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Volcano Stratigraphic Investigation of the Post-Collisional Middle Eocene Magmatism Around İzmir-Ankara-Erzincan Suture Zone (NE, Turkey)

İzmir-Ankara-Erzincan Sütur Zonu (KD, Türkiye) Boyunca Gelişen Çarpışma Sonrası Orta Eosen Magmatizmasının Volkano-Stratigrafik Olarak Araştırılması

Gönenç Göçmengil*[1], **Zekiye Karacık**[1] , **Ş. Can Genç**[1]

[1] *Geological Engineering Department, Faculty of Mines, Istanbul Technical University, Istanbul, Turkey. 34469*

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Abstract: The obliteration of the Neo-Tethyan Ocean along the northern part of Turkey leads the development of the İzmir-Ankara-Erzincan suture zone (IAESZ). After the suturing stage; extension and magmatism concomitantly developed on the both sides and along the IAESZ during the middle Eocene. During this stage, the areas confining to Almus, Yıldızeli, and Yıldızdağ regions have experienced a severe magmatic activity. Middle Eocene magmatism in Almus and Yıldızeli areas are represented by the volcano-sedimentary successions. Besides, in Yıldızdağ region, gabbroic and dioritic intrusives are the dominant manifestations of magmatism. The volcano-sedimentary successions from Almus and Yıldızeli areas represented by shallow marine sedimentary units at the lower parts and lava flows and volcanoclastic units at the middle to upper parts. Eight volcano-sedimentary sections from Almus and Yıldızeli measured to demonstrate the evolution of the magmatic units developed coevally along the both sides of the suture zone. In both regions; three different volcanic episodes are differentiated based on stratigraphy. First episode includes amphibole-basaltic andesite, andesite, and dacite. Second episode contains basalt and pyroxene-basaltic andesite lavas and third episode represented by trachyte and trachyandesite dikes and stocks. The field data from the all regions demonstrated that middle Eocene magmatic units along the post-collision zone concominantly developed in a wide area and triggering of the magmatism controlled by the region-scale delamination and/or lithospheric removal processes.

Keywords: Izmir-Ankara-Erzincan suture zone, middle Eocene, post-collisional magmatism, Volcano-stratigraphy.

Öz: *Neo-Tetis Okyanusunun, Türkiye'nin kuzey kesiminde yitimi sonucunda İzmir-Ankara-Erzincan sütur zonu (IAESZ) gelişmiştir. Sutürlaşma sürecinin bitmesi sonrasında, IAESZ'nin her iki tarafı ve üzerinde gerilme ve magmatizma eş zamanlı olarak gelişmiştir. Bu dönem boyunca, Almus, Yıldızeli ve Yıldızdağ bölgelerinde yoğun magmatik aktivite gelişmiştir. Almus ve Yıldızeli bölgesindeki Orta Eosen magmatizması volkano-sedimentar birimler ile temsil edilmektedir. Buna karşın Yıldızdağ bölgesindeki gabroyik ve diyoritik kayalar magmatizmanın genel unsurlarıdır. Almus ve Yıldızeli bölgelerindeki volkano-sedimanter kayalar alt kesimlerinde sığ denizel sedimanter kayalar, orta ve üst kesimlerinde ise lav akıntıları ve volkanoklastik birimler ile temsil edilmektedir. Almus ve Yıldızeli bölgelerindeki eş zamanlı olarak gelişen magmatik birimlerin evrimini anlamak adına sekiz adet volkano-sedimanter istif ölçülmüştür. Her iki bölgede, stratigrafiye bağlı olarak üç farklı volkanik dönem ayırtlanmıştır. İlk evre amfibollü bazaltik andezit, andezit ve dasitlerden oluşur. İkinci evre bazalt ve piroksenli bazaltik andezitler ve üçüncü evre ise trakit ve trakiandezit dayk ve stoklarından meydana gelmektedir. Bütün bölgelerden elde edilen arazi verisi sonucunda orta-Eosen magmatik birimlerinin eş zamanlı olarak çarpışma sonrası dönemde geliştiği ve magmatizmayı tetikleyen olayın bölgesel ölçekte bir delaminasyon veya litosferik ayrılma süreçleri ile kontrol edildiği görülmektedir.*

Anahtar Kelimeler: çarpışma sonrası magmatizma, orta Eosen, volkano-stratigrafi, İzmir-Ankara-Erzincan sütur zonu.

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* Correspondence/*Yazışma: gocmengil@itu.edu.tr*

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INTRODUCTION

Continental collisional orogenies juxtaposed different tectonic units with distinct geological characteristics along the narrow contractional zones and developed heterogeneous crustal entities. These heterogeneous areas constitute the major weakness zones in the continental plates that can be ideal places for development of the tectonic activities, post-collisional melt generation, extraction and subsequent magmatism (Turner et al., 1992).

Despite the variable petrological processes related with the magmatism, post-collisional areas also display stratigraphic sequences which documents the building stages of complex volcanic edifices (Western Anatolia: Yılmaz et al., 2000; Dönmez et al., 2004; Karacık, 2006; Gülmez et al., 2013; Karacık et al., 2013; Ersoy et al., 2014; Eastern Anatolia: Keskin et al., 1998; Özdemir et al., 2006; Oyan et al., 2016; Tibet: Chung et al., 2005; Sulu Belt: Fan et al., 2001; NW Iran: Jahangiri, 2007). Furthermore, understanding the development of the style and facies of the post collisional volcanism and coeval intrusive units can give valuable information about the stages of development of the continental crust and evolution of post-subduction tectonic setting.

Anatolian Plate has a complex tectonic evolution which is document the obliteration of the different portions of the Tethyan Ocean, collision of the different tectonic blocks and subsequent syn to post collisional magmatism since the Paleozoic (Şengör and Yılmaz 1981; Yılmaz et al., 1997a; Okay and Tüysüz 1999). The vanishing of the Northern branch of the Neo-Tethyan ocean in Cretaceous and subsequent collision of the Pontides and Anatolide-Tauride micro-continents (together with Central Anatolian Crystalline Complex: (CACC)) in Paleocene give rise to a long and narrow suture zone called İzmir-Ankara-Erzincan (IAESZ) at the northern part of the Anatolian Plate (Şengör and Yılmaz 1981; Okay and Tüysüz 1999) (Figure 1a). Around both sides and along this suture zone, post-collisional Eocene magmatism developed through western to eastern part of the Anatolian Plate and represented by granitoids (Harris et al., 1994; Topuz et al., 2005; Arslan and Aslan 2006; Okay and Satır 2006; Karslı et al., 2007, 2012; Boztuğ., 2008; Karacık et al., 2008; Ustaömer et al., 2009; Altunkaynak et al., 2012; Gülmez et al., 2013; Kaygusuz and Öztürk 2015) gabbroic intrusions (Boztuğ et al., 1998; Temizel et al., 2014; Eyüboğlu et al., 2016) and calc-alkaline, mildly alkaline and shoshonitic volcanic products (Figure 1b; Peccerillo and Taylor 1975; Ercan et al., 1998; Keskin et al., 2008 and references therein; Karslı et al., 2011, Kaygusuz et al., 2011; Aydınçakır and Şen 2013; Arslan et al., 2013 and references therein; Dokuz et al., 2013; Gülmez et al., 2013; Aslan et al., 2014; Aydınçakır, 2014; Sipahi et al., 2014; Yücel et al., 2014; Kasapoğlu et al., 2016; Temizel et al., 2016, Ersoy et al., 2017). Besides, similar units also crop out through the Balkans (Marchev et al., 2004) to Caucasus regions (Sahakyan et al., 2016).

We focus on the middle Eocene aged volcano-sedimentary units from Almus (Tokat), Yıldızeli (Sivas) and intrusive units from the Yıldızdağ (Sivas) areas to understand the development of post-collisional Eocene magmatism along the IAESZ (Figure 1b). In the literature, volcano-sedimentary units along the IAESZ collectively named as Middle Eocene Volcano Sedimentary Belt (MEVSB after Keskin et al., 2008) which are extensively studied in various regions (Keskin et al., 2008 and references therein). A few works have been done to understand the early Cenozoic evolution of these units at the aforementioned regions except geological mapping (Terlemez and Yılmaz 1980; Yılmaz, 1984; Yılmaz et al., 1997b; Mesci and Gürsoy 2002) and scarce geochemical data (Alpaslan, 2000, Koçbulut et al., 2001). Furthermore; there are only three publications trying to deduce crystallization ages of these units. A radiometric dating from Almus area basaltic andesite gives 45.3 ± 3.1 million year ages (M.a.) and 41.8 ± 1.3 M.a. ages by K-Ar method for a paleomagnetic study (Platzman et al., 1994). Also a recent study in westernmost part of the Yıldızeli area postulated sporadic ages between Ar-Ar method and gives 57.2 ± 2 and 45.1±1.3 M.a. (Akçay and Beyazpirinç, 2017). On the other hand, recent publication by Göçmengil et al., (2018) display 40-41 M.a. for the trachytic lavas in Almus and Yıldızeli regions. Hence, there are very few attempts to correlate the stratigraphic evolution of the middle Eocene volcano-sedimentary suites along the southern edge of Pontides (Terlemez and Yılmaz 1980; Yılmaz et al., 1997b; Keskin et al., 2008).

On the other hand, gabbroic units along Yıldızdağ area (Okay, 1955; Yılmaz and Ercan, 1984; Boztuğ et al., 1998) are studied in terms of general geology and geochemical data, however, the main geological feautures of these region also still poorly constrained.

In this study; 1:25000 scale field mapping and volcano-stratigraphic studies have been used on MEVSB units and coeval intrusives to generate: (i) a temporal and lateral stratigraphic variation and correlation of the volcano-sedimentary sequences and intrusives along the Almus-Yıldızdağ and Yıldızeli regions (ii) deduce the broad geological features of the magmatism and (iii) discuss the possible tectono-magmatic processes operated at the early to middle Eocene time interval.

GEOLOGICAL OUTLINE

In this section, main geological features of the basement and cover units of the three different areas will be presented according to our new geological maps along the three different areas. Detailed characteristics of the middle Eocene units in these areas will be explained more extensively at the next chapters.

Almus Area

In Almus (Tokat) area, basement units consist of Paleozoic-Mesozoic Tokat Massif and Bakımlıdağ Complex units (Yılmaz, 1984; Bozkurt and Koçyiğit 1996; Özcan and Aksay 1996; Yılmaz et al., 1997b; Sümengen, 2013a, 2013b). Tokat Massif comprises low grade metamorphic units which are represented by metabasite, marble, serpantinite, mica-schist, amphibolite and scarce blueschist. Bakımlıdağ Complex made up of gabbro, serpentinite and cross cutting dolerite dikes. All these basement units are unconformably overlain by middle Eocene volcano-sedimentary successions (Bozkurt and Koçyiğit 1996; Figure 2 and Figure 5a). Neogene sedimentary units (Gökköy formation; or Almus formation according to definition of Terlemez and Yılmaz 1980) and Quaternary sedimentary successions are the youngest units in the area and unconformably overlain the older units.

