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New Results on the Lithostratigraphy of the Kazdağ Massif in Northwest Turkey

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Abstract: The high-grade metamorphic rocks of the Kazdağ mountain range, termed the Kazdağ Group, crop out as a tectonic window under the Karakaya Complex in northwestern Turkey. The Kazdağ Group forms a doubly plunging, NE–SW-trending anticliniorium. During our regional geological mapping of the Kazdağ Group, we have subdivided the metamorphic rocks into four formations. The lowermost unit is the Fındıklı formation, which comprises amphibole-gneiss, marble and minor amphibolite. It crops out mainly in the southern part of the Kazdağ Massif. The marble horizons within the Fındıklı formation have been named the Altınoluk and Babadağ marble members. The overlying unit, comprising metadunite and orthoamphibolite, is the Tozlu formation, which in turn is overlain by the Sarıkız marble. The uppermost unit, which crops out in the northern parts of Kazdağ Massif, is the Sutuven formation that comprises sillimanite-gneiss, migmatite and minor marble, amphibolite and granitic gneiss. All these formations underwent a common metamorphism and share a mutual foliation. The metamorphic rocks of the Kazdağ Group are in tectonic contact with the surrounding Permian to Miocene rocks and are intruded by the Oligo–Miocene granodiorites. The oldest rocks, which stratigraphically overlie the Kazdağ Group, are Pliocene and younger in age. There is no data on the chronostratigraphy of the Kazdağ Group, but the isotopic age of the latest metamorphism affecting the Kazdağ Group is Oligo–Miocene. The Kazdağ Group has attained its present tectonic position as a metamorphic core complex by domal uplift through post-Miocene detachment faults.

Key Words: Kazdağ, northwestern Turkey, metamorphic rocks, lithostratigraphy, extension, core complex

Kazdağ Masifi'nin Stratigrafisinde Yeni Bulgular

Özet: Kazdağı oluşturan yüksek dereceli metamorfik kayalar kuzeybatı Anadolu'da Karakaya Kompleksi altından bir tektonik pencere olarak yüzeyler. Kazdağ Masifi'nin yapısı, kıvrım ekseni NE–SW doğrultulu ve her iki yöne dalımlı bir antiklinoryum şeklindedir. Yaptığımız jeolojik haritalama çalışmasında, amfibolit fasiyesinde metamorfizma geçirmiş olan Kazdağ Grubu metamorfitleri alttan üste doğru Fındıklı ve Tozlu formasyonları, Sarıkız mermeri ve Sutuven formasyonu olarak ayırtladık. Masifin güney kesimlerinde yüzeyleyen amfibollü gnays, mermer ve yer yer amfibolit ardalanmasından oluşan Fındıklı formasyonu içerisinde Altınoluk ve Babadağ mermer üyeleri tanımlanmıştır. Masifin orta kesimlerinde yeralan metadunit ve ortoamfibolit kapsayan metaofiyolitik kayaçlar Tozlu formasyonu, ofiyolitler üzerinde yer alan mermer seviyesi Sarıkız mermeri olarak ayırtlanmıştır. Kazdağı metamorfiklerinin en üst seviyelerinde bulunan sillimanit gnays, biyotit gnays, granitik gnays ve yer yer migmatit içerikli seviyeler Sutuven formasyonu olarak tanımlanmıştır. Sutuven formasyonu içerisinde ayrıca ince mermer ile amfibolit seviye ve mercekleri de vardır. Metamorfizma öncesi evrede muhtemelen tektono-stratigrafik olarak istiflenmiş olan bu formasyonlar beraberce metamorfizma geçirmiş ve birlikte foliasyon kazanmıştır. Kazdağ metamorfitleri çevrelerinde mostra veren Permiyen–Miyosen yaştaki kayaçlarla tektonik dokanaklar oluşturmakta, ve Oligo–Miyosen yaşlı granitler tarafından kesilmektedir. Kazdağ metamorfitleri üzerinde stratigrafik dokanakla yer alan en yaşlı birim Pliyosen yaştadır. Stratigrafik yaşının saptanmasında yeterli veri bulunamayan Kazdağ metamorfik kayaçlarının son metamorfizma yaşı, önceki araştırıcılar tarafından jeokronolojik yöntemle Oligo–Miyosen olarak belirlenmiştir. Kazdağ Masifi, Miyosen sonrasında gelişen sıyrılma ve yanal atımlı faylarla, bir metamorfik çekirdek kompleks olarak dom şeklinde yükselerek bugünkü konumunu kazanmıştır.

