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ARAL İ. OKAY

M. CEMAL GÖNCÜOĞLU

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The Karakaya Complex: A Review of Data and Concepts

ARAL İ. OKAY[1] & M. CEMAL GÖNCÜOĞLU[2]

[1] Eurasian Institute of Earth Sciences, and Department of Geology, İstanbul Technical University, Ayazağa, TR-80626 İstanbul - Turkey (e-mail: okay@itu.edu.tr)

[2] Department of Geological Engineering, Middle East Technical University, TR-06531 Ankara - Turkey (e-mail: mcgoncu@metu.edu.tr)

Abstract: The Karakaya Complex in the Pontides consists of highly deformed and partly metamorphosed clastic and volcanic series of Permian and Triassic age. It is generally subdivided into two parts: The structurally lower part, called the Lower Karakaya Complex, consists of a mafic lava-mafic pyroclastite-shale-limestone succession metamorphosed in the greenschist and blueschist facies during the Late Palaeozoic or Triassic. The structurally upper part is made up of highly deformed Permian and Triassic clastic, volcaniclastic and volcanic rocks with exotic limestone blocks. There are currently two different models for the depositional setting and tectonic evolution of the Karakaya Complex. The rift model assumes that the Karakaya Complex was formed in a Late Permian rift, which developed into a marginal oceanic basin and closed by the latest Triassic. The subduction-accretion model regards the Karakaya Complex as subduction-accretion units of the Palaeo-Tethys.

Key Words: Karakaya Complex, Sakarya terrane, tectonics

Karakaya Kompleksi: Tanımı ve Oluşum Modelleri

Özet: Karakaya Kompleksi şiddetlice deforme olmuş, kısmen metamorfizma geçirmiş Permiyen ve Triyas yaşta klastik ve volkanik serilerden yapılmıştır. Karakaya Kompleksi genellikle iki bölüme ayrılır: yapısal ve muhtemelen stratigrafik olarak altta yer alan Alt Karakaya Kompleksi, Paleozoyik sonu veya Triyas'ta yeşilşist ve mavişist fasiyesinde metamorfizma geçirmiş mafik lav, mafik piroklastik kaya, şeyl, ve kireçtaşı ardalanmasından oluşmuştur. Üst Karakaya Kompleksi ise kuvvetlice deforme olmuş Permiyen veya Triyas yaşta klastik, volkanoklastik ve volkanik kayalardan oluşur. Üst Karakaya Kompleksi içinde çok sayıda Karbonifer ve Permiyen yaşta ortama yabancı kireçtaşı blokları yer alır. Karakaya Kompleksi'nin çökelme ortamını ve tektonik gelişimini izah eden iki model bulunmaktadır. Rift modelinde, Karakaya Kompleksi kayaları Geç Permiyen yaşında bir riftte oluşmuş, bu rift daha sonra okyanusal bir kenar denize dönüşmüş ve en Geç Triyas'ta kapanmıştır. Dalma-batma-eklenme modeline göre ise Karakaya Kompleksi, Paleo-Tetis'in Triyas'ta kuzeye Lavrasya aktif kıta kenarı boyunca dalma-batması ile oluşmuş bir eklenir prizmayı temsil eder.

Anahtar Sözcükler: Karakaya Kompleksi, Sakarya parçası, tektonik

Introduction

The Karakaya Complex is a general tectonostratigraphic term for the strongly deformed and locally metamorphosed Permo–Triassic orogenic series in the Pontides. The name Karakaya Formation was introduced in 1975 (Bingöl *et al.* 1975); however, pre-Jurassic clastic rocks with exotic limestone blocks were known earlier from Anatolia. Bailey & McCallien (1950, 1953) and Erol (1956) mapped and described a deformed greywacke series with exotic Permian and Carboniferous limestone blocks, which formed part of the famous Ankara mélange (for a detailed story of the discovery of the Ankara mélange see Şengör 2003). Brinkmann (1971) described olistoliths of Carboniferous and Permian limestone in what he considered a matrix of Palaeozoic greywacke in northwestern Anatolia. However, Bingöl *et al.* (1975) were the first to draw attention to the wide distribution of the pre-Jurassic blocky series from the Biga Peninsula in northwestern Anatolia through Bilecik to Ankara. They described the Karakaya Formation as consisting of "feldspathic sandstone, quartzite, conglomerate, siltstone, which is intercalated with spilitic basalt, mudstone and radiolarian chert". A characteristic feature of the Karakaya Formation was the presence of exotic blocks of Permian and Carboniferous limestone. The Karakaya Formation was said to have undergone low-grade metamorphism. An Early Triassic age was assigned to the Karakaya Formation by Bingöl *et al.* (1975) based on Middle Triassic carbonates, which were believed to lie stratigraphically over the Karakaya Formation. Bingöl *et al.* (1975) suggested an intra-continental rift environment for deposition of the Karakaya Formation with the Permo-Carboniferous limestone blocks sliding down into the basin from the rift shoulders.

A radically different interpretation of the Karakaya Complex was provided by Tekeli in 1981. Based on his extensive field experience in the Ankara region and in the Tokat Massif in the eastern Pontides, he suggested that the pre-Jurassic orogenic rocks of the Pontides, for which he used the name North Anatolian Belt rather than the Karakaya Complex, represent a subduction-accretion complex of Late Palaeozoic–Early Mesozoic age. These two models, the rift model and the subduction-accretion model for the origin of the Karakaya Complex, have been competing ever since. Tekeli (1981) also extended the distribution of the Karakaya Complex from the Ankara region to the Tokat Massif in the eastern Pontides, and divided the Karakaya Complex into two units: a lower metamorphic sequence and an upper blocky series, which he called the North Anatolian mélange.

The Karakaya Formation was renamed the Karakaya Complex by Şengör *et al.* (1984), who largely followed the interpretation of Tekeli (1981). "Complex" is defined in the International Stratigraphic Guide as "a lithostratigraphic unit composed of diverse types of any class or classes of rocks (sedimentary, igneous and metamorphic) and characterised by irregularly mixed lithology or by highly complicated structural relations...", and is a more appropriate stratigraphic term than the "Karakaya Formation". The next development in the research on the Karakaya Complex was the recognition that the Karakaya Complex consists of several mappable rock units. This was implicit in Tekeli (1981), when he divided the Karakaya Complex into a lower metamorphic unit, and an upper blocky series. Various mappable tectonostratigraphic and stratigraphic units have been differentiated within the Karakaya Complex in various regional studies since 1975 (e.g., Akyürek & Soysal 1983; Akyürek *et al.* 1984; Koçyiğit 1987; Kaya *et al.* 1989; Okay *et al.* 1991; Altıner & Koçyiğit 1993; Pickett & Robertson 1996; Y. Yılmaz *et al.* 1997a; Göncüoğlu *et al.* 2000).

Definition and Distribution of the Karakaya Complex

There is general agreement that the Karakaya Complex is restricted to the Sakarya Zone (Okay 1989) or Sakarya Composite Terrane (Göncüoğlu *et al.* 1997) of the Pontides (Figure 1), and is absent in the rest of the Pontides and in the Anatolide-Tauride Block.

The pre-Jurassic rocks in the Sakarya terrane of the Pontides can be grouped into four categories (Figures 2 and 3): (a) Highly deformed clastic and volcaniclastic rock series with or without exotic limestone blocks, which may show a low to very low-grade regional metamorphism; (b) a strongly deformed low-grade metamorphic unit consisting mainly of metabasite, phyllite and marble; (c) granitoids and their low- to medium-grade metamorphic hosts including metaclastics, and felsic metatuffs with rare black cherty limestones (Göncüoğlu *et al.* 1987; Turhan *et al.* 2004). The granitoids generally form small, isolated outcrops throughout the Sakarya terrane (Figures 2 & 3); their intrusion ages range from Devonian to Carboniferous (Çoğulu & Krummenacher 1967; Okay *et al.* 1996, 2002; Delaloye & Bingöl 2000); (d) a high-grade metamorphic unit composed of gneiss, marble, amphibolite, which crops out mainly in the Kazdağ and Uludağ ranges, in the Devrekani and Pulur massifs (Figures 2 & 3). Zircons from gneisses in the Kazdağ and Pulur massifs have produced Carboniferous isotopic ages (319–331 Ma, Okay *et al.* 1996; Topuz *et al.* 2004a). Similar Carboniferous K/Ar ages (311 ± 6 Ma) are also reported from the Devrekani Massif (Aydın *et al.* 1995).

