Geodinamica Acta 23/4 (2010) 167-183

Geodinamica Acta

The Nature of the Crustal Structure of the Eastern Anatolian Plateau, Turkey

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Received: 15/11/09, accepted: 31/06/2010

Abstract

The Eastern Anatolian Plateau (EAP) of Turkey, with an elevation ranging from 1700 to 2000 m, is located between the Eastern Pontide Arc to the north and the Arabian Platform to the south. In this region, pre-Maastrichtian tectonic units representing the crust crop out in only a few localities. As they are covered by Maastrichtian-Quaternary rock units, it is difficult to study the nature and mutual relationships of these pre-Maastrichtian tectonic units.

The palaeotectonic units of the EAP comprise two different levels in the present study: (1) The *lower level* consists of platform-type carbonates and their metamorphic equivalents. These units may represent the Taurus Platform and its metamorphic equivalents. (2) The *upper level* consists of an ophiolitic-mélange prism which is made up mainly of oceanic crust; the prism comprises a complex of ophiolite, ophiolitic mélange, and fore-arc deposits. This upper unit represents a subduction-accretion prism and may have originated partly from the North Anatolian Suture to the north, and partly from the South-eastern Anatolian Suture to the south.

Continental crustal rocks were thrust over by the ophiolitic mélange prism; thus outcrops of them are scarce in the region as they are exposed in tectonic windows through the ophiolitic thrust sheets.

The pre-Maastrichtian tectonic units of the EAP are blanketed by Maastrichtian to Quaternary volcanic and sedimentary rock units; these sequences include successive transgressive and regressive intervals and overlie the palaeotectonic units along a pronounced unconformity. Olistostromal units are abundant in the Eocene sedimentary units and were derived from the ophiolites and ophiolitic mélange. The Maastrichtian-Quaternary cover is made up of collisional and post-collisional deposits across the whole region.

Although the EAP has been experiencing considerable N-S compression, it has not been affected by significant crustal thickening because of the strike-slip tectonic regime that is dominant in the region.

Keywords: Eastern Anatolian Plateau, continental crust, ophiolite, mélange prism.

1. Introduction

The Eastern Anatolian Plateau (EAP) has a mean elevation of 1700-2000 m and lies between the Eastern Pontide Arc to the north and the Arabian Platform to the south (Fig. 1 A and B), and is geographically situated between central Anatolia and central Iran. On the basis of these data, the plateau is dominated by strike-slip faults that forms two main sets: a sinistrial NE-SW striking set and a dextral NW-SE striking set [1, 2]. In addition, many researchers have studied and documented neomagmatism of the region as collision and postcollision related volcanism [3–7].

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doi:10.3166/ga.23.167-183

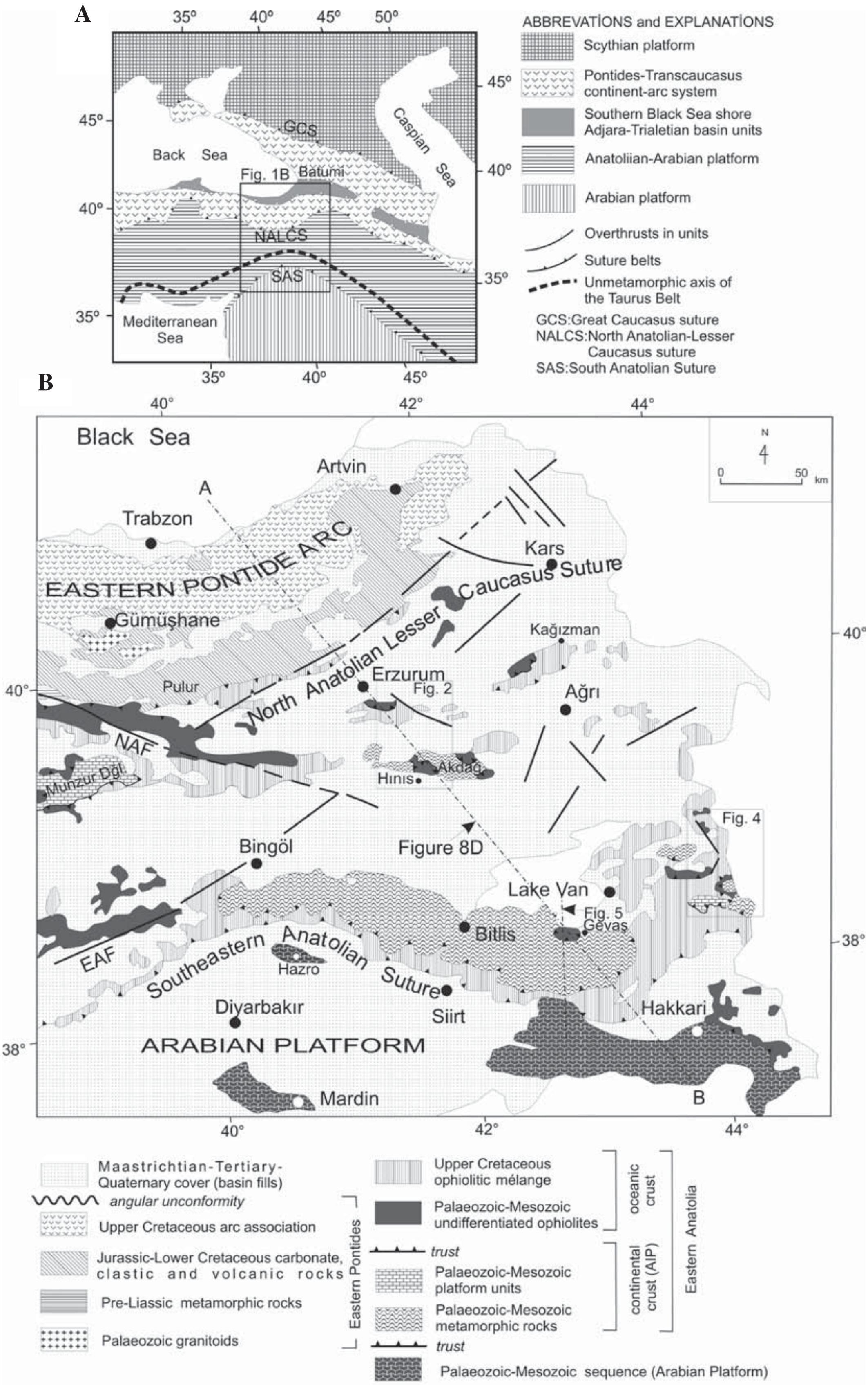


Fig. 1: Location map of the study area **(A)** Simplified palaeotectonic map of the East Anatolian Plateau and surroundings **(B)**. NAF, North Anatolian Fault; EAF, East Anatolian Fault; AIP, Anatolian-Iranian Platform *(Numerous sources)*.

In so far as neotectonic deposits of the EAP are widespread and cover most of the palaeotectonic units, it is difficult to study complete sequences of the palaeotectonic units in vertical sections as well as their lateral relationships.

Despite the scarcity of exposure of the palaeotectonic units of the EAP, preliminary studies [8, 9] to the east of Lake Van documented the ophiolitic mélange as basement in eastern Anatolia. This ophiolitic mélange, as a whole, was subsequently interpreted as a mélange prism [10]; this interpretation led to an assumption that the crust of the region is 55 km thick [11].

However, in recent years, geophysical studies of the EAP and surrounding regions [12–14] have shown that the crust underlying eastern Anatolia has an estimated thickness of 45 km; in other words, these geophysical findings have not confirmed the crustal thickness [10, 11]. In light of the most recent geophysical data, it was suggested that the EAP is supported not only by a thick crust but also by hot mantle and the basement of eastern Anatolia comprises of mélange prism [15]. On the other hand, it was suggested that there should be mantle lithosphere beneath the Eastern Anatolian Accretionary Complex (EAAC), at a depth of 60-80 km [16]. However, these interpretations do not reflect pre-Maastrichtian stratigraphy of the region.

This study aims to document the lithologic characteristics of and lithostratigraphic relationships among the palaeotectonic units of eastern Anatolia despite their limited areal exposure due to presence of the thick, Maastrichtian-Quaternary volcanic and sedimentary cover.

2. Main tectonic units of eastern Turkey

In eastern Turkey, the main tectonic units (from north to south) are the eastern Pontide arc, the Anatolian-Iranian Platform and the Arabian Platform (Fig. 1B). These main units are separated from each other by two suture zones: (1) the North Anatolian-Lesser Caucasus ophiolitic suture in the north; and (2) the south-eastern Anatolian ophiolitic suture in the south. The rock associations of these two suture zones comprise mainly ophiolite, ophiolitic mélange, and fore-arc and ensimatic arc units [17]. The ophiolitic associations of the North Anatolian-Lesser Caucasus suture zone and the south-eastern Anatolian suture zone have both been emplaced with southward and northward imbricated structures, respectively (Fig. 1B).

The *Eastern Pontide Arc* represents continental-arc system [18]. The arc system was active during Late Cretaceous time in its western part [17] and it was active during the Late Jurassic-Cretaceous in its eastern part [18]. This difference is interpreted, on the whole, to have resulted from the interference between a spreading ridge and a subduction zone during Late Jurassic-Cretaceous time in the Eastern Pontide Arc [19].

The Eastern Pontide Arc consists mainly of submarine and terrestrial volcanic rocks intercalated with marine sediments and granitoid intrusions in an extensional-arc setting [17]. In the easternmost part of the arc, magmatic activity ceased before Maastrichtian time [19].

The *Anatolian-Iranian Platform,* representing a passive continental margin [20], includes the Eastern Taurus Belt in Turkey and the Sanandaj-Sirjan Belt in Iran. The Central Anatolian Massif of Turkey and the Akdağ Metamorphics of eastern Anatolia are the metamorphic equivalents of lithostratigraphic units occurring in the Eastern Taurus Belt of Turkey. Similarly, the Central Iranian Massif is the metamorphic equivalent of lithostratigraphic units that formed in the Sanandaj-Sirjan Belt of Iran, constituting the southern continental margin of the Anatolian-Iranian Platform [21].

The *Arabian Platform*, representing the northern margin of the Arabian continent [22, 23], is made up of Precambrian to Late Cretaceous shallow-marine clastic rock units and limestones. These rocks reflect sedimentary environments during four geological time intervals: (1) Precambrian-Cambrian; (2) Permian-Triassic; (3) Triassic-Jurassic; and (4) Early Cretaceous-Late Cretaceous [24]. The geological units of the northern Arabian Platform underwent extensive compressional deformation, characterized by recumbent folds, and also contain many thrust faults [2, 22].

The North Anatolian-Lesser Caucasus ophiolitic suture comprises ophiolitic rocks, ophiolitic mélange and ensimatic-arc rocks and separates the Eastern Pontide Arc from the Anatolian-Iranian Platform in the south [25]. The south-eastern Anatolian ophiolitic suture also comprises ophiolitic rocks, ophiolitic mélanges and ensimatic-arc rocks [26, 27] and separates the Anatolian-Iranian Platform from the Arabian Platform. Along both suture zones, Maastrichtian rock units transgressively overlie the pre-Maastrichtian tectonic units.