Anahtar Sözcükler: Kazdağ, kuzeybatı Türkiye, metamorfik kayalar, litostratigrafi, gerilme, çekirdek kompleks

Introduction

This paper reports the preliminary results of a lithostratigraphic investigation of the Kazdağ Massif within a wider project on the geology of the Biga peninsula. The Kazdağ Massif is the name given to a high-grade metamorphic complex, called the Kazdağ Group, which crops out in the Kazdağ Mountains in the Biga peninsula in northwestern Turkey (Figure 1). Tectonically, the Kazdağ Group lies in the Sakarya Zone and exposes the lowest crustal levels in northwestern Turkey. The Kazdağ Group was uplifted as a result of post-Miocene extensional tectonics, and as a consequence the metamorphic rocks exhibit faulted contacts with the surrounding pre-Miocene rocks. The Kazdağ Massif is now generally regarded as an Oligo–Miocene metamorphic core complex (Okay *et al.* 1991; Okay & Satır 2000).

The Kazdağ Group forms structurally a doubly plunging, NE–SW-trending anticlinorium. From its base upwards it consists of amphibole-bearing gneiss with marble intercalations, metaophiolite, marble and gneiss. The base of the Kazdağ Group has not been observed, and the Kazdağ Group is tectonically overlain by Permian to Miocene sedimentary, magmatic and metamorphic rocks (Figure 2). Triassic low-grade metamorphic and sedimentary rocks to the east and north of the Kazdağ

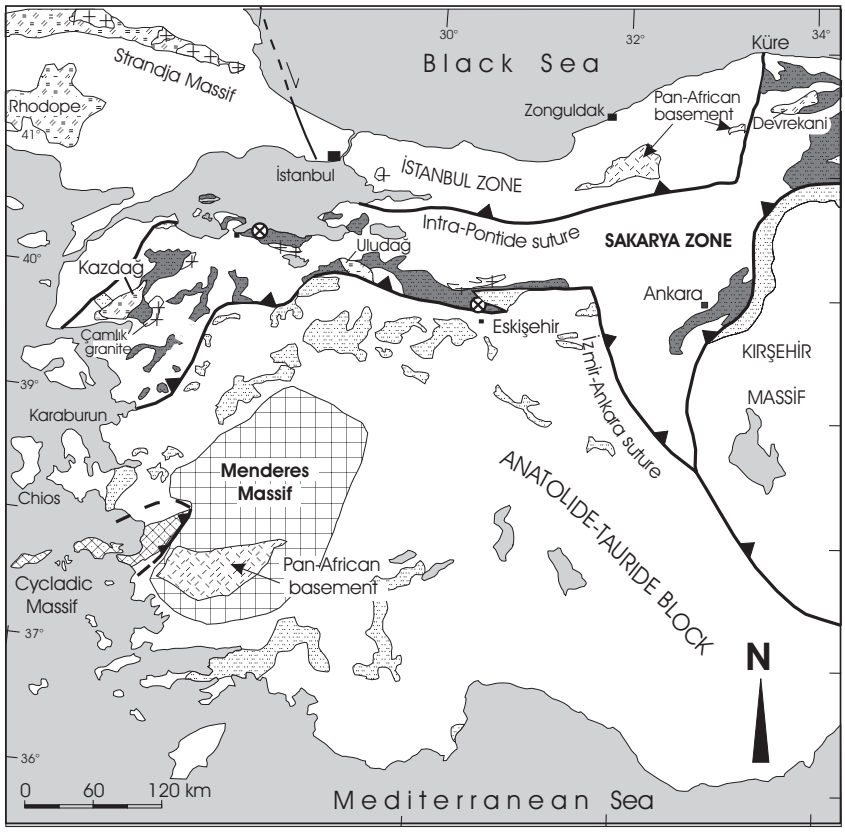

Figure 1. Geological map of western Turkey illustrating the tectonic setting of Kazdağ Massif (modified from Okay *et al.* 2004).

