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The Ankara Mélange: an indicator of Tethyan evolution of Anatolia

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Abstract: The Ankara Mélange is a complex formed by imbricated slices of limestone block mélanges (Karakaya and Hisarlıkaya Formations), Neotethyan ophiolites (Eldivan, Ahlat and Edige ophiolites), post-ophiolitic cover units (Mart and Kavak formations) and Tectonic Mélange Unit (Hisarköy Formation or Dereköy Mélange). The Karakaya and Hisarlıkaya formations are roughly similar and consist mainly of limestone block mélange. Nevertheless, they represent some important geological differences indicating different geological evolution. Consequently, the Karakaya and Hisarlıkaya formations are interpreted as Eurasian and Gondwanian marginal units formed by fragmentation of the Gondwanian carbonate platform during the continental rifting of the Neotethys in the Middle Triassic time. During the latest Triassic, Neotethyan lithosphere began to subduct beneath the Eurasian continent and caused intense deformation of the marginal units. The Eldivan, Ahlat and Edige ophiolites represent different fragments of the Neotethyan oceanic lithosphere emplaced onto the Gondwanian margin during the Albian–Aptian, middle Turonian and middle Campanian, respectively. The Eldivan Ophiolite is a NE–SW trending and a nearly complete assemblage composed, from bottom to top, of a volcanic-sedimentary unit, a metamorphic unit, peridotite tectonites, cumulates and sheeted dykes. The Eldivan Ophiolite is unconformably covered by Cenomanian–Lower Turonian sedimentary unit. The Eldivan Ophiolite is overthrust by the Ahlat Ophiolite in the north and Edige Ophiolite in the west. The Ahlat ophiolite is an east–west oriented assemblage comprised of volcanic-sedimentary unit, metamorphic unit, peridotite tectonites and cumulates. The Edige Ophiolite consists of a volcanic-sedimentary unit, peridotite tectonites, dunite, wherlite, pyroxenite and gabbro cumulates. The Tectonic Mélange Unit is a chaotic formation of various blocks derived from ophiolites, from the Karakaya and Hisarlıkaya formations and from post-ophiolitic sedimentary units. It was formed during the collision between Anatolian Promontory and Eurasian Continent in the middle Campanian time.

Keywords: Ankara Mélange, Neotethys, geodynamic evolution, Anatolia, Turkey.

Introduction

Anatolia is an east–west oriented peninsula principally formed by the collision of the Gondwanian and Eurasian continents (Fig. 1). During Mesozoic times, the Tethyan Ocean formed a gulf towards the west between the two continents. Various hypotheses have been suggested on the shape and the evolution of the Tethyan embayment including single or multi-branched Tethys; opening and closure times of the Neotethyan Ocean; as well as the time and the polarity of the Tethyan subduction (Ricou et al. 1975; Bijou-Duval et al. 1977; Şengör & Yılmaz 1981; Knipper et al. 1986; Okay & Tüysüz 1999; Stampfli 2000; Okay et al. 2002; Robertson 2002; Çakır 2009).

The suggestion of various hypotheses and models are probably due to the choice of unsuitable formations as geodynamical indicators. Consequently, a synthesis from the appropriate formation is strongly needed. The Ankara Mélange composed of ophiolites and marginal formations is regarded as a key formation for interpreting the geological evolution of Anatolia.

This study evaluates the actual geological data and reinterprets former ones (Norman 1972, 1973, 1985; Batman 1978, 1981; Çapan et al. 1983; Akyürek et al. 1984, 1996; Hakyemez et al. 1986; Koçyiğit 1987, 1991; Tankut 1990; Dilek & Thy 2006; Çelik et al. 2011, 2013; Rojay 2013; Sarıfakıoğlu et al. 2014) obtained from the Ankara Mélange and proposes a new synthetic model.

Geological characteristics of the Ankara Mélange

The Ankara Mélange is situated in the central part of the İzmir-Ankara-Erzincan suture zone, around Ankara and Çankırı cities, between Haymana and Korgun towns with 160 km in length and 50 km in width (Fig. 2).

It is a complex formed by imbricated slices of limestone block mélanges (Karakaya and Hisarlıkaya Formations), Neotethyan ophiolites (Eldivan, Ahlat and Edige ophiolites), post-ophiolitic cover units (Mart and Kavak formations) and Tectonic Mélange Unit (Fig. 3).

Therefore the Ankara Mélange includes eight different units represented by three chaotic complexes (Karakaya, Hisarlıkaya and Hisarköy formations) according to the mélange definition of Festa et al. (2010, 2012), three ophiolites (Eldivan, Ahlat and Edige Ophiolites) and two post-ophiolitic sedimentary units (Mart and Kavak formations).