3. Stratigraphic framework of eastern Anatolia

The area east of Lake Van and the area between Erzurum and Hınıs are typical localities for observing the pre-Maastrichtiantectonic units and their volcanic and sedimentary cover. The geology of the area between Pasinler and Hınıs (Erzurum) (Fig. 2) have been studied in detail [28, 29] and the area east of Lake Van [8, 9, 30]. In the footsteps of those studies, both of those areas and also the Ağrı-Kağızman and Gevaş (south of Lake Van) areas have been revised in detail on the basis of the findings of the present study. Detailed explanations of the lithological characteristics, stratigraphic and structural relations of the pre-Maastrichtian tectonic units and their volcanic and sedimentary cover are given in the following sections.

3.1. Pre-Maastrichtian tectonic units

Pre-Maastrichtian tectonic units exposed in the EAP comprise continental-crustal rock units and a tectonically overlying mélange prism.

The ***continental crust*** of eastern Anatolia is made up of three lithostratigraphic units from the base to the top: (1) the Akdağ Metamorphics, (2) the Tepedam Metamorphics, and (3) Hasandağ Unit. The *Akdağ Metamorphics*, cropping out

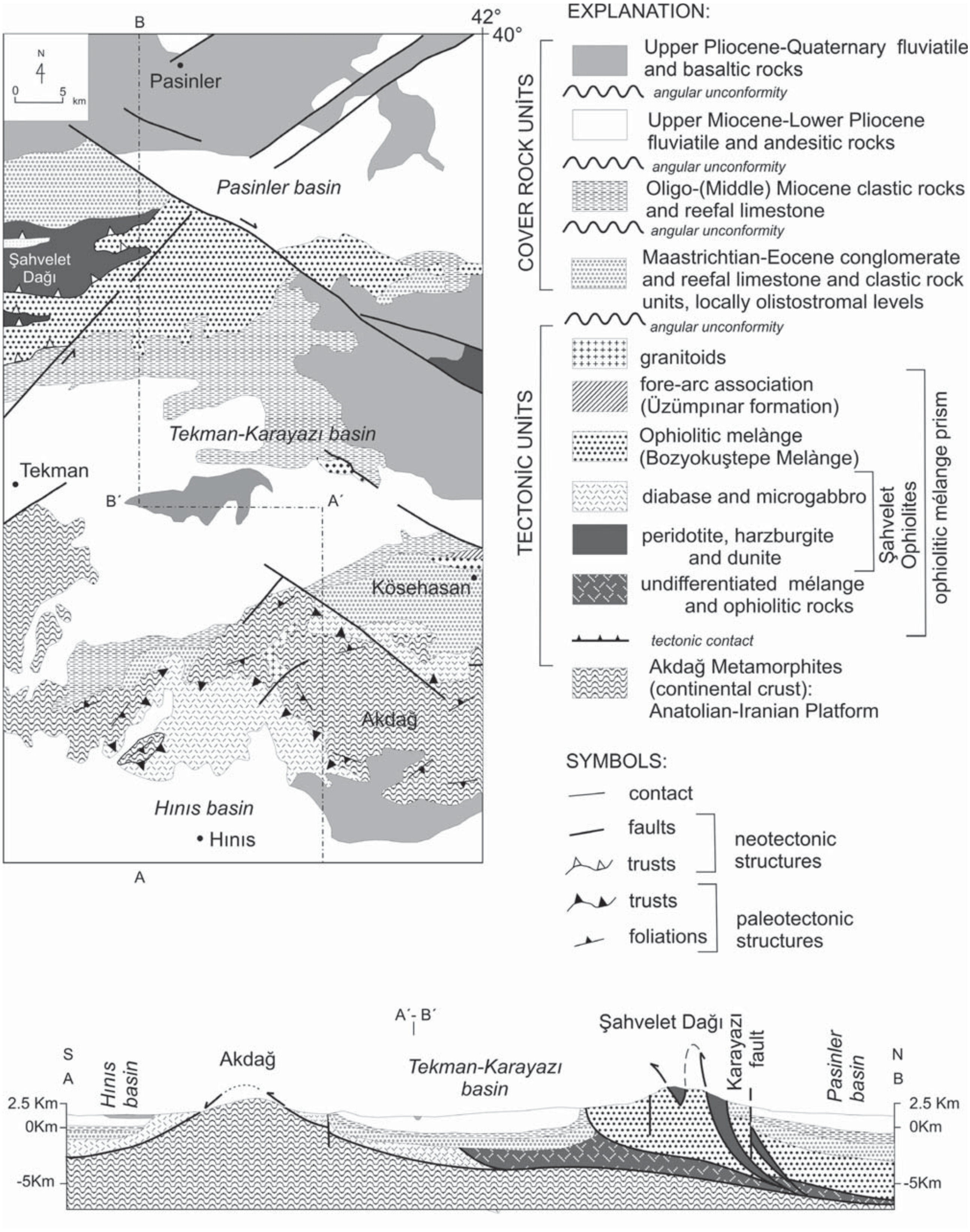


Fig. 2: Geological map and cross-section of the area between Pasinler and Hınıs (Erzurum), [28, 29]. See Fig. 1B for location.

in the central part of eastern Anatolia *(Figure 2)*, comprise gneiss, amphibolite and mica schists in their lower part and marble and calc-schists in their upper part. These metamorphic units are generally well-foliated and intensively folded. On the basis of petrographic analysis, the following metamorphic units have been determined: 1) amphibolite-gneiss, 2) amphibolite-pyroxene gneiss, 3) garnet- biotite gneiss, 4) cordierite-almandine-sillimanite-quartz gneiss, 5) garnet-mica schist, 6) calc-schist, and 7) saccharoidal marble. The index-mineral assemblages of the metamorphic facies, presented above, indicate a medium- to high-grade metamorphic event corresponding to the *amphibolite facies,* in which temperatures range from 500 to 600°C and pressure from 4 to 5 kb according to the criteria of [31]. These metamorphic rocks are intruded by a granite, which is attributed to syn-collisional crustal thickening, then post-collisional processes and subsequently to partial melting of the Akdağ Metamorphics and ophiolitic rocks of the Hınıs area [32].

The metamorphic lithofacies in vertical sections of the Akdağ Metamorphics appear to have been derived from primary rock units ranging, in ascending order, from volcanic rocks, quartzite, sandstone, clay and siltstone, to limestone.

The Akdağ Metamorphics crop out from beneath obducted ophiolite and mélange (Fig. 3A, B and C) as a tectonic window and represent the lower continental tectonic unit in the Hınıs area [28]. In this area, Maastrichtian reefal limestone – with a polygenetic basal conglomerate – overlies ophiolitic and metamorphic rocks.

On the basis of rock types, stratigraphic succession, degree of metamorphism and their relationships to the ophiolites, it can be suggested that the Akdağ Metamorphics are similar to the sequence of the Central Anatolian Massif in the vicinity of Akdağmadeni-Yıldızeli [33, 34]. Both the Akdağ Metamorphics and the central Anatolian sequences consist predominantly of gneiss and medium- to high-grade schist in their lower levels, and calc-schist and marble in their upper levels. Furthermore, metamorphic mineral assemblages in both sequences reflect metamorphism in the *amphibolite facies*. In both localities, these lithological units are covered unconformably by Maastrichtian sediments. It was suggested that the metamorphic rocks cropping out around Yıldızeli represent continental crust [35, 36]. It is likely that the Akdağ Metamorphics, which are situated approximately in the central part of eastern Anatolia, also represent continental crust.

The second continental-crust-type pre-Maastrichtian tectonic association in eastern Anatolia includes the Palaeozoic Tepedam Metamorphics and the Palaeozoic-Mesozoic Hasandağ Unit [30]; these units crop out east of Lake Van (Fig. 4).

The *Tepedam Metamorphics* comprise an alternation of metaclastic rock units, phyllite, schist, marble and, locally, metavolcanic levels. This metamorphic sequence may be equivalent to the lower stratigraphic level of the Akdağ Metamorphics.

The *Hasandağ Unit* contains a non-metamorphic sequence which comprises, in ascending order, Silurian-Devonian clastic rock units, locally dolomitic limestone levels, Carboniferous sandstone, siltstone and claystone alternations, Permian shallow-marine limestone, Lower Triassic grey-yellowish siltstone, marl and limestone interbeds, Upper Triassic-Jurassic shallow-marine limestone (including interbedded-dolomitic limestone units) [30]. In light of the aforementioned lithologic characteristics, as well as its fossil content, the Hasandağ Unit can likely be correlated with the non-metamorphosed successions of the Eastern Tauride Autochthon in the Sarız area [37, 38]. On the basis of this suggested correlation, it may be inferred that the Hasandağ Unit in eastern Anatolia probably represents the eastern continuation of and is equivalent to the Silurian-Jurassic sequence of the Taurus Platform. The Hasandağ Unit is interpreted as a block within the ophiolitic mélange [9, 10]. However, it bears a strong resemblance to the tectonostratigraphic unit that rests upon the Tepedam Metamorphics and is tectonically underlain by ophiolitic mélange (Fig. 3D and E and Fig. 4; see cross section).

The ophiolitic mélange was originally obducted over the Hasandağ Unit from north to south (Fig. 3D and E). But in this area, the Hasandağ Unit was thrusted along post-Eocene structures over the ophiolitic mélange as well. Overturned folds are associated with post-Eocene overthrusts (Fig. 4) are dominant. Although the setting of post-Eocene overturned folds and thrusts is similar to those of the pre-Maastrichtian thrusts, their ages are quite different. Therefore, it is possible to suggest that the study area was under the control of the similar compressional tectonic regime in different geological times.

Ophiolitic mélanges and fore-arc deposits comprise an oceanic-crustal assemblage, composed of ophiolitic rocks and ophiolitic mélange, and fore-arc sequence alternations. In the region between Erzurum and Hınıs (Fig. 1B), these oceanic assemblage are represented by the Şahvelet Ophiolites, the Bozyokuştepe Ophiolitic Mélange and the Üzümpınar Formation (fore-arc sequence) [29].

The *Şahvelet Ophiolites* comprise mainly serpentinite, peridotite, gabbro, diabase dykes and lavas. Serpentinite is the most widespread lithologic subunit of this ophiolite and locally contains bastitized orthopyroxene, clinopyroxene and chromite. The peridotite is composed of olivine, clinopyroxene, orthopyroxene and spinel, and a wehrlitic composition. Gabbro, actually gabbronorite or olivine gabbronorite, consists of minor olivine, augite (locally uralitized), equigranular feldspar, titanite and spinel [29]. Diabase has intersertal or ophitic texture, with its main constituents being long, thin albite lamellae, pyroxene, and opaque minerals set in a microlitic, glassy matrix. The pillow lavas, displaying a well-developed flow texture, contain olivine, uralitized pyroxene and plagioclase. The different lithofacies of the ophiolites are separated from one another by sharp tectonic contacts. The diabase dykes cut across the lower units of the ophiolitic sequence. Therefore, this ophiolitic association is accepted as a tectonic mélange rather than as a complete ophiolitic sequence.