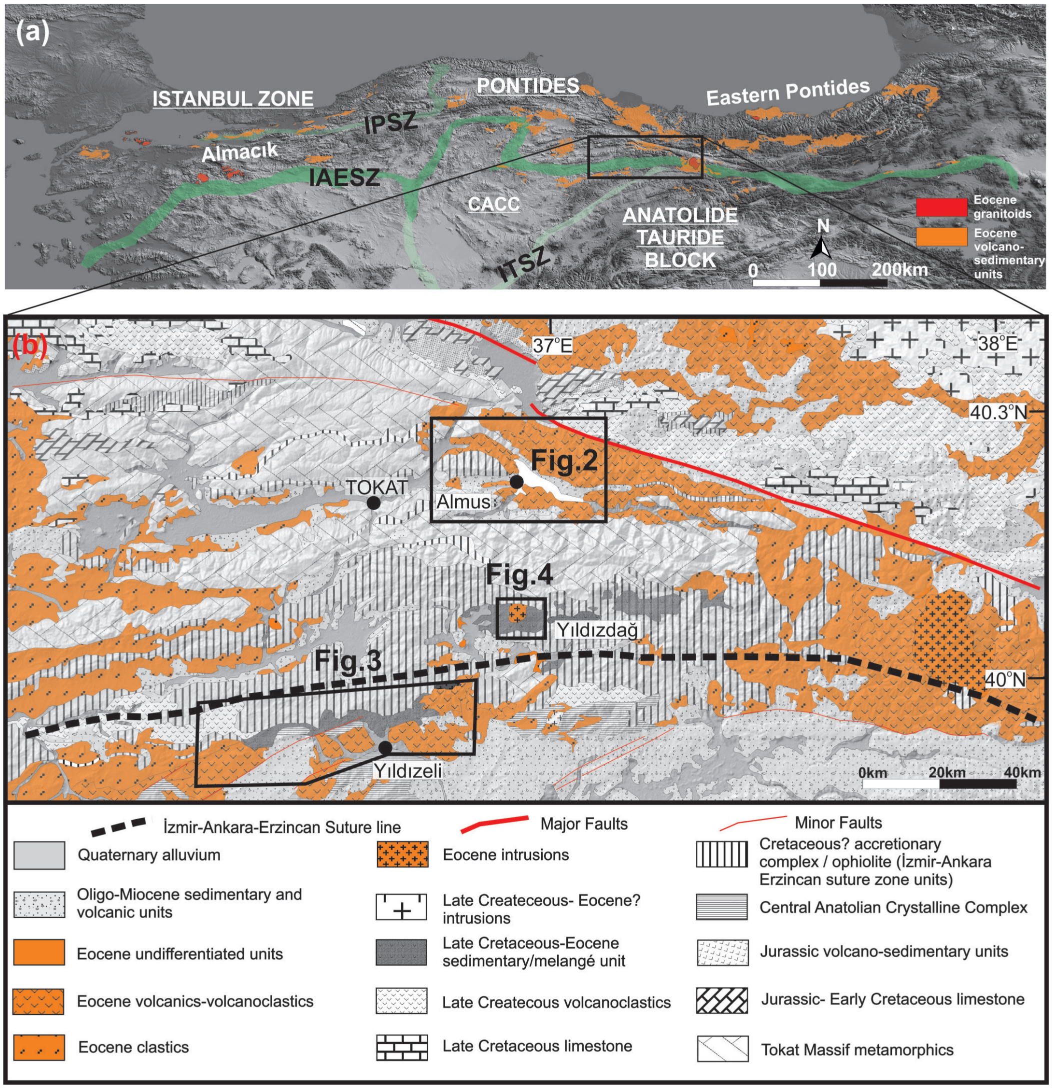

Figure 1. a) Geological map of the Eocene volcanic units in the northern part of the Turkey. (IPSZ: Intra-Pontide Suture Zone, IAESZ : İzmir-Ankara-Erzincan Suture Zone, ITSZ: Intra-Tauride Suture Zone, CACC: Central Anatolian Crystalline Complex). **b)** Simplified geological map of the NE part of the Turkey. Locations of the study areas are marked in rectangular. Both maps are simplified from the MTA (2002) geological map of Turkey.

***Şekil 1. a)** Türkiye'nin kuzey kesimlerinde yer alan Eosen yaşlı volkanik birimlerin dağılımı (IPSZ: İntra-Pontid Sütur Zonu, IAESZ: İzmir-Ankara-Erzincan Sütur Zonu, ITSZ: Intra-Torid Sütur Zonu, OAKK: Orta Anadolu Kristalen Kompleksi). **b)** Türkiye'nin KD kesiminin genelleştirilmiş jeoloji haritası. Her iki harita da MTA (2002) Türkiye Jeoloji haritasından sadeleştirilmiştir.*

Almus dextral strike slip fault zone cut all the units in W-E direction (Bozkurt and Koçyiğit, 1996). The other prominent tectonic feature is a NW-SE oriented reverse and normal faults at the northern part of the Almus town center (Figure 2).

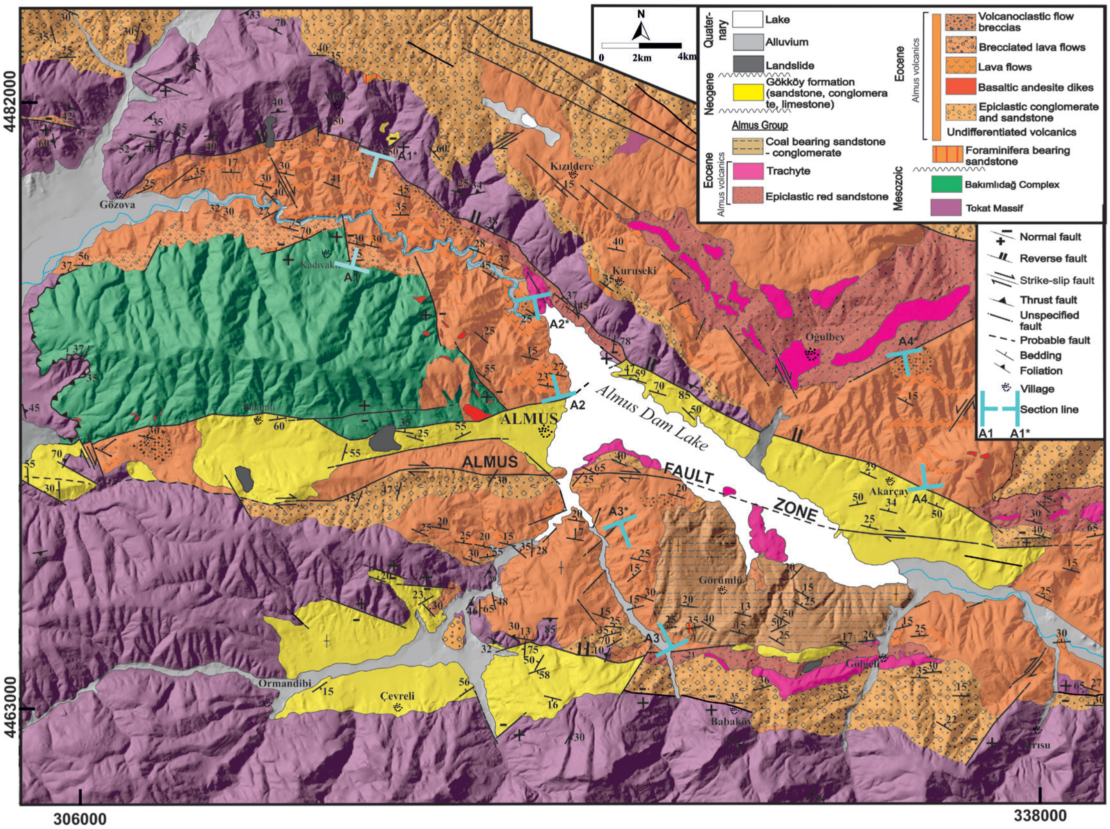

Figure 2. Geological map of the Almus area and surroundings (past mapping efforts in the literature are: Bozkurt and Koçyiğit 1996; Sümengen et al., 2013a; 2013b)

Şekil 2. *Almus bölgesi ve çevresinin jeoloji haritası (Bölgedeki eski haritalama çalışmaları: Bozkurt ve Koçyiğit 1996; Sümengen ve diğ., 2013a; 2013b).*

Yıldızeli Area

In Yıldızeli area, basement units made up of metamorphic and magmatic units of Central Anatolian Crystalline Complex (CACC; Kırşehir Massif); IAESZ accretionary complex units and Cretaceous to Early Eocene Hıdırnalı Group units (Figure 3 and 5b; Yılmaz et al., 1997b).

CACC represented by marble, quartzite, phyllite, mica-schist and scarce garnet amphibolite together with plutonic units. CACC in the area was reported as Akdağ metamorphics (Tatar, 1977; Gökten 1993), Yıldızeli metamorphics (Alpaslan et al., 1996) or Akdağmadeni metamorphic (Yılmaz, 1984). The age of metamorphism in the area is constrained as 68 to 77 M.a. (Alpaslan et al., 1996). Intrusive units in the CACC are represented by Banaz Syenite which is crop out at the easternmost part of the Yıldızeli region (Figure 3). The generation of the Banaz syenite is constrained by Ar-Ar method as 68.93 ± 2.13 M.a. 75.76 ± 1.46 M.a. by mixed biotite and amphibole seperates (our own unpublished data).

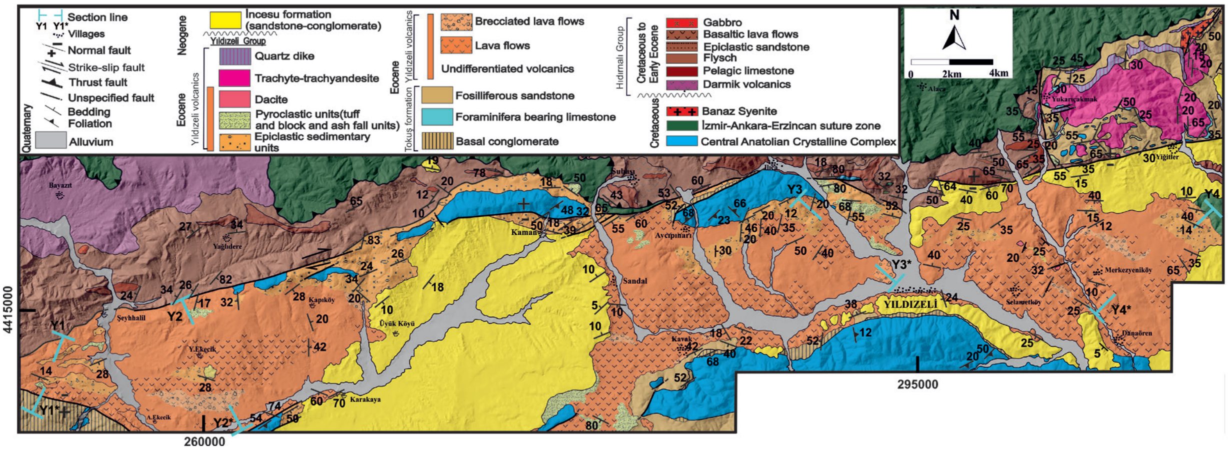

Figure 3. Geological map of the Yıldızeli area and surroundings (past mapping efforts in the literature are: Tatar 1977; Yılmaz 1984; Koçbulut ve Tatar 2001; Mesci and Gürsoy, 2002; Akçay and Büyükpirinç 2017)

Şekil 3. *Yıldızeli bölgesi ve çevresinin jeoloji haritası (bölgedeki eski haritalama çalışmaları: Tatar 1977, Yılmaz 1984; Mesci ve Gürsoy, 2002; Akçay ve Beyazpirinç, 2017).*

Cretaceous IAESZ units are represented by a accretionary complex unit consist of fault bounded blocks of metabasite, gabbro, serpantinite, amphibolite, chert, basalt, gabbro, and dolerite (Tatar, 1977; Yılmaz, 1984; Yılmaz et al, 1997a; Çörtük et al., 2016, Özkan et al., 2017). Hıdırnalı Group made up of highly deformed mixture of sandstone-shale alternation (flysch), epiclastic sandstone, basaltic lava flows and sills and scarce pyroclastic units. In addition to that; in some areas, the sedimentary package turns into a wild flysch which bears the mega blocks of chert bearing, Cretaceous red pelagic limestone (up to 1 km^2 surface exposure) and serpentinite (Tatar, 1977). Some parts of these units previously described as Kılıçlı Olistostrome (Yılmaz 1984; Yılmaz et al., 1995), Boğazköy formation (Yılmaz et al., 1995) and Paleogene Flysch (Tatar, 1977). There are widespread and extensively altered basaltic andesites (Darmik volcanics, Yılmaz et al., 1995) which crops out at the western portion of the Hıdırnalı Group. We interpreted this unit together with the volcanic lithologies of the Hıdırnalı Group considering their rock type and stratigraphic position. Apart from these; in the western part of the Hıdırnalı Group, small scale (<200 meter in diameter) gabbroic/dioritic intrusion cut the sedimentary units near the northern part of the Şeyhhalil village.

The tectonic setting of the Hıdırnalı Group was interpreted as a remnant fore-arc basin which is active throughout the closure and suturing stages of the northern branch of the Neotethys Ocean (Yılmaz et al., 1997b; Keskin et al., 2008).

Similarly to Almus area, middle Eocene volcano-sedimentary units unconformably overlie the older units around the Yıldızeli area. Commonly, the basement and middle Eocene units dissected by NE-SW trending faults (Figure 3). In some areas, older and younger faults are intersecting with each other. Furthermore, IAESZ units thrust over the younger units along the northern part of the Yıldızeli area at the post-Eocene time; (Tatar, 1977, Yılmaz, 1984; Yılmaz et al., 1997b; Mesci and Gürsoy, 2002, Akçay and Beyazpirinç, 2017) however the exact timing of thrusting is not settled. All the older units sealed by Neogene İncesu Formation and Quaternary sedimentary units.

Yıldızdağ Area

IAESZ units which are situated between these two areas host the Hıdırnalı Group units with crosscutting intrusives. The intrusive units are made up of gabbroic intrusion, diorite dikes and stocks, namely Yıldızdağ magmatic complex (Okay, 1955; Yılmaz and Ercan 1984; Boztuğ et al., 1998, Figure 4). The basement units in the area are represented by IAESZ units, CACC and Hıdırnalı Group. All these units display tectonic contacts with each other (Figure 4). Gabbros and dioritic dykes cut the Hıdırnalı Group units with intrusive contacts and produced contact metamorphic aureole. Neogene and younger sedimentary units (alluvium, moraine and talus deposits) seal all the older units. Based on a bulk rock geochemical data, Boztuğ et al., (1998) suggest that they are tholeiitic and calc-alkaline in character and generated in a post-collisional within plate setting.