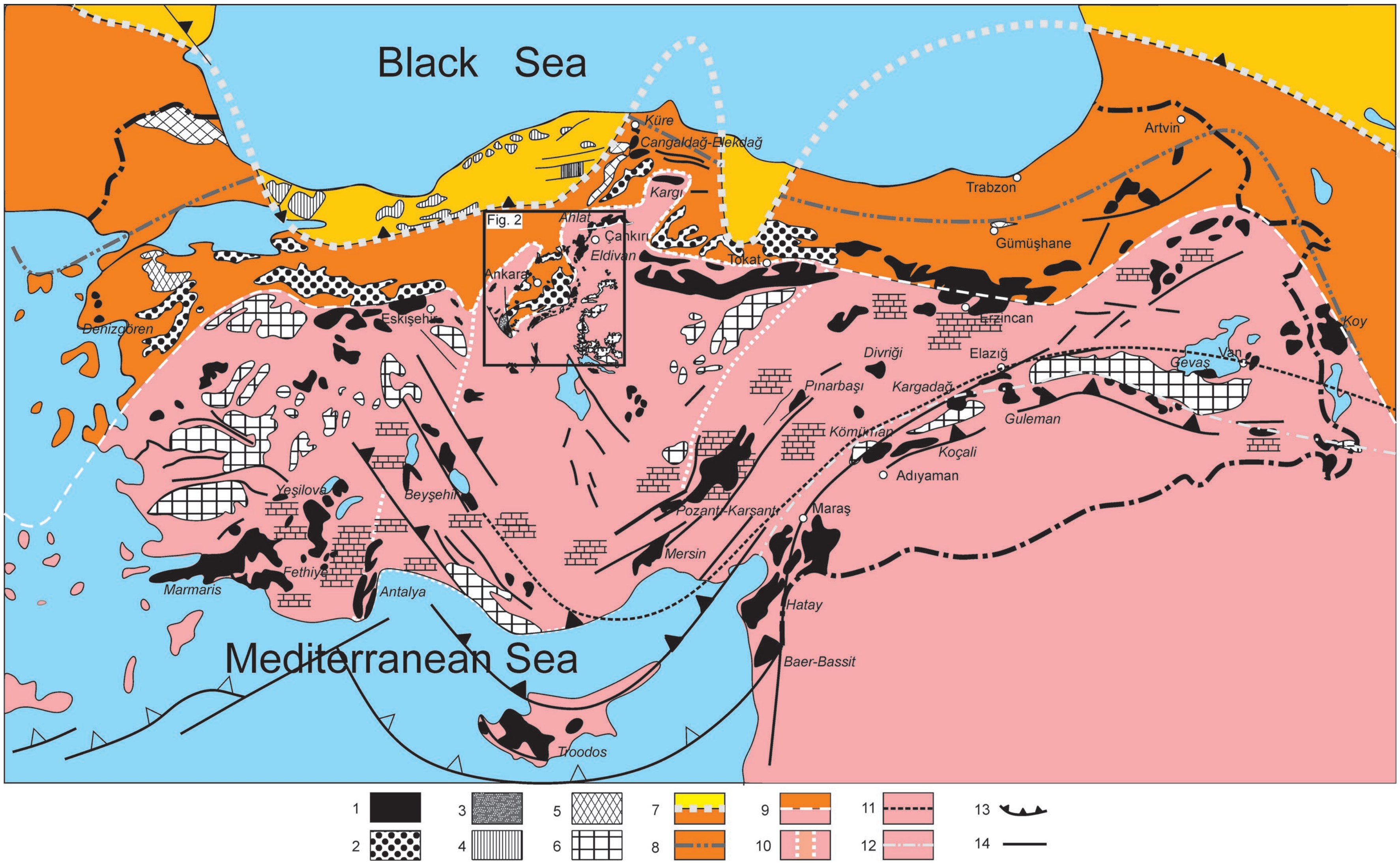

Fig. 1. Position of the Ankara Mélange and Anatolian Ophiolites within the Aegean, Anatolian and Arabian Promontories in a simplified geological map of Turkey (modified from Çakır, 2009). **1** — Ophiolite; **2** — Karakaya Formation; **3** — Hisarlıkaya Formation; **4** — Basement rocks belonging to Eurasian Continent during the Palaeotethyan and Neotethyan period; **5** — Basement rocks belonging to Gondwanian Continent during the Palaeotethyan period and Eurasian Continent during the Neotethyan period; **6** — Basement rocks belonging to Gondwanian Continent during the Palaeotethyan and Neotethyan period; **7** — Palaeotethyan suture; **8** — Vardar-Küre suture; **9** — Neotethyan suture; **10** — Sutures between Aegean-Anatolian-Arabian promontories; **11** — Elazığ and Hazar sutures; **12** — Maden suture; **13** — Thrust front; **14** — Fault.

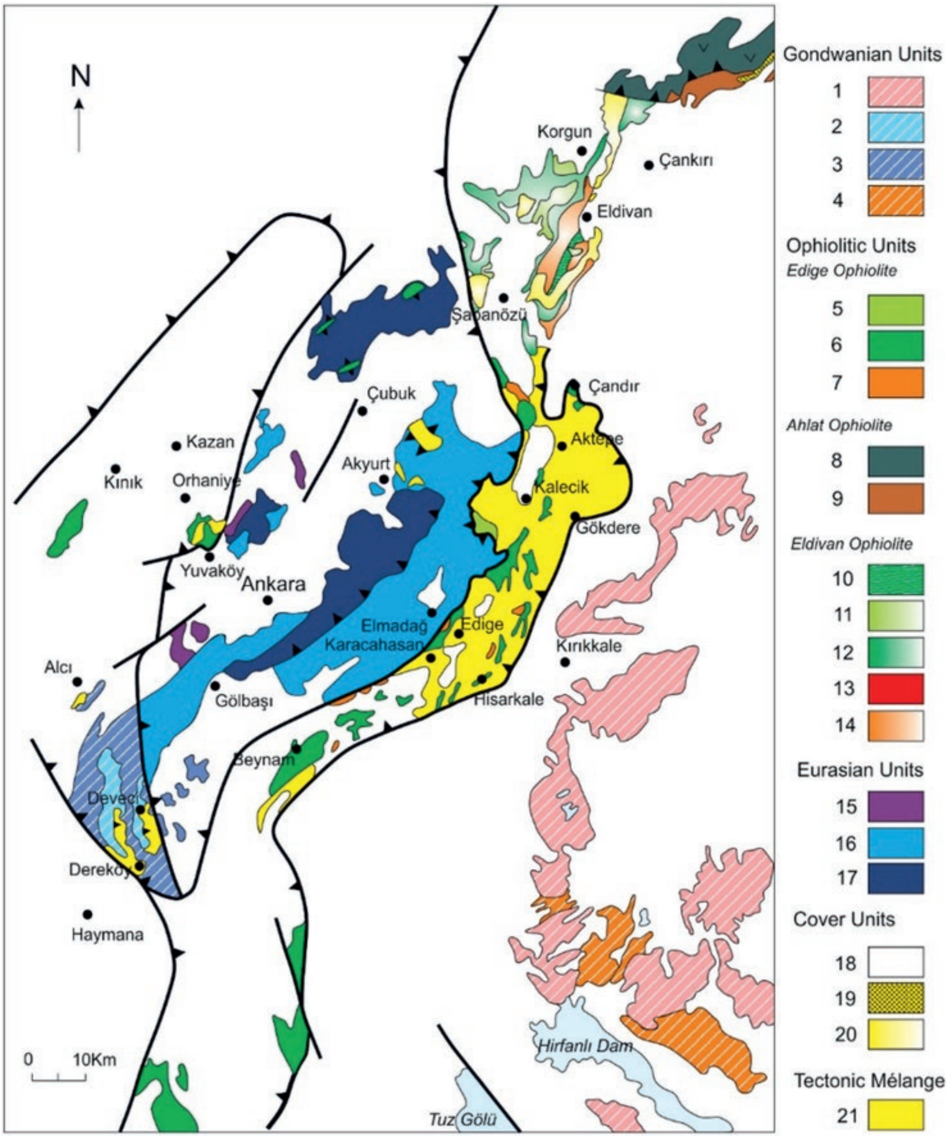

Fig. 2. Geological map of the Ankara Mélange (synthesized from Batman 1978, 1981; Akyürek et al. 1984; Koçyiğit 1987, 1991, 2013; Gökalp1999; Üner,2010; Çakır & Üner 2014). GONDWANIAN UNITS: **1** — Kırşehir Granitoides; (Late Cretaceous); **2** — Lalelik Formation (Upper Jurassic–Lower Cretaceous limestone-claystone cover unit of the Hisarlıkaya Formation); **3** — Hisarlıkaya Formation (Middle–Upper Triassic limestone block mélange); **4** — Kırşehir metamorphites (Palaeozoic–Mesozoic basement unit). OPHIOLITIC UNITS: *Edige Ophiolite:* **5** — cumulates (Late Cretaceous); **6** — peridotite tectonites (late Cretaceous); **7** — radiolaritic series (Late Triassic–Late Cretaceous); *Ahlat Ophiolite:* **8** — tectonites (Late Cretaceous); **9** — radiolaritic series (Late Triassic–Early Turonian); *Eldivan Ophiolite:* **10** — sheeted dyke complex (Middle–Late Jurassic); **11** — cumulates (Middle–Late Jurassic); **12** — tectonites (Middle–Late Jurassic); **13** — metamorphic unit (Middle Jurassic); **14** — radiolaritic series (Late Triassic–Barremian). EURASIAN UNITS: **15** — Ankara Group (Lower Jurassic–lower Campanian cover unit of the Karakaya formation); **16** — limestone block mélange (Middle–Late Triassic); **17** — epimetamorphic unit (Lower Triassic); POST-OPHIOLITIC UNITS: **18** — Memlik, Maltepe and Yuva formations (middle Campanian to recent); **19** — Kavak Formation (late Turonian–Maastrichtian cover unit of the Ahlat Ophiolite); **20** — Mart Formation (Cenomanian–early Turonian cover unit of the Eldivan Ophiolite); TECTONIC MÉLANGE UNIT: **21** — Hisarköy or Dereköy formations (middle Campanian).