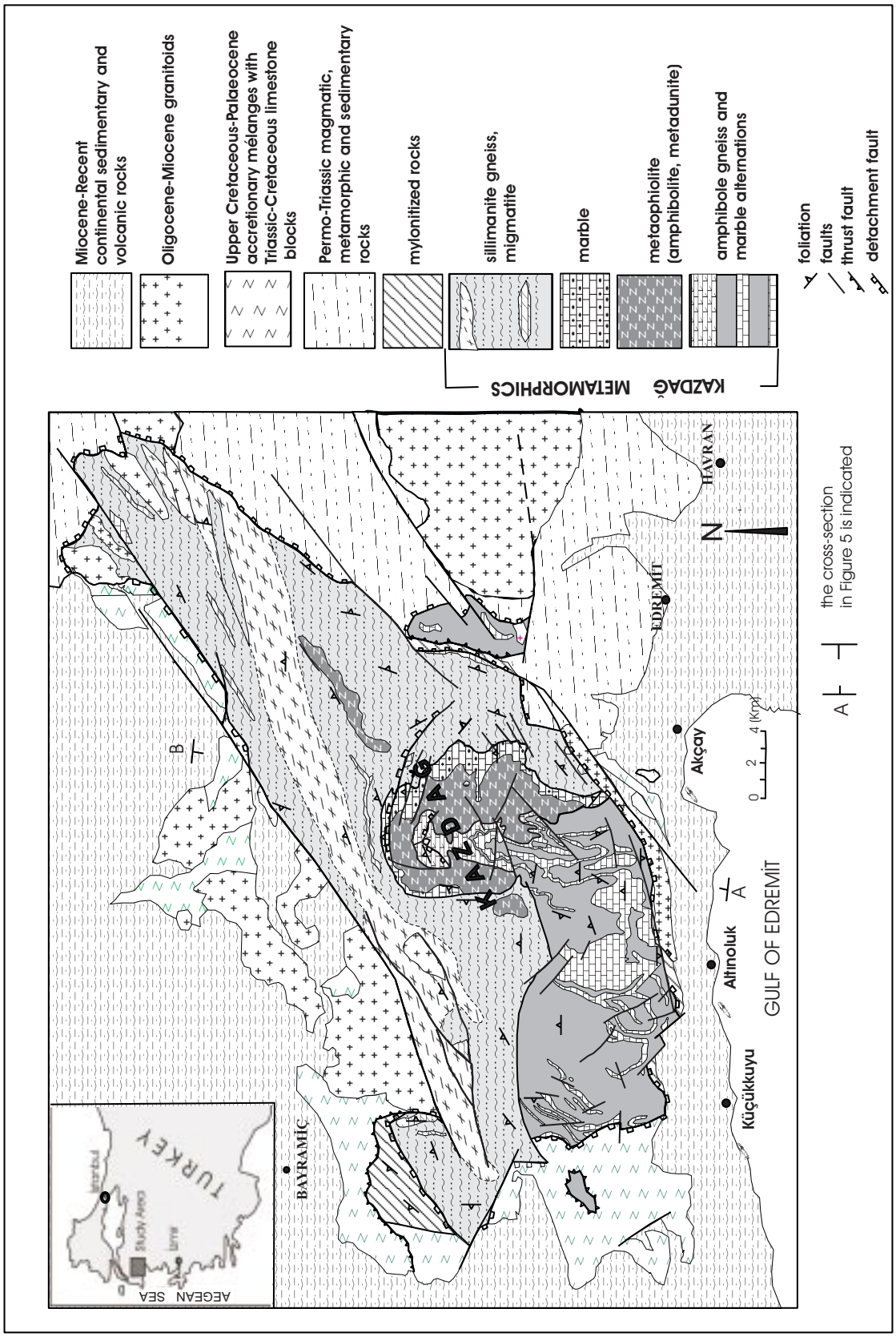

Figure 2. Geological map of Kazdağ Massif.

Group, which include blocks of Permo–Carboniferous limestone olistoliths, have been described as the Karakaya Formation by Bingöl *et al.* (1975). West of the Kazdağ Massif lies the Çetmi Mélange, described in detail by Okay *et al.* (1991) and Okay & Satır (2000). The Çetmi Mélange of Late Cretaceous–Palaeocene age, comprises mafic volcanic and volcaniclastic rocks, limestone blocks of Late Triassic to Late Cretaceous age, and tectonic slices of shale, greywacke, radiolarian chert, serpentinite, garnet-mica schist and eclogite. The Çetmi Mélange and the Karakaya Complex around the Kazdağ Massif are unconformably overlain by the Miocene lacustrine sediments and volcanic rocks (Figure 2). These Miocene deposits have tectonic contacts with the Kazdağ Group. Oligo–Miocene granitoid rocks crop out widely within the Kazdağ Group and the surrounding rocks, showing both intrusive and tectonic contacts with the host rocks. All these rocks, including the Kazdağ Group, are unconformably overlain by the fluviatile and alluvial sediments of the Bayramiç formation of Plio-Quaternary age (Siyako *et al.* 1989).