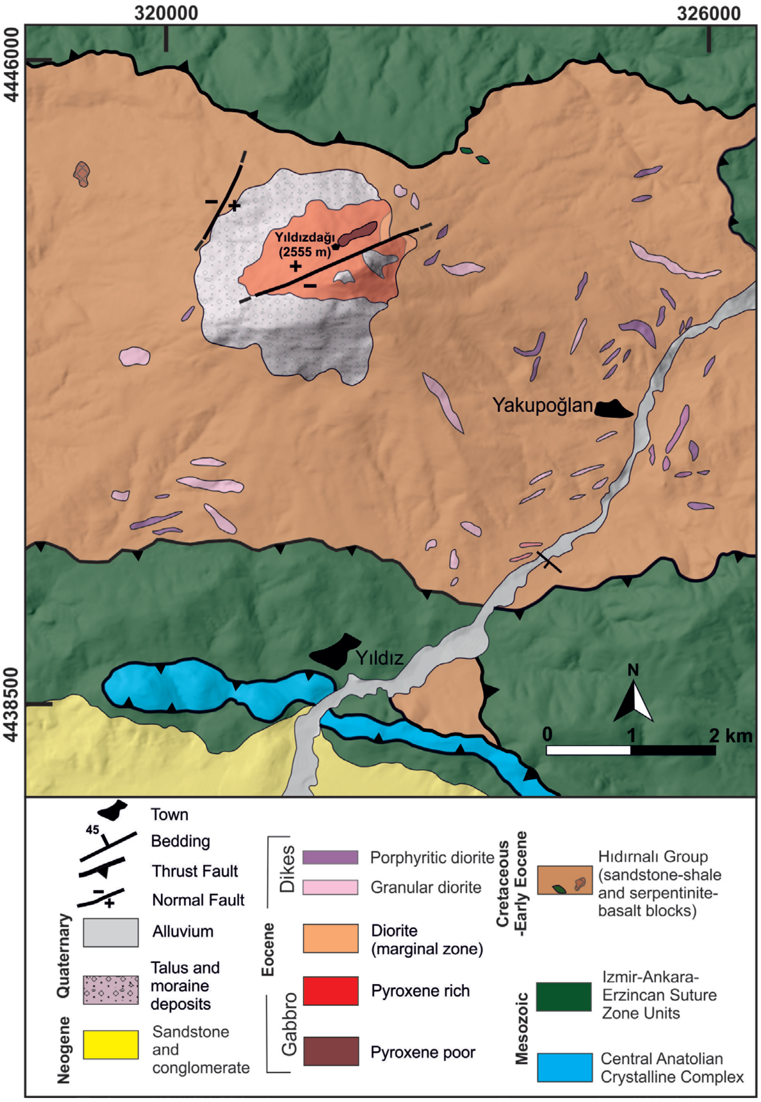

Figure 4. Geological map of Yıldızdağ magmatic complex

Şekil 4. *Yıldızdağ magmatik kompleksinin jeoloji haritası*

STRATIGRAPHY OF MIDDLE EOCENE MAGMATIC UNITS

Middle Eocene magmatic units in the Almus and Yıldızeli regions are represented by lava flows in MEVSB units as mentioned above. Furthermore, intrusive units in Yıldızdağ area consist of gabbroic and dioritic intrusives.

MEVSB units crops out along and both northern and southern part of IAESZ (generally along the Pontides range) and share similar stratigraphic order (Keskin et al. 2008). At the base of the volcano-sedimentary sections there are *foraminifera* bearing sandstone, conglomerate and limestone alternation indicating the shallow marine environment. Development of the marine transgression along the MEVSB is related with the onset of extensional phase along the Pontides at this time interval (Gülmez et al., 2013, Arslan et al., 2013). This facies changed into a sub-aerial type and contains volcanic, pyroclastic and epiclastic units from the beginning of the lowermost part of the sections (Genç and Yılmaz 1997; Keskin et al., 2008; Gülmez et al., 2013). Geochemically; most of the lavas display subduction related signatures with calc-alkaline geochemical character. Also, in some areas; alkaline lava flows exposed through the uppermost part of the sections (Keskin et al., 2008 and literature therein).

In the following sections, field characteristics and stratigraphy of MEVSB units in Almus and Yıldızeli areas will be discussed under the names of Almus Group and Yıldızeli Group respectively. Furthermore the intrusive units in Yıldızdağ area will be presented as Yıldızdağ magmatic complex.

Almus Group

The Almus Group consists of volcano-sedimentary successions and crops out along the Almus Dam Lake and its surroundings (Figure 2). Some parts of this volcano-sedimentary unit have been mapped under the name of Haydaroğlu formation (Yılmaz, 1984), Doğanşar Formation (Terlemez and Yılmaz, 1980), Çökelikkışla formation and Kadıvakfı Limestone (Özcan and Aksay, 1996). To avoid the confusion we collectively named all these units as Almus Group.

Almus Group contains sedimentary and volcanic sequences with different thickness and variations. The volcano-sedimentary units have flat dips through the north and crops out along W-E and NW-SE directions. Sedimentary part contains basal conglomerates, fosilliferous sandstones and coal bearing sandstone with scarce conglomerates (Figure 2 and 5a). Basalt conglomerate is poorly-sorted and generally contain metamorphic (metabasites, phyllites, schists) and volcanic (andesites, basaltic andesites) pebbles and cobbles. The average sizes of the gravels are 7-8 cm in diameter. *Foraminifera* bearing sandstone has limited outcrops at the lower part of the Almus Group (Figure 2). The lava flows and concomitant epiclastic units are also intercalated laterally and vertically with the basal conglomerates from the lowermost part of the stratigraphic sections.

Fosilliferous sandstones are also developed at the lowermost part of the the stratigraphic sections and close to the stratigraphic contacts with the basement units. They contain piles of abundant foramifera and display steep dips due to normal faulting. Coal bearing sandstone and conglomerates crop out at the relatively upper parts of the section, and overlay conformably the Almus volcanics (Figure 5a). This unit dominantly contain medium to thin sandstone layers with thin (2 to 20 cm) coal horizons and rare conglomerate interlayers.

Almus volcanics which are constitute the major part of the Almus Group; contains lava flows, brecciated lavas, volcanoclastic flow breccias, epiclastic units together with the dikes and volcanic plugs. The terminology for describing the volcanic/volcanoclastic rocks used here are after Cas and Wright (1987). Substantial part of the Almus volcanics are made up of thin intercalations of lava flows and brecciated lavas (Figures 6a and 6b). Furthermore, volcanoclastic flow breccias are minor in volume comparing to the other units. Aforementioned units are also randomly intercalated with each other together with epiclastic units along whole range of Almus area. The intact stratigraphic relationships of these units can be traced at the northern and northwestern part of the Almus town center, near the Almus dam lake. In these areas mappable units marked by different symbols but other parts, are grouped as “undifferentiated lava flows” in Figure 2. In order to understand the temporal and lateral variations and volcanological evolution of the area, four different stratigraphic sections have been measured and outlined briefly in the end of this section.

Lava flows are represented by basalt, basaltic andesite, andesite and rare dacite, displaying different colors due to pervasive alteration and often have flow foliation (Figure 6b) together with columnar jointing. The thickness of the lava flows varies between 1m to 5 meters. Basalt is generally aphanitic textured and characterized by the presence of olivine + pyroxene + plagioclase phenocrysts. Basaltic andesite and andesite are the dominant lava types in the Almus volcanic unit. They display a wide range of textures such as porphyritic, microlithic and pilotaxitic. They have amphibole + pyroxene + biotite as mafic, and plagioclase as felsic mineral phase with different modal proportions. For these reasons they classified as *amphibole basaltic andesite* and *pyroxene basaltic andesite* respectively (Figure 6c). Dacites are aphanitic rocks with quartz + biotite + amphibole phenocrysts. The amphibole-bearing basaltic andesites can also found as dikes, sills and rarely plugs. They cut both the basement and the lower part of the Almus Group units (Figure 6d). The sills are common in the basement units and their width generally varies between 50 cm to 10-15 meter. The typical outcrops of these dikes can be traced along the northern part of the Almus Fault zone (Figure 2).

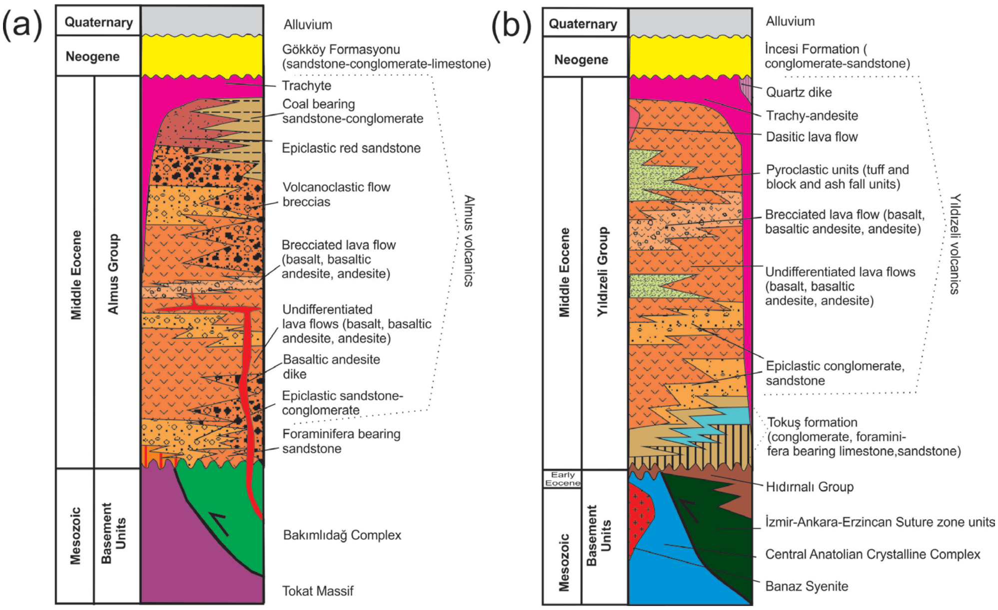

Figure 5. Generalized stratigraphic sections of **a)** Almus and **b)** Yıldızeli regions (modified after Göçmengil et al., 2018)

Şekil 5. *a) Almus ve b) Yıldızeli bölgelerinin genelleştirilmiş stratigrafik kesitleri (Göçmengil ve diğ., 2018'den değiştirilmiştir)*

Brecciated lava flows are corresponding to deformed angular andesite, basaltic andesitic lava blocks which are bounded by the same composition lavas (Figure 7a). Their generation controlled by the fracturing of the lava itself during the propagation of the viscous flowing (i.e. flow fragmentation, autobrecciation). They constitute the major part of the Almus volcanics and found along whole range of Almus Group. The thickness of brecciated lava flows varies from 10-15 cm to 3 meters. The most common blocks are amphibole- and pyroxene-bearing basaltic andesites and andesite with varying sizes (20 cm to 1 meter). The matrix is basaltic andesite in composition and contains rounded, octagonal pyroxenes and plagioclase laths.

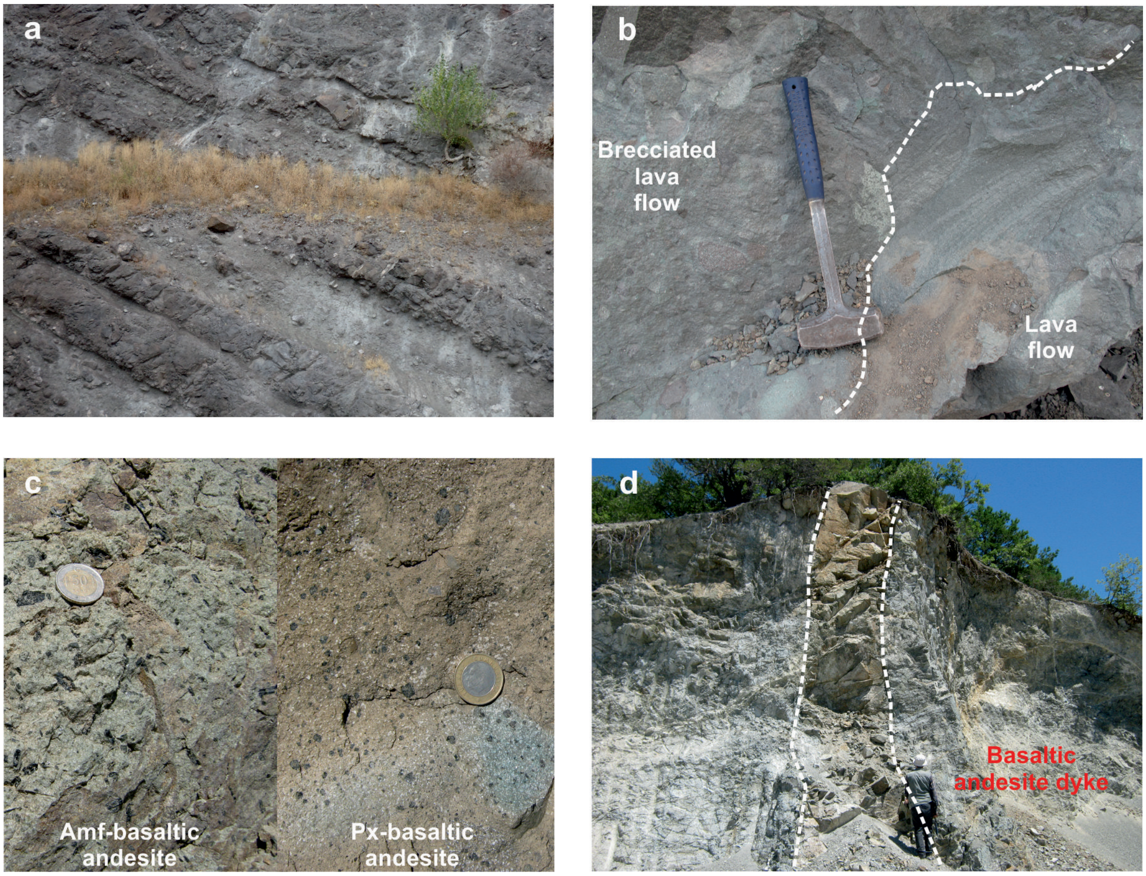

Figure 6. a) Regular stratigraphic order of lava and brecciated lava flow alternation in Almus volcanic. **b)** Magmatic foliation in lava flow and alternation of brecciated lava flow. **c)** General view of the amphibole basaltic andesite, pyroxene basaltic andesite.**d)** Basaltic andesite dike which is cut the Bakımlıdağ Complex unit.

