Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. **13**, 2004, pp. 145-176. *Copyright ©TÜBİTAK*

Geology and Correlation of the Ezine Zone: A Rhodope Fragment in NW Turkey?

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Abstract: In northwestern Turkey, the Denizgören ophiolite and its sedimentary substratum, the Ezine Group, are enigmatic geological objects whose evolution remains problematic. Based on long-term fieldwork, we here propose a solution for their genesis and correlation. The whole of the Ezine Group, more than three km thick, is characterised by the systematic occurrence of carbonate rocks in the greenschist facies. It has been subdivided into three conformable formations: the Geyikli Formation, with a slight terrigeneous detrital nature, (Middle)–Late Permian in age; the Karadağ Formation, with platform-type sedimentation with local detrital input, Late Permian (Djulfian) in age; the Çamköy Formation, with a pronounced carbonate detrital nature, of Spathian to Carnian age. Based on facies organisation and distribution, the Çamköy Formation is interpreted as a syn-rift sequence, following a strong transgressive subsidence phase represented by the Geyikli and Karadağ formations. The Denizgören ophiolite, comprising serpentinised peridotite, tectonically overlies the Ezine Group along a metabasite unit, interpreted as its metamorphic sole. The latter shows an inverted metamorphic gradient, and consists of mylonitised prasinites and amphibolites with oceanic geochemical signatures. The Ar/Ar age of the amphibolite facies indicates a Barremian age (125 Ma), quite different from that of the Ezine Group. A major problem is that the Ezine Group and the Denizgören ophiolite (plus its metamorphic sole) have no lateral equivalent in the whole Aegean domain. However, we suggest that the Ezine Group represents a fragment of the Rhodopian passive margin, consequence of the Permo–Triassic rifting of the future Maliac/Meliata Ocean, also observed in Greece. The emplacement of the Denizgören ophiolite over the Ezine Group occured within the framework of the Balkanic orogen, a major compressional event, which affected the whole Rhodope area, and was characterised by northward nappe emplacement during Jurassic–Early Cretaceous times.

Key Words: northwestern Turkey, Ezine Group, Permo–Triassic, syn-rift sequence, Denizgören ophiolite, Barremian, metamorphic sole, Rhodope margin, Maliac/Meliata Ocean

Ezine Zonu'nun Jeolojisi ve Korelasyonu: Kuzeybatı Anadolu'da Rodoplardan Bir Parça

Özet: Kuzeybatı Anadolu'da Biga yarımadasında yüzeyleyen Denizgören ofiyoliti ve onun altında yer alan Ezine Grubu metasedimenter kayaları Ege bölgesinin jeolojisi kapsamında iyi anlaşılmamış, problemli kaya birimleridir. Bölgede sürdürdüğümüz uzun süreli arazi çalışmaları sonucunda, bu kaya birimleri ayrıntılı tanımlamakta ve korelasyonu ve kökenleri hakkında bir çözüm öne sürmekteyiz. Sedimenter kalınlığı üç kilometreyi geçen Ezine Grubu ağırlıklı olarak yeşilşist fasiyesinde metamorfizma geçirmiş karbonat kayalarından yapılmıştır. Ezine Grubu birbirleri ile geçişli olan üç formasyona ayrılmıştır. Bunlar sırası ile, en altta yer alan karbonatların yanısıra karasal kökenli detritikler kapsayan (Orta)–Geç Permiyen yaşta Geyikli Formasyonu, büyük ölçüde platform tipi karbonat kayalarından oluşan Geç Permiyen (Culfiyen) yaşta Karadağ Formasyonu, ve en üstte yer alan Spatiyen–Karniyen yaş aralığında çökelmiş karbonat ve detritik kayalardan oluşan Çamköy Formasyonu'dur. Fasiyes tipi, geometrisi ve dağılımına bakarak Çamköy Formasyonu riftleşme ile eşzamanlı bir çökel istif olarak yorumlanmıştır. Bu riftleşme fazı, Geyikli ve Karadağ formasyonlarının çökelmeleri ile tanımlanan yaygın, kuvvetli transgressif bir çökme fazını takip etmiştir. Serpantinleşmiş peridotitlerden yapılmış Denizgören ofiyoliti, arada metabazit tektonik dilimleri olmak üzere, Ezine grubu üzerinde yer alır. Bu iki birim arasındaki metabazit tektonik dilimleri, Denizgören ofiyolitinin kıtaya yerleşmesi sırasında oluşmuş ofiyolit tabanı metamorfitleri olarak yorumlanır. Devrik bir metamorfik zonlanma gösteren metabazitler, okyanusal kabuk tipi jeokimyasal özellikler gösteren milonitleşmiş prazinitler ve amfibolitlerden yapılmıştır. Amfibolitlerde yapılan Ar/Ar izotopik analizleri Barremiyen (125 My) yaşları vermektedir. Denizgören ofiyoliti ve altındaki Ezine Grubu'nun yaş ve litostratigrafi açısından Ege bölgesinde benzerleri yoktur. Buna karşın, biz Ezine Grubu'nun, Permo–Triyas riftleşmesi ile oluşmuş Maliak/Meliata okyanusunun kuzeyindeki Rodop pasif kıta kenarının bir parçası olduğunu önermekteyiz. Denizgören ofiyolitinin

Ezine Grubu'nu üzerlemesi, tüm Rodopları etkileyen ve Jura–Erken Kretase'de kuzeye doğru nap yerleşmesi ile tanımlanan Balkan orojenezinin bir parçasını oluşturmaktadır.