The ophiolites show evidence of metamorphism. For instance, chlorite, actinolite and zoisite are well-developed in the gabbros; plagioclase is altered, pyroxene is amphibolized and locally

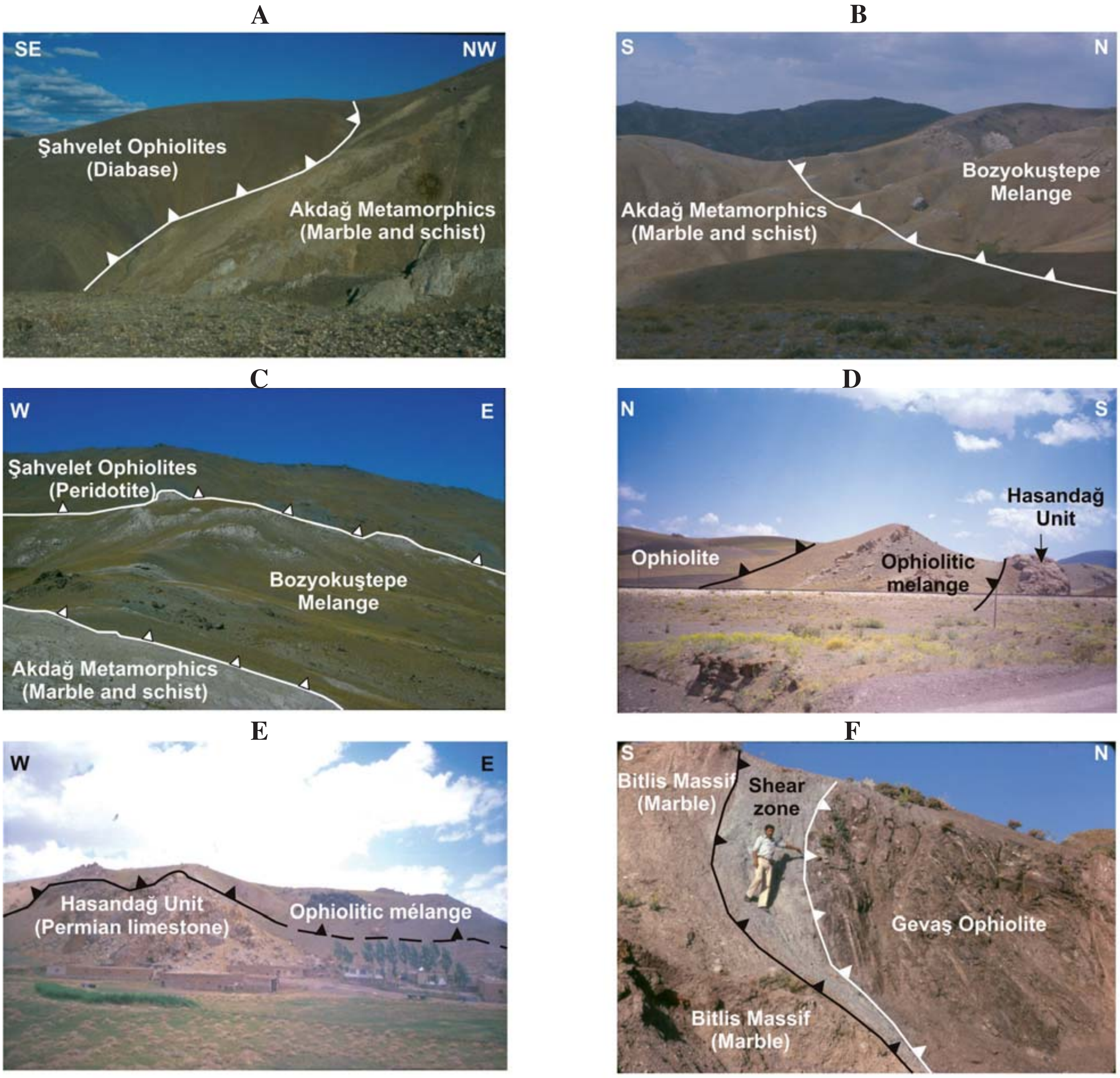


Fig. 3: Views showing the relationships between palaeotectonic units in different parts of the study area. Hınıs area: **A)** A view of the southern contact of the Akdağ Metamorphics and obducted by diabase and gabbro, Mirseyid village; **B)** A view from east to west of the northern contact of the Akdağ Metamorphics and tectonically overlying ophiolitic mélange, south of Sakaltutan Dağı; **C)** A view from south to north of the northern contact of the Akdağ Metamorphics and tectonically overlying ophiolitic mélange and ophiolite nappe, respectively, south of Sakaltutan Dağı; Van-Saray area: **D)** A view from west to east of Palaeozoic carbonates and tectonically overlying ophiolitic mélange, east of Hasan Dağı, Çaybağı village; **E)** A view from south to north of Palaeozoic carbonates and tectonically overlying ophiolitic mélange east of Hasan Dağı, Çaybağı village; Bitlis-Gevaş area: **F)** View of a tectonic contact between marble and an ophiolitic complex, Bitlis-Mutki Kaşak village.

epidote and chlorite are developed in diabase [29]. These metamorphic mineral assemblages may have developed in the primary ophiolite environment and represent dynamic metamorphism, more specifically the type of low-temperature, low-pressure metamorphism typical of active convergent-plate margins.

Along the basal contact of the diabase in the ophiolite slices, a pronounced cataclastic deformation with mylonitic and brecciated textures is typical. In some metamorphic facies, plagioclase is altered to epidote and chlorite, and actinolite is partially converted to glaucophane [28]. These assemblages characterize low-temperature, high-pressure metamorphism.

The *Bozyokuştepe Mélange* is made up of various types of blocks in a fine-grained clastic matrix; igneous and sedimentary clasts are typical in this matrix. Chert and pelagic limestone predominate among the sedimentary clasts of the matrix. In addition, the matrix of the mélange locally contains polygenic conglomerate intercalations which may represent debris flow or deep-sea channel deposits truncating deep-sea

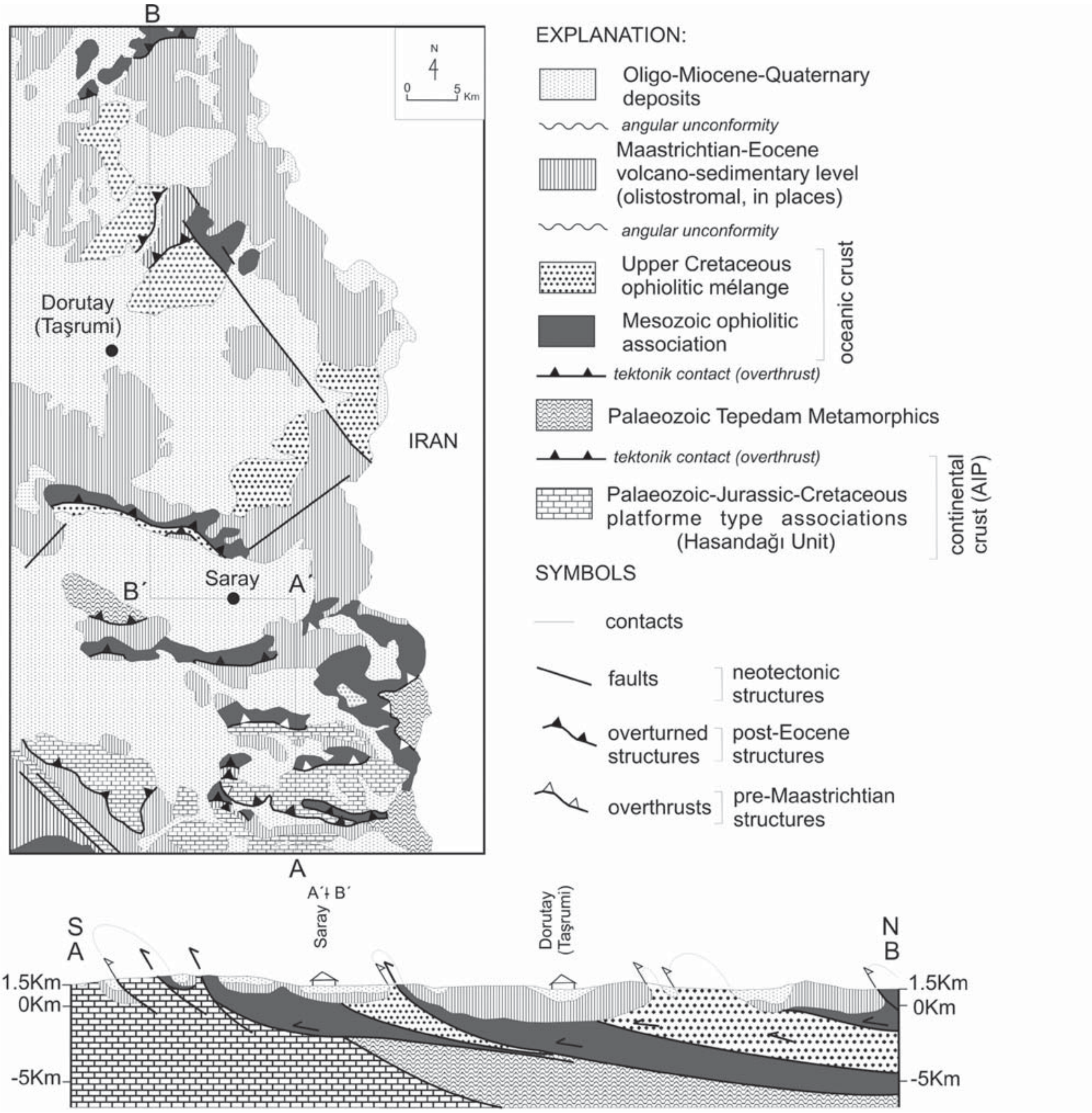


Fig. 4: Geologic map and cross-section of the area east of Lake Van: AIP, Anatolian- Iranian Platform ([30], personal observations and evaluations). See Fig. 1B for location.

fan sedimentation of the mélange. Some sedimentary structures, such as graded bedding, current structures (sole marks and flutes) and overturned folds, characterize the sedimentation via density currents upon a steep slope. Mylonites and breccias are abundant in different levels of the mélange, and especially at the tectonic basal contacts of subunits within the mélange. It is likely that this unit may have developed on a very steep, unstable slope of a convergent plate boundary where episodic sedimentation was probably triggered either by earthquakes or by gravity- induced density currents. Structural deformations, such as mylonite and breccia, typify the deformation caused by dynamic metamorphism during the emplacement of the obducted ophiolitic units via regional compressional tectonism.