There is general agreement that the pre-Jurassic sedimentary series of (a) is part of the Karakaya Complex, whereas the pre-Jurassic granitoids and the Carboniferous (Hercynian) metamorphic rocks (c and d) are outside the definition of the Karakaya Complex. There is no consensus on the affinity of the low-grade metamorphic series of (b). In many publications (e.g., Akyürek & Soysal 1983; Akyürek *et al.* 1984; Rojay & Göncüoğlu 1997) the epimetamorphic series is regarded as basement to the Karakaya Complex, whereas in other studies (e.g., Koçyiğit 1987, 1991; Okay *et al.* 1991; Pickett & Robertson 1996, 2004) it forms an integral part of the Karakaya Complex. A critical point in this argument is the metamorphic and depositional age of the epimetamorphic series. A Triassic or Permian depositional or isotopic age of the low-grade metamorphic rocks would logically classify them as a part of the Karakaya

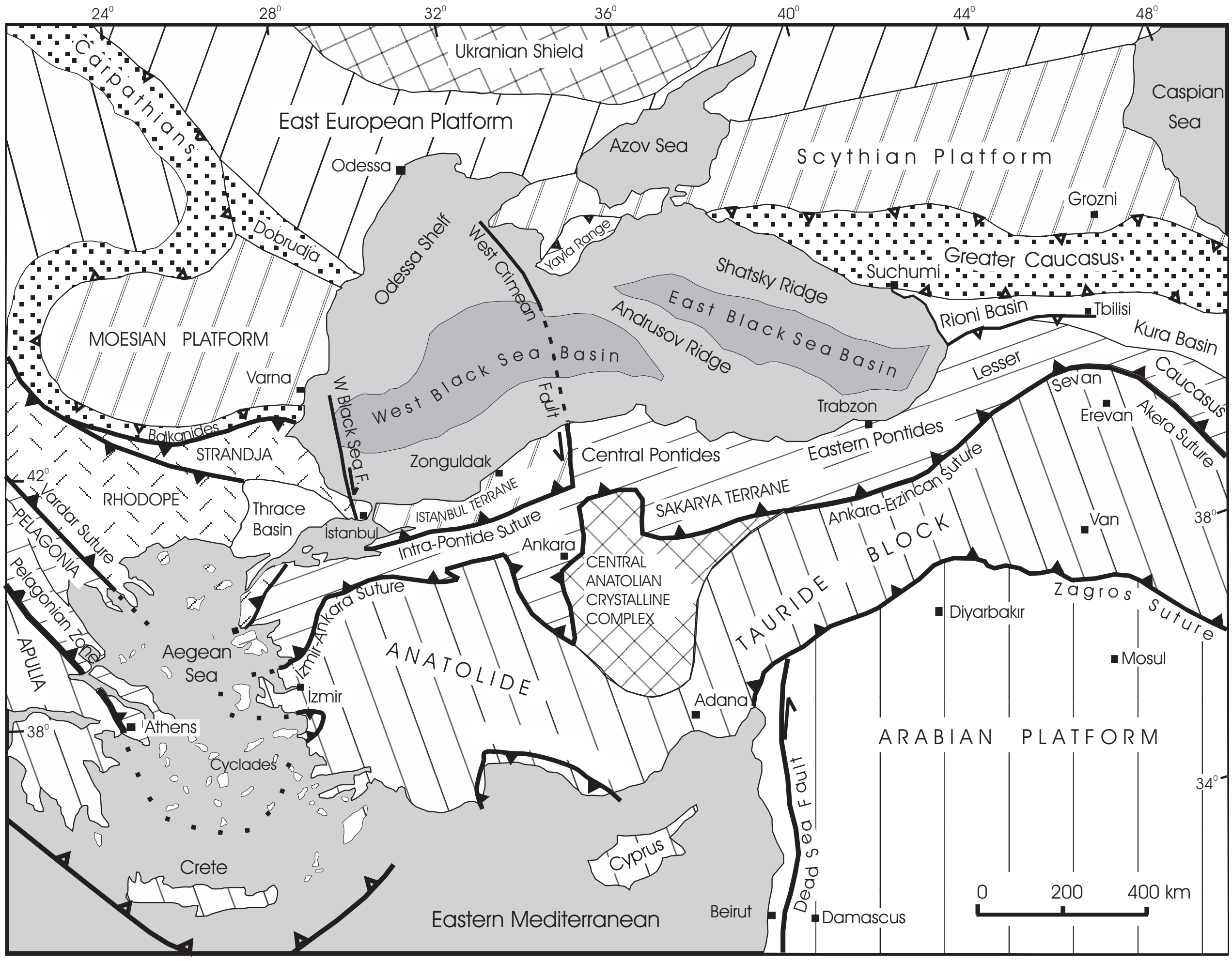

Figure 1. Tectonic map of the eastern Mediterranean region showing the major terranes and the bounding sutures. The filled triangles indicate the polarity of subduction (modified from Okay & Tüysüz 1999).

Complex, whereas a Carboniferous age would group them with the Hercynian basement rocks. So far isotopic dating of the low-grade metamorphic series in the Bandırma region (Okay & Monié 1997) and north of Eskişehir (Okay *et al.* 2002) has yielded latest Triassic ages (205–203 Ma), whereas those from the Pulur Massif yielded Early Permian Ar-Ar and Rb-Sr ages (263-260 Ma: Topuz *et al.* 2004b). Scarce palaeontological data from the metabasite-phyllite-marble series from northwestern Anatolia indicates Triassic ages (Kaya & Mostler 1992; Kozur *et al.* 2000). Although arguments on the affinity of the metabasite-phyllite-marble series have not been settled, we describe provisionally the pre-Jurassic epimetamorphic series under the heading of the Lower Karakaya Complex, and the overlying clastic and volcaniclastic series under the Upper Karakaya Complex.

The Lower Karakaya Complex

The Lower Karakaya Complex crop outs extensively across the Sakarya terrane. It has been mapped under various names, including the Çavdartepe Formation in the Kozak region (Akyürek & Soysal 1983), the Nilüfer Unit in northwest Anatolia (Okay *et al.* 1991), the İznik metamorphics in the Armutlu Peninsula (Göncüoğlu *et al.* 1987), the Bozüyük (Ayaroğlu 1979) or Tepeköy metamorphics (Göncüoğlu *et al.* 2000) north of Eskişehir, the Yenişehir metamorphic group in the

