Turkish Journal of Earth Sciences

http://journals.tubitak.gov.tr/earth/

Research Article

Turkish J Earth Sci
(2019) 28:
© TÜBİTAK
doi:10.3906/yer-1805-20

Structural evolution of the Eastern Anatolian Basins: an example from collisional to postcollisional tectonic processes, Turkey

Ali YILMAZ[1,*], **Hüseyin YILMAZ**[2]

[1]12497. Sok. Çamlıca Vadi Sitesi, A blok, no. 17, Ümit Mahallesi, Çankaya, Ankara, Turkey
[2]Department of Geophysical Engineering, Faculty of Engineering, Cumhuriyet University, Sivas, Turkey

Received: 15.05.2018 • **Accepted/Published Online:** 31.12.2018 • **Final Version:** 00.00.2019

Abstract: The Eastern Anatolian Basins (EABs) started to develop on a mosaic, made up of forearc deposits of the Eastern Pontide Arc (EPA), continental metamorphic rocks of the Anatolian-Iranian Platform (AIP), and obducted ophiolitic units of the North Anatolian Ophiolitic Belt (NAOB) and Southeastern Anatolian Ophiolitic Belt (SAOB). The basement rocks of the East Anatolian Region represent a continental fragment positioned between the EPA to the north and the Arabian Platform to the south. In appearance, it can be said that there are many different basins in the Eastern Anatolian Region. This paper reports on three of them that were studied as a part of the work, defining the setting and structural evolution of the EABs as a whole. These are, from north to south, the Oltu-Balkaya Basin, the Tekman-Karayazı Basin, and the Muş Basin. The EABs started to develop in the beginning of the Maastrichtian age with tectonic subsidence. They then evolved as collisional foreland basins on the AIP and ophiolitic units of the NAOB and SAOB during the Paleocene and Early Eocene period, as well. The fill of these basins is represented by basal conglomerate, shallow marine limestone, and clastic rock units. During deposition of this fill, syncollisional Paleocene peraluminous leucogranitic magmatism developed along the Eastern Pontides. From the Middle Eocene to the Quaternary age, different superimposed postcollisional basins developed over the collisional foreland basin fill. In this time interval, a shallow marine-continental molasse deposition was accompanied with high-K calc-alkaline volcanism, which may be attributed to postcollisional magmatism in the Eastern Anatolian Region. As a result, for the structural evolution of EABs, it can be said that the EABs represent a foreland basin in the Maastrichtian-Early Eocene and superimposed postcollisional basins in the Middle Eocene-Quaternary interval.

Key words: Eastern Anatolian Basins, evolution, collision, postcollision

1. Introduction

A simplified paleotectonic map of the Eastern Anatolian Plateau and its surroundings is seen in Figure 1. The Eastern Anatolian Plateau is constrained by the North Anatolian-Lesser Caucasus Suture (NALCS) (and/or İzmir-Ankara-Erzincan suture of Turkey) to the north and the Southeastern Anatolian Suture (SEAS) (and/or Bitlis-Zagros Suture) to the south. Continental metamorphic rock units, ophiolites with mélanges of the North Anatolian Ophiolitic Belt (NAOB) and Southeastern Anatolian Ophiolitic Belt (SAOB), and forearc units of the Eastern Pontide Arc (EPA) represent the pre-Maastrichtian to Quaternary sequence in the region.

The Eastern Anatolian Basins (EAB) have been interpreted, in general, as intermountainous basins lying between metamorphic massifs (Kurtman and Akkuş, 1971) and/or intermountainous with pull-apart basins (Şaroğlu and Yılmaz, 1986). Up to rather recent reassessments, the pre-Neogene basement was interpreted as consisting largely of accretionary complexes, formed at the junction of several crustal blocks with irregular margins, similar to the Makran accretionary wedge in Iran (Şengör et al., 2003, 2008). This interpretation was brought into question by Yılmaz et al. (2010) and mainly continental basement was then suggested for the base of the East Anatolian Region (EAR). On the basis of Topuz et al. (2017), the Neoproterozoic-Early Paleozoic provenance of detrital zircons in the metaquartzite in the region was seen to indicate a substantial component of continental basement beneath the Neogene to Quaternary cover, as well. There are several studies of some individual basins in the region (Özdemir, 1981; Koçyiğit et al., 1985; Gedik, 1986; Yılmaz et al., 1988, 1990; Akay, 1989; Bozkuş, 1990; Temiz et al., 2002; Konak and Hakyemez, 2008; Yılmaz and Yılmaz,

* Correspondence: ylmazali06@gmail.com

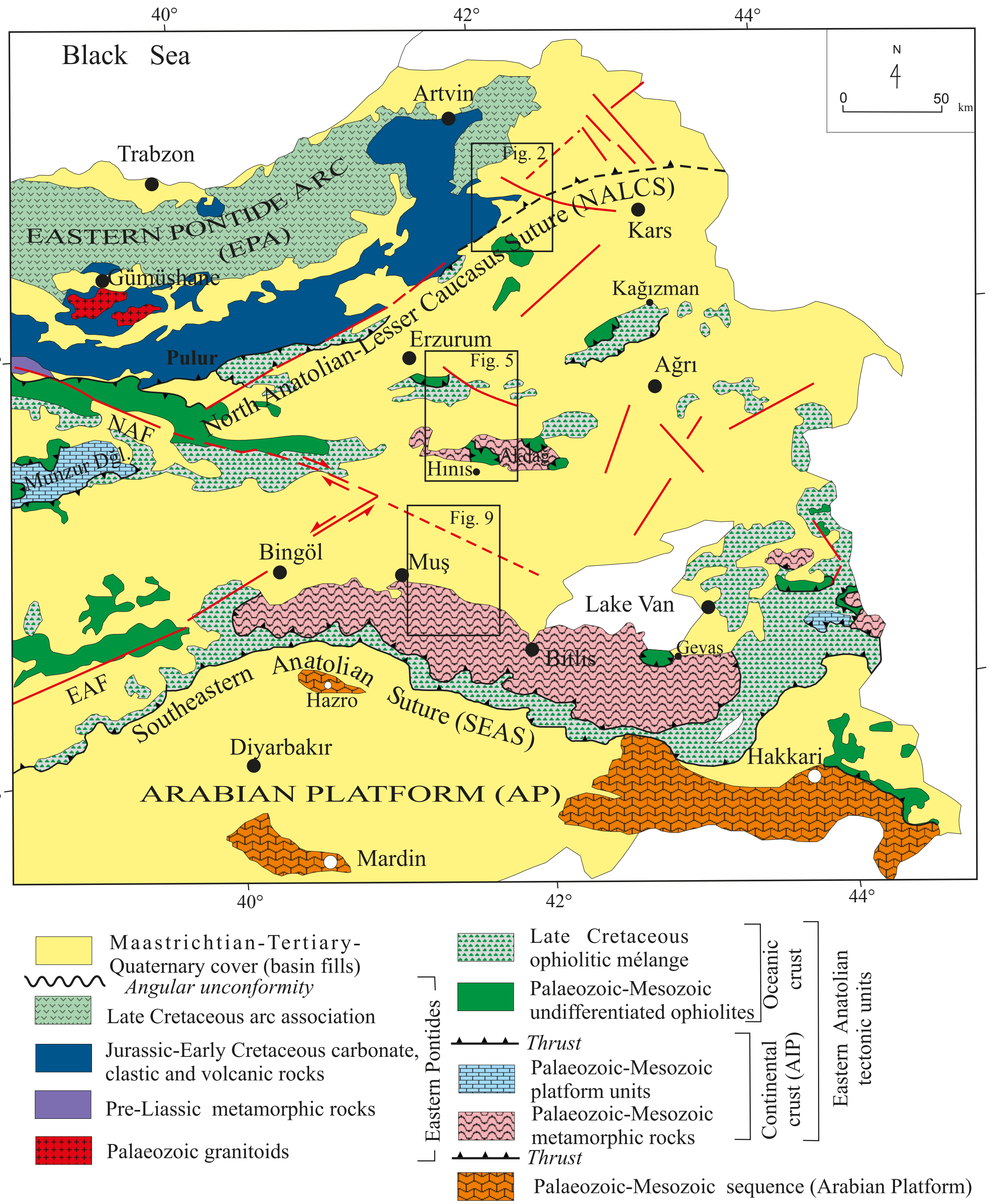

Figure 1. Simplified paleotectonic map of the East Anatolian Plateau and location maps of the studied basins. NAF, North Anatolian Fault; EAF, East Anatolian Fault; AIP, Anatolian-Iranian Platform (numerous sources).

2016). As a result, it is evident that there are different views about the characteristic features of the basement rock units and overlying basin fills of the Eastern Anatolian Plateau.

The EABs have not been studied in detail as a whole. The purpose of this study is to illuminate the late Cretaceous-Quaternary period of the region, taking into account the characteristic features of the sedimentary rock units and the magmatism of the Eastern Anatolian Plateau. On the basis of the studies presented here, the age of ophiolites, ophiolitic mélanges, and forearc deposits is pre-Maastrichtian in the region and there is a regional unconformity between the pre-Maastrichtian tectonic units and Maastrichtian-Quaternary basin fills.

Within the framework of this study, the characteristic features of the EABs are here documented to suggest an evolutionary model for the basins. The Oltu-Balkaya Basin to the north, Tekman-Karayazı Basin in the central part, and Muş Basin to the south of the EAR were selected to evaluate and create a model for this purpose.

In the present paper, the main characteristic features of the selected basins have been identified in order to evaluate the regional framework and then all the data have been correlated. In the conclusion, a model including collisional and postcollisional processes is presented.

2. Eastern Anatolian Basins

The EAR represents a high plateau in Turkey. It is situated between the EPA to the north and the Arabian Platform to the south (Figure 1). In addition, the North Anatolian-Lesser Caucasus Suture (NALCS) delineates the northern side, while the Southeastern Anatolian Suture delineates the southern side of the Eastern Anatolian Plateau (EAP). The basement of the EAR is made up of the continental crust and obducted ophiolitic and overlying forearc units (Yılmaz et al., 2010).

Many basins, such as the Oltu-Balkaya Basin, Kağızman-Tuzluca Basin, Ağrı Basin, Tercan Basin, Erzurum-Pasinler Basin, Tekman-Karayazı Basin, Çaldıran Basin, Hınıs Basin, and Muş Basin, occurred in the EAR. Of them, the Oltu-Balkaya Basin, which occurred on the northern side, the Tekman-Karayazı Basin, which occurred in the central part, and the Muş Basin, which occurred on the southern edge of the EAR, were selected for this research project. These basins are useful for such a study because they show typical and characteristic features of the other EABs. In the following sections, the main characteristic features of these selected basins are presented.

2.1. The Oltu-Balkaya Basin

In dimensions the Oltu-Balkaya Basin is characterized by a width of 25 km and a length of 50 km, as represented by the present-day outcrop area. The basin is located approximately 100 km to the northeast of Erzurum Province (Figure 1) and lies parallel to the general trends of the basement rock units, in a NE-SW direction.

The Oltu-Balkaya Basin is located close to the southern edge of the EPA and lies over a mosaic, which is made up of the forearc deposits of the EPA and obducted ophiolitic products of the NALCS. Because of its coal deposits, the Oltu-Balkaya Basin has been studied in detail by several researchers (Özdemir, 1981; MTA, 2002; Konak and Hakyemez, 2008; Yılmaz and Yılmaz, 2016). After these studies, a geological map presenting the cross-section and a stratigraphic section of the basin was compiled (Figures 2 and 3). The Oltu-Balkaya Basin fill was deposited on the Jurassic-Cretaceous forearc units (Figure 4A) of the EPA and ophiolites and mélanges of the NALCS. The stratigraphic sequence and fossil content of the area are presented in Figure 3. There is a clear unconformity between the pre-Maastrichtian paleotectonic units and the Maastrichtian-Early Eocene basin fill (Figure 3). In the studied area, the forearc deposits were deformed and thrust over Oligo-Miocene clastic rocks, from north to south, to the north of the region that was examined (Figure 4B).

The basin's fill as a whole represents a Maastrichtian-Quaternary rock association and starts with Maastrichtian conglomerate and continues upwards into Paleocene-Early Eocene reefal limestone and deltaic sandstone (Figure 3). The Ziyarettepe formation is on the EPA; however, the Bahçelikışla and Vişneli formations are found mainly on the ophiolitic units. The Bahçelikışla formation is a product of a marine and deltaic environment, which overlies the ophiolitic mélange in some places. However, this formation was thrust over by the mélange at some locations. The unit passes transitionally to the Vişneli formation (Konak and Hakyemez, 2008), which is represented by Early Eocene clastics and turbiditic rocks that were deposited in a gradually deepening marine environment. Because of the young cover rocks, it is not possible to directly see a lateral transition between Maastrichtian-Paleocene-Early Eocene rock units.

The Middle-Late Eocene sequence is represented by nummulite-bearing clastics and andesitic volcanoclastic rocks with basalts. There is an unconformity between the Middle Eocene sequence and the older units (Figure 3). For instance, the unconformity between an ophiolitic mélange and Middle Eocene clastic rocks is seen in Figure 4C.

The Oligo-Miocene sequence starts with continental red conglomerates and continues upwards into olivine basalt and fluviolacustrine deposits including coal levels, andesitic tuff, gypsum with clastic rocks, massive gypsum levels, and andesite with clastic rocks in order of ascent (Figure 3). There are lateral and vertical facies that change in short intervals along the Oligo-Miocene sequence.

