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Research paper

Comparisons of the suture zones along a geotraverse from the Scythian Platform to the Arabian Platform

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ABSTRACT

The area from the Greater Caucasus to the southeast Turkey is characterized and shaped by several major continental blocks. These are Scythian Platform, Pontian–Transcaucasus Continent-Arc System (PTCAS), the Anatolian–Iranian and the Arabian Platforms. The aim of this paper is to define these continental blocks and describe and also compare their boundary relationships along the suture zones. The Scythian Platform displays the evidence of the Hercynian and Alpine orogens. This platform is separated from the PTCAS by the Greater Caucasus Suture Zone. The incipient collision began along this suture zone before middle–late Carboniferous whereas the final collision occurred before Oligocene. The PTCAS can be divided into four structural units: (1) the Georgian Block – northern part of the Pontian–Transcaucasian island-arc, (2) the southern and eastern Black Sea Coast–Adjara–Trialeti Unit, (3) the Artvin–Bolnisi Unit, comprising the northern part of the southern Transcaucasus, and (4) the Imbricated Bayburt–Garabagh Unit. The PTCAS could be separated from the Anatolian–Iranian Platform by the North Anatolian–Lesser Caucasus Suture (NALCS) zone. The initial collision was developed in this suture zone during Senonian–early Eocene and final collision before middle Eocene or Oligocene–Miocene. The Anatolian–Iranian Platform (AIP) is made up of the Tauride Platform and its metamorphic equivalents together with Iranian Platform. It could be separated from the Arabian Platform by the Southeastern Anatolian Suture (SEAS) zone. The collision ended before late Miocene along this suture zone. The southernmost continental block of the geotraverse is the Arabian Platform, which constitutes the northern part of the Arabian–African Plate. This platform includes a sequence from the Precambrian felsic volcanic and clastic rocks to the Campanian–early Maastrichtian flyschoidal clastics. All the suture zones include MORB and SSZ-types ophiolites in different ages. However, the ages of the suture zones and the crustal thicknesses along the suture zones are different, as the age becoming younger, the thickness decreasing from north to south. The emplacements of the ophiolites have similar pattern of a flower structure, reflecting both the north- and south-dipping overthrusts along the suture zones.

1. Introduction

The study area is located along a geotraverse from the Scythian Platform in the north to the Arabian Platform in the south (Fig. 1). This area is critical for tectonic domains of the continental fragments derived from Eurasia and Gondwanan plates and also for evaluating their boundary relationships on the land.

There are numerous studies in different scales and topics on the geology of the Caucasus, eastern and southeastern Anatolian regions. In these studies, the geological and geophysical data of each region have been evaluated separately, so that it is barely possible to understand the relationships in between the continental fragments along the presented geotraverse, as a whole.

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The thickness of the crust along the Caucasus was defined by Sollogub (1980) and Adamia et al. (1980, 1984, 1991). Based on these data, the Caucasus Terrane is underlain by continental crust represented by a granitic and basaltic basement with an overlying sedimentary cover. Only the central parts of the Black Sea and the southern Caspian Sea have sub-oceanic crust. The thickness of the crust varies from 20 to 60 km with significant lateral variations in thickness of the sedimentary successions. The thickness of the sedimentary cover varies from a few meters to 12 km over the Scythian Platform and reaches up to 12 km in some foredeep-type depressions.

The crustal thicknesses of the eastern and southeastern Anatolian regions have been defined by Zor et al. (2003) and Angus et al. (2006). Their result is that, there are differences in crustal thickness of eastern Turkey which reaches at least 50 km in the north along the NALCS zone, but it is only about 40–42 km thick in the south, along the SEAS zone. They also argue that, the crustal thickness of the Arabian Platform is thinner than that of East Anatolian crust which is thought to be thicker than 40–42 km.

In the framework of geophysical data presented above and also by Adamia et al. (1980, 1991), Yılmaz et al. (2010), it is possible to infer the thickness of the crust, density of the rocks, seismic velocity and inclusions with velocity along the geotraverse. The designed cross-sections are the interpretations of these inferences.

Important structural units of the eastern Pontides and Caucasus have been defined and correlated by Adamia (1975), Khain (1975), Adamia et al. (1981, 1984, 1991), Şengör (1984) and Yılmaz et al. (2000, 2010). The geology of the eastern Anatolian Region has been evaluated, from different views by Şengör and Yılmaz (1981), Dewey et al. (1986), Yılmaz et al. (1988, 1990), Koçyiğit et al. (2001) and Şengör et al. (2003, 2008). This region was reinterpreted in working group studies by Stephenson et al. (2004) throughout the project of Transmed Transect VIII crossing eastern part of the central Anatolian Region to the west of East Anatolia and those fulfilled in Middle East Basin Evolution (MEBE) Programme (Sosson et al., 2010). The geological and geophysical data and cross sections along the central Iranian Region (Geisse et al., 1983) and also MEBE Programme carried out in Iran (Brunet et al., 2009) make it easy to understand the relationships and crustal thicknesses along the suture zones, respectively far to the east and west regions of the presented geotraverse. In addition, the southeastern Anatolian Region has been the scene of geological and local geophysical studies for a long time, because of the presence of hydrocarbon deposits (Perinçek, 1979; Yazgan, 1983; Kaymakçı et al., 2010; Kuşçu et al., 2010 and references therein).

A complementary study of the region is limited and/or in part to such a geotraverse from the Greater Caucasus to the southeastern Anatolia, including huge continental blocks with structural suturing zones separating them from each other. They have not previously been evaluated in the light of recent geological and geophysical data. The selected profile comes across the most properly within the region, where the suturing relationships between Eurasia and Gondwana including also the eastern Anatolian Region can be reviewed on the land in detail.

The aim of this study is to interpret the main characteristics of the continental fragments, such as the crustal thickness, macrostructures and rock associations with emphases on their collisional periods, the present tectonic setting and comparisons of the suture zones based on the new geological and geophysical data.

In this framework, a geotraverse from the Scythian Platform in the north to the Arabian Platform in the south is provided in detail and data related to the huge continents (e.g. Eurasia and Gondwana) have been presented.

2. Tectonic overview of the region

The study area, between the Scythian Platform in the north to the Arabian Platform in the south, represents a geotraverse approximately in a north–south direction (Fig. 1). This area constitutes a part of the eastern Mediterranean Orogenic Belt, where it is possible to determine the relationships of the continental blocks derived from both Eurasian and Gondwanian plates.

On the basis of the main geological characteristics, the rock units of the northern part of the Geotraverse are divided into tectonic zones, which lie between the Scythian Platform to the north and the Anatolide–Iranian Platform (AIP) to the south. The tectonic zones of the Caucasus were defined by Khain (1975), Adamia et al. (2011) and Somin (2011) and classified into three zones. From north to south, they are the Greater Caucasus, Transcaucasus and Lesser Caucasus. Each zone has pre-Variscan, Variscan, pre-Liassic, Liassic and post-Liassic units reflecting different geotectonic environments.

Adamia et al. (1984, 1995a,b) suggested that the southern Transcaucasus (the Pontian and Somkheti–Kafan) zone can be divided into two subtectonic zones, namely the Artvin–Bolnisi zone to the north and the Bayburt–Garabagh Imbricated Zone to the south, which are situated to the north of the North Anatolian–Lesser Caucasus Ophiolitic Belt.

On the other hand, Ketin (1966) defined main tectonic units of Turkey. The pre-Alpine and Alpine terranes of Turkey have been presented by Göncüoğlu et al. (1997) and tectonic units with Tethyan sutures of Turkey have been defined by Okay and Tüysüz (1999).

Tectonic classification of Turkey is different from the Caucasus and Iranian regions. The selected geotraverse represents not only Turkish Terrane but also the Caucasus and Iranian regions. Therefore, in this study, taking into consideration of the Caucasus and the Middle East area, the tectonic classification made by Yılmaz et al. (2000, 2010) has been preferred. This classification makes it easy to correlate tectonic units of Turkey with surrounding regions. On the basis of this study, the main regional tectonic units, from north to south, are the Scythian Platform, the Great Caucasus Fold-Thrust Belt (GCFTB), Pontian–Transcaucasus Continent-Arc System (PTCAS), North Anatolian–Lesser Caucasus suture (NALCS), Anatolian–Iranian Platform (AIP) and Arabian Platform. In this framework, the PTCAS is the eastern extension of the Sakarya Zone; the Anatolian–Iranian Platform is the eastern extension of the Anatolide–Tauride Block of Turkey (Okay and Tüysüz, 1999).

In addition, based on the data presented by Somin (1991, 2007, 2011) and Adamia et al. (1984, 1978, 2011), the Scythian Platform, the GCFTB, and the PTCAS may have been a single tectonic unit of the Eurasia at the beginning of Palaeozoic and also during the Jurassic–Cretaceous and Tertiary times (Figs. 2 and 3). Similarly, the Anatolian–Iranian Platform and the Arabian Platform may have been a unique part of the Gondwana in late Proterozoic, Palaeozoic, beginning of Mesozoic and also during late Tertiary times (Fig. 3). In this framework, North Anatolian–Lesser Caucasus suture is a real suture, separating Eurasia- and Gondwana-derived tectonic domains (Figs. 3–5).

3. The tectonic units and suture zones along the geotraverse from Caucasus to southeastern Anatolia

On the basis of the stratigraphic and structural characteristics and boundary relationships, the tectonic domains of the region from north to south can be divided into subtectonic units in the area between Scythian Platform and Arabian Platform. The stratigraphic sections of the subtectonic units are shown in Figs. 2 and 3. The continental fragments are often separated from each other by

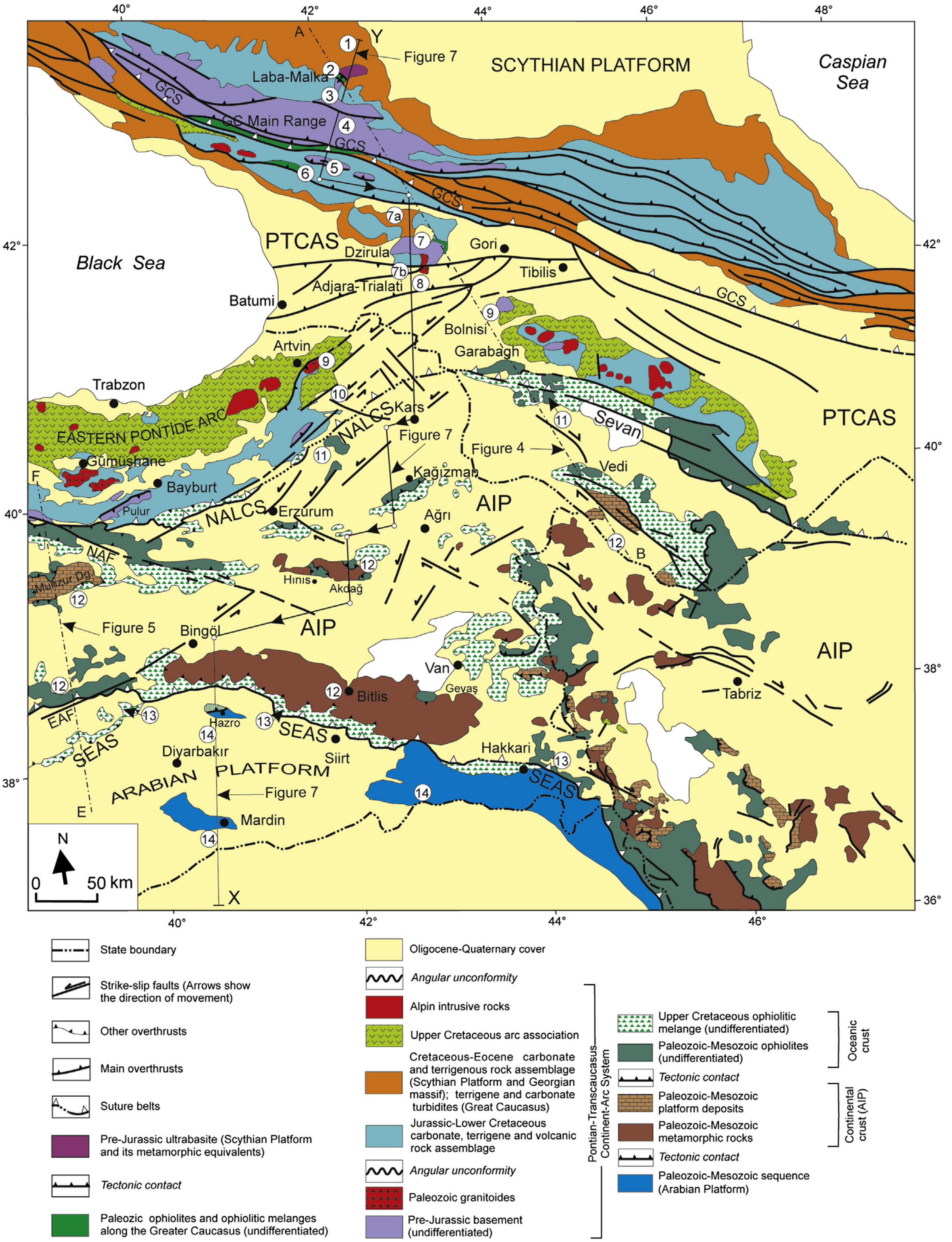

Figure 1. Sketch Geological map depicting the terranes of the Caucasus north–central the Middle–East region. NAF: North Anatolian Fault, EAF: East Anatolian Fault, AIP: Anatolian–Iranian platform, PTCAS: Pontian–Transcaucasus Continent-Arc System, GCS: Greater Caucasus Suture, NALCS: North Anatolian–Lesser Caucasus Suture, SEAS: Southeastern Anatolian Suture (from numerous sources). Encircled numbers indicate place of logs cited in the text.