Early studies on the Kazdağ Group in the 1950s and 1960s described the metamorphic rock types without providing details on its lithostratigraphy (Geis 1953; Kaaden 1959; Schuiling 1959; Gümüş 1964; Aslaner 1965). The first detailed study on the Kazdağ metamorphic rocks was by Bingöl (1968, 1969), who subdivided the metamorphic rocks into three units: at the base he recognised a basic-ultrabasic series of metadunite, metagabbro and amphibolite, which is overlain by a "silico-aluminous" series of schist and gneiss; and the uppermost unit is a carbonate series consisting of marble. Bingöl (1968, 1969) also provided detailed information on the petrology and geochemistry of the Kazdağ Group. Gözler *et al.* (1984) classified the amphibolite-facies metamorphic rocks, from the base upwards, as migmatite, gneiss, marble, amphibolite and metadunite-serpentinite, and indicated that the high-grade metamorphic rocks pass upward into lower grade ones. Sulzer (1990), in his detailed structural and petrofabric study of the Kazdağ Group, differentiated a mylonitic paragneiss-migmatite-amphibolite series at the base, to which he speculatively assigned a Palaeozoic age. This series was reportedly overlain by metaophiolitic rocks of unknown age and, at the top of the sequence, orthogneisses of presumed Mesozoic age occur. Sulzer (1990) claimed that this whole sequence was tectonically assembled during the Early Tertiary in a subduction-zone setting. Okay *et al.* (1991) and Okay & Satır (2000) described a thick, extensional mylonite zone above the gneisses of the Kazdağ Group; they stated that the contacts of the Kazdağ Group with the surrounding pre-Miocene rocks are tectonic and that the Kazdağ Group forms an extensional metamorphic core complex of Oligo–Miocene age, and was exhumed for the first time in the Plio-Quaternary. Isotopic age data from the Kazdağ Group have been provided by Bingöl (1968), Okay *et al.* (1996), and Okay & Satır (2000). These data indicate an early high-grade metamorphism of Mid–Carboniferous age, strongly overprinted by a second phase of high-grade metamorphism in the Oligo–Miocene which was related to extension in the Aegean region.

Lithostratigraphy of the Kazdağ Group

During our regional geological mapping of the Kazdağ Group, we have subdivided the metamorphic rocks into four formations (Figure 3). These are, from the base upward: the Fındıklı formation, consisting of amphibole-bearing gneiss and marble; the Tozlu formation, which comprises the metaophiolite; the Sarıkız marble; and the Sutuven formation comprising gneiss and migmatite. These formations are described below.

Fındıklı Formation

The Fındıklı formation, which is named for the first time in this study, consists of an intercalation of amphibole-bearing gneiss and marble. In previous studies the Fındıklı formation was included in the amphibolite unit of the metaophiolite (Bingöl *et al.* 1975). The Fındıklı formation crops out in the basal parts of the Kazdağ anticlinorium on the southern flanks of Kazdağ Mountain in the area of the Fındıklı, Şahin and Mıhlı streams (Figure 4). The name of the formation comes from the Fındıklı stream, and its type locality is east of the Arıtaşı village within the Fındıklı stream. The lower contact of the Fındıklı formation is not exposed; it is covered by the Tozlu and Sutuven formations.

The Fındıklı formation consists of a regular intercalation of amphibole-bearing gneiss and marble horizons. The gneiss horizons are 10- to 150-m thick and are made up of bluish green, fine- to medium-grained, well-banded gneiss, and has transitional contacts with the marbles. The upper part of the Fındıklı formation is made up of an augen-gneiss horizon, 10- to 30-m thick.