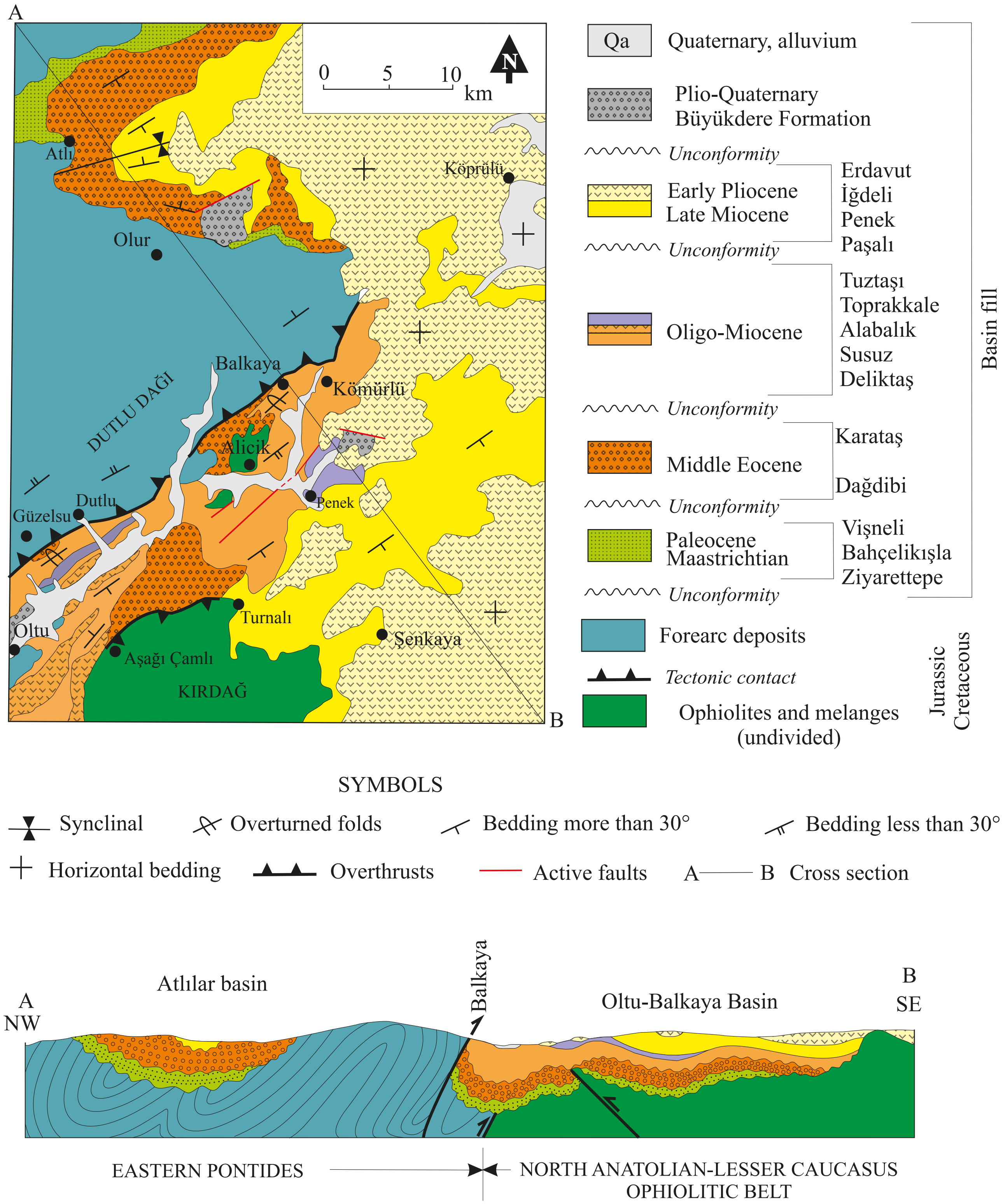

Figure 2. Geological map and cross-section of the Oltu-Balkaya Basin (after Özdemir, 1981; Konak and Hakyemez, 2008; MTA, 2002; Yılmaz and Yılmaz, 2016 and new revision). See Figure 1 for locations.

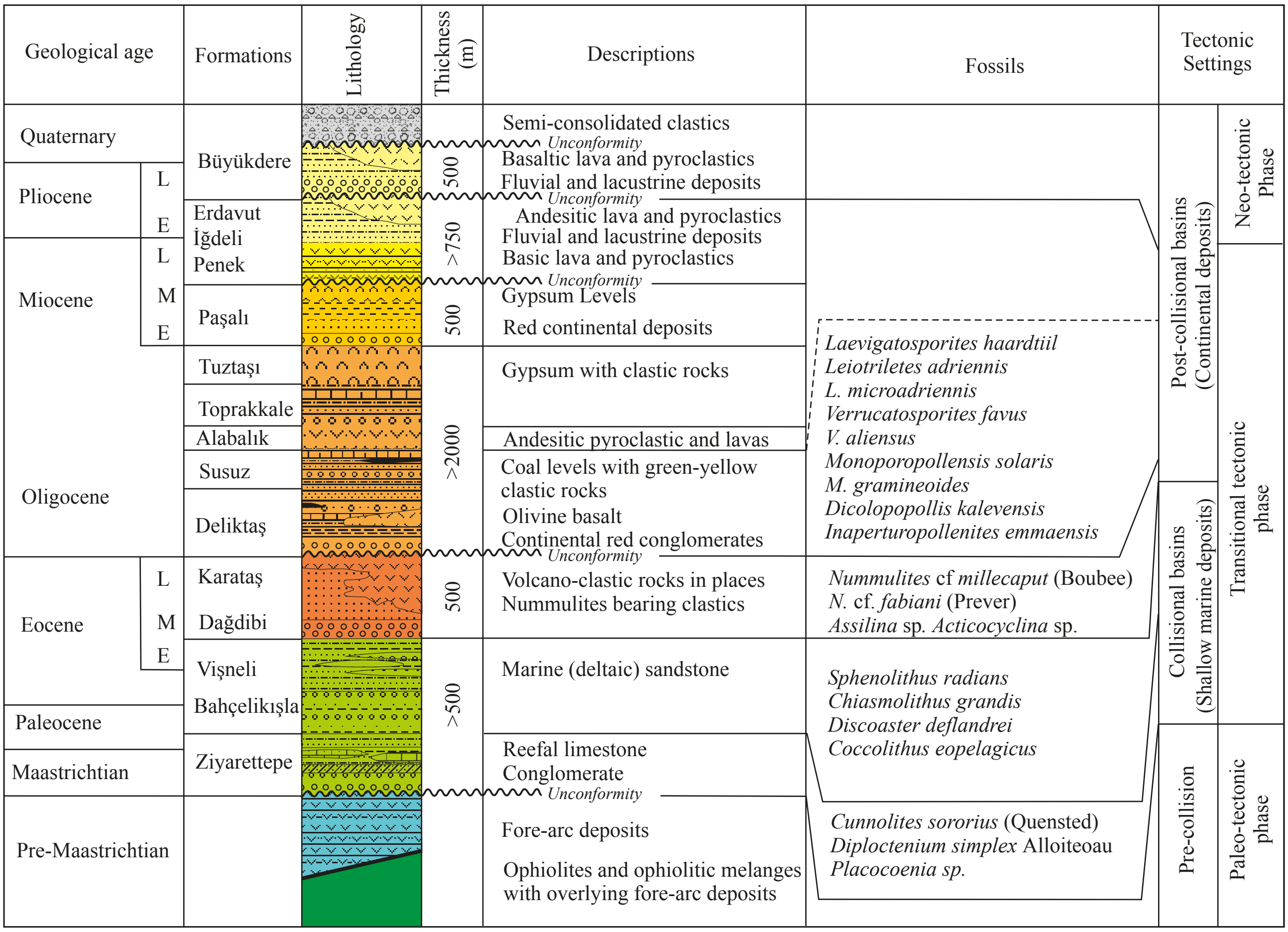

Figure 3. Stratigraphic section of the Oltu-Balkaya Basin and surroundings (after Özdemir, 1981; Bozkuş, 1990; Konak and Hakyemez, 2008; Yılmaz and Yılmaz, 2016 and new revision).

There is a clear angular unconformity between the Oligo-Miocene and Eocene units (Figure 4C) and also a local overthrust (Figure 4D). Basaltic lava and pyroclastic rocks outcrop as a level in the Oligo-Miocene continental deposits, just to the south of the Oltu-Bahçecik area (Figure 4E). However, there is a local unconformity between the Oligocene Tuztaşı formation and the Early Miocene Paşalı formation (Figure 3).

Late Miocene-Early Pliocene fluvial and lacustrine deposits, the Penek and İğdeli formations overlie the Middle Miocene and older units unconformably. The andesitic volcanism (Erdavut volcanics) in the area occurred during the end of the Early Pliocene age. Late Pliocene-Quaternary fluvial to lacustrine deposits (Büyükdere formation), including basaltic lava and pyroclastics, overlie all the older units unconformably. The unconformity between the Oligo-Miocene continental deposits and Late Pliocene-Quaternary deposits is seen in Figure 4F.

There are no Late Miocene-Pliocene and Quaternary marine rock units in the region. The late Miocene-Quaternary time is therefore interpreted as the last continental period of the region.

The Oltu-Balkaya Basin is characterized by folds striking approximately NE-SW and a thrust fault striking NE-SW, which dips about 40° towards the north (Figure 2). These structures represent a NW-SE-directed compressional tectonic regime that prevailed in the basin at least during the Late Oligocene-Miocene time, because the Late Pliocene-Quaternary beds are horizontal and have not been folded later on. Therefore, it is interpreted that the Late Pliocene-Quaternary unit represents the Neotectonic phase of the postcollisional period.

2.2. Tekman-Karayazı Basin

This basin is located in the central part of the EAR, between the peaks of Şahvelet Dağ and Akdağ. It is 30 km in width and 70 km in length and is located approximately

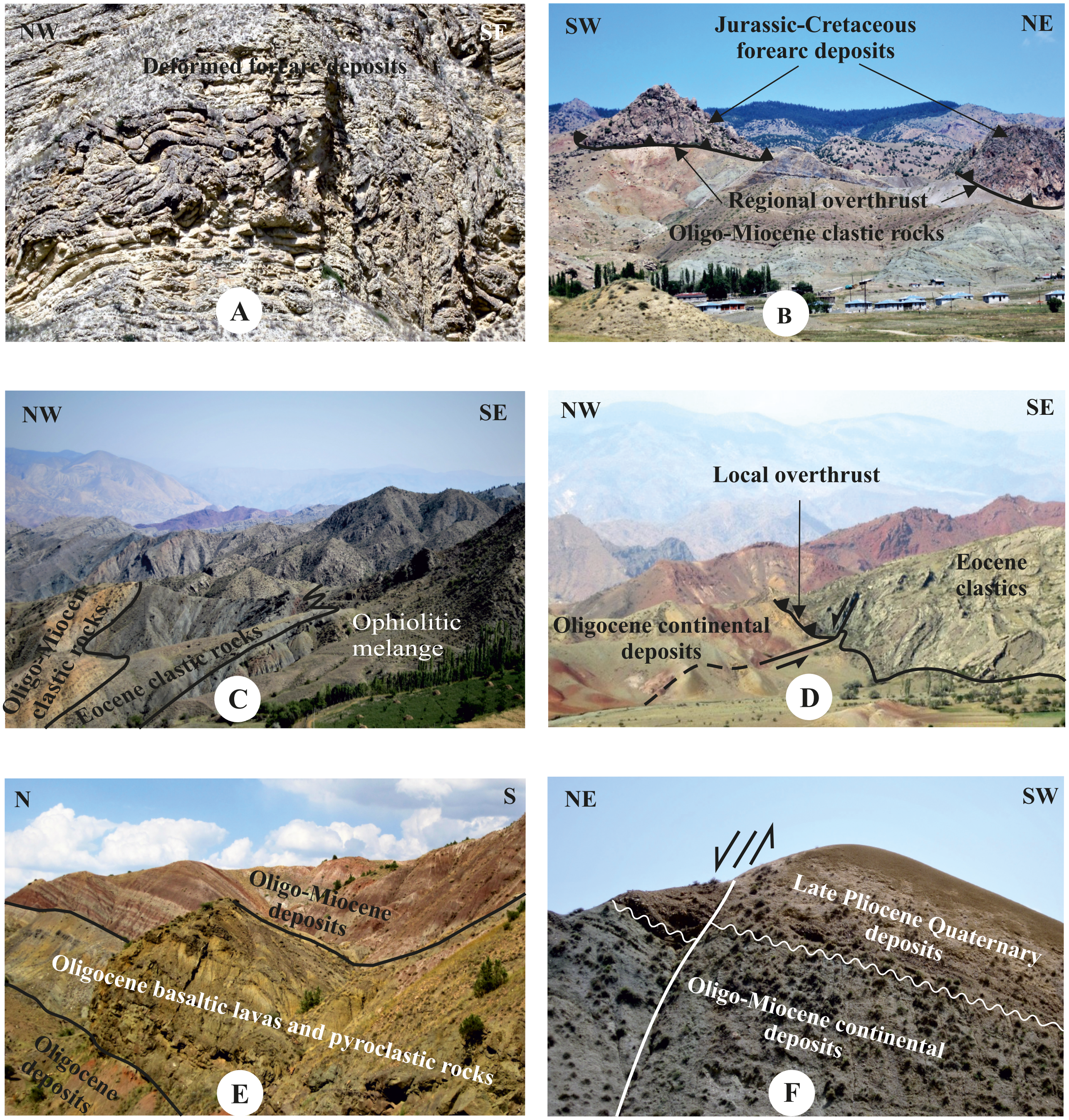

Figure 4. Field photos from the Oltu-Balkaya Basin. A) A view from deformed Jurassic-Cretaceous forearc sequence to the South of Olur area, to the north of the basin. B) The northern contact of the basin. Oligo-Miocene clastics including coal beds and tectonically overlay by forearc deposits, to the north of Balkaya. C) The southern contact of the basin. Unconformity between Late Cretaceous ophiolitic mélange, Eocene marine clastics, and Oligo-Miocene continental deposits, to the east of Aşağı Çamlı area. D) Local overthrust between Eocene clastics and Oligocene continental deposits, to the northeast of Turnallı village. E) Basaltic volcanic level in the Oligo-Miocene continental deposits, just to the southeast of Oltu town. F) Oligo-Miocene sequence and unconformably overlying Late Pliocene-Quaternary deposits, just to the north of Oltu town.