The Karakaya and Hisarlıkaya formations are tectonosedimentary chaotic complex situated on both sides of the ophiolites. They were formed during the rifting of the Neotethyan ocean in the Middle Triassic by fragmentation of a Gondwanian carbonate platform and evolved differently.

The Eldivan, Ahlat and Edige ophiolites represent three different fragments of the Neotethyan oceanic lithosphere emplaced onto the Anatolian Promontory of the Gondwanian continent during Albian–Aptian, Middle Turonian and Middle Campanian times respectively.

The Mart and Kavak formations are post-ophiolitic series formed during Cenomanian–lower Turonian and Upper Turonian–Lower Campanian times, respectively.

The Tectonic Mélange Unit (Hisarköy Formation or Dereköy Mélange) is a tectonic chaotic complex which contains the fragments of the Karakaya Formation, Hisarlıkaya Formation, Lalelik formation, ophiolites, Mart and Kavak formations.

Consequently the main characteristic of the Ankara Mélange is the close relationships between the ophiolites and the marginal formations represented mainly by limestone block mélanges. The ophiolites and their covers are sandwiched between the two limestone block mélanges, Karakaya Formation at the top (Fig. 4) and Hisarlıkaya Formation at the bottom (Fig. 5).

Karakaya Formation

The Karakaya Formation consists of the limestone block mélange at the top and the metamorphic unit at the bottom.

The metamorphic unit is composed of thinly foliated and strongly folded phyllites and schists. The mineralogical assemblage containing chlorite, sericite, albite, quartz, calcite, epidote, actinolite, glaucophane and graphite indicates a low-temperature/high-pressure metamorphism. The ophiolitic blocks observed

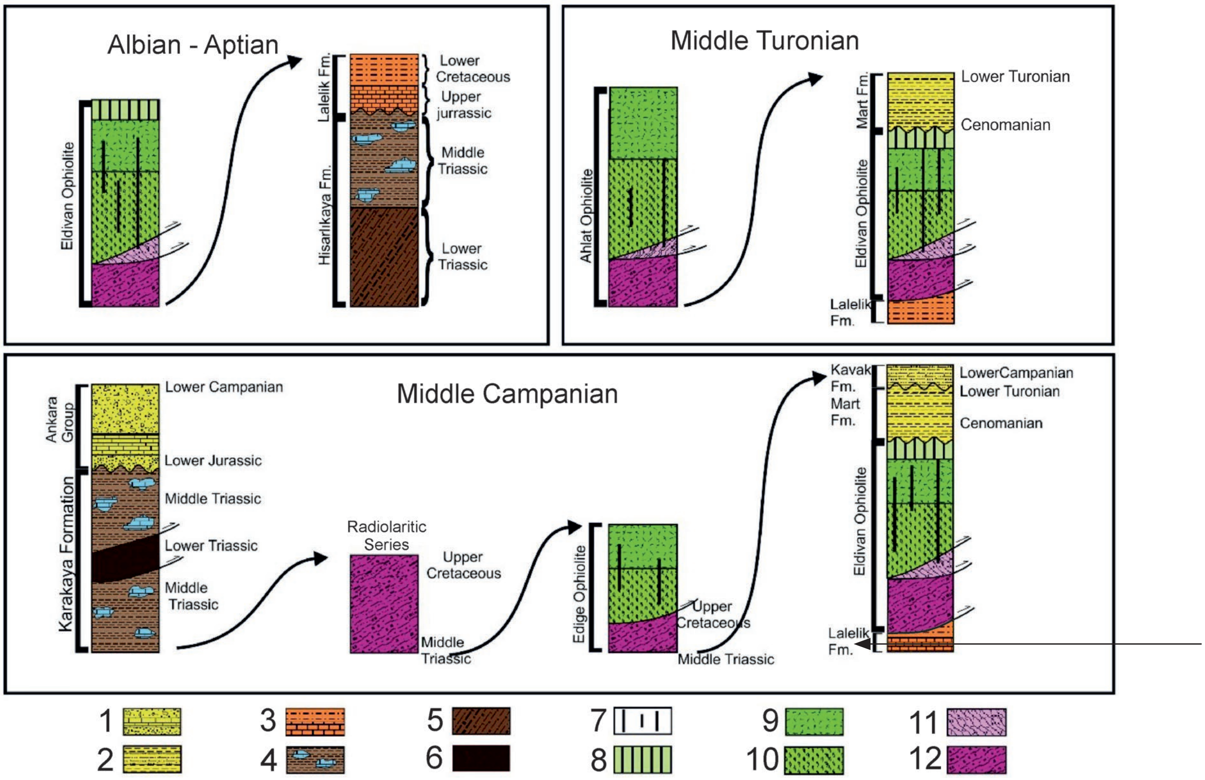

Fig. 3. Geological sections and emplacements of the main Ankara Mélange units between the Albian–Aptian and Middle Campanian times. **1** — Cover unit of the Karakaya Formation (Ankara group); **2** — Cover units of the Eldivan and Ahlat Ophiolites (Mart and Kavak formations); **3** — Cover unit of the Hisarlıkaya Formation (Lalelik Formation); **4** — Limestone block mélanges; **5** — Lower unit of the Hisarlıkaya Formation (conglomerate, sandstone and shale); **6** — Lower unit of the Karakaya Formation (phyllites and schists); **7** — Isolated diabase dykes; **8** — Sheeted diabase dykes; **9** — Cumulates (dunite, wherlite, pyroxenite, gabbro, diorite, plagiogranite); **10** — Peridotite tectonites (harzburgite, dunite); **11** — Ophiolitic metamorphic rocks; **12** — Radiolaritic series.

northeast of the Hasanoğlan and Çubuk region were affected by a similar deformation style. The fossils found in the phyllites (*Meandrospira pusilla, Earlandia tintinniformis*) indicate the Early Triassic age (Akyürek et al. 1984). The metamorphic unit is cut by isolated diabase dykes.

The limestone block mélange consists mainly of shallow marine limestones blocks surrounded by a matrix of greywacke, siltstone and shale. Furthermore some blocks of greywacke-shale alternation, radiolarite-chert-shale-limestone alternation and rare ophiolitic rocks are also observed (Norman 1972, 1973; Koçyiğit 1991). Limestone blocks have various sizes ranging from a few metres to hundreds of metres, and contain characteristic fossils of Carboniferous, Permian and Triassic ages (Bilgütay 1968; Koçyiğit 1987, 1991). Alkaline spilitic basalts occur at different parts of the limestone block mélange generally as pillow lavas alternating with limestones, shales and radiolarian cherts of Anisian age (Koçyiğit 1987; Floyd 1993; Sayıt 2005) and also as thin veins surrounding and cutting the limestone blocks. The major part of the matrix represented by graywackes does not contain any fossils, but the matrix formed by the alternation of fine layered sandstones, siltstones and shales yield fossils indicating an Anisian age (Bilgütay 1968; Koçyiğit 1987).