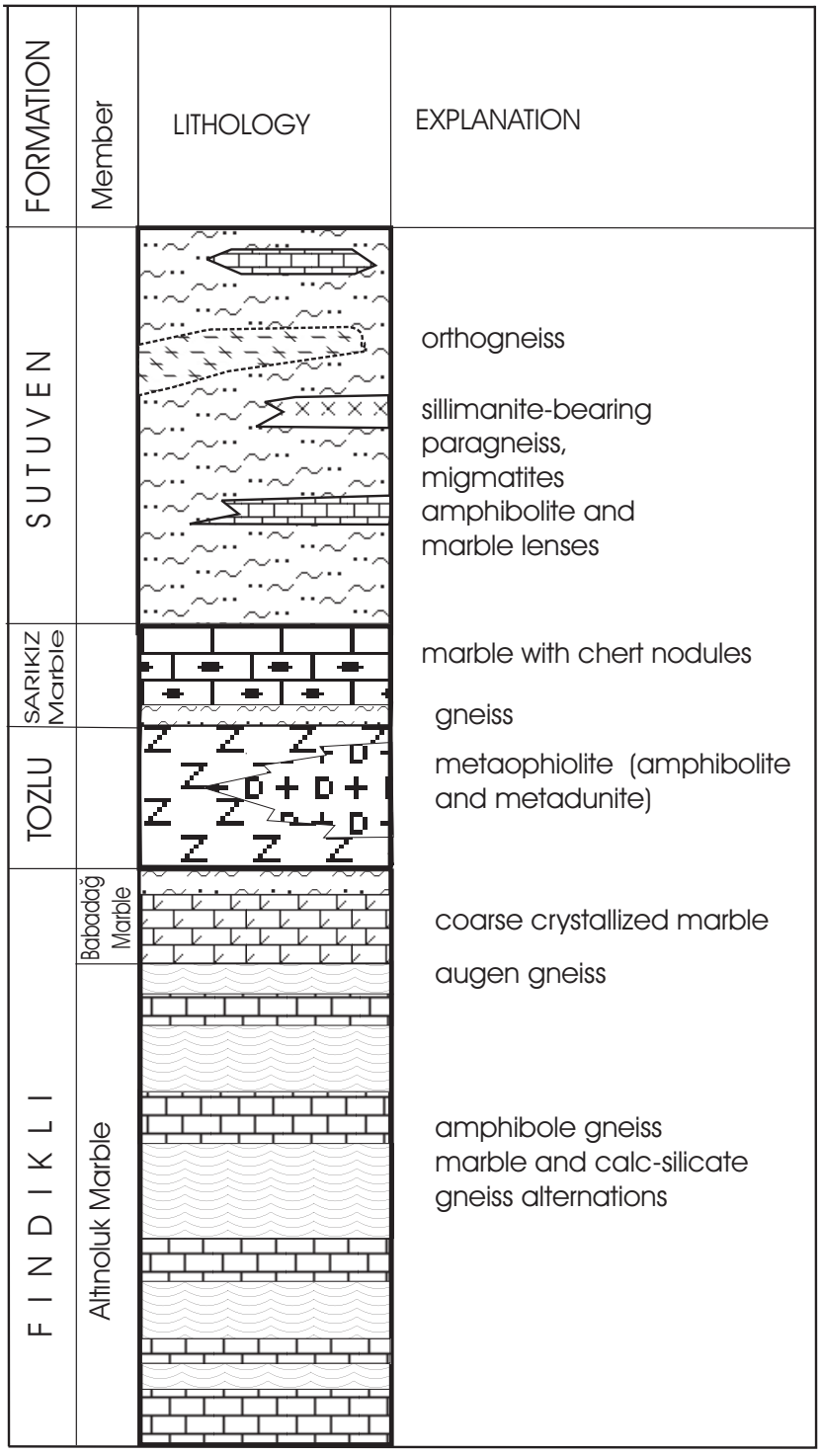

Figure 3. Generalised stratigraphic section of the Kazdağ Group.