Şekil 6. a) *Almus volkaniklerinde lav ve breşik lav ardalanmasından oluşan düzenli stratigrafik seri.* ***b)*** *Breşik lav akıntısı ve magmatik foliasyon gösteren lav akıntısı ardalanması .* ***c)*** *Amfibollü bazaltik andezit ve piroksenli bazaltik andezitin genel görünümü.* ***d)*** *Bakımlıdağ Kompleksini kesen bazaltik andezit daykı.*

Volcanoclastic flow breccias are corresponding to large - mega fragmented blocks with varying size ranges 10-20 cm to 3-5 meter in diameter (Figure 7b). They are generally crops out at the northern part of the Almus town center. Thicknesses of the volcanoclastic flow breccias can be up to 10-15 meter. In general, they are chaotically distributed, notwithstanding in some areas they show poorly graded-stratified portions. They are moderately heterogeneous in terms of composition by the presence of basalt, basaltic andesite and andesite blocks. The blocks are generally sub-rounded to angular in shape and matrix of the units also derived from the bulldozed fragments of the lava blocks. In some areas, there are sporadic blocks with jigsaw patterns can also be found. This can be related with a limited movement of the volcanic material from their primary position. The characteristics of the given above can be tentatively ascribed to instant movement or the collapse of a volcanic edifice as a debris flow. In the literature similar units with jigsaw patterns and heterogenic epiclastic breccia are termed as debris flow deposits or debris flow deposits spawned from debris avalanches (Bernard et al., 2009 and references therein). The presence of scattered jigsaw cracks and fits together with mixed facies characteristics indicate that the volcanoclastic flow breccias can be interpreted as re-deposited debris avalanches.

Several places along the Almus region are tentavily ascribed to eruption centres since these areas host coarse grained thick volcanoclastic flow breccias deposits. Possible eruption centers situated at the southern and western portion of the Almus town center (Figure 2).

Epiclastic sedimentary units show distinct thickness (cm to 30-35 meter) and shape along the different parts of the stratigraphic sections. They are represented by sandstone and conglomerates and can be found together with concomitantly developed with lavas and brecciated lava flows. Due to extensive alteration, epiclastic units can display different colors such as green, grey and yellow. The majority of minerals in the epiclastic rocks are pyroxene, plagioclase and volcanic fragments derived from the intercalating volcanic units. In addition to that there is specific epiclastic unit which is mapped as “Epiclastic red sandstone”. This unit generally crops out at the uppermost part of the stratigraphic sequences (Figure 5a). It consists of poorly consolidated medium to thick layers of red sandstone and conglomerate horizons.

Trachyte dikes and plugs are widely distributed eastern part of the study area (Göçmengil et al., 2018). They are generally NW-SE/NE-SW oriented at the northern part and W-E oriented at the southern part of the study area. Their widths can be up to 700-800 meter in diameter and they cut the whole volcano-sedimentary package (Figure 7c). They display both aphanitic and porphyritic textures and consist of varied sized phenocrysts of sanidine and minor plagioclase and quartz (Figure 7d).

Volcano-sedimentary development of the Almus Group and particularly Almus volcanics, have been investigated by four different measured stratigraphic sections (MSS) (Figure 8). MSS in Almus are labeled as A1-A1*; A2-A2*; A3-A3*; A4-A4*. Their thickness varies ~70 to ~ 250 meters (Figure 8). Except A1-A1*; all other sections are cut by W-E trending strike slip faults and the base of the sections is disrupted. But in overall, MSS display the similar stratigraphic order. Major part of the four sections has been represented by the alternation of brecciated lava flows and lava flows. Sedimentary units and volcanoclastic flow breccias are the second order units of all sections. The sediment represented by epiclastic units and *foraminifera* bearing sandstone are only represented at the base of the MSS of A1-A1*.

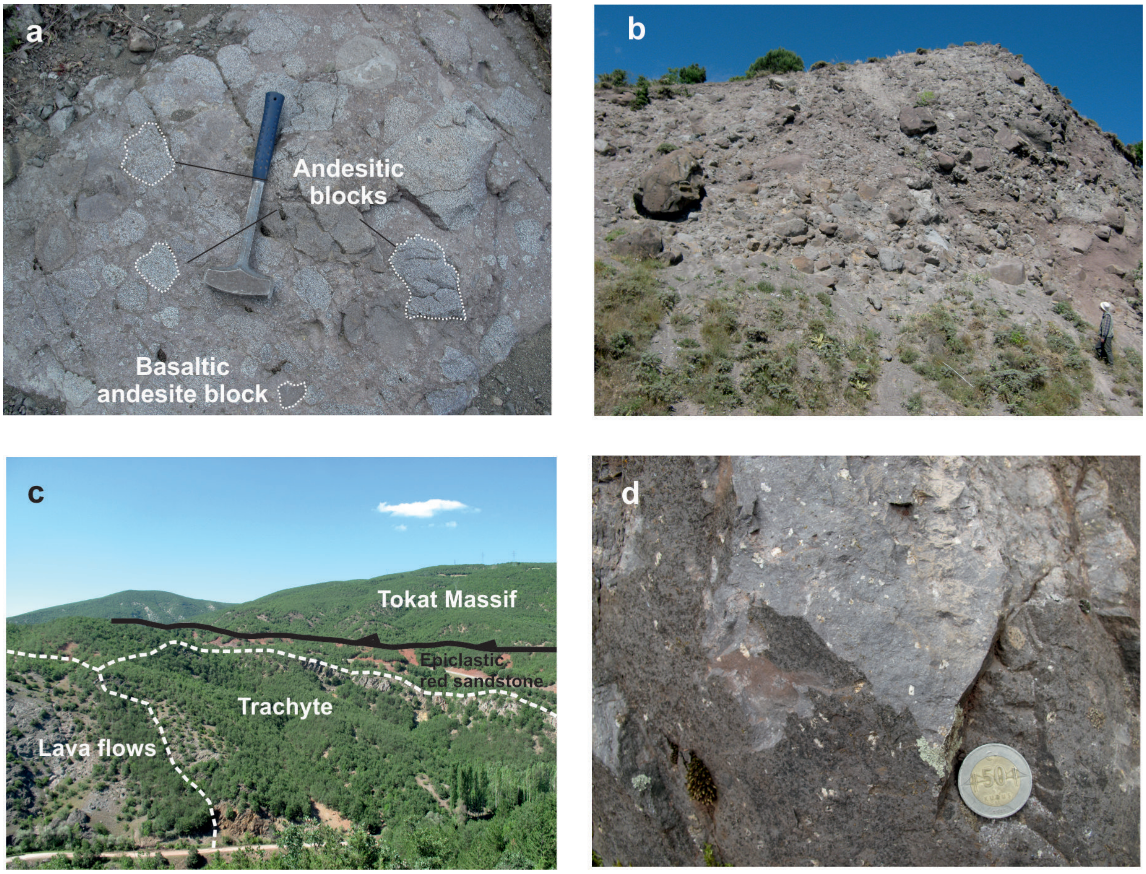

Figure 7. a) Angular blocks of andesite and basaltic andesite in the brecciated lava flows. **b)** Different sized blocks and mega-blocks of the chaotic volcanoclastic flow deposits. **c)** General view of trachyte dike/plug which is cut the epiclastic red sandstone and andesitic lavas. **d)** Small sanidine phenocrysts in the trachyte dike (from Göçmengil et al., 2018).

***Şekil 7. a)** Breşik lav akıntıları içerisinde yer alan köşeli andezit ve bazaltik andezit blokları. **b)** Kaotik volkanoklastik akma birimleri içerisinde yer alan değişik boydaki blok ve mega-bloklar. **c)** Epiklastik kırmızı kumtaşı ve andezitik lavları kesen trakit dayk/tıkaçının genel görünümü. **d)** Trakit daykı içersinde yer alan ufak sanidin fenokristalleri (Göçmengil ve diğ., 2018'den alınmıştır).*

Brecciated and massive lava flows are both sharply and gradually alternated with each other and generally represented by basaltic andesitic (mainly pyroxene, rarely amphibole bearing basaltic andesite) and andesitic lava flows (more amphibole dominated lava flows) except for the A1-A1* section which have not contain any amphibole bearing lava. Through the middle to upper part of the stratigraphic order, olivine-bearing basalts are crops out (Figure 8).

The other prominent feature for the Almus Group is the presence of volcanoclastic flow breccias at the uppermost parts of MSS. Flow breccias are geographically distributed at the NW-SE trending zones in the northern part of the Almus dam lake (Figure 2 and 8).

At the top of the sections, epiclastic red sandstone units are detected in the A1-A1* section and marks the sub-aerial conditions are much considerable during last phase of volcanism. The last product of the volcanism in the area is marked by trachyte which is detected at the section A2-A2*. This unit cut the uppermost part of the section and constitutes the final products of the volcanism.

When we consider the whole MSS along the Almus region, the volcano-sedimentary sequence started with *foraminifera* bearing sandstone and epiclastic sandstone-conglomerate alternation. These units are intercalated with pyroxene-bearing basaltic andesite and brecciated lava flows but nearly all sections (except A1-A1*) amphibole-bearing basaltic andesite which have varying thickness (3-20 meter) are crops out. To the top of stratigraphic sections pyroxene-bearing basaltic andesites and brecciated lava flows are dominated. Olivine basalt layers have thicknesses of 1-2 to 15-20 meter and situated at the middle to upper part of the all sections. Also the uppermost part of the all sections, volcanoclastic flow breccias are dominant which are generally distributed at the northern part of the Almus dam lake. The youngest Eocene units in the area are represented by trachyte dikes and epiclastic red sandstone units.

Yıldızeli Group.

Middle Eocene volcano-sedimentary successions in Yıldızeli area investigated under the different sub-units in the previous studies. Sedimentary rocks are classified as Tokuş Formation (Yılmaz, 1984; İnan and İnan 1999) and the intermediate to basic volcanic rocks are presented as the Kaletepe volcanics and Pazarcık volcanics (Yılmaz et al., 1995; Alpaslan 2000). More silicic members of the volcanic unit are named as Çakmak trachyte and Pamukpınar tuff (Yılmaz et al., 1995; Alpaslan, 1997).

To investigate the middle Eocene sequence more thoroughly, we named the whole MEVSB package in the Yıldızeli areas under Yıldızeli Group. The sedimentary and volcanic parts of the Yıldızeli Group named as Tokuş Formation, Yıldızeli volcanics respectively (Figure 5b).

The Yıldızeli Group is spread over W-E direction around the Yıldızeli town which is bounded by IAESZ units and Hıdırnalı Group from the north and CACC from the southern part (Figure 3). The northern boundary of the Yıldızeli Group is dissected by NE-SW directed strike slip faults and late stage thrust faults (Figure 3). Even though the volcano-sedimentary package of the Yıldızeli Group situated at the southern part IAESZ, they display similar lithological order like Almus Group (Figure 5b).

Tokuş formation constitutes the bottom of the middle Eocene volcano-sedimentary succession. It consists of the basal conglomerates, *foraminifera* bearing sandstones and limestone alternation. Basal conglomerates contain quartzite, marble, syenite pebbles and cobbles where it covers the basement units of CACC; besides same unit comprise chert, metabasite, basalt, gabbro and serpentinite where it covers the IAESZ and/or Hıdırnalı Group. Pebbles and cobbles are poorly sorted; sub-rounded and have sizes varies between 1-2 cm to 25-30 cm.