The metamorphic unit passes into the limestone block mélange toward the top generally with the appearance of the limestone blocks within the matrix of siltstone, sandstone and conglomerate. This situation is well observed in the southern part of Ankara. The metamorphic unit also passes laterally towards the southeast, into limestone block mélange. Nevertheless, the metamorphic unit overthrusts the limestone block mélange around Kalecik and Hasanoğlan villages to the east of Ankara city. The overthrust of the metamorphic unit onto the limestone block mélange should have occurred in the Late Triassic as the metamorphic unit overlies the Middle Triassic (Anisian) levels of the limestone block mélange and both units were covered by the Lower Jurassic to Upper Cretaceous sedimentary formations (Ankara Group) with an angular unconformity.

The Ankara Group is a thick sedimentary sequence (~2000 m) ranging from the Early Jurassic (Upper Hettangian) to Upper Cretaceous (Lower Campanian). From bottom to top the Ankara Group is composed of conglomerates, shallow marine clastics with intercalation of Rosso Ammonitico facies carbonates, fine-grained clastics, sedimentary mélange and fine grained clastics (Koçyiğit 1987).

Hisarlıkaya Formation

The Hisarlıkaya Formation consist mainly of limestone block mélange in the upper levels, conglomerate, sandstone

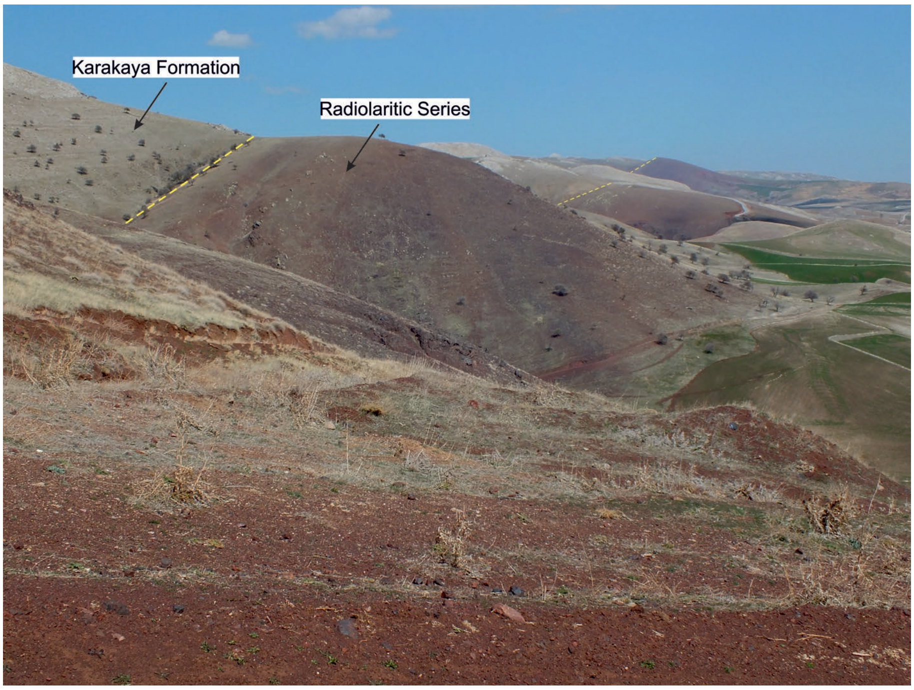

Fig. 4. View of the limestone block mélange (Karakaya Formation) overthrusting the radiolaritic series. The contact with the Edige Ophiolite is covered by young sediments. Southwest of Karacahasan village.

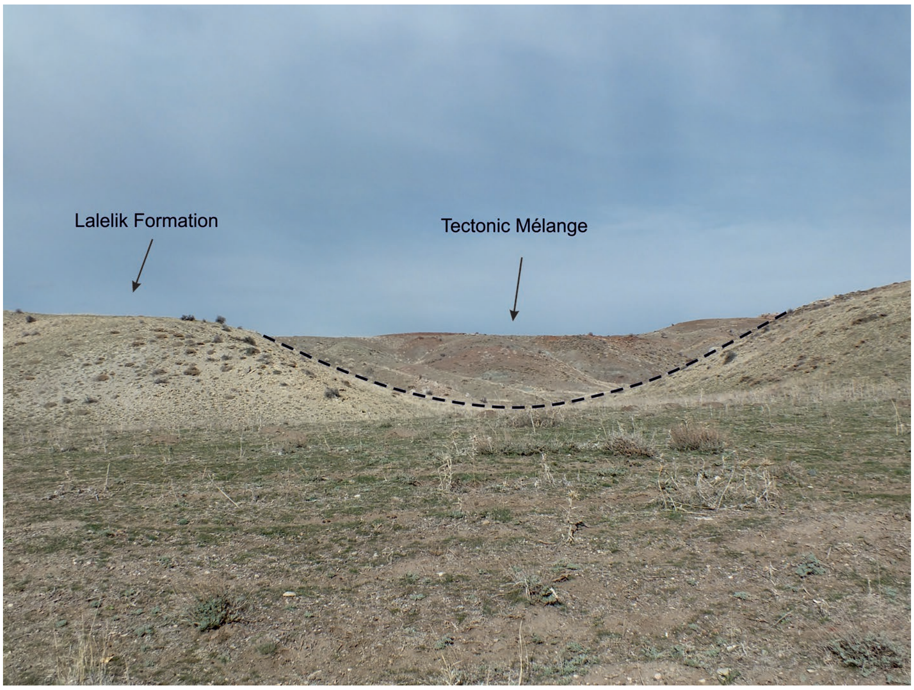

Fig. 5. View of Dereköy Mélange (tectonic mélange) overthrusting the Lalelik Formation. West of Develi village.

and shale alternations at middle levels and dark grey shales at lower levels (Fig. 3). It crops out well in the vicinity of Dereköy and Develi villages at the north of the Haymana town. No fossils are observed in shales and sandstones. Limestone blocks have metric and decametric sizes and contain some fossils of the Carboniferous, Permian and Triassic ages (Erol 1956; Batman 1978). Mafic dykes occur at different levels.

The Hisarlıkaya Formation is unconformably covered by the Lalelik Formation which is formed from bottom to top by layered micritic limestones (>220 m) with chert intercalations and by red or grey coloured and well laminated claystone (>91 m) with limestone and chert intercalations (Batman 1978). Fossil data indicates the Late Jurassic age (Tithonian) at lower levels. Consequently, the top levels were estimated as Lower Cretaceous (Batman 1978).

In the Northeast of Haymana town, around Dereköy and Deveci villages, the Lalelik Formation is overthrust by the Tectonic Mélange Unit (Dereköy Mélange) (Fig. 5).

