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Stratigraphy and geochronology of the Eocene volcanosedimentary units in the Hekimhan–Darende (Malatya) region: implications for the development of the Gürün Curl

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Abstract: We present new radiometric (Ar–Ar) age data from the volcanic rocks occurring in the Eocene strata in the Hekimhan and Gürün–Darende (Malaya) regions. The Eocene units in these regions are represented separately by the Tohma and Darende formations, respectively. The two basaltic volcanic interlayers in the Tohma Formation, occurring in the lower and upper parts of the succession, yielded Ar–Ar isochron ages of 51.75 ± 0.76 and 42.66 ± 0.43 Ma, respectively, indicating a deposition age of Ypresian–Lutetian interval for the unit. The andesitic volcanic rocks in the basal parts of the Darende Formation yielded an Ar–Ar isochron age of 37.35 ± 0.72 Ma, revealing that the unit was deposited at least in the Bartonian–Priabonian interval, much younger than the nummilites-bearing sedimentary units seen in the Hekimhan area. Based on these data, we present a revised stratigraphy of these units. Based on the age data from these units, it can be suggested that two distinct sectors of the Anatolide–Tauride Block, the Akdere and Munzur sectors, which were separated originally by a transform fault, were tectonically juxtaposed and eroded in the Paleocene times, representing the initial stage of the Gürün Curl, the most prominent structural feature of eastern Taurides in the region.

Key words: Hekimhan Basin, Darende Basin, Eocene, Gürün Curl

1. Introduction

Eocene marine sedimentary units associated with magmatic rocks are extensively exposed in Central Eastern Anatolia (Figure 1a). The stratigraphy of Eocene marine sedimentary units in the Gürün, Darende, and Hekimhan regions, located west-northwest of Malatya (Figure 1b), has been studied by several researchers. They have proposed variable ages based on fossil records for these units (Figure 2). Regarding the Eocene units in the vicinity of Gürün and Darende, the suggested ages are mainly within the Lutetian–Bartonian interval (e.g., Akkuş, 1971; Kurtman, 1978; Nazik, 1993; Gürbüz and Gül, 2005; Nazik et al, 2006; Booth et al., 2013; Metin, 2018). However, a wider depositional age has been suggested for the units exposed around the Hekimhan region, ranging from Paleocene to the latest Eocene (e.g., Leo et al., 1978; Örçen, 1986; Yılmaz, 1991; Bozkaya and Yalçın, 1992; Gürer, 1994; Booth et al., 2014; Sümengen, 2016). Notably, all the Eocene sedimentary units in this area contain volcanic intercalations at several levels of the sequence, providing an opportunity to determine their absolute deposition ages based on radiometric methods.

The study area is also located where the Tauride units buckle southeastward between the Gürün and the Malatya faults (see Figure 1a). This crustal-scale structure is known as the Gürün Curl (Lefebvre et al., 2013; van Hinsbergen et al., 2020). However, the origin and tectonic evolution of the Gürün Curl are still uncertain. Robertson et al. (2013) proposed the existence of a NE–SW trending transform fault in the region, related to the curling. van Hinsbergen et al. (2020) interpreted that the eastern margin of the Gürün Curl was a transform fault during the Paleocene–early Eocene. Ersoy et al. (2024a, 2024b) proposed that this structure started to form after the juxtaposition of different sectors of the Anatolide–Tauride Block (ATB) after the latest Cretaceous. Therefore, the stratigraphy and depositional ages of the Eocene units that cover the basement units related to the Gürün Curl are particularly crucial for understanding this structure.

Herein, we present detailed geological maps of two regions around Darende and Hekimhan, where the stratigraphic relationships of the volcanic and sedimentary units are well exposed. We dated the volcanic rocks by the Ar–Ar method. Based on the field studies and the

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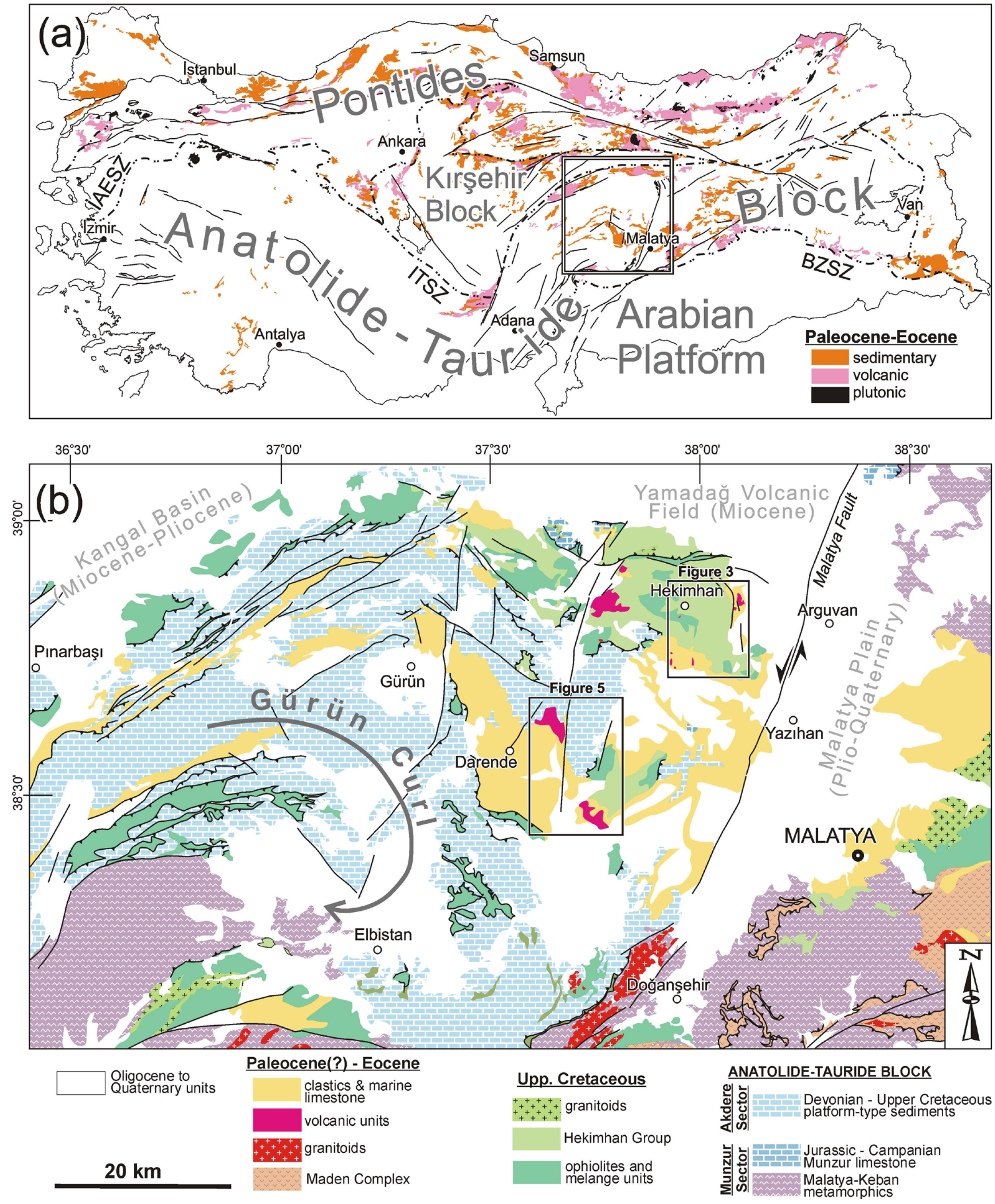

Figure 1. (a) Simplified geological and tectonic map of Türkiye showing the distribution of the Eocene units. IAESZ: İzmir–Ankara–Erzincan Suture Zone; ITSZ: Inner Tauride Suture Zone; BZSZ: Bitlis–Zagros Suture Zone. (b) Simplified geological map of the Hekimhan Basin and environs showing the distribution of the pre-Eocene basement units and the Eocene sedimentary and magmatic units (compiled from 1:500,000 scaled Geological Map of Türkiye, 2002).

radiometric data, we present a revised stratigraphy for the Eocene units in the region. Additionally, considering these new data, we suggest that the initiation stage of the Gürün Curl occurred in the Paleocene.