Anahtar Sözcükler: Kuzeybatı Anadolu, Ezine Grubu, Permo–Triyas, Denizgören ofiyoliti, Barremiyen, metamorfik taban, Rodop kenarı, Maliak/Meliata okyanusu

Introduction

The study of ophiolite belts is of major interest to unravel the palaeotectonic evolution of oceanic domains and related margins. This approach led to major advances in the understanding of the geology of the Tethyan realm, and particularly of the eastern Mediterranean domain (Ricou 1971; Bernoulli & Laubscher 1972; Gansser 1974; Şengör & Yılmaz 1981; Dercourt *et al.* 1986). However, even if the major sutures are increasingly studied and are better understood, open questions still remain about some problematic areas.

The Ezine Zone of northwestern Turkey (Biga Peninsula) is such a place, insofar as no convincing explanation of its geological evolution has yet been advanced (see Robertson 2002 for a discussion). It comprises the Denizgören ophiolite, which tectonically overlies a carbonate sedimentary sequence of Permian age (Kalafatçıoğlu 1963; Okay *et al.* 1991), here defined as the Ezine Group. The main problems concern (i) the Cretaceous age of the metamorphic sole of the ophiolite (Okay *et al.* 1996), compared with the Permian age of the sedimentary sequence, and (ii) the genesis and correlations of the latter, and its affinity to the Permo–Triassic Karakaya Complex.

Following a detailed field investigation (mapping at a 1/20,000 scale and exhaustive sampling), we propose a coherent solution for the two aforementioned points. After an introduction to the geological context, we describe and interpret the sedimentary sequence (Ezine Group), with a special focus on its age constraints; then, we characterise the Denizgören peridotite, and give a precise description of its metamorphic sole. Finally, the discussion deals with lateral correlations of both units, and their possible affinities with the Sakarya (i.e. Karakaya) or Rhodope domains.

Geological Framework

The Biga Peninsula is bounded on its east by the westernmost end of the Sakarya Zone, and in the north by the Rhodope-Strandja Zone; the Aegean Sea marks its western and southern limits (Figure 1).

The Sakarya Zone

The Sakarya Zone is an E-W-trending continental fragment, about 1500-km long and 120-km wide, characterised at its base by the widespread occurrence of Triassic subduction-accretion complexes, called the Karakaya Complex in its western part (Bingöl *et al.* 1975; Tekeli 1981). The Karakaya Complex is generally subdivided into four units; the lower unit, named the Nilüfer Unit is a metabasite-marble-phyllite sequence with Triassic eclogites (Okay & Monié 1997; Okay *et al.* 2001) and blueschist lenses (Okay *et al.* 2002). The other units, grouped together here, tectonically overlie the Nilüfer Unit; these Çal, Hodul and Orhanlar greywacke units (Dışkaya Formation of Kaya 1991) are made up of unmetamorphosed but chaotically deformed clastic and basic volcanic rocks of Triassic age, with exotic blocks of Carboniferous and Permian neritic limestone and basalt, and Carboniferous and Permian radiolarian chert, plus Kozur & Kaya 1994; Leven & Okay 1996). From tectonic point of view, the Nilüfer Unit is either considered as an oceanic plateau (Okay 2000) or a seamount (Pickett & Robertson 1996). The Karakaya mélanges (mainly the Hodul Unit) may be seen as fore-arc/foreland basin deposits, related to the subduction of the Palaeotethys along the southern margin of Eurasia (Stampfli *et al.* 2003).

The deformed and partially metamorphosed Karakaya Complex is unconformably overlain by Liassic terrigeneous to shallow marine clastic sedimentary rocks (Altıner *et al.* 1991). The Liassic clastics are in turn unconformably overlain by Middle to Upper Jurassic platform-type neritic limestones, Lower Cretaceous pelagic limestones and Upper Cretaceous-Palaeocene volcanic and sedimentary rocks (e.g., Rojay & Altıner 1998). Senonian andesitic volcanism cropping out in the northern part of the Sakarya Zone is directly related to the northward subduction of the closing oceanic space south of the Sakarya continent.

The Rhodope-Strandja Zone

The Rhodope Massif is directly correlated with the Strandja Zone of Turkey and southeastern Bulgaria,