Clastic rocks comprising the matrix of the mélange show a weak foliation which suggests that the matrix may have undergone dynamic metamorphism. Large blocks in the ophiolitic mélange are derived from ophiolites, metamorphic rocks and limestones of various ages. Ophiolitic blocks are chiefly serpentinite, peridotite, gabbro and diabase. The sizes

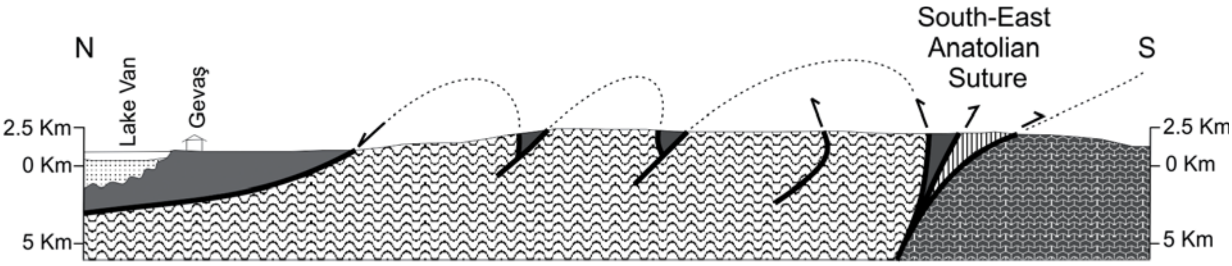


Fig. 5: A cross-section from the southern part of the eastern Anatolian region, Gevaş area, east of the Bitlis Province (see Fig. 1B for location).

of ophiolitic blocks increase upward, especially in vertical sections. Metamorphic blocks are schist and marble, and the shapes of these blocks are lenticular and generally ~100 m in size. Contacts of all blocks are mylonitized and brecciated and, thus, are probably tectonic in origin.

In various limestone blocks within the ophiolitic mélange along the Pasinler-Hınıs highway, the following faunal content has been determined: *Involutina* sp. (sinuosa group), *Ammobaculites* sp., and *Hedbergella* sp., *Ticinella* sp., *Lenticulina* sp. and radiolaria.

• To the northeast of Hınıs and Kösehasan villages near Akdağ, the following faunal content was determined in some limestone blocks: *Orbitolina* sp., *Praeglobotruncana* sp., *Rotalipora* sp., *Planomalina* sp. and *Globigerina* sp.

• The aforementioned faunal assemblages of the blocks within the ophiolitic mélange correspond to Early Late Cretaceous age. In addition to these faunal assemblages, the limestone blocks from Triassic to Cenomanian intervals confirm this suggested depositional age.

• A *fore-arc association* is represented by the *Üzümpınar Formation*, which conformably overlies the Bozyokuştepe Mélange [29]. This unit consists mainly of reddish Santonian-Campanian pelagic limestone with clastic intercalations. The reddish, locally grey or greenish, medium- and thin, regularly bedded limestone is characterized by widespread, intensive fracturing and tight folds. Claystone and sandstone intercalations occur locally within the formation. These clastic rock units are more abundant in the lower levels and are of tectonic and olistostromal character.

In the pelagic limestone subunits of the Üzümpınar Formation around the village of Kösehasan, the following faunal associations were determined: *Globotruncana limnneiana* (d'Orb.), *Globotruncana* cf. *calcarata* (Cushman),*Globotruncana* cf. *arca* (Cushman), *Globotruncana* cf. *bulloides* (Vogler), *Globotruncana* cf. *calcarata* (Cushman), *Globotruncana* sp., and *Pseudotextularia* sp [29].

The aforementioned fossil assemblages suggest a Late Senonian (probably Campanian) age [29] for the Üzümpınar Formation. Although different names have been suggested for the ophiolites and ophiolitic mélanges of eastern part of the Lake Van area, these units are similar to the ophiolitic associations exposed between Erzurum and Hınıs. In both localities, these units appear similar with respect to lithostratigraphy and geological age. In the same way, it can be postulated that all of these ophiolitic units may have been derived from a northern suture zone, moved from north to south and emplaced to their present positions. Both the ophiolites and metamorphic rocks exposed between Erzurum and Hınıs were cut by granitoids after Late Cretaceous time. In setting, composition and texture, similar granitoids have been interpreted as products of collisional and post-collisional phase in the eastern Pontides and central Anatolia [39, 40].

Pre-Maastrichtian tectonic relationships in other localities can also be defined. In this framework, two more cross-sections have been studied in detail and are presented in the following section in order to elucidate structural relations between other continental fragments, oceanic assemblages and cover.

The first cross-section is from the southern part of the EAP in the Gevaş area (Fig. 5). The Bitlis Massif is a palaeotectonic unit which comprises the basement of the eastern Anatolian region. This metamorphic massif, situated in the southern and south-eastern parts of the Taurus (Autochthon) Platform, represents another metamorphic equivalent of the Anatolian-Iranian platform.

• The northern part of this section was also studied in detail [41]. On the basis of that study, it was initially thought that the Gevaş ophiolite was obducted from north to south onto the carbonates of the Bitlis Massif, as shown in Figure 5.

• It has been suggested that a synkinematic shear zone developed between the ophiolites and metamorphic units (Fig. 3 F) of the Bitlis Massif, around the town of Gevaş south of Lake Van. All cataclastic textures and deformations may have occurred during the emplacement of the ophiolites and formation of the ophiolitic mélange.

However, it was suggested that the Gevaş ophiolite represents a suture between the Bitlis Massif and northern fragments [42, 43]. But, there are no eastern or western lateral

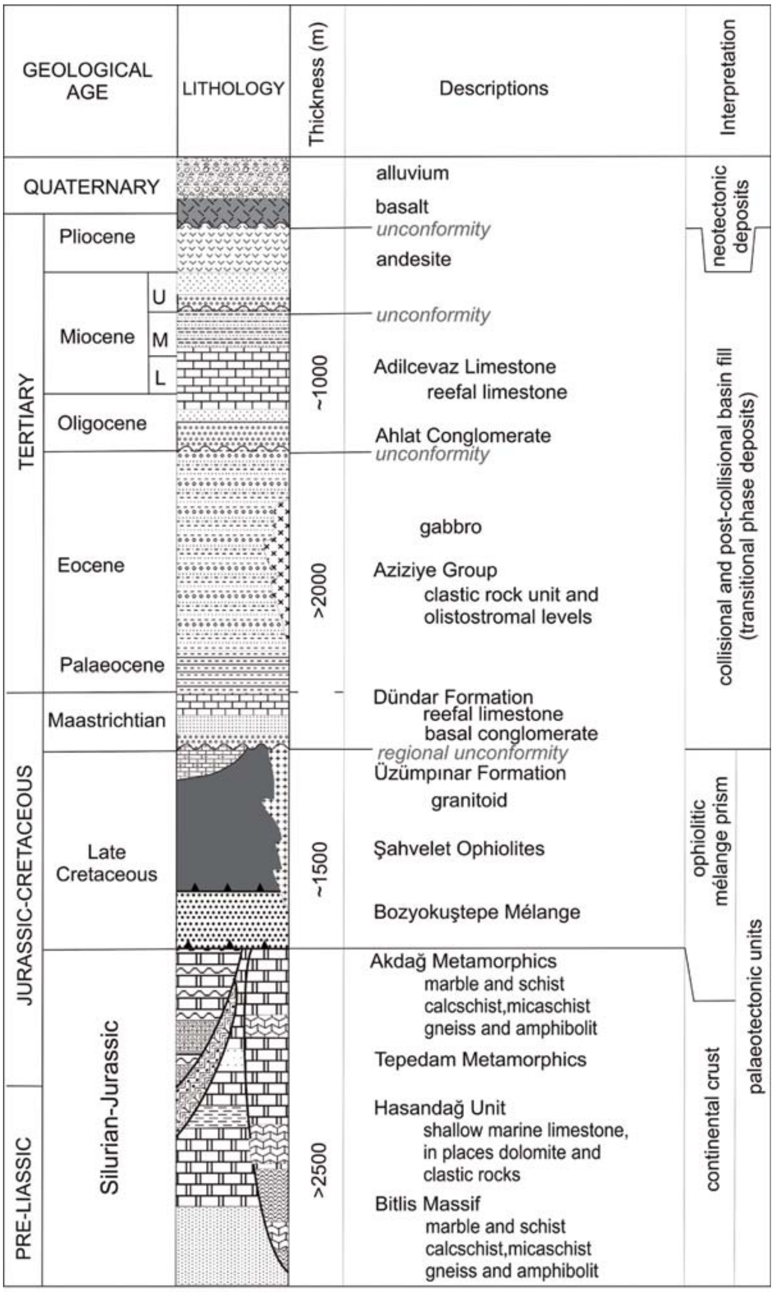


Fig. 6: Generalized and simplified columnar section of the eastern Anatolian region (after [28, 29]and new field observations).

continuations of the ophiolite and no other data indicating a suture. Thus, it is difficult to support such an argument.

In fact, there is also no data indicating movement from south to north. However, the Gevaş ophiolite (Fig. 1B) is situated in an area to the south and southeast of the Hasandağ unit (southeast of Lake Van), an unmetamorphic part of the Anatolian-Iranian Platform. Along the Eastern Tauride Belt, the unmetamorphic sequence of this platform is a definitive indicator that separates the northern Neo-Tethyan ophiolites in Turkey. In this framework, the Gevaş ophiolite may have originated from the south-eastern Anatolian suture zone.

A second cross-section, showing relationships of the northern part of the EAP in the Kağızman-Ağrı area, was also studied. In this section, the Maastrichtian-Quaternary cover overlies ophiolitic mélange and ophiolites. The southern contact of the ophiolitic mélange reflects an overturned structure; unconformities can be observed along northern contacts. Moreover, on the basis of a geological-geophysical profile presented by [20], there is continental crust in the Nahçivan area, which represents the southern part of the Lesser Caucasus ophiolitic belt. The Kağızman ophiolites are equivalent to the Vedi ophiolitic zone to the east and the Şahvelet ophiolites in the west. There is continental crust beneath the mélange in both areas. Therefore, there is likely continental crust beneath the ophiolitic sheets of the Kağızman area, as well.

3.2. Pre-Maastrichtian unconformity and its importance

The pronounced Pre-Maastrichtian unconformity between underlying tectonic units, such as the Akdağ Metamorphics with the Şahvelet Ophiolites and the Maastrichtian Dündar Formation, can be seen clearly in the area between Akdağ and the village of Kösehasan village (Fig. 6). Here, polygenic conglomerate at the base of Maastrichtian limestone overlies both the metamorphic rocks, representing continental crust, and the diabase, representing ophiolites derived from the oceanic crust (Fig. 6). The clasts of the conglomerate were derived from both metamorphic rocks and ophiolitic rocks. Therefore, the conglomerate indicates an erosional phase following emplacement of the ophiolites.