2. Regional geology

Central Eastern Anatolia comprises distinct tectonostratigraphic rock units: (1) the Pontides, positioned to the north, (2) the ATB to the south, (3) the

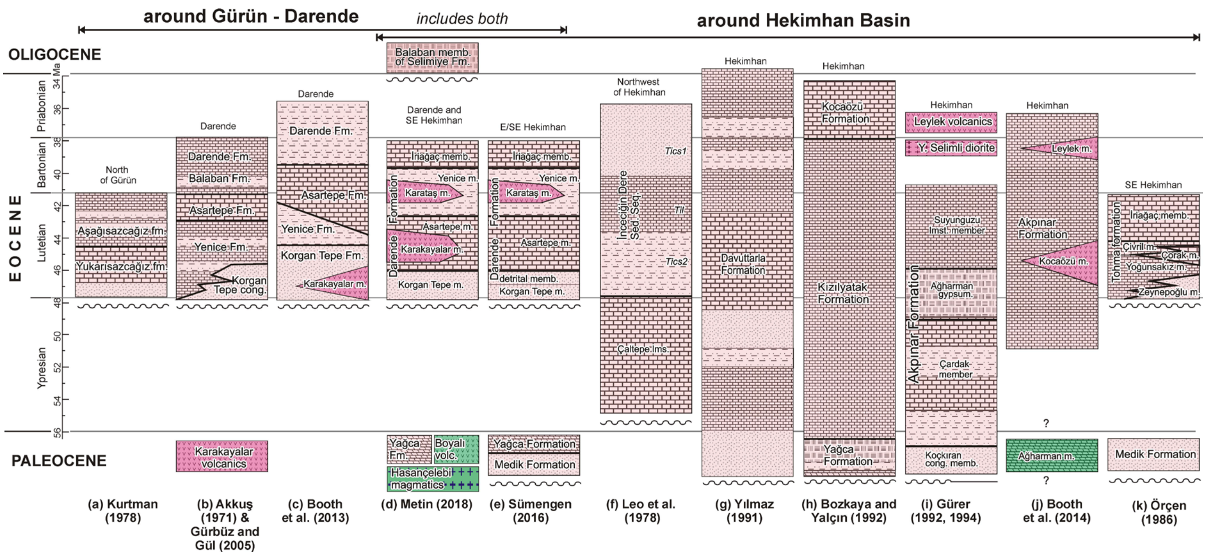

Figure 2. Stratigraphic comparison of the Eocene units in the Hekimhan and Darende regions. The green patterns indicate the unit is Late Cretaceous in age.

Kırşehir Block situated between (1) and (2), and (4) the Arabian Plate in the southeastern region (Figure 1a). The Pontides represent the southern active continental margin of the Eurasian plate and consist of a Variscan basement, unconformable overlying Jurassic to Early Cretaceous volcanics and platform sediments, and Late Cretaceous arc magmatics (Okay and Şahintürk, 1997; Okay and Nikishin, 2015). The arc magmatism is extensively related to the northward subduction of the northern branch of the Neotethys beneath the Pontides (e.g., Oğuz-Saka et al., 2023). The ATB represents a small continental fragment surrounded by Neotethys oceans and is composed of a Precambrian crystalline basement (Gondwana) unconformably overlain by a Palaeozoic–Mesozoic clastic–carbonate succession (Ketin, 1966; Özgül, 1976). The ATB rifted from the northern margin of Gondwana during the latest Permian–Early Triassic and collided with the Pontides during the latest Cretaceous to Eocene times (Şengör and Yilmaz, 1981; Okay and Şahintürk, 1997; Jafari et al., 2023).

The southeastern part of the ATB is characterized by another arc magmatism that developed in the Late Cretaceous (Santonian–middle Campanian Baskil Arc; Yazgan and Chessex, 1991; Parlak, 2006; Topuz et al., 2017). The Hekimhan Basin in the study area represents a back-arc extension of this subduction system (Yazgan and Chessex, 1991; Gürer, 1994; Ersoy et al., 2024a). The deposition in the Hekimhan Basin continued up to the latest Maastrichtian (see Ersoy et al., 2024b and references therein). The basement of the Hekimhan Basin is made up of ophiolite and mélange units (e.g., Parlak, 2016), Munzur limestone (Ozgul and Tursucu, 1984), and Malatya-Keban metamorphics (Bingöl, 1984), all of which are cut by arc- and back-arc-related magmatics (e.g., Perinçek and Kozlu, 1984; Yazgan and Chessex, 1991). However, the Baskil Arc is not seen in the western parts of the ATB, where the platform-type sedimentation continued up to the Maastrichtian (e.g., Atabey, 1993). Based on these observations, Ersoy et al. (2024b) have proposed that the ATB underwent two distinct Late Cretaceous tectonostratigraphic and -magmatic evolutions in its Akdere (western) and Munzur (eastern) sectors. They also proposed that these two sectors were originally separated by a transform fault, which is thought to align approximately parallel to the currently active Malatya Fault Zone (Figure 1b). However, due to the intense imbrication and multiple deformations that have occurred since the Paleocene to the present under regional N–S contraction, the exact position of the transform fault and its surface deformational structures in the ATB cannot be definitively traced at this time. Ersoy et al. (2024b) suggest that the tectonic juxtaposition of the Akdere and Munzur sectors represents the initial stage of formation of the "Gürün Curl" where the ATB buckled southwards (see Figure 1b; Lefebvre et al., 2013; van Hinsbergen et al., 2020).

The Eocene marine sedimentary units, with or without magmatic rocks, are widely exposed in Central Eastern Anatolia (Figure 1a). In detail, the syn- to postcollisional Eocene rock units throughout the eastern Pontide orogenic belt (see Okay and Şahintürk, 1997) are dominated by volcanic and plutonic rocks (e.g., Keskin et al., 2008; Topuz et al., 2011; Karsli et al., 2013; Eyuboglu et al., 2017; Göçmengil et al., 2018). The syn- to postcollisional Paleocene to Eocene sedimentary units in the Ulukışla and

Sivas foreland basins are also intercalated with volcanic rocks (e.g., Gökten and Floyd, 1987; Alpaslan et al., 2006). Further southeast, another Eocene unit with volcanic intercalations is represented by the Maden Complex (Perinçek and Özkaya, 1981; Yazgan and Chessex, 1991; Yiğitbaş and Yılmaz, 1996), but no radiometric data have been obtained from these units. The Eocene sedimentary units around Malatya (Figure 1b), which do not contain volcanic intercalation, have been associated with the Maden Basin further SE (Yeşilyurt Group; Önal and Kaya, 2007). Similar units further east around Elazığ are known as the Seske and Kırkgeçit formations (e.g., Çelik, 2013; Alkaç and Aksoy, 2022, references therein).

3. Stratigraphy of the Eocene units

3.1. The Hekimhan region

In the south and east of Hekimhan (Figure 3), the Eocene volcanosedimentary units unconformably overlie the ophiolite, ophiolitic mélange units, and the Hekimhan Group. From bottom to top, the middle Campanian–Maastrichtian Hekimhan Group is composed of conglomerates, neritic (reef) limestones, turbiditic sandstone–mudstone alternations, volcanogenic rocks, marl, limestone, and evaporites (gypsum) (see Gürer, 1994; Booth et al., 2014; Ersoy et al., 2024b, references therein).