Intercalation of *foraminifera* bearing sandstones and limestones are medium to thinly beddeded and display grey and yellow colours (Figure 3). Marble olistoliths and olistostromes which were derived from the CACC are commonly found in the Tokuş formation. Presence of these large blocks (up to 1 km in diameter) can be related with tectonic controlled active deposition during the beginning of the middle Eocene.

Yıldızeli volcanics consist of lava flows, brecciated lavas, volcanoclastic flow breccias, pyroclastic and epiclastic units with late stage stocks and dikes. Majority of the volcanic units in the area is represented by alternation of lava flows and brecciated lavas (Figure 9a). Pyroclastic rocks (Figure 9b) are distributed in W-E direction and generally situated at the lower to middle part of the general stratigraphic order. On the other hand, epiclastic sedimentary units are randomly intercalated with other volcanic lithologies (Figure 9c). Thinly intercalations of these rocks together with the other volcanic and/or volcanogenic rocks are differentiated as "undifferentiated volcanic units" on the geology map. Volcanological evolution of the Yıldızeli area isinvestigated by four different measured stratigraphic sections which will be discussed in the end of this section.

Yıldızeli lava flows consisting of basalt, basaltic andesite, andesite and dacite. Their thickness varies between 1 to 5 m and in some areas. They display distinct columnar jointing and flow foliation (Figure 9d). In some areas due to interaction with the water rich sedimentary units some portion of the lavas display peperitic textures (Figure 10a). Lavas of the Yıldızeli volcanic unit are mainly formed from the basalt, basaltic andesite, andesite and dacites. Basalts are generally dark grey in colour and consist of olivine + pyroxene + plagioclase phenocrysts. Nearly all olivines are iddingsitized due to the pervasive alteration. Basaltic andesites green and grey in colour, they have pyroxene ± amphibole ± plagioclase phenocrysts and display microlitic and porphyritic textures. Pyroxene phenocrysts are relatively large (up to 0. 5 cm) comparing to the other phenocrysts (generally <0.2 cm). Andesites are yellow and grey and display the same mineralogical compositions with the basaltic andesites, with the exception of its higher amphibole contents. Amphibole phenocrysts dominantly display acicular shapes (Figure 10b). Dacitic lavas display prominent magmatic flow foliation and are comprised of quartz + plagioclase + biotite phenocrysts with hypocrytalline matrix.

Brecciated lava flows display grey, green and violet color. Majority of the blocks are basalt, basaltic andesite and andesite in composition and generally enveloped by altered basaltic andesitic matrix. The size of the blocks varies between 10 cm to 1 meter.

Volcanoclastic flow breccias crop out in limited areas such as the eastern part of the Yıldızeli area. They are generally coarse grained, poorly sorted and contain heterogeneous lithologies of lava block and sedimentary lithic units in chaotic distribution. Blocks of andesite and basaltic andesite have subrounded to sharp contacts and their size is varies between 15-20cm to 3 meter in diameter. Besides sedimentary lithic units which is made up of sandstone, chert, and basaltic clasts and 3-5 cm to 15 cm in diameter. The general characteristics of these units are similar to debris flow units (e.g. Bernard et al., 2009).

Pyroclastic rocks are represented by ash tuff, lapilli tuff and ash-block tuffs (Figure 9b and Figure 10c). Ash tuff and lapilli tuff units are generally situated at the base of the pyroclastic deposits. They consist of mainly ash and lapilli sized juvenile particles, pumices, minerals and a few amount of lithic and accidental fragments (Figure 10c). Their thickness can be up to 5 meter and display well developed mm to cm scale stratification. The colors of the lithologies are yellow, white and grey due to extensive alteration. In some areas cross stratified portions can be detected.

Through the top of the pyroclastic piles, ash-block deposits are advancing (Figure 10c). These deposits composed of matrix of lapilli, ash and pumice together with sub rounded different sized blocks. The thickness of this part is changed from 1 to 4 meter that displays chaotic internal structure. Pumice fragments are reached 3-5 cm in diameter in some layers. Lithic fragments are derived from epiclastic units and lavas and 1-3 cm in average in size. The blocks in pyroclastic units are basaltic andesite in composition and their sizes vary between 15-20 cm in diameter and they can be up to 1.5 meter in some areas.

Depositional characteristics and thin lamination of ash tuff and lapilli tuff deposits represent similarities to pyroclastic fall units.

Besides, lapilli and block sized fragment rich, chaotic layers at the upper part of the pyroclastic piles can be derived from block and ash flow mechanism.

Epiclastic units are generally scarce; however, they can be seen as thin intercalated layers within all volcanic units (Figure 8c). They display different thickness (cm to 5-10 meters), generally thin to medium layered and display yellow, grey and brown in colors. The major part of the epiclastic units are represented by sandstone and conglomerate alternations (Figure 9c). They consist of mafic minerals and volcanic fragments of andesite and basaltic andesite.

The youngest volcanic unit in the Yıldızeli volcanics is represented by trachyte and trachyandesite stocks and lavas which are named as “Latitporfir” (Tatar, 1977); “Yukarıçakmak volcanics” (Yılmaz et al., 1995) and “Çakmak trachyte-porphyr”, (Alpaslan, 1997) in the previous studies. The trachyte and trachyandesitic lavas are only crops out at the eastern part of the study area and covers approximately 15km^2 (Figure 3). These lava flows constitute a dome-like shape and disrupts the original bedding of Tokuş formation. Trachytic and trachyandesitic lava flows are generally grey, purple and violet in color. The trachyandesite stocks in Yıldızeli area show distinct magmatic foliation through the east. Due to high viscosity, the distribution of the trachyandesitic lava flow is not widespread. Besides, there are also sporadic epiclastic sedimentary sandstones (5 cm to 30-40 cm in thickness) within the trachytic flows. Furthermore, different sized and oriented quartz dikes are detected at the northern part of the trachyte-trachyandesite stock (Figure 3). There are also extensive silicification and hematitization within the contact of the trachyte-trachyandesite and carbonate rich units of Tokuş Formation.

Trachyte and trachyandesite lavas display distinct porphyritic and trachytic texture and comprise sanidine + amphibole + biotite ± quartz ± pyroxene phenocrysts. Sanidine phenocrysts can be up to 8 cm and display compositional zoning (Figure 10d). Lobate shaped monzonitic enclaves with varying sizes (5 to 35 cm) are occasionally found within these lavas (Figure 10d).

Four different sections have been measured to understand the volcanological evolution of the middle Eocene sequence in Yıldızeli area, likely to the Almus area. The thickness of the MSS of Yıldızeli varies between 80-150 meters. The sections are comprised brecciated lava flows, epiclastic units, pyroclastic rocks, lava flows and volcanoclastic flow breccias (Figure 11). Major parts of the sections are made up alternation of brecciated lava flows and epiclastic units. The lava flows and pyroclastic units are less voluminous and volcanoclastic flow breccias are scarce. There are also basal conglomerates which are marked by the presence of pebbles and cobbles from the basement units. Basal conglomerates are located at the base of the sections Y3-Y3* and Y4-Y4* and their thickness is less than 5 meter.

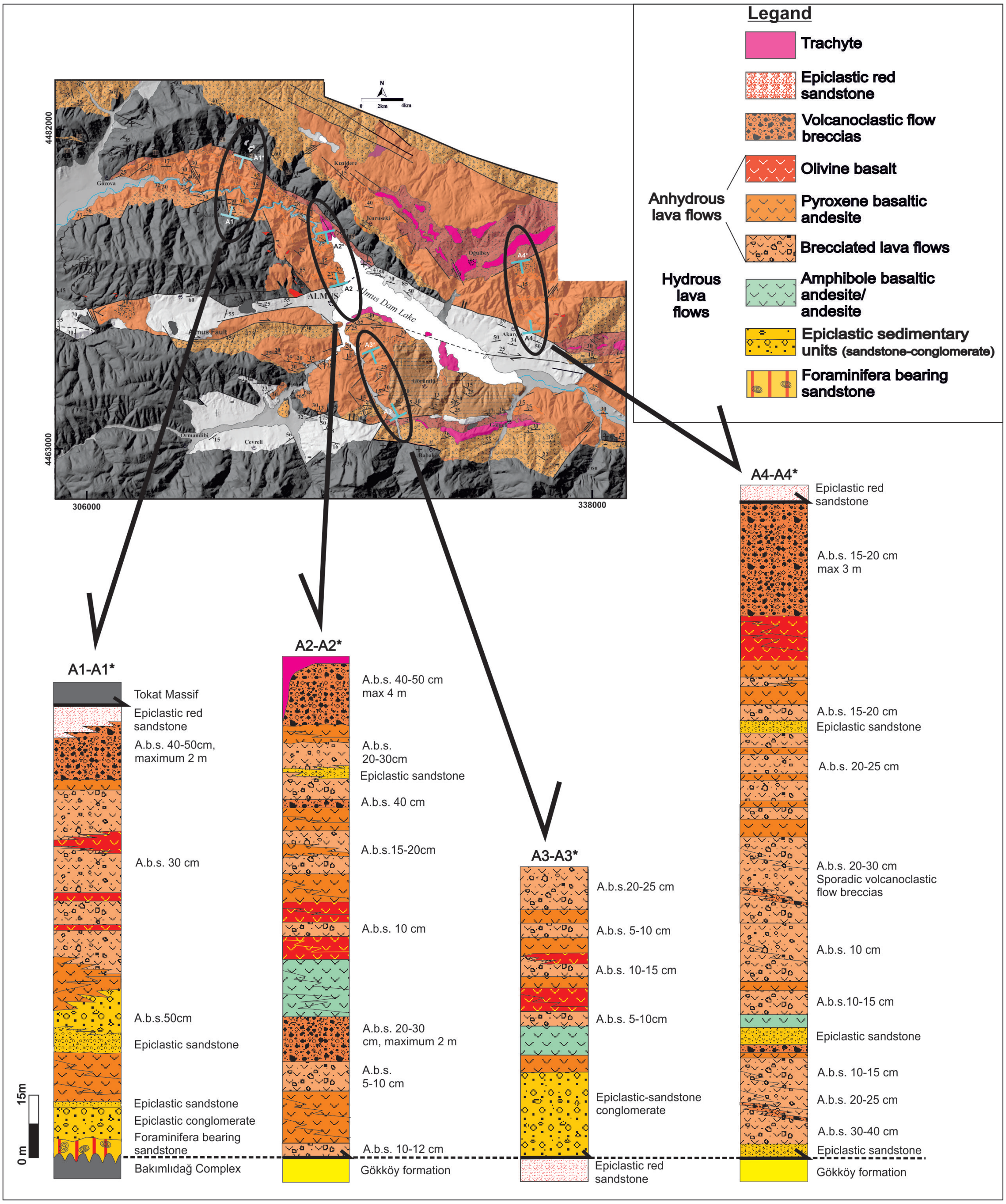

Figure 8. Measured stratigraphic sections along the Almus area (abbreviations: a.b.s: average block size). The evolution of the sections is discussed in the text.