Maastrichtian rock units unconformably overlie tectonic units not only in eastern Anatolia, but also in other adjacent areas, such as in Iran to the east [44], along the Munzur Mountains to the west [45], the eastern Pontides to the north [19], and the Bitlis Massif [46] and Arabian Platform [22, 23] to the south.

It is likely that all of the tectonic units of eastern Anatolia and surrounding areas completed their development before the Maastrichtian, and that the Maastrichtian unconformity indicates a transitional phase from palaeotectonic to neotectonic periods. This new phase is also includes collisional and post-collisional periods in an interval during which a thick Maastrichtian-Miocene volcanic and sedimentary cover developed and further enhanced thickening of the continental crust, up to approximately 3 km more (Fig. 6).

3.3. Volcanic and sedimentary cover

• Maastrichtian-Quaternary volcanic and sedimentary cover unconformably overlies palaeotectonic units on a regional scale (Fig. 6). This sedimentary cover is generally made up of regular alternations of transgressive and regressive lithofacies. During the Middle-Late Miocene, the eastern Anatolian region is believed to have been completely uplifted or became exposed as a fragment of highland representing the final regressive stage [28].

• Maastrichtian polygenic conglomerate, transgressively overlying the tectonic units, can be observed along the Arabian Platform in the south-eastern Anatolian region [22, 45, 46] and over much of Iran [44] and the Caucasus [19, 25].

• The *Dündar Formation* represents the lowermost level of the Maastrichtian sedimentary cover, which comprises mainly basal conglomerate and reefal limestone. The basal conglomerate is made up of well-rounded, well-sorted pebbles of different origins within a fine-grained matrix. The clasts of the conglomerate are derived from ophiolitic and metamorphic rock units. The reefal limestones are medium-to thick-bedded and, locally, are massive and contain abundant rudistids and shells [28].

The Dündar Formation unconformably overlies both the continental metamorphic rocks and the ophiolites. Therefore, the ophiolitic units that tectonically overlie the metamorphic rocks may have been juxtaposed prior to Maastrichtian time.

The *Aziziye Group* includes Palaeocene to Eocene sequences and overlies the Dündar Formation along a gradational contact. In its upper levels, this group includes olistostromal interbeds. This sequence can be divided into different levels.

The lower unit of the group comprises Palaeocene sandstone, siltstone, limestone and marl. It is medium- to thin-bedded and regularly stratified. Sole marks, gradations, parallel and convolute laminations are widespread in the clastic-rock units. The micritic carbonates contain abundant foraminifera. The sedimentation of the lower level probably represents deep-sea fans (lobes) which may have formed in a low energy, deep-sea depositional environment where turbidity currents were predominant [28].

The upper unit of the Aziziye Group comprises olistostromal levels and conformably overlying shallow-marine limestones. The sedimentary regime in the Palaeocene partly continued into the beginning of the Eocene. The olistostromal members in the upper part of the Aziziye Group are derived mainly from ophiolites and ophiolitic mélange and have Middle Eocene ages. These levels graded into a regressive sequence towards the end of Eocene. Eocene shallow-marine limestones with lenticular structures have been deposited in this stage.

As a result, it can be suggested that the Maastrichtian-Eocene sequence began with a transgression or with a rapid sea-level rise and ended with a regressive sequence (shallowing-upward sequence).

The *Ahlat Conglomerate*, occurring in a transgressive sequence, comprises mainly reddish, continental polygenic conglomerate of Oligocene age [47, 48]. This formation is also known as the Ahlat Formation [28]. This unit can be separated from Eocene rocks by grey conglomerate with local reddish color; the reddish color probably reflects terrestrial environmental conditions. In addition, wedging and cross-bedding are widespread in this unit. Coarse-grained materials appear to occur as channel structures that truncate the underlying sedimentary units. The Ahlat Conglomerate is transitional to a succession of clastic-rock and gypsum-rich units. These data suggest that this formation probably represents alluvial-fan deposits, which laterally changed into playa lakes where evaporites likely precipitated under arid climatic conditions.

The *Adilcevaz Limestone* comprises Lower Miocene, grey, medium- to thick-bedded, shallow-marine reefal limestone that contains abundant marine macro- and microfauna [47]. The sequence of bioclastic limestone generally contains fragments of reef-forming organisms and, locally, has oolitic subunits and intraclasts. These lithologic characteristics probably indicate a high-energy, reef-flat depositional site. This Lower Miocene limestone passes upward into a grey, whitish marl-clayey limestone- claystone alternation. Gradational and parallel – even laminated – structures are observed in the wackestone and packstone alternation. Gastropod and bivalve shells are abundant in the grainstone and wackestone subunits.

When deposited, this formation was probably a progradational sequence. In the grainstone and wackestone units of the marl (mudstone), a fining-upward texture capped by fine-grained, parallel laminae, may have originated from storm and storm counter-currents. The fining-upward texture is likely to have originated from progressively waning storm currents; however, fine-grained, evenly parallel capping laminae may reflect deposition of a suspension cloud from storm counter-currents.

The Oligocene-Lower Miocene sequence is represented by two major shallowing-upward cyclical units. The base of each cyclical sequence is marked by a sharp basal contact, probably suggesting a rapid rise in sea level. Each lithologic unit between overlying and underlying basal contacts begins with a deeper sedimentary lithofacies and upward, gradually changes to shallower lithofacies and, still farther up, to continental lithologic units. The first shallowing-upward sequence characterizes sedimentation from the beginning to the end of the Oligocene. Again, in the Miocene, sedimentation was marked by a rapid transgression and upward, graded into shallower or farther-landward lithofacies. Ultimately, this shallowing-upward sequence was capped by continental deposits in the middle of the Miocene. During that time, it is clear that eastern Anatolia, on the whole, became an exposed highland.

During the Late Miocene and Early Pliocene, fluvial to lacustrine clastic-rock units and andesitic volcanic rocks that unconformably overlie older rock units were formed and extended as thick, widespread sheets over the whole of eastern Anatolia. Upper Pliocene-Quaternary fluvial to lacustrine deposits with basaltic volcanic intervals resulted from neotectonic activity, which developed under the influence of a strike-slip fault system in eastern Anatolia [2]. Plio-

Quaternary basalts and pyroclastic rocks are horizontal and unconformably overlie older rock units throughout the region; this sequence has not been folded or imbricated. However, undeformed basaltic and continental sedimentary layers of eastern Anatolia suggest that crustal thickening has neither occurred in the recent geologic past nor is occurring at present.

The cover is a product of an intracontinental basin, representing collisional and post- collisional basin fills. Reworked ophiolitic and mélange material is scarce and of small scale.

4. Regional correlations

The EAP, located between the Eastern Pontide Arc (North Anatolian Suture) to the north and the Arabian Platform (south-eastern Anatolian suture or Bitlis Suture) to the south, has been interpreted as a part of the Anatolian-Iranian Platform during the pre-Maastrichtian tectonic period. The pre-Maastrichtian tectonic units (platform and mélange complexes) of the region were deformed pervasively, and covered by relatively younger sedimentary- and volcanic-rock units. Thus, it is difficult to observe the setting and relationships of the palaeotectonic units of eastern Anatolia and their lateral continuations between central Anatolia and central Iran.

Classification of palaeotectonic units in the Eastern Tauride Belt is well known, mainly in the Gürün area [37, 38]. This classification may be used for the EAP, as well.

For instance, the Gürün Relative Autocthon (which is known as the Geyikdağı Unit by [37] is not metamorphic and the autochton is oriented approximately along E-W axis. This axis separates the northern ophiolites and mélanges from the southern ophiolites and mélanges, which were emplaced during the Late Cretaceous in both regions. However, the Gürün Relative Autocthon hosts an unbroken depositional sequence from Palaeozoic to Early Eocene times. In this respect, this axis is the line which can be used to separate the northern tectonic units from the southern tectonic units [38].

However, it is not possible to trace the relative autocthon to the east because of the Gürün Middle Eocene and post-Eocene basin fills. From the Gürün Basin to the east, the Malatya Basin, Bingöl and Muş basins and finally Lake Van basin follow each other and these basins contain younger deposits than the deposit of the Gürün Basin. But the Hasandağ Unit in the easternmost, which was defined by [30], has characteristics similar to the Gürün Relative Autocthon with regard to rock units, sequence and fossil content. Thus, the proposed line, from the Sarız-Gürün area to the east of Lake Van, can be used to separate the northern and southern ophiolitic units of the eastern Anatolian region (Fig. 1A and B).

The area north of the line, underlain mainly by the Şahvelet Ophiolites and mélanges, the Eleşkirt-Kağızman Ophiolites, and also ophiolites in the northern part of the Hasandağ Unit, should belong to the northern ocean, which has been termed the northern branch of Neo-Tethys [10].

South of the line, an area underlain mainly by the Gevaş Ophiolite, the İspendere and Göksun Ophiolites, and also ophiolites on the southern side of the Hasandağ Unit, should belong to the southern ocean, which has been termed the southern branch of Neo-Tethys.

In addition, the Munzurdağ Limestone [45] is a non-metamorphic unit, but the Akdağ Metamorphics of the Hınıs area should be the metamorphic equivalents of the northern part of the Eastern Tauride Belt, such as the Hınzırdağ Metamorphics and the CACC. The Munzurdağ Limestone and Akdağ Metamorphics both crop out from beneath the mélange as tectonic windows. On the other hand, the Bitlis Massif is the southern metamorphic equivalent of the Eastern Tauride Belt, such as Keban-Malatya Metamorphics, and represents the basement to ophiolitic mélanges in the north.