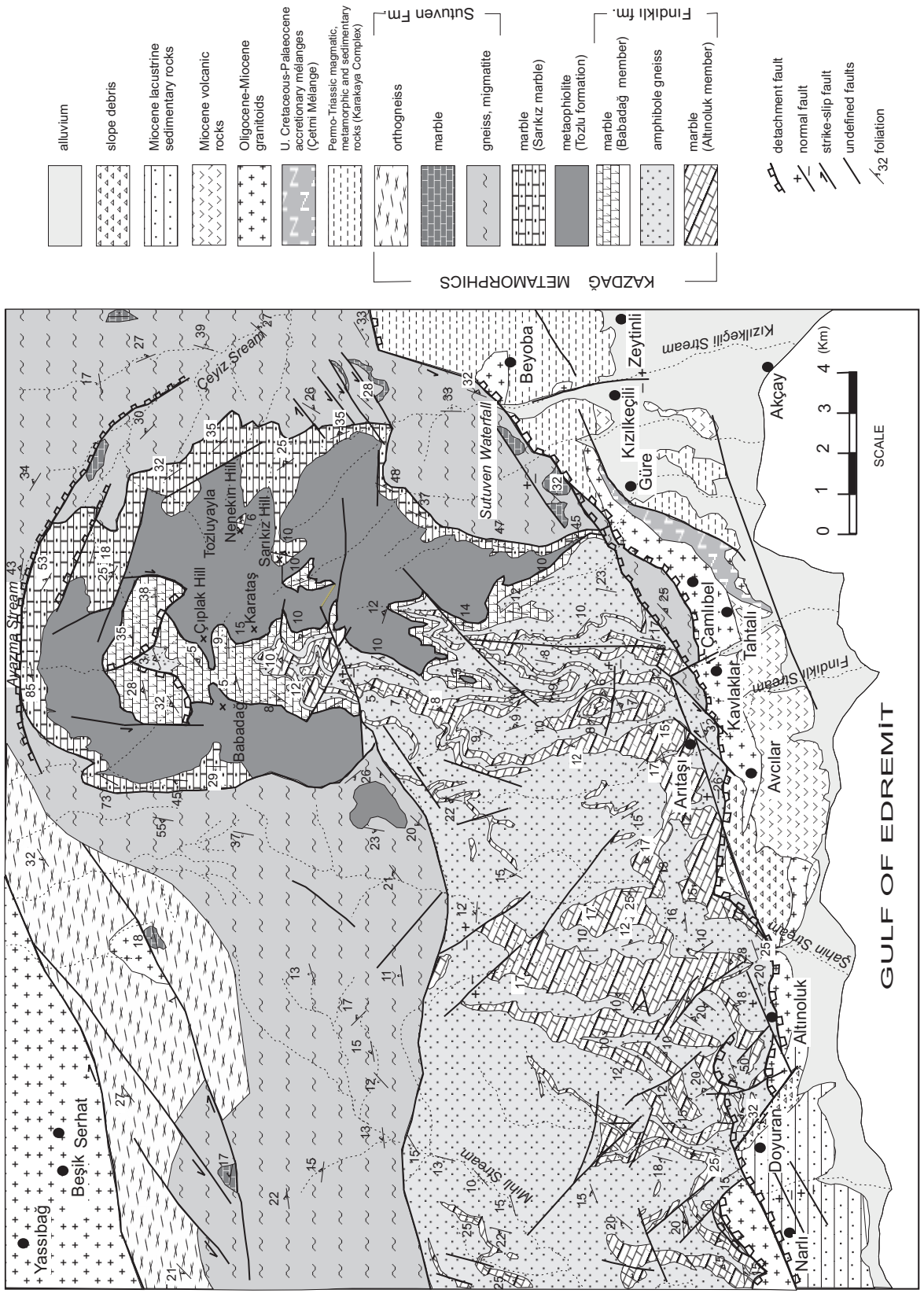

Figure 4. Detailed geological map of the central part of the Kazdağ Massif.

Amphiboles are ubiquitous in gneisses of the Fındıklı formation; the next most common mafic minerals are epidote in the lower levels, mica in the intermediate levels, and garnet in the upper parts of the formation.

The marbles in the Fındıklı formation form six to seven horizons, 10 to 75 m in thickness (Figures 4 & 5). The structurally highest marble horizon immediately below the metaophiolites forms a distinct marker horizon and is named the Babadağ marble member. The other marble horizons in the Fındıklı formation are ascribed to the Altınoluk marble member. The marble occurs as white, fine- to medium-grained, thin- to medium-banded rocks with a sugary texture. The Babadağ marble horizon differs from the other marble horizons by being more massive and coarser grained.

Tozlu Formation

The Tozlu Formation, which consists of meta-ophiolitic rocks, has been named by Bingöl *et al.* (1975). It crops out in the summit region of Kazdağ (Figure 5), and its type locality is in the Tozlu Yayla. The Tozlu formation consists mainly of metadunite and amphibolite. These rock types are typically intimately intermixed; however, there is a tendency for the amphibolites to dominate in the lower and upper levels of the formation, and the metadunites in the central part. Tight to isoclinal folding is widespread in the banded amphibolites and metadunites. Coarse-grained amphibolites generally have streaky or spotted textures resulting from the preferential distribution of hornblende and plagioclase in the rock. These orthoamphibolites, which have develop through the metamorphism of gabbroic and other basic magmatic rocks, have been referred to in former studies as metagabbros (Bingöl 1968, 1969; Bingöl *et al.* 1975).

In previous studies, meta ophiolites of the Tozlu formation were regarded as the base of the Kazdağ Group. However, our mapping has shown that the Tozlu formation lies above the Babadağ marble member of the Fındıklı formation, probably with a pre-metamorphic tectonic contact, and is overlain by the Sarıkız marble (Figures 4 & 5).

Sarıkız Marble

The Sarıkız marble, which consists predominantly of metacarbonates, was named by Bingöl *et al.* (1975). The Sarıkız marble has an atoll-like outcrop pattern (Figure 4) as a result of the antiformal structure of the Kazdağ Group, and crops out mainly on the Sarıkız and Nenekırı hills and at the Ayazma locality.

