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Development of an Oblique Subduction Zone—Tectonic Evolution of the Tethys Suture Zone in Southeast Turkey

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Abstract

The Southeast Anatolian orogen, part of the Mediterranean-Himalayan orogenic belt, may be divided into three approximately E-W–trending zones. From south to north, they are the Arabian platform, an imbricated zone, and a nappe zone. The eastern part of the Arabian platform includes a lower Paleozoic to lower Miocene sedimentary sequence and ophiolitic rocks that were obducted on the platform during Late Cretaceous time. Also, in the eastern part of the nappe zone consisting of lower and upper nappe packages, three major Paleocene–Oligocene deformational phases occurred, related to late–early Paleocene–early Eocene, late Lutetian, and late Oligocene nappe emplacements. These amalgamated nappes collided with the Arabian plate and were welded onto it at the latest stage of the orogenic evolution during late early Miocene time. The imbricated zone consists of units that were compressed and sandwiched between the nappes and the Arabian platform.

In the nappe and imbricated zones, various island-arc volcanics and associated units developed related to the northward subduction of Neotethys during the Late Cretaceous to the late Oligocene. The ages of volcanic units decrease from west to east. This reflects oblique subduction of the ocean floor; its remnant presently underlies the northerly nappes.

Introduction

THE SOUTHEAST ANATOLIAN BELT constitutes the western part of the Bitlis-Zagros orogen (Fig. 1A), and is a good example of a collision-related mountain range (Şengör and Kidd, 1979; Şengör and Yilmaz, 1981). It may be divided into three major tectonic zones (Figs. 1B and 2): from south to north, the Arabian platform, an imbricated zone, and a nappe zone (Yilmaz, 1993).

The Arabian platform represents a thick autochthonous sedimentary succession of early Paleozoic to Miocene age (Sungurlu, 1974; Perinçek, 1990; Yilmaz, 1993). The nappe zone and imbricated zone consist essentially of metamorphic and ophiolitic associations (Yilmaz et al., 1993). Within these zones, various Upper Cretaceous to Eocene volcanosedimentary units are present; they include the Yüksekova Group, the Helete volcanics, and the Maden Group (Table 1). The Yüksekova Group and the Helete volcanics are products of island-arc volcanism developed on an ophiolitic basement (Şengör and Yilmaz, 1981; Hempton and Savci, 1982; Tarhan, 1986; Yigitbas, 1989). The former formed during Late Cretaceous to early Eocene time, and the latter developed during middle to late Eocene time (Yilmaz et al., 1993); in contrast, the Maden Group was deposited in a back-arc basin behind (i.e., north of) the Helete volcanic chain during middle Eocene time (Yigitbas, 1989; Yigitbas and Yilmaz, 1996a). However, field observations and geochemical data obtained in the eastern part of the Southeast Anatolian orogenic belt indicate the presence of young island-arc volcanic activity, from late Lutetian to late Oligocene time (Gövelek volcanics; Elmas, 1992, 1994; Table 1). The existence of this volcanic unit necessitates re-evaluation of the evolution of the Southeast Anatolian orogenic belt.

In this paper, field observations derived from different tectonic units of the region are presented first, and then the Cretaceous to Oligocene island-arc volcanic associations are compared. Finally, in light of

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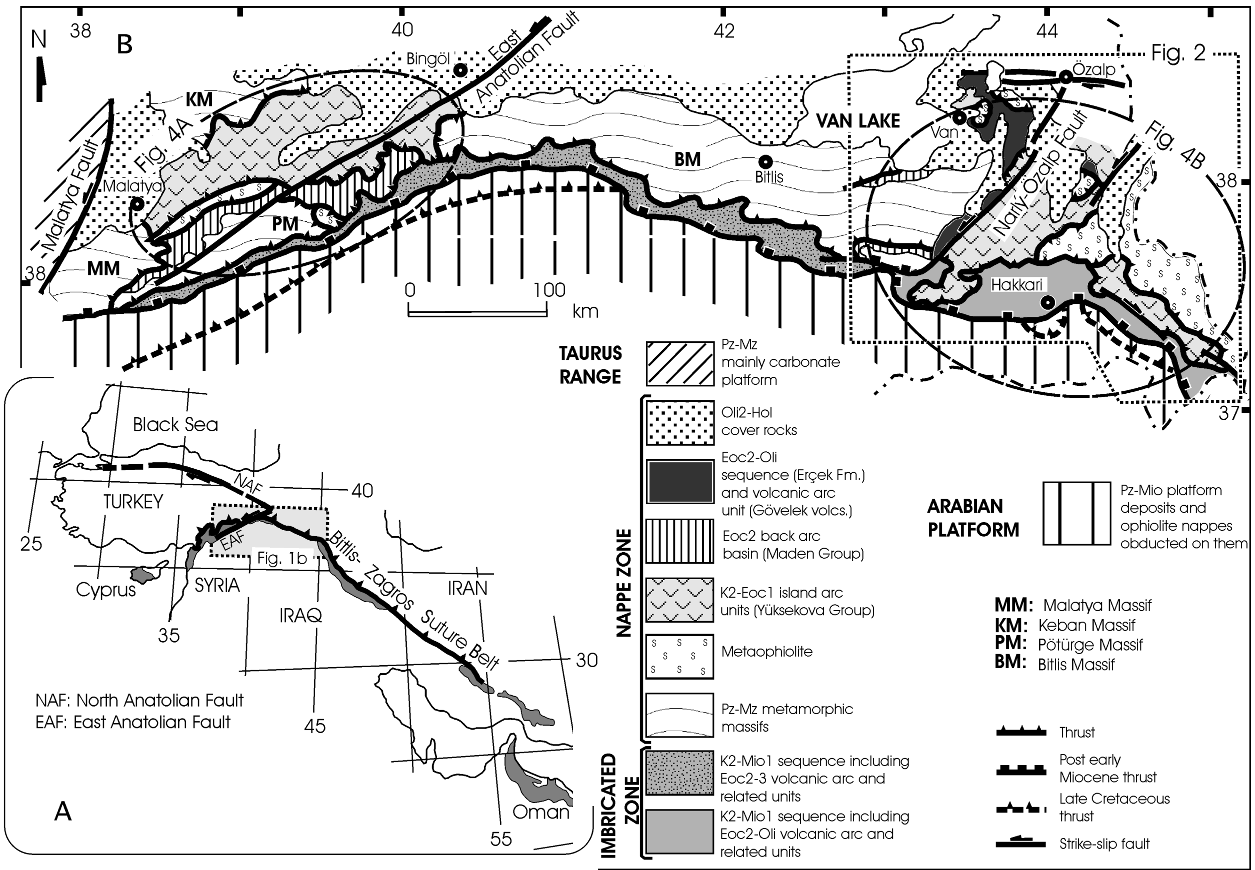

FIG. 1. A. Location map showing the Bitlis-Zagros suture belt. Ophiolite outcrops are shown as grey patches. Adapted from Ricou (1971) and Yilmaz (1993). B. Simplified geologic-tectonic map of the Southeast Anatolian orogenic belt (modified from Perinçek, 1979; Yigitbas and Yilmaz, 1996a).