70 km to the south-southeast of Erzurum Province (Figure 1). The basin is also parallel to the general trends of the basement rock units in an E-W direction. The Tekman-Karayazı Basin was interpreted as an intermountainous basin by Kurtman and Akkuş (1971) and also by Şaroğlu and Yılmaz (1986).

The Tekman-Karayazı Basin started to form on both the continental Akdağ metamorphics and obducted overlying mélange prism together. The Akdağ metamorphics crop out from beneath obducted ophiolite and mélange as a tectonic window (Figure 5, see cross-section). On the basis of the north-dipping thrusts, it is possible to suggest that the ophiolites originated from the northern branch of the Neo-Tethys. The stratigraphic and fossil content of the basin fill are presented in Figure 6.

The setting of tectonic contact between Akdağ metamorphic rock units and obducted ophiolites can be seen in Figure 7A. A general view of the granitoids is presented in Figure 7B. These granitoids intruded in the metamorphic rocks, in a fragile environment and in ophiolites, in some places together. For a geochronological evaluation, plagioclase minerals from only one sample were analyzed using the $^{40}Ar/^{39}Ar$ method by Dr Yakov Kapusta at Actlabs, Canada. In this determination, an 83.9 ± 2.3 Ma radiometric age (Cenomanian) was obtained from granitoids (Figure 8). Figure 8A shows the $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ diagram; Figure 8B shows the age (Ma) vs. cumulative $\%^{39}Ar$ diagram. In conclusion, it can be said that the age of the granitoids has been determined as Late Cretaceous.

These intruded rocks are attributed to syncollisional crustal thickening, then postcollisional processes and subsequently to a partial melting of the Akdağ metamorphics and ophiolitic rocks of the Hınıs area (Öner et al., 2007). From this, it is possible to suggest also that the subduction started in the beginning of the Late Cretaceous period and collision occurred thereafter.

Maastrichtian reefal limestone with a polygenetic basal conglomerate (Dündar formation) overlies ophiolitic and metamorphic rocks together (Figures 5, 6, and 7C), and passes upwards into Paleocene-Early Eocene clastic rocks (the Sevik formation). Middle Eocene conglomerate with nummulite-bearing limestone overlies the Paleocene-Early Eocene clastic rocks unconformably (Figures 6 and 7C). In some places, olistostromal levels can be seen in the upper level of the Middle Eocene sequence. Similar levels occurred along the low angle gravity fault zones as suggested by Karig and Kozlu (1990). In the Tekman-Karayazı Basin, olistostromal levels are located along the overthrust zones, controlling the northern contacts of the basin. From this it may be understood that these levels may be the product of the compressional tectonic regime. The uppermost level of the Eocene sequence represents a regressive sandstone and conglomerate alternation.

Oligo-Miocene reddish conglomerate with limestone, sandstone, and gypsum levels overlies the Middle Eocene clastic rocks unconformably. Figure 7D shows an unconformity between Eocene clastics (the Kösehasan formation) and Early Miocene reefal limestone (the Hanedüzü formation) directly. There is also a local unconformity between Oligocene clastics and Early-Middle Miocene reefal limestone (Figure 6). Middle Miocene marl and clayey limestone passes upwards into the Middle Miocene volcanoclastics rock units (the Mescitli formation) conformably (Figure 7E).

Late Miocene fluvial and lacustrine clastic rocks (the Alibonca formation) overlie the Middle Miocene marl and clayey limestone (the Mescitli formation) unconformably (Figure 7F) and pass upwards into the andesite with pyroclastics rocks (the Bingöldağı volcanics). Late Pliocene fluvial clastic rocks (the Zırnak formation) overlie all the older units unconformably also, and pass upwards into the basalt lavas and related pyroclastic rocks (the Karayazı volcanics).

The Tekman-Karayazı Basin is characterized by tectonic structures of different ages. For instance, one of the important paleotectonic structures is an overthrust between the Akdağ metamorphics and the Şahvelet ophiolites, and the relationship between them represents a tectonic window. The neotectonic structures of the basin are characterized by E-W trending folds, thrust faults striking approximately E-W, and dips about 45° towards the north along the southern Şahvelet Dağ and the NW-SE trending dextral strike-slip faults and NE-SW trending sinistral faults, as well. These structures, as a whole, represent the N-S directed compressional tectonic regime that prevailed in the basin at least during the Late Oligocene-Miocene time. Late Pliocene-Quaternary beds are horizontal and have not been folded later on.

2.3. Muş Basin

The Muş Basin is situated to the south of the EAR, on the Bitlis Massif, which represents the Eastern Taurus Platform and ophiolitic units together (Figure 9). The basin is characterized as 35 km in width and 75 km in length and is located approximately 30 km to the north-northeast of Muş Province (Figure 1). This basin is also parallel to the general trends of the basement rock units, but it lies in a NW-SE direction. The Muş Basin was interpreted as an intermountainous basin by Kurtman and Akkuş (1971) and Şaroğlu and Yılmaz (1986) and/or as a postcollisional cratonic basin by Akay (1989).

In the Bitlis area, the Bitlis Massif metamorphic rocks crop out from beneath obducted ophiolites and mélanges (Göncüoğlu and Turhan, 1983; Yılmaz et al., 2010). Mainly in the Mutki area, Maastrichtian conglomerate overlies the metamorphics and ophiolitic units together.

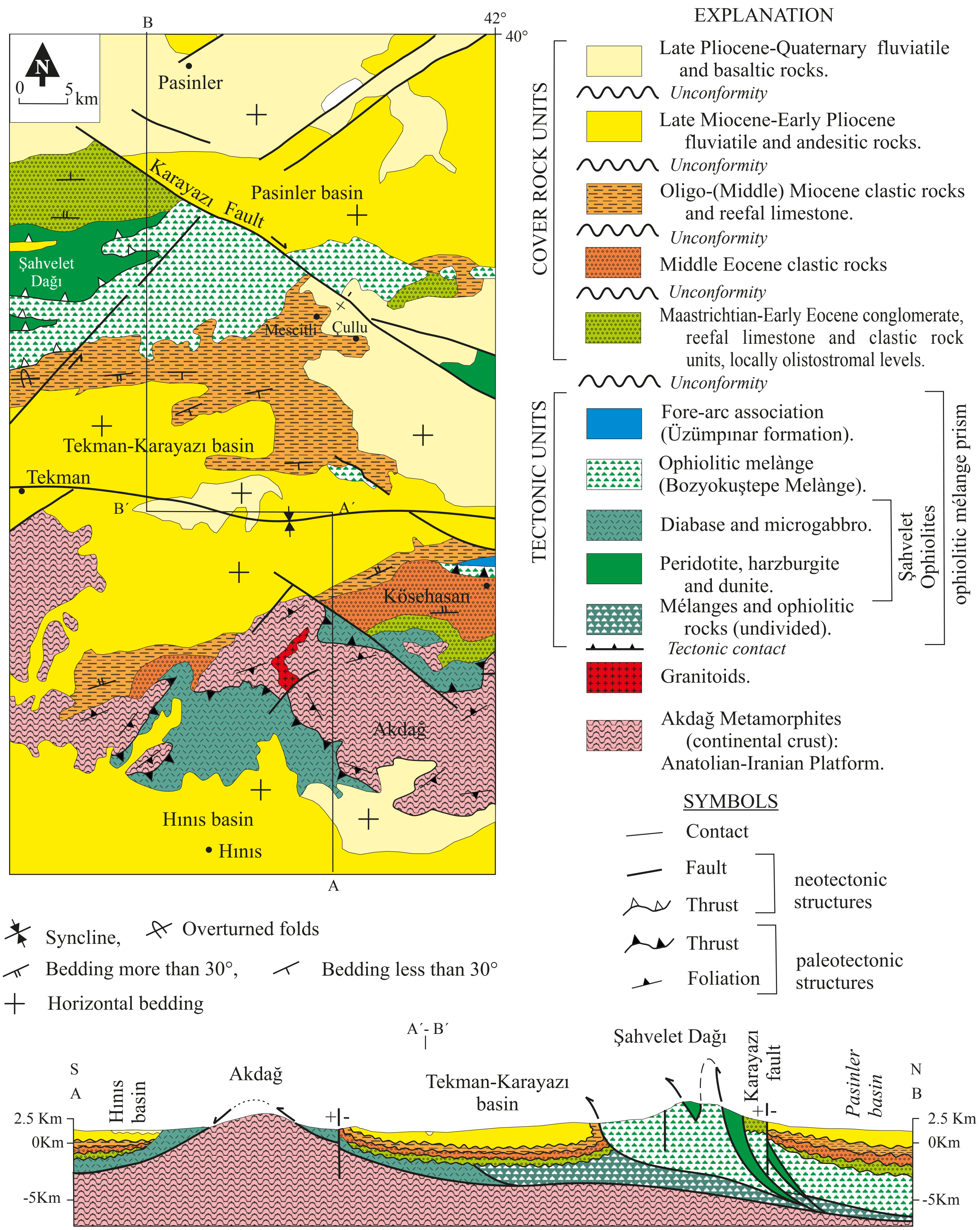

Figure 5. Geological map and cross-section of the Tekman-Karayazı Basin (Erzurum) (after Gedik, 1986; Yılmaz et al., 1988, 2010). See Figure 1 for location.

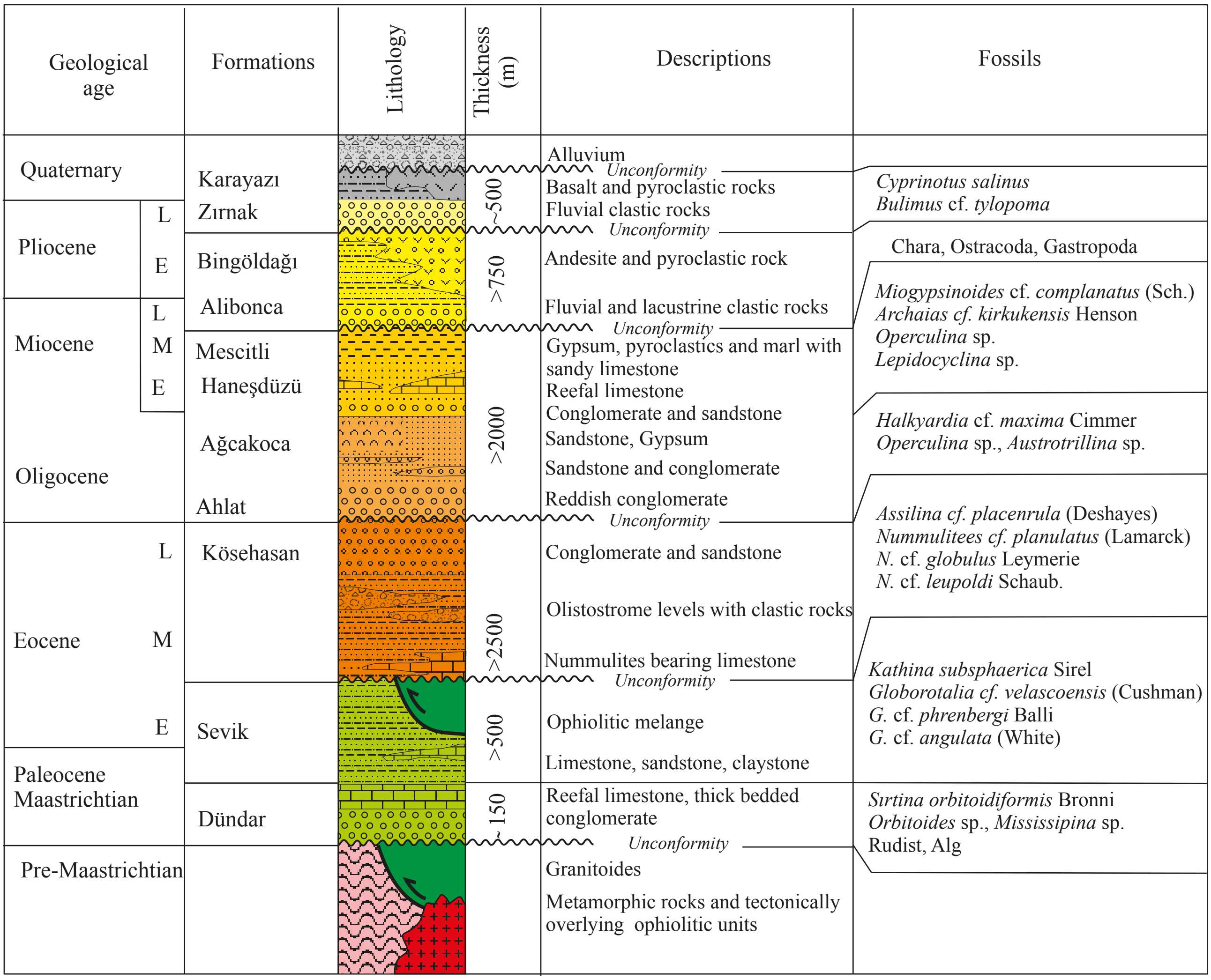

Figure 6. Stratigraphic section of the Tekman-Karayazı Basin and surrounding area (after Yılmaz et al. 1988; Yılmaz et al. 2010).