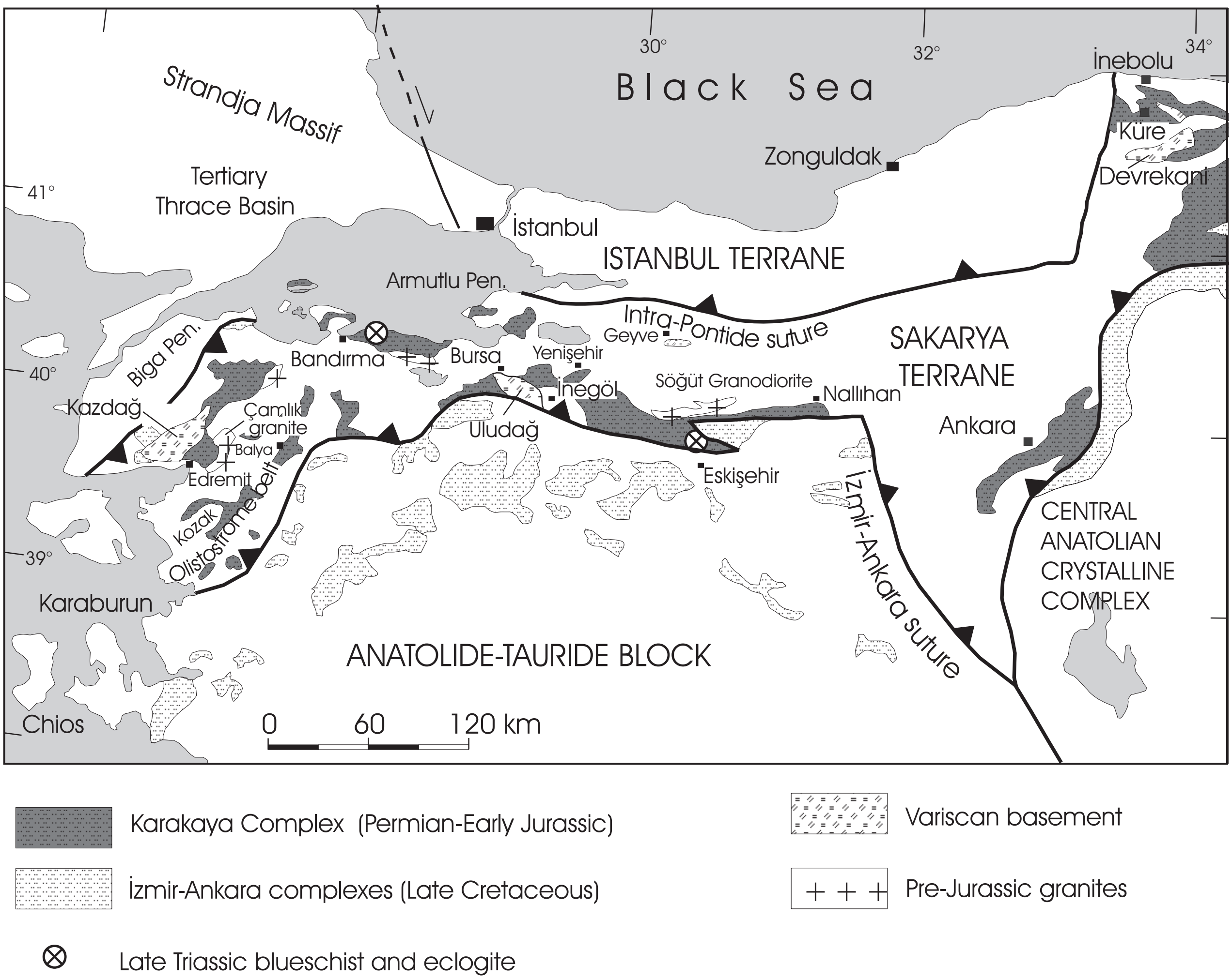

Figure 2. Tectonic map of western Anatolia showing the distribution of the Karakaya Complex and related units.

Yenişehir-İnegöl area (Genç & Yılmaz 1995), the Emir Formation (Akyürek *et al.* 1984) or the Tokat Group (Koçyiğit 1987) in the Ankara region, the Gümüşoluğu, Kunduz and Bekirli formations and the Çangaldağ Complex in the central Pontides (Tüysüz 1990; Tüysüz & Yiğitbaş 1994; Ustaömer & Robertson 1994, 1999), the Tozanlı Complex (Seymen 1993, 1997), the lower Yeşilırmak group (Tüysüz 1996; Y. Yılmaz *et al.* 1997a) or the Turhal metamorphics (A. Yılmaz & H. Yılmaz 2004) in the Tokat Massif, the Ağvanis Group in the Ağvanis Massif (Okay 1984), and the Hossa Group in the Pulur Massif (Okay 1996).

The Lower Karakaya Complex consists of a highly deformed sequence of metabasites intercalated with phyllite and marble. These three lithologies make up over 90% of the Lower Karakaya Complex. They are accompanied by minor amounts of metachert, metagabbro and serpentinite. The marble occurs both as syndepositional beds and as olistoliths. Due to intense boudinage, it is frequently difficult to distinguish boudins from olistoliths. The Lower Karakaya Complex is strongly affected by the Cretaceous and Eocene Alpide tectonics, and is locally tectonically imbricated with Upper Cretaceous Neo-Tethyan accretionary complexes (e.g., Rojay 1995; Bozkurt *et al.* 1997; Göncüoğlu *et al.* 2000; Okay *et al.* 2002). Therefore, it is difficult to be certain of the age of the ultramafic rocks within the Lower Karakaya Complex. However, the linear belt of serpentinized ultramafic rock and gabbro within the metabasites east of Bursa (Genç 1987, 1992; Genç &

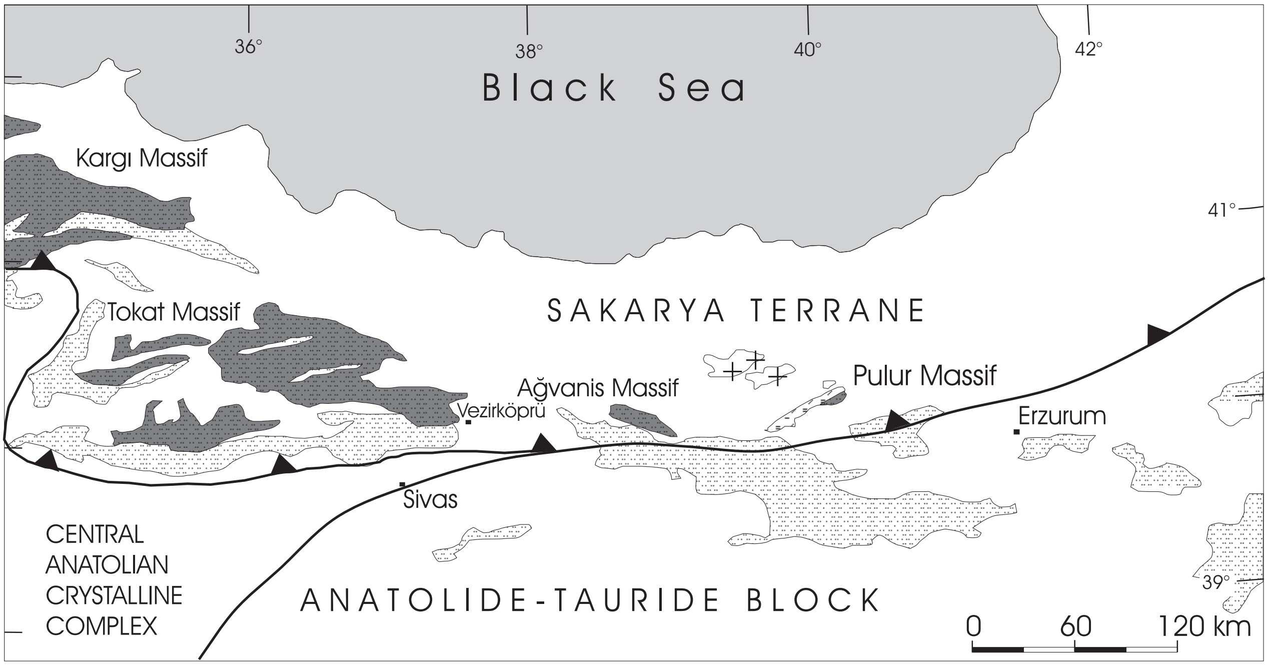

Figure 3. Tectonic map of eastern Anatolia showing the distribution of the Karakaya Complex and related units. For the legend see Figure 3.

Yılmaz 1995), and that southwest of Biga (Okay *et al.* 1991), and some of the ultramafic rocks in the Tokat Massif (Y. Yılmaz *et al.* 1997a) are most probably pre-Jurassic in age.

Rocks of the Lower Karakaya Complex are generally foliated, isoclinally folded and are cut by a large number of shear zones. The structural thickness in the Bursa region, where the lower and upper tectonic contacts of the Lower Karakaya Complex are present, is ~5 km, the original thickness is difficult to estimate but is certainly over one kilometre. The Lower Karakaya Complex is generally metamorphosed in the low greenschist facies; however, in some regions metamorphism reaches albite-epidote amphibolite, blueschist and eclogite facies. The blueschist- and eclogite-facies rocks form tectonic slices within the predominantly greenschist-facies rocks. A single eclogite lens is described in the greenschist-facies metabasites east of Bandırma (Okay & Monié 1997). A large thrust sheet of blueschist-facies metabasites occur north of Eskişehir (Okay *et al.* 2002). Rojay & Göncüoğlu (1997) describe sodic amphibole-bearing metabasites in the Tokat Massif around Amasya. Y. Yılmaz (1979) has mapped metamorphic isograds within the Lower Karakaya Complex ranging from lower greenschist to albite-epidote-amphibolite facies. The mafic volcanic rocks in the Lower Karakaya complex generally give a within-plate geochemical signature, generally interpreted as reflecting formation in an oceanic island (Çapan & Floyd 1985; Floyd 1993; Pickett & Robertson 1996 2004; Yalınız & Göncüoğlu 2002).

Although the pre-Jurassic metabasite-phyllite-marble series crop out extensively in the Sakarya terrane, palaeontological data from this series are limited. Early Triassic conodonts are reported from marbles intercalated with metabasites from south of Bursa, from the type locality of the Nilüfer Unit (Kozur *et al.* 2000), and Middle Triassic conodonts are described from the Kozak Dağ in northwest Anatolia (Kaya & Mostler 1992). Lower Triassic foraminifera are described from bands in a slightly metamorphic detrital series with diabase and spilite horizons (Akyüret *et al.* 1979).