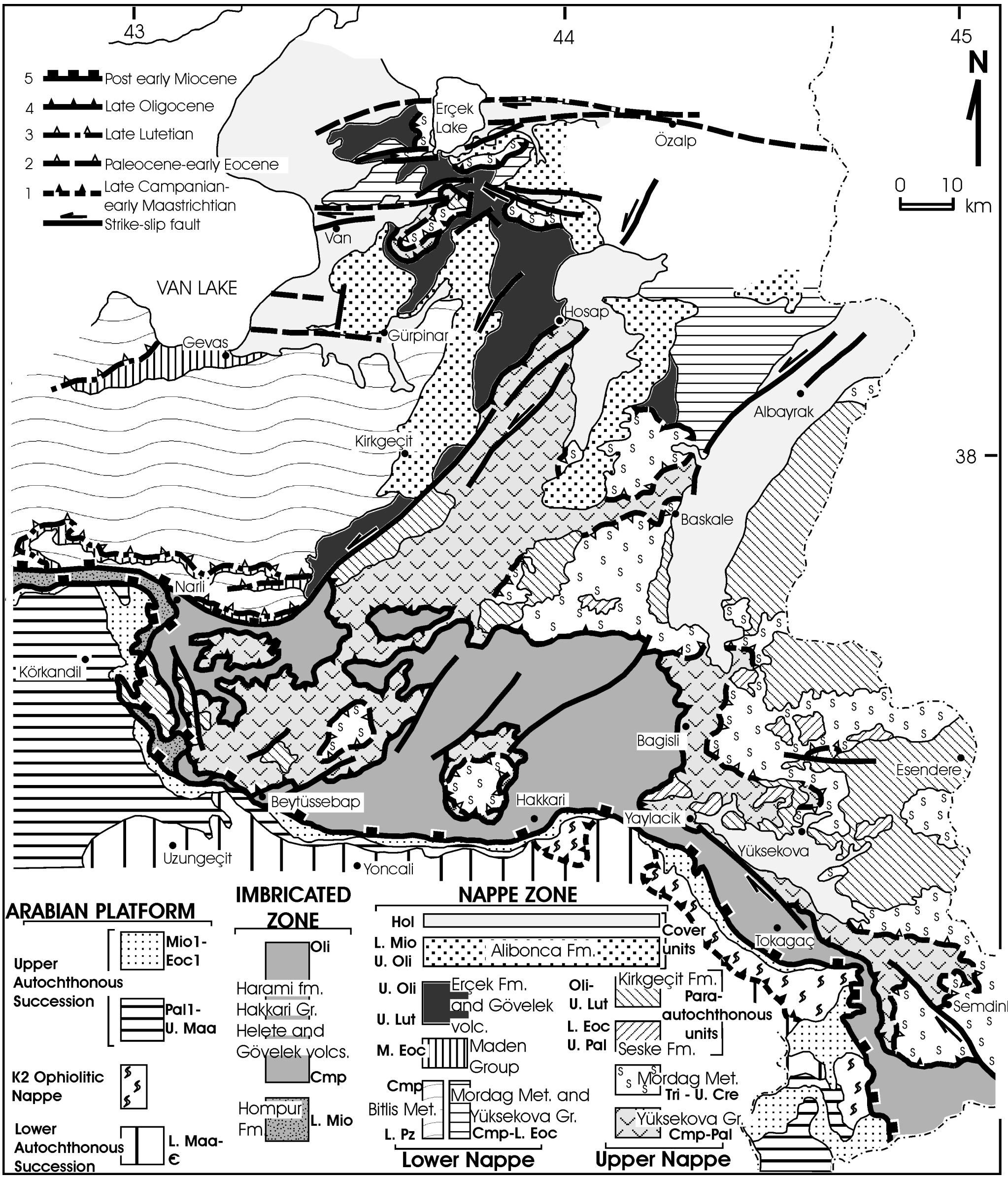

FIG. 2. Simplified geological map of the eastern part of the Southeast Anatolian orogenic belt (the area between Baskale, Körkandil, and Semdinli partially modified after Perinçek, 1990). The location of this map is shown in Figure 1B.

the new data, the geological evolution of the eastern part of the Southeast Anatolian orogenic belt will be reviewed.

Regional Framework

In Southeast Anatolia, the Arabian platform represents a mainly autochthonous sedimentary succession (Fig. 3) that accumulated largely in marine environments from early Paleozoic to Miocene time (Sungurlu, 1974; Yilmaz, 1984; Perinçek, 1990; Perinçek et al., 1991). In the western part of Southeast Anatolia, several ophiolite nappes were emplaced onto the platform during the Late Cretaceous and Eocene periods (Perinçek, 1979; Yigitbas

TABLE 1. Characteristic Features of Volcanic Associations of Southeast Anatolia

Reference	Formation	Lithology	Age	Tectonic environment
Hempton and Savci, 1982; Tarhan, 1986	Yüksekova group	Basic and intermediate lavas and associated sedimentary rocks built on an ophiolitic substratum	Upper Jurassic–lower Eocene	Ensimatic island arc
Yazgan, 1981	Yüksekova complex	Basic volcanics, pelagic sediments	Upper Cretaceous	Island arc developed on the continental crust
Yazgan, 1981	Maden complex	Basalts, dacites, limestone, sediments with blocks	Middle Eocene	Island arc developed on the continental and oceanic crusts
Perinçek and Özkaya, 1981; Hempton, 1984	Maden complex–Maden mélange	Basalt, volcaniclastics, limestone and clastics	Middle Eocene	Back-arc basin
Erdogan, 1982	Maden group	Mafic volcanics, pyroclastics, pelagic sediments	Maastrichtian–Upper Eocene	Ensimatic immature island arc
Özçelik, 1982, 1985	Maden complex	Basalt, pyroclastics, limestone, calc-schist, and clastics	Middle Eocene	Ensimatic immature island arc developed on marginal basin
Aktas and Robertson, 1985	Maden group	Volcanics and sediments	Paleocene–Eocene	Fore-arc basin
Aktas and Robertson, 1985	Karadere Formation	Mafic lavas, clastics	Middle Eocene	Short-lived pull-apart basin
Yigitbas and Yilmaz, 1996a	Maden group	Basal clastics, basaltic lavas and sediments	Middle Eocene	Back-arc pull-apart basin
Yigitbas, 1989; Yilmaz et al., 1993	Helete volcanics	Basic-intermediate volcanic succession and sediments	Middle–Upper Eocene	Ensimatic island arc
Elmas, 1994	Gövekek volcanics	Andesite, dacite, rhyolite, volcaniclastics, and turbidites	Upper Lutetian–Upper Oligocene	Island arc developed on an ophiolitic mélange