the suture zones. For instance, the Greater Caucasus Suture Zone separates the Scythian Platform with its former active margin from the Pontian–Transcaucasus Continent-Arc System (Figs. 1 and 2). The North Anatolian–Lesser Caucasus Suture zone separates the Pontian–Transcaucasus Continent-Arc System from the Anatolian–Iranian Platform. The southeastern Anatolian Suture zone separates the Anatolian–Iranian Platform from the Arabian Platform (Figs. 1 and 3). The main characteristics of the continental

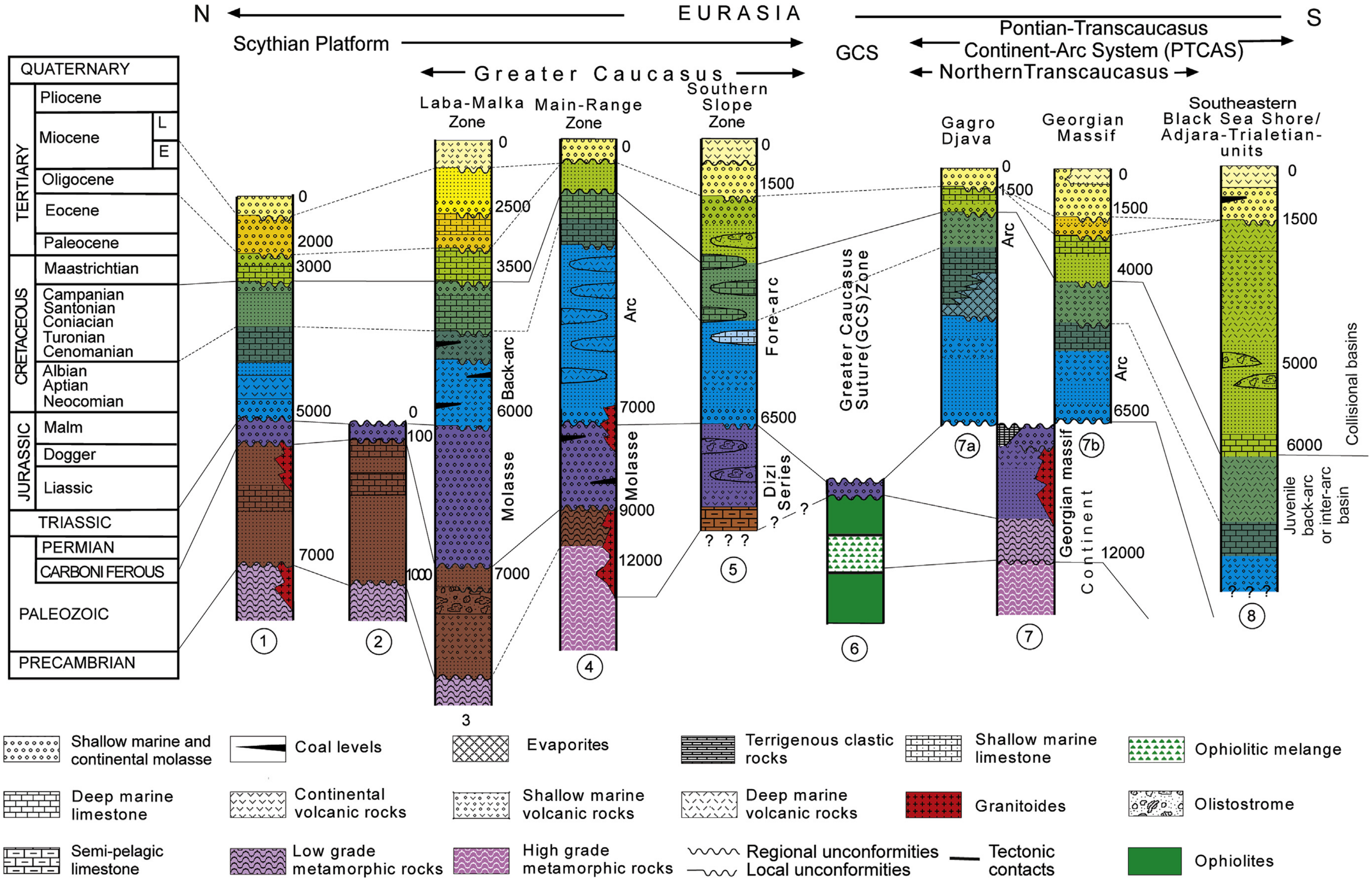

Figure 2. Correlative columnar sections of the Eurasian tectonic units (After Kutelia, 1983; Adamia et al., 1984; Yılmaz, 1989a; Yılmaz et al., 2000, and new interpretations). For location of logs see Fig. 1.

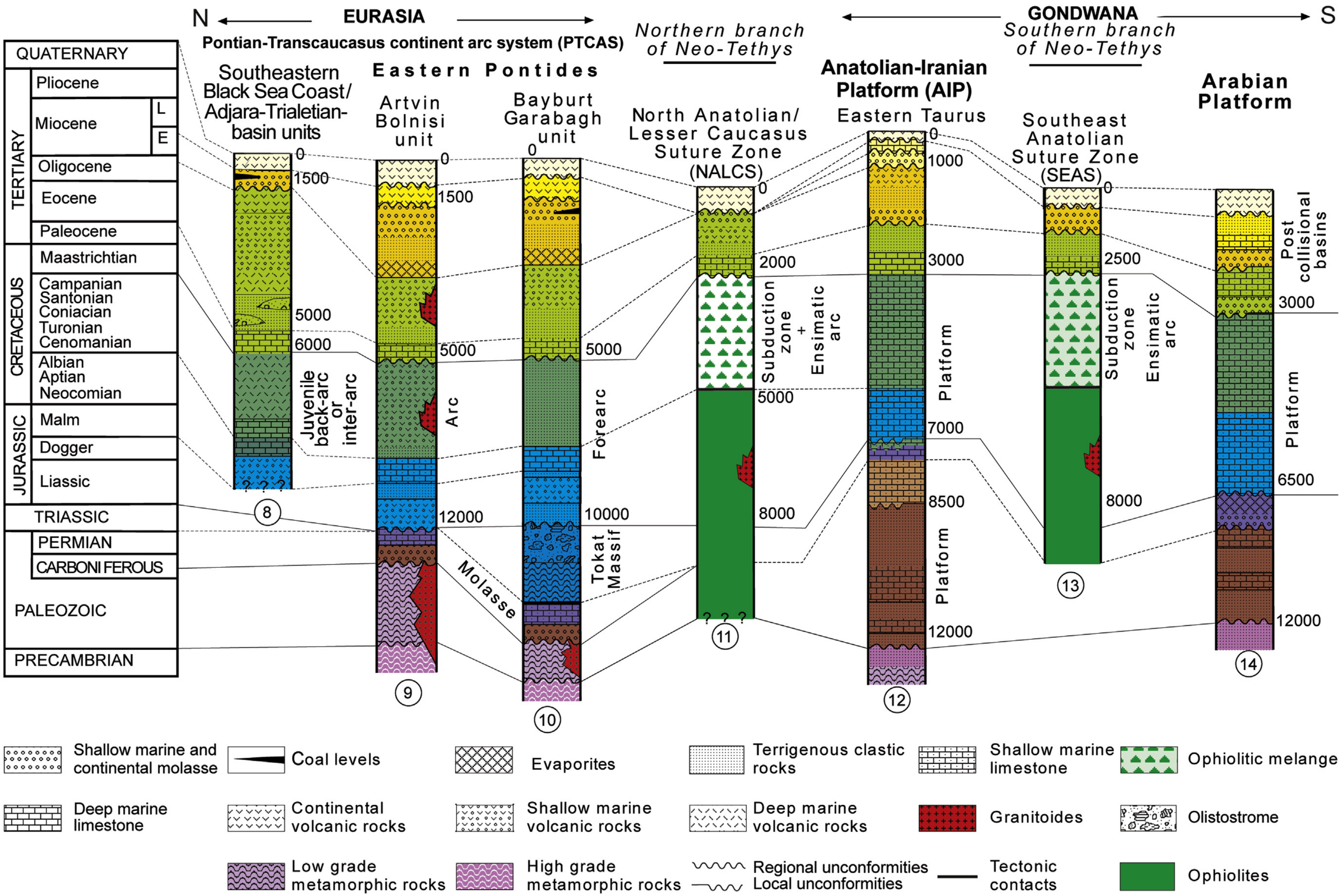

Figure 3. Correlative columnar sections of the tectonic units of the central and eastern Anatolia in Turkey (After Gedikoğlu et al., 1979; Perinçek, 1979; Özsayar et al., 1981; Adamia et al., 1984; Bektaş, 1984; Yılmaz, 1985a, 1989a; Akdeniz, 1988; Akdeniz et al., 1994; Yılmaz et al., 2000 and new interpretations). For location of logs see Fig. 1.

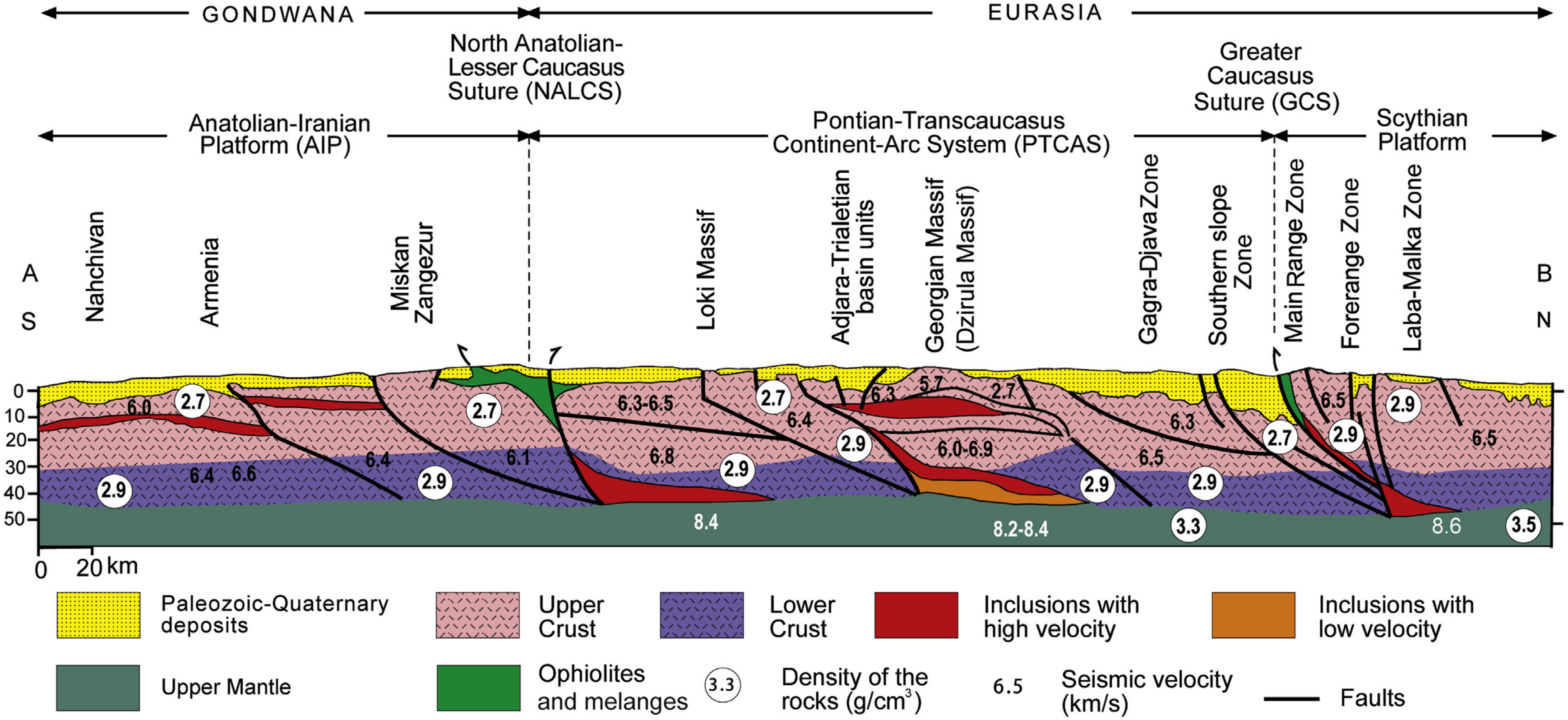

Figure 4. Interpretative cross section (A–B) of the region between Anatolian–Iranian Platform and Scythian Platform based on geological and geophysical data (After Adamia et al., 1980, 1984, 1991; Yılmaz et al., 2000 and new interpretations). See Fig. 1 for location of the cross-section.