The Sarıkız marble starts above the metaophiolites of the Tozlu formation with a thin paragneiss layer. At a few localities, such as immediately north of Tozluyayla on the Kazdağ road, metaconglomerates with clasts derived from the ophiolites have been recognised, although because of high-grade metamorphism and strong deformation it is difficult to be certain on the nature of the protolith. The paragneisses pass gradationally upward into marbles, which form a single horizon 25- to 100-m thick. The marble is fine- to medium- grained, and is medium- to coarse-banded. The carbonates locally contain siliceous nodules 3- to 5-cm long. The upper contact of the Sarıkız formation with the Sutuven formation is sharp.

Sutuven Formation

Gneisses in the uppermost part of the Kazdağ Group have been named the Sutuven formation. The Sutuven formation corresponds to the "silico-aluminous series" of Bingöl (1968, 1969) or the Bozağaçtepe formation of Bingöl *et al.* (1975). The Sutuven formation rests with a sharp contact on the Sarıkız marble and Fındıklı formation. It is in fault contact with surrounding Permian to Miocene rocks, and is intruded by Oligo–Miocene granodiorites.

The type locality of the Sutuven formation is in the Sutuven waterfall north of the village of Zeytinli. Most of the northern parts of Kazdağ is underlain by the Sutuven formation. The Sutuven formation comprises mainly grey, dark grey, and brown, well-banded quartzo-feldspathic gneisses. These gneisses, which constitute the dominant lithology, comprise thin marble, amphibolite and granitic gneiss horizons and lenses. Furthermore, migmatisation is widely observed in gneisses of the Sutuven formation. Gneisses of the Sutuven formation are petrologically characterized through the presence of biotite, sillimanite, garnet, and hornblende along with ubiquitous quartz and feldspar.

The continuous, NE–SW-trending orthogneiss band in the northern and northwestern parts of Kazdağ cuts the gneisses of the Sutuven formation but at the same time shows banding and lineation subparallel to that of the neighbouring gneisses. The Oligo–Miocene granodiorites,