For this reason, obducted ophiolitic units with overlying Maastrichtian clastics and limestone have been added to the cross-section (Figure 9) and stratigraphic section (Figure 10), in spite of not being seen on the geological map of the Muş Basin. In addition, Eocene shallow marine clastic rocks and limestones overlie the older tectonic units, mainly in the Gevaş area (Yılmaz et al., 1981).

In the southern part of the Muş Basin, Quaternary deposits directly overlie metamorphic rocks of the Bitlis Massif, unconformably, along the northern contact of the Massif (Figure 11A). The stratigraphic section and fossil content of the Muş Basin fill are presented in Figure 10.

In the Muş area that was studied, Middle Eocene clastic rocks, which are known as the Kızılağaç formation, include an alternation of shale, claystone, sandstone, and conglomerate and represent the lowermost level of the basin fill.

Oligocene rock units begin with a reddish conglomerate of the Ahlat formation and pass transitionally upwards into claystone and siltstone of the Norkavak formation (Figure 11B). In the middle part of the Oligocene sequence (the Gerisor formation) there are synsedimentary gravity faults (Figure 11C); in the upper part of the Oligocene sequence (the Ebülbahar formation) folding and local overthrusts (Figure 11D) are dominant. These relationships may be indicators of the opening (extensional) and closing (compressional) tectonic regime of the Oligocene basin. Conglomerate, sandstone, claystone, and siltstone alternations of the Oligocene sequence pass upwards into the Sergen formation. The Sergen formation represents a

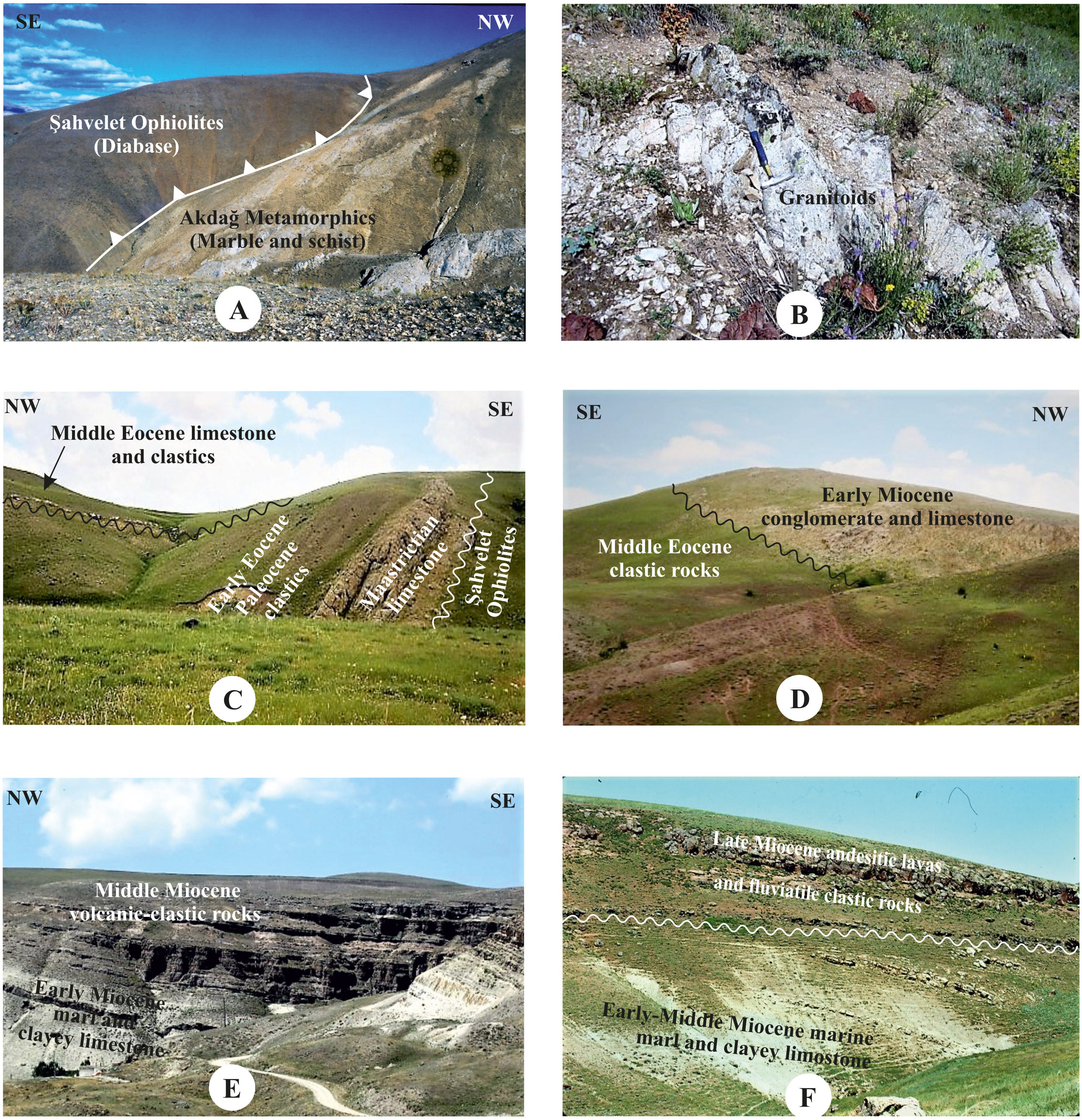

Figure 7. Field photos from the Tekman-Karayazı Basin. A) Akdağ metamorphics and obducted ophiolites (gabbro and diabase) to the west of Akdağ and north of Hınıs town. B) Granitoids to the northeast of Akdağ and south of Tozlu Yayla. C) Ophiolites (gabbro) and unconformably overlying Maastrichtian-Paleocene reefal limestone with clastic rocks and Middle Eocene limestone with clastic rock units, respectively, to the north of Akdağ and southwest of Kösehasan village, between Dündar and Zeyno villages. D) Eocene clastic rock units and unconformably overlying Early Miocene conglomerate and reefal limestone to the northwest of Kösehasan village. E) Transition in the Early-Middle Miocene sequence from marine marl and clayey limestone to deltaic volcano clastic rocks, to the northeast of Mescitli-Çullu area. F) Early-Middle Miocene marine marl with clayey limestone and unconformably overlying Late Miocene fluviatile clastics and andesitic lavas to the northeast of Kösehasan village.

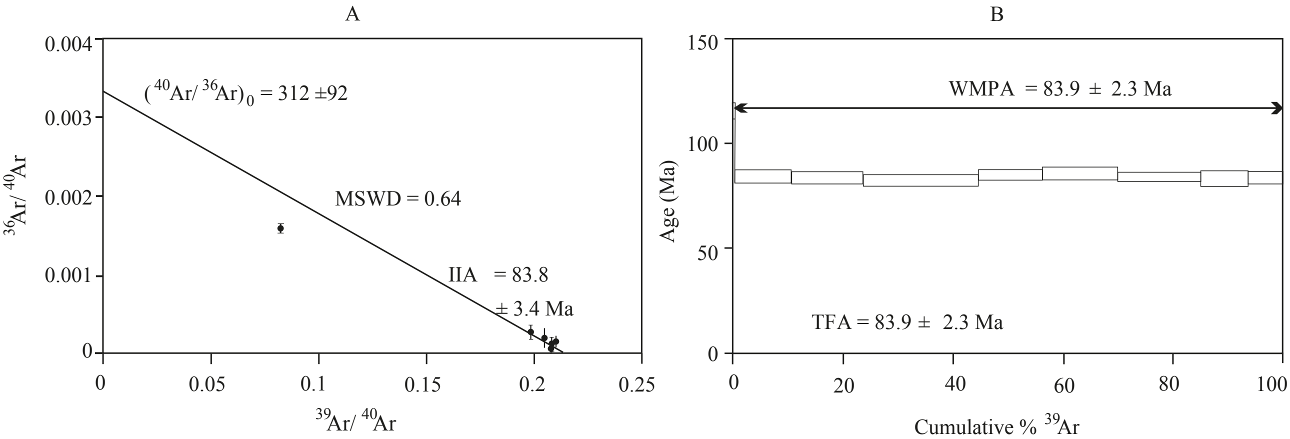

Figure 8. Isochronous and plateau age of granitoids intruded in the Akdağ metamorphics. A) $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$; B) Age (Ma) vs. Cumulative %^{39}Ar diagram (see Figure 5 for location of geochronological rock sample, R).

transitional unit (Figure 11E) between an Oligocene clastic sequence and Early Miocene Adilcevaz reefal limestone. The thickness of the Oligocene-Lower Miocene sequence is about 4000 m and the sequence overlies the Middle Eocene clastic rock units unconformably (Figure 10).

Late Miocene-Early Pliocene fluvial deposits and andesite with pyroclastic rocks (the Elçiler formation) overlie the Oligo-Middle Miocene sequence unconformably. Late Pliocene-Quaternary clastics, in association with basaltic lavas, overlie the older rock units unconformably, as well. Solhan basaltic lavas represent the upper part of the Late Pliocene-Quaternary sequence (Akay et al., 1989), although they are dated as late Miocene (Şaroğlu and Yılmaz, 1986).

The Muş Basin is characterized by E-W trending folds and NW-SE trending dextral strike-slip faults. These structures represent the N-S directed compressional tectonic regime that prevailed during the formation of the basin. Late Pliocene-Quaternary beds of the basin are approximately horizontal and have not been folded much later on. These beds are deformed only by the strike-slip faults, which have a thrust component (Figure 11F).

3. Correlation of the basin fills

All basin fills represent the Maastrichtian-Quaternary sequence and the fills overlie the paleotectonic units unconformably. It is possible to see this unconformity in Eastern Anatolia and everywhere from the Eastern Pontides to the Arabian Platform. The basement of the fills is made up of a mosaic, representing both continental crust and tectonically overlying ophiolitic units. Each basin fill can be separated as formations and members (Figures 3, 6, and 10). A correlative table showing stratigraphic sections of the basin fills as a whole is presented in Figure 12.

3.1. Maastrichtian-Early Eocene

In the lower level of the basin fills, Maastrichtian clastic rocks start with polygenetic conglomerate and transitionally pass upwards into reefal limestone and then Paleocene-Early Eocene clastic rock units. In the Paleocene, hemipelagic units and in the Early Eocene delta-marine clastic rocks were deposited. There are no volcanic levels in the basin fills. Maastrichtian-Early Eocene sequences of the basin fills show similar characteristic features and have been interpreted as the fills of syncollisional foreland basins.

3.2. Middle Eocene

Middle Eocene units regionally overlie the collisional foreland basin fills unconformably, throughout the region, from the EPA to the north to the Bitlis Massif to the south. These clastic rocks represent shallow marine deposits and volcanoclastic units.

In the Oltu-Balkaya Basin, nummulite-bearing clastics represent the lower level (the Dağdibi formation) and volcanoclastic rocks represent the upper level (the Karataş formation) (Figure 3). However, in the Tekman-Karayazı and Muş Basins, clastics are the dominant rock units (Figures 6 and 10). In addition, olistostromal levels can be seen along northern tectonic contacts of the Tekman-Karayazı basin fill (Figures 6 and 12). These levels represent reworked materials of the ophiolitic mélange. It can be suggested that the Middle Eocene saw the beginning of the first postcollision phase.