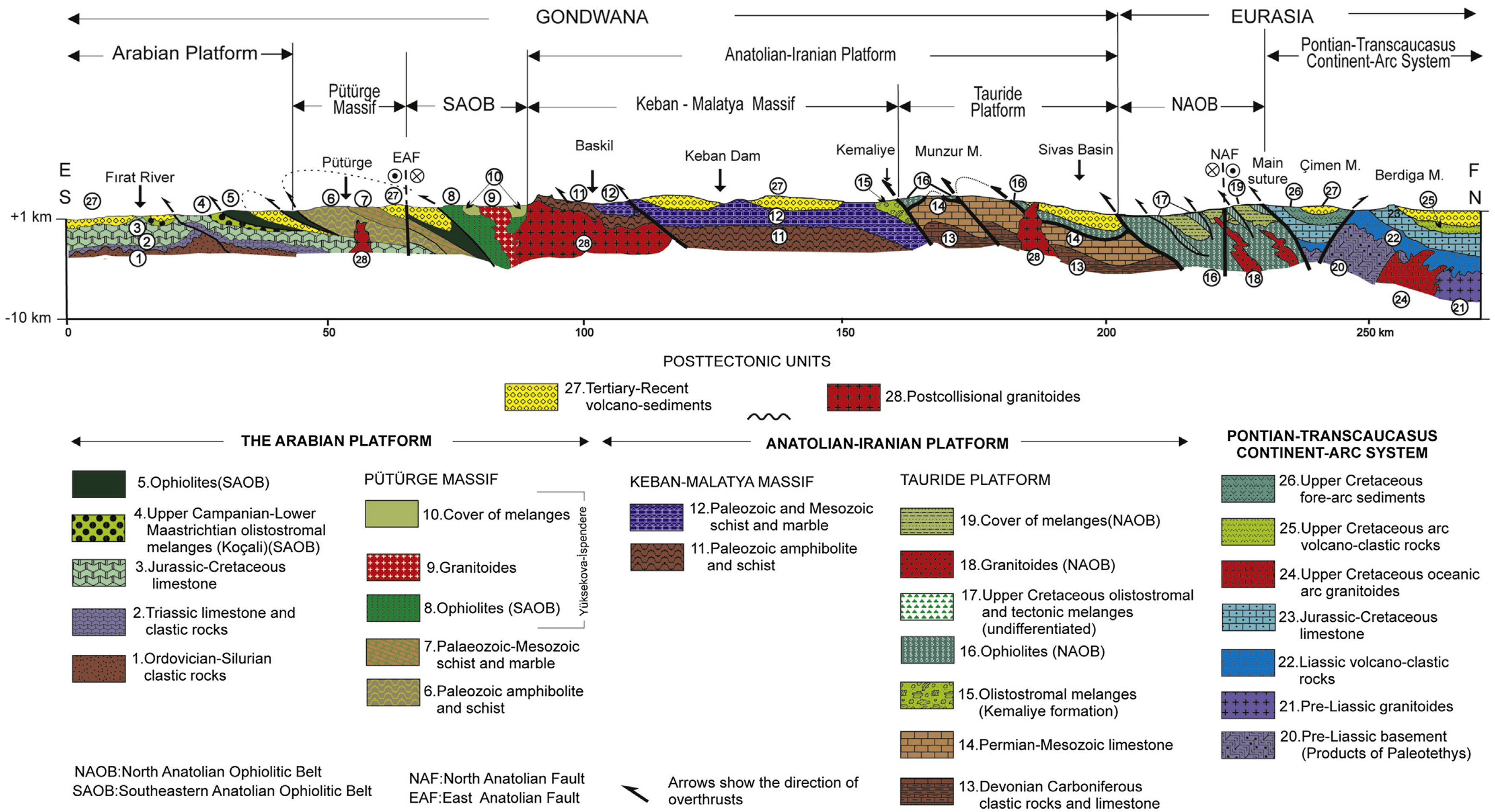

Figure 5. Geological cross-section (E–F) from the Pontian–Transcaucasus Continent-Arc System to the Arabian Platform in Turkey (After complementary data by Özgül, 1981; Yazgan, 1983; Yılmaz, 1985a and new interpretations). See Fig. 1 for location.

fragments and the suture zones separating them will be described in the following sections.

3.1. The Scythian Platform

The Scythian Platform represents a southern part of the Eurasian continent. The metamorphic rocks of greenschist facies as the remnants of this platform are exposed in the form of tectonic slices within the Greater Caucasus zone (Belov, 1981; Adamia et al., 1987, 2011; Nikishin et al., 1998, 2012; Dercourt et al., 2000; Somin, 2011).

Precambrian (?)–lower Palaeozoic volcano-clastic rocks forming lowermost part of the platform, undergone greenschist metamorphism and was intruded by middle–late Palaeozoic granitoids, which are products of Variscan orogeny. The lower–middle Palaeozoic fine-grained terrigenous clastics overlie the older units and then together have subsequently undergone low-grade metamorphism. These sediments were intruded by the upper Palaeozoic granitoids (Belov et al., 1978; Adamia et al., 1987; Somin, 2007, 2011). Carboniferous–Triassic molasse unconformably overlies the older Palaeozoic rock units and is overlain unconformably by the lower Jurassic clastics with calc-alkaline volcanics. These volcanic rocks change upwards to Jurassic–Cretaceous platform carbonates and then to early Palaeogene clastics (Adamia et al., 1984) respectively (Fig. 2 and log 1).

3.2. Tectonic zones of the Greater Caucasus

The Greater Caucasus is located between Black Sea and Caspian Sea and represented by a northwest–southeast trending mountain range more than 1100 km long as the former active margin of the Scythian Platform.

Along the Greater Caucasus, the Carboniferous–Triassic molasse unconformably overlies the Palaeozoic rock units of the Scythian Platform and also northernmost (Main Range Zone) tectonic units of the Greater Caucasus together. After the Triassic period, this region was rifted again and new basins developed during the Mesozoic. Therefore, the Greater Caucasus region can be divided into the following tectonic zones (Figs. 1 and 2) which are, from north to south, (1) the Laba–Malka Zone (the Bechasin and the Fore Range subzones), (2) the Main Range Zone, and (3) the Southern Slope Zone, representing back arc, arc and fore-arc tectonic settings respectively (Adamia et al., 1984, 2011). These tectonic units, in fact, may have represented the southern active margin of the East European Platform.

3.2.1. The Laba–Malka Zone

The Laba–Malka Zone is composed of two subzones namely, the Bechasin and the Fore Range subzones which belong to the southern edge of the Scythian Platform. Characteristic features of these subzones are presented in the following.

3.2.1.1. Bechasin subzone. It is located at the northernmost part of the Greater Caucasus mountain system. From tectonic point of view, this subzone is the southernmost basement exposure of the Scythian Platform. In the Bechasin subzone, the Lake Baikaline basement is represented by metavolcano-sedimentary and metamorphic rocks. It includes a greenschist-blueschist basement and overlying transgressive sedimentary cover. The new age data (486 ± 2.6 Ma) on zircons of metapsammite of the Boulgen complex demonstrated that both units are lower Palaeozoic in age although tectonic wedges of Cadomian basement also exist there (Somin, 2007, 2011). Cambrian–Silurian clastics unconformably overlie the basement and pass upwards into the Silurian–early Carboniferous terrigenous clastics and carbonates (Belov et al., 1978). The middle Carboniferous–Permian molasse unconformably overlies the older rock units, whereas the Mesozoic cover is here in a subhorizontal position.

During the Jurassic, new basins developed on the molasse. On the basis of lateral and vertical facies changes of Liassic and post-Liassic rocks, the Laba–Malka zone has been divided into three subzones, the Bechasin and the Fore Range subzones of the Northern Slope, and the Calcareous subzone of Daghestan. The lower–middle Jurassic terrigenous sediments unconformably overlie the older rock units, which contain coal and calc-alkaline volcanic rocks (Adamia et al., 1984).

3.2.1.2. Fore Range subzone. The rock units of relative autochthon in the north and allochthon in the south indicate widespread lateral and vertical facies changes. The Fore Range subzone is mainly composed of sedimentary, volcanic and plutonic rocks of early–middle Palaeozoic age (Omelchenko and Belov, 1983). The succession of the relative autochthon is represented by lower Palaeozoic metavolcano-sedimentary rocks and Silurian–Devonian clastics containing tuff, basaltic lava sheets and olistostromal levels derived from ophiolites (Khain, 1984). The new data indicate that the lowermost unit of this zone remarkably displays an ensimatic type HP/LT island arc setting with tectonically overlying ophiolite (Somin, 2011). Devonian–lower Carboniferous terrigenous deposits with volcanic intercalations overlie the older rocks with a local unconformity and represent the island arc sequence (Fig. 2) (Adamia et al., 1984).

3.2.2. The Main Range zone

This zone is situated to the south of the Laba–Malka and Fore Range subzones corresponding approximately to the main axis of the Greater Caucasus. It consists of various metamorphic and magmatic rocks of Palaeozoic age (Adamia et al., 1984, 2004, 2011; Somin, 2007, 2011).

The lowermost level of this zone is made up of lower–middle Palaeozoic gneisses, migmatites, Variscan I and S-type granitoids and amphibolites, interlayered with schists including recrystallized and crinoidal limestone lenses. This sequence was undergone metamorphism in amphibolite facies during Variscan orogeny and intruded by upper Palaeozoic granitoids (Adamia et al., 1987; Somin, 2007). Middle and upper Carboniferous–Permian molassic sequence unconformably overlies the metamorphic-magmatic complex (Belov, 1981).

In the Main Range zone, middle Carboniferous–Permian molasse and lower–middle Jurassic volcano-sedimentary rocks unconformably overlie the older Palaeozoic units and upwards are overlain by the upper Jurassic–Cretaceous carbonates with a local unconformity. This unconformity probably developed during the middle–late Jurassic granite intrusion. Paleogene clastics overlie unconformably the Cretaceous carbonates along this zone (Fig. 2).

3.2.3. The Southern Slope Zone

It is the boundary zone of the Greater Caucasus situated to the south of the Main Range zone. The oldest rocks of this zone outcrop along the Svaneti Uplift named as Dizi Series by Kutelia (1983). The lower part is represented by a Devonian semi-pelagic to clastic sequence with cherts, turbidites, volcano-clastic rocks and marbles (Fig. 2, log 5). This level passes upwards into Carboniferous–Triassic semi-pelagic clastic rocks deposited in a marginal sea located at the north of the PTCAS.

Along the Southern Slope Zone, the lower–middle Jurassic volcano-sedimentary rocks overlie the Triassic rocks with a local unconformity. An upper Jurassic–Paleocene sequence is represented by an alternation of turbiditic clastics and clayey limestones and upwards passes into the Eocene terrigenous turbidites with olistostromal levels.