Şekil 8. *Almus bölgesinden ölçülmüş olan stratigrafik kesitler (kısaltmalar: o.b.b: ortalama blok boyutu). Kesitlerin evrimi metin içerisinde tartışılmıştır.*

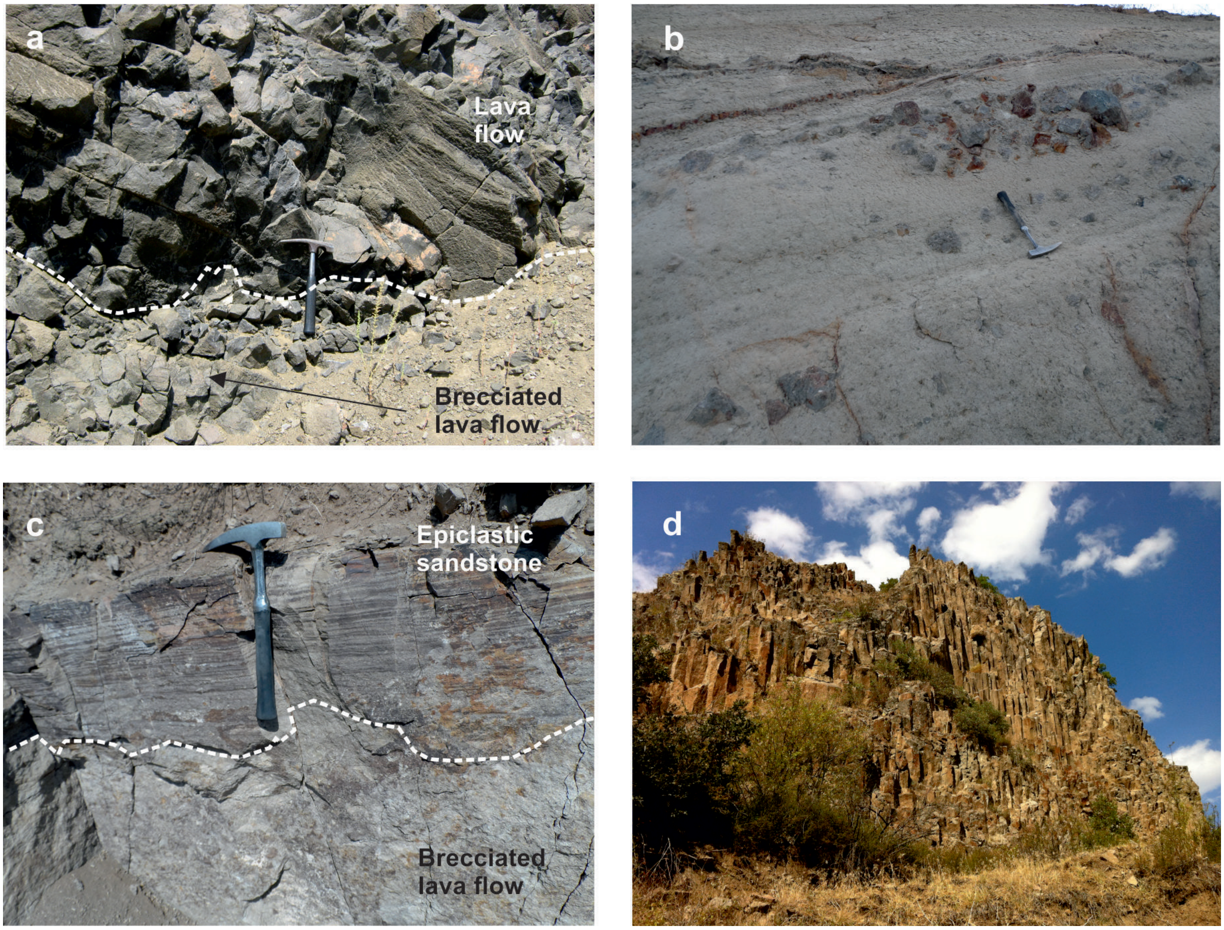

Figure 9. a) Basaltic andesitic lava flows and brecciated lava flows relations **b)** General view of alternation of ash tuff, lapilli tuff and block rich layers. **c)** Thinly laminated epiclastic sedimentary units (sandstone) and brecciated lava flow contact zone. **d)** Distinct columnar jointing in basaltic lava flows.

Şekil 9. a) *Bazaltik andezitik lav ve breşik lav akıntısının arazi ilişkisi.* ***b)*** *Kül tüfü, lapilli tüf ve blokça zengin kesimlerin ardalanmasının genel görünümü.* ***c)*** *İnce katmanlı epiklastik sedimanter birimler (kumtaşı) ve breşik lav akıntısının kontak zonu.* ***d)*** *Bazaltik lav akıntılarında yer alan belirgin sütunsu çatlaklar*

Lower parts of the sections from Yıldızeli region are dominated by the epiclastic sedimentary units together with amphibole basaltic andesite and andesite. At the middle to upper part of the Yıldızeli MSS, pyroclastic units; pyroxene basaltic andesite lavas and related brecciated flows are became more dominant lithologies. The pyroclastic units can be traced along the sections Y1-Y1*; Y2-Y2* and Y3-Y3* and corresponding to explosive stages of volcanism in Yıldızeli region Through the top of the MSS; brecciated lava flows, olivine basalt and pyroxene basaltic andesite are advance and they are constitute the main products at the upper part of the MSS in Yıldızeli area (Figure 11). Epiclastic sedimentary units are intercalated with all other lithologies most commonly in the Y4-Y4* section.

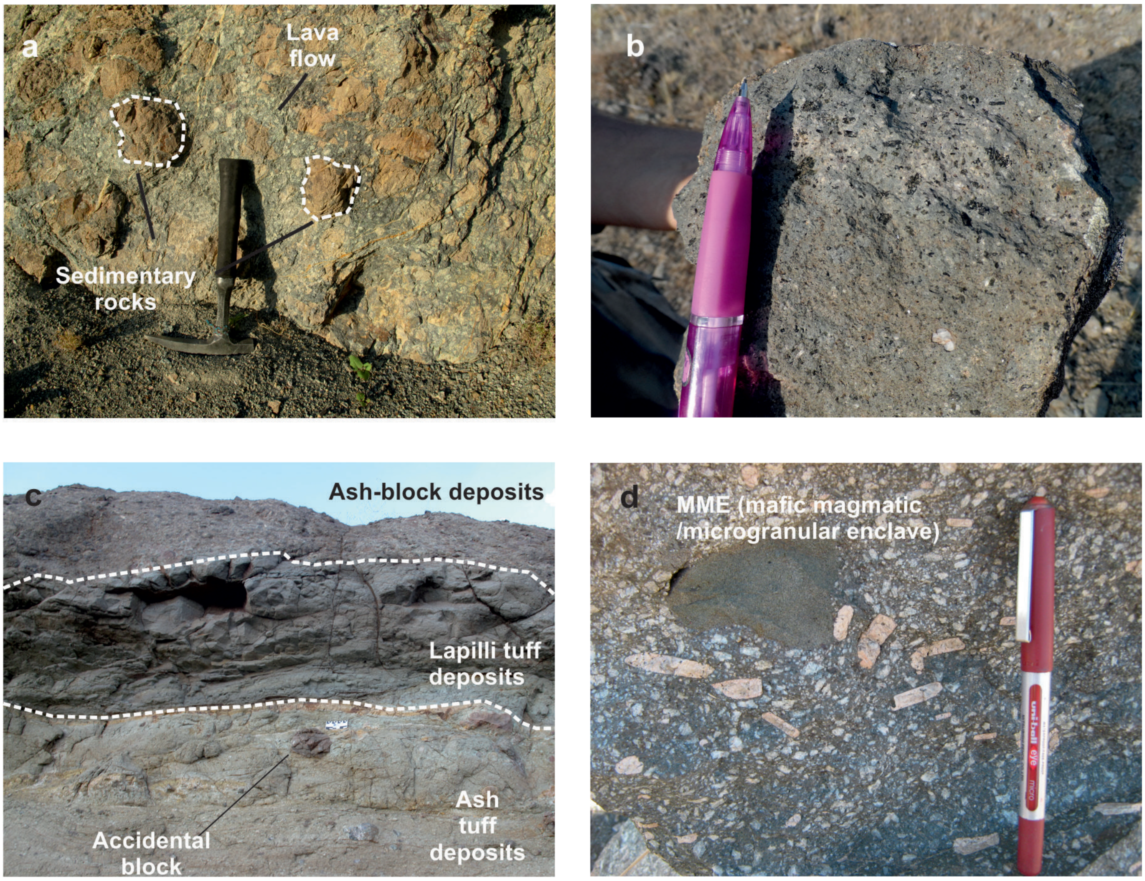

Figure 10. a) Peperitic textures between lava and sedimentary rock interactions. **b)** Acicular shaped amphibole phenocrysts in andesitic lava flows. **c)** General view of the pyroclastic deposits in Yıldızeli region. Ash block deposits become more dominant through the upper part of the pyroclastic pile. **d)** General view of the trachyte-trachyandesite lavas with mega sanidines and monzonitic enclaves (from Göçmengil et al., 2018).

***Şekil 10. a)** Lav ve sedimanter kaya etkileşimiyle gelişen pepetirik dokular. **b)** Andezitik lav akıntılarında yer alan iğnemsi şekilli amfibol fenokristalleri. **c)** Yıldızeli bölgesinde yer alan piroklastik çökellerin genel görünümü. Kül blok çökelleri piroklastik istifin üst kısmına doğru daha baskın hale geliyor. **d)** Mega-sanidin ve monzonitik anklavlar içeren trakit-trakiandezit lavlarının genel görünümü (Göçmengil ve diğ., 2018'den).*

Generation of the middle Eocene sequence along the Yıldızeli area is started with the basal conglomerates and shallow marine sedimentary units; during this stage volcanism also concominantly started and mainly produced amphibole basaltic andesite, andesite and brecciated lava flows which are intercalated with the shallow marine units. Through the middle part pyroclastic deposits and volcanoclastic flow breccias (only in Y4-Y4*) are advance. Upper part of the volcanic succesions mainly represented by pyroxene basaltic andesite, olivine basalt, and accompanying brecciated lava flows. Notwithstanding the youngest volcanic products in the area are trachyte-trachyandesitic lava flows.

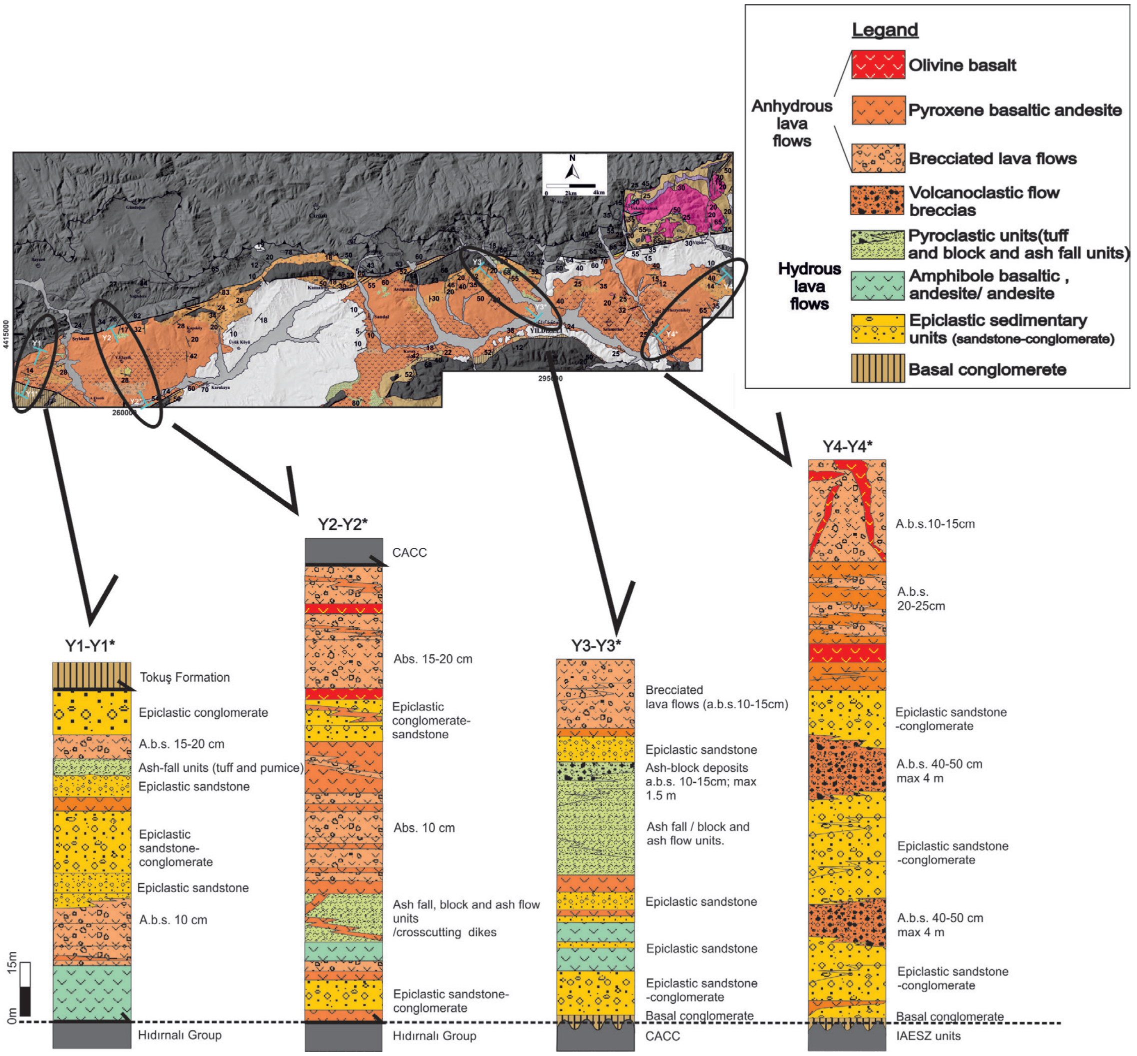

Figure 11. Measured stratigraphic sections along the Yıldızeli area (abbreviations are same as Figure 8). The evolution of the sections is discussed in the text.

Şekil 11. *Yıldızeli bölgesinden ölçülen stratigrafik kesitler (kısatlamalar Şekil 8'deki ile aynıdır). Kesitlerin evrimi metin içinde tartışılmıştır.*

Yıldızdağ magmatic complex

Main bulk of the Yıldızdağ magmatic complex represented by a NE-SW orientated gabbroic intrusion. It covers approximately 2 km^2 surface area and cut the Hıdırnalı Group units. The large part of the contact between two units is sealed by slope waste and moraine deposits (Figure 4). The boundary of the two units and the contact metamorphism can be seen at the eastern portion of the intrusion. Apart from the main body; diorite dikes with varying orientation are also cut the gabbroic main body and the Hıdırnalı Group units as a dyke swarm.