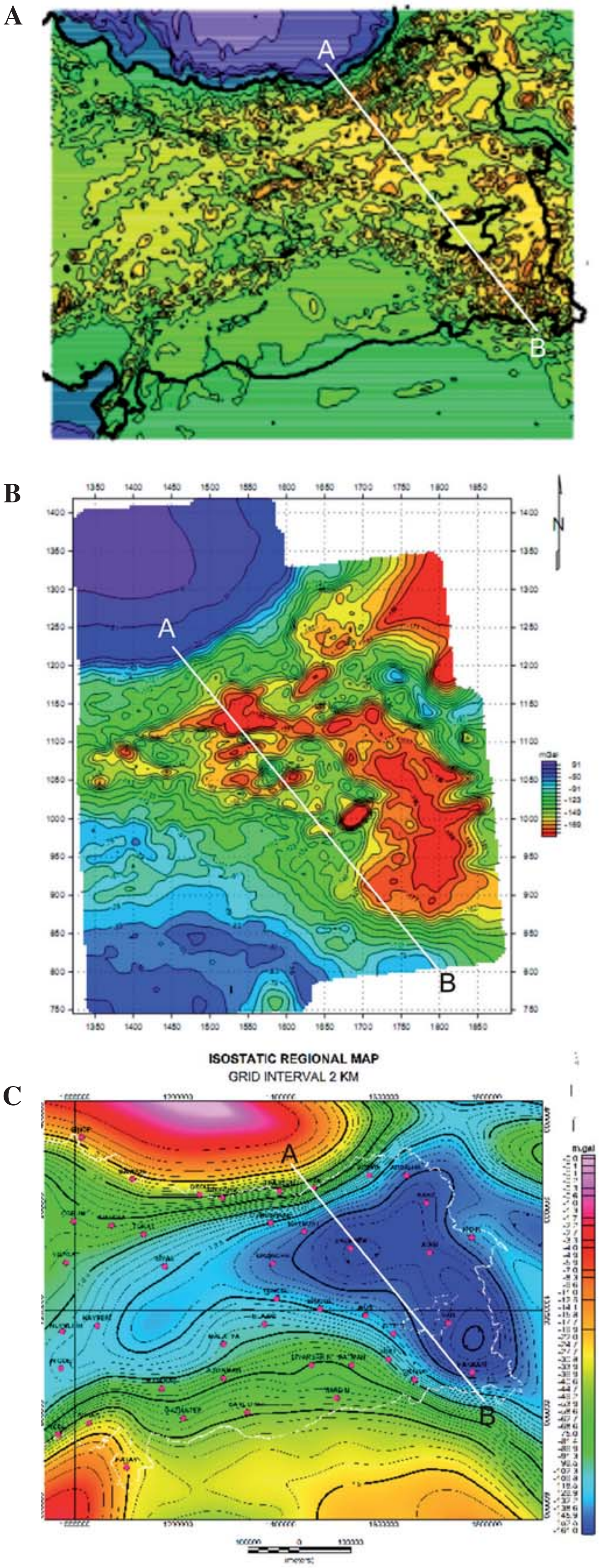
The Central Anatolian Crystalline Complex (CACC) has been studied in detail. Almost all of the researchers who have studied the central Anatolian granitoids suggest a collisional-related genesis [49–51] except [52], who proposed an Andean-type arc-related origin.

On the basis of similarities between the CACC and the Akdağ Metamorphics – with respect to structural setting (as basement beneath ophiolitic mélange) and being intruded by collisional-related granitoid rocks – it may be suggested that the Akdağ Metamorphics appear to be the eastern extension of the CACC into eastern Anatolia.

Despite the uncertainty in geological age, the Akdağ Metamorphics exposed between Erzurum and Hınıs in eastern Anatolia may be correlated with the CACC [33, 34] and the Central Iranian Massif (i.e., Lut Massif) [53, 54]. These comparisons have been made on the basis of rock-unit types, lithological characteristics, stratigraphic sequence, and degree of metamorphism. In addition, the eastern part of the Central Anatolian Massif in the Yıldızeli area has been interpreted as continental crust by [35, 36]. On the basis of these evaluations, it can be concluded that the Akdağ Metamorphics, having formed at the lowermost level in the palaeotectonic framework of eastern Anatolia, probably represent continental crust.

On the basis of lithostratigraphic characteristics and stratigraphy, the Palaeozoic-Mesozoic platform unit in the area east of Lake Van [30]can be correlated with the non-metamorphic autochthonous unit of the Sarız (Kayseri) and Munzur Dağ (Erzincan) areas of the Eastern Taurus Platform [37, 45]. The sequence in the Palaeozoic-Mesozoic platform unit east of Lake Van also represents a part of the continental crust in the eastern Anatolian region.

On the other hand, after regional correlation of the non-metamorphosed section of the Eastern Taurus Belt and the CACC, it may be suggested that the massif is a northern metamorphic equivalent of the non-metamorphosed autochthonous section of the belt [38]. In addition, the Bitlis Massif of south-eastern Anatolia, representing a farther- eastward continuation of the Keban-Malatya unit, may be a southern metamorphic equivalent of the Gürün Relative Autochthon. The Bitlis Massif continues farther eastward into the Sanandaj-Sirjan Zone of Iran [55]. It can be speculated that the metamorphic and non-metamorphic units of the Eastern Taurus Belt continue beneath the cover of the eastern Anatolian region into central Iran. If the Maastrichtian-



Quaternary volcanic and sedimentary units had not extensively covered the ophiolitic associations in central Anatolia and central Iran, the Central Anatolian and Central Iranian Metamorphic massifs would have exposed beneath the obducted ophiolites as tectonic windows. With regard to tectonostratigraphic setting, these two regions exhibit considerable similarities.

Ophiolitic mélanges, which are mainly products of oceanic accretion, tectonically overlie continental-crustal units in eastern Anatolia and along the Eastern Taurus Belt. Many of the ophiolitic rocks of eastern Anatolia were derived from the Northern Anatolian-Lesser Caucasus suture, and the rest from the south-eastern Anatolian suture (Fig. 1A and B).

5. Geophysical data and evaluation

In previous studies, the crustal thickness of eastern Anatolia was estimated to be 55 km, and this estimated crustal thickness was thought to result mainly from the existence of subduction-accretion prisms in the region [10, 11]. However, on the basis of seismic data [56, 57], the crustal thickness of eastern Anatolia is now believed to be approximately 45 km. Similarly, about 45 km of crustal thickness was perceived from the eastward continuation of Eastern Anatolian Plateau in Iran [53, 54, 58]. Moreover, it is understood that the crust and lithosphere are anomalously thin beneath the EAP [16, 57].

All these geological and geophysical interpretations undoubtedly were made on the basis of an assumption that the basement of eastern Anatolia is composed of a mélange prism and/or dyke complex [7, [42].

If the basement of the region is made up of stacks of ophiolitic mélange prisms, the crustal thickness of 45 km is incompatible with the approximately 2 km high elevation of the region due to isostatic balance. In this context, both the geological and geophysical characteristics of the region need to be revised. Consequently, Bouger gravity and regional isostatic data from the EAP have been evaluated in the context of topography, geophysical and geological features.

In the present study, geological and geophysical data from eastern Anatolia have been reassessed. A summary of the data is given in Figures 7 and 8; a topographic map of the region is given in Figure 7A, a gravity map in Figure 7B, and a regional isostatic map in Figure 7C.

On the topographic map, grid intervals are 2x2 km, as indicated by the < http://www-surf.larc.nasa.gov/surf/pages/digielev.htm > internet site. In addition, Figure 8A gives the topographic profile. As seen on that profile, the highest elevations are around Erzurum and in the area between Van and Hakkari. On the basis of these data, the topography is highest near the northern and southern suture zones, where collisions occured. Moreover, elevation is high in the Hınıs area, where the continental Akdağ Metamorphics crop out from beneath ophiolitic material. Thus, it is collisional zones and areas where continental crust crops out that have the highest average elevations. This result differs from the previous data [56, 57] and also from the previous interpretations of [42].

Fig. 7: Different maps of the EAP and surrounding areas.
A) topographic map, **B)** Bouger gravity map, **C)** regional isostatic map.

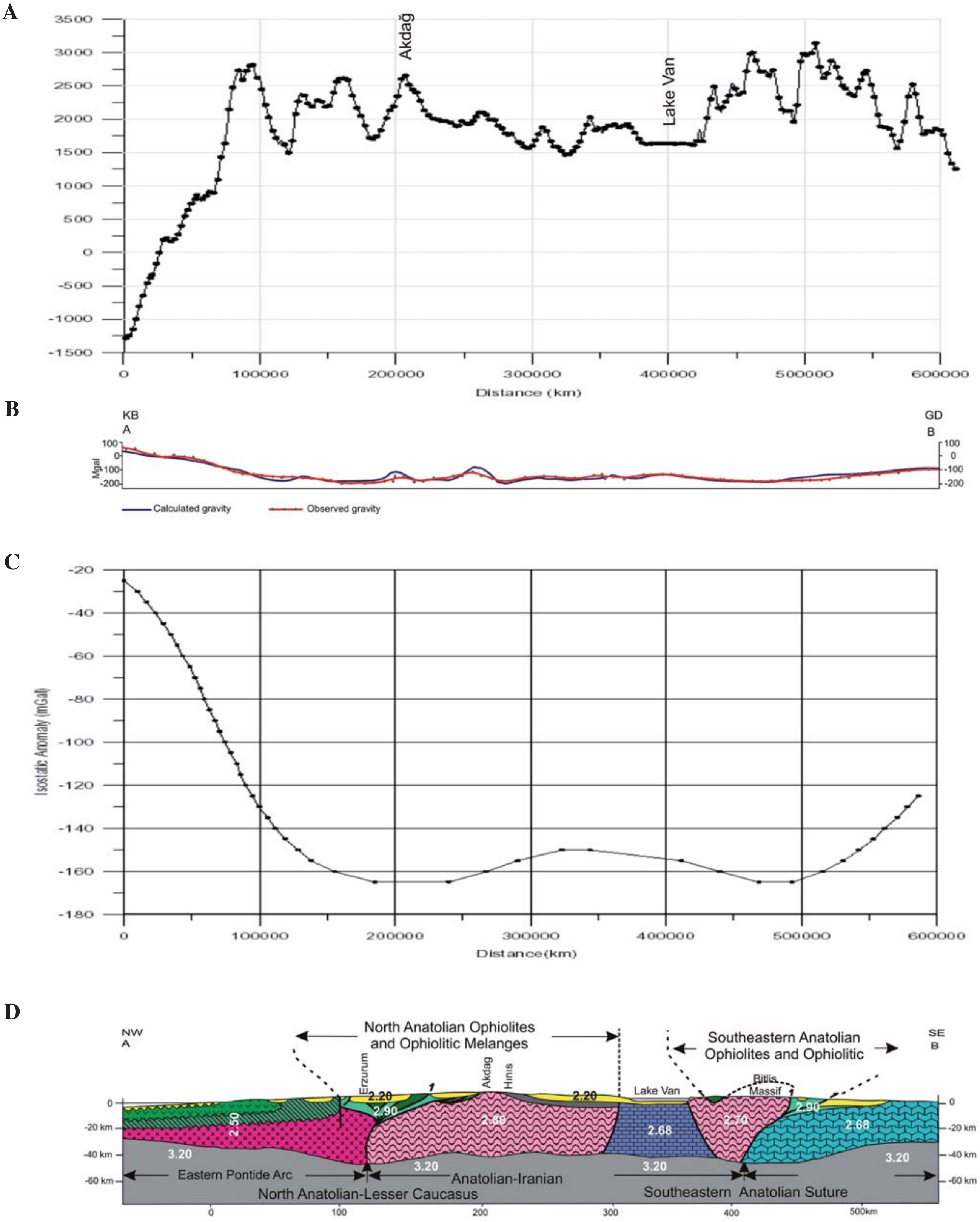


Fig. 8: Different profiles of the EAP and surrounding areas. **A**) topographic profile, **B)** calculated and observed Bouguer gravity profiles, **C)** regional isostatic profile, **D)** a generalized geological and geophysical profile of the study area along the A-B section. (See Figures 1B and 7 for location).