The Dizi basin was the relict of Protottethys and might have been represented the northern passive margin of Transcaucasian island-arc system. The Dizi basin was continuously developed throughout the Palaeozoic although it was affected by the Variscan and Eo-Cimmerian tectonic events which were caused the Basin only getting narrowing, but not completely closed. Thus the Dizi basin development continued during the Mesozoic–early Cenozoic (Adamia et al., 2011). The Dizi series was connected with Transcaucasian massif and its northern vergence seems to reflect southward subduction of the ensimatic-type island arc crust (Somin, 2011).

The Great Caucasus represents an intracontinental tectonic system originating from structural inversion of a Palaeozoic–Mesozoic and early Cenozoic back-arc basin (Dizi basin) during late Cenozoic in response to the convergence of the Africa–Arabian and Eurasian lithospheric plates. However, there is no a direct evidence of initial contact relationship between ophiolitic units and Dizi series and also conformable boundary between Jurassic and pre-Jurassic units (Figs. 6 and 7).

In the Southern Slope, the south-vergent isoclinal folds and south directed overthrusts are widely observed. These structures are the products of progressive deformation developed during the fore-arc evolution. From this zone to the Transcaucasus (Median) Massif, the pelagic facies change laterally from shallow marine to continental facies.

The Oligocene–lower Miocene Maycopian series are represented by a molasse, including continental deposits from conglomerate, sandstone, claystone to sandy-argillaceous gypsiferous facies that overlie in places the older rock units unconformably and also continuously surround the Greater Caucasus.

3.3. *The Greater Caucasus Suture Zone (GCSZ)*

The Scythian Platform with its former active margin is separated from the PTCAS by the Greater Caucasus Suture Zone.

The Atsgara (Rechepsta) Composite Complex was previously described for first time as an allochtonous oceanic mass overlain by the Devonian volcano-sedimentary sequence, at Abishira–Akhuba and Dzhuga localities (Baranov and Grekov, 1980).

The ophiolitic rock exposures occupy a medial position between the Main Range and Southern Slope zones of the Greater Caucasus. The series of the ophiolitic complex is tectonically inverted, i.e. there is a structurally descending order from the “sole” metabasite to hyperbasite, gabbro, basalt and sedimentary cover. The sheeted dykes are observed in some localities. The structurally upper unit of the complex is ultrabasic rocks represented by a series of tectonic slices and allochthonous bodies. They consist of serpentinized harzburgites composed of enstatite-bronsite, olivine, diopside and abundant secondary minerals such as antigorite, bastite, tremolite-actinolite amphibole, chlorite, talk, carbonate and magnetite (Somin, 2011).

The Pass area of the Main Range zone is supposed to be the root zone of this suture. The ophiolites of the region are interpreted as the products of the Greater Caucasian Suture zone. Based on the data it is to proposed that the main subduction zone of the Greater Caucasus was disposed in the southernmost part of the Main Range zone, magmatic and metamorphic events within this zone were probably associated with the activity of this subduction zone during the middle Palaeozoic (Somin, 2011). The Main Caucasian Thrust Fault separates pre-Jurassic crystalline rocks of the Main Range Zone from those of Southern Slope and the Transcaucasus pre-Jurassic crystalline units (Figs. 6 and 7).

In fact, there is no a common agreement on the location of the GCS and it is still under debate. For instance, the Dizi series of the Southern Slope Zone of the Greater Caucasus have been interpreted as the northern margin of the Pontian–Transcaucasus fragment (Şengör, 1984; Yılmaz, 1989). In contrast, the Dizi series and overlying cover have been interpreted as the fill of a diachronous basin developed between the active margin of the Scythian Platform and the Pontian–Transcaucasus fragment (Yanev and Adamia, 2010). This is another interpretation related to the location of the GCS. By considering the framework of these interpretations, it is possible to suggest that the location of the GCS is somewhere between the Southern Slope Zone and the PTCAS, as seen in Fig. 2.

The suturing of the Transcaucasus Massifs into the Eurasian continental margin had been completed by the 330 Ma and was followed by the emplacement of the Granitic series (Shavishvili, 1983; Somin, 1991, 2011; Zakariadze et al., 2007). The upper Carboniferous–Triassic molasse containing coal levels and local volcanic intercalations unconformably overlie these units and ophiolites presented above.

In general, the allochthonous rock units of the Greater Caucasus are represented by a complex comprising diabase, microgabbro (dyke complex), gabbro-norite and serpentinized harzburgite. On the basis of the K-Ar age data, the age of ophiolites ranges between 360 and 370 Ma, corresponding to middle–late Devonian (Khain, 1984). However, Knipper (1980) suggested that the ophiolites were of pre-Silurian in age and interpreted them as the crust of a marginal sea which obducted on island arc sequence to the north at the beginning of the early Carboniferous.

Detailed geochemical studies show that the composition of metabasite series of the Palaeozoic metaophiolitic complexes, forming the southern margin of the crystalline core of the Greater Caucasus, corresponds to the T-type MORB and supra-subduction (SSZ) settings. The accretion of these ophiolites to the continental fragments was occurred during the middle Palaeozoic, apparently, at the boundary of the early–middle Carboniferous (Adamia et al., 1978, 2004; Sun and McDonough, 1989; Zakariadze et al., 2012).

In addition, the early Mesozoic evolution of the Greater Caucasus, Triassic–Jurassic sedimentary and magmatic history indicate rifting and back-arc related events (McCann et al., 2010; Adamia et al., 2011). Then, Mesozoic–early Tertiary stratigraphies of the Scythian Platform and Transcaucasus region can be correlatable as the Eurasian units. Because, both stratigraphic units unconformably overlie the older units and start with conglomerate and sandstone alternation with volcanic interlayers and pass into the platform type carbonates. There are no pelagic deep marine strata, depicting the existence of an oceanic basin. In this framework, there is no new formation of the oceanic basin along the Greater Caucasus during Mesozoic and Cenozoic times.

The Mesozoic Tethys in the Greater Caucasus was inherited from the Palaeotethys. In the Mesozoic and early Cenozoic, the Greater Caucasus and Transcaucasus were a counterpart of the northern Tethyan realm, the southern active margin of the Eurasia lithospheric plate, and the Oligocene–Neogene and Quaternary basins situated within the Transcaucasian intermontane depression mark the syn- and post-collisional evolution of the region (Sosson et al., 2010; Adamia et al., 2011). To the south of the Palaeotethys, a long strip of microcontinenetal blocks rifted away from north of Gondwana at the end of the Palaeozoic. As parts of Turkey and Iran, these blocks are collectively known as the Cimmerian blocks as their original contiguity is questionable (Brunet et al., 2009).

Along the Greater Caucasus, the north-dipping Alpine overthrusts are dominant, in spite of presence of local south-directed ones. For this reason, the tectonic setting of the suture zone along the Greater Caucasus has been discussed for a long time. On the basis of geophysical data and field-studies (Adamia et al., 1984, 1991), the main pre-Alpine overthrust is thought to have developed along the southern contact of the Greater Caucasus meta-ophiolites and the suture may originally be northward polarity.

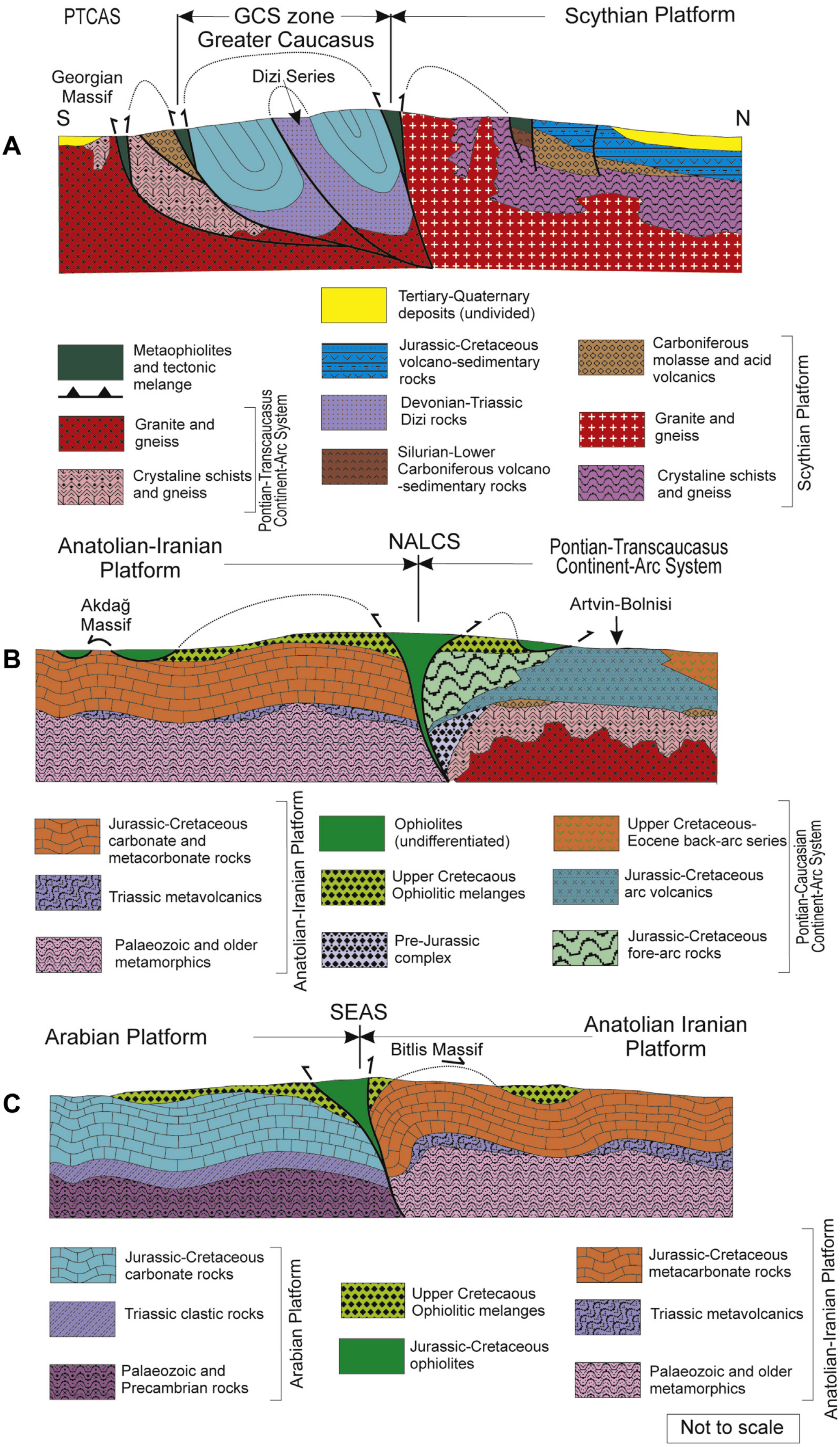

Figure 6. Interpretative cross sections along Geotraverse showing main structural relationships between the Scythian Platform and the Arabian Platform. A: GCS (Great Caucasus Suture) and PTCAS (Pontian–Transcaucasus Continent-Arc System), B: NALCS (North Anatolian–Lesser Caucasian Suture), C: SEAS (Southeastern Anatolian Suture). See Figs. 1 and 7 for location.