In the Kazdağ and Uludağ massifs, the Lower Karakaya Complex lies tectonically over Carboniferous gneisses; in the Kazdağ Massif this tectonic contact is an Oligocene detachment fault (Yaltırak 2003). In the Devrekani and Pulur massifs, metabasite-phyllite-marble sequence lies tectonically beneath Carboniferous gneisses. The Lower Karakaya Complex is overlain by the clastic rocks of the Upper Karakaya Complex; the contact is well exposed at Kozak Dağı and south of Uludağ, and is probably a sheared unconformity (Akyürek & Soysal 1983; Okay & Siyako 1993). In the subduction-accretion model, this unconformity marks the basal contact of the fore-arc sequence over the accretionary complex. In the rift model, the same is interpreted as transgressions on different rift segments.

Isotopic age data on the Lower Karakaya Complex exists in three regions. Ar-Ar phengite and amphibole ages from an eclogite, east of Bandırma (Okay & Monié 1997), and from the blueschist- and high-pressure greenschist-facies metabasites from north of Eskişehir (Okay *et al.* 2002) have yielded very similar latest Triassic ages (205–203 Ma). In the Pulur Massif in the eastern Pontides, the metabasite-phyllite-marble series, the Hossa Group of Okay (1996), have yielded Early Permian (263–260 Ma) Ar-Ar and Rb-Sr phengite and amphibole ages (Topuz *et al.* 2004b).

The Upper Karakaya Complex

The Upper Karakaya Complex is made up of several tectonostratigraphic units. The highly deformed nature of these units makes their separation and correlation across the Sakarya terrane problematic. However, there is general agreement that part of the Upper Karakaya Complex in northwestern Anatolia includes a thick series of arkosic sandstones, which is also present in the original definition of the Karakaya Formation (Bingöl *et al.* 1975). A second Karakaya series in the Sakarya terrane is greywacke with exotic limestone blocks, which crops out mainly in the Ankara region and in the Tokat Massif. A third series comprises basalts, olistostromes, and grain flows with Upper Permian limestone clasts. A fourth series, called the Akgöl Formation in the central Pontides, consists predominantly of dark shales.

Arkosic Sandstone Series

The arkosic sandstone series has been mapped in the Bursa region as the Dışkaya Formation (Kaya *et al.* 1986; Kaya 1991), in the Biga Peninsula as the Hodul Unit (Okay *et al.* 1991) or the Ortaoba Unit (Pickett & Robertson 1996), in the Kozak region as the Kınık Formation (Akyürek & Soysal 1983), in the Yenişehir-İnegöl region as the Kendirli Formation (Altıner & Koçyiğit 1993; Genç & Yılmaz 1995), and in the Nallıhan area as the Soğukkuyu metamorphics (Göncüoğlu *et al.* 2000). The pre-Jurassic arkosic sandstone series apparently does not occur east of Eskişehir.

In the Biga Peninsula, the arkosic sandstone series crop out in a long linear belt from Bergama, through Manyas to Bursa, and northeast of Bursa. It consists of arkosic sandstones intercalated with shales and siltstones, which pass upward into olistostromes and debris flows with blocks of basalt, and Carboniferous and Permian limestone (Akyol 1982; Okay *et al.* 1991; Leven & Okay 1996). Some of the basic volcanic rocks may also be syndepositional flows. A rare block of Carboniferous chert and pelagic limestone is described from the arkosic sandstones northeast of Balya (Okay & Mostler 1994). In the region north of Bursa, the arkosic sandstones and intercalated shales contain a large number of olistoliths of Permian and Triassic (Scythian, Anisian and Ladinian) limestone and mafic volcanic rock (Kaya *et al.* 1986; Wiedmann *et al.* 1992).

The age of the arkosic sandstone sequence is at least partly Late Triassic (Norian) based on macrofauna, chiefly species of *Halobia*, from the İvrindi (Leven & Okay 1996; Okay & Altıner 2004), Balya (Bittner 1892; Aygen 1956; Leven & Okay 1996) and Iğdır-Bursa regions (Erk 1942; Kaya *et al.* 1986; Wiedmann *et al.* 1992). The Ladinian limestone blocks in the arkosic sandstone series north of Bursa (Wiedmann *et al.* 1992) also provide a lower age for the series. Göncüoğlu *et al.* (2004) describe an Upper Permian radiolarian chert in the arkosic sandstones in the Geyve area, and suggest that it is syndepositional with the clastic rocks. If the syndepositional character of the Upper Permian chert is confirmed, then this would extend the depositional age of the arkosic sandstone series back to the Late Permian, at least in the Geyve region.

In the Kozak region the arkosic sandstones rest on the Lower Karakaya Complex (Akyürek & Soysal 1983; Kaya & Mostler 1992; Okay & Siyako 1993). The contact is interpreted variously as transitional (Akyürek & Soysal 1983), unconformable (Kaya & Mostler 1992) or as a sheared unconformity (Okay & Siyako 1993). A similar stratigraphic contact is reported from the İnegöl area (Altıner & Koçyiğit 1993). In the region north of Edremit, an Upper Triassic arkosic sandstone and siltstone sequence rests unconformably over the Devonian Çamlık granodiorite (Gümüş 1964; Okay *et al.* 1991). Although this sequence is sometimes regarded outside the definition of the Karakaya Complex because of its little-deformed character, similarities in age and lithology suggest that it was part of the same depositional basin.

Greywacke Series

The well-known greywacke series with exotic Permo-Carboniferous limestone blocks in the Ankara region probably forms a lateral facies of the arkosic sandstone series, described above. The greywacke series in the Ankara region is described and mapped as the Elmadağ blocky series (Erol 1956), mélange with limestone blocks (Norman 1975), Kulm flysch formation (Erk 1977), Hisarlıkaya Formation (Batman 1978) and Elmadağ Formation (Okan 1982; Akyürek *et al.* 1984). Akyürek *et al.* (1984) regard the Elmadağ Formation of Middle to Late Triassic age, based on foraminifera in limestones, which were believed to be syndepositional. Koçyiğit (1987) considered the greywacke series in the Ankara region (Kısıküstü Formation) to be the matrix of a wild flysch complex and assigned a Middle to Late Triassic age to this unit. In the Tokat Massif, the equivalents of the greywacke series have been mapped as the Karakaya Complex (Seymen 1993), the upper Yeşilırmak Group (Yılmaz *et al.* 1997a), or as the Devecidağ Complex (A. Yılmaz & H. Yılmaz 2004). In northwestern Turkey, the greywacke series has been mapped as the Orhanlar Greywacke by Brinkmann (1971) and Okay *et al.* (1991). The Orhanlar Greywacke includes small blocks of Lower Carboniferous limestone, and is unconformably overlain by Liassic sandstones. South of Bursa, the Orhanlar Greywacke lies over the Lower Karakaya Complex, and the contact is interpreted either as an unconformity (Kaya *et al.* 1989) or as a shear zone (Okay *et al.* 1998).

Basalt, Limestone, Grain Flows, Debris Flows, and Olistostrome Series

This series consists mainly of grain and debris flows and olistostromes with basalt and Upper Permian limestone clasts. The mass flows are intercalated with basaltic lava flows, calciturbidites, pelagic limestone, shale, greywacke and scarce radiolarian chert. Because of the disrupted character of the sequence, it is difficult to establish a regular stratigraphy. The stratigraphic relationship of this unit, if any, with the clastic series, described above, is also not clearly established. This unit has been mapped as the Çal Unit in the Biga Peninsula (Blanc 1965; Okay *et al.* 1991), possibly as the Abadiye Formation in the İnegöl region (Genç & Yılmaz 1995), and as the Ortaköy Formation in the Ankara region (Akyürek *et al.* 1984).

On the Biga Peninsula, the Çal Unit contains Upper Permian radiolarian cherts (Kozur & Kaya 1994; Kozur 1997), pelagic Lower Triassic limestones (Kozur *et al.* 2000) and Middle Triassic (Anisian) limestones, the latter are mapped as the Camialan limestone (Okay *et al.* 1991). Similar Middle Triassic limestones associated with mafic volcanic rocks have been described from the Ankara region (Koçyiğit 1987; Altıner & Koçyiğit 1993).

On the Armutlu Peninsula, red, thin-bedded pelagic limestones associated with shales contain Upper Triassic conodonts (Önder & Göncüoğlu 1989), whereas conodont findings from grey, thick-bedded limestones associated with spilites to the south of Yenişehir (Genç 1992) suggest a Lower Triassic depositional age.

