğlu MC (eds) Geology of Taurus Belt. Internat Symp Proc, Maden Tetkik ve Arama Enstitüsü, pp 181–198
- Platt JP (1986) Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks. *Geol Soc Am Bull* 97:1037–1053
- Polat H (1970) Armutlu-Esmepuru-Yukarı Bağdın (K.Maraş) alanının jeolojisi. MTA derleme rapor 4985: 36p (in Turkish with English abstract)
- Rigo de Righi M, Cortesini A (1964) Gravity tectonics in foothills structure belt of southeast Anatolia. *Am Ass Petrol Geol Bull* 48:1911–1939
- Robertson AHF (2000) Mesozoic–Tertiary tectono-sedimentary evolution of a South Tethyan oceanic basin and its margins in southern Turkey. In: Bozkurt E, Winchester JA, Piper JDA (eds) Tectonics and Magmatism in Turkey and Surrounding Area. *Geol Soc, London, Spec Publ* 173: 97–138
- Robertson AHF (2002) Overview of the genesis and emplacement of Mesozoic ophiolites in the Eastern Mediterranean Tethyan region. *Lithos* 65:1–67
- Robertson AHF, Dixon JE (1984) Introduction: aspects of the geological evolution of the Eastern Mediterranean. In: Dixon JE, Robertson AHF (eds) The Geological Evolution of the Eastern Mediterranean, *Geol Soc London, Spec Publ* 17:1–74
- Robertson AHF, Ünlügenç UC (2001) Tectonic evolution of Neotethys in the Easternmost Mediterranean (an Adana perspective) In: 4th International Turkish Geology Symposium, 24–28 Sept. Çukurova University, Adana, Abstract, p 14
- Robertson AHF, Ünlügenç UC, İnan N, Taşlı N (2004) The Misis–Adıran Complex: a Mid Tertiary mélangé related to late-stage subduction of the Southern Neotethys in S Turkey. *J Asian Earth Sci* 22:413–453
- Robertson AHF, Ustaömer T, Parlak O, Ünlügenç UC, Taşlı K, İnan N (2006) The Berit transect of the Tauride thrust belt, S Turkey: Late Cretaceous–Early Cenozoic accretionary/collisional processes related to closure of the Southern Neotethys. *J Asian Earth Sci* 27:108–145
- Robertson AHF, Parlak O, Rızaoğlu T, Ünlügenç U, İnan N, Taşlı K., Ustaömer T (2007) Tectonic evolution of the South Tethyan ocean: evidence from the Eastern Taurus Mountains (Elazığ region, SE Turkey). In: Ries AC, Butler RWH, Graham RH (eds) Deformation of the continental crust: The Legacy of Mike Coward. *Geol Soc, London, Spec Publ*, 272, 231–270
- Robertson AHF, Parlak O, Ustaömer T (2012) Overview of the Paleozoic–Neogene evolution of Neotethys in the Eastern Mediterranean region (southern Turkey, Cyprus, Syria). *Petrol Geosci* 18(381):404
- Robertson AHF, McCay GA, Taşlı K, Yıldız A (2014) Eocene development of the northerly active continental margin of the Southern Neotethys in the Kyrenia Range, north Cyprus. *Geol Mag* 151:692–731
- Robertson AHF, Boulton SJ, Taşlı K, Yıldırım N, İnan N, Yıldız A, Parlak O (2015a) Late Cretaceous–Miocene sedimentary development of the Arabian continental margin in SE Turkey (Adıyaman Region): implications for regional palaeogeography and the closure history of Southern Neotethys. *J Asian Earth Sci*
- Robertson AHF, Parlak O, Yıldırım N, Dumitrica P, Taşlı K (2015b) Triassic rifting and Jurassic–Cretaceous passive

- margin development of the Southern Neotethys: evidence from the Adıyaman area, SE Turkey. *Internat. J Earth Sci*
- Schmidt GC (1961) Stratigraphic nomenclature for the Adana region petroleum district VII, vol 6. Petroleum Administration Bull, Ankara, pp 47–63