Three different lithologies are identified in gabbroic main body of Yıldızdağ magmatic complex. These are pyroxene rich and pyroxene poor gabbro (anorthositic) and marginal zone diorites. Main part of the intrusion is represented by pyroxene rich gabbro which represents micro-rhtymic lamination (Figure 12a). The second unit, pyroxene poor gabbro, displays a limited outcrop and has more anorthositic character. Both gabbroic lithologies are crosscutting and layered with each other in random order (Figure 12b). Both units are marked by presence of pyroxene + olivine + plagioclase ± amphibole ± biotite minerals in varying order and display ophitic textures. Gabbroic rocks gradually pass into the diorites in the eastern portion of the intrusion (Figure 4). These marginal zone diorites display sub-ophitic texture, and made up of plagioclase + amphibole ± pyroxene minerals (Figure 12c). Apart from these units, there are scarce troctolitic enclaves embedded in the gabbroic main body which are 5-40 cm in diameter and display poligonal textures.

Dioritic dikes cut the both gabbroic main body and the Hıdırnalı Group units (Figure 12d). The width of the dikes dispersed 5-10 cm to 20-25 meter. They display porphyrithic, sub-ophitic and microgranular textures and made up of plagioclase + amphibole ± pyroxene minerals. They display different orientation such as NE-SW; NW-SE and N-S but the main dominant trend is NE-SW.

Yıldızdağ magmatic complex is a zonal magmatic body with a gabbroic center, a dioritic marginal zone and related NE-SW and NW-SE oriented dioritic dikes.

All volcanic lavas and plutonic are names compatible with the whole rock –geochemical features presented in recent studies (Figure 13, Göçmengil et al., 2017, 2018).

Figure 12. a) Micro-rythmic layering in pyroxene rich gabbro. **b)** Pyroxene rich and poor gabbroic unit alternation in main body of Yıldızdağ gabbro. **c)** General view of the marginal zone diorites. **d)** Dioritic dyke in the sandstone units of Hıdırnalı Group

Şekil 12. a) *Piroksence zengin gabroda gözlenen mikro-ritmik katmanlanma.* ***b)*** Yıldızdağ gabrosu ana kütlesi içerisinde yer alan piroksence zengin ve piroksence fakir gabro ardalanması. ***c)*** *Kenar zonu diyoritlerinin genel görünümü.* ***d)*** Hıdırnalı Grubu içerisinde yer alan diyoritik dayk.

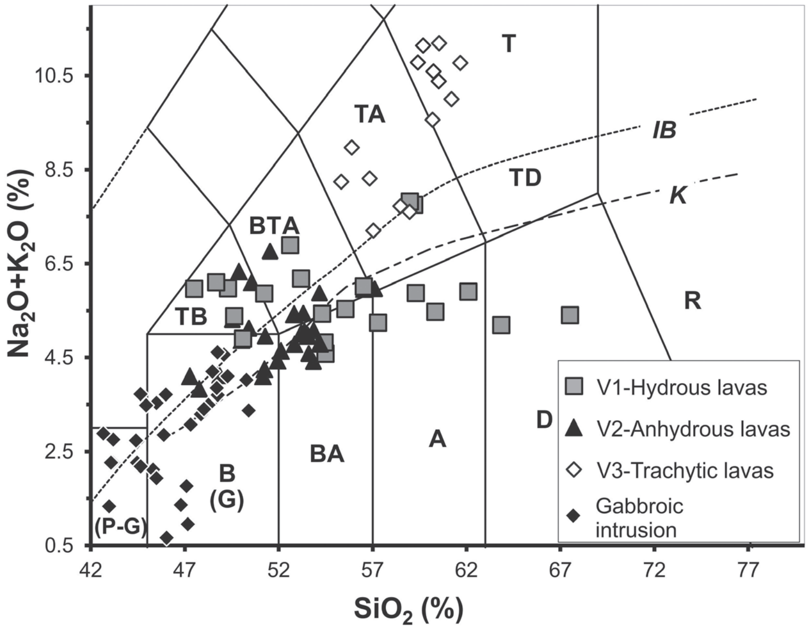

Figure 13. Total alkali vs silica diagram (Le Maitre et al., 1986) for the three stage lavas from Almus and Yıldızeli regions and plutonic rocks of the Yıldızdağ complex. (data taken from Göçmengil et al., 2017, 2018 TB: trachybasalt; BTA: basaltic trachy- andesite; TA: trachy-andesite; T: trachyte; B: basalt; BA: basaltic andesite; A: andesite; D: dacite; R: Rhyolite, G: Gabbro, P: Peridot Gabro; IB: Irvine and Baragar (1971), K: Kuno 1966).

Şekil 13. *Almus ve Yıldızeli bölgelerindeki üç farklı seri lav ve Yıldızdağ kompleksinde yer alan plütonik kayaların toplam alkaliye karşı silika diyagramı (Le Maitre ve diğ., 1986; veriler Göçmengil ve diğ., 2017'den alınmıştır, TB: Trakibazalt, BTA: bazaltik traki-andezit; TA: traki-andezit; T: trakit; B: bazalt; BA: bazaltik andezit; A: andezit; D: dasit; R: riyolit, G: Gabro; P: Peritod Gabro; IB: Irvine ve Baragar (1971), K: Kuno, 1966).*

DISCUSSION

Early Cenozoic tectono-magmatic events along the NE part of IAESZ.

Almus region also did not contain any prominent Paleocene unit similarly to whole range of IAESZ. Whereas in southernmost extreme of the study area (Yıldızeli area) there are poorly known and/or suspected Paleocene aged sedimentary units which are sandwiched inside or tectonicaly overlain by IAESZ units (Figure 1b and 14a). These unitcrops out at the northern part of the Yıldızeli region and have been described in the literature by different names as mentioned above (Paleogene Flysch, Tatar 1977; Kılıçlı Olistostromal Unit, Yılmaz et al., 1995; Hıdırnalı Group, Yılmaz et al., 1997b, Keskin et al., 2008; Boğazköy Formation, Akçay and Beyazpirinç, 2017). Paleocene units corresponding to a trapped-remnant basin which have been fed by accretionary complex units; paleo-forearc basin together with the metamorphic and magmatic units of the CACC during the collisional stages between Pontides and CACC (Keskin et al., 2008; Figure 14a). The abundance of the different mega olistoliths (pelagic limestones, serpentines, recrystallized limestones, marble, phyllite and rare spilitic basalt blocks) surrounded by the sedimentary package of the Hıdırnalı Group suggest that this unit developed during the compressional stage of the collision event. The age of the sedimentary matrix of the Hıdırnalı Group documented as Cretaceous to Early Eocene (Yılmaz et al., 1997b). However, the ages of the basaltic lava flows and differentiation of the sedimentary package of the Hıdırnalı Group still poorly defined and needs further examination.

The first products of Early Cenozoic magmatism are marked by sporadic adakitic intrusive units along the northeastern part of the IAESZ (~ 57 Ma to 48 Ma) and possibly related with the syn-collisional stage along the Anatolide-Tauride and Pontides tectonic blocks (Topuz et al., 2005; Karslı et al., 2011; Eyüboğlu et al., 2013). This phase is interpreted as products of the melting of thickened continental crust which is active at that time interval (Topuz et al., 2011).

At the beginning of the Lutetian, a region wide subsidence together with the change of tectonic contractional to extensional phase takes place along the IAESZ (Keskin et al., 2008 and references therein) which is also dominantly effects Yıldızeli and Almus areas (Figure 13b). The reason for the subsidence and transition from contractional to extensional phase are interpreted as slab-pull down force effect of the subducted oceanic lithosphere of northern Neo-Tethyan oceanic slab under the Pontides (Keskin et al., 2008) or tectonic collapse of the thickened continental crust (Topuz et al., 2011) for the Central and Eastern Pontides regions respectively.

Geological record of the region-wide subsidence, transgression and marine sedimentation along the both sides of the suture zone represented by the deposition of the sedimentary units in Almus Group and Tokuş Formation in the Yıldızeli area (Figure 14b).

This shallow marine sedimentation disrupted by the concomitant magmatism along the both sides and probably along the suture zone itself during the middle Lutetian with the development of volcanic products and intrusive units. First products of the volcanism started at the shallow marine environment as depicted by the presence of the peperitic textures and intercaleted foraminifera bearing sandstones and volcanics. Volcanism started with hydrous and anhydrous mineral-rich lava flows (amphibole-bearing basaltic andesite and andesite/pyroxene-bearing basaltic andesite) brecciated lava flows and coeval volcanoclastics and epiclastics. There are also sporadic pyroclastic units also accompanied the volcanism in Yıldızeli area contrary to Almus which documents the explosive stages also operational at that region. During the course of volcanism, pyroxene-bearing basaltic andesite and olivine basalt lavas are become dominant lithologies in both areas. After the development of the more anhydrous mineral rich volcanic units; volcanism shift towards the more acidic members by the presence of trachyte and trachyandesite dykes, plugs and stocks and these products marks the final manifestations of the volcanism for both regions. This late stage pulse can be accounted for the more silica rich, assimilation and fractional crystallization induced magmatism in the eastern part of the Pontides (Arslan et al., 2013; Yücel et al., 2014; Temizel et al., 2016, Göçmengil et al., 2018).

Additionally, gabbroic intrusions and coevally developed dioritic dykes probably developed in same magmatic phase with the first phase hydrous volcanic activity of the Almus and Yıldızeli region. This interpretation is evidenced by the presence of widespread hydrous minerals (amphibole, biotite) in the gabbroic intrusion and its marginal dioritic zones. Furthermore, sporadic hydrous Eocene gabbroic intrusive are also reported along the other sections of the Eastern Pontides (e.g. Temizel et al., 2014; Eyüboğlu et al., 2016) which can be accounted to the same magmatic phase. On the other hand, Boztuğ et al., (1998) propose that Yıldızdağ gabbroic units derived from %25 partial melting of upper mantle units. However, Yıldızdağ magmatic units are heterogenous in cm to mm scale with cumulate settling and common occurance of the hydrous minerals contradicts with direct melting origin from the upper mantle. Thus, generation of the gabbroic intrusion probably generated by melting of water rich magma source areas which contain amphibole, phlogopite in varying degrees which is suggested for middle Eocene volcanic units by Göçmengil et al., (2018).

Generation of the middle Eocene post-collisional magmatism along the Almus, Yıldızeli and Yıldızdağ areas.

The measured stratigraphic sections demonstrate that, even though the volcanic units developed on different tectonic blocks, they display similar style of volcano-sedimentary evolution. The data presented above can be supportive for all magmatic units decribed above probably governed by the same tectono-magmatic event which is developed along the whole scale of lithospheric mantle below the IAESZ at the Eocene.

Wide spread occurrence of the middle Eocene magmatic units along the both sides of the suture zone and other parts of the Pontides; CACC and even Caucasus suggest that the possibilty of slab break off related magmatism is less feasible to explain the generation of the middle Eocene magmatism along the IAESZ, since the Eocene magmatic units are not confined in a narrow range. Additionally, distinct geochemical features of the middle Eocene volcanic rocks such as alkalinity (Keskin et al., 2008) is not related with the deep sourced asthenospheric melts since these lavas display low Mg# contents; low Ni (ppm) with highly fractionated geochemical patterns (Göçmengil et al., 2017; 2018). Hence recent publication of Göçmengil et al (2018) suggest that the first and second stage volcanic episode of Almus and Yıldızeli regions might be related with melting of metasomatized peridotitic mantle in lithospheric depths.

Regarding the geological data in the literature, given below, and the data presented above, the possible governing agent of Early Cenozoic tectono-magmatic events are more compatible with the development of collision related Rayleigh-Taylor instability changes and subsequent delamination and/or lithospheric removal process related mechanisms.

Rayleigh-Taylor instabilities and delamination and/or lithospheric removal processes can generate the melting of the sub-continental lithospheric mantle (SCLM) and can help to generate the various magmatic products along the major orogenic zones around the world such as Trans-Mexican Belt (Mori et al., 2009); Sierra Nevada, (Elkins-Tanton and Grove, 2003); Andean Arc (Kay and Kay, 1993) and Mediterranean region (Lustrino, 2005).

Tectonic stacking of the Pontides and the CACC at the Paleocene generate continental thickening which gave rise the generation of Early Eocene aged adakitic intrusive rocks (Topuz et al., 2011; Karslı et al., 2011; Eyüboğlu et al., 2013). Ongoing contraction probably lead the development of the density differences in the SCLM which subsequently leading to the development of delamination and/or lithospheric removal related processes is also suggested for the other parts of the Eastern Pontides (Arslan et al., 2013; Temizel et al., 2016).