The stratigraphy and fossil records of the Eocene marine deposits in this area have been studied by Örçen (1986), Bozkaya and Yalçın (1992), Gürer (1994), Booth et al. (2014), and Sümengen (2016). Several unit names have been proposed in these studies (Figure 2). We follow those suggested by Örçen (1986), who proposed that the Lutetian Tohma Formation unconformably overlies the Medik Formation. The Medik Formation is composed of well-lithified boulder conglomerates made up of unsorted and unrounded clasts mainly derived from Tauride limestones. This unit crops out in the southeast of the study area and is accepted as Paleocene in age. The unconformably overlying Tohma Formation is composed of conglomerates and overlying sandstone, marl, and limestone alternations that were deposited in a marine environment.

The Tohma Formation is made up of five members: Zeynepoğlu, Yoğunsakız, Çorak, Çivril, and İriağaç

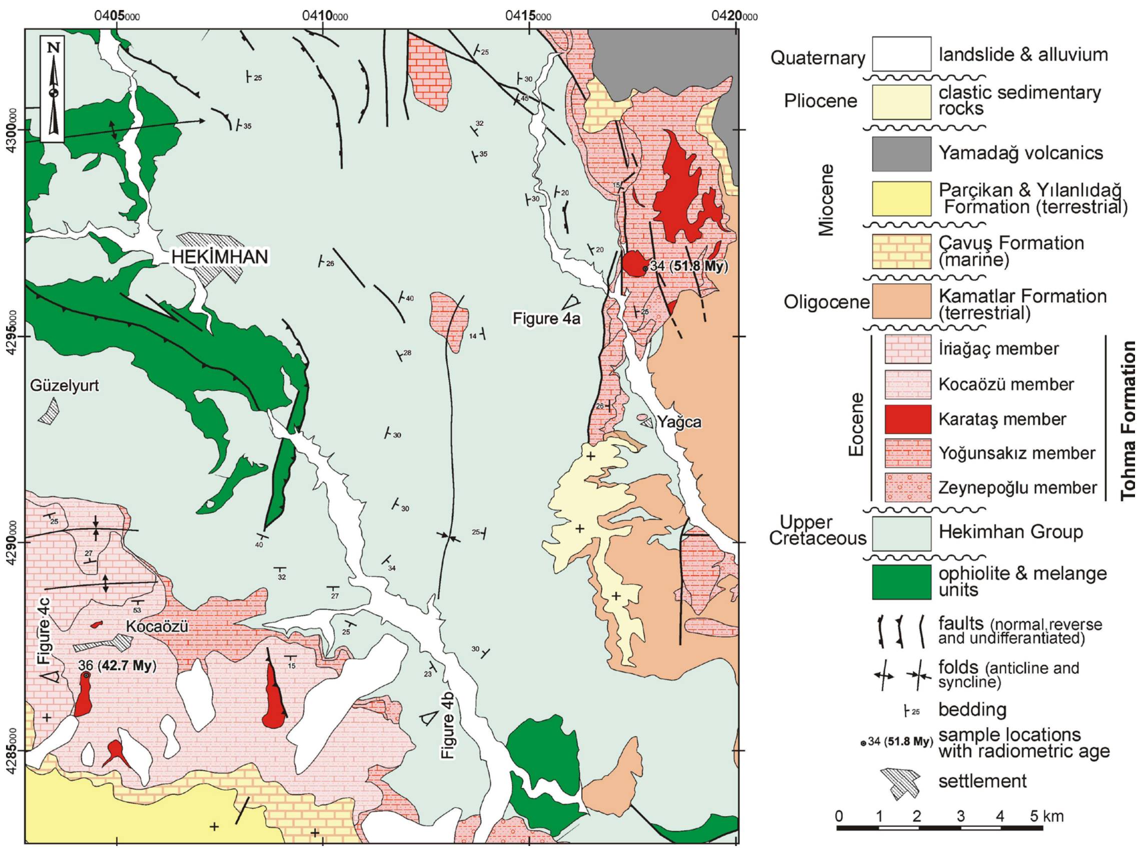

Figure 3. Geological map of the Hekimhan region (produced based on findings in the present study and previous works cited in the text). The sample numbers and obtained ages are shown. Coordinates are in Universal Transverse Mercator (UTM) format (zone: 37S). See Figure 1 for the location.

members (Örçen, 1986). The white marl, claystone, and sandstone alternations around the villages of Kocaözü and Yağca (see Figure 3), which were named the Kocaözü Formation by Bozkaya and Yalçın (1992), correspond to the Çorak and Çivril members. Hence, we compiled the stratigraphic nomenclature proposed in these two studies.

East of Hekimhan, nummulites-bearing reddish pebblestones and sandstones (Zeynepoğlu member; Örçen, 1986) of the Tohma Formation unconformably overlie the latest Cretaceous evaporites (Figures 3 and 4a). This unit is transitionally overlain by the yellowish to white marl and limestones (Yoğunsakız member; Örçen, 1986). The sedimentary sequence continues with white marl, claystone, and sandstone alternation (the Kocaözü member; Bozkaya and Yalçın, 1992) and finally massive limestones (İriağaç member; Örçen, 1986) at the top (Figures 4a and 4b). The details of the sedimentary units can be found in Örçen (1986), Gürer (1992), Bozkaya and Yalçın (1992), and Booth et al. (2014). Importantly, the Tohma Formation is cut and intercalated with basaltic rocks of the Karataş member, which were located at both the base and the top of the Kocaözü member (Figure 4c). This volcanic unit occurs as a lava dome cutting the Zeynepoğlu and Yoğunsakız members at Karataş Hill, east of Hekimhan, and also interfingering lava flows and pyroclastics in the Kocaözü member at the same locality (Figure 4a). The unit is also seen in the upper parts of the Kocaözü Formation (Figure 4b), revealing that the basaltic volcanism, forming the Karataş member, continued in several pulses. The hyaloporphyric basaltic rocks of the Karataş member are mainly composed of olivine, clinopyroxene, plagioclase, and opaque mineral phenocrysts embedded in a glassy matrix (Figure 5). Some samples show a holocrystalline subophitic texture with the same mineralogical composition (Figure 5b). Based on petrographic, mineralogic, and geochemical features (Table), the samples are classified as subalkaline basalt (Figure 5c).

The Eocene units in the Hekimhan area are unconformably overlain by the Oligocene terrestrial conglomerates of the Kamatlar Formation (Gürer, 1992), Miocene marine limestones of the Çavuş Formation (Örçen, 1986), Miocene terrestrial sediments and volcanics (Parçikan and Yılanlıdağ formations, and Yamadağ volcanics; Metin, 2018), and the Pliocene to Recent sedimentary rocks (Figure 3).

3.2. The Gürün–Darende region

The Eocene units exposed around the Gürün and Darende region unconformably overlie the (1) Jurassic to Maastrichtian limestones of the Akdere Sector of the Taurides, (2) Late Cretaceous ophiolitic mélange units, and (3) middle Campanian–Maastrichtian Hekimhan Group and form their common sedimentary cover. Our field studies showed that the Jurassic–Maastrichtian limestones of the Akdere Sector overthrust the ophiolitic mélange and Hekimhan Group, and the tectonic contact is also covered by the Eocene succession (Figure 6), verifying the pre-Eocene tectonic juxtaposition.