- Şengör AMC, Yılmaz Y (1981) Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophysics* 75:181–241
- Şengör AMC, Görür N, Şaroğlu F (1985) Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. *Soc Econ Paleont Mineral. Spec Publ*, pp 227–264
- Sungurlu O (1974) VI Bölge kuzey sahalarının jeolojisi (Geology of northern part of petroleum district-VI). *Türkiye Petrol Kongresi Tebliğler Dergisi* 2:85–107
- Sungurlu O, Arpat E (1978) Türkiye doğu kesiminin jeolojisi ve beklenir kabuk yapısı (Geology of the Eastern Turkey and structure of the crust). *Türkiye Petrolleri Arama Grubu Raporları* 104:1–8
- Tuna D (1973) VI. Bölge litostratigrafi birimleri adlamasının açıklayıcı raporu: TPAO. Rapor no. 813, 13s, Ankara (unpublished)
- Uzunçimen S, Tekin UK, Bedi Y, Perinçek D, Varol E, Soykan H (2011) Discovery of the Late Triassic (Middle Carnian–Rhaetian) radiolarians in the volcano-sedimentary sequences of the Koçali Complex, SE Turkey: correlation with the other Tauride units. *J Asian Earth Sci* 40:180–200
- Von Huene R, Ranero CR, Vannucchi P (2004) Genetic model of subduction erosion. *Geology* 32:913–916
- Yazgan E (1984) Geodynamic evolution of the eastern Taurus region (Malatya–Elazığ area, Turkey). In: *Proceedings of the International Symposium, Geology of Taurus Belt*, MTA, Ankara, pp 199–208
- Yıldırım M (1989) Kahramanmaraş kuzeyindeki (Engizek–Nurhak dağları) tektonik birimlerinin jeolojik, petrolojik incelemesi. İstanbul Üniversitesi Fen Bilimleri Enstitüsü (Doktora Tezi) (TPAO Arama Grubu, Rapor: 2970)
- Yıldırım N, Parlak O, Robertson AHF (2012) Geochemistry and tectonic significance of the Koçali ophiolite and the related Koçali mélangé, Adıyaman region, SE Turkey. 62th Geological Congress of Turkey, April 2012, Ankara, Abstract
- Yılmaz Y (1993) New evidence and model on the evolution of the southeast Anatolian orogen. *Geol Soc Am Bull* 105:251–271
- Yılmaz H (1999) Geology of the Sürgü Area (Doğanşehir–Malatya) in the Eastern Taurus. *Bull Fac Eng Cumhuriyet Univ* 16:95–106
- Yılmaz Y, Gürer ÖF (1996) The Geology and evaluation of Misis–Andırın Belt, around Andırın (Kahramanmaraş). *Turk Jo Earth Sci* 5:39–55
- Yılmaz Y, Yıldırım M (1996) Geology and evaluation of the Nap Region (the Metamorphic Massifs) of the Southeast Anatolian Orogenic Belt. *Turk J Earth Sci* 5:21–38
- Yılmaz Y, Gürpınar O, Kozlu H, Gül MA, Yiğitbaş E, Yıldırım M, Genç C, Keskin M (1987) Maraş kuzeyinin jeolojisi (Andırın–Berit–Engizek–Nurhak–Binboğa Dağları) yapı ve jeolojik evrimi. İstanbul Üniversitesi, Mühendislik Fakültesi
- Yılmaz Y, Gürpınar O, Yiğitbaş E (1988) Tectonic evolution of the Miocene basin at the Amanos Mountain and the Maraş region. *Turk Assoc Petrol Geol Bull* 1(1):52–72
- Yılmaz A, Bedi Y, Uysal Ş, Yusufoglu H, Atabey E, Aydın N (1992) Doğu Toroslarda Uzunyayla ile Beritdağı arasının jeolojisi. MTA Rapor No: 9543
- Yılmaz A, Bedi Y, Uysal Ş, Aydın N (1993a) Doğu Toroslarda Uzunyayla ile Beritdağı arasının jeolojik yapısı. *Türkiye Petrol Jeologları Derneği Bülteni* 5:69–87
- Yılmaz Y, Yiğitbaş E, Genç ŞC (1993b) Ophiolitic and metamorphic assemblages of southeast Anatolia and their significance in the geological evolution of the orogenic belt. *Tectonics* 12:1280–1297