The tectonic loading and density changes of the sub-continental lithospheric mantle can help the subsiding of the whole region and can be responsible for the generation of the region wide transgression (Figure 14b). Furthermore, coevally developed magmatic pulse in the all three distinct region can be governed by sinking and denuding of the dense parts of the sub-continental lithospheric mantle (Figure 14c) which is exemplified in many Alpine-Himalayan belt post-collisional magmatic regions (Göğüş et al., 2016 and references therein). We tentatively suggest that this mechanism also be suitable for the post-collisional middle Eocene magmatism along the Almus-Yıldızdağ-Yıldızeli range.

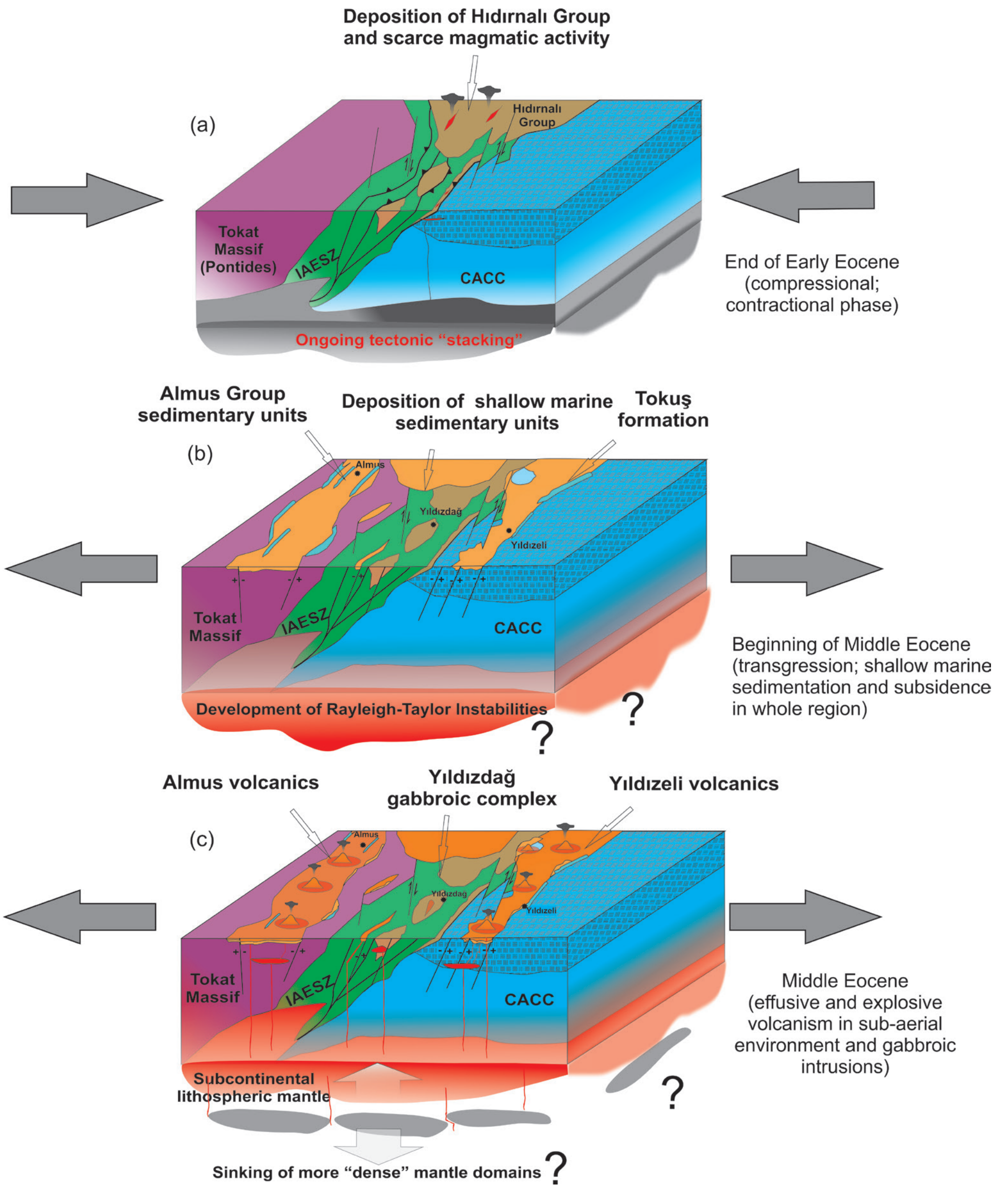

Figure 14. Cartoons which showing the Early Cenozoic tectono-magmatic evolution of the southern part of the Pontides region, with special reference to Almus, Yıldızdağ and Yıldızeli areas (Inspired by schematic cartoons of Keskin et al., 2008). **a)** Early Eoecene tectono-magmatic evolution of the aforementioned regions. This time interval marks a contractional phase in the southern side of Pontides region due to collisional stages. In this time interval trapped remnant basin Hıdırnalı Group is developed. Concomitantly with the sedimentation, sporadic magmatism is also developed. **b)** Regionwide extension and coeval transgression concominantly developped with middle Eocene shallow water sedimentation. Tokuş formation and sedimentary part of the Almus Group are deposited unconformably at the basement units in the southern part of the Pontides. **c)** During the later stages of middle Eocene, magmatism developed along the whole range of IAESZ and volcanic and coevally intrusive units are coevally developed. In Almus area volcanism represented by mainly by effusive products. Besides, in Yıldızeli area both effusive and explosive volcanism is active. In Yıldızdağ region only intrusive (gabbro and diorite) units are developed. The reason of the region-wide concomitant magmatic pulse can be tentatively ascribed to a denuding and sinking sub-continental lithospheric mantle domains after the collisional phase along the IAESZ.

Şekil 14. *Pontid bölgesinin güney kesiminin erken Senozoyik tektono-magmatik evrimini Almus, Yıldızeli ve Yıldızdağ bölgesi özelinde gösteren çizimler (Keskin ve diğ., 2008'deki matik çizimlerden esinlenilmiştir). a) Söz konusu bölgelerin Erken Eosen tektono-magmatik evrimi. Bu dönem çarpışma süreçlerine bağlı olarak Pontidlerin güneyinde sıkışmalı bir evreye karşılık gelmektedir. Bu zaman aralığında sıkışık kalık havza Hıdırnalı Grubu gelişmiştir. Sedimantasyonla eş zamanlı olarak nadir magmatizma da oluşmuştur. b) Bölgesel gerilme, eş zamanlı olarak gelişen transgresyon ve Orta Eosen sığ denizel sedimantasyonu. Tokuş Formasyonu ve Almus Grubu'na ait sedimanter birimler bu dönemde Pontidlerin güney kısmındaki temel birimleri uyumsuz olarak örtmektedir. c) Orta Eosen döneminin ilerlerleyen zamanlarında, magmatizma IAESZ bölgesinin bütün kesimlerinde gözlenmekte olup bu dönemde eş zamanlı olarak volkanik ve intrüzif birimler gelişmiştir. Almus bölgesinde volkanizma genel olarak efüzif ürünlerle temsil edilir. Buna karşın Yıldızeli bölgesinde hem efüzif hem de patlamalı volkanizma aktif olmuştur. Yıldızdağ bölgesinde ise sadece intrüzif birimler gelişmiştir. Bölgesel olarak eş zamanlı oluşan bu magmatik evrenin gelişimi muhtemelen çarpışma sonrasında IAESZ boyunca yer alan kıta altı litosferik manto kesimlerinin soyulması ve batması ile ilişkilendirilebilir.*

CONCLUSIONS

Geological mapping and volcano-stratigraphy along the NE part of the IAESZ demonstrate that the middle Eocene magmatism coevally developped along a vast area. Intrusive part of the magmatism is manifested by hydrous mineral-rich gabbroic intrusions and small-scale dioritic dike swarm in the Yıldızdağ area. Besides, volcanic units from the Almus and Yıldızeli areas are developed in volcano-sedimentary packages which are called Almus Group and Yıldızeli Group respectively. Measured stratigraphic sections along the Almus and Yıldızeli sections demonstrate that, volcanism started at shallow marine environment depicted by alternating fossilliferous sedimentary units with lava flows. Through the middle to upper parts of the sections, explosive and effusive volcanic products together with epiclastic and volcanoclastic units are advance. Measured stratigraphic sections from the both areas demonstrate that the lava flows share the similar stratigraphic order of (i) amphibole-bearing basaltic andesite, andesite dacite at the lower stages; (ii) pyroxene-bearing basaltic andesite, olivine basalt at the middle to upper parts and (iii) trachyte and trachyandesite dikes, plugs and stocks at the top of the sections even though they developed on different tectonic blocks. The re-appraisal of the available geological data from the literature for the magmatism along the Early Cenozoic time is much compatible with a delamination and/or lithospheric removal related processes for the generation of the middle Eocene magmatism along the Almus-Yıldızdağ-Yıldızeli range, however this interpretation highly tentative and should be confirmed by further petrological studies.

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GENİŞLETİLMİŞ ÖZET

Neo-Tetis okyanusunun kuzey kolunun kapanması İzmir-Ankara-Erzincan sütur zonunun (IAESZ) oluşmasına sebep olmuştur. Süturlaşma süreci Pontid tektonik bloğu ile Anatolid Toridler *ve bununla beraber Orta-Anadolu Kristalen Masifi'nin Paleosen döneminde çarpışmasıyla gelişmiştir (Şengör ve Yılmaz 1981). Bu çarpışma dönemi Erken Eosen zamanına kadar sürmekte olup bütün tektonik bloklarda aşınmaya sebep olmuştur (Okay ve Tüysüz 1999). Çarpışma ile eş zamanlı olarak Geç Paleosen-Erken Eosen döneminde, IAESZ'nin orta ve doğu kesiminin güneyinde adakitik magmatizma gelişmiştir (Topuz ve diğ., 2005; Karslı ve diğ., 2011). Bu dönemden sonra gelen orta-Eosen döneminde ise kalk-alkali ve alkali magmatizma yaygınlaşmıştır (Keskin ve diğ., 2008). Almus, Yıldızeli ve Yıldızdağ bölgelerinde bu dönemde yaygın bir magmatizma gelişmiş olup, bu magmatizma ürünlerinin jeolojik ve stratigrafik gelişimi; istiflenmesi, yanal ve düşey değişimleri ayrıntılı olarak ortaya konmamıştır. Orta Eosen magmatizması Almus ve Yıldızeli bölgelerinde volkano-sedimentar istiflerle temsil edilmektedir. Buna karşın Yıldızdağ bölgesinde gabroik ve dioritik sokulumlar magmatizmanın genel ürünleridir. Almus ve Yıldızeli bölgesindeki volcano-sedimanter istifler alt kesimlerinde sığ denizel çökeller; orta ve üst kesimleride ise lav akıntıları ve volkanoklastik birimler ile temsil edilmektedir. Almus ve Yıldızeli bölgelerinden ölçülen sekiz adet volkano-sedimanter istif ile sütur zonunun iki farklı tarafında yer alan, eş zamanda oluşmuş volkanik birimlerin evrimi anlaşılmaya çalışılmıştır. Her iki bölgede üç stratigrafiye bağlı olarak farklı volkanik evre tespit edilmiştir. İlk evre ürünleri amfibollü bazaltik andezit, andezit ve dasitlerden oluşmaktadır. İkinci evre bazaltlar ve piroksenli bazaltik andezitlerden meydana gelmektedir. Üçüncü evre ürünleri ise trakit ve trakiandezit dayk ve stoklarından oluşmaktadır. Çalışılan üç alandan elde edilen veriler stratigrafik olarak volkanizmanın, üzerinde geliştiği tektonik bloktan bağımsız olarak benzer zamanda ve şekilde meydana geldiğini ortaya koymaktadır. Bunun yanı sıra sokulum kayaçları içeren Yıldızdağ bölgesinin de volkanizmanın birinci evresi ile benzer zamanda oluşmuş olabileceği düşünülmektedir. Literatürdeki yeni yapılan yayınlarda bölgedeki ilk evre ve ikinci evre volkanizmanın, metasomatize olmuş peridotitik bir kaynak alanın kısmi ergimesi ile oluşabileceği iddia edilmiştir (Göçmengil ve diğ., 2018). Elde edilen veriler bütün bölgelerde oluşan magmatizmanın benzer bir tektono-magmatik olay sonucunda gerçekleşmiş olabileceğine işaret eder. Bu süreç delaminasyon veya litosferik ayrılma ile gelişmiş olup, kıta altı litosferinin aşınması ile alt kıta kabuğunda ergime ve buna bağlı geniş bir bölgede eş zamanlı magmatizmanın gelişmesi ile açıklanabilir. Bu durum Akdeniz bölgesindeki çarpışma sonrası magmatizmasının da ana sebeplerden biri olarak görülmekte olup (Lustrino, 2005, Göğüş ve diğ., 2016), IAESZ'nin doğu kesiminde gerçekleşen erken Senozoyik magmatizmasını da açıklayabilir.*

ORCID

Gönenç Göçmengil https://orcid.org/0000-0002-1955-8026

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