The stratigraphy and paleontological ages of the Eocene marine deposits in this region have been studied by Akkuş (1971), Kurtman (1978), Nazik (1993), Gürbüz and Gül (2005), Dinçer and Avşar (2012), and Booth et al. (2013). Most of these studies used the unit names introduced by Akkuş (1971), who described five sedimentary formations (Korgan Tepe, Yenice, Asartepe, Balaban, and Darende formations) and one volcanic unit (Karakayalar volcanics; Figure 2). Later, Booth et al. (2013) revised this stratigraphy by including the Karakayalar member in the Korgan Tepe Formation. Metin (2018) has also used the same names for the Darende region, as member names under the Darende Formation. They suggested that the Balaban member is Oligocene in age and unconformably overlies the Darende Formation. In light of these previous works and our new field-based data, the stratigraphy of the Eocene units in the Darende region can be summarized as follows.

In the north of Darende, the Eocene volcanosedimentary succession begins with conglomerates (Korgantepe member; Akkuş, 1971, Figure 6) that unconformably overlie the Jurassic–Late Cretaceous limestones of the Akdere Sector of the Anatolide–Tauride Platform. The Korgantepe member rests unconformably also on the ophiolitic mélange units and Late Cretaceous Hekimhan Group around the village of Hisarcık. The succession continues with marine lithologies including sandstone, mudstone, marl, and limestone (the Yenice member). Remarkably, the Yenice member is intercalated with andesitic volcanogenic rocks (the Karakayalar member). This relation is seen in the Karakayalar area, north of Darende, and in the Hisarcık area further southeast (Figures 6, 7a, and 7b). The andesitic volcanic rocks are predominantly composed of monolithic volcanic breccias and local lava flows, which are made up of amphibole-phyric black andesites (Figure 7c). The andesitic rocks of the unit are uniformly composed of euhedral plagioclase, amphibole, orthopyroxene, and small clinopyroxene phenocrysts embedded in a glass-rich matrix (Figure 5d). These rocks are classified as subalkaline andesite based on petrographic and geochemical features (Figure 5c; Table).

The Eocene succession continues with massive limestones with abundant macrofossils (the Asartepe member), and the marls, gypsum, and sandstones at the top (the Balaban member) (Akkuş, 1971; Gürbüz and Gül, 2005; Booth et al., 2013; Figure 6). The field studies reveal that the Asartepe Formation, as well as the Yenice Formation elsewhere, rests unconformably on the basement directly (Figure 6).

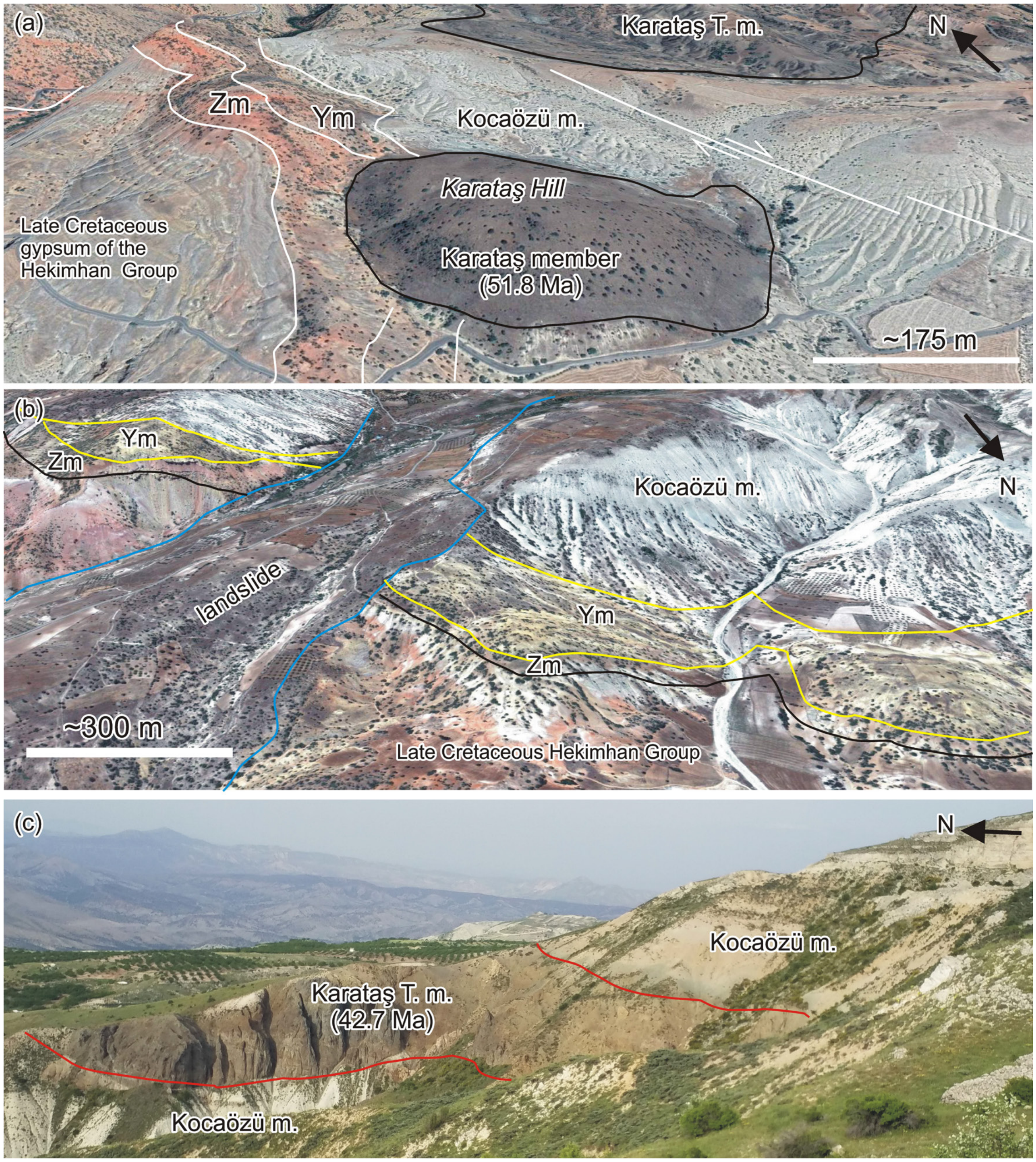

Figure 4. Satellite and field views of the Eocene units in the Hekimhan area (see Figure 3 for the locations). (a) Google Earth view of the Karataş Hill at the eastern part of the Hekimhan Basin showing the stratigraphic relations of the lower parts of the Tohma Formation. (b) Google Earth view of the Kocaözü area showing the stratigraphic relations of the Tohma Formation. (c) Field view of the upper parts of the Tohma Formation showing the basaltic intercalations in the unit. Ym: Yoğunsakız member; Zm: Zeynepoğlu member.

The Eocene units in the study area are unconformably overlain by the Miocene marine limestones of the Çavuş Formation (Örçen, 1986), Miocene volcanic rocks with mainly basaltic compositions (Kepezdağ volcanics; Ekici, 2016), and the Quaternary alluvium (Figure 6).

4. Age data

Three samples from the volcanic rocks (two samples from the Karataş Tepe member and one sample from the Karakayalar member) were dated by the whole rock $^{40}Ar/^{39}Ar$ method at the University of Nevada Las Vegas.