3.3. Oligocene-Early/Middle Miocene

Oligocene deposits start with reddish polygenetic conglomerate. This unit is known as the Deliktaş formation in the Oltu-Balkaya Basin and as the Ahlat formation in the Tekman-Karayazı and Muş Basins. It is made up of a typical molasse, representing continental deposit. Then, in

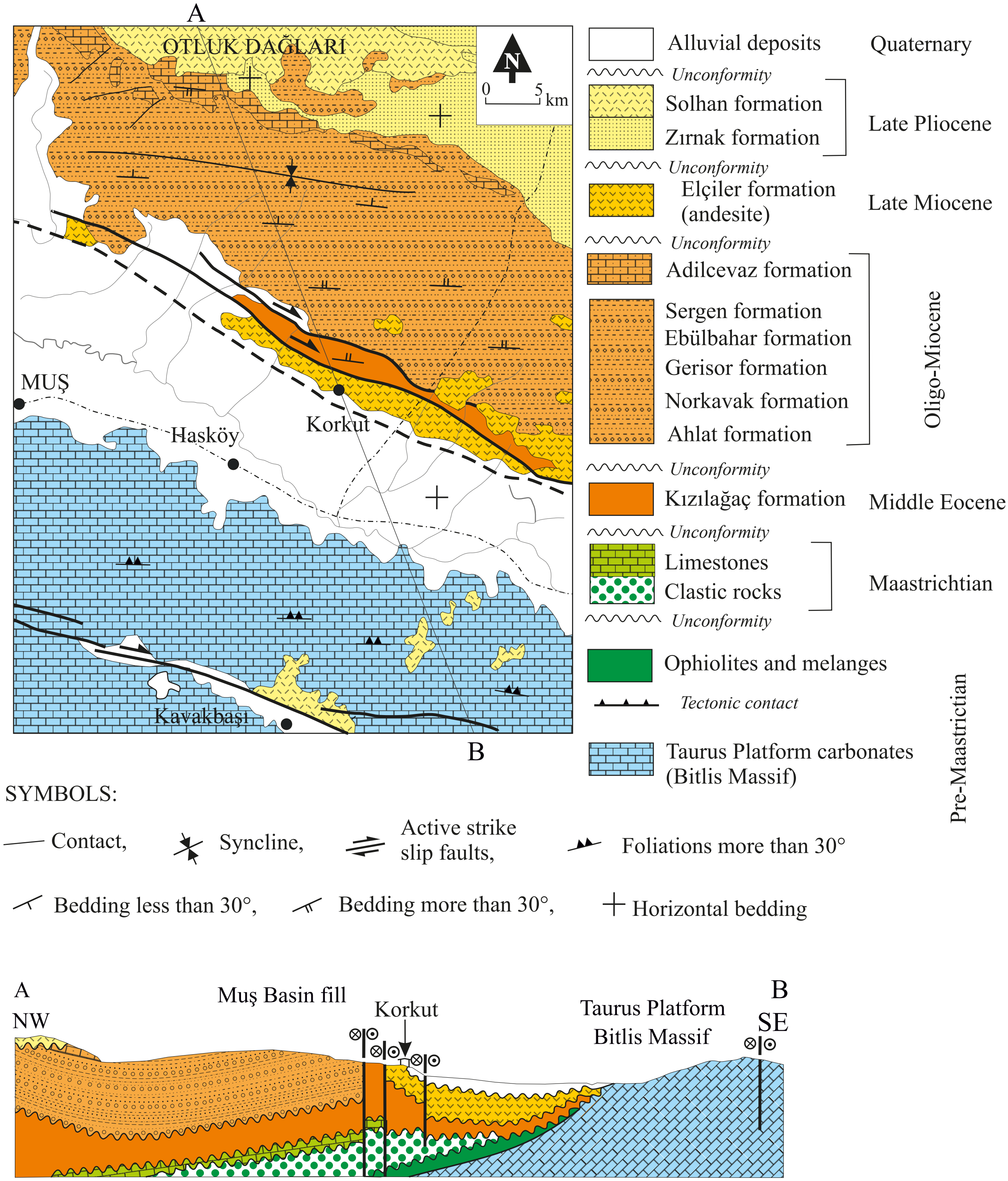

Figure 9. Geological map and cross-section of the Muş Basin (after Uysal, 1986; Akay, 1989; Akay et al., 1989; MTA, 2002 and new revision). See Figure 1 for location.

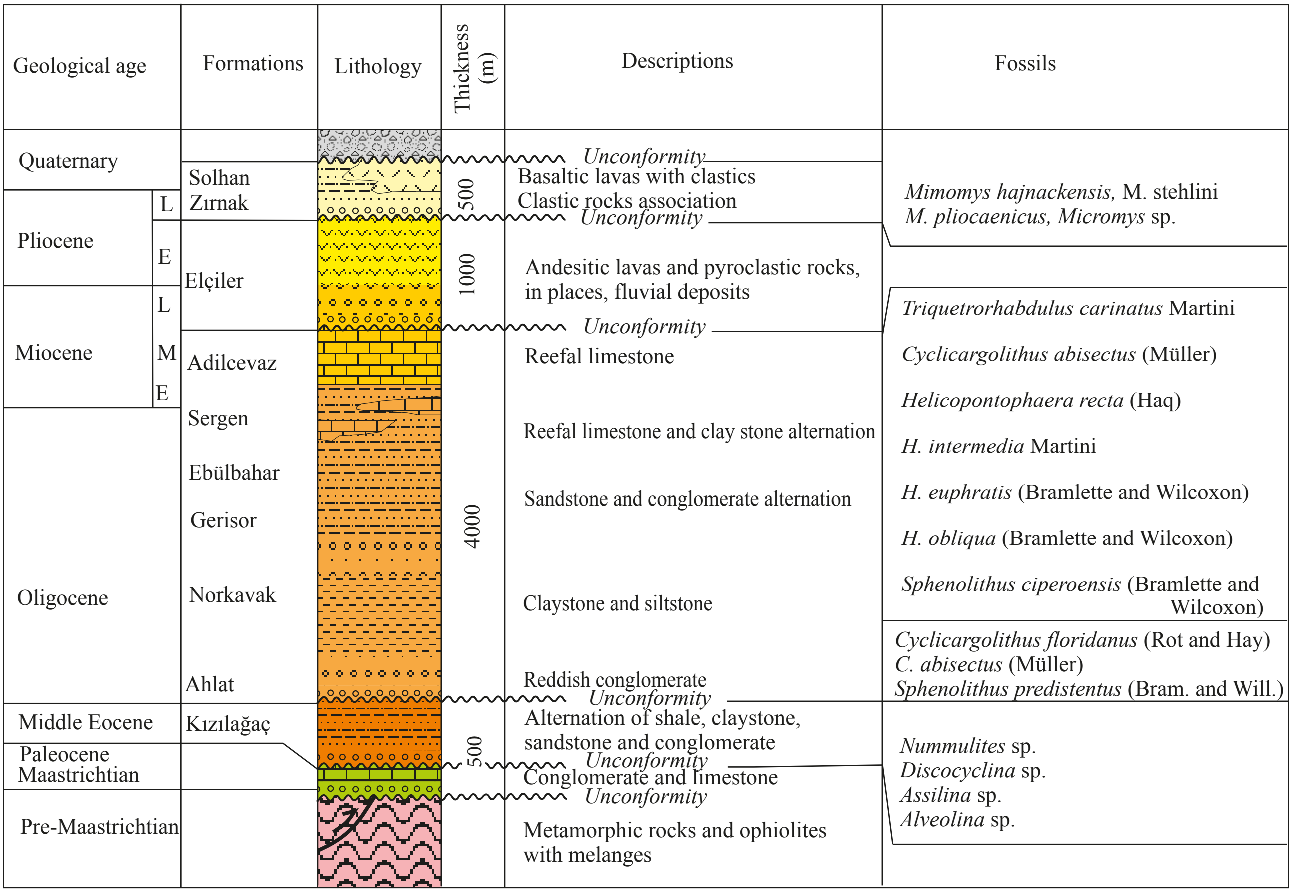

Figure 10. Stratigraphic section of the Muş Basin and surrounding area (after Uysal, 1986; Akay et al., 1989 and new revision).

the Oligocene-Early/Middle Miocene sequence within the Oltu-Balkaya Basin, from bottom to top, there are basaltic and andesitic lavas with volcanoclastic levels, coal-bearing levels, and gypsum with clastic rocks that have been separated from each other (Figures 3 and 12). There is a local unconformity between Oligocene and Early Miocene rock units in this sequence and also in the Tekman-Karayazı basin fill. However, there are no volcanic and pyroclastic levels in the Oligocene-Early/Middle Miocene sequence of the Tekman-Karayazı and Muş Basins (Figures 6, 10 and 12), but Oligocene continental deposits pass upwards into the Early Miocene reefal deposits transitionally along the Muş Basin.

In general, the Oligocene-Early Miocene sequence of all the basin fills represents shallow marine and continental deposits. There are sharp lateral and vertical facies change in the basin fills. In spite of these changes, the Haneşdüzü formation of the Tekman-Karayazı Basin and the Adilcevaz formation of the Muş Basin can be correlated in age and in their shallow marine facial character. All rock units of the fills are folded tightly and imbricated on a great scale. Therefore, the formation of the Oligocene-Early Miocene basin fills represents typical molasses and also the second and hard postcollision phase.

3.4. Late Miocene-Early Pliocene and Late Pliocene-Quaternary

Late Miocene-Quaternary units represent only continental (fluvial to lacustrine) deposits and the third or last postcollision phase, as a whole. Continental sedimentation is accompanied by different types of volcanism.

For instance, Late Miocene-Early Pliocene clastic rocks with andesitic rocks were deposited in the continental basins along the EAR from north to south. These fluvial to lacustrine deposits with andesitic lavas and pyroclastic rocks overlie the older units with a regional unconformity and represent the last stage of postcollision. Basaltic lavas and pyroclastic rocks (the Penek formation) exist only in the lower level of the Oltu-Balkaya Basin (Figure 3). The

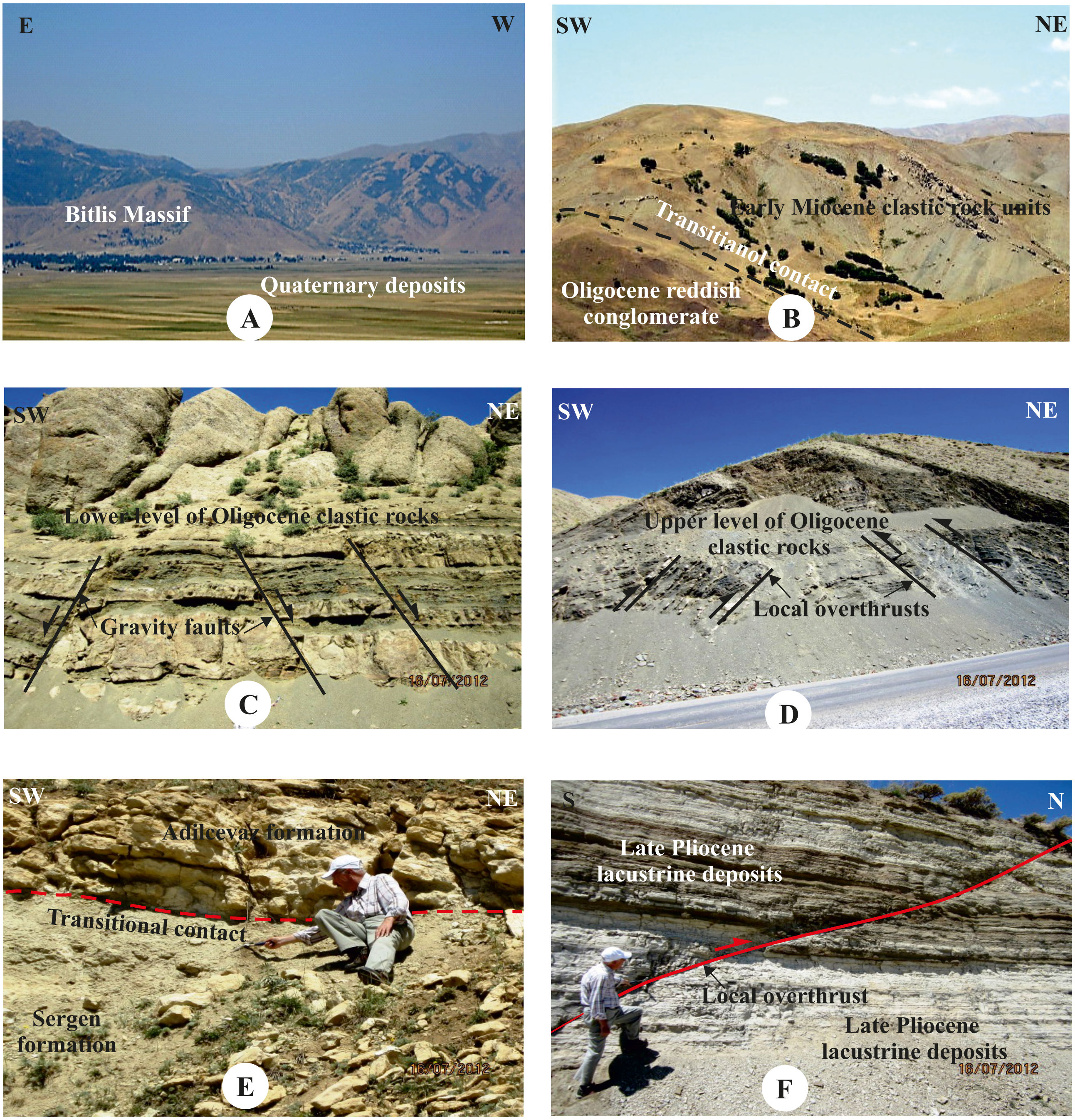

Figure 11. Field photos from the Muş Basin. A) Bitlis Massif and unconformably overlying Quaternary deposits, a view from north (Hasköy town) to south. B) A sequence from Oligocene reddish Ahlat formation (conglomerate) to green clastic rock units, northeast of Korkut town (along Nurkavak river and north of Güneyik village). C) Synsedimentary gravity faults in the lower part of the Oligocene sequence, to the northwest of Korkut town (to north of Yedipınar village). D, Synsedimentary folds and thrusts in the upper part of the Oligocene sequence, to the north of Yedipınar village. E) Vertical transition from Oligocene-Early Miocene marls (Sergen formation) to Early Miocene reefal limestone (Adilcevaz formation) to the north of Korkut town and south of Otluk Dağları (to the north of Yedipınar village). F) A strike-slip fault with thrust component in the late Pliocene clastic rocks including coal beds to the northwest part of the study area (west of Otluk Dağları; 1 km to the south of Keçideresi village).