In this study, gravity data were taken from the 1/2,000000-scale Bouguer gravity map of Turkey [59]. A density of 2.40 gr/cm^3 was used in terrain correction, and a density of 2.67 gr/cm^3 was used to calculate Bouguer anomalies.

Figure 8B shows calculated and observed gravity anomalies. Bouguer anomaly values along the A-B profile were interpreted by the two-dimensional forward modelling module of the WinGlink software. In general, we have used three different crustal densities in the eastern Anatolia region. The first was 2.2-2.7 gr/cm^3, representing a low-density unit at the surface. The second was 2.8-3.0 gr/cm^3, representing upper crust. The density of the last unit was 3.3 gr/cm^3 and represents upper mantle. As seen on the profiles, the gravity anomalies are best fitted and vary between -200mGal and 160 mGal along the EAP. They are quite low around Erzurum and the area between Van and Hakkari – in other words, near the suture zones – where mean elevation is 2500 m high. In addition, these anomalies are high in the Black Sea area and at the Arabian Platform, but are low and have an undulating structure along the EAP. These features may be a result of basement heterogenity originating from the distributions of different rock units, such as continental metamorphic rocks and /or mélange.

Figure 8C gives a regional isostatic profile. In the preparation of the regional isostatic map, we used an average crustal thickness of 40 km, an average crustal-density value of 2.67 gr/cm^3, a mantle density of 3.2 gr/ cm^3, and a sea-water density of 1.27 gr/cm^3. During our evaluations, values of altitudes from the < http://www-surf.larc.nasa.gov/surf/pages/ digielev. htm > internet site were used, and a topographic correction of up to 165-km radius was made, assuming a constant surface density of 2.40 gr/cm^3.

On the basis of this regional isostatic profile, the anomaly values are also low along the northern and southern suture zones where collisions occurred, but are high mainly near the Black Sea and the Arabian Platform. In reality, there is a relationship between isostatic anomalies and the thickness of the crust. In this context, the crust is thick, where the isostatic anomaly is high. On the basis of this evaluation, the crust of the EAP is thicker than the crust of the Black Sea area and the southern part of the region, near the Arabian Platform occurred.

In the context of these geological and geophysical characteristics, seven masses of varying density have been recognized along the A-B profile (Figure 8D). The densities of these masses are 3.2 gr/cm^3, 2.9 gr/cm^3, 2.8 gr/cm^3, 2.70 gr/ m^3, 2.68 gr/cm^3, 2.5 gr/cm^3 and 2.2 gr/cm^3. These figures are, generally speaking, accepted in most studies. In addition, oceanic-crustal masses have high densities and are located at the top of the section, whereas continental-crustal masses have low densities and are located at the bottom of the vertical section in the EAP.

The settings of the two different crustal levels are seen clearly via correlation of the geological and geophysical profiles. It can be suggested that ophiolitic mélange was derived from the oceanic crust, overlying metamorphic massifs and platform-type carbonates. It is clear that continental crust constitutes the lower level. From information presented above concerning the A-B profile, it may be suggested that the high topography with the 45-km-thick crust of the EAP can be balanced with a standard mantle, in the framework of isostasy.

6. Conclusions and discussion

Although numerous studies have been carried out in eastern Anatolia, studies of the pre-Maastrichtian tectonic units and the upper-crustal structure of eastern Anatolia have been few. Paucity of such studies is linked mainly to the presence of a thick, widespread volcanic and sedimentary cover that unconformably overlies the palaeotectonic units throughout the region. As a result, in this region, evaluating relationships and features of the palaeotectonic units at small-outcrop scale led to different interpretations of palaeotectonic settings and structures.

To determine with greater detail the presence of continental crust beneath the ophiolitic-mélange prism, the present study suggests that an extensive study and reevaluation of the region needs to be carried out, from east of Lake Van to Erzurum and Hınıs, and from the Ağrı-Kağızman area to the south of Lake Van (Gevaş area), where outcrop of palaeotectonic units is relatively abundant.

In these areas, palaeotectonic crustal units are not only represented by ophiolitic mélange units but also by continental-crustal units. In fact, crustal shortening and thickening may have led to the high topographic relief in the region, as suggested by [1].

In order to fit the presently accepted thickness of continental crust of the region to their former model, it was suggested that most of the EAP is devoid of mantle lithosphere [15]. However, it is difficult to balance the high topography of eastern Anatolia with a standard mantle lithosphere when one accepts a 45 km of thickness for the continental crust, and realizes that the subduction-accretion prism contributed significant additional thickness to the continental crust of the region. Therefore, it was suggested that there should be mantle lithosphere beneath the EAAC, at a depth range of 60 to 80 km [16].

The interpretations outlined above do not reflect the geological characteristics of the EAP. In fact, the existence of continental crust beneath the mélange prisms of the Hınıs area has already been mentioned [28, 29, 60]. The present study has reevaluated the characteristics of lithofacies and the vertical and lateral relationships of palaeotectonic outcrops in different parts of eastern Anatolia. Figure 8A-C indicates that the thickness of the crust in the central part of eastern Anatolia is thicker than other parts of the region.

In the present study, it is understood that the crustal thickness calculated from gravity data does not coincide broadly with the thickness proposed [56, 57]. In detail, there are some differences. For example, on the basis of gravity data, the thickness of the crust along the EAP is also greater than that of the Eastern Pontide Arc and the Arabian Platform; that is to say, estimations of crustal thickness may be differ when acquired via various methods.

On the basis of the data and evaluations presented above, the following conclusions may be drawn at last:

Typical continental crust, comprising metamorphic and platform-type carbonate rocks, appears to be present beneath the subduction-accretion complex of the eastern Anatolia region. As a result, when the data presented above are evaluated, it is possible to accept that the lowermost level of eastern Anatolia is made up of continental crust and tectonically overlying ophiolitic mélange.

The volcanic and sedimentary cover, which blankets the palaeotectonic units of eastern Anatolia, ranges from Maastrichtian to Quaternary in age and is characterized by imbricated structure along sutures. However, in the Hınıs-Akdağ area, in roughly the central part of eastern Anatolia, open folds and a pre-Maastrichtian regional unconformity are predominant features. In addition, pre-Miocene, pre-Upper Miocene and pre-Plio-Quaternary unconformities can also be observed clearly in the central part of the EAP. This cover represents collisional and post-collisional basin fills, all products of intra-continental basins.

In eastern Anatolia, the crust is thicker than the crust on the northern side of the Pontides and in the Black Sea region, and also than that of the Arabian platform. All of these data indicate that rigid, continental metamorphic crust is present along the EAP.

The Plio-Quaternary sequence, reflecting the neotectonic regime [2], is unfolded across the entire region; only along active faults are beds steepened. Therefore, it can be concluded that the EAP has experienced N-S compression, but that this compression has not resulted in considerable crustal thickening due to the current (dominant) strike–slip tectonic regime in the region.

Acknowledgements

The present paper is a synthesis of the various presentations we made a MTA (General Directorate of Mineral Research and Exploration). The manuscript has been improved after critisizing by reviewers and editor Jean Van Den Driessche. We are grateful for their constructive comments. Without their helpful comments, this paper might have never seen the light of day.

References

[1] Şaroğlu F., Güner Y., Kidd W.S.F., Şengör A.M.C., Neotectonics of eastern Anatolia: new evidence for crustal shortening and thickening in a collision zone. Eos Transactions 360 (American Geophysical Union) (1980) 61–17.

[2] Koçyiğit A., Yılmaz A., Adamia S., Kuloshvili S., Neotectonics of East Anatolian Plateau (Turkey) and Lesser Caucasus: implications of transition from thrusting to strike-slipe faulting. Geodinamica Acta 14/1–3 (2001) 177–195.

[3] Tokel S., Doğu Anadolu' da kabuk deformasyon mekanizması ve genç volkanitlerin petrojenezi (Mechanism of crustal deformation and petrogenesis of the Neogene volcanics of eastern Anatolia), In: Ketin Sempozyumu, Bildiriler (Proceedings). Geological Society of Turkey, Ankara (1984) 121–130.

[4] Yılmaz Y., Şaroğlu F., Güner Y., Initiation of the neomagmatism in East Anatolia. Tectonophysics, 134 (1987)177–199.

[5] Pearce J.A., Bender J.F., DeLong S.E., Kidd W.S.F., Low P.J., Güner Y., Şaroğlu F., Yılmaz Y., Moorbath S., Mitchel J.G., Genesis of collision volcanism in east Anatolia, Turkey. Journal of Volcanology and Geothermal Research 44 (1998) 189–229.

[6] Keskin M., Pearce J.A., Mitchell J.G., Volcano-stratigraphy and geochemistry of collision-related volcanism on the Erzurum-Kars Plateau, north-eastern Turkey, Journal of Volcanology and Geothermal Research 55 (1998) 355–404.

[7] Keskin., M., Magma generation by slab steepening and break off beneath a subduction accretion complex: an alternative model for collisional volcanism in eastern Anatolia, Turkey. Geophysical Research Letters 30/24 (2003) 8046, doi:10.1029/2003GL018019.

[8] Arni P., Tectonische Grundzüge Ostanatoliens und benachbarter Gebiete. Veröff. Inst. Lagerstattenfosch, Turkei, Ser. B, 490 p (1939).

[9] Ketin İ., A brief report on the result of geological observations made in the area between Lake Van and Iranian border. Bulletin of the Geological Society of Turkey (in Turkish with English abstract) 20 (1977) 79–85.

[10] Şengör A.M.C., Yılmaz Y., Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75 (1981)181–241.

[11] Dewey J.F., Hempton M.R., Kidd W.S.F., Şaroğlu F., Şengör A.M.C., Shortening of the continental lithosphere: the neotectonics of eastern Anatolia - young collision tectonics, In: M.P. Coward and A.C. Ries (eds.) Geological Society, London, Special Publication 19 (R.M. Shackleton volume) (1986) 3–36.

[12] Gök R., Türkelli N., Sandvol E., Seber D., Barazangi M., Regional wave propagation in Turkey and surrounding regions. Geophysical Research Letters 27/3 (2000) 429–432.

[13] Gök R., Sandvol E., Türkelli N., Seber D., Barazangi M., Sn attenuation in the Anatolian-Iranian plateau and surrounding regions. Geophysical Research Letters 30/24 (2003) 8042.

[14] Al-Lazki A.I., Seber D., Sandvol E., Türkelli N., Mohamed R., Barazangi M., Tomographic Pn velocity and anisotropy structure beneath the Anatolian Plateau (Eastern Turkey) and surrounding regions. Geophysical Research Letters 30/24 (2003) 8043.

[15] Şengör A.M.C., Özeren S., Zor E., Genç T., East Anatolian high plateau as a mantle-supported, N-S shortened domal structure. Geophysical Research Letters 30/24 (2003) 8044, doi:10.1029/2003GL017858.