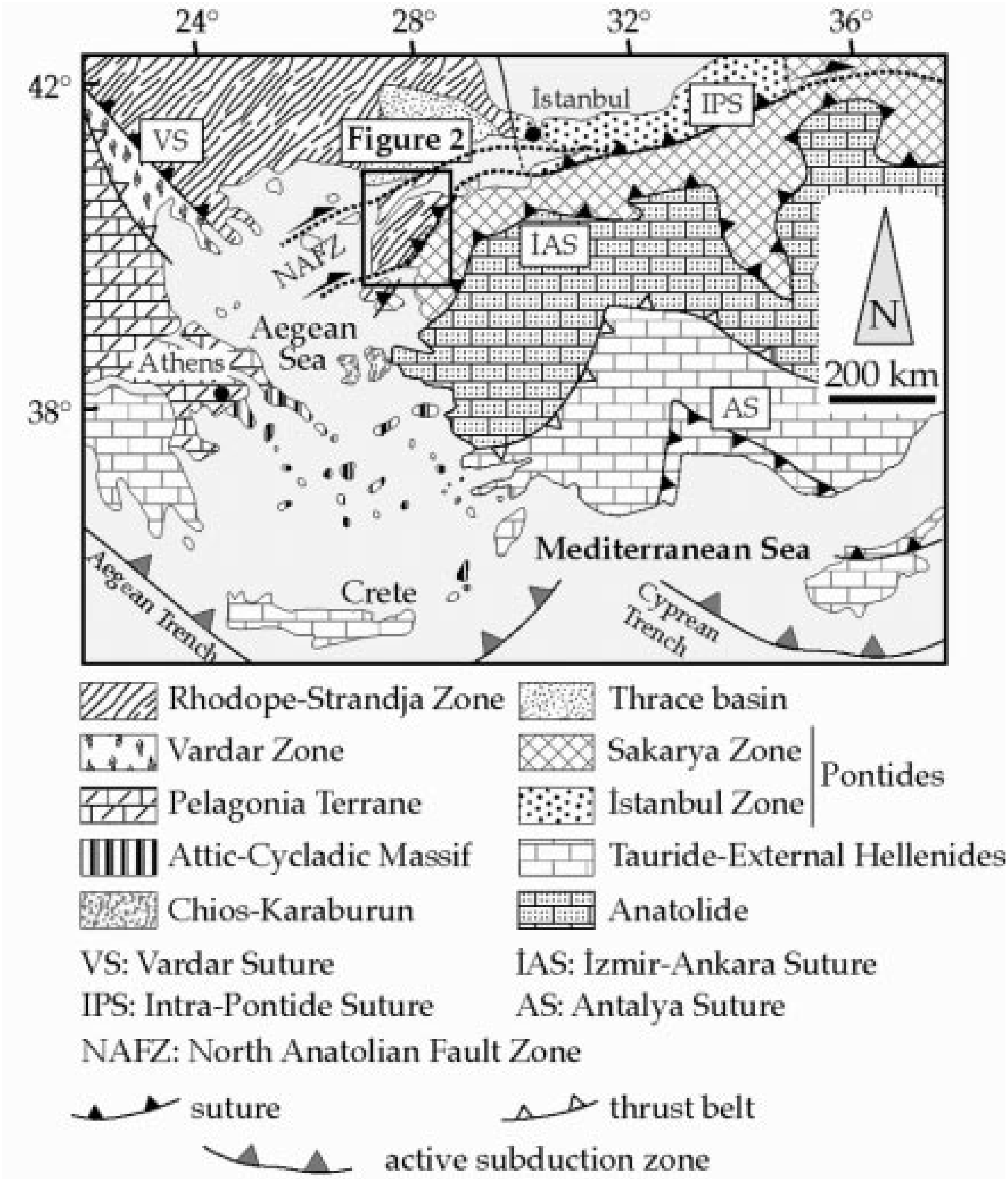


Figure 1. Structural map of the Aegean domain, with the main sutures and palaeotectonic features; modified from Bozkurt & Mittwede (2001) and Okay *et al.* (2001).

which represents its eastern continuation. From a stratigraphic point of view, it comprises a basement of highly deformed amphibolite-facies metamorphosed rocks intruded by late Variscan extensional Permian granites (Okay *et al.* 2001). This basement is unconformably overlain by a Triassic transgressive sequence made up of continental to shallow-marine metasediments. This sequence extends up to the Mid-Jurassic in the Bulgarian part of the Strandja Zone (Chatalov 1988). An important deformational regime operated in the Late Jurassic–Early Cretaceous involving the aforementioned units (Austrian phase or Balkanic orogen *s.l.*, Georgiev *et al.* 2001). The deformation is covered by Cenomanian conglomerates and shallow-marine limestones, followed by Senonian arc-related magmatic rocks. All the existing units were ultimately involved in the Alpide orogen s.l., creating a new generation of northward-directed thrusts in the latest Cretaceous–Oligocene. In Turkish southern Thrace, the Strandja Zone is covered by the sediments of the Tertiary Thrace Basin, which disguise the structural relation between the Strandja Zone and the Biga Peninsula.

Geology of the Biga Peninsula

The geology of the Biga Peninsula (Figure 2) is dominated by the widespread occurrence of plutonic and associated volcanic rocks, related to the transition from a collisional to an extensional tectonic regime during the Tertiary (Borsi *et al.* 1972; Ercan *et al.* 1995; Yılmaz *et al.* 2001). Apart from the magmatic rocks, noteworthy features of the Biga Peninsula also include (i) various units of the Karakaya Complex, cropping out along its eastern border, (ii) the Denizgören ophiolite, overlying the Permo–Triassic sedimentary Ezine Group, discussed in this paper, (iii) the accretion-related Mid-Cretaceous Çetmi mélange (Beccaletto & Stampfli 2002), and (iv) high-grade metamorphic rocks systematically occurring at the base of the previous units (Okay & Satır 2000a, b).

The N–S-trending association of the sedimentary Ezine Group and the overlying Denizgören ophiolite (plus its metamorphic sole) are located north of Ezine in the western part of the Biga Peninsula (Figure 2). The ophiolite and the sedimentary sequence are in tectonic contact with the underlying high-grade metamorphic rocks of the Çamlıca mica schists (Okay & Satır 2000b).

The Ezine Group

The whole greenschist-facies sedimentary sequence cropping out west and northwest of the city of Ezine (Karadağ Unit, Okay *et al.* 1991) is renamed the Ezine Group (Figures 3 & 4); it has been subdivided into three new lithostratigraphic units based on common stratigraphic features: from bottom to top, we distinguish the Geyikli formation with a slight terrigeneous detrital nature, then the Karadağ formation with platform-type sedimentation with local detrital input, and the Çamköy formation with a pronounced detrital nature. Sedimentological descriptions, as well as micropalaeontological investigations and determinations, have been hampered by the recrystallised nature of the lithologies.

The Geyikli Formation

The Geyikli formation crops out poorly between the village of Geyikli to the west and the village of Gökçebayır to the east (Figure 3). Its thickness may be estimated at about 1500 m maximum. It has been subdivided into four members, which show a roughly north–south alignment; they are described below, in ascending order.

The Lower Member

This member mainly crops out directly south of the village of Geyikli (Figure 3), and comprises silty to sandy recrystallised limestones, with bed thicknesses varying from a few cm up to 2 m. Subparallel to crossebeddedd mm-scale foresets are common. Argillaceous layers, a few mm to a few cm in thickness, are locally interlayered in the detrital limestones; the whole sequence shows m- to dm-scale open folding. The basal contact of the member is unknown as it is covered by Quaternary deposits. Its upper contact marks the transition to intermediate member n°1; based on facies similarities, it is thought to be stratigraphic, even though the contact is not clearly visible in the field.