et al., 1992). However, in the eastern part of the region, only the Late Cretaceous ophiolite nappe is present (Perinçek, 1990). In this region, the Arabian platform succession may be divided into two units from the bottom to the top: the lower and upper autochthonous successions (Fig. 3). The Late Cretaceous ophiolite nappe crops out especially well at the two ends of Southeast Anatolia (Fig. 1B), where the Mesozoic sequence is not buried under the Miocene thrusts (Perinçek, 1979; Yilmaz, 1993).

Along the contact of the Arabian platform with the nappe zone, volcanic and sedimentary units of Cretaceous to Miocene age were compressed and imbricated to form a narrow (up to 5 km in width) zone of imbrication (Fig. 3). The bottom of the section is represented by a lower Miocene flysch succession (the Hompur Formation). The succession is tectonically overlain by a pelagic limestone, shale, chert, and marl sequence (Harami Formation) of Late Cretaceous–early Eocene age that developed

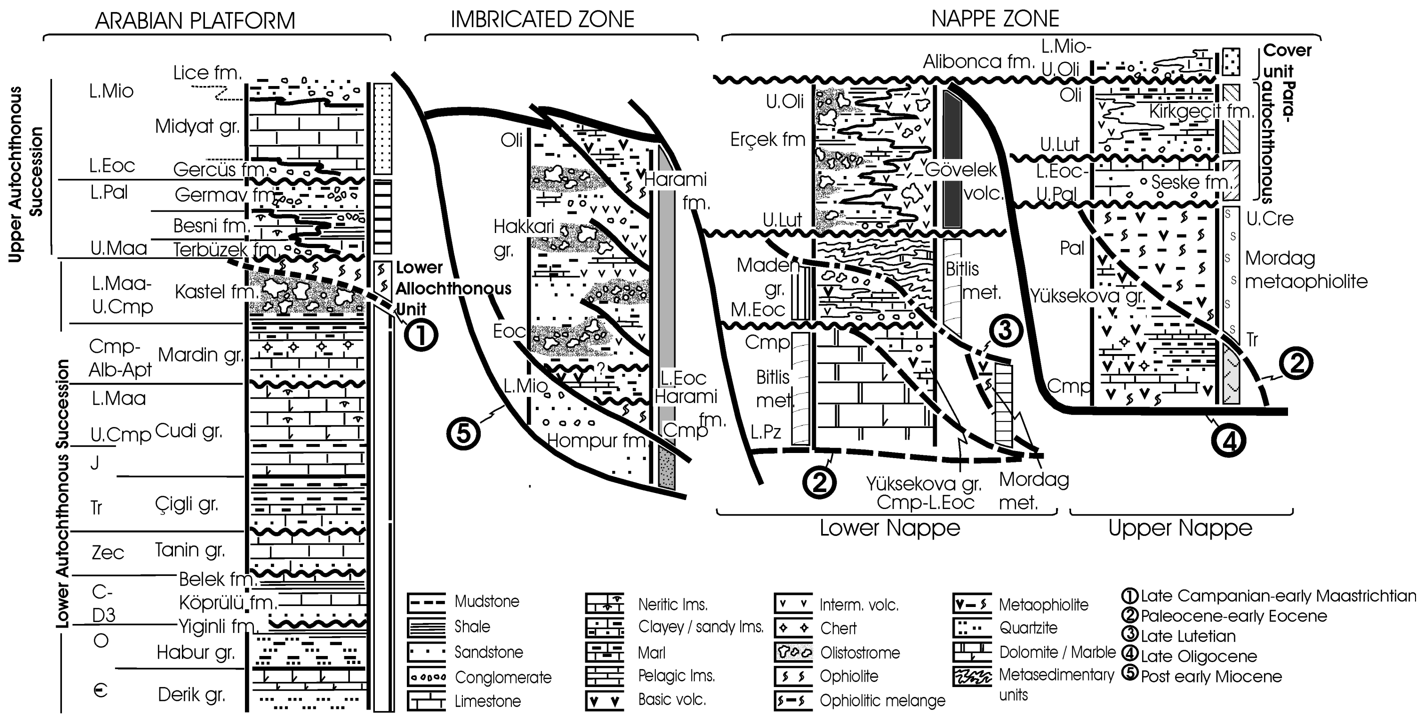

FIG. 3. Generalized columnar sections across the eastern part of the Southeast Anatolian orogenic belt. The narrow columns beside the sections show the map pattern of the rock units in Figure 2. Numbers indicate progressive southerly movement phases that caused the amalgamation of the nappes. Main thrusting stages are as follows: 1 = Late Campanian–early Maastrichtian (ophiolite obduction onto the Arabian platform); 2 = Late-early Paleocene–late-early Eocene (the end of Yüksekova island-arc volcanic activity); 3 = Late Lutetian (closure of the Maden basin); 4 = Late Oligocene (end of Gövelek island-arc volcanic activity); 5 = after the early Miocene (collective emplacement of the units in the nappe area onto the Arabian platform).

on an ophiolitic basement (Perinçek, 1979; Yilmaz, 1993). They are unconformably overlain by an Eocene–Oligocene (Perinçek, 1978) turbiditic unit (the Hakkari Group) containing intermediate to acidic lava interbeds and ophiolite, volcanite, and metamorphic blocks (Perinçek, 1990). This association is a tectonic mixture of the Savran/Alacik formations (Yilmaz, 1993) and the Helete volcanics (Yigitbas, 1989) in the western part of the imbricated zone, and the Erçek Formation and Gövelek volcanics (Elmas, 1994, 1996) in the nappe zone. The sequence is overthrust by the Harami Formation. Between thrust slices, the stratigraphic sequences are reversed with older units overlying the younger units.