[16] Angus D.A., Wilson D.C., Sandvol E., Ni J.F., Lithospheric structure of the Arabian and Eurasian Collision Zone in eastern Turkey from S-wave receiver functions. Geophysical Journal International 166 (2006)1335–1346.

[17] Okay A.I., Şahintürk Ö., Geology of the eastern Pontides. In: A.G.

Robinson (ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Region. Association of American Petroleum Geologists Memoir 68 (1997) 291–311.

[18] Adamia Sh., Lordkipanidze M.B., Zakariadze G.S., Evolution of active continental margin as examplified by the alpine history of the Caucasus. Tectonophysics 40 (1977)183–199.

[19] Yılmaz A., Adamia S., Chabukiani A., Chkhotua T., Erdoğan K., Tuzcu S., Karabıyıkoğlu M., Structural correlation of the southern Transcaucasus (Georgia)-eastern Pontides (Turkey). Geological Society, London, Special Publication 173 (2000) 171–182.

[20] Adamia Sh., Excursions Guidebook, International Geological Congress, XXVII Session, Moscow. Tbilisi, Khelovneba, 1984, 224 p.

[21] Berberian M., King G.C.P., Towards a paleogeography and tectonic evolution of Iran. Canadian Journal of Earth Sciences 18 (1981) 210–265.

[22] Yazgan, E., 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, 1983, 17 p.

[23] Yazgan E., Chessex, R., Geology and tectonic evolution of the southeastern Taurides in the region of Malatya. Bulletin of the Turkish Association of Petroleum Geologists (in Turkish with English abstract) 3/1 (1991)1–42.

[24] Perinçek D., Interrelations of the Arabian and Anatolian Plates. In: Guide Book Excursion B, First Geological Congress of the Middle East. Geological Society of Turkey, Ankara, 1979, 34 p.

[25] Yılmaz A., Tectonic zones of the Caucasus and their continuations in northeastern Turkey: a correlation. Bulletin of Mineral Research and Exploration (in Turkish with English abstract) 109 (1989) 89 –106.

[26] Tarhan N., New data on the Elbistan ensimatic island-arc sediments and age. Jeoloji Mühendisliği Dergisi (in Turkish with English abstract) 23 (1985) 3–8.

[27] Yılmaz Y., Geology of the Cilo Ophiolite: an ancient ensimatic island arc fragment on the Arabian platform, SE Turkey. Ofioliti 10 (2/3) (1985) 457–484.

[28] Yılmaz A., Terlemez İ., Uysal Ş., Some stratigraphic and tectonic characteristics of the area around Hınıs (southeast of Erzurum). Bulletin of Mineral Research and Exploration 108 (1988) 1–21.

[29] Yılmaz A., Terlemez İ., Uysal Ş., Geological characteristics and structural evolution of the ophiolitic units around Sakaltutan Dağ (Erzurum), Turkey. Middle East Technical University Journal of Pure and Applied Sciences 21/1–3 (1990) 221–235.

[30] Şenel M., 1:100 000 Ölçekli açınsama nitelikli Türkiye Jeoloji Haritaları Serisi, Başkale-H38 paftası (1:100000-scale Special Geological Maps of Turkey, Sheet H38), General Directorate Mineral Research and Exploration (MTA), Ankara,1987,12 p.

[31] Winkler H.G.F., Petrogenesis of metamorphic rocks, 4th edition, Springer-Verlag, New York, 1976, 344 p.

[32] Öner F., Alpaslan M., Boztuğ D., Kuşçu M., Geochemie und petrogenese der intrusivgesteine von Ağören in Ostanatolien, Türkei (Geochemistry and petrogenesis of the Ağören intrusives in eastern Anatolia, Turkey). Chemie der Erde-Geochemistry (2007) (doi:10.1016/j.chemer.2005.01.007).

[33] Yılmaz A., Inner structure and age of emplacement of the ophiolitic melange between Tokat and Sivas provinces. Bulletin of Geological Society of Turkey (in Turkish with English abstract) 24/1 (1981) 31–86.

[34] Yılmaz A., Geological characteristics and setting of ophiolitic melange around Tokat (Dumanlı dağı) and Sivas (Çeltek dağı) region. Bulletin of Mineral Research and Exploration (in Turkish with English abstract) 99/100 (1984)1–18.

[35] Alpaslan M., Yıldızeli yöresi (Sivas batısı) metamorfitlerinin petrolojik incelemesi (Petrologic study of metamorphites in the Yıldızeli area, west of Sivas, Turkey), Cumhuriyet Üniversitesi, Fen Bilimleri Enstitüsü., PhD thesis, (in Turkish with English abstract) Sivas, 1993, 359 p.

[36]Alpaslan M., Guezou J.C., Bonhomme M.G., Boztuğ D., Yıldızeli Metasedimenter Grubu içindeki Fındıcak Metamorfiti'nin metamorfizması ve yaşı (The metamorphism and the age of the Fındıcak metamorphite in the Yıldızeli metasedimentary group). Bulletin of Geological Society of Turkey (in Turkish with English abstract) 39/1 (1996)19-29.

[37] Özgül N., Some geological aspects of the Taurus orogenic belt, Turkey, Bulletin of Geological Society of Turkey (in Turkish with English abstract) 19/1 (1976) 65–78.

[38] Yılmaz A., Bedi Y., Uysal Ş., Yusufoğlu H., Aydın Ş.N., Geological structure of the area between Uzunyayla and Berit Dağ along the eastern Taurides. Bulletin of Turkish Association of Petroleum Geologists (in Turkish with English abstract) 5/1 (1993) 69–87.

[39] Yılmaz S., Boztuğ D., Öztürk A., Geological setting, petrographic and geochemical characteristics of the Cretaceous-Tertiary igneous rocks in the Hekimhan-Hasançelebi area, northwest Malatya, Turkey. Geological Journal 8 (1993) 383–398.

[40] Boztuğ D., Yılmaz S., Keskin Y., İç-Doğu Anadolu Alkalin Provensindeki Kösedağ Plütonu (Suşehri-KD Sivas) Doğu Kesiminin Petrografisi ve Petrojenezi (Petrography, petrochemistry and petrogenesis of the eastern part of Kösedağ pluton from the east-central Anatolian alkaline province, Suşehri, NE Sivas). Bulletin of Geological Society of Turkey (in Turkish with English abstract) 37/2 (1994)1–14.

[41] Yılmaz Y., Dilek Y., Işık H., The geology of Gevaş Ophiolite and a synkinematic shear zone. Bulletin of the Geological Society of Turkey (in Turkish with English abstract) 24 (1981) 37–44.

[42] Şengün M., Anadolu'nun Kenet Kuşakları ve Jeolojik Evrimine İrdelemeli ve Eleştirel Bir Bakış (Suture zones of Anatolia and a scrutinising, critical evaluation of its geological evolution). Maden Tetkik ve Arama Dergisi 133 (2006) 1–26.

[43] Şengör A.M.C., Özeren M.S., Keskin M., Sakınç M., Özbakır A. D., Kayan İ, Eastern Turkish high plateau as a small Turkic-type orogen: implications for post- collisional crust-forming processes in Turkic-type orogens. Earth Science Reviews 90 (2008) 1– 48.

[44] Nogole-Sadat M. A. A., 1989. Review of tectonosedimantary zonation in Iran, 28 th International Geological Congress, Abstractcs, Volume 2/3, Washington, D. C. USA, July 9-19 ,1989, p. 522.

[45] Özgül N., Munzur dağlarının jeolojisi (Geology of the Munzurdağ, Turkey). Mineral Research and Exploration (MTA) Report 6995 Ankara, 1981, 136 p. (in Turkish with English abstract).

[46] Göncüoğlu C., Turhan N., Geology of the Bitlis Metamorphics, In: O. Tekeli and M. C. Göncüoğlu (eds.), The Geology of the Taurus Belt, Proceedings International Symposium, Ankara (1983) 237–244.

[47] Demirtaşlı E., Pisoni C., The Geology of Ahlat-Adilcevaz area (North of Lake Van) . Bulletin of Mineral Research and Exploration, 64 (1965) 22–36.

[48] Gelati R., Miocene marine sequence from lake Van, Eastern Turkey, Rıvısta Italıana dı Paleontologia e Stratigrafia , 81 (1975) 477–490.

[49] Düzgören-Aydın N., Malpas W., Göncüoğlu M.C., Erler A., A review of the nature of magmatism in Central Anatolia during the

Mesozoic post-collisonal period. International Geology Review 43 (2001) 695–710.

[50] İlbeyli N., Pearce J.A., Thirwall M.F., Mitchell J.G., Petrogenesis of collision-related plutonics in central Anatolia, Turkey. Lithos 72 (2004)163–182.

[51] Boztuğ D., Harlavan Y., Arehart G.B., Satır M., Avcı N., K-Ar age, whole-rock and isotope geochemistry of A-type granitoids in the Divrigi-Sivas region, eastern-central Anatolia, Turkey. Lithos 97/1–2 (2007)193–218.

[52] Kadıoğlu Y.K., Dilek Y., Güleç N., Foland K.A., Tectonomagmatic evolution of bimodal plutons in the Central Anatolian Crystalline Complex, Turkey. Journal of Geology 111 (2003) 671–690.

[53] Dehghani G. A., Makris J., The gravity field and crustal structure of Iran. In: V. Madelet (ed.), Geodynamic Project (Geotraverse) in Iran, Final Report, Report No. 51. Geological Survey of Iran, Tehran, 1983, 51–68.

[54] Geisse P., Makris J., Akashe B., Seismic crustal studies of southern Iran between the Central Iran and Zagros Belt, In: V. Madelet (ed.), Geodynamic Project (Geotraverse) in Iran, Final Report, Geological Survey of Iran, Report No. 51. Tehran, 1983, 71–89.

[55] Yılmaz A., Yazgan E., Structural evolution of the eastern Taurus in the Cretaceous-Tertiary Period, In: International Earth Sciences Colloquium on the Aegean Regions, Proceedings 2 İzmir, (1990) 345–356.

[56] Sandvol E., Seber D., Barazangi M., Türkeli N., Gürbüz C., Kuleli S., Karabulut H., Zor E., Gök R., Bekler T., Arpat E., Bayraktutan S., Eastern Turkey seismic experiment. IRIS Newsletter, 1 (2000).

[57] Zor E., Sandvol E., Gürbüz C., Türkelli N., Seber D., Barazangi M., The crustal structure of the East Anatolian Plateau from receiver functions. Geophysical Research Letters 30(24) (2003) 8044.

[58] Maggi A., Jackson J.A., McKenzie D., Priestley K., Earthquake focal depths, effective elastic thickness and the strength of the continental lithosphere. Geology 28/6 (2000) 495–498.

[59] MTA, Bouguer gravity anomaly map of Turkey, scale 1/2000000. General Directorate of Mineral Research and Exploration, Ankara,1999.

[60] Yılmaz A., Thoughts on crustal structure of eastern Anatolia, Turkey, In: 28th International Geological Congress, Abstracts Volume 3/3, Washington (1989).