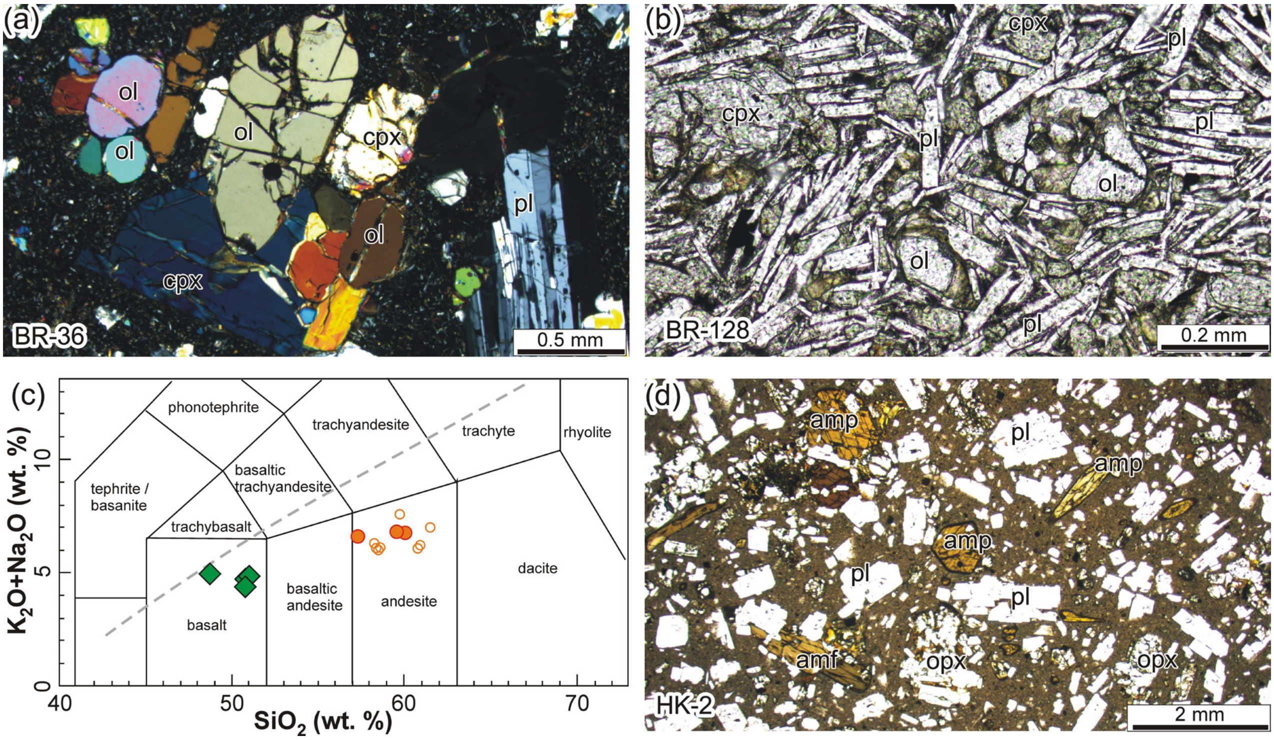

Figure 5. (a, b) Microphotos of the samples BR-36 and BR-128 from the Karataş member. (c) Total alkali (K_2O+Na_2O wt. %) vs. silica (SiO_2 wt. %) (TAS) (Le Bas et al., 1986) classification of the basalt and andesite samples from the Karataş (green diamonds) and Karakayalar members (orange circles; open symbols are from Booth et al., 2013). (d) Microphoto of the samples HK-2 from the Karakayalar member.

Table. Major element compositions (wt. %) of the volcanic rock samples from the Karataş and Karakayalar members.

Sample	BR-34	BR-35	BR-36	BR-128	HK-1	HK-2	HK-3	BR-169
Unit	Karataş				Karakayalar			
SiO_2	48.77	48.99	47.10	47.31	58.02	58.92	58.12	56.10
Al_2O_3	16.22	16.60	19.31	15.85	17.57	17.30	17.41	17.47
Fe_2O_3	7.69	7.48	8.78	7.82	5.20	5.11	5.40	6.31
MgO	10.04	9.68	4.93	7.17	3.85	3.86	3.90	4.39
CaO	8.88	8.95	11.97	11.03	6.95	6.93	6.83	7.59
Na_2O	2.78	2.81	2.86	2.46	3.25	3.47	3.30	3.29
K_2O	0.66	0.74	0.81	0.75	1.80	1.68	1.78	1.67
TiO_2	0.92	0.92	0.85	0.69	0.69	0.67	0.69	0.75
P_2O_5	0.15	0.14	0.14	0.10	0.16	0.15	0.16	0.18
MnO	0.13	0.13	0.15	0.13	0.09	0.09	0.09	0.13
L.O.I.	3.40	3.20	2.80	6.00	2.20	1.50	2.00	1.40

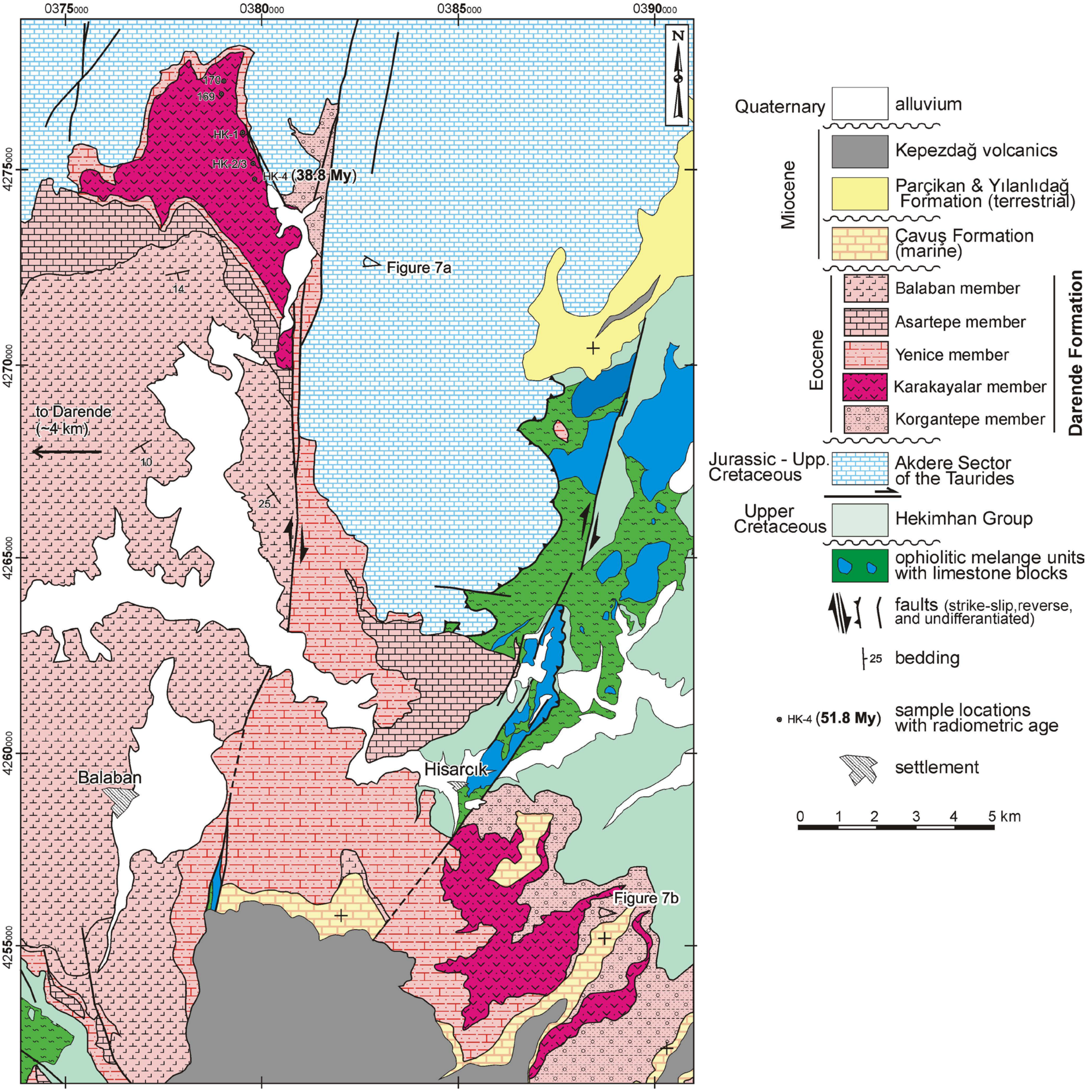

Figure 6. Geological map of the Darende region (produced based on findings in the present study and previous works cited in the text). The sample numbers and obtained ages are shown. Coordinates are in Universal Transverse Mercator (UTM) format (zone: 37S). See Figure 1b for the location.