Toward the north, the nappe zone is composed of two tectonic packages, the lower and upper nappes (Fig. 3). They are separated from each other by a southerly vergent thrust zone (Yilmaz et al., 1987). The lower nappe (Figs. 3 and 4) consists predominantly of a metamorphosed sedimentary sequence of early Paleozoic–Campanian age (Yilmaz et al., 1987). The metamorphic massifs of Southeast Anatolia are the Keban, Malatya, Pötürge, and Bitlis massifs, from west to east (Perinçek, 1979, 1980a; Yilmaz, 1993) (Fig. 1B).

In the lower nappe (Fig. 3), a Lutetian volcanosedimentary sequence (the Maden Group) (Perinçek and Özkaya, 1981; Hempton, 1984; Yigitbas and Yilmaz, 1996a) rests with a normal contact on the Upper Cretaceous–Eocene volcanosedimentary association (the Yüksekova Group) (Perinçek and Özkaya, 1981), ophiolitic rocks (Berit metaophiolite) (Perinçek, 1979), and the Bitlis massif (Yilmaz, 1993). The Maden Group was overthrust by the Bitlis nappe.

In the eastern part of Southeast Anatolia, the Bitlis massif and the Maden Group are overlain by an upper Lutetian–upper Oligocene sedimentary sequence (the Erçek Formation) (Elmas, 1992) and lavas (the Gövelek volcanics) (Elmas, 1994; Fig. 3). In the north, the Erçek Formation rests on both the Campanian–lower Eocene volcanosedimentary rocks (the Yüksekova Group) and ophiolitic rocks tectonically overlying them (Fig. 2).

The upper nappe consists of ophiolitic, volcanic, and sedimentary associations (Fig. 3). At the base of the section, a lava-sediment association (Yüksekova Group) was built on an ophiolitic foundation. They are tectonically overlain by a weakly metamorphosed ophiolite association known as the Mordag metaophiolite (Perinçek, 1990). The metaophiolitic rocks comprise numerous tectonic slices of the Bitlis massif (Elmas, 1996).

In the eastern part of Southeast Anatolia, the following criteria indicate that metaophiolitic rocks had been emplaced southward in late–early Paleocene time: (1) metaophiolite was thrust onto Campanian–Paleocene volcanosedimentary units of the Yüksekova Group; and (2) they are collectively overlain by an upper Paleocene unit (Figs. 2 and 3). The cover unit consists from bottom to top of an upper Paleocene–lower Eocene (Perinçek, 1979, 1990) sedimentary sequence (the Seske Formation), and upper Lutetian–Oligocene (Elmas, 1992, 1996) sedimentary rocks (the Kirkgeçit Formation) (Perinçek, 1979, 1980b) containing intermediate lava interbeds.

The lower and upper nappes are blanketed by a common cover sedimentary succession of latest Oligocene–early Miocene age (Elmas, 1996) (Figs. 2 and 4). This is a turbiditic unit, known as the Alibonca Formation (Soytürk, 1973).

Cretaceous-Oligocene Volcanosedimentary Assemblages in the Eastern Part of the Southeast Anatolian Orogenic Belt

Various volcanosedimentary associations of Late Cretaceous–Eocene age occur within the nappe zone of the Southeast Anatolian orogenic belt. These are the Yüksekova Group, the Helete volcanics, and the Maden Group (Table 1).

The Yüksekova Group (Erdogan, 1977; Yazgan, 1981) is a consanguineous sequence (Fig. 5) that was laid down on an ophiolite basement (Berit metaophiolite) (Perinçek, 1979). The group consists of lavas and interbedded pelagic sediments that are Late Cretaceous to early Eocene in age. In the eastern part of the Southeast Anatolian orogenic belt, the volcanics are intercalated with Campanian–Paleocene pelagic sediments (Elmas, 1992, 1996). The sequence was tectonized by the ophiolite emplacement (Mordag metaophiolite) during late–early Paleocene time. Southeast of Lake Van, the age of the sediments extend to the early Eocene. The unit is present in the lower and upper nappes in the eastern part of the orogenic belt (Fig. 3).

The Helete volcanics (Yigitbas, 1989; Yilmaz, 1993) (Fig. 5 and Table 1) of middle to late Eocene age (Yigitbas and Yilmaz, 1996a), consist mostly of intermediate lavas and associated pyroclastic rocks with rare sedimentary interbeds. In the western areas of Southeast Anatolia, the unit occurs as a