The Intermediate Member n°1 (IM1)

This thin member is relatively well exposed along the road from Geyikli to Gökçebayır village (Figure 3), but recent road reconstruction has damaged outcrops. This member consists of alternations of detrital recrystallised limestones and silvery, green, metashales and metamarls. The thickness of the detrital limestones varies from 30 cm to about 10 m. Some quartz pebbles are reworked in the detrital limestones. The transition to intermediate member n°2 seems to be gradational.

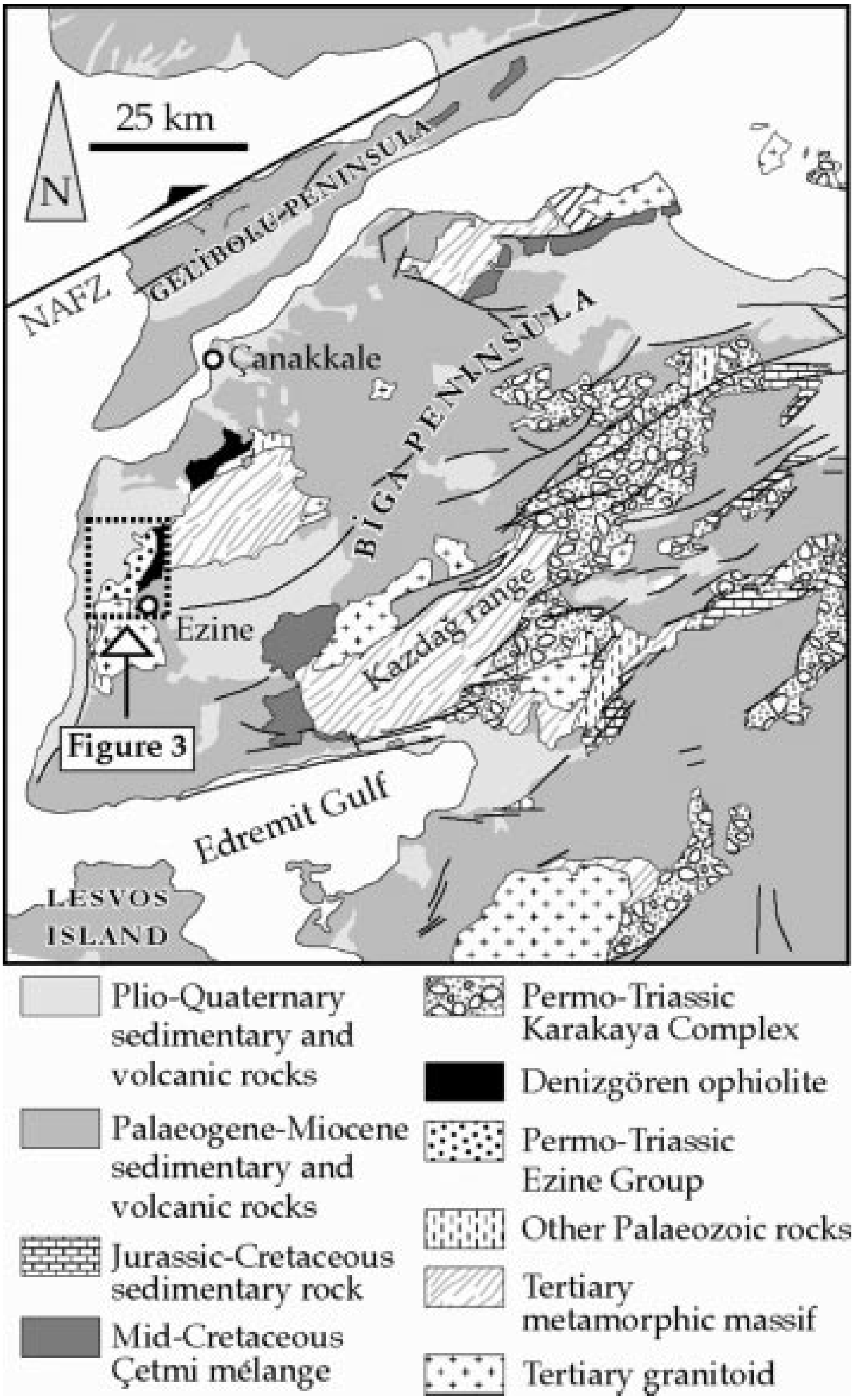


Figure 2. Geological map of the Biga Peninsula, with the location of the study area; modified from Siyako *et al.* (1989).