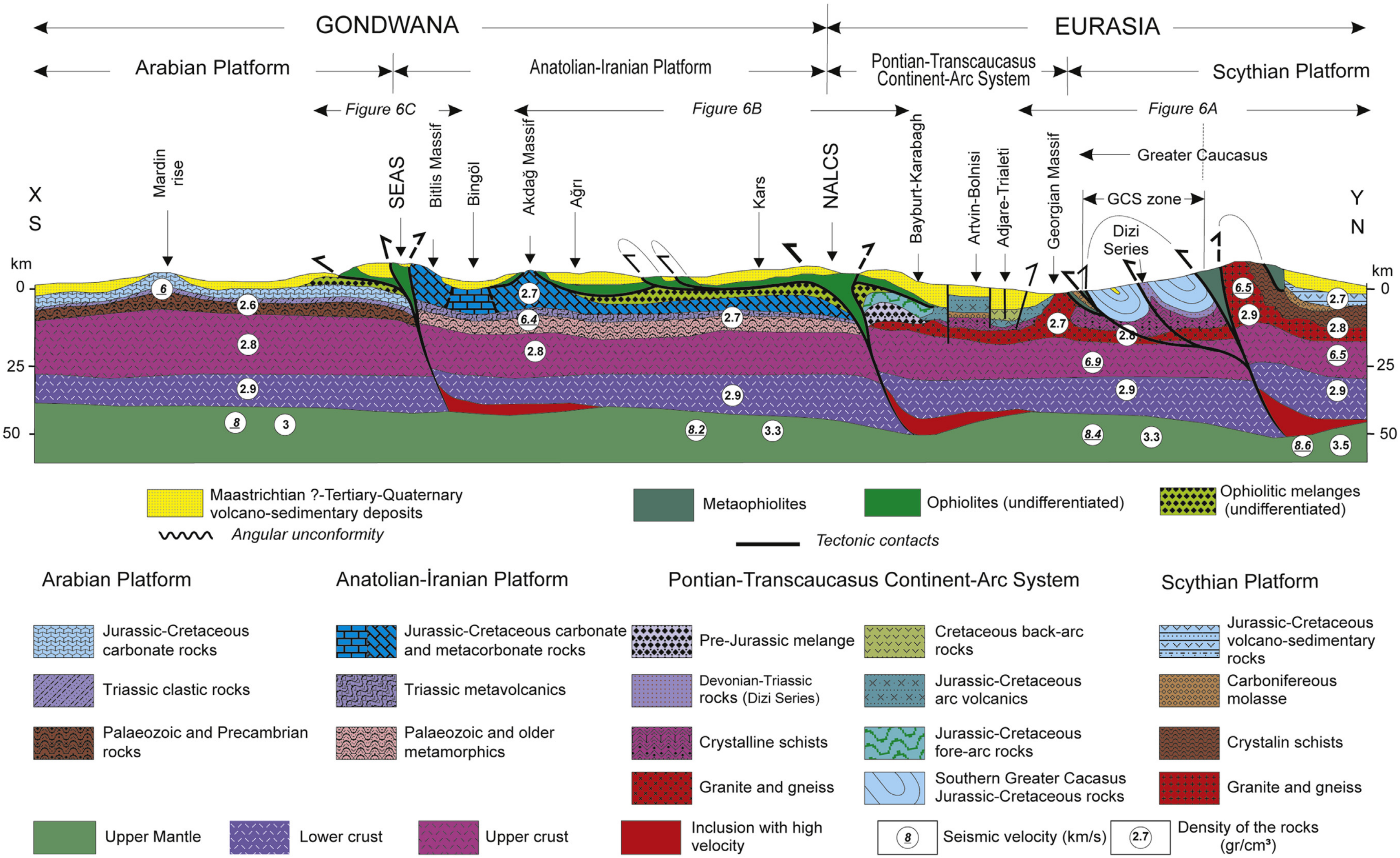

Figure 7. Cross-section (X–Y) based on the integrated geological and geophysical data of the area along the geotraverse. See Fig. 1 for location.

As a result, it can be summarized that the MORB-type and supra-subduction (SSZ) ophiolites are exposed along GCS, as some of them are in late Visean age. The present-day configuration of the ophiolites shows a flower structure, represented both by the north- and south-dipping overthrusts (Fig. 4). The incipient collision along the suture started to develop during the Carboniferous and ended at least before the Oligocene.

3.4. The Pontian–Transcaucasus Continent-Arc System (PTCAS)

The Pontian–Transcaucasus Continent-Arc System is situated between the Southern Slope Zone of Great Caucasus Suture in the north and the North Anatolian–Lesser Caucasus Suture in the south (Figs. 1–4). The $^{40}Ar/^{39}Ar$ ages from the Transcaucasus massifs provide insights into the long duration of magmatic activity from Variscan to Alpine history of the Eurasian margin (Roland et al., 2011).

In spite of complexity of PTCAS, it is well known that the system, in general, acted as an active continental margin during Palaeozoic–Cretaceous. For this reason, it was named as the Pontian–Transcaucasus Continent-Arc System (Adamia et al., 1997; Yılmaz et al., 2010).

The Palaeozoic massifs are Dzirula (and/or Georgian) massif to the north and Khrami, Murguz, Loki and Artvin massifs to the south. The Dzirula massif is made up of late Proterozoic ultramafic-metabasite units, Precambrian–Palaeozoic gneisses and migmatites, Cambrian–Devonian metavolcano-clastic rocks and phyllites. These units, in general, have been delineated by tectonic contacts. There may be an unconformity between Cambrian–Devonian rocks and metamorphic complexes. In these massifs, the reefal limestones with Brachiopoda, Corals, Foraminifera and Sponges of late Visean–Namurian age are cropped out. Carboniferous rhyolitic calc-alkaline volcanics are also exposed in the massifs (Yanev and Adamia, 2010).

In general, upper Carboniferous–Permian molasse is commonly observed in the Pulur massif along the eastern Pontides at the Turkish part (Akdeniz, 1988; Akdeniz et al., 1994; Okay and Leven, 1996) and also along the PTCAS in the Georgian and Khrami Massifs in Georgia (Belov et al., 1978). Therefore, it can be suggested that the Scythian Platform and the PTCAS once represented one continental fragment, at least during late Carboniferous–Permian times. Triassic units of the Karakaya Complex include volcano-clastic units along the southern side of this system crop out along southern of the central and western Pontides. But this complex may have been accreted to the NALCS along eastern Pontides and Caucasus.

At the beginning of the Jurassic, new basins were developed both along the Scythian Platform and PTCAS. Therefore, it can be suggested that the whole region, from the Scythian Platform to the PTCAS, was under the effect of the extensional tectonic regime at this time. The Liassic and post-Liassic units of the PTCAS have been divided into several zones, which are from north to south, the Georgian Massif and the Gagra-Djava zone, the southeastern Black Sea coast–Adjara–Trialeti zone, and the eastern Pontide–Somkheti–Kafan (Garabagh) zone including the Artvin–Bolnisi and Bayburt–Garabagh units.

3.4.1. Georgian block and Gagra–Djava zone

The lower–middle Jurassic volcanoclastic rocks unconformably overlie the older rocks. Calc-alkaline volcanics, including massive sulphide deposits, occurred in the island-arc/back-arc basins during the Bajocian. Upper Jurassic–lower Cretaceous gypsum-bearing clastics, alkaline volcanic levels and platform carbonates overlie the Bathonian coal-bearing clastics and Bajocian volcanics with a local unconformity. This level is conformably followed upward by Neocomian limestones, Albian–Cenomanian carbonates and clastics, Senonian alkaline volcanics (Beridze et al., 1984) and upper Cretaceous–lower Tertiary carbonates and clastics. It has been accepted that the back-arc and inter-arc basins occurred at the eastern part of this zone during late Jurassic.

3.4.2. Southeastern Black Sea coast–Adjara–Trialeti zone (SEBATZ)

It is situated between the Georgian Massif to the north and Artvin–Bolnisi Unit to the south. This zone is represented by a NE–SW trending structural unit and extending from the Iori River in the east to the southern Black Sea coasts in northern Turkey (Yılmaz et al., 2000, 2001). Its northern margin is delineated by a northward-directed overthrust. The southern border is not clear, as it has the same basement as the Artvin–Bolnisi Unit.

Within the SEBATZ, Aptian–Turonian volcano-clastics and Turonian–Senonian limestones constitute the lowermost part in Georgia (Gamkrelidze, 1964; Nadareishvili, 1980). The Paleocene–lower Eocene turbiditic clastics conformably overlie the Maastrichtian–Danian limestones which are also resting conformably on the arc association of Pontian and Artvin–Bolnisi unit in southern Georgia and Turkey. The middle Eocene sequence includes, from bottom to top, tuff, turbiditic and basaltic volcanics, dellenitic volcanics and also basaltic volcano-clastic rocks and passing upward into the upper Eocene terrigenous turbiditic and shoshonitic volcanics conformably. The thickness of the sequence is not less than 5 km. The lower part of middle Eocene basaltic volcanics is represented by the back-arc basin, whereas the upper part of middle Eocene and upper Eocene shoshonitic volcanics indicate the characteristics of the mature arc volcanism (Lordkipanidze et al., 1984, 1989).

It was previously suggested that the southern tectonic contact of the Adjara–Trialeti Zone continues from the Turkish–Georgian border directly into the Black Sea Basin (Pejatovic, 1971). After a structural correlation made between the southern Transcaucasus (Georgia) and eastern Pontides (Turkey), it is concluded that the Adjara–Trialeti zone and southern Transcaucasus are equivalent to the eastern Pontides and eastern Black Sea basin. In addition, after revising the extensions of the units in the region, it is claimed that the southern tectonic contact of the Adjara–Trialeti Zone continues along the easternmost Black Sea Coast in Turkey (Yılmaz, 1989a,b; Yılmaz et al., 2000, 2001).

3.4.3. Eastern Pontide and Somkheti-Kafan (Garabagh) zone

It represents the southern Transcaucasus, which is the eastern continuation of the Pontian zone (Figs. 1 and 4). The eastern Pontide Arc is represented by a palaeo-convergent-plate margin and continental-arc system. The arc system was formerly active during the late Cretaceous in its western part (Bektaş, 1984; Okay and Şahintürk, 1997), but was active during the Jurassic–Cretaceous in its eastern part (Adamia et al., 1977, 1995). This difference is generally interpreted to have resulted from interference between a spreading ridge and a subduction zone developed during the late Jurassic–Cretaceous along the lesser Caucasus and southern side of the eastern Pontide Arc (Yılmaz et al., 2000).

The eastern Pontide Arc consists mainly of submarine and terrestrial volcanic rocks, intercalated with marine sediments and granitoid intrusions in an extensional-arc setting (Okay and Şahintürk, 1997). At the easternmost part of this arc, the magmatic activity ceased before the Maastrichtian age but restarted again during the Eocene (Yılmaz et al., 2000).

This zone is located to the north of the lesser Caucasian Ophiolitic Belt and is divided into two subunits, the Artvin–Bolnisi unit to the north and the Bayburt–Garabagh Imbricated unit to the south.

3.4.3.1. *Artvin–Bolnisi unit.* It extends from the Artvin area in the west to the southern coast of Caspian Sea in the east. Although the northern border is less distinct than the southern one, it adjoins strongly deformed and imbricated Mesozoic basalt and black shale assemblages of the Bayburt–Garabagh unit. The Artvin–Bolnisi Unit is composed of a migmatitic core and gneissic envelope observed at the lowermost part of the Khrami, Loki and Murguz massifs (Fig. 4). Carboniferous subaerial acidic volcano-sedimentary rocks unconformably overlie the metamorphic rocks in these massifs (Adamia et al., 1984, 2011).

^{40}Ar/^{39}Ar incremental dating on muscovite and biotite fractions from the mica schists and fine-grained gneisses of the Kurtoğlu metamorphic complex in Gümüşhane area yielded plateau ages of ~323 Ma, representing Variscan orogenesis (Topuz et al., 2007). The Gümüşhane pluton has a high-K calc-alkaline I-type granodiorite/granite complex, cutting the Precambrian–lower Palaeozoic units. The pluton forms an important component of the pre-Liassic basement of the eastern Pontides, which is regarded as a late phase of Hercynian orogeny in the eastern Pontides (Topuz et al., 2010).

This rock association, Carboniferous–Permian molasse and shallow marine carbonates are unconformably overlain by lower–middle Jurassic clastics and calc-alkaline arc volcanics. The sequence is then followed by upper Jurassic–lower Cretaceous carbonates and clastic rocks, upper Cretaceous alkaline and calc-alkaline arc association, Maastrichtian–Danian carbonates, Paleocene–lower Eocene clastics, middle Eocene calc-alkaline volcano-clastic rocks and upper Eocene clastics with local unconformities. Topuz et al. (2011) and Eyuboğlu et al. (2013) also suggested that Eocene adakite-like magmatism represents post-collisional magmatism.

3.4.3.2. Bayburt–Garabagh unit. It lies between the Artvin–Bolnisi unit and the North Anatolian–Lesser Caucasus ophiolitic belt, in area from Bayburt to Garabagh. It is made up of, at least, pre-Maastrichtian rock units of different origin and tectonostratigraphic zones, some of which are small outcrops of a crystalline basement. These rock types are upper Carboniferous flora-bearing andesitic volcano-clastics and lower–middle Jurassic black slates with shallow marine limestone and deep-marine radiolarian chert-bearing turbidites (Adamia et al., 1987).