Ophiolites

Ophiolites of the Ankara Mélange are represented by three different fragments of the Neotethyan oceanic lithosphere. These are the Eldivan, Ahlat and Edige ophiolites obducted onto the Anatolian promontory of the Gondwanian continent in the Albian–Aptian, Middle Turonian and Middle Campanian times, respectively.

Eldivan Ophiolite

The Eldivan Ophiolite is a nearly complete assemblage composed of volcanic-sedimentary unit (radiolaritic series), metamorphic unit, peridotite tectonites (harzburgites, dunites), cumulates (dunites, wherlites, pyroxenites, gabbros, diorites, plagiogranites) and sheeted dykes (Fig. 3).

The volcanic-sedimentary unit outcrops largely under the peridotite tectonites (Akyürek 1981; Üner 2010; Üner & Çakır 2011; Üner et al. 2014). It is composed of thin layered sedimentary rocks such as red coloured radiolarian cherts,

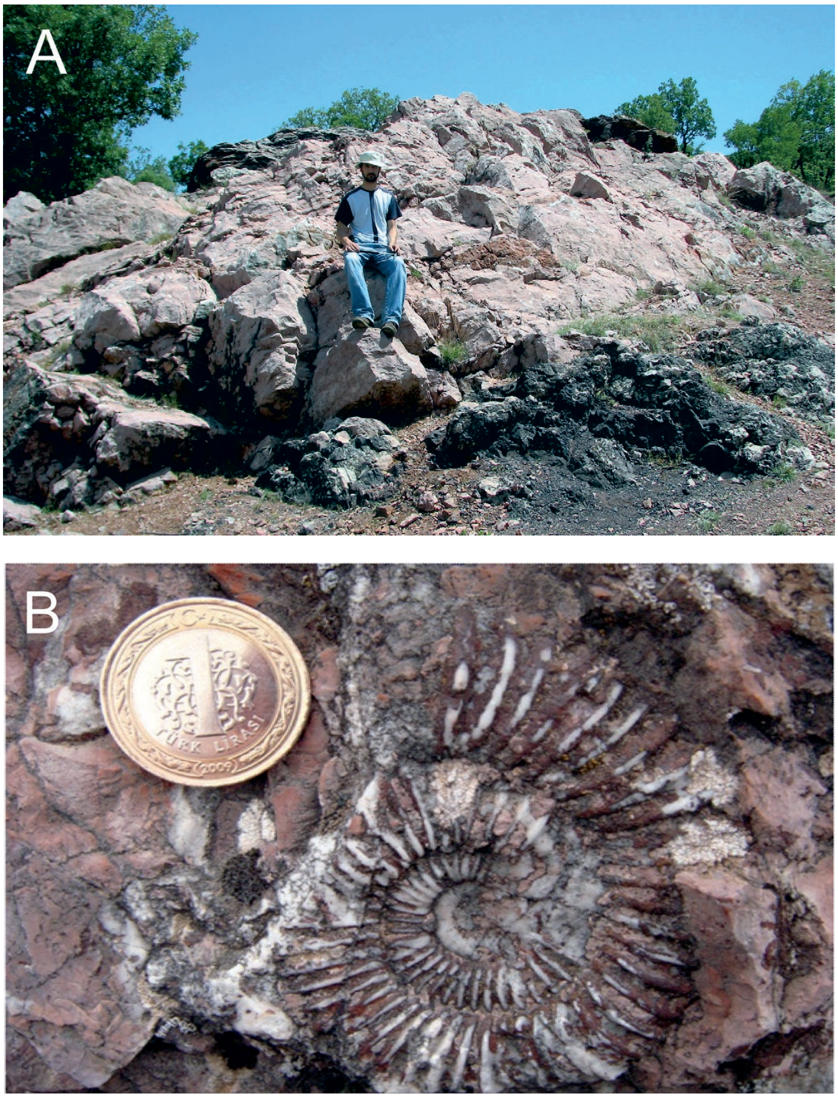

Fig. 6. A — Pink coloured limestone blocks in the lower levels of the radiolaritic series. Eldivan Ophiolite at the southeast of the Akçalı village. The limestone blocks are surrounded and cut by alkali basaltic lavas. **B** — An Ammonite fossil with diameter of 4cm in the limestone block. The limestone block also contains several Halobia (not visible on the photo).

red or green coloured shales, pelagic limestones and alkali basalts. The lower levels contain pink coloured limestone blocks with chert interbeds, surrounded and cut by basaltic lavas and veins (Fig. 6A). Halobia and Ammonite fossils indicate probable Late Triassic age (Fig. 6B). The upper levels were dated as Berriasian-Barremian from radiolarian fossils (Üner 2010).

Metamorphic rocks occur between the peridotite tectonites and volcanic-sedimentary unit as thin (~50 m) and discontinuous tectonic slices (Üner 2010; Üner & Çakır 2011). They consist of amphibolites, calcschists, quartzites, micaschists and epidosites. Microtectonic analysis indicates at least three deformation phases. Temperature and pressure conditions were calculated from hornblende and plagioclase composition to 501–683 °C and 3.5–5 kbar respectively. Ar^{40}/Ar^{39} ages from amphibole were estimated to 166.9±1.1 Ma and 177.08±0.96 Ma which indicate an intra-oceanic subduction in Middle Jurassic time (Çelik et al. 2011).

Peridotite tectonites are mainly composed of harzburgites which include regular dunite and pyroxenite bands, irregular dunite zones and chromitite bodies. Harzburgite and dunite tectonites have plastic deformation traces represented by foliation, lineation and folds. They are cut by gabbro and pyroxenite veins generally parallel to the foliation planes and by isolated diabase dikes with chilled margins.

The cumulates consist of undeformed dunites, wherlites, pyroxenites, gabbros, diorites and plagiogranites from bottom to top. They overlie the peridotite tectonites by a dunite-wherlite-pyroxenite alternation. The layering in the cumulates is parallel to the tectonite-cumulate contact and foliation planes in the tectonites. Toward the top, the gabbros, diorites and plagiogranites become the dominant lithologies (Üner et al. 2014). Plagiogranites crop out largely at the top of the cumulates as massive bodies and dykes. The zircon age of the plagiogranite dyke was estimated to 179±15 Ma (Dilek & Thy 2006) and gabbro cumulates yielded the $^{40}Ar/^{39}Ar$ amphibole-plateau age of 150 Ma (Çelik et al. 2013).

Isolated diabase dykes cut all the units except the volcanic-sedimentary unit.

Sheeted dykes occur at the top of the cumulates and cut the gabbros, diorites and plagiogranites with high angles to the layering (Fig. 7). They have generally E–W orientation and a steep dip angle. Sheeted dykes have the ophitic texture formed mainly of plagioclase and hornblende.

The Eldivan Ophiolite is unconformably covered by a sedimentary series composed of conglomerate, sandstone, mudstone, radiolarian chert and pelagic limestone (Mart Formation). Fossil data from the pelagic limestones provided the Cenomanian–Turonian age (Akyürek et al. 1984). Therefore the Eldivan Ophiolite could have been emplaced onto the Gondwanian margin between the Barremian (the youngest level of the underlying radiolaritic series) and the Cenomanian (the oldest unit of the cover).