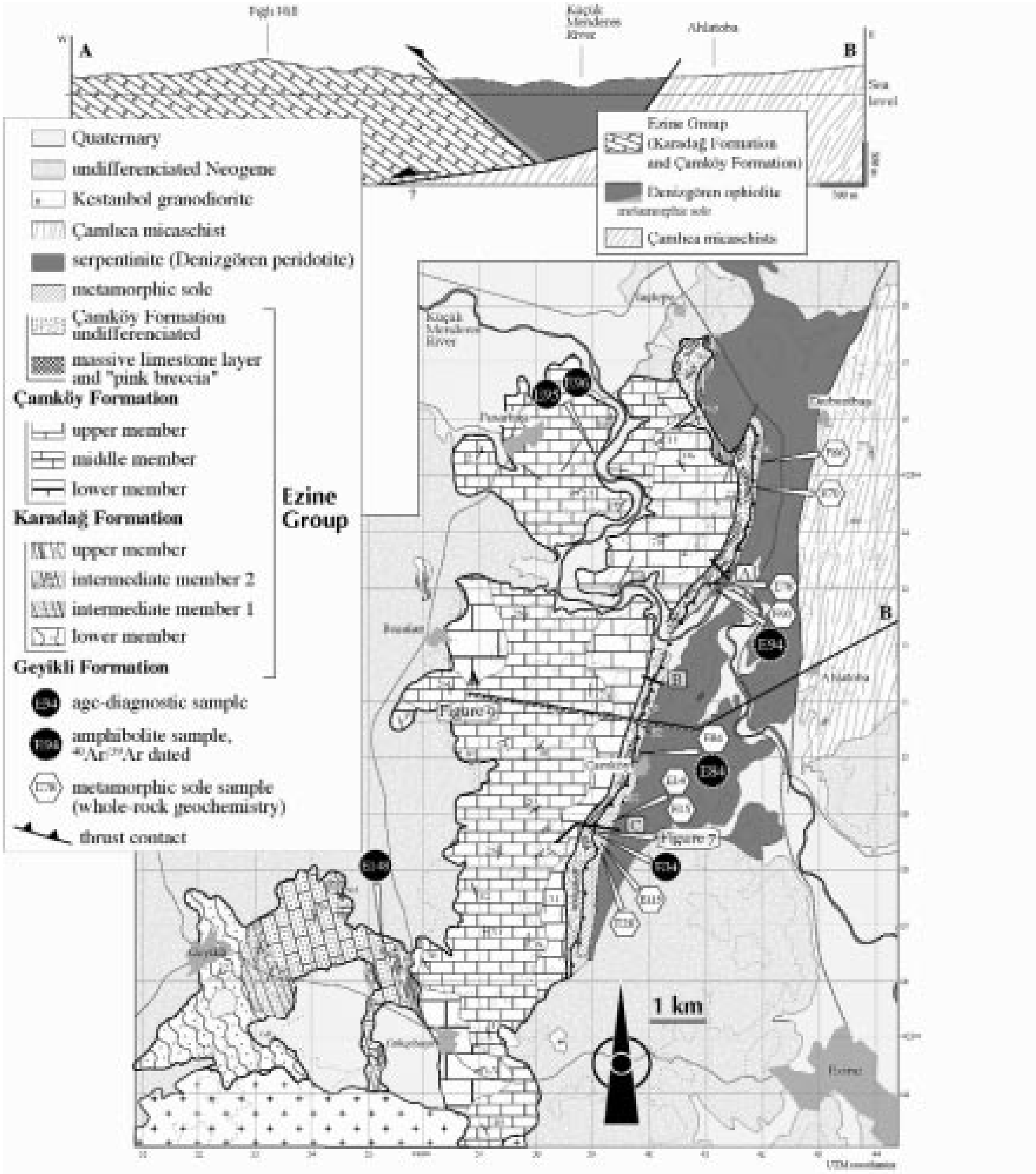


Figure 3. Geological map and cross-section of the Ezine Zone (Denizgören ophiolite and Ezine Group); location of key samples and cross-sections.

The Intermediate Member n°2 (IM2)

This member crops out north of the road from Geyikli to Gökçebayır. It comprises recrystallised detrital limestones and rare recrystallised carbonate sandstones, a few dm thick, and showing a characteristic yellowish patina. These facies pass upward into massive, slightly detrital, dark grey fetid limestones, occurring as olistoliths (Figure 4). The transition occurs in two