Jurassic–Neocomian limestones and volcanics, which are cut by small intrusions of the granitoids and diorites, upper Cretaceous turbiditic and volcano-clastic sequence, strongly deformed and intersliced with ophiolites of the North Anatolian–Lesser Caucasus Belt. These deposits are deformed into south-vergent isoclinal folds and displaced by imbricated thrust faults. Therefore, the boundary relationships between rock types are tectonic. In addition, the Bayburt–Garabagh unit of the Lesser Caucasus is interpreted as a fore-arc association and the Eocene transgressions are recorded on Liassic, late Jurassic, Albian–Cenomanian, Maastrichtian and Paleocene units (Lordkipanidze et al., 1989).

The area, from the SEBATZ in the north up to the Imbricated Bayburt–Garabagh unit in the south is known as the arc-related associations in Turkish side (Yılmaz et al., 2000). However, from north to south, the system can be defined by back arc, arc and forearc assemblages, mainly during the Cretaceous (Gedikoğlu et al., 1979; Özsayar et al., 1981; Bektaş, 1984; Okay and Şahintürk, 1997; Yılmaz et al., 2000). The Pontides can be separated from the Anatolian–Iranian platform (Yılmaz et al., 2000) by the NALCS (Yılmaz, 1985a; Okay and Tüysüz, 1999).

3.5. North Anatolian–Lesser Caucasian suture (NALCS)

This suture zone is generally accepted as being the major Tethyan suture in Turkey and surrounding regions. It is situated between the PTCAS to the north and the Anatolian–Iranian Platform (AIP) to the south (Figs. 4 and 5), where the ophiolites of this belt are divided into two "subzones" indicating considerable similarities (Yılmaz, 1989a; Yılmaz et al., 2000). These are: (1) Ankara–Erzincan/Sevan–Akera–Zangezur Ophiolitic zone located to the north and (2) northern Tauride–Tecer–Divriği–Erzurum–Kağızman/Vedi Ophiolite located to the south.

The Tecer–Divriği Ophiolites situated at southeast of the Sivas province are interpreted by Koçyiğit (1990) as a product of the Inner Tauride Ocean of Şengör and Yılmaz (1981). These ophiolites, continuing eastward to Erzurum–Kağızman and also the Vedi Zone of the Lesser Caucasus and Khoy ophiolites in NW Iran, may also have been the products of the northern branch of the Neo-Tethyan Ocean. In fact, they are connected to each other beneath the Maastrichtian–Tertiary cover of the Sivas Basin (Yılmaz and Yılmaz, 2006). This phenomenon is also known within the Lesser Caucasus (Sosson et al., 2009, 2010), where the allochthonous disposition of the Vedi Ophiolites was confirmed by Knipper (1980). As a result, the ophiolitic rock units of the northern and southern subbelts may have been the products of the same suture.

In Turkey and also in the Lesser Caucasus, the ophiolites are mainly made up of serpentinite and ultrabasic rocks, layered gabbro, dyke complex and volcano-sedimentary cover (Fig. 3), but lacking of a complete ophiolitic sequence in the most localities, both at north and to the south of the suture zone. The age of ophiolites along this belt ranges from Palaeozoic to late Cretaceous (Zakariadze et al., 1983, 2007; Yılmaz, 1989a; Knipper, 1990). Therefore, Adamia et al. (1981) and Nikishin et al. (2012) suggested the existence of Palaeotethys along this suture, as well. On the other hand, Transcaucasus massifs include Neoproterozoic–early Cambrian ophiolites and arc assemblages together and provide evidence for pan-African crustal evolution, as a Paleo-Tethyan subduction zone dipping beneath the southern margin of Eurasia (Zakariadze et al., 2007).

It is agreed that Jurassic–lower Cretaceous volcanics of ophiolites are represented by MORB-type/SSZ-type tholeiites and boninitic series (Zakariadze et al., 1983), whereas upper Cretaceous volcanics of ophiolites are represented by island arc type basaltic rock series. On the basis of Radiolarian fossils, middle Jurassic (Bajocian) age obtained from the Vedi Ophiolite (Danelian et al., 2008). In addition, the Sevan–Akera Ophiolites are represented by MORB-type boninitic and alkaline series and ^{40}Ar/^{39}Ar age method on amphibole-bearing gabbros yields a middle Jurassic age (165.3 ± 1.7 Ma) (Galoyan et al., 2009). It may imply to the age of oceanic crust formation.

Pre-Liassic and Jurassic–Cretaceous ophiolites are amalgamated with each other, not only in Turkey but also in the Caucasus due to tectonic deformations (Adamia et al., 1978; Knipper, 1980; Yılmaz, 1981a, 1989a; Zakariadze et al., 1983; Yılmaz and Yılmaz, 2004). It has been confirmed later on that, this suture includes MORB and SSZ-type ophiolites together in Turkey (e.g., Okay and Şahintürk, 1997).

Many tectonic models on the polarity of the subduction zone have been suggested for the late Cretaceous–early Cenozoic tectonic assembly of the İzmir–Ankara–Erzincan (or North Anatolian–Lesser Caucasus) suture zone (Tüysüz, 1990; Okay and Şahintürk, 1997; Ustaömer and Robertson, 1997; Rice et al., 2006).

Sosson et al. (2010) in their study found evidence for the presence of two subduction zones in middle Jurassic to late Cretaceous Epoch. One of them (in a supra-subduction zone context) is responsible for the opening of a back-arc basin comparable with the ophiolites of the Lesser Caucasus. The other subduction zone developed directly to the south of the PTCAS. On the basis of Sosson et al. (2010), the obduction occurred during the late Coniacian to Santonian and the collision of the South Armenian Block with Eurasia started during the Paleocene.

The melanges and olistostromal deposits were developed in a compressional tectonic setting resulted in uplifting of the ophiolites emplaced on to the southern Transcaucasus zone to the north and the Anatolian–Iranian platform to the south (Knipper, 1980, 1991). Similar emplacement mechanism was confirmed by Yılmaz and Yılmaz (2004) in the area between Tokat and Sivas provinces. The age of the amalgamated deposits ranges from Triassic to early Coniacian within the Lesser Caucasus (Zakariadze et al., 1983; Knipper, 1991), whereas is late Campanian–Maastrichtian in the North Anatolian region (Yılmaz, 1981b).

On the other hand, the blueschists in metaophiolites are recorded both in northwest Turkey (Okay et al., 2006) and northern Armenia (Roland et al., 2009) and dated as 100–90 Ma and 95–80 Ma respectively, which indicate the emplacement period of ophiolites. In addition, it is also suggested that the ophiolites obducted before the late Coniacian (Gasanov, 1986) and/or, at least before Paleocene (Sosson et al., 2010); in the east, whereas before the late Campanian in the west (Yılmaz and Yılmaz, 2006). Rice et al. (2009) suggested that upper Paleocene–Eocene clastics are the oldest unit unconformably overlying the upper Cretaceous melange in the Erzincan area. Their idea is not valid in a regional framework since the reworked materials of ophiolites and melanges in the upper Paleocene–Eocene sequence have not been separated from the upper Cretaceous accretionary prism in the study area by this research group.

In addition, Rice et al. (2006) claimed that the incipient 'soft' collision was followed by widespread Paleocene–early Eocene deposition of shelf carbonates and coarse clastic sediments on deformed and emplaced accretionary mélange, arc and ophiolitic units. Final closure of the northern Neotethys was occurred during the middle Eocene, resulted in development of large-scale southward imbrication with north-directed backthrusting in some areas. Roland et al. (2012) pointed out that the collision along this zone occurred during Eocene. Ustaömer and Robertson (2010) proposed that the Artvin region was telescoped during the middle Eocene continental collision. They also claimed that the geological evolution of the region may have been correlated with the Pontides further west and the southern and northern Transcaucasus to the east. It is well known that middle Eocene clastic rocks unconformably overlie the older tectonic units and also ophiolitic rock units in the eastern Pontides (Yılmaz, 1985a). It has been then suggested that the collision within the suture zone may have been started in the Paleocen–Eocene at the NW Turkey (Okay and Whitney, 2010), before middle Eocene in the NE Turkey (Topuz et al., 2011), and before Oligocene–early Miocene in the Caucasus (Adamia et al., 2011).

The structural elements and their evolutions, which are responsible for the emplacement of the ophiolites, are well-defined mainly between Tokat and Sivas provinces (Yılmaz and Yılmaz, 2004). In this area, the structures reflecting the emplacement of the ophiolitic rock units display a pattern of flower structure and similar structures are dominant on both side of the suture zone.

In conclusion, a preferable tectonic model for the NALCS zone involves a northward subduction of continental margin arc magmatism in the north and SSZ zone in the south. MORB- and SSZ-type ophiolites occurred respectively within the northern branch of Neotethyan Ocean (or the Tethyan Ocean). The age of the ophiolites ranges from Palaeozoic to late Cretaceous–Eocene (Khoy ophiolites) and collision in the suture zone may have been occurred at least before middle Eocene–Oligocene. The emplacement of ophiolites shows a flower structure, reflecting the north- and south-dipping overthrusts.

3.6. *Anatolian–Iranian Platform (AIP)*

The Anatolian–Iranian Platform (AIP) is located between the NALCS and SEAS zones and consists of metamorphic equivalents such as the central Anatolian and eastern Anatolian (Akdağ) massifs to the north, and the Keban–Malatya and Bitlis Massifs to the south. The subplatform concept for Iranian part, which represents the northern part of Gondwanaland, was proposed by Belov (1968). The metamorphic rocks and Devonian limestones of the Miskhan–Zangezur zone of the Lesser Caucasus represent the northernmost part of the Anatolian–Iranian Platform (Belov, 1981; Adamia et al., 1984).

The massifs along the northern and southern parts of the Tauride platform and also their probable eastwards continuations (Iranian part), have a lowermost level which is composed of Precambrian (?)–Palaeozoic schist, migmatite, amphibolite, marble, quartzite and phyllite. For instance, the Bitlis Massif includes a large exposure of Precambrian continental crust in which detrital zircon grains from host paragneisses yielded Neoproterozoic ages (992–627 Ma). It was affected by Cadomian arc magmatism representing the northern margin of Gondwanaland (Ustaömer et al., 2009, 2012).

Devonian–Carboniferous sediments and Permian neritic carbonates of the unit have undergone metamorphism in greenschist and lower facies (Belov, 1981). These rock assemlages are followed by Triassic limestones, dolomites and clastics and Jurassic–Cretaceous platform type carbonates (Fig. 3). The contacts between Palaeozoic and Mesozoic units are tectonic in places.

The Menderes Massif and central Anatolian massifs are also the metamorphic equivalents of the Tauride Platform. Precambrian, Palaeozoic and Mesozoic sequences of these massifs have been separated from each other (Dora et al., 1991; Göncüoğlu et al., 1997), and can be correlated to the Tauride Platform. The amphibolites in the massifs are originated from alkaline basalts, ascribed to the Triassic rifting event (Floyd et al., 2002).

The non-metamorphic platform, mainly the Tauride platform in Turkey has not undergone metamorphism and located between its metamorphic equivalent sub-belts. This non-metamorphic platform was divided into many subtectonic units by Özgül (1976, 1981). The lowermost part of the platform is made up of Precambrian anchimetamorphic clastic rocks deposited in shallow marine to sabkha environments (Kozlu and Göncüoğlu, 1997). They are conformably overlain by Cambrian–Carboniferous shallow marine clastics interbedded with carbonates. Permian neritic carbonates overlie unconformably the older rocks and pass upwards into Triassic carbonates including clastic interbeds. The sequence is, in turn, followed by Jurassic–Cretaceous platform type carbonates and Maastrichtian–lower Eocene semipelagic turbidites without any break in sedimentation, mainly in the Gürün basin. The middle Eocene clastics unconformably overlie the older rocks and represented by a transgressive sequence which separates the northern and southern oceanic associations from each other (Figs. 3 and 5).

The AIP, representing a passive continental margin (Adamia et al., 1984), comprises the eastern Tauride Belt (mainly the Bitlis Massif) in Turkey and Sanandaj–Sirjan Belt in Iran (Yılmaz and Yazgan, 1990). The Sanandaj–Sirjan Belt constitutes the southern continental margin of the Anatolian–Iranian Platform in Iran (Berberian and King, 1981). These sub-belts are the southern metamorphic equivalent of the AIP. The central Anatolian Massif of Turkey and the Akdağ Metamorphics of eastern Anatolia are the northern metamorphic equivalents of AIP (Yılmaz et al., 2010). Similarly, the central Iranian Massif may be the northern metamorphic equivalent of AIP as well.