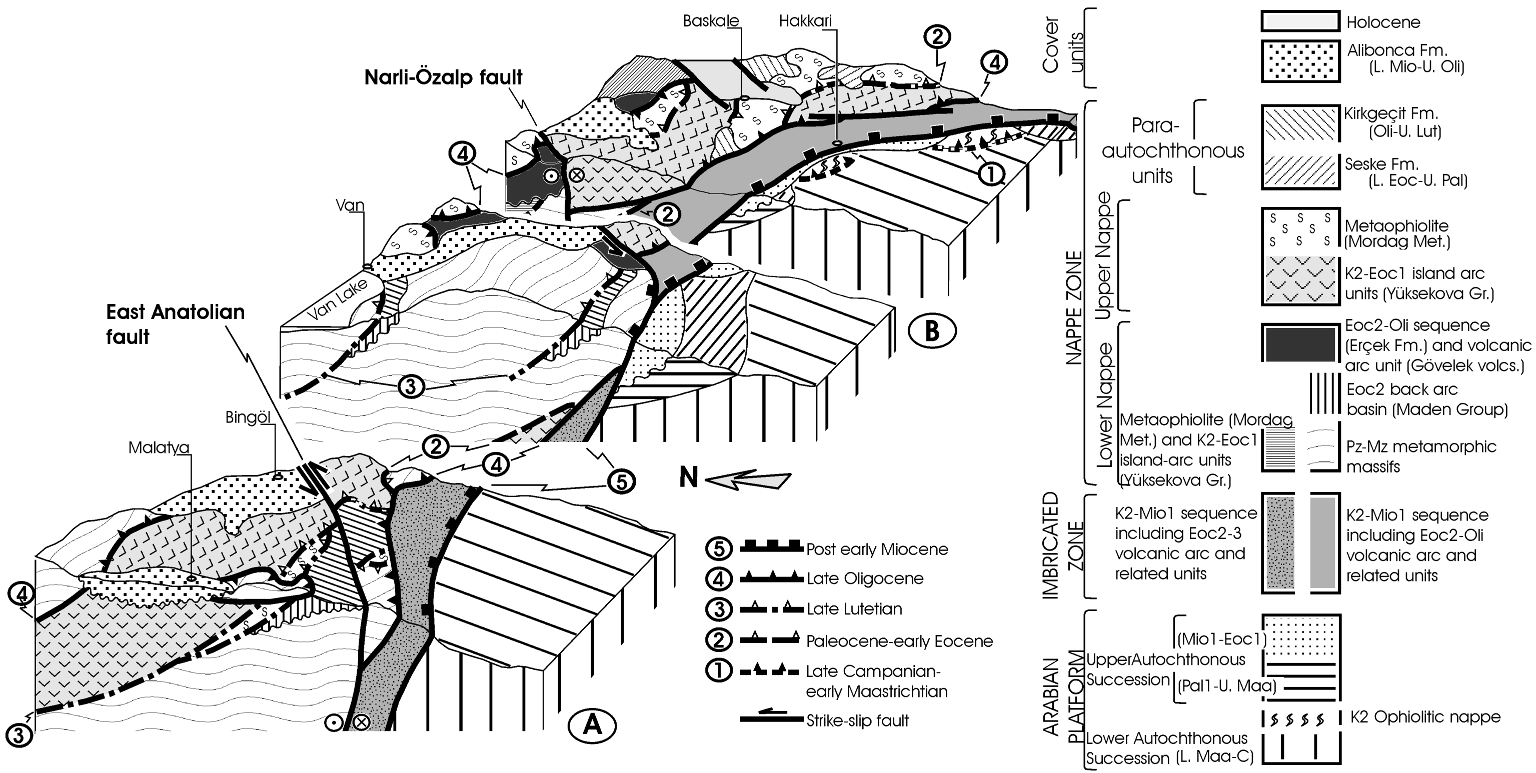

FIG. 4. Diagrams showing tectonic-stratigraphic relationships of units of the Southeast Anatolian orogenic belt (see Fig. 1B for location).

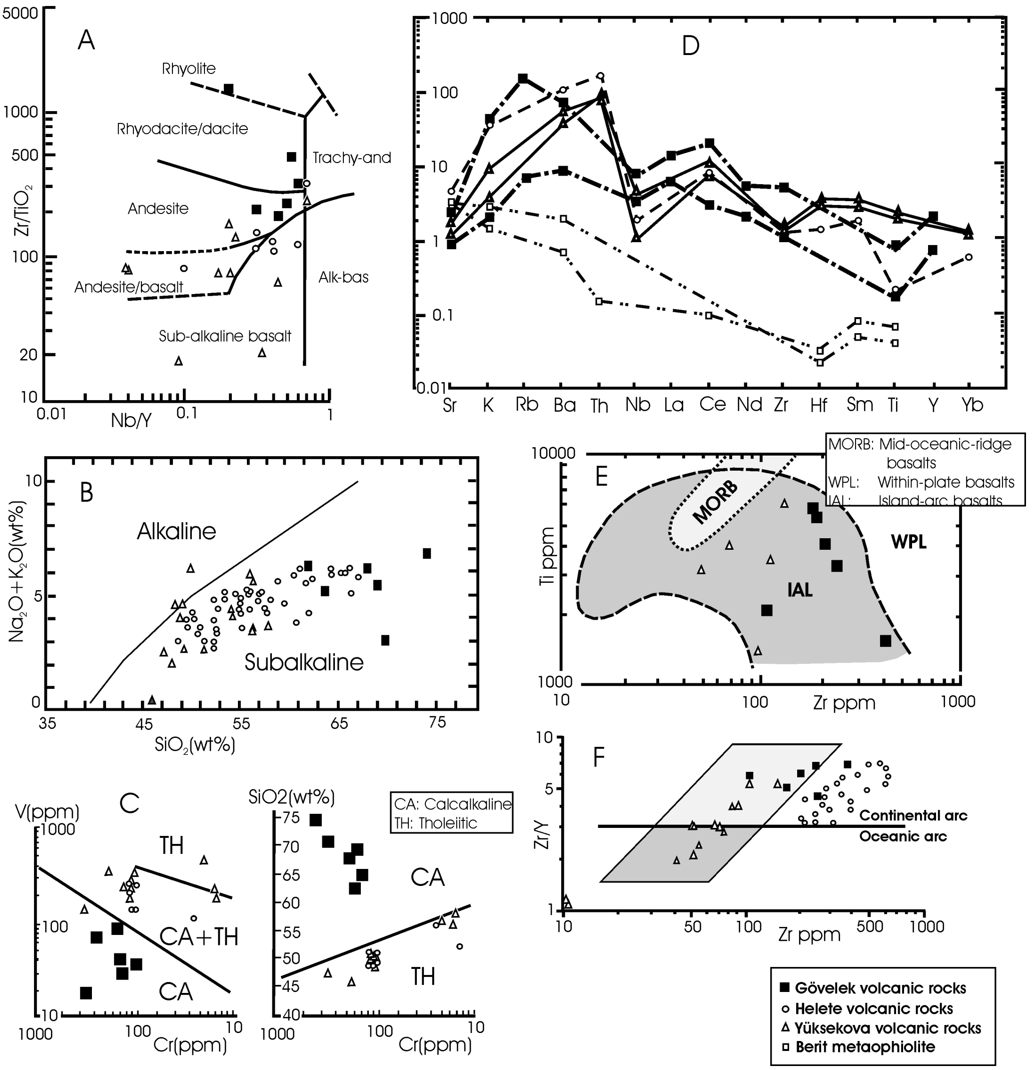

FIG. 5. A. Zr/TiO_2 and Nb/Y plot (after Winchester and Floyd, 1977). B. SiO_2 and $Na_2O + K_2O$ plot (after Irvine and Baragar, 1971). C. V-Cr and SiO_2-Cr diagrams of Miyashiro and Shido (1975). D. MORB-normalized trace-element plots (diagram after Pearce, 1983). E. Ti-Zr discrimination diagram of Pearce (1982). F. Tectonomagmatic discrimination diagram of Pearce and Norry (1979). Geochemical data for the Yüksekova volcanics were obtained from Yazgan (1981), and Aktas and Robertson (1985). Data for Helete volcanics are after Yigitbas and Yilmaz (1996a), and Aktas and Robertson (1985). Data for Gövelek volcanics are after Elmas (1994).

tectonic slice between the metamorphite nappe on the north and upper Eocene–Oligocene wild flysch deposits (Savran and Alacik formations) on the south (Yilmaz, 1993). In the eastern areas, the lower nappe is equivalent to the metamorphic nappe; also the Hakkari Group of Eocene–Oligocene age in the imbricated zone is the equivalent of the wild flysch deposits. In the eastern areas, units similar to the Helete volcanics are present within thrust slices of the imbricated zone.