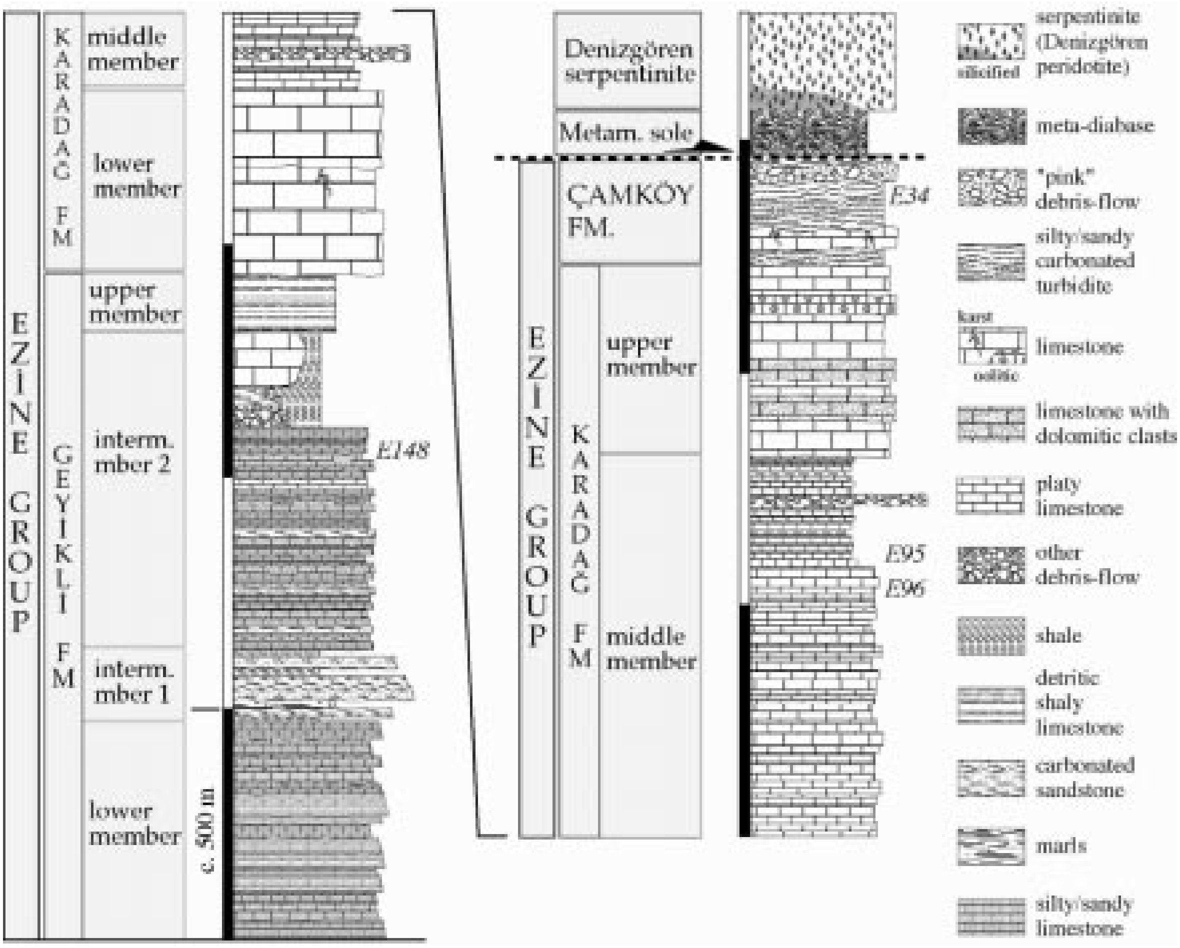


Figure 4. Synthetic stratigraphic column of the Ezine area, showing the different lithostratigraphic units; numbers refer to age-diagnostic samples.

different ways: either through a coarse to conglomeratic few-meter thick detrital carbonate sequence (Bayırgölü Hill), or through a dark grey to black metashale sequence (Zindan Hill). The transition to the upper member is not observable around Bayırgölü Hill; it seems to be stratigraphic east of Zindan Hill, where the dark shale passes upward into the detrital shaly limestones of the upper member.

The Upper Member

This thin member crops out northwest and southeast of Gökçebayır (Figure 3). It is made up of thin layers of recrystallised, yellowish to grey, detrital shaly limestones (calcschists). This member marks the termination of the Geyikli formation. The transition with the overlying Karadağ formation is clearly stratigraphic and can be seen in the quarries north of Gökçebayır and east of Bozalan village. Another lateral facies comprises alternations of oxidized carbonate sandy turbidites and greenish siltstone; no direct contact between this facies and the Karadağ formation has been observed.

Age of the Geyikli Formation

The whole sequence is dominated by detrital facies, and only a *Permocalculus* sp. has been found in a wackestone/packstone layer from the upper part of IM2 (sample E148, location in Figures 3 & 4, photograph in Plate 1, and stratigraphic range of the sample in Table 1); by analogy with similar Tethyan fauna and facies, this Gymnocodiacae algae is attributed to the (Middle)–Late Permian.

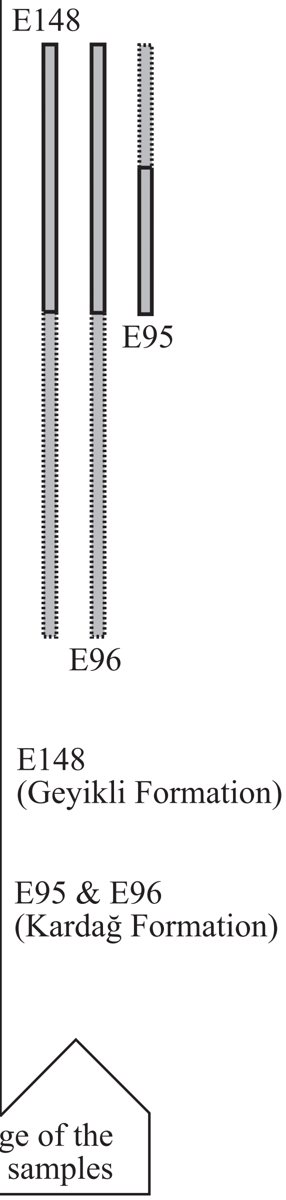
Depositional Environment of the Geyikli Formation

The four members of the Geyikli formation are considered to be in stratigraphic continuity and show a total estimated maximum thickness of about 1500 m. The formation consists largely of carbonates but with a strong detrital component, represented by quartz grains and locally quartz pebbles; the lower member and IM1 may represent open marine detrital sedimentation (coastal fan), with possible deepening in IM1 (typical turbiditic facies). IM2 is typical of a shallowing sequence marked by the occurrence of a *Gymnocodiacae* algae in slightly detrital limestones. The upper part of IM2 is marked by small-scale lateral facies variations; the dark massive limestone olistoliths at the top of IM2 prefigure

Table 1. Stratigraphic range of Permian age-diagnostic samples in the GSSP and Tethyan stages.

Series	GSSP Stages	Tethyan Stages
Lopingian (Upper Permian)	Changsingian	Dorashamian
	Wuchiapingian	Djulfian
Guadalupian (Middle Permian)	Capitanian	Midian
	Wordian	Murgabian
	Roadian	Kubergandian
Cisuralian (Lower Permian)	Kungurian	Bolarian
	Artinskian	Artinskian
	Sakmarian	Sakmarian
	Asselian	Asselian

GSSP: Global Stratotype Section and Point



the emplacement of the carbonate platform of the Karadağ Formation (e.g., olistoliths in front of the prograding platform). The upper member records quiet detrital sedimentation before the installation of the platform.

The Karadağ Formation

The Karadağ formation makes up most of the pre-Neogene outcrops northwest of Ezine (Figure 3). It has been subdivided into three successive members, showing a clear N–S alignment. They are described below, in ascending order.