The EAP (East Anatolian Plateau) is located between the NALCS zone to the north and SEAS zone to the south and considered as a part of the AIP during the palaeotectonic period. In this framework, the Bitlis Massif represents the southern metamorphic equivalent of the AIP. Although the Bitlis Massif has been interpreted as a deformed and metamorphosed part of the Arabian Platform

(Göncüoğlu et al., 1997), it is similar to the Keban–Malatya Metamorphic Unit of the eastern Tauride Belt (Yılmaz et al., 1993a) in terms of stratigraphic succession and rock units.

In conclusion, it is inferred that the SEAS zone should be placed at the southern side of the Bitlis Massif. The palaeotectonic units (platform-type deposits and mélange complexes) of the EAP were deformed pervasively and covered by relatively younger sedimentary- and volcanic-rock units (Yılmaz et al., 2010). Thus, it is difficult to observe the tectonic setting and contact relationships of the palaeotectonic units of eastern Anatolia and their lateral continuities between central Anatolia and central Iran. Nevertheless, the field data of the Hınıs (Erzurum) area indicate that a rigid continental metamorphic crust is present beneath the ophiolites and cover rocks of the EAP (Yılmaz et al., 1990).

3.7. *Southeastern Anatolian Suture (SEAS) zone*

This suture zone is the second Tethyan suture in Turkey and surrounding regions. It is situated between the AIP to the north and Arabian Platform to the south. The ophiolitic outcrops of this suture zone are exposed to the north and south of the suture zone (Fig. 1). Therefore, the location of the suture is still under debate. For instance, some suggest that the suture zone lies to the south of the Bitlis and Pütürge massifs (Şengör and Yılmaz, 1981; Yılmaz, 1993), while others argue that it is located to the north of these massifs (Yazgan, 1983; Michard et al., 1984).

Similar discussions also exist at the Iranian side. As an example, the ophiolites of the SAOB in the southeastern Anatolian region may be comparable to the ophiolites exposed in the area between Iran and Iraq (Adamia et al., 1980; Adib and Pamic, 1980; Alavi, 1994; Babaei et al., 2005) to the Semail ophiolites at north of Oman (Searle et al., 1980) on the basis of similar characteristic features, geotectonic setting and age.

The Neyriz Ophiolitic Complex occurs in NW–SE-trending Main Thrust Zone in the Zagros Range which is the equivalent of the Arabian Platform in Turkey. It is suggested that the emplacement of the Neyriz Ophiolitic Complex occurred also during the late Cretaceous and it may be considered as a product of island-arc and/or MORB-type setting. Furthermore, the uppermost Cretaceous (probably Maastrichtian)–Paleocene clastic rocks contain fragments of ophiolite-radiolarite materials, indicating subaerial weathering of the ophiolitic rocks (Alavi, 1994; Babaei et al., 2005). On the other hand, the ophiolites of the Kermanshah area are represented by the MORB- and SSZ-type ophiolites and emplaced along this suture zone between the Zagros and Sanandaj–Sirjan zones (Allahyari et al., 2010). The suture zone continues to Iran as the eastern continuation of the SEAS zone. However, the Sanandaj–Sirjan zone (Alavi, 1994) is the eastward extension of the Bitlis Massif (Yılmaz and Yazgan, 1990), which is a part of the Anatolide–Tauride Platform.

On the other hand, according to Shirdashtzadeh et al. (2011), the geochemical data of the Nain and Ashin–Zavar ophiolites point to an island arc tholeiitic affinity for the amphibolitic rocks and to a MORB nature for the pillow lavas and sheeted dykes that are related to a back-arc basin. The ophiolitic suture was developed between the Sanandaj–Sirjan zone and central–East Iranian microcontinent before middle Eocene. This suture may be the eastern continuation of the Bitlis suture in Turkey. However, on the basis of data presented by Berberian and King (1981), the Sanandaj–Sirjan unit represents the passive continental margin of the Iranian Platform. In Turkey, the Bitlis Massif is the western continuation of the Sanandaj–Sirjan unit (Yılmaz and Yazgan, 1990). Then, lower Cretaceous stratigraphic level of the Bitlis Massif reflects the passive continental margin of the Anatolid–Tauride Platform as well. In addition, the upper Cretaceous intrusive bodies of the Bitlis Massif may be the products of the subduction zone to the south of the massif as the degree of metamorphism in the Bitlis Massif decreases from lower to upper levels. In this framework, the stratigraphic and tectonic correlations presented by Yılmaz et al. (2010) and also the data shown in Figs. 5–7, as well, reveal the real location of the SEAS zone to be the south of the Bitlis Massif, but north of the Pütürge Massif. The Keban–Malatya Metamorphics and the Bitlis Massif have similar stratigraphic sequences and represent the southern metamorphic edge of the Anatolide–Tauride Platform. In contrast, the Pütürge Massif is dissimilar from both metamorphic units due to its relatively high degree of metamorphism and different rock assemblages. As a conclusion, the SEAS zone should take place between the Bitlis Massif and the Arabian Platform (Fig. 5).

The southeastern Anatolian Ophiolitic Belt (SAOB) is made up of different imbricated structural units including oceanic and island arc assemblages (Tarhan, 1985; Yılmaz, 1985b), ophiolitic melanges (Perinçek, 1979; Yılmaz et al., 1993a) and/or supra-subduction tectonic setting including arc and fore-arc environments (Parlak et al., 2009) developed in the southern branch of Neotethys (Şengör and Yılmaz, 1981; Yılmaz et al., 1993a; Robertson et al., 2006). The ophiolitic units and ensimatic arc associations in the region are considered to be in Pre-Maastrichtian age (Yazgan, 1983; Yılmaz and Yazgan, 1990; Yılmaz et al., 1993a,b,c).

Ophiolitic units are composed of ophiolitic mélanges and polydeformed rocks such as amphibolites, migmatites, pyroxenites and garnet-peridodites, cut by dioritic to granodioritic magmatic rocks that have been radiometrically (K/Ar age data) dated as Coniacian–Santonian (Yazgan and Chessex, 1991). ^{40}Ar/^{39}Ar dating of white mica from different parageneses in the Bitlis Massif reveals a 74–79 Ma (Campanian) as the date of peak metamorphism and rapid exhumation in almost isothermal greenschist stage at 67–70 Ma (Maastrichtian) (Oberhänsli et al., 2012).

The Koçali complex, as an ophiolitic mélange, partly points to a subduction mélange which formed from a possibly north-dipping intra-oceanic subduction of the ocean floor during the late Cretaceous (Yılmaz, 1993). Geochemical data from the volcanics in the Koçali Complex indicates the presence of two different type of late Triassic rock groups characterized by E-MORB and OIB-type mantle sources (Varol et al., 2011).

The ensimatic arc located to the north of the Pütürge Massif is represented by gabbro, diorite, monzonite, granodiorite and acidic volcano-sedimentary cover. The fore-arc association is represented by ophiolitic slices with shared volcanoclastic deposits of Turonian–Campanian age. This unit is interpreted as an accretionary wedge in front of the ensimatic arc in the south (Fig. 5).

The palaeontological data from pelagic sediments of the epi-ophiolitic rocks indicate that the age of the ophiolites is Jurassic–Cretaceous and they probably represent MORB- (Erendil, 1983) and SSZ-type settings (Parlak et al., 2009) together. The ophiolitic rock units of this belt are interpreted as a product of the southern branch of the Neotethyan Ocean (Şengör and Yılmaz, 1981).

The emplacement mechanism for ophiolites along the SAOB is similar to the mechanism for those along the NAOB. Along the North Anatolian Suture, ^{40}Ar/^{39}Ar ages give insights for the subduction and collage from the middle to late Cretaceous (95–80 Ma), whereas along the South Anatolian suture, late Cretaceous (74–71 Ma) ages exhibit subduction of the southern Neotethys. These data have been interpreted that a subduction jump was developed from the northern to the southern boundary of the Anatolide–Tauride Platform at 80–75 Ma (Roland et al., 2011). Most of data along SAOB show that subduction is dominant mainly during late Cretaceous. However, the Tauride Non-metamorphic Belt (crustal unit) separates the NAOB ophiolitic associations from the SAOB ophiolitic associations (Fig. 1).

The collision of the Arabian Platform with Eurasia beneath the Bitlis Massif is still debated. After the closure of the southern branch of Neo-Tethys, different ages have been proposed for collision, such as Maastrichtian (Yazgan, 1983), middle to late Eocene age (Hempton, 1985), a late Eocene to Oligocene (Yılmaz, 1993), early–middle Miocene (Robertson et al., 2007). In addition, on the basis of apatite fission track dating, uplift and final exhumation of the Bitlis range by 18–13 Ma (middle to late Miocene) has been documented (Okay et al., 2010). Moreover, the upper Miocene molasse deposits unconformably overlie the older tectonic units throughout the region. Therefore, the collision may have been ended by the late Miocene along the suture (Yılmaz et al., 1993a,b,c; Görür and Tüysüz, 2001; Koçyiğit et al., 2001; Kaymakçı et al., 2006, 2010; Gans et al., 2009; Husing et al., 2009; Okay et al., 2010; Yusufoğlu, 2013).

The north- and south-dipping overthrusts are dominant along this suture zone. For instance, north-directed overthrusts have been defined mainly at the Göksun area (Yılmaz et al., 1993a) and Gevaş area (Yılmaz et al., 2010). The south-directed overthrusts have been defined to the north of the Arabian Platform in detail (Perinçek, 1979; Yılmaz, 1993). The structures reflecting the emplacement of the ophiolitic rock units show a flower structure, which are dominant along both sides of the suture.

In conclusion, a preferable tectonic model for the SEAS zone should involve northward subductions including MORB- and SSZ-type ophiolites together. Subduction is dominant during late Cretaceous–early Tertiary, the collision along the suture may have occurred before late Miocene. Present-day configuration of ophiolite emplacement shows a flower structure, because of the north- and south-dipping overthrusts.

3.8. Arabian Platform

The Arabian Platform is a part of Gondwanaland and represents the northern part of the Arabian Continent. The lowermost level of the Arabian Platform in southeastern Turkey is the Precambrian submarine lavas and pyroclastics with shale and red epiclastic intercalations (Göncüoğlu, 1997) and overlain unconformably by Cambrian polygenetic conglomerate, sandstone, siltstone and shales, including limestone and dolomitic interbeds (Yazgan and Chessex, 1991). Ordovician, Silurian and Devonian shallow marine clastics conformably overlie the Cambrian beds. During the Carboniferous period, the region was subjected to tectonic movements resulted in uplifting and subsequently related regression implying to an unconformity. The upper Palaeozoic sequence displays an interfingering facies of subcontinental, littoral and shallow marine sediments. In general, the Cambrian to Carboniferous sequence is dominated by clastic rocks, whereas the Permian to Eocene sequence is composed largely of shallow marine carbonates (Perinçek, 1990).

The Precambrian–Palaeozoic sequences of the Anatolide–Tauride Platform and Arabian Platform have similar stratigraphic and depositional characteristics. On the basis of clay mineralogy (Bozkaya et al., 2009), the Palaeozoic sequence of the Arabian Platform around Hazro (Diyarbakır) High entirely resembles the Palaeozoic sequence of the Geyikdağı Unit (Özgül, 1976) along the eastern Taurus Belt. Since the Permian, the peri-Arabian domain represents the northern Gondwana passive margin after the drifting of the Cimmerian blocks and concomitant opening of Neotethys as well (Angiolini et al., 2003; Moix et al., 2008). In addition, it can be said that the Taurus Platform and the Arabian Platform were the same platform, at least, prior to the Mesozoic Era.

The lower Triassic sequence is represented by shales, sandstone and sandy limestone alternation. The region is characterized by a regional uplift from late Triassic to Barremian time (Fig. 3). The Barremian to earliest Turonian rocks is represented by a reefal limestone with dolomitic interbeds. After a non-depositional period during Coniacian and Santonian, a foredeep basin formed during the Campanian–early Maastrichtian time, which is represented by a flysch-type sequence; its products are derived from the ophiolites and arc-forearc deposits in the north. Upper Maastrichtian–lower Miocene shallow marine carbonates with clastics represent a foreland deposition. Eocene bimodal volcanism (Erler, 1984), related to the opening and southward propagation of foreland basins and deformation of foreland sediments are following events (Göncüoğlu, 2010).