The Akgöl Formation

In most studies, the Akgöl Formation is treated separately from the Karakaya Complex; however, it shows many of the features of the Upper Karakaya Complex, which crops out to the southeast and southwest of the Akgöl Formation. The Akgöl Formation consists of dark grey to black shales and siltstones intercalated with rare turbiditic sandstones, more than 1500 metres thick. It crops out in the central Pontides between İnebolu and Vezirköprü (Figure 3), and is commonly correlated with the Tauridian flysch series in Crimea. Aydın *et al.* (1982, 1986) and Gedik & Korkmaz (1984) describe spilite, diabase, gabbro and serpentinite blocks in the clastics of the Akgöl Formation. The geochemistry of the mafic volcanic rocks indicates that the ophiolitic rocks were generated above a subduction zone (Ustaömer & Robertson 1994, 1999). Middle Triassic (Anisian) limestone blocks are also reported from the Akgöl Formation (Önder 1988; Kozur *et al.* 2000). Based on trace fossils, Kozur *et al.* (2000) suggest a Late Triassic (Carnian–Norian) age for the clastic rocks, whereas Ketin (1962) reported Liassic ammonites and belemnites, and Aydın *et al.* (1986) Upper Triassic–Liassic foraminifera from the Akgöl Formation. Recently, Middle Jurassic (Bathonian–Callovian) radiolaria were described from mudstone layers in basalts ascribed to the Akgöl Formation (Bragin *et al.* 2002); however, this Middle Jurassic series may belong to a different tectonostratigraphic unit cropping out along the boundary between the Sakarya and İstanbul terranes (Okan Tüysüz, personal communication). The Akgöl Formation is cut by Mid–Jurassic granitoids (O. Yılmaz & Boztuğ 1986; Boztuğ *et al.* 1984) with Rb-Sr ages of 165–154 Ma (Aydın *et al.* 1995) and is unconformably overlain by Upper Jurassic limestones.

Origin of Exotic Blocks in the Karakaya Complex

The Karakaya Complex is characterised by the presence of numerous Carboniferous and Permian limestone olistoliths. The origin of these limestone blocks has been a persistent problem. The age of the limestone blocks in the Sakarya terrane ranges from Early Carboniferous (Visean) to latest Permian (e.g., Kahler & Kahler 1979; Akyürek *et al.* 1984; Bozkurt 1990; Leven 1995; Leven & Okay 1996). In addition, a Silurian (Alp 1972) or Early Devonian (Çapkınoğlu & Bektaş 1999) limestone olistolith is also described from the Tokat Massif in the eastern Pontides (Figure 3). The neritic character of the Permo–Carboniferous limestones and their long age ranges suggests that the limestones were deposited onto normal continental crust. Neritic Permo–Carboniferous limestone sequences are present in the Anatolide-Tauride Block, which could be the source of the limestone blocks; alternatively Permo–Carboniferous limestones could have been present on the southern margin of Laurasia, although there is no *in-situ* deposit known at present. The only significant Permian limestone sequence north of the Sakarya terrane is found in the western part of the Biga Peninsula (Kalafatçıoğlu 1963; Okay *et al.* 1991; Beccaletto & Jenny 2004).

There is no consensus regarding the faunal affinity of the limestone blocks. Leven & Okay (1996) suggested that the foraminifer faunas in the limestone blocks have Laurasian affinities, which is disputed by Altıner *et al.* (2000), who reported that the foraminifer faunas in the northernmost part of the Anatolide-Tauride Block are similar to those in the Karakaya blocks. The density and size of the limestone blocks increase toward the İzmir-Ankara suture, supporting a southern, Anatolide-Tauride origin for the limestone blocks.

Age of Deformation of the Karakaya Complex

In northwestern and central Anatolia, the Liassic Bayırköy Formation lies unconformably over the Karakaya Complex and provides a firm upper age limit for the deposition and deformation of the Karakaya Complex. The basal age of the Bayırköy Formation is established as Sinemurian based on ammonites, brachiopods and foraminifera (Alkaya 1981; Altıner *et al.* 1991). Based on a single ammonite, Cope (1991) extended the age of the Bayırköy Formation down to Hettangian; however, the Hettangian age needs to be verified. In the central Pontides the Jurassic continental sandstones and conglomerates, which are the equivalents of the Bayırköy Formation, have not been dated, however, the overlying neritic limestones are Upper Jurassic in age (Aydın *et al.* 1982). The Mid-Jurassic granitoids in the central Pontides (165–154 Ma, Aydın *et al.* 1995), which are intrusive into the Akgöl Formation, provide an additional upper limit for the deformation. Therefore, deformation associated with the Karakaya Complex was over by the Sinemurian (200–195 Ma) in the west and in the east, but probably lasted until the Bathonian (~165 Ma) in the central Pontides. Isotopic ages from northwestern Anatolia (Okay & Monié 1997; Okay *et al.* 2002) indicate that regional metamorphism and associated deformation was going on in the latest Triassic. In the subduction-accretion model, deformation and metamorphism are expected to be a semi-continuous process, as long as subduction remains active.

Late Triassic deformation in the Upper Karakaya Complex is weak at the western margin of the Sakarya Zone. In the southwestern Biga Peninsula, northeast of Edremit, there is no angular unconformity between the Upper Triassic arkosic series and the overlying Jurassic clastic rocks. This relationship has been interpreted either as a parallel unconformity (Okay *et al.* 1991), or as continuous deposition throughout the Late Triassic–Jurassic interval (Koçyiğit & Altıner 1990). The Triassic clastic series has been dated as Norian using macrofossils, whereas the base of the limestones, which overlies presumably Liassic clastic rocks, is Bajocian–Bathonian based on ammonite fauna (Altıner *et al.* 1991). As there is no evidence for the presence of Rhaetian and Early Jurassic stages in the Edremit section, it is not possible to demonstrate continuous deposition across the Triassic–Jurassic interval.

Tectonic Models for the Genesis of the Karakaya Complex

Basically there are two different models, each with many different variations, for the depositional environment and tectonic evolution of the Karakaya Complex. The first is the rift model initially suggested by Bingöl *et al.* (1975), and the second is the subduction-accretion hypothesis put forward by Tekeli (1981). Although both models involve a final stage of subduction and accretion, in the first hypothesis, rifting has an important role in the deposition of the sediments and in the origin of the exotic blocks. These models are discussed below in more detail.

Rift Model for Karakaya Complex

This model was initially proposed by Bingöl *et al.* (1975), and was developed by Y. Yılmaz (1981), Şengör & Yılmaz (1981), Şengör *et al.* (1984), Şengör (1984), Koçyiğit (1987), Genç & Yılmaz (1995), and Göncüoğlu *et al.* (2000). The model assumes that the Karakaya Complex was deposited in a Late Permian rift, which developed into a small oceanic marginal basin, and closed in the Late Triassic, by southward subduction. Figures 4, 5 and 6 are taken from Koçyiğit (1987), Genç & Yılmaz (1995), Yılmaz (1981) and Göncüoğlu *et al.* (2000) and illustrate the rift hypothesis. Initially the Karakaya rift was assumed to be purely intracontinental (Bingöl *et al.* 1975); however, presence of undoubtedly oceanic crustal lithologies in the Karakaya complex led to the suggestion that the Karakaya rift developed into an oceanic marginal basin (Şengör & Yılmaz 1981). The closure of the Karakaya basin in the Late Triassic created a Karakaya suture, shown on maps in Şengör & Yılmaz (1981) and Şengör *et al.* (1984). Most of the proponents of the rift hypothesis regard the Karakaya marginal basin to have opened on the northern margin of the Anatolide-Tauride Block above the southward-subducting Palaeo-Tethys ocean (Figures 5 & 6). In the rift hypothesis the exotic Permian and Carboniferous limestone blocks are derived from uplifted rift shoulders. The problems associated with the rift hypothesis are as follows:

1. In the rift model, the Karakaya marginal basin separates two blocks to the north and south of the basin (Figures 5 & 6). The closure of the basin by southward subduction must have resulted in the telescoping of the Karakaya basinal sediments between these two continental blocks. However, these continental blocks have never been clearly defined in the field. Rocks of the Karakaya Complex occur throughout the Sakarya terrane from the İzmir-Ankara suture to the Intra-Pontide suture (Figures 2 & 3). Triassic blueschists, characteristic markers of the suture zones, are found adjacent to the İzmir-Ankara suture zone (Okay *et al.* 2002). The Karakaya suture shown in some palaeogeographic maps (Şengör & Yılmaz 1981; Şengör *et al.* 1984; Y. Yılmaz *et al.* 1997b) could not be mapped in the field.
2. In the rift hypothesis it is assumed that prior to the rifting, the northern margin of the Anatolide-Tauride Block was characterised by a Hercynian metamorphic basement overlain unconformably by the Permo–Carboniferous sedimentary rocks (Figures 4, 5 & 6). However, up to now, there has been no description in the Sakarya terrane of a stratigraphic contact between a Permo–Carboniferous sedimentary sequence and a Hercynian basement. Turhan *et al.* (2004), in this volume, provide the first detailed description of a stratigraphic contact between an Upper Permian sandstone-limestone sequence, and underlying metamorphic rocks. The sedimentary sequence is dated on the basis of the limestone. If the limestone is confirmed to be a synsedimentary deposit rather than a block, then this would be a significant argument for the rift hypothesis. Some of the dated pre-Jurassic metamorphic rocks in the Sakarya terrane are Triassic (Okay & Monié 1997; Okay *et al.* 2002) or Permian in age (Topuz *et al.* 2004b), and can be excluded to form a basement to a Permo–Carboniferous sedimentary sequence. However, in northwestern Anatolia (Göncüoğlu *et al.* 1987) and in the north-central Pontides (Serveçay Group of Kozur *et al.* 2000), extensive outcrops of pre-Permian and pre-Triassic low-grade metamorphic rocks have been reported, which could represent this Hercynian basement. The presence of exotic blocks of pelagic limestone and radiolarian chert of early Late Carboniferous age (Bashkirian, Okay & Mostler 1994), huge blocks of platform-type limestones of Asselian to Midian age and the dominance of clasts of deformed granitoids, quartz schist (Göncüoğlu *et al.* 1987; Okay *et al.* 1991) and black metachert (Turhan *et al.* 2004) could also be indicative of derivation from a pre-Karakaya metamorphic basement and its Permian cover.

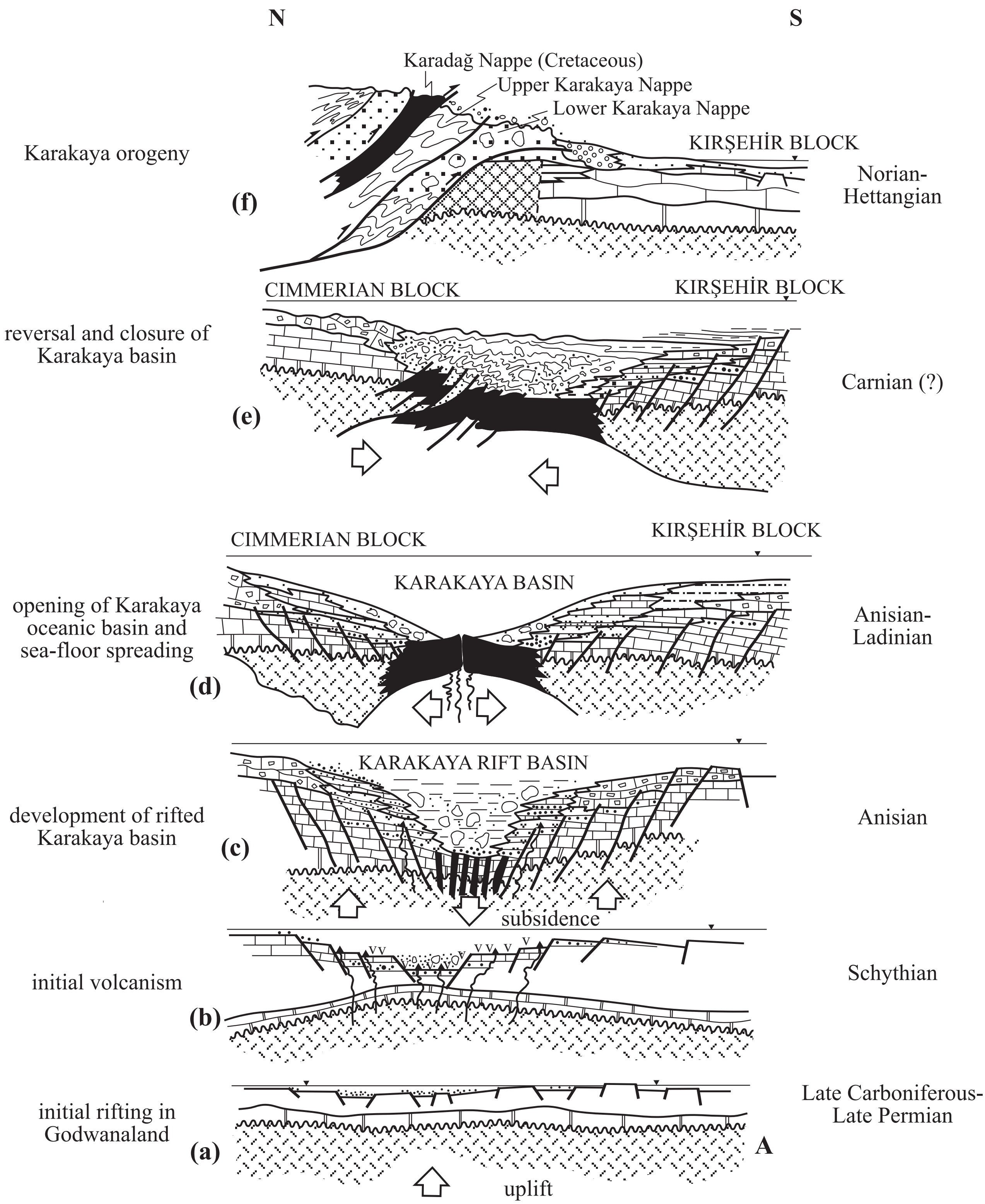

Figure 4. Rift model for the evolution of the Karakaya Complex (Koçyiğit 1987).

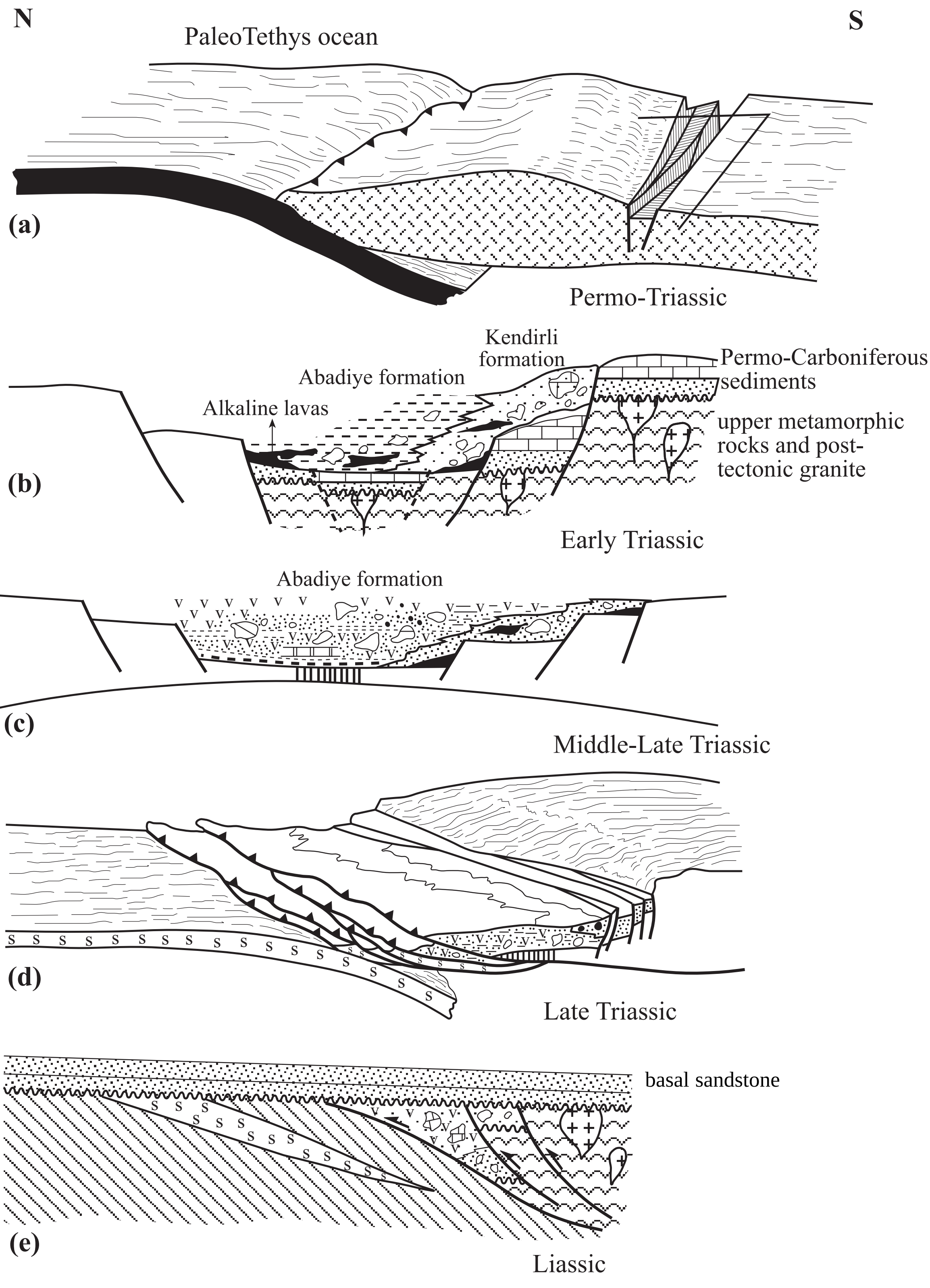

Figure 5. Rift model for the evolution of the Karakaya Complex (Genç & Yılmaz 1995).