The Lower Member

This member comprises thickly-bedded to massive grey recrystallised limestones that crop out around Gökçebayır and Bozalan villages. Its thickness is estimated to be about 400 m. As previously said, it is in conformable stratigraphic contact with the underlying calcschists of the upper member of the Geyikli formation. Some scarce dm-scale karstic features are present; coral structures occur locally, but are difficult to recognise due to the general recrystallisation. Another facies, cropping out southeast of Bozalan, comprises thinly to thickly bedded (10 cm to 6 m), light grey limestones, and is also included in the lower member. The top of each bed is marked by a cm-thick red oxidised horizon, interpreted either as inundation or a condensed surface. The transition to the middle member is stratigraphic and can be observed north of Gökçebayır (Figure 3).

The Middle Member

This member is the most extensive unit in the Ezine Group. It crops out along a N–S line from Taşlıtepe village in the north to Gökçebayır in the south. Its total thickness may be estimated at about 1000 m. The whole sequence is gently folded. The main facies is made of dark grey (sometimes light pink), thinly to medium-bedded (a few dm thick in general) recrystallised limestone. Pyrite, bird's-eyes and traces of fossils occur locally. Toward the top of the unit, the grey limestones pass progressively upward into light pink, greenish and dark grey, thinly bedded platy limestones. These platy limestones are locally associated with dark metashale. In places, scarce chert nodules intercalated in grey thinly bedded recrystallised limestones have been found.

Toward the base of the unit, there is a first conglomeratic layer, intercalated in the dark grey limestones; its thickness varies between 1 and 10 m (Figure 4). The conglomerate is either monogenic (grey recrystallised limestone pebbles) or polymict (grey and red recrystallised limestone pebbles, green phyllite); the subrounded pebbles reach a size of 15 cm and the matrix is always calcite. A second conglomeratic layer, similar to the first, occurs toward the top of the sequence, generally above the platy limestones. Its thickness is roughly a few meters and, in two places, clear bedding and pebble alignment (N–S) is observed; the conglomerate is either monogenic (grey recrystallised limestone pebbles) or polymict (white, beige and dark grey recrystallised limestone pebbles). The subangular to subrounded pebbles reach a size of 10 cm; the matrix is always made of pinkish to yellowish calcite. All the facies described above, show important variability in their thicknesses, but are always present along strike. The middle member passes conformably and progressively upward into the upper member.

The Upper Member

The upper member crops out east of, and parallel to, the middle member (Figure 3). At first glance, it seems to be totally made up of thickly-bedded white recrystallised limestones (50 cm to 6 m thick). Its thickness may be estimated at about 500 m maximum. Two different facies, whose external aspects are almost the same, have been distinguished: one is made of resedimented carbonate, with a very minor terrigeneous fraction, reworking sub-mm-scale fragments of dolomitic limestone; these clasts accentuate a parallel lamination. The other facies does not show any clear transport features; on the contrary, it displays locally oolitic grainstone microfacies. Some traces of a Middle–Late Permian *Gymnocodiacea* algae have been also observed at one locality toward the top of the member, below the oolitic limestones. The transition between the upper member of the Karadağ formation and the overlying detrital Çamköy formation is generally obliterated by recent fault activity. However, it is considered to be primary (conformable), based on local observations and facies similarities and continuities.

Age of the Karadağ Formation

No fossils have been found in the lower and upper members of the Karadağ formation. Only in one place of the middle member east of Pınarbaşı village, a dark grey-light pink recrystallised limestone layer has preserved the following foraminifera-algae assemblage (sample E96, location in Figures 3 & 4, photographs of the age-diagnostic taxa in Plate 1, and stratigraphic range of the assemblage in Table 1): *Staffella* sp., *Nankinella* sp., *Gyroporella* sp., *Hemigordius* sp., *Globivalvulina* sp., *Geinitzina* sp., *Nodosaria* sp., *Agathaminna* sp., *Pseudovermiporella* sp, *Staffella* aff. *sphaerica* (ABICH), *Permocalculus plumosus* ELIOTT, ostracods, bryozoans, microgasteropods and echinoids, characteristic of the (Middle)-Late Permian. Moreover, sample E95 (location in Figures 3 & 4, pictures of the age-diagnostic taxa in Plate 1, and stratigraphic range of the sample in Table 1), from the same place, has preserved *Rectostipulina quadrata* JENNY-DESHUSSES, characteristic of the Late Permian, and specially Djulfian. The middle member of the Karadağ formation is therefore considered to be Late Permian (Djulfian). These ages refine those already reported from the same vicinity by Kalafatçıoğlu (1963), Gözler *et al.* (1984), and Okay *et al.* (1991).

Depositional Environment of the Karadağ Formation

The three members of the Karadağ formation are in stratigraphic continuity and have a maximum thickness of about 1700 m. The lower member marks the initiation of the prograding platform over the more distal carbonate-detrital deposits. Few inundation events must have occurred, as proved by the occurrence of scarce karst features. The middle member, almost one-km thick, records typical lagoonal-type sedimentation, as shown by the microfaunal assemblage and the regular succession of dark facies with restricted features (pyrite, bird's-eyes). The upper part of the middle member reflects a deepening of the depositional environment, with thinly bedded platy limestones intercalated with chert nodules and/or dark shale layers. This quiet environment is interrupted by two, few-m thick conglomeratic episodes (debris-flows), in the lower and upper part of the member. Both of them are reworking separately the underlying carbonate lithologies, as well as lithologies unrelated to the Ezine Group (e.g., the green phyllites); these two events may be considered to prefigure the strongly disturbed sedimentation of the Çamköy formation. The upper member is characterised by an increase in energy; the latter is marked either by transportation of very fine erosional products of landward dolomitic deposits, or by the emplacement of oolitic bars.

The Çamköy Formation

The Çamköy formation crops out as a narrow band (about 300 m wide) east of and stratigraphically above the Karadağ formation. At first sight, the Çamköy formation shows complex organisation without any internal order. However, this is not quite the case, and several facies occurring roughly in the same order have been identified (Figure 5).