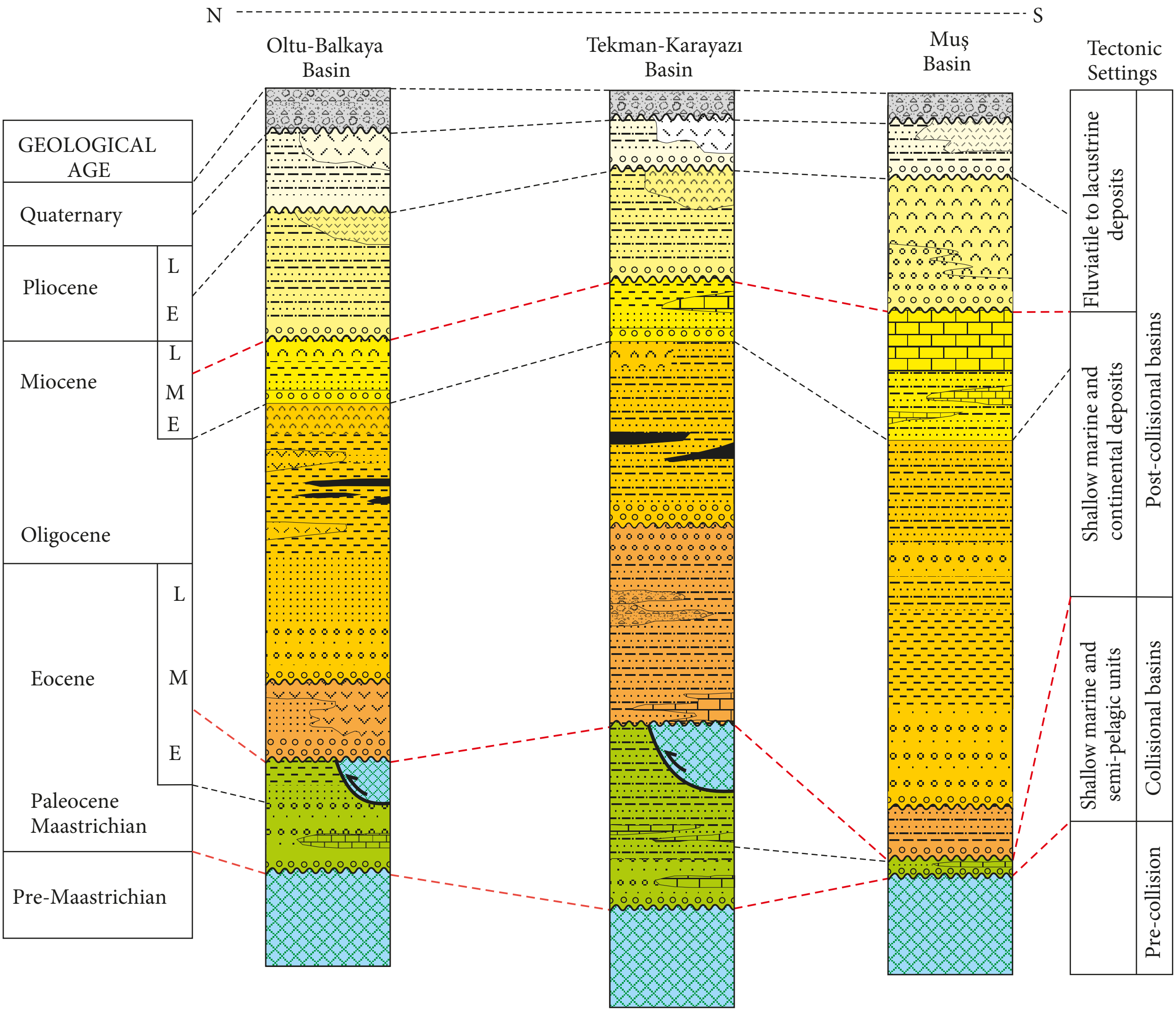

Figure 12. Lithostratigraphic correlational table of the Eastern Anatolian Basins and their tectonic settings (see Figures 3, 6, and 10 for explanations).

İğdeli formation of the Oltu-Balkaya Basin, the Alibonca formation of the Tekman-Karayazı Basin, and the lower of the Elçiler formation in the Muş Basin represent fluvial to lacustrine deposits and can be correlated in age and depositional environment. The Erdavut formation of the Oltu-Balkaya Basin, the Bingöldağı formation of the Tekman-Karayazı Basin, and the upper part of the Elçiler formation in the Muş Basin represent andesitic lavas and pyroclastic rocks and can be correlated in age, setting, and composition (Figures 3, 6, and 10). However, the units presented above were deformed together and approximately E-W trending folds occurred during the formation of the new basins.

Late Pliocene-Quaternary fluvial to lacustrine deposits and basaltic lavas with related pyroclastic rocks occurred in the continental basins as well. The lower level of the Büyükdere formation in the Oltu-Balkaya Basin and the Zırnak formation of the Tekman-Karayazı and Muş Basins can be correlated in age and depositional environments. In addition, the upper part of the Büyükdere formation in the Oltu-Balkaya Basin, the Karayazı formation of the Tekman-Karayazı Basin, and the Solhan formation of the Muş Basin represent basaltic lavas and pyroclastics and can be correlated in age and composition (Figures 3, 6, and 10). The upper Pliocene-Quaternary sequence has not been deformed much and beds of the sequence are approximately horizontal, mainly in the central part of the basins; they were deformed only along near the strike-slip faults. Therefore, this level of the fills should have occurred during the Neotectonic phase (Koçyiğit et al., 2001) of the postcollisional period.

As a conclusion to these correlations, it is possible to suggest that the EABs show similar stratigraphic and tectonic features, although there are local differences, from north to south in the EAR (Figure 12). Despite the current differences in the basin fills, there may be common transitions between the basins. Therefore, all the basins may be in contact with each other, from north to south and also from west to east. Because of the Late Miocene-Quaternary widespread terrestrial clastic and volcanic cover, it is not possible to see real relationships between the basin fills of the EAR.

4. Structural evolution of the Eastern Anatolian Basins

The EAR is located between the Eastern Pontides to the north and the Arabian Continent to the south and it represents the Anatolide-Tauride Platform (Okay and Tüysüz, 1999) of Turkey and/or the Anatolian-Iranian Platform (Yılmaz et al., 2010). This region evolved as a cratonic-tectonic unit depending on convergence of the Eastern Pontides and Arabian Continent from the Maastrichtian to the Recent. For the evolution of the EABs, it is better to separate the stages of precollision, collision, and postcollision from each other. In spite of there being no effort to integrate the presented data, there are sufficient data about separation of the collisional and postcollisional stages of the EABs.

4.1. Precollision stage

On the basis of geological data obtained from Eastern Anatolia, it is possible to envisage the geotectonic setting presented in Figure 13A for the Cenomanian-Campanian interval. There is a general consensus on this configuration of Turkey for the Late Cretaceous period (Yılmaz and Yılmaz, 2013 and references therein). All rock units of the basement of Eastern Anatolia are of pre-Maastrichtian age (Yılmaz et al., 2010; Topuz et al., 2017 and references therein). The Pre-Maastrichtian mosaic of the EAR represents the precollision tectonic units and it is clear that there are ensimatic arcs along the northern and southern branches of the Neo-Tethys. There should be the Anatolian-Iranian Platform (AIP) between branches of the Neo-Tethys. The age of the mélanges and presence of ophiolites together along the NAOB and SAOB between the EPA and AIP support the configuration shown in Figure 13A (Yılmaz and Yılmaz, 2013 and references therein).

4.2. Collisional stage

Syncollisional magmatism is dominant along the EPA in Northeast Anatolia and also in the Central Anatolian Region to the west and it occurred during the Maastrichtian-Early Eocene (Boztuğ et al., 2003, 2006). In the same time interval, a syncollisional basin developed between the AIP and the Somkheto-Karabakh zone (Sosson et al., 2010), which is an eastern continuation of the Eastern Pontides, to the east of the Oltu-Balkaya Basin. This syncollisional event occurred between the EPA and the AIP. In this stage, the EABs evolved as a large single basin. Taking into consideration the regional tectonics of the basins (Figure 13B), it is possible to interpret the Maastrichtian-Early Eocene sequence of the EAR as a product of the syncollisional foreland basins and the metamorphic age of the AIP should be pre-Maastrichtian. Closing and also collision along the northern and southern branches of the Neo-Tethys may have occurred at different periods. For the northern branch of the Neo-Tethys, mainly for NE Turkey, Rice et al. (2006) suggested that the incipient 'soft' collision along the suture zone was followed by widespread Paleocene-Early Eocene sediments on deformed and emplaced mélange, arc, and ophiolitic units. The final closure of the 'hard' collision of the Northern Neo-Tethys occurred during the Middle Eocene. In addition, sedimentary sequences on both sides of a suture are expected to show similar depositional characteristics on the continental margins. In this respect, the collision between the EPA and the AIP should then be at least pre-Middle Eocene.

Maastrichtian polygenetic conglomerate overlies the older tectonic units unconformably and passes upwards into Maastrichtian reefal limestone and then Paleocene-Early Eocene clastic rock associations. There is a regional unconformity between the basement mosaic and sedimentary cover. In addition, there is no link between the pelagic levels of the ophiolites (and/or forearc deposits) and the basin fills, implying that the EABs did not develop on the oceanic crust.

The collision age of the Arabian Platform (AP) with Eurasia (in this study the AIP) is still, however, debated. Different ages have been proposed for the collision that would have occurred after the closure of the southern branch of the Neo-Tethys. These include suggestions such as the Maastrichtian (Yazgan, 1983) and/or Middle to Late Eocene age (Hempton, 1985), Late Eocene to Oligocene (Yılmaz, 1993), Late Oligocene to Early Miocene (Yılmaz et al., 2007), or Early-Middle Miocene (Robertson et al., 2007), and a time interval before the Late Miocene has also been put forward (Şengör and Kidd, 1979; Dewey et al., 1986; Şengör et al., 2003). Uplift of the final exhumation of the Bitlis Massif range by 18–13 Ma (Middle to Late Miocene) has been documented on the basis of apatite fission track dating (Okay et al., 2010). In addition, Late Miocene continental deposits overlie all the older units unconformably, from north to south along the SAOB suture and throughout the region. Therefore, the collision between the AIP and AP may have ended at the latest before the Late Miocene.

4.3. Postcollisional stage

After development of syncollisional foreland basins in the north of the EAR during the Late Maastrichtian-Early Eocene period, the basins gained the characteristics of a transition from soft collision to postcollision (and/or of the hard-final collision suggested by Draut and Clift, 2001). Topuz et al. (2005, 2011) suggested that Eocene magmatism represents postcollisional adakite-like activity within the Agvanis Massif along the southern side of the EPA. Middle Eocene units, including Eocene magmatism of this region, overlie the older rock units unconformably on a regional scale (Yılmaz, 1985). Therefore, the collision may have been completed before the Middle Eocene, between the EPA and the AIP.

Taking into consideration all the details about the basin fills and their correlations that were explained above, it may be possible to envisage the following for the EAR. The postcollisional stage may be divided into three phases: the first phase, second and/or hard phase, and last phase. These phases can be evaluated in the framework of arc/continent and continent/continent collisions after Draut and Clift (2001).

The first postcollision phase occurred during the Middle Eocene in the north of the EAR. The Middle Eocene shallow marine clastic rock units overlie all the older units unconformably, from north to south, throughout the region and surrounding regions. This level of the basin fill represents primitive molasses and the studied area was emergent as a land at the end of the Eocene and the beginning of the Oligocene periods. Shallow marine deposition was accompanied by Middle-Late Eocene postcollision with high potassium calc-alkaline magmatism in the Oltu-Balkaya region (Konak and Hakyemez, 2008), as well. As a result, it can be suggested that postcollisional basin formations started at the beginning of the Middle Eocene and Middle Eocene primitive molasses may be accepted as a product of the first postcollision stage.

The second or hard phase of the postcollision period occurred during the Oligocene-Early/Middle Miocene. The paleogeography of Eastern Anatolia was diversified in the beginning of the Oligocene age. A regional transgression occurred during this period in Eastern Anatolia. Oligocene-Early/Middle Miocene deposits represent typical molasses as shallow marine and continental deposits. In addition, the basin fills exhibit sharp changes in vertical and lateral facies, characterized by many local unconformities. The region pursued its existence as a postcollisional setting, where volcanism with high potassium was effective (Konak and Hakyemez, 2008).

In the Middle of the Miocene period, a widespread compression occurred throughout Eastern Anatolia and the whole region became land, due to hard postcollision between the EPA and AIP. Thrust to reverse faults and overturned to horizontal folds are dominant structures in Oligocene-Early Miocene basin fills. Therefore, the Oligocene-Early/Middle Miocene fill of the basins may be accepted as a product of the second or hard stage of the postcollision period.