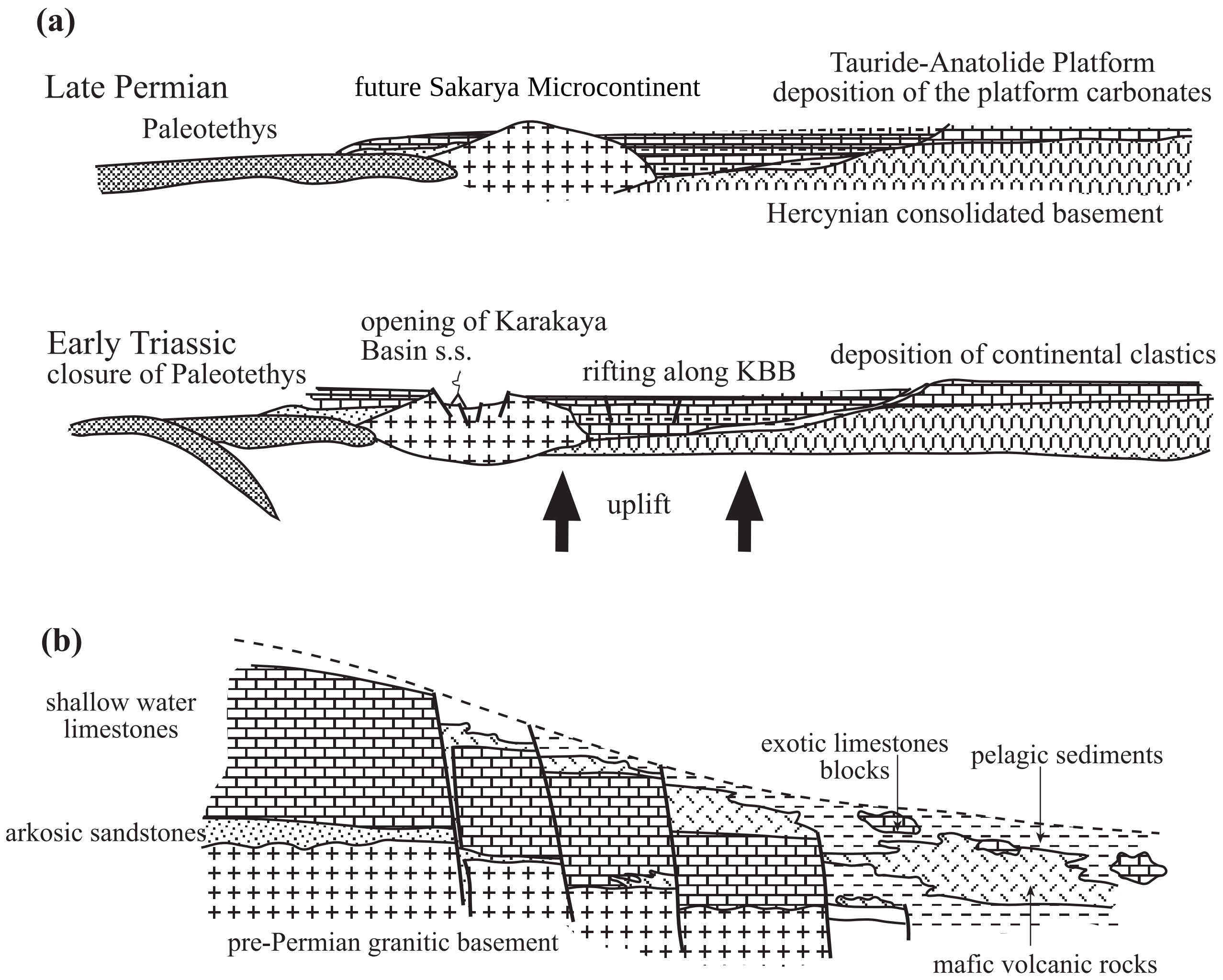

Figure 6. (a) Rift model for the genesis of the Karakaya Complex involving back-arc rifting on the northern margin of the Tauride-Anatolide Platform (modified from Göncüoğlu *et al.* 2000). KBB, Kütahya-Bolkardağ Belt. (b) Relation between the Hercynian basement, the Permo–Carboniferous limestones and the volcanic and clastic rocks as expected in the rift model (Yılmaz 1981).

3. In the rift hypothesis, rifting leading to the opening of the Karakaya basin occurred in the Late Permian and Early Triassic; this must have been followed by thermal subsidence in the Middle to Late Triassic. Therefore, the limestone blocks from the rift shoulders must have been derived in the Late Permian and Early Triassic. However, the major part of the Permian and Carboniferous limestone blocks occur in Upper Triassic sandstones (Okay *et al.* 1991). This is especially true for an olistostromal belt extending from the Aegean Sea to Manyas, immediately west of the İzmir-Ankara suture (Figure 2).

Subduction-Accretion Model for the Karakaya Complex

The subduction-accretion model for the genesis of the Karakaya Complex was first proposed by Tekeli (1981), and developed by Pickett *et al.* (1995), Pickett &

Robertson (1996) and Okay (2000). The model assumes that the Karakaya Complex formed by subduction-accretion of the oceanic crust during the Late Palaeozoic–Triassic. The various units of the Karakaya Complex are regarded as having formed either during steady-state subduction of oceanic crust, or during subduction of oceanic seamounts, oceanic plateau, or narrow continental fragments (Figures 7 & 8). In the subduction-accretion model, the Lower Karakaya Complex represents partially subducted oceanic seamounts (Figure 7, Pickett & Robertson 1996, 2004) or a large oceanic plateau (Figure 8, Okay 2000). The subduction is generally assumed to be northward under the active Laurasian margin. Problems associated with the subduction-accretion model are as follows:

1. In the subduction-accretion model, there is no obvious explanation for the origin of the exotic and platform-type Permian and Carboniferous limestone blocks.
2. In the subduction-accretion model, a Triassic magmatic arc is expected on the Laurasian margin due to the northward subduction of the Tethyan ocean. Such a magmatic arc is not recognised.
3. In the subduction-accretion model, the Lower Karakaya Complex is regarded as accreted oceanic crust (oceanic island or oceanic plateau), which is unconformably overlain by a Norian clastic wedge (Hodul Unit) (Figure 8). The overlap between the isotopic age of the HP/LT metamorphism of the Lower Karakaya Complex in northwestern Anatolia (215–205 Ma), and the Norian age of the overlying sequence poses a problem. However, recent isotopic and biostratigraphic studies have modified the boundaries of the Late Triassic stages. Gallet *et al.* (2003) indicate 227–202 Ma and 202–200 Ma for the Norian and Rhaetian stages, respectively, which contrasts with earlier estimates of 223.4–209.5 and 209.5–208.0 Ma by Harland *et al.* (1989).
4. In the subduction-accretion model there is no obvious mechanism for the opening of Neo-Tethys, and the closing of Palaeo-Tethys.
5. Limited geochemical data from Triassic volcanic rocks of some of the units of the Karakaya Complex (e.g., Genç & Yılmaz 1995) are indicative of a rift setting rather than an oceanic- lithosphere affiliation.