The Maden Group has a narrow age span within the middle Eocene epoch (Yazgan, 1981; Perinçek and Özkaya, 1981; Özçelik, 1982, 1985; Hempton, 1984; Aktas and Robertson, 1985; Yigitbas and

Yilmaz, 1996a) (Table 1) and represents the contents of a short-lived basin located behind the Helete volcanic chain (Yilmaz et al., 1987; Yilmaz, 1993). The base of the Maden sequence is a basal clastic unit commonly accompanied by partly subaerial alkaline lavas (Perinçek, 1979, 1980b; Erdogan, 1982; Yilmaz et al., 1987; Yigitbas and Yilmaz, 1996a). They are followed by reefal limestones that pass upward into deep-sea sedimentary rocks, and interbedded tholeiitic basalts (Erdogan, 1982; Özçelik, 1982; Aktas and Robertson, 1985). An increasing number of debris-flow deposits are present toward the top of the succession (Yilmaz et al., 1993; Yigitbas and Yilmaz, 1996a). Geochemical data obtained from the Maden Group suggest an enriched mantle source and fall into the MORB and ""within-plate basalts"" fields (Yigitbas and Yilmaz, 1996a). The unit occurs in the lower nappe in the eastern part of the Southeast Anatolian orogenic belt (Figs. 3 and 4).

In the eastern part of the Southeast Anatolian orogenic belt, between Lake Van and the town of Hakkari, there is yet another newly discovered island-arc volcanic association, the Gövelek volcanics (Elmas, 1992, 1994) (Table 1). These units consist of andesite, dacite, rhyolite lavas (Fig. 5), and associated pyroclastic rocks. They are intercalated with upper Lutetian–upper Oligocene sedimentary rocks of the Erçek Formation (Elmas, 1992) (Fig. 3). The unit begins with an olistostromal sequence and basal clastics including reefal limestone layers. The olistostromal sequence consists entirely of ophiolitic pebbles and blocks which are embedded in a volcaniclastic matrix. The basal clastic rocks pass upward into a thick sedimentary succession consisting of sandstone, conglomerate, mudstone, marl, sandy limestone alternation, and pelagic limestone layers. In some areas, the sequence includes also red claystone and gypsum layers. Olistostrome and debris-flow conglomerate layers are common in the Erçek Formation. The sequence is weakly tectonized along thrust contacts.

The Erçek Formation and Gövelek volcanics overlie the Bitlis massif and the Maden Group (Fig. 2). Northeast of Lake Van, the Erçek Formation rests also on Campanian–lower Eocene volcanosedimentary rocks of the Yüksekova Group; it is tectonically overlain by the Mordag metaophiolite. The lithologic characteristics and the age of the Erçek Formation in the lower nappe indicate that the unit is the equivalent of the Hakkari Group in the imbricated zone. The Erçek Formation and the Gövelek volcanics are tectonically overlain by the upper nappe stack (Figs. 2 and 3).

Comparative Geochemical Characteristics of the Cretaceous–Oligocene Island-Arc Volcanics in the Eastern Part of the Southeast Anatolian Orogenic Belt

The purpose of this section is to present geochemical data for the stratigraphically and/or tectonically different Mesozoic and Tertiary island-arc volcanic assemblages (the Yüksekova, Helete, and Gövelek lavas) and to compare their geochemical features. In the Zr/TiO_2 and Nb/Y diagram of Winchester and Floyd (1977), the analyses that represent the Mesozoic and Tertiary volcanic rocks cover a broad compositional spectrum from basalt to rhyolite (Fig. 5A). The Gövelek volcanic rocks cluster mostly within andesite and rhyodacite/dacite fields; one sample lies within the rhyolite field. The Yüksekova and Helete volcanic rocks cluster mostly within the subalkaline basalt and andesite/basalt fields, but some samples extend into the neighboring andesite and trachyandesite fields.

Most of the samples are silica saturated, and fall into the subalkaline field (Fig. 5B) on the basis of their alkali and silica contents using the total alkali vs. SiO_2 diagram of Irvine and Baragar (1971). In Figure 5B an increase in the subalkalinity is evident from the Yüksekova volcanics to the Gövelek volcanics. The V-Cr and SiO_2-Cr diagrams of Miyashiro and Shido (1975) (Fig. 5C) indicate that the Gövelek volcanic rocks are calc-alkaline, whereas the Yüksekova and Helete rocks are calcalkaline/tholeiitic.

Incompatible trace element patterns, normalized to MORB after Pearce (1983), are shown in Figure 5D, and have been used to contrast source compositions across the different volcanic provinces. The data from basaltic lavas of the Berit metaophiolite are also included for comparison. The order of incompatibility during melting increases from Sr to Th and Yb to Th (Pearce, 1983) in the patterns of the Yüksekova and Helete volcanic rocks (Yigitbas and Yilmaz, 1996a), whereas from Sr to Rb and Y or Ti to Rb in the patterns of the Gövelek volcanic rocks. The Yüksekova and Helete patterns show enrichment in LIL elements (Sr, K, Rb, Ba, Th, and LREEs) and HFS elements (Nb and Zr) relative to the MORB-normalizing values. The patterns are selectively enriched in Sr, K, Rb, Ba, and Th, but give negative anomalies in Nb. This pattern of selective LIL element enrichment can be attributed to a subduction origin (Yigitbas and Yilmaz, 1996a). Gövelek patterns also show enrichment in Sr, K, Rb, Ba, Ce, and La, and negative anomalies in Nb and Ti. These features, together with the high Ba/Nb (3.5–25.1) and K/Ti (0.2–15.8), and low Nb/Y (0.2–0.6) and Ti/Y (24–143) ratios indicate a source region in the mantle, enriched by subduction processes (Pearce et al., 1984).