The basalt samples BR-34 and BR-36 were collected from the lower and upper parts of the Eocene succession in the east and west of Hekimhan, respectively. Sample BR-34 yielded a plateau age of 50.47 ± 0.96 Ma (MSWD = 11.24) and an inverse isochron age of 51.75 ± 0.76 Ma (MSWD = 2.57) during mid-temperature steps (Figure 8a). Sample BR-36 produced a plateau age of 43.65 ± 0.91 Ma (MSWD = 16.97) and an inverse isochron age of 42.66 ± 0.43 Ma (MSWD = 1.75) at mid- to high-temperature steps (Figure 8b). The isochron ages are recommended for these samples. The andesite sample (HK-4) collected from the Karakayalar member of the Darende Formation revealed a plateau age of 38.78 ± 0.38 Ma (MSWD = 4.17) and an inverse isochron age of 37.35 ± 0.72 Ma (MSWD = 1.33) (Figure 8c). The isochron age is more reliable and recommended for the sample.

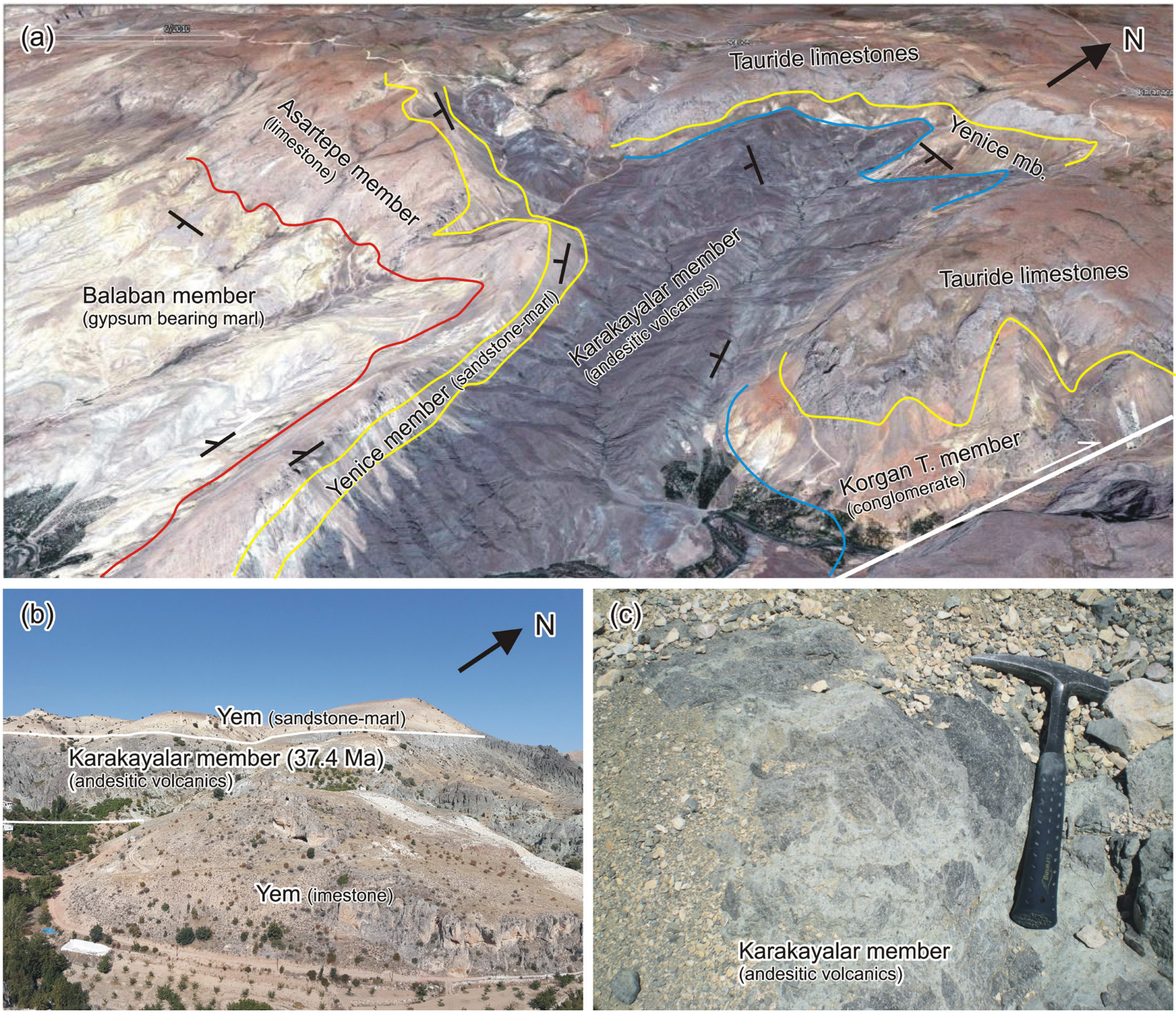

Figure 7. Satellite and field views of the Eocene units in the Darende area (see Figure 6 for the locations). (a) Google Earth view of the Korgan Hill and Karakayalar area. (b) Field view of the Darende Formation showing the andesitic volcanic intercalations (Karakayalar member) in the marls (Yenice member; Yem). (c) Close-up view of the andesitic volcanic breccia of the Karakayalar member.

5. Discussion

5.1. Stratigraphic revision of the Eocene units

Örçen (1986) proposed that the Medik Formation is Paleocene and the Tohma Formation is Lutetian in age. However, the new Ar–Ar age data of 51.75 ± 0.76 Ma obtained from the basalt sample BR-34 collected from the lava dome at the basal parts of the Tohma Formation (i.e. cutting the Zeynepoğlu and Yoğunsakız members; Figure 4a) show that the basal parts of the unit should have been deposited during, at least, the early Ypresian. The lava flows of this volcanic center interfinger with the lower parts of the Kocaözü Formation, indicating that this unit started to deposit during the middle Ypresian. This finding confirms the fossil-based ages proposed by Bozkaya and Yalçın (1992) for the lower parts of the succession (their Kızılyatak Formation, see Figure 2h). Gürer (1992) has also provided a fossil record indicating a Paleocene age for the units exposed around Hekimhan. All these lines of evidence indicate that the deposition of the Tohma Formation in the Hekimhan area began at least during the early Ypresian. In this case, the Medik Formation of Örçen (1986) could have been deposited in the late Paleocene to early Ypresian interval.