Conclusions

The Karakaya Complex consists of highly deformed and partly metamorphosed clastic and volcanic series of Permian and Triassic age. It is generally subdivided into two parts. The lower part consists of a mafic lava-mafic pyroclastite-shale-limestone succession metamorphosed in the greenschist and blueschist facies during the Late Palaeozoic or Triassic. The upper part is made up of highly deformed Permian and Triassic clastic, volcaniclastic and volcanic rocks with exotic limestone blocks. There are currently two different models for the depositional setting and tectonic evolution of the Karakaya Complex. The rift model assumes that the Karakaya Complex was deposited in a rift, which developed into a marginal oceanic basin and closed by the latest Triassic. The subduction-accretion model regards the Karakaya Complex as subduction-accretion units of Palaeo-Tethys.

Although our knowledge on the internal structure and tectonostratigraphy of the Karakaya Complex has increased considerably in the last 15 years, there is still a need for precise structural, biostratigraphic, geochemical and petrological studies. The correlation of the different Karakaya Complex units across the Sakarya terrrane is also an unsolved problem. The correlation and the related problem of standardising the stratigraphic nomenclature are made difficult by the strongly deformed nature of the Karakaya Complex, and by the many local studies, each providing its own stratigraphic scheme. Most of the regional studies in the last twenty years have been conducted in northwestern Anatolia; therefore, evolutionary models for the Karakaya Complex have been based mainly on geological data from the western Sakarya terrane. It is hoped that future studies in the eastern Pontides, especially in the Tokat Massif, will redress this bias in Karakaya studies.

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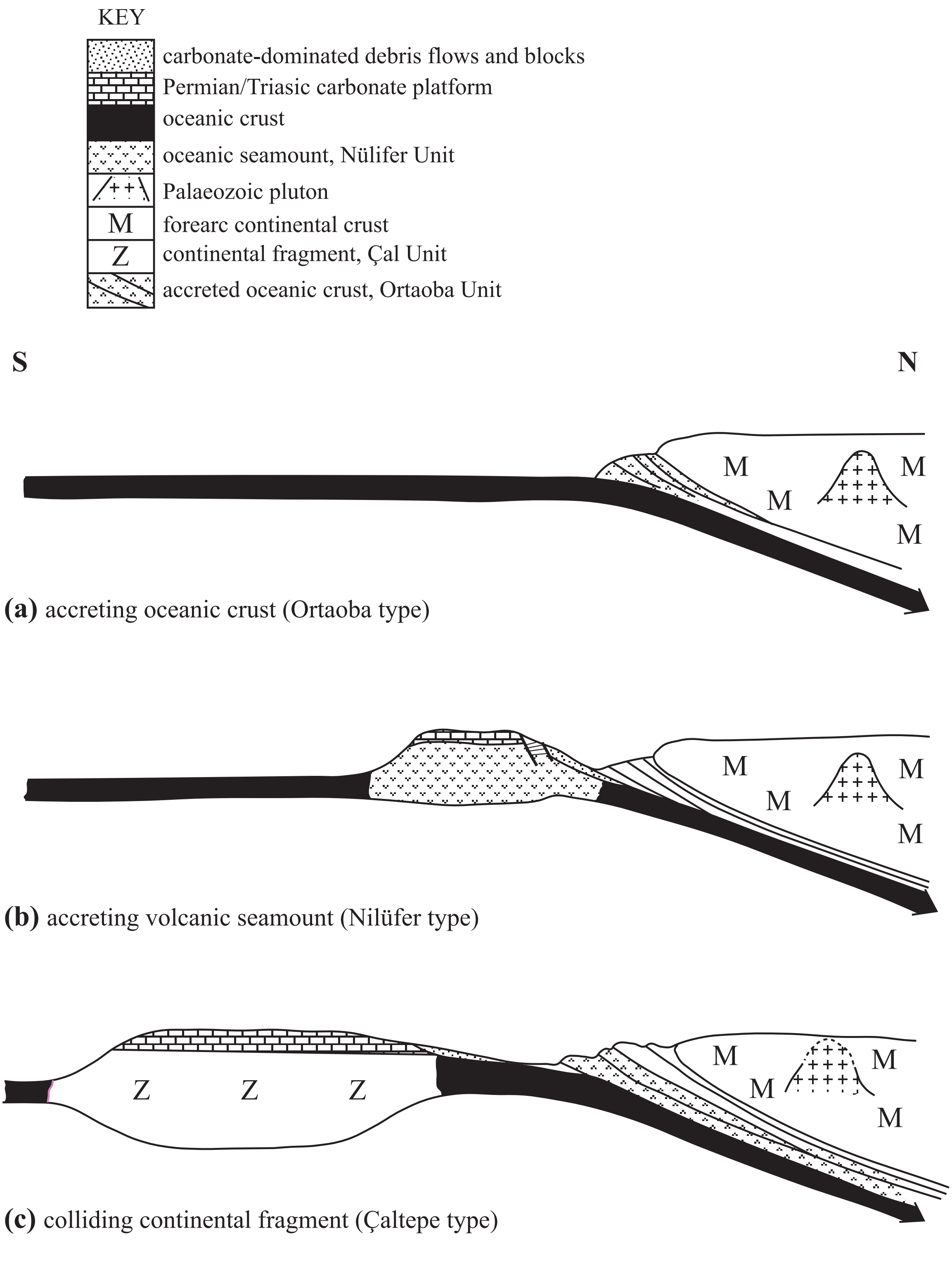

Figure 7. Subduction-accretion model for the evolution of the Karakaya Complex (modified from Pickett & Robertson 2004). The Karakaya Complex is made up of subduction-accretion units of normal oceanic crust (a) of oceanic seamounts (b) and small continental fragments (c).

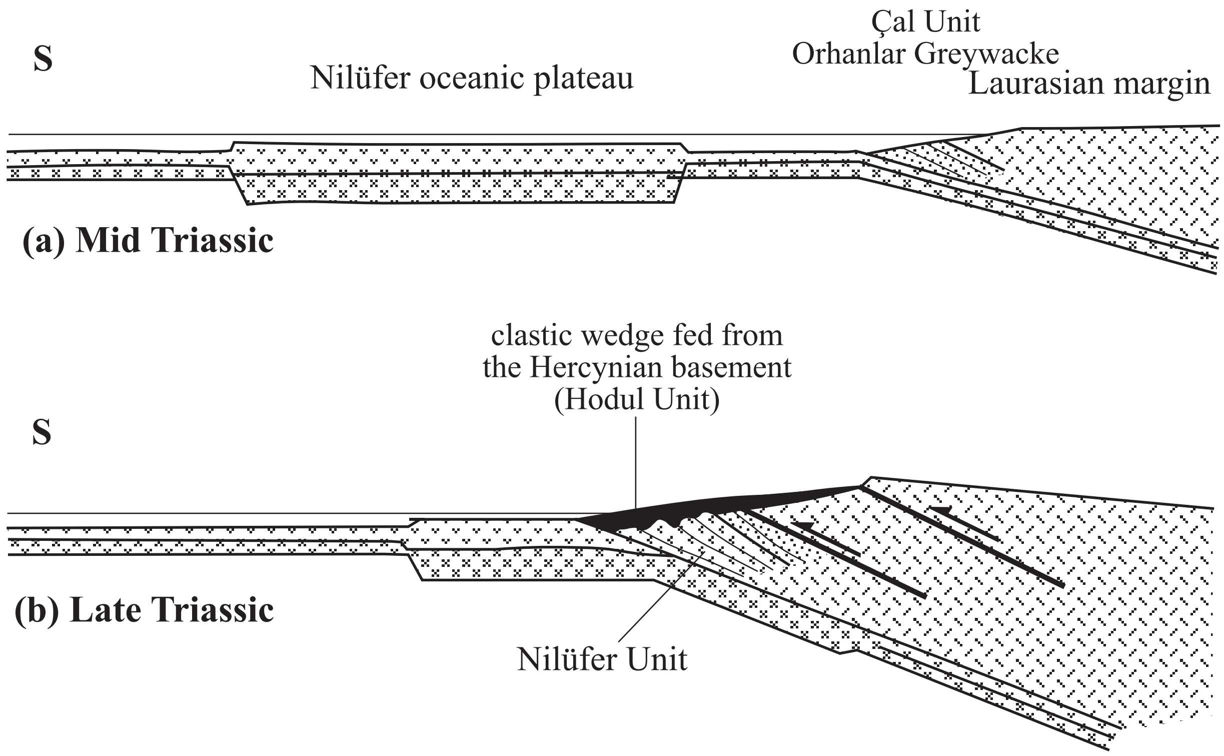

Figure 8. Subduction-accretion model for the evolution of the Karakaya Complex (Okay 2000). The Lower Karakaya Complex forms by the subduction-accretion of an oceanic plateau, whereas the Upper Karakaya Complex represents an accretionary complex and a deformed fore-arc.

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