A palaeomagnetic study was carried out on the radiolarian cherts and pillow lavas which occur within sandstone, marls and pelagic limestones in the lower levels of the cover unit

Fig. 7. View of sheeted dykes cutting the roof of the cumulates (diorites and plagiogranites). Dykes are oriented E–W/60S. Their thickness changes between 20–60 cm. North of Şabanözü village.

(Çapan et al. 1983). According to Çapan et al. (1983), the Eldivan ophiolite was situated at 11°N during the Cenomanian time (90 Ma). Its actual situation (~40°N) shows that the Eldivan Ophiolite has been moved at least 3200 km towards the north as a part of the Gondwanian continent after its emplacement.

The Eldivan ophiolite and Mart formation were overthrusted by the Ahlat ophiolite. The contact is well observed to the Northeast of Korgun town where the brecciated and serpentinized peridotite tectonites overthrust the lower Turonian level of the Mart Formation (Fig. 8).

Fig. 8. View of the thrust contact between the Ahlat Ophiolite and the Mart Formation. North of Korgun village.

Ahlat Ophiolite

The Ahlat ophiolite is an east–west oriented assemblage formed of a volcanic-sedimentary unit, metamorphic unit, peridotite tectonites and cumulates.

The volcanic-sedimentary unit (radiolaritic series) crops out largely at the base of the peridotite tectonites. It is composed of red coloured radiolarian cherts, shales, pelagic limestones and basic volcanic rocks. Palaeontological data from the middle and upper levels of the volcanic-sedimentary unit indicate Middle-Late Jurassic (Üner 2010) and Turonian ages (Hakyemez et al. 1986).

Fig. 9. View of isolated diabase dyke cutting the serpentinized peridotite tectonites of the Edige Ophiolite. Edige Village. The dyke has a thickness of 5 m and an orientation of N75NW25.

The metamorphic unit occurs as thin tectonic slices between peridotite tectonites and volcanic-sedimentary unit. It consists of amphibolite, tremolite-actinolite schist and epidote-garnet schist. The mineral paragenesis points to greenschist facies metamorphic conditions.

The peridotite tectonites consist mainly of serpentinized harzburgites, rare dunites, and chromitite bodies. The harzburgite and dunite tectonites exhibit traces of plastic deformation such as foliation, lineation and folds. They are cut by pegmatoid gabbro and pyroxenite veins generally parallel to the foliation planes.

The cumulates occur as several hectometric sized pockets within the upper part of the harzburgite tectonites. They are mainly composed of gabbros.

Isolated diabase dykes cut the tectonites and cumulates.

The Ahlat ophiolite is overlain by a detritic sedimentary unit of Late Turonian to Maastrichtian age (Kavak formation). Therefore the Ahlat ophiolite should have been obducted during middle Turonian time as it overthrust the Lower Turonian level of the Mart formation (Fig. 8).

Edige Ophiolite

The Edige ophiolite occurs as several tectonic slices within the tectonic mélange zone. The most important slice crops out around the village of Edige with a length of 10 km and width of 0.6 to 2.6 km (Fig. 2). It is composed of volcanic-sedimentary unit (radiolaritic series), peridotite tectonites, peridotite, pyroxenite and gabbros cumulates (Tankut & Sayın 1990). Peridotite tectonites and cumulates are cut by isolated diabase dykes oriented generally NE–SW (Fig. 9)

Another important fragment of the Edige ophiolite occurs on the Beynam Hill in the vicinity of Karaali village (Fig. 2). It consists of imbricated slices of harzburgite tectonites, cumulate gabbros, radiolarian cherts and basaltic volcanics with Cyprus type massif sulphide deposits. Peridotite tectonites and cumulates are cut by isolated diabase dykes. In this region, the Edige ophiolite overthrust the Cenomanian-Campanian clastics with Liassic limestone blocks (Akyürek et al. 1996; Imer 2006) within the tectonic mélange unit. Therefore Edige ophiolite should have been emplaced during the Middle Campanian as it is overlain by the Late Campanian–Eocene detritic sedimentary series.

Tectonic Mélange Unit

The Tectonic Mélange Unit is a chaotic formation composed of various blocks derived from ophiolites (peridotites, pyroxenites, gabbros, basaltic volcanic rocks, radiolarian cherts), from the Karakaya and Hisarlıkaya formations (Palaeozoic and Mesozoic limestones, detritic sedimentary rocks), from the Lalelik formation (Jurassic limestones) and from post-ophiolitic cover units (Cenomanian–early Campanian sedimentary rocks, basic volcanic rocks). It is known as the Ophiolitic block mélange (Norman 1973, 1985), Dereköy formation (Batman 1978; 1981), Hisarköy formation (Akyürek et al. 1984), Ophiolite mélange (Tankut 1990), Anatolian complex (Koçyiğit 1991) and Cretaceous mélange with ophiolitic blocks (Rojay 2013). It outcrops between Çandır and Haymana towns within the large thrust fault zones. To the north of Haymana town, around Dereköy and Deveci villages, the Tectonic Mélange Unit is sandwiched between the Karakaya Formation at the top and the Hisarlıkaya Formation at the bottom. The Tectonic Mélange Unit is covered unconformably by a post-tectonic sedimentary series of middle Campanian–middle Eocene age indicating that it was formed during Early–Middle Campanian.

Discussion and geodynamical evolution

The main characteristic of the Ankara Mélange is the close relationships between limestone block mélanges (Karakaya and Hisarlıkaya formations) and Neotethyan ophiolites. The Karakaya and Hisarlıkaya Formations are located on both sides of the ophiolites, the Karakaya Formation at the top and the Hisarlıkaya Formation at the bottom. The Karakaya and Hisarlıkaya Formations are roughly similar and comprise Carboniferous, Permian and Triassic limestone blocks cemented by Middle Triassic clastics. Consequently the Karakaya and Hisarlıkaya formations are incorrectly considered as different slices of the same unit and interpreted either as the fragments of the Triassic Karakaya Ocean (Şengör & Yılmaz 1981; Koçyiğit 1987; Genç & Yılmaz 1995; Göncüoğlu et al. 2000) or as a subduction-accretion complex related to the northward subduction of the Palaeotethyan oceanic lithosphere (Tekeli 1981; Picket & Robertson 1996; Okay 2000; Okay & Göncüoğlu 2004).

Nevertheless the lower unit and the cover series of the Karakaya and Hisarlıkaya formations have important geological differences. The lower unit of the Karakaya Formation is composed of metamorphic rocks such as phyllites and schists while the lower unit of the Hisarlıkaya Formation is formed from clastics such as conglomerate, sandstone and dark grey shales. The unconformable cover series of the Karakaya Formation (Ankara group) are represented by the Lower Jurassic–Upper Cretaceous (upper Hettangian–lower Campanian) sedimentary sequence composed of conglomerates, shallow marine clastics with intercalation of Rosso Ammonitico facies carbonates, fine-grained clastics and sedimentary mélange (Koçyiğit 1987), while the cover unit of the Hisarlıkaya Formation is composed of the Upper Jurassic-Lower Cretaceous layered micritic limestones and claystone (Batman 1978).