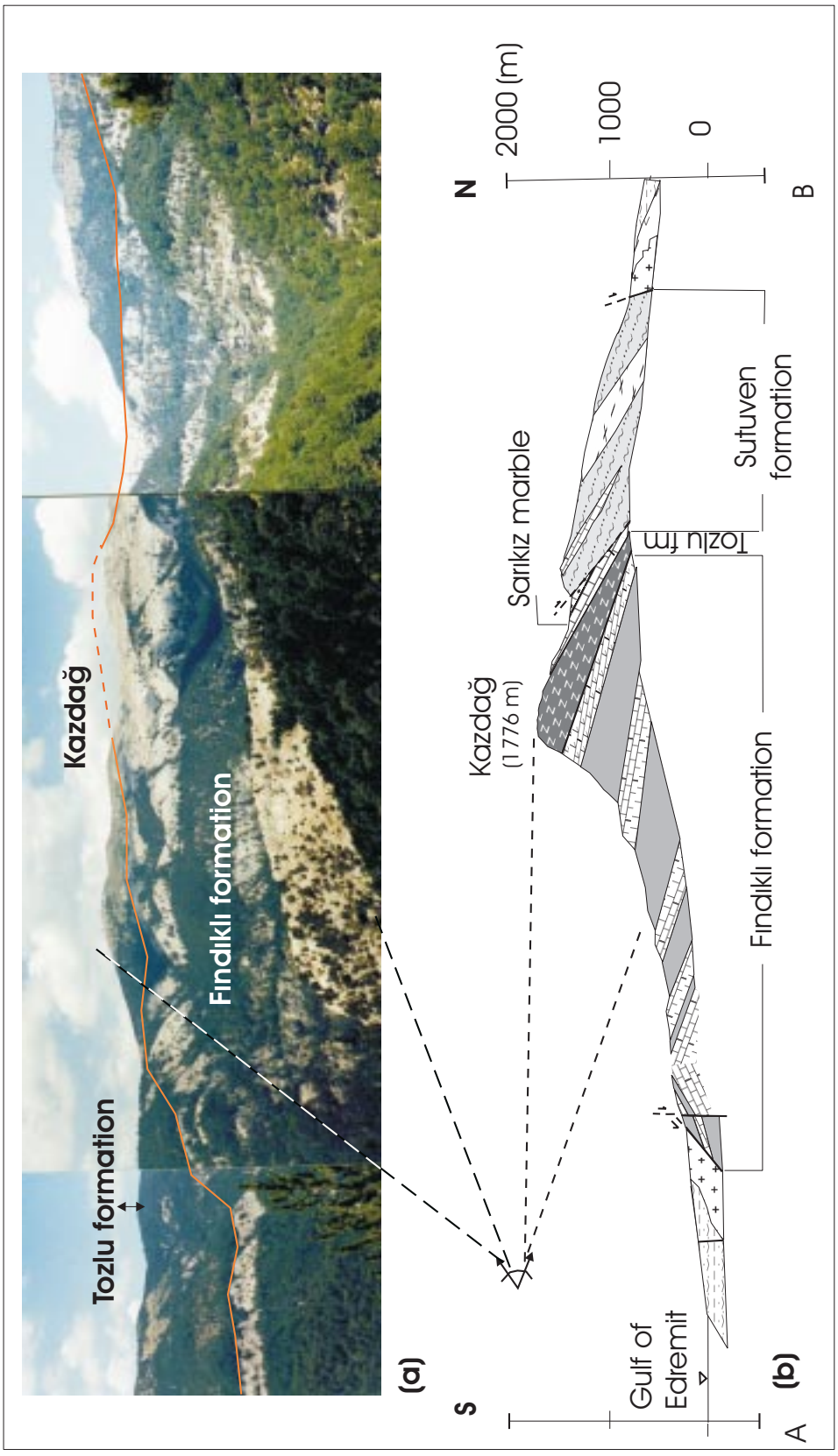

Figure 5. (**a**) Photograph of meta-ophiolitic rocks (Tozlu formation) lying over the amphibole-gneiss and marble of the Fındıklı formation. The photograph is taken from the Fındıklı stream looking north toward the summit region of Kazdağ. (**b**) Geological section of the Kazdağ region. For location of the section and for lithological symbols, see Figure 2.

which crop out northwest of the Kazdağ Group, generally do not show any banding or lineation. This suggests that the orthogneisses intruded the Sutuven formation prior to the last phase of metamorphism. However, Okay & Satır (2000) have mapped banding and lineation in the Oligo–Miocene Evciler granodiorite along its southern contacts with the Sutuven formation; the banding and lineation in the granodiorite are reportedly subparallel to that in the neighbouring gneisses.

Discussion and Conclusions

In this study the Kazdağ Group, consisting of high-grade metamorphic rocks, has been subdivided into four formations. These are, in ascending order, the Fındıklı and Tozlu formations, the Sarıkız marble and the Sutuven formation. In previous studies the metaophiolites, which make up the Tozlu formation, were regarded either as the structurally lowest unit in the Kazdağ Group (Bingöl 1968, 1969; Bingöl *et al.* 1975) or as the uppermost unit (Gözler *et al.* 1984). Our geological mapping has shown that the metaophiolites are underlain by an amphibole-bearing gneiss – marble unit (Fındıklı formation) and are overlain by the Sarıkız marble.

Metamorphism in the Kazdağ Group has been dated using zircon Pb-Pb and mica Rb-Sr and K-Ar methods on gneisses from the Fındıklı and Sutuven formations. The zircon Pb-Pb data from the gneisses yield Mid–Carboniferous ages (308 ± 16 Ma, Okay *et al.* 1996), whereas the biotite and muscovite Rb-Sr and K-Ar ages are Oligo–Miocene (19–22 Ma, Bingöl 1968, 1969; Okay & Satır 2000). These isotopic data have been interpreted as indicating two periods of high-grade metamorphism; the initial one during the Mid–Carboniferous and a later one in the Oligo–Miocene. The P-T conditions of the high-grade metamorphism have been estimated as 640 ± 50 °C and 5 ± 1 kbar (Okay & Satır 2000).

The metaophiolites of the Tozlu formation and the Sarıkız marble pinch out toward the west, where the Sutuven formation directly overlies the Fındıklı formation (Figures 2 & 4). This relationship suggests the presence of tectonic contacts between the Fındıklı and Tozlu formations, and between the Sarıkız marble and the Sutuven formation. However, any such tectonic contacts must pre-date the last phase of high-grade metamorphism, since foliation and lineation in these formations are all subparallel.

Metamorphic rocks of the Kazdağ Group form an anticlinorium with an axis that trends NE–SW. The contacts of the Kazdağ metamorphic rocks with the surrounding sedimentary, magmatic and metamorphic rocks are generally low-angle normal faults of detachment-fault character. The detachment faults dip northward to the north of the Kazdağ anticlinorium, and southward to the south of the Kazdağ anticlinorium. The detachment faults are cut by strike-slip faults on the northwestern and southeastern limbs of the anticlinorium. In so far as clasts of the Kazdağ metamorphic rocks are found only in the Pliocene deposits, the exhumation of Kazdağ can be identified as a Pliocene event, as suggested by Okay & Satır (2000).

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