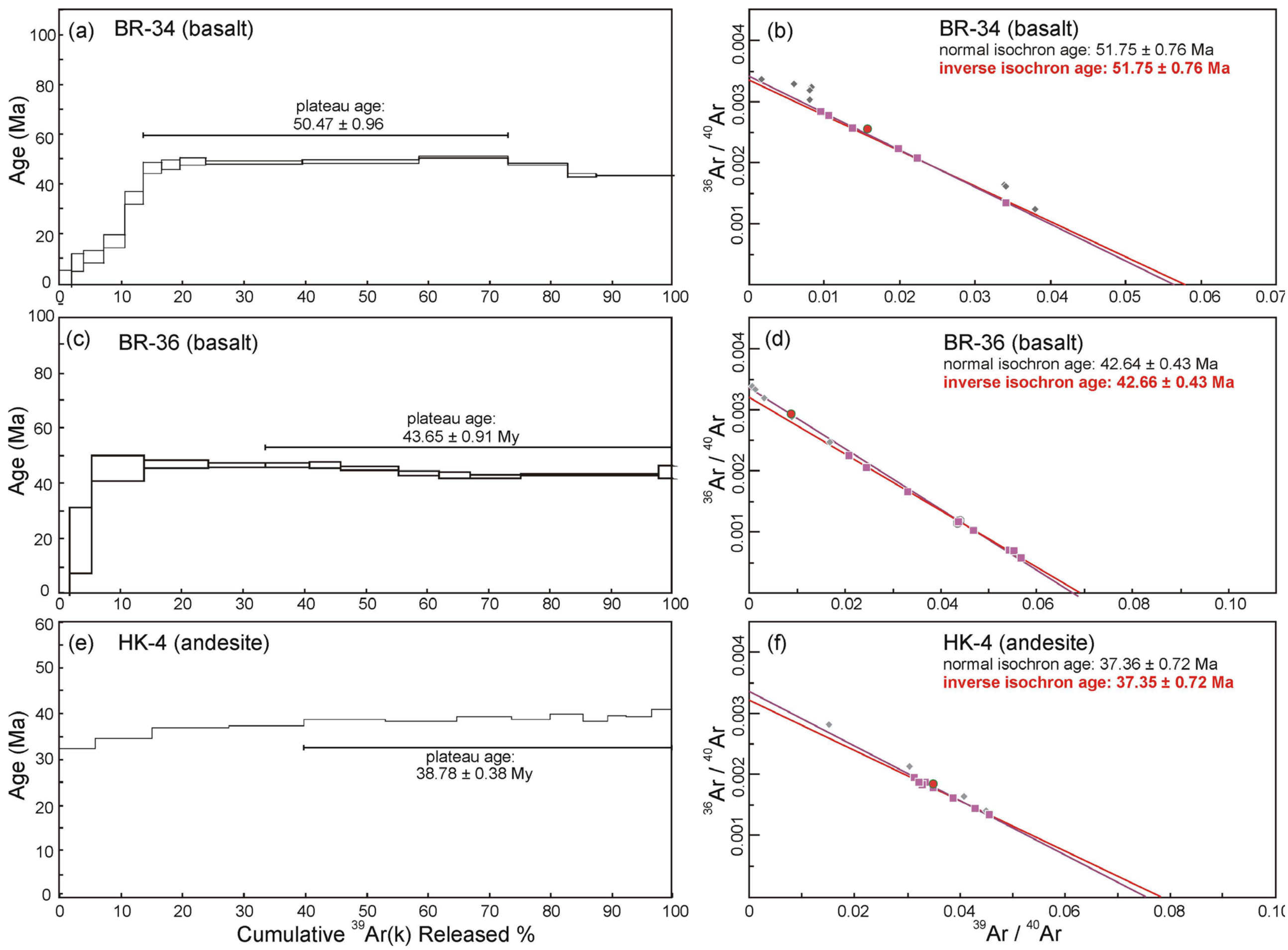

Figure 8. Ar–Ar age spectra of the analyzed magmatic rock samples from the Eocene units in the study area. BR-34 and BR-36 (a–d) are from the Karataş member in the lower and upper parts of the Tohma Formation, respectively; HK-4 (e, f) is from the Karakayalar member of the Darende Formation.

Bozkaya and Yalçın (1992) suggested that the Kocaözü member is of Priabonian age (Figure 2h). However, the sample BR-36 collected from the Karataş basalt member in the upper part of the Tohma Formation (the Kocaözü member; see Figure 4c) yielded an Ar–Ar isochron age of 42.66 ± 0.43 Ma, indicating an upper Lutetian age for the Kocaözü member. Considering the age of sample BR-34, these new data demonstrate that the Kocaözü member was deposited in the middle Ypresian to late Lutetian. Our unpublished radiometric ages of Eocene volcanic rocks exposed at other sites in the Hekimhan region (e.g., andesitic to rhyolitic rocks to the west of Hekimhan) confirm that the magmatic activity associated with the deposition of the Tohma Formation began in the middle Ypresian and continued into the late Lutetian. Based on these observations, the revised Eocene stratigraphy of the Tohma Formation in the Hekimhan area is shown in Figure 9a.

The stratigraphy of the Eocene units in the Darende area was first studied by Akkuş (1971), who suggested that the deposition of these units began in the Lutetian and continued until the Priabonian (see also Booth et al., 2013; Figure 2b). The correlative units exposed in the Gürün area, further northwest, have also been dated as Lutetian based on the fossil record (Kurtman, 1978; Figure 2a). However, the andesite sample HK-4 from the Karakayalar member yielded an Ar–Ar age of 37.35 ± 0.72 Ma, indicating that the Karakayalar volcanism occurred during the late Bartonian. Therefore, this age indicates that the overlying Yenice, Asartepe, and Balaban members of the Darende Formation were deposited after the late Bartonian, although previous studies suggested a Lutetian age for the unit based on the fossil records (Akkuş, 1971; Gürbüz and Gül, 2005; Booth et al., 2013). Metin (2018) suggested that the gypsum-bearing Balaban member is Oligocene in age, and unconformably overlies the other

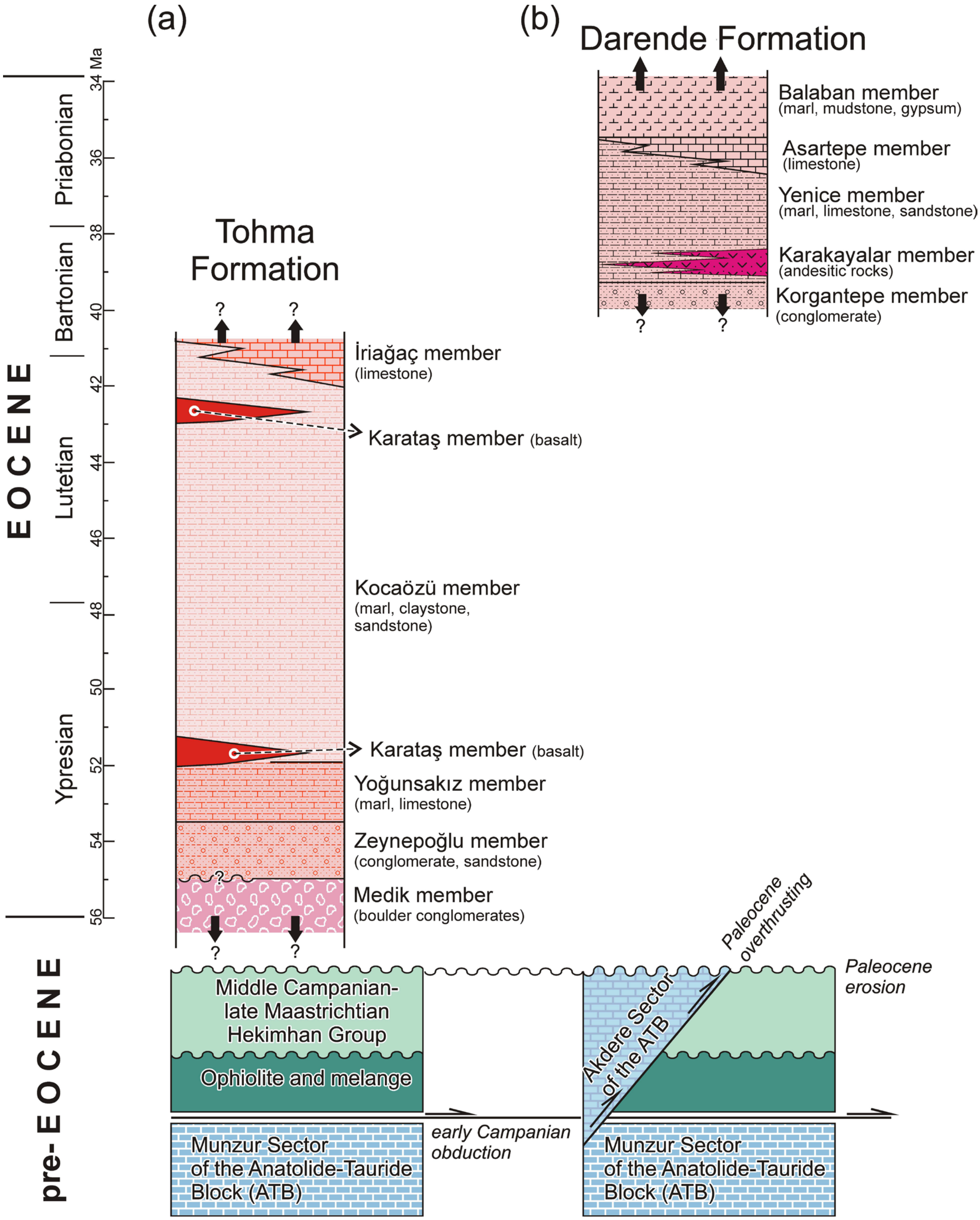

Figure 9. Revised stratigraphy of the Tohma and Darende formations.