Therefore we interpret the Karakaya and Hisarlıkaya formations as the marginal units formed during rifting of the Neotethys by the fragmentation of Gondwanian carbonate platform in Middle Triassic times (Fig. 10A). Before rifting of the Neotethys, the northern part of Gondwana should have been represented by a single carbonate platform, because the

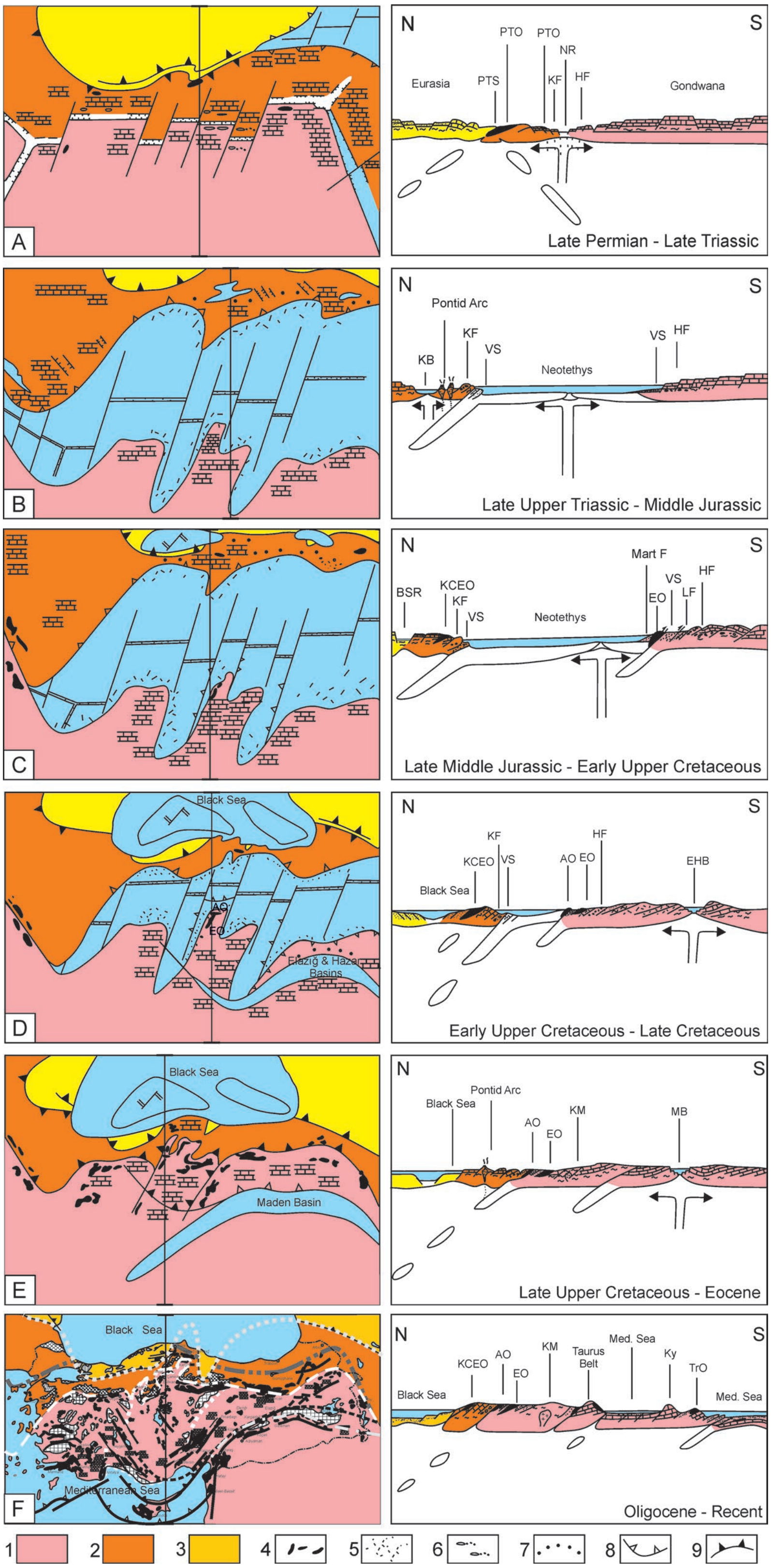

Fig. 10. Schematic interpretation of the geodynamical evolution of Anatolia from Late Permian to Recent (modified from Çakır 2009). Cross-sections represent the indicated part of the maps with larger scale in the N-S direction. **1** — Gondwanian continent during Palaeozoic and Mesozoic; **2** — Gondwanian continent during Palaeozoic and Eurasian continent during Mesozoic; **3** — Eurasian continent during Palaeozoic and Mesozoic; **4** — Ophiolite; **5** — Radiolaritic series; **6** — Limestone block mélanges; **7** — Magmatic arc; **8** — Subduction; **9** — Overthrusting.

A — *Late Permian-Late Triassic:* rifting and opening of the Neotethyan Ocean following the closure of the Paleotethys in Late Permian-Lower Triassic time.

B — *Late Upper Triassic-Middle Jurassic:* beginning of the northward subduction of the Neotethyan Oceanic lithosphere (late Upper Triassic). Beginning of Pontid arc magmatism (Liassic). Opening of the Vardar-Küre-Artvin marginal basins (Liassic).

C — *Late Middle Jurassic-Early Upper Cretaceous*: emplacement of the Küre-Cangaldağ-Elekdağ ophiolites (Late Middle Jurassic). Emplacement of the Vardar Ophiolites (Late Jurassic-Lower Cretaceous). Closure of the Vardar-Küre-Artvin marginal basins (Late Jurassic-Early Cretaceous) Emplacement of Dinaro-Hellenic Ophiolites (Late Upper Jurassic-Early Cretaceous). Closure of the western part of the Neotethyan Ocean (Early Cretaceous). Emplacement of the Eldivan Ophiolite (Aptian-Albian). Opening of the Black-Sea (Albian).

D — *Early Upper Cretaceous-late Cretaceous*: emplacement of Ahlat Ophiolite onto the northern margin of the Anatolian Promontory (Turonian). Beginning of the southern subduction of the eastern part of the Neotethyan oceanic lithosphere. Baskil-Yüksekova arc magmatism (Turonian) and opening of Elazığ and Hazar back-arc basins in the early Campanian and Maastrichtian, respectively.

E — *late Upper Cretaceous-Eocene*-Emplacement of Edige ophiolite onto the cover of the Eldivan Ophiolite (Middle Campanian). Emplacement of Guleman and İspendere-Kömürhan-Karadağ Ophiolites (late Campanian). Closure of the Elazığ Back-Arc Basin (Late Campanian) and opening of Hazar basin (Maastrichtian). Emplacement of the major parts of Anatolian Ophiolites and closure of the central part of the Neotethyan Ocean (Late Maastrichtian-Paleocene). Opening of the Maden marginal basin within the Arabian promontory (middle Eocene). Closure of the Maden Basin and emplacement of the Maden complex. (late Eocene).

F — *Oligocene-Recent*: Opening of the Eastern Mediterranean basin (Oligo-Miocene). Reoverthrusting of some Neotethyan ophiolites (late Miocene).