The third and last post-collision phase occurred during the Late Miocene-Quaternary interval. Karig and Kozlu (1990) suggested that strike-slip motion, with both extensional and compressional components that varied spatially and temporally, dominated the evolution of the Central Anatolian region, after a late Cretaceous collision closed the Neotethyan ocean basin between the Arabian block and Tauride arc. In addition, geochemical and Sr-Nd-Pb isotope characteristics of the Late Miocene to Pliocene volcanic rocks from the Kandilli (Erzurum) area of Eastern Anatolia show implications for magma evolution of an extension-related origin (Kaygusuz et al, 2017). These determinations mark a phase in which the basins opened during the beginning of the Late Miocene to Pliocene interval.

In the EAR, Late Miocene-Quaternary fills of the basins represent continental deposits as a whole. Moreover, the Late Miocene molasse deposits unconformably overlie all the older tectonic units throughout the region. At the beginning of this period, the EAR and surrounding regions may have been a scene of extensional tectonic regime as a unique integrated continent. In addition, on the basis of apatite fission track dating, uplift and final exhumation of the Bitlis Massif range by 18–13 Ma (Middle to Late Miocene) has been documented (Okay et al., 2010) for the postcollision. The Late Miocene-Quaternary sequence representing fluvial to lacustrine deposits and volcanic rock units can be divided into two subsequences.

The first subsequence of the Late Miocene-Early Pliocene time is characterized by limited alkaline and widespread andesitic calc-alkaline volcanism (Yılmaz et al., 1987). Therefore, the Late Miocene to Quaternary molasse represents the postcollision along the Southeastern Anatolian Suture. In the beginning of the late Miocene age, a new regional unconformity occurred depending on the subsidence. However, Rebai et al. (1993) suggested that active tectonics in the Lesser Caucasus, to the northeast of the EAR, show a coexistence of compressive and extensional structures, but the presented evidence shows that the compressional-contractional tectonic regime became dominant in the Early Pliocene. Therefore, compressional features are dominant structures in the first subsequence, whereas strike-slip features are dominant structures in the later subsequence.

The second subsequence represents the second stage of the postcollisional and Neotectonic regime, as well. That Neotectonic phase therefore started from the Late Pliocene onwards and Eastern Anatolia was subdivided into many continental wedges bounded by the NE-SW-trending sinistral to NW-SE-trending dextral conjugate strike-slip faults. During the development of these active faults, new pull-apart basins accompanied by basaltic volcanics occurred on the older basin fills in different parts of the EAR.

Late Pliocene-Quaternary sequences, which rest with angular unconformity on all the older rocks, are nearly flat-lying and they are dominated by strike-slip faulting accompanied by mostly alkali volcanic activity implying an inversion in the tectonic regime. Alignment of hot springs, cinder cones, drainage offsets, and linear valleys are the characteristic features of strike-slip fault patterns and earthquakes strongly suggest that most of the segments' strike-slip faults are still active (Koçyiğit et al., 1985, 2001).

As a result, it can be summarized that a foreland collisional basin occurred during the Maastrichtian-Early Eocene period and superimposed postcollisional basins that developed over the collisional basin fill during the Middle Eocene-Quaternary. Subsidence and rising of the EAR occurred from the Middle Eocene to the Quaternary, many times. For this reason, the thickness of the Middle Eocene to Quaternary units varies considerably from one place to another (Figures 12, 13C, and 13D). During the same time interval, angular unconformities occurred between the Middle Eocene, Oligocene-Early Miocene, and Late Miocene-Early Pliocene units in the compressional-contractional and compressional-extensional tectonic regime throughout Eastern Anatolia. Since the Late Pliocene to the Recent, NE-SW sinistral strike-slip faults with reverse components occurred in the distinctive transpressive tectonic regime, under a N-S directed compression (Yılmaz and Yılmaz, 2016).

East and Southeast Anatolia have been the scene of new neotectonic studies. For instance, Seyitoğlu et al. (2018) suggested that a reevaluation of the active fault lines and seismicity of the Turkish-Iranian Plateau indicates that rhomboidal cells might partially eliminate the postcollisional N-S contraction between the Arabian and Eurasian Plates, and the internal structure of the Southeast Anatolian Wedge contains many thrusts/blind thrusts, some of which may be potential sources of future earthquakes (Seyitoğlu et al., 2017a).

5. Discussion and conclusions

The precollision setting of the region is a controversial topic. One of the important questions raised by this setting is the polarity of the subduction. For instance, north-dipping subduction was suggested by Şengör and Yılmaz (1981) and then accepted by Yılmaz et al. (1995), Topuz et al., (2013), and Yılmaz and Yılmaz (2013 and references therein). This model is widely accepted and proposes that the ophiolitic units that are exposed between the Pontide arc and the Tauride belt are remnants of a suprasubduction zone ophiolite, as well. In addition, double north-dipping subduction zones have been suggested to describe the tectonic evolution of the northern branch of the Neo-Tethys, in the Jurassic and/or Early Jurassic (Göçmengil et al., 2013; Topuz et al., 2013; Uysal et al., 2015), Jurassic-Cretaceous (Parlak et al., 2013; Robertson et al., 2013), Cretaceous (Sarıfakıoğlu et al., 2009), and Late Cretaceous periods (Yılmaz and Yılmaz, 2013; Beyazpirinç et al., 2018).

In general, there are similarities in both age and setting between the basins in Central Anatolia and Eastern Anatolia. For instance, the Central Anatolian basins have been generally accepted as having originated and developed through collisional and postcollisional compressional tectonics over the years (Görür et al., 1984, 1998; Gürer and Aldanmaz, 2002; Yılmaz and Yılmaz, 2006). However, Seyitoğlu et al. (2017b) suggested that the Upper Cretaceous-Eocene sedimentary basins in Central Anatolia were supradetachment basins rather than collision or arc-related basins as previously suggested.

It can therefore be seen that there are many uncertainties about the precollision setting and each of the models has both pros and cons. The EABs are located along the southern part of the NAOB in the study area and occurred after collision. The dominant setting of overthrusts in the studied region is north-dipping and the AIP represents the metamorphic equivalent of a passive continental fragment.

The general sedimentary sequence of the EABs does not reflect its affinities with units deposited on the oceanic crust, because of the nature of the basin fills, which show characteristics of shallow marine (corals and rudist limestone)-continental facies. In addition, rapid and important changes in facies occur in both horizontal and vertical directions and the abundance of regional and local unconformities support subaerial conditions.

The northern branch of the Neo-Tethys should have been closed before formation of the EABs. Pelagic limestones of the Üzümpınar formation on the mélange directly to the north of Kösehasan represent a forearc unit and provide evidence for an age from the Santonian to Campanian, indicating that the oceanic environment was persistent in the area until the Campanian (Yılmaz et al., 2010).

The EABs therefore appear to be collisional foreland basins with postcollisional intracratonic setting rather than oceanic basins above an oceanic crust.

The Akdağ metamorphic unit (Yılmaz et al., 1988, 2010) is not an isolated block in the EAR and it may

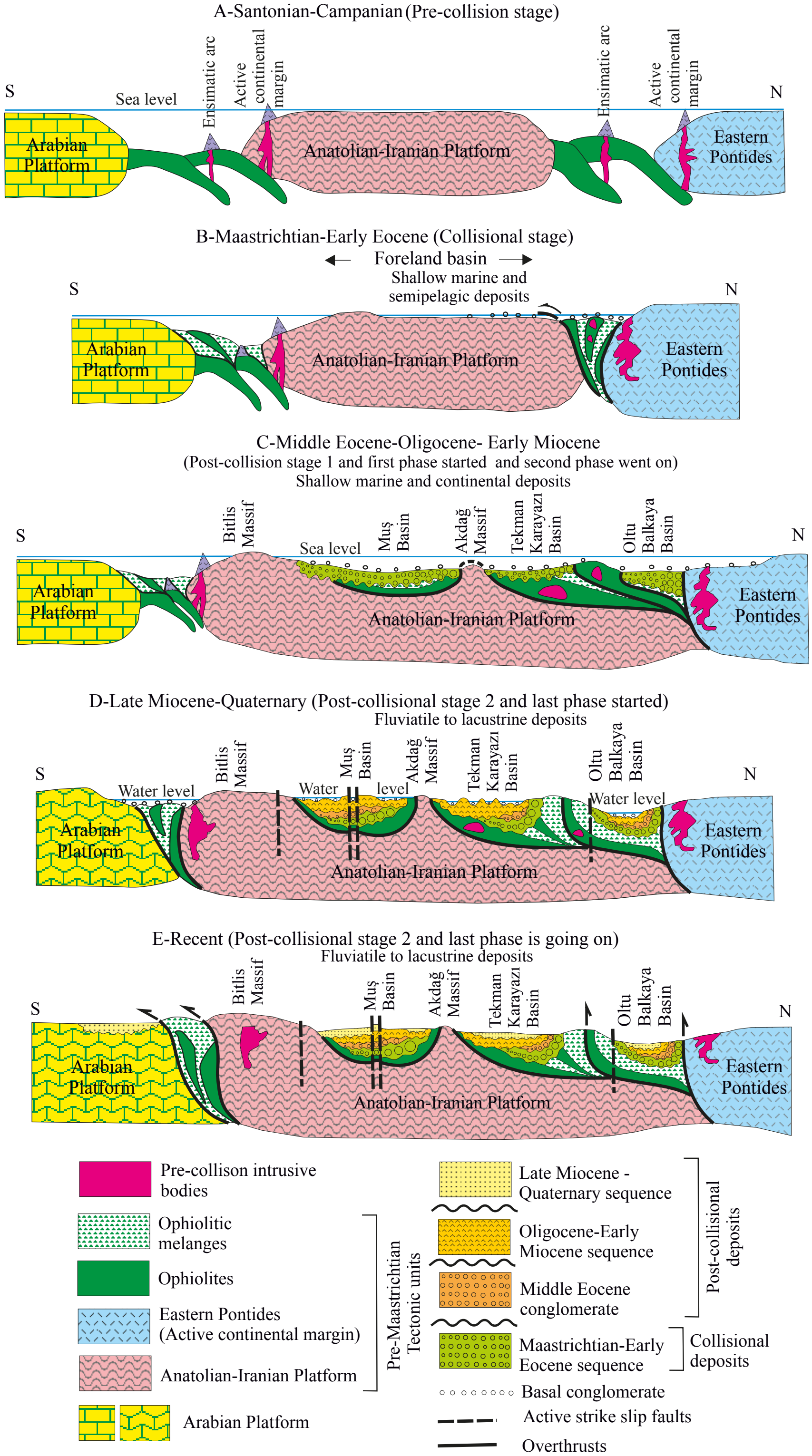

Figure 13. Simplified diagrams showing important stages of structural evolution of the Eastern Anatolian Basins from Late Cretaceous to Quaternary. No scale.

represent the northern extension of the AIP (and/or the Eastern Tauride Platform) that outcropped as a tectonic window beneath ophiolitic units.

On the basis of the information presented above, the following remarks and constraints are proposed in conclusion:

1. The EABs appear to have a continental crust basement with obducted ophiolitic units. There is not only an oceanic crust and/or mélange prism as the base unit. Pre-Maastrichtian continental metamorphic rock units, ophiolites with mélanges, and forearc deposits of the EAR are the main tectonic units representing the precollision stage in the region (Figures 12 and 13A).

2. The EAR is located between two main suture zones of Turkey, the NALCS to the north and SEAS to the south. The location and setting of these suture zones were defined by Yılmaz and Yılmaz (2013) and Yılmaz et al. (2014). Maastrichtian-Quaternary sedimentary fill of the EABs has records of the collision and postcollision stages (Figures 13B–13E) that occurred along both suture zones. The timing of continental collisions and postcollisions along the suture zones is different from each other.

3. The collision along the NALCS occurred during the Paleocene-Early Eocene. Middle Eocene-Oligocene-Early/Middle Miocene sequences represent records of the postcollision, as defined by the geochemical data presented by Topuz et al. (2011) along the NALCS. The first emergence of the EAR above sea level occurred between the Early and Middle Eocene, as well.

4. In addition, the collision along the SEAS occurred between the Early/Middle Miocene and Late Miocene. Its reflection in the sequence of the EAR is the regional unconformity between Early/Middle Miocene and Late Miocene. The second and/or final emergence of the EAR above sea level occurred between the Early/Middle Miocene and Late Miocene. Widespread Late Miocene and Quaternary terrestrial clastic rocks and volcanic rocks of the EAR are products of the final postcollision.

5. One of the differences between the basins is that there is a local unconformity between Oligocene and Miocene sequences in the Oltu-Balkaya and Tekman-Karayazı Basins, while these sequences are transitional in the Muş Basin.

6. After the stratigraphic features of the three basins presented above are considered, it can be forecast that these basins underwent a similar structural evolution.

7. In conclusion, first collisional and then postcollisional basins developed as superimposed basins. The Neotectonic regime that is indicated by the dextral and sinistral active faults of the region developed in the late Pliocene-Quaternary time interval. During this time, pull-apart basins occurred over the fill of collisional and postcollisional basins.

In conclusion, the EABs have undergone a complex tectonic evolution in the frame of collisional and postcollisional stages, developed on a mosaic including the continental crust also on the AIP between the EPA and AP. They started as extensional subsiding basins and as foreland-basin and then evolved into collisional and postcollisional continental basins. As a whole, the EABs evolved as superimposed basins from the Maastrichtian to Quaternary time interval.

Acknowledgment

This work was financially supported by the funds of the Cumhuriyet University Scientific Projects Unit as an M-462 individual research project.

References

Akay E (1989). Evolution of the post-collisional cratonic basins, in Eastern Taurus. Bull Min Res Exp 109: 77-88.