Eocene units in the region. However, the field studies show that the unit transitionally overlies the Asartepe member at many locations along the Darende–Kuluncak road sections, as previously suggested by Akkuş (1971) and Booth et al. (2013). Overall, it can be concluded that the Darende Formation is Bartonian–Priabonian in age. However, there is no upper limit to the deposition of the Darende Formation, particularly for the Balaban member, and therefore the age of this unit could be extended into the Oligocene.

Based on the field observations and new radiometric data, the revised stratigraphic sections of the Darende and Tohma formations are shown and compared in Figure 9. However, the stratigraphic relation between the Tohma and Darende formations is still unclear. These units may form either a continuous succession or two distinct sequences and further field studies are required to resolve this issue. Nevertheless, the data show that the shallow marine conditions persisted throughout the Eocene times.

5.2. Tectonic implications

According to Ersoy et al. (2024b), the ATB in Central Eastern Anatolia underwent distinct tectonic events in its Akdere and Munzur sectors during the Late Cretaceous. The middle Campanian–Maastrichtian Hekimhan Group was deposited on the Munzur Sector of the ATB. The Munzur Sector includes the Malatya–Keban metamorphics and the Jurassic to Santonian Munzur limestone, which underwent ophiolite obduction in early–middle Campanian. On the other hand, the Akdere Sector of the ATB is composed of Jurassic to Maastrichtian neritic to pelagic units, which means that while the Hekimhan Basin was opened and filled on the Munzur Sector as a back-arc basin of the Baskil continental arc, the Akdere Sector was still in a platform setting until the Maastrichtian time. Therefore, these two sectors should be separated by a transform fault, at least during the Late Cretaceous. An important point here is that the rock units of the Akdere and Munzur sectors of the ATB are now covered by the Paleocene(?)–Eocene units. Therefore, the depositional ages of the Tohma and Darende formations are crucial for understanding the tectonic evolution of the region, where several tectonostratigraphic units were juxtaposed, exhumed, eroded, and then covered by these common sedimentary cover units. The region is also represented by southward buckled Tauride units, a tectonic structure named the Gürün Curl (see Figure 2; Lefebvre et al., 2013; van Hinsbergen et al., 2020). Ersoy et al. (2024b) suggested that this structure started to form after the latest Cretaceous, probably in the Paleocene. Therefore, the stratigraphy and depositional ages of the Tohma and Darende formations are also crucial for understanding the evolution of the Gürün Curl. Given the problem of whether the Tohma and Darende formations are continuous or two distinct sequences, several alternative models are discussed below.

The field relations show that the Paleocene(?)–Lutetian Tohma Formation unconformably overlies the middle Campanian–Maastrichtian Hekimhan Group of the Munzur Sector (Figure 3), as well as the ophiolite units (the latter relation is seen in the north of the Kuluncak area; Gürer, 1994). However, the Medik Member in the southeast of the Hekimhan area, which represents the base of the Eocene succession, is mainly composed of limestone clasts derived from either the Munzur or Akdere sectors of the ATB. If the Medik member is composed of limestones derived from the Munzur Sector, it can be concluded that this unit was deposited after deep erosion of the Hekimhan Group and the underlying ophiolitic units (i.e. it requires exhumation of the Munzur limestone). However, this model can be ruled out because the basement units of the Medik member in the southeast of Hekimhan are represented by the Hekimhan Group and the ophiolitic rocks (Örçen, 1986; Figure 1b). If, on the other hand, the Medik member is derived from the limestones of the Akdere Sector, it is more reasonable that both sectors of the ATB should have been juxtaposed before the deposition of the Medik member. In this case, the juxtaposition of the tectonostratigraphic units should have occurred in the Paleocene times, since the depositional age of the underlying Hekimhan Group continued until the end of the Maastrichtian.

In the Gürün and Darende regions, the middle Bartonian–Priabonian Darende Group unconformably overlies the Jurassic to Maastrichtian limestones of the Akdere Sector of the ATB, as well as the ophiolitic units and the Hekimhan Group (see Figure 6). The Akdere Sector here tectonically overthrusts the Hekimhan Group (see Ersoy et al., 2024b). Similarly, in the north of Hisarcık (Figure 6), the Jurassic to Maastrichtian limestones of the Akdere Sector tectonically overlie both the ophiolitic units and the middle Campanian–Maastrichtian Hekimhan Group. The tectonic contact is covered by the Darende Formation. These relations indicate that the pre-Eocene units should be tectonically juxtaposed before the deposition of the Darende Formation.

In the light of these observations, two tectonic models can be proposed:

(1) The Tohma and Darende formations represent two different sequences separated by a regional unconformity. In this case, it can be concluded that the Tohma Formation was deposited at least contemporaneously with the juxtaposition of the Akdere and Munzur sectors during the Paleocene–Eocene, and the Darende Formation was deposited after the amalgamation.

(2) More simply and reasonably, the Tohma and Darende formations are continuous sequences without an unconformity, indicating that the tectonic juxtaposition of the Akdere and Munzur sectors and subsequent erosion were completed in the Paleocene. In this case, the Darende Basin was formed in response to transgression that developed in the late Eocene.

As a result, the amalgamation of the Akdere and Munzur sectors, i.e. the tectonic transport of the Akdere Sector onto the Munzur Sector, which represents the initial shaping of the Gürün Curl (Lefebvre et al., 2013; van Hinsbergen et al., 2020; Ersoy et al., 2024b), occurred in the Paleocene and was further shaped by ongoing contractional events in the region.

6. Conclusions

Based on the previous data, as well as the new field-based studies, we propose that the Eocene units in the Hekimhan and Gürün–Darende regions are represented by two distinct successions: the Tohma and Darende formations, respectively. Two basaltic lava flows occur at the lower and upper parts of the Tohma Formation. These volcanic rocks yielded Ar–Ar isochron ages of 51.75 ± 0.76 and 42.66 ± 0.43 Ma, respectively. These data reveal that the unit was deposited in the Ypresian–Lutetian interval. The Darende Formation includes one andesitic volcanic intercalation at the lower part of the sequence. The andesitic volcanics yielded an Ar–Ar isochron age of 37.35 ± 0.72 Ma, revealing that the Darende Formation was deposited at least in the Bartonian–Priabonian interval. The stratigraphic relation between the Tohma and Darende formations remains unclear. These units may form either a continuous succession or two distinct sequences deposited in two different basins and further field studies are required to resolve this issue. The age data from these units indicate that distinct parts of the ATB, the Akdere and Munzur sectors, were juxtaposed and consequently eroded in the Paleocene times. This time, hence, also represents the incipient formation of the Gürün Curl, which is a prominent structural feature of the eastern Taurides in the region.

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