PTS — Palaeotethyan suture; **PTO** — Palaeotethyan Ophiolite; **NR** — Neotethyan rifting; **KB** — Küre back-arc basin; **KF** — Karakaya formation; **VS** — Volcanic and sedimentary unit (Radiolaritic series). **HF** — Hisarlıkaya Formation; **BSR** — Black-Sea rifting; **KCEO** — Küre-Cangaldağ-Elekdağ Ophiolite; **EO** — Eldivan Ophiolite; **LF** — Lalelik Formation; **AO** — Ahlat Ophiolite; **EO** — Edige Ophiolite; **EHB** — Elazığ and Hazar Basins; **MB** — Maden Basin; **KM** — Kırşehir Massif; **TrO** — Troodos Ophiolite; **Kr** — Kyrenia range; **Med. Sea** — Mediteranean Sea.

Permian carbonate blocks in the Karakaya Formation have similar palaeontological and biofacies characteristics as various Upper Permian platform margin deposits of the Taurides (Altıner et al. 2000).

Consequently, we suggest that in the Anatolian region, Neotethys opened as a single ocean and formed three gulfs towards the south (Çakır 2009). Following the rifting, the Karakaya and Hisarlıkaya formations should be evaluated differently at opposite sides of the Neotethys; the Karakaya formation in the north and the Hisarlıkaya formation in the south. After the collision of Gondwana and Eurasia, in the middle Campanian time, the Neotethyan Ophiolites were sandwiched between the Karakaya Formation at the top and the Hisarlıkaya Formation at the bottom.

During the latest Triassic, Neotethyan oceanic lithosphere began to subduct towards the north, under the Eurasian continent (Fig. 10B), causing deformation and imbrication of the marginal formations (Karakaya Formation and radiolaritic series). The high pressure metamorphism of some Neotethyan ophiolites along the İzmir–Ankara–Erzincan suture zone supports this suggestion. The oldest radiometric ages from the high pressure metamorphic rocks associated with the Neotethyan ophiolite to the north of Eskişehir town range between 204 and 215 Ma, (Okay et al. 2002). The average ages (204–205 Ma) indicate that the subduction of the Neotethyan oceanic lithosphere began 30–40My after the rifting of the Neotethyan Ocean.

During the latest Triassic and Liassic times, probably due to the subduction of the Neotethyan oceanic lithosphere, the Küre marginal basin opened and the Pontide arc magmatism was initiated (Çakır et al. 2006).

During the Middle Jurassic the intraoceanic subduction of the Neotethyan oceanic lithosphere took place.

During the uppermost Early Cretaceous (Aptian–Albian), following the intraoceanic subduction along the fracture zone, the Eldivan Ophiolite was emplaced onto the northwestern margin of the Central Anatolian promontory (Fig. 10C) and moved to the north as a part of the Gondwanian continent. At that time the Eldivan Ophiolite was situated 3200 km to the south of its present day location.

In the Turonian, during the northward movement of Gondwana, the Ahlat Ophiolite was obducted onto the northern margin of the Anatolian Promontory, overthrusting partially the Eldivan Ophiolite and its cover (Mart Formation)

During the Turonian, while the general northward subduction was going on, the eastern part of the Neotethyan oceanic lithosphere was subducted southward under the northern margin of the Arabian Promontory (Şengör & Yılmaz 1981; Michard et al. 1984) and also partially under the Anatolian promontory (Fig. 10D). Therefore, we suggest that during the Turonian–Campanian period (90–76 Ma), calc-alkaline magmatism (Baskil-Yüksekova magmatic complex) took place and the Elazığ, Hazar and Maden basins were opened successively in Campanian, Maastrichtian and Eocene times respectively (Fig. 10D–E).

The initial collision between the Eurasian and Gondwanian continents occurred in the early–middle Campanian. Therefore the Eurasian active continental marginal units (Karakaya Formation and radiolaritic series) and the remnant oceanic lithospheric fragments (Edige Ophiolites) were overthrust onto the Gondwanian passive marginal units with the earlier emplaced ophiolites and their post-emplacement cover (Fig. 10E–F).

Conclusions

Geological data from the North Central Anatolian region indicate that the Ankara Mélange consists of several units formed from the rifting to the partial closure of the Neotethyan Ocean. These units represented by the marginal formations (Karakaya and Hisarlıkaya formations), ophiolites (Eldivan, Ahlat and Edige ophiolites), post-ophiolitic cover unit (Mart and Kavak formations) and Tectonic Mélange Unit were imbricated during the first collision between the Gondwanian and Eurasian continents. Consequently the Ankara Mélange is regarded as a key formation for understanding the geodynamic history of Anatolia.

Based on the critical review of various ophiolite belts in the Anatolian Peninsula and our own research in the Ankara Mélange we have shown that in the Anatolian region the Neotethys was opened as a single ocean during Middle–Late Triassic times. At that time the Karakaya and Hisarlıkaya formations, the main units of the Ankara Mélange, were formed by the fragmentation of the Gondwanian carbonate platform. Consequently the Karakaya and Hisarlıkaya formations represent the Mesozoic marginal units of the Eurasian and Gondwanian continents, respectively. During the oceanic period of the Neotethys, the northern margin of Gondwana had a indented shape represented by Arabian, Anatolian, Aegean and Adriatic promontories from east to west. The fossil ridge axis was nearly oriented N70–90E.

Neotethyan oceanic lithosphere has been subducted toward the north under Eurasian continent since latest Triassic time and caused the intense deformation and high pressure metamorphism of the Eurasian marginal units (volcanic-sedimentary unit and Karakaya Formation). The opening of the Küre marginal basin and the beginning of the Pontid arc magmatism occurred in Liassic time within the Eurasian continent onto the suprasubduction position.

While the general northward subduction was going on, the eastern part of the Neotethyan oceanic lithosphere was subducted southward under the Arabian promontory from the Turonian. This event caused the Baskil-Yüksekova arc magmatism during the Turonian-Campanian and successive opening of the Elazığ, Hazar and Maden back-arc basins during the Campanian, Maastrichtian and Eocene times respectively.

The geological data indicate that the ophiolites of the Ankara mélange represent three different fragments of the Neotethyan oceanic lithosphere obducted at different times.

The Eldivan Ophiolite is a NE–SW oriented and almost complete assemblage emplaced onto the northwestern margin of the Anatolian promontory during Albian–Aptian. The Ahlat Ophiolite is an E–W oriented and incomplete asssemblage emplaced onto the northern margin of the Anatolian Promontory during the Middle Turonian. The Edige ophiolite represented by several tectonic slices was emplaced in the Middle Campanian just before the first collision between Gondwana and Eurasia.

The Tectonic Mélange Unit is a chaotic formation composed of various blocks derived from ophiolites, from the Karakaya and Hisarlıkaya formations, from the Lalelik formation and from Cenomanian–Early Campanian post-ophiolitic cover units.

The first collision between the Anatolian Promontory of the Gondwanian continent and the southern margin of the Eurasian Continent occurred in the Middle Campanian as the Ankara Mélange is covered unconformably by the post-tectonic sedimentary series of middle Campanian–middle Eocene age.

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