Akay E, Erkan E, Ünay E (1989). Stratigraphy of the Muş Tertiary Basin. Bull Min Res Exp 109: 59-76.

Beyazpirinç M, Akçay AE, Yılmaz A, Sönmez MK (2018). A Late Cretaceous ensimatic arc developed during closure of the northern branch of Neo-Tethys (central-northern Turkey). Geosci Front (in press).

Bozkuş C (1990). Stratigraphy (coal) of the north-eastern part of Oltu-Narman Tertiary basin. Bull Geol Soc Turkey 33: 47-56 (in Turkish with English abstract).

Boztuğ D, Erçin AI, Kuruçelik MK, Göç D, Kömür I, Iskenderoğlu A (2006). Geochemical characteristics of the composite Kaçkar batholith generate. J Asian Earth Sci 27: 286-302.

Boztuğ D, Kusçu I, Erçin AI, Avcı N, Şahin SY (2003). Mineral deposits associated with the pre-, syn- and post-collisional granitoids of the neo-Tethyan convergence system between the Eurasian and Anatolian plates in NE and Central Turkey. In: Eliopoulos D, editor. Mineral Exploration and Sustainable Development. Rotterdam, the Netherlands: Millpress, pp. 1141-1144.

Dewey JF, Hempton MR, Kidd WSF, Saroglu F, Şengör AMC (1986). Shortening of the continental lithosphere: the neotectonics of eastern Anatolia - young collision tectonics. Geol Soc Spec Publ 19: 3-36.

Draut AE, Clift PD (2001). Geochemical evolution of arc magmatism during arc-continent collision, South Mayo, Ireland. Geology 29: 543-546.

Gedik A (1986). Tekman (Erzurum) havzasının jeolojisi ve petrol olanakları. MTA Dergisi 103/104: 1-24 (in Turkish).

Göçmengil G, Altıntaş İE, Topuz G, Çelik ÖF, Özkan M (2013). Diverse tectonic settings of formation of the metaigneous rocks in the Jurassic metamorphic accretionary complexes (Refahiye, NE Turkey) and their geodynamic implications. Geodin Acta 26: 294-310.

Göncüoğlu C, Turhan N (1983). Geology of the Bitlis Metamorphics. In: Tekeli O, Göncüoğlu MC, editors. The Geology of the Taurus Belt International Symposium Proceedings, pp. 237-244.

Görür N, Oktay FY, Seymen İ, Şengör AMC (1984). Palaeotectonic evolution of the Tuzgölü basin complex, central Turkey: sedimentary record of a Neo - Tethyan closure. Geol Soc Spec Publ 17: 467-482.

Görür N, Tüysüz O, Şengör AMC (1998). Tectonic evolution of the Central Anatolian basins. Int Geol Rev 40: 831-850.

Gürer ÖF, Aldanmaz E (2002). Origin of the Cretaceous-Tertiary sedimentary basins within the Tauride-Anatolide platform in Turkey. Geol Mag 139: 191-197.

Hempton MR (1985). Structure and deformation history of the Bitlis Suture near Lake Hazar, SE Turkey. Geol Soc Am Bull 96: 223-243.

Karig DE, Kozlu H (1990). Late Palaeogene-Neogene evolution of the triple junction region near Maraş, south-central Turkey. J Geol Soc London 147: 1023-1034.

Kaygusuz A, Aslan Z, Aydınçakır E, Yücel C, Güçer A, Şen C (2017). Geochemical and Sr-Nd-Pb isotope characteristics of the Miocene to Pliocene volcanic rocks from the Kandilli (Erzurum) area, Eastern Anatolia: implications for magma evolution in extension - related origin. Lithos 296: 332-351.

Koçyiğit A, Öztürk A, İnan S, Gürsoy H (1985). Karasu havzasının (Erzurum) tektonomorfolojisi ve mekanik yorumu. Cumhuriyet University Journal of Engineering Faculty Series A Earth Sciences 2: 3-15 (in Turkish).

Koçyiğit A, Yılmaz A, Adamia S, Kuloshvili S (2001). Neotectonics of East Anatolian Plateau (Turkey) and Lesser Caucasus: implications of transition from thrusting to strike-slip faulting. Geodin Acta 14: 177-195.

Konak N, Hakyemez Y (2008). Geological map of Turkey in scale 1:100.000, Tortum H47 sheet (in Turkish). Ankara, Turkey: General Directorate of Mineral Research and Exploration.

Kurtman F, Akkuş MF (1971). Doğu Anadolu'daki ara basenler ve bunların petrol olanakları. Bull Min Res Exp 77: 1-9 (in Turkish).

MTA (2002). Geological Map of Turkey, at 1/500.000 scale. Ankara, Turkey: General Directorate of Mineral Research and Exploration.

Okay AI, Tüysüz O (1999). Tethyan sutures of northern Turkey. Geol Soc Spec Publ 156: 475-515.

Okay AI, Zatin M, Cavazza W (2010). Apatite fission-track data for the Miocene Arabia-Eurasia collision. Geology 38: 35-43.

Öner F, Alpaslan M, Boztuğ D, Kuşçu M (2007). Geochemie und Petrogenese der Intrusivgesteine von Ağören in Ostanatolien/Türkei. Chemie der Erde 67: 241-249 (in German).

Özdemir İ (1981). Oltu-Balkaya (Erzurum) kömürlü Neojen havzasının ekonomik jeolojisi. MSc, Ankara University, Ankara, Turkey (in Turkish).

Parlak O, Çolakoğlu A, Dönmez C, Sayek H, Yıldırım N, Turkel A, Odabaşı I (2013). Geochemistry and tectonic significance of ophiolites along the İzmir-Ankara-Erzincan Suture Zone in Northeastern Anatolia. Geol Soc Spec Publ 372: 76-106.

Rebai S, Philip H, Dorbath L, Borissoff B, Haessler H, Cisternas A (1993). Active tectonics in the Lesser Caucasus: coexistence of compressive and extensional structures. Tectonics 12: 1089-1114.

Rice SP, Robertson AHF, Ustaömer T (2006). Late Cretaceous-Early Cenozoic tectonic evolution of the Eurasian active margin in the Central and Eastern Pontides, northern Turkey. Geol Soc Spec Publ 260: 413-445.

Robertson AHF, Parlak O, Rizaoglu T, Ünlügenç U, Inan N, Taslı K, Ustaömer T (2007). Tectonic evolution of the South Tethyan ocean: evidence from the Eastern Taurus Mountains (Elazıg region, SE. Turkey). Geol Soc Spec Publ 272: 231-270.

Sarıfakıoğlu E, Özen H, Winchester JA (2009). Petrogenesis of the Refahiye ophiolite and its tectonic significance for Neotethyan ophiolites along the İzmir-Ankara-Erzincan Suture Zone. Turk J Earth Sci 18: 187-207.

Şaroğlu F, Yılmaz Y (1986). Doğu Anadolu'da Neotektonik dönemdeki jeolojik evrim ve havza modelleri. Bull Min Res Exp 107: 73-94 (in Turkish).

Şengör AMC, Kidd WSF (1979). Post-collisional tectonics of the Turkish-Iranian plateau and a comparison with Tibet. Tectonophysics 55: 361-376.

Şengör AMC, Özeren MS, Keskin M, Sakınç M, Özbakır AD, Kayan İ (2008). Eastern Turkish high plateau as a small Turkic-type orogen: implications for post-collisional crust-forming processes in Turkic-type orogens. Earth-Sci Rev 90: 1-48.

Şengör AMC, Özeren S, Zor E, Genç T (2003). East Anatolian high plateau as a mantle-supported, N-S shortened domal structure. Geophys Res Lett 30: 8044.

Şengör AMC, Yılmaz Y (1981). Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75: 181-241.

Seyitoğlu G, Esat K, Kaypak B (2017a). The neo-tectonics of southeast Turkey, northern Syria, and Iraq: the internal structure of the Southeast Anatolian Wedge and its relationship with recent earthquakes. Turk J Earth Sci 26: 105-126.

Seyitoğlu G, Esat K, Kaypak B, Tooric M, Aktuğ B (2018). The Neotectonics of Eastern Turkey, Northwest Iran, Armenia, Nahçivan and Southern Azerbaycan: the rhomboidal cell model in the internal deformation of Turkish - Iranian Plateau. In: 71st Geological Congress of Turkey Proceedings, pp. 661-664.

Seyitoğlu G, Işık V, Gürbüz E, Gürbüz A (2017b). The discovery of a low-angle normal fault in the Taurus Mountains: the İvriz detachment and implications concerning the Cenozoic geology of southern Turkey. Turk J Earth Sci 26: 189-205.

Sosson M, Rolland Y, Danelian T, Muller C, Melkonyan R, Adamia S, Kangarli T, Avagyan A, Galoyan G (2010). Subductions, obduction and collision in the Lesser Caucasus (Armenia, Azerbaijan, Georgia), new insights. Geol Soc Spec Publ 340: 329-352.

Temiz H, Guezou JC, Tatar O, Ünlügenç UC, Poisson A (2002). Tectonostratigraphy of the Tercan-Çayirli Basin: implications for the Neogene-Quaternary tectonic deformation of the Northeast Anatolian Block, Turkey. Int Geol Rev 44: 243-253.

Topuz G, Altherr R, Schwarz WH, Siebel W, Satir M, Dokuz A (2005). Post-collisional plutonism with adakite-like signatures: the Eocene Saraycik granodiorite (Eastern Pontides, Turkey). Contrib Mineral Petr 150: 441-455.

Topuz G, Candan O, Zack T, Yılmaz A (2017). East Anatolian plateau constructed over a continental basement: no evidence for the East Anatolian accretionary complex. Geology 45: 791-794.

Topuz G, Göçmengil G, Rolland Y, Çelik ÖF, Zack T, Schmidt AK (2013). Jurassic accretionary complex and ophiolite from northeast Turkey: no evidence for the Cimmerian continental ribbon. Geology 41: 255-258.

Topuz G, Okay AI, Altherr R, Schwartz WH, Siebel W, Zark T, Satır M, Şen C (2011). Post-collisional adakite-like magmatism in the Agvanis Massif and implications for the evolution of the Eocene magmatism in the eastern Pontides (NE Turkey). Lithos 125: 131-150.

Uysal I, Ersoy EY, Dilek Y, Escayola M, Sarifakioğlu E, Saka S, Hirata T (2015). Depletion and refertilization of the Tethyan oceanic upper mantle as revealed by the early Jurassic Refahiye ophiolite, NE Anatolia-Turkey. Gondwana Res 27: 594-611.

Uysal Ş (1986). Muş Tersiyer havzasının stratigrafisi ve Üst Lütesiyen'in varlığı. MTA Dergisi 105/106: 69-74 (in Turkish).

Yazgan E (1983). A geotraverse between the Arabian Platform and the Munzur Nappes. In: International Symposium on the Geology of the Taurus Belt, Guide Book for Excursion V, Ankara.

Yılmaz A (1985). Main geological characteristics and structural evolution of the region between the Kelkit Creek and Munzur Mountains. Bull Geol Soc Turkey 28: 79-92.

Yılmaz A, Adamia S, Yılmaz H (2014). Comparisons of the suture zones along a geo-traverse from the Scythian Platform to the Arabian Platform. Geosci Front 5: 855-875.

Yılmaz A, Terlemez İ, Uysal Ş (1988). Some stratigraphic and tectonic characteristics of the area around Hınıs (southeast of Erzurum). Bull Min Res Exp 108: 1-21.

Yılmaz A, Terlemez İ, Uysal Ş (1990). Geological characteristics and structural evolution of the ophiolitic units around Sakaltutan Dağ (Erzurum), Turkey. METU Journal of Pure and Applied Sciences 21: 221 - 235.

Yılmaz A, Yılmaz H (2006). Characteristic features and structural evolution of a post-collisional basin: the Sivas basin, Central Anatolia, Turkey. J Asian Earth Sci 27: 164-176.

Yılmaz A, Yılmaz H (2013). Ophiolites and ophiolitic melanges of turkey, a review. Bull Geol Soc Turkey 56: 61-114.

Yılmaz A, Yılmaz H, Kaya C, Boztuğ D (2010). The nature of the crustal structure of the Eastern Anatolian Plateau, Turkey. Geodin Acta 23: 167-183.

Yılmaz H, Alpaslan M, Temel A (2007). Two-stages volcanism in the western part of Southeastern Anatolian Orogen: petrologic and geodynamic implications. Int Geol Rev 49: 120-141.

Yılmaz H, Yılmaz A (2016). Tectonic setting and structural evolution of post-Late Cretaceous the Oltu-Balkaya Basin (NE Turkey). Bull Geol Soc Turkey 59: 1-25 (in Turkish with English summary).

Yılmaz Y (1993). New evidence and model on the evolution of the southeast Anatolian orogen. Geol Soc Am Bull 105: 251-271.

Yılmaz Y, Dilek Y, Işık H (1981). The geology of Gevaş Ophiolite and a synkinematic shear zone. Bull Geol Soc Turkey 24: 37-44 (in Turkish with English abstract).

Yılmaz Y, Genç ŞC, Yiğitbaş E, Bozcu M, Yılmaz K (1995). Geological evolution of the late Mesozoic continental margin of the northwestern Anatolia. Tectonophysics 243: 155-171.

Yılmaz Y, Şaroğlu F, Güner Y (1987). Initiation of the neomagmatism in East Anatolia. Tectonophysics 134: 177-199.