Tectonomagmatic discrimination diagrams are used to identify the setting of the Yüksekova, Helete, and Gövelek volcanic rocks. In the diagram of Pearce (1982) (Fig. 5E) the Yüksekova and Gövelek volcanics plot within the island-arc lava field. The Yüksekova, Helete, and Gövelek lavas are very similar to one another, and indicate selective enrichment as observed in the island-arc lava patterns. But, in the diagram of Pearce and Norry (1979) (Fig. 5F), the Yüksekova lavas are separated clearly from the Helete and Gövelek lavas. In this diagram, the Yüksekova lavas mostly appear to have been underlain by oceanic crust, whereas the Helete and Gövelek lavas may have been developed on a mélange prism.

Geologic Evolution of the Eastern Part of the Southeast Anatolian Orogenic Belt

The paleogeography of the eastern part of Southeast Anatolia was defined by the Neotethys ocean to the north and a continental assemblage (the Arabian plate) to the south, prior to Late Cretaceous time (Şengör and Yilmaz, 1981). To the west, the southern branch of Neotethys formed between the Arabian plate and the Taurus belt (Fig. 6A). The metamorphic units belong to the Taurus belt (Yilmaz et al., 1987; Yilmaz, 1993).

The Paleozoic is represented by continental–shallow marine deposits on the Taurus belt and the Arabian platform (Sungurlu, 1974). The region developed into an Atlantic-type continental margin by the Late Triassic period (Fig. 6A) with a well-defined carbonate platform, slope, continental rise, and abyssal plain facing north, where Neotethyan oceanic floor is inferred to have formed (Yilmaz et al., 1987; Fourcade et al., 1991). The units constitute the lower autochthonous succession of the Arabian platform (Fig. 3).

An olistostromal syntectonic unit (the Kastel Formation) (Fig. 3), dominated by ophiolite blocks, is an indicator of ophiolite obduction onto the Arabian platform during late Campanian–early Maastrichtian time (Fig. 6B). During Late Cretaceous–early Eocene time, the northward subduction of Neotethyan oceanic floor resulted in the development of Yüksekova island-arc volcanism (Yazgan, 1981; Hempton, 1984; Tarhan, 1986; Aktas and Robertson, 1985; Yilmaz et al., 1987). In the western part of the Southeast Anatolian orogenic belt, Yüksekova island-arc volcanism waned at the end of the early Eocene, possibly related to southward transportation of nappes (Yilmaz, 1993). This may be interpreted as a continent-arc collision, because the metamorphic massifs of Southeast Anatolia forming the nappes originated in the north and were attached to the Taurus Range (Şengör and Yilmaz, 1981). In the easternmost part of Southeast Anatolia, the Yüksekova Group formed mainly on an ophiolite basement (Figs. 1B and 6B). Then, the group was overthrust by ophiolitic rocks (the Mordag metaophiolite) moving to the south. In the upper nappe, the age of the Yüksekova Group can reach to the Paleocene (Fig. 3), whereas in the lower nappe, the Yüksekova Group has a lower Eocene upper age limit. In the imbricated zone, the Late Cretaceous–early Eocene interval is represented by a pelagic sedimentary rock association (the Harami Formation) (Fig. 6B) that might have developed in a fore-arc environment simultaneously with the Yüksekova Group. In the upper nappe, the island-arc volcanic rocks of Campanian–Paleocene age, and the overlying ophiolite nappe were blanketed by the Seske Formation (Fig. 3) during late Paleocene time (Perinçek, 1980b) (Fig. 6C). The Seske Formation is the time-equivalent of the top levels of the Yüksekova and Harami sequences, in the lower nappe and in the imbricated zone, respectively. These data indicate collectively that, in the northeastern part of Southeast Anatolia, Yüksekova island-arc volcanic activity ended in late–early Paleocene time, possibly due to the southward advance of the ophiolitic nappe. In the southeastern areas, arc volcanism waned at the end of the early Eocene (Fig. 6C).

During middle Eocene time (Fig. 6D), Yüksekova island-arc volcanism possibly migrated southward, where a new and well-developed volcanic chain (the Helete island-arc volcanism) was active (Yilmaz, 1993). Contemporaneously, the Maden Group was formed in a short-lived back-arc basin behind the Helete volcanic chain (Fig. 6D). The Maden basin closed at the end of the middle Eocene, possibly related to the southward advance of the nappes that were emplaced onto the Maden Group (Yilmaz, 1993; Yigitbas and Yilmaz, 1996a).

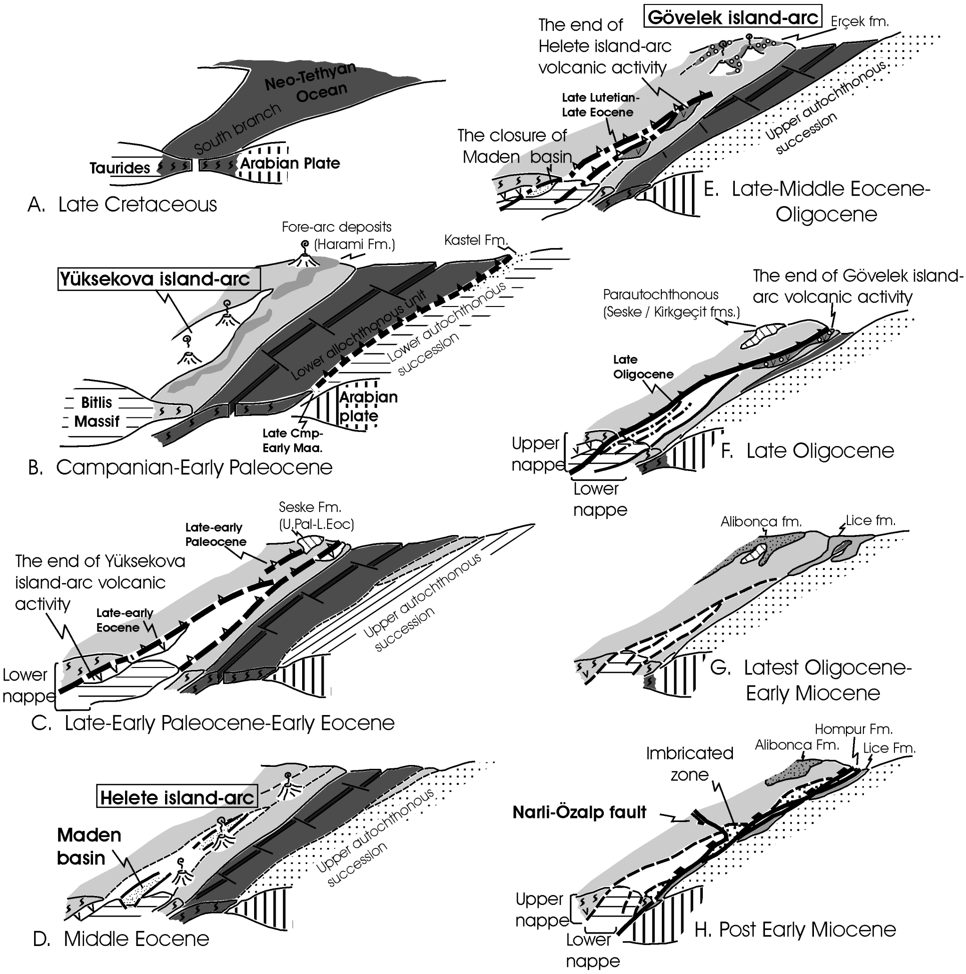

FIG. 6. Block diagrams depicting the tectonic evolution of the eastern part of the Southeast Anatolian orogenic belt from Late Cretaceous to Miocene time.