However, Kuşçu et al. (2010) suggested that late Cretaceous–middle Eocene calc-alkaline to alkaline magmatism in the southeastern Anatolian orogenic belt represents a transition from arc to post-collisional setting and emplaced within the southeastern Anatolian orogenic belt. In addition, five different deformational phases have been recognized in the SE Anatolian orogen in the late Cretaceous–Quaternary sequence (Kaymakçı et al., 2010). The fourth deformational phase is characterized by N–S compression due to collision by the end of middle Miocene (11–3.5 Ma). Upper Miocene–Quaternary molassic clastics overlie unconformably the older rocks (Fig. 3) and represent a post collisional sequence.

4. Discussion

To evaluate the geotraverse, it will be better to make a comparison between the thickness of the crust and their recent setting of the suture belts together. In this framework, it can be said that the crustal thickness along the GCS zone reaches at least 55 km, in places, whereas it is about 50 km and 40–42 km thick in the NALCS and the SEAS zones respectively. In contrast, the crustal thickness is less than 40 km at both the Scythian Platform in the north and the Arabian Platform in the south.

4.1. The Greater Caucasus Suture (GCS) zone

In the northern part of the study area, the GCS zone (Fig. 6A) separates the Scythian Platform by its former active margin, from the PTCAS. In this area, Precambrian–early Palaeozoic units of both continental fragments have similar sequential characteristic features. There is a clear unconformity between the Precambrian and Cambrian units. Therefore, Paleo-Tethyan Ocean may have been opened at the beginning of Palaeozoic Era.

Carboniferous–Triassic continental deposits overlie unconformably the late Proterozoic–Palaeozoic rock units of the continental fragments and ophiolitic units. Therefore, incipient collision of the Paleo-Tethyan Ocean may have been essentially occurred before the Carboniferous period. On the basis of correlation between the Jurassic–Cretaceous and Tertiary sequences of the Scythian and PTCAS, it is not possible to suggest the presence of an oceanic basin between them, except long-lived the Dizi Basin (Adamia et al., 2011). After closing of the Dizi Basin, the final collision occurred along the Greater Caucasus and Oligo-Miocene molassic sediments deposited later on.

Along the Greater Caucasus, the south-directed Alpine overthrusts are dominant (Figs. 4–7), but north-directed overthrusts also occur, in places. For this reason, the tectonic setting of the suture along the Greater Caucasus has been discussed for a long time. On the basis of geophysical data and field-study observations (Adamia et al., 1984, 1991), the main pre-Alpine overthrust was developed along the contact between the Main Range Zone and Palaeozoic metaophiolites. The setting of this suture zone may originally be southeast-directed (Fig. 4).

To present the tectonic setting of suture belt and ophiolites together, the setting of ophiolites have been shown in an exaggerated way on the cross-section (Fig. 6A). In this way, it is possible to see the relationships between different ophiolitic rock exposures better than before along the Greater Caucasus. In this framework, it has been thought that ophiolitic outcrops at the Georgian Massif and the Laba-Malka–Fore Range Zone may be tectonically transported products of the Greater Caucasus Ophiolitic Belt (Adamia et al., 1978; Somin, 2011). As a result, it is thought that the ophiolites of the Greater Caucasus may have been uplifted following the collision developed between the Scythian Platform and the PTCAS and then flanking like a flower. The present-day setting of the ophiolites may have occurred after the erosion of the Greater Caucasus Mountain System in a long time.

4.2. North Anatolian–Lesser Caucasus Suture (NALCS) zone

In the central part of the study area, the NALCS zone separates the PTCAS from the AIP (Figs. 4, 5 and 6B). This suture zone demarcates the Eurasia- and Gondwana-derived fragments from each other. Therefore it is a main suture in the East Mediterranean region. Along the suture, Precambrian units and younger rock assemblages of both continental fragments have different characteristic features. For instance, Precambrian–Palaeozoic units of the PTCAS are metamorphosed basic-ultrabasic rocks, plagiogranites, granites and gneisses, whereas, Precambrian units of the AIP are made up of Precambrian crystalline and clastic rocks, together.

In addition, the Palaeozoic and Mesozoic stratigraphic sequences of the two sides are also different. For example, the PTCAS represents a continent during the Palaeozoic, Triassic, Jurassic and Cretaceous. However, in places, it represents a subduction zone and/or fore-arc environments during the Palaeozoic–Triassic periods and a typical arc and/or active continental margin during the Jurassic–late Cretaceous (Fig. 3). The PTCAS may be a part of the continental margin of Eurasia, mainly during the late Palaeozoic–Mesozoic. In contrast, the Palaeozoic and Mesozoic stratigraphy of the AIP represents a passive continental margin, which is a part of Gondwanaland.

The ophiolites and melanges in the NALCS zone are the products of the northern branch of the Neo-Tethys (Şengör and Yılmaz, 1981). On the basis of data presented above, this branch of the ocean opened in Triassic to the west, whereas in Jurassic to the east of Turkey. There are Palaeozoic and/or at least pre-Jurassic ophiolites along the suture zone as well. Therefore, the opening age of this branch is open for discussion. This branch of the ocean started to close in the Cretaceous and incipient collision between the PTCAS and AIP started at the end of Cretaceous where final collision along the suture occurred at middle Eocene.

In fact, there is no a common agreement on the collisional events between the Eurasian and Gondwana margins. It is suggested that collision started in the late Eocene (Barrier and Vrielynck, 2008; Barrier et al., 2008) and lasted until the early Miocene (Brunet et al., 2009). However, middle Eocene shallow marine clastics and limestone overlie all of the tectonic units including also ophiolites within the suture (Yılmaz, 1985a; Akdeniz, 1988; Akdeniz et al., 1994; Konak and Hakyemez, 1996; Konak et al., 2009), but also in the Lesser Caucasus (Sosson et al., 2010). This unconformity indicates that the final collision occurred before the middle Eocene, as confirmed by the geochemical data presented by Topuz et al. (2011).

Along the NALCS zone, south-directed overthrusts are dominant. In the Oltu area (Konak and Hakyemez, 1996; Konak et al., 2009) and the northern Erzurum area (Akdeniz, 1988; Akdeniz et al., 1994) north-directed overthrusts are also defined along the northern contacts of the ophiolitic units. Southern contacts of the ophiolitic units were defined by Yılmaz et al. (1988, 1990), mainly in the eastern Anatolian region and northern and southern contacts of the ophiolitic units together were studied in detail, an area between Tokat and Sivas provinces (Yılmaz and Yılmaz, 2004). These studies also present a detailed picture of the north- and south-directed overthrusts. All data indicate that the obduction of ophiolitic units resembles a pattern of flower structure.

As a result, MORB- and SSZ-type of ophiolites are exposed within the suture zone and it is thought that the ophiolites of the NALCS may have been uplifted because of the collision between the PTCAS to the north and the AIP to the south. Consequently, the ophiolites and ophiolitic melanges were emplaced like a typical flower structure to the north and south as a whole and then eroded. The present-day setting of the ophiolites and ophiolitic melanges in the area is a result of erosion and the formation of recent basins.

4.3. Southeastern Anatolian Suture (SEAS) zone

In the southern part of the study area, the SEAS zone separates the AIP in the north from the Arabian Platform in the south (Figs. 5 and 6C). The Precambrian units of both platforms have similar characteristic of rock assemblages, made up of highly altered volcanoclastic rocks and overlain unconformably by Cambrian polygenetic conglomerates. The lithologies as well as the depositional environments of the Infra-Cambrian units of the eastern Taurides can be correlated with similar units of the Arabian Platform in Turkey (Kozlu and Göncüoğlu, 1997). In addition, Palaeozoic units of both platforms can be correlated in terms of stratigraphic sequences and rock associations. Therefore, it can be suggested that both AIP in the north and Arabian Platform in the south were parts of Gondwanaland prior to the Mesozoic.

Triassic units of the AIP and the Arabian Platform are different from each other. For instance, Triassic rocks of the AIP indicate platform-type deposition and locally metamorphic with volcanic interlayers. In this platform both lower and upper contacts of the Triassic rock units are conformable whereas those of the Arabian Platform are unconformable and represented by continental to subcontinental clastic rocks. In addition, the non-depositional periods were locally developed between the late Triassic and Santonian interval and a foredeep basin formed during the Campanian–early Maastrichtian time, in which flysch-type sequence was deposited in the north of the Arabian Platform. In comparison, the AIP to the north includes a reefal limestone level between the Triassic–Campanian.

Therefore, the southeastern Anatolian ophiolitic sequences must have been occurred at the beginning of Mesozoic time, continued up to the Cretaceous, between the AIP and Arabian Platform along the southern edge of the Bitlis Massif. Upper Maastrichtian–lower Miocene shallow marine carbonates with clastic rocks and upper Miocene–Quaternary molassic clastics unconformably overlie the ophiolites, ophiolitic melanges and older rocks, respectively.

The ophiolites with mélanges in this suture zone represent the southern branch of the Neo-Tethys (Şengör and Yılmaz, 1981). All the data presented above indicate that, this branch of the ocean was opened at the end of Permian and/or beginning of the Triassic, whereas it started to close at the beginning of Cretaceous. The incipient collision started at the end of Cretaceous, before Maastrichtian. The final collision occurred before late Miocene.

Along the SEAS zone, south-directed overthrusts are also dominant. In Gevaş area (Yılmaz et al., 1981) and the Göksun area (Yılmaz et al., 1993a), north-directed overthrusts are defined along northern contacts of the ophiolitic units.

5. Conclusions

When the geological and geophysical characteristics of the geotraverse from the Scythian Platform in the north, to the Arabian Platform in the south have been reviewed and together with above discussions, the following findings have been obtained.

(1) First and inevitable finding is that, it is not necessary to put a suture zone, wherever you saw ophiolites with mélanges. It should have been seen all necessary components of different continents with subduction system between the continents. For an acceptable suture, the whole system including different continental fragments and the data showing a subduction should have been seen. The rock associations of the presented suture zones mainly comprise ophiolite and ophiolitic mélange, and fore-arc, ensimatic arc units, that is, a system of subduction as a whole. The ophiolitic associations of the all suture zones were initially emplaced with south- and north-directed imbricated structures, respectively.

(2) Second important finding is that, all presented suture zones (Fig. 7) have some common characteristic features. They all include MORB-, WP- and SSZ-type ophiolites together, but in different ages. For instance, the age of the ophiolites along the GCS zone is pre-middle Carboniferous, whereas those of within the NALCS zone are Palaeozoic and Mesozoic age. The age of the ophiolites along the SEAS zone is Mesozoic. The emplacements of ophiolites are similar and show a flower structure, because of the north- and south-dipping overthrusts along the sutures. However, it is not possible to see the whole flower structure in present-day, because of younger deformational and erosional events.

(3) The incipient collision occurred first along the GCS zone in the north, then between PTCAS and AIP along the NALCS zone and between AIP and the Arabian Platform along the SEAS zone in the south, respectively. Therefore, it can be suggested that the incipient collision migrated from north to south progressively.

(4) The continental crust along the GCS is older and thicker (approximately 55 km) than the other sutures (Fig. 7). The incipient collision occurred before middle Carboniferous at the Greater Caucasus. In addition, the time interval of this collisional process along the suture is longer than those of the other sutures.

(5) The NALCS zone is situated between the GCS and the SEAS zone. The continental crust along the NALCS is approximately 50 km thick and the age of the ophiolitic obduction is of Coniacian to Campanian interval where the collision was occurred before the middle Eocene.

(6) The continental crust along the SEAS zone is thinner (approximately 40–42 km) and younger than other sutures. The final continent-continent collision occurred at the end of middle Miocene along this suture zone. Therefore, it can be suggested that the thickness of the crust increases over the time depending on the collisional periods (Fig. 7). In addition, it can also be inferred that the crust of regions in old collision-related sutures is thicker than those in younger ones.

(7) Another emphasized important finding of this study is that the northern and southern branches of the Tethyan and Neo-Tethyan Oceans were not integrated in the eastern Anatolian Region; as seen from the profiles (Figs. 4, 5 and 7), instead, there is a continental crust beneath the obducted ophiolitic units and overlying cover, which has been defined as the AIP.

In fact, late Maastrichtian to Quaternary rock units overlie all of the palaeotectonic units unconformably from north to south along the geotraverse throughout the region, except some local long-lived marine (not oceanic) basins, such as the Dizi and southern Black Sea Coast–Adjara–Trialeti and the Gürün Basins.

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