The Yüksekova, Helete, and Gövelek volcanic assemblages represent products of connective arc environments. The Yüksekova arc was formed during Late Cretaceous to early Eocene time. This volcanism survived into the Paleocene in the northeastern areas. The Helete arc was developed during middle to late Eocene time, and the Gövelek arc was formed during late Lutetian–Oligocene time. The Yüksekova Group crops out in the northern part of the orogenic belt, whereas the Helete volcanic association is restricted to southern areas. Outcrops of the Gövelek volcanics are limited in the eastern part of the orogenic belt. The Yüksekova volcanic suit developed mostly on an ophiolitic foundation, but it is also common on the metamorphic units, particularly in the westernmost part of the nappes (Yazgan, 1981). However, the Helete volcanics and particularly the Gövelek volcanics were formed on an accretionary ophiolitic mélange prism. Geochemically, the Gövelek volcanics are calc-alkaline, whereas the Yüksekova and Helete volcanics are calcalkaline/tholeiitic (Fig. 5C).

Yigitbas and Yilmaz (1996b) suggested that oblique subduction of the mid-oceanic ridge underneath the northerly situated Yüksekova ensimatic island-arc complex caused a gradual cessation of the island-arc system. The Helete volcanic activity and back-arc Maden basin were short lived due to the obliteration of the mid-oceanic ridge (Figs. 6D and 6E). Farther east, the oceanic environment and mid-oceanic ridge survived to the end of the Oligocene (Fig. 6E). The northward subduction of oceanic floor resulted in the development of new island-arc volcanic activitiy (Gövelek volcanics) dating from the late Lutetian (Elmas, 1994). Volcanic activity continued to the late Oligocene, but is not observed in the western area. Gövelek volcanism is an eastward continuation of the Helete island-arc volcanism. In addition, stratigraphic features of the late Lutetian–late Oligocene deposits (the Erçek Formation), intercalated with the Gövelek volcanic rocks, are an indicator of the southward thrusts (Elmas, 1992). We postulate that the sedimentary deposits developed in back-arc and fore-arc basins.

Gövelek volcanic activity ended at the end of the Oligocene, due to destruction of the mid-oceanic ridge, and to southward advance of the upper nappe which was emplaced onto the Gövelek island-arc volcanics (Fig. 6F). The sedimentary and volcanic units (parautochthonous units/Kirkgeçit Formation) (Perinçek, 1979, 1980b) that were carried southward on the late Oligocene nappe package are the equivalent of the upper Lutetian–upper Oligocene Erçek Formation.

Latest Oligocene–early Miocene time (Fig. 6G) saw the removal of some of the morphological complexities. In the area between the Arabian platform and the nappe zone, deposition continued from the Late Cretaceous to the end of the early Miocene. The northern part of the nappes was overlain by the uppermost Oligocene–lowermost Miocene deposits, the Alibonca Formation.

At the end of early Miocene time (Fig. 6H), the nappes as a package were emplaced onto the Arabian platform. The Southeast Anatolian metamorphic massifs were bounded by a NE-SW–trending left-lateral strike-slip fault (the Narli-Özalp fault; Fig. 1B) in the east. To the west of the Narli-Özalp fault, the Bitlis metamorphics in the lower nappe appear as the highest tectonic unit of the Southeast Anatolian orogenic belt.

Conclusions

1. In the eastern part of Southeast Anatolia, the Arabian platform succession is divided into two subdivisions, the lower and upper autochthonous sedimentary successions. They are separated by a Late Cretaceous ophiolite nappe.

2. The nappe zone is composed of two nappe packages, the lower and upper nappes. The lower nappe comprises the regionally metamorphosed sedimentary sequence of early Paleozoic–Campanian age (Bitlis massif), the middle Eocene back-arc basin fill (the Maden Group), and the Campanian–lower Eocene volcanosedimentary succession of the Yüksekova Group. Overlying them, an upper Lutetian–upper Oligocene sedimentary sequence (the Erçek Formation) is accompanied by island-arc volcanic rocks (Gövelek volcanics).

The upper nappe comprises island-arc volcanic rocks of Campanian–Paleocene age (the Yüksekova Group) and an overlying ophiolite slab (Mordag metaophiolite). The nappe is overlain by parautochthonous units (the Seske and Kirkgeçit formations).

3. Upper Cretaceous–Oligocene volcanic associations are represented by a variety of rocks from subalkaline basalt to rhyolite. The Yüksekova, Helete, and Gövelek volcanics show a geochemical shift from calcalkaline/tholeiitic to calcalkaline, respectively. Spider diagrams indicate selective enrichment, as is observed in the island-arc lava patterns. The Yüksekova lavas rest on oceanic crust, whereas the Helete and Gövelek lavas are underlain by mélange prism.

The Yüksekova, Helete, and Gövelek island-arc volcanics developed during the Late Cretaceous–Paleocene, middle–late Eocene, and late Lutetian to Oligocene periods, respectively. The Yüksekova volcanics crop out in the northern part of the orogenic belt. However, the Helete volcanic association is restricted to the southern areas. The Gövelek volcanics were formed in the eastern part of the orogenic belt.

4. In the Southeast Anatolian orogenic belt, the presence of late Lutetian–late Oligocene island-arc volcanic activity (Gövelek volcanism) is documented for the first time in this work. This volcanic activity may be viewed as the easterly continuation of the Helete island-arc volcanism, which ranges in age from the middle Eocene to the Oligocene. This age progression may be due to an oblique subduction of the mid-oceanic ridge consumed underneath the more northerly nappe units.

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