Light Pink Debris-Flows

These thickly bedded conglomerates (up to 5-m thick with an average thicknesses of 0.5–1 m) crop out mainly toward the top of the sequence, in tectonic contact with metabasites. They always comprise the same kinds of carbonate clasts (Figure 6): (1) elongated recrystallised white limestone, sometimes with (dark) grey layers, up to 50-cm long and 10-cm wide; (2) subangular to rounded dark pink recrystallised limestone, with diameters up to 20 cm; (3) light pink or grey recrystallised limestone, with no preferential shape; (4) light pink/yellow dolomite; (5) dolomitic limestone. These clasts look like the typical Hallstatt facies. The matrix is made of the same lithologies as the clasts; it consists everywhere of carbonate, and is locally dolomitised; its colour varies from light pink to yellowish. The clasts display broadly two morphologies: one rounded to subangular, as classical conglomerate pebbles; the other elongated, and with the pebbles looking like fragments of (banded) limestone layers.

Silty to Sandy Carbonate Turbidite

These thinly bedded recrystallised detrital (with quartz) limestones (average thickness of about 5 cm with a maximum of 30 cm) display a grey patina and a white, grey or light pink fracture. They occur mainly at the base of the light pink debris-flows.

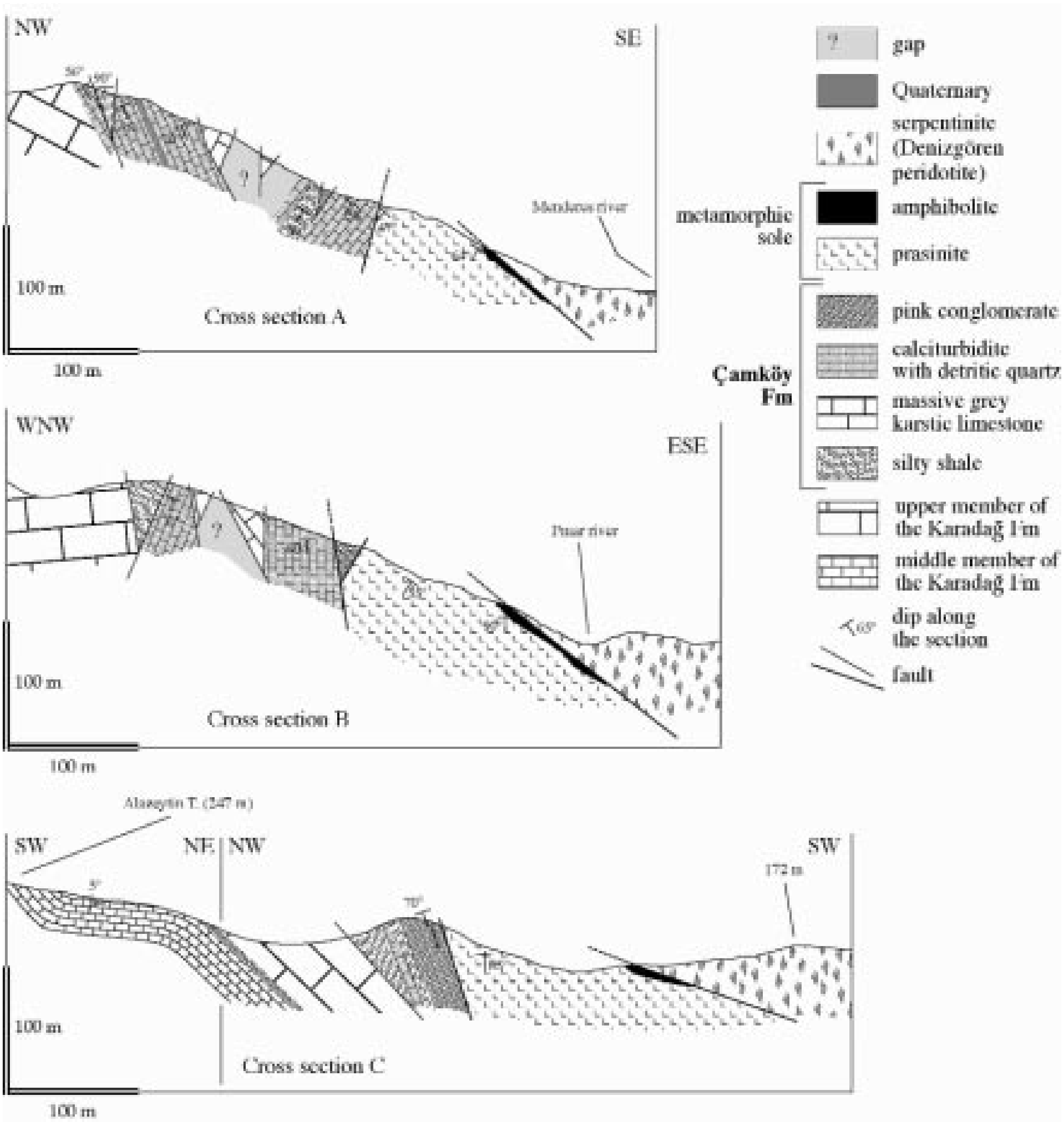


Figure 5. Selected cross-sections through the Çamköy formation; location given in Figure 2.

Karstic Massive Grey Limestone

These massive grey limestones (up to 3-m thick) are always found toward the base of the sequence, possibly as olistoliths. They are characterised by local but well-preserved karstification features. They may also have a detrital component, and are locally dolomitised.

In addition to the facies described above, several other minor facies occur, either in several places or only locally. These are green shales, sometimes interfingering with thinly bedded carbonate turbidites, shaly siltstones, green cherts, green tuffites and sandstones, and red pelagic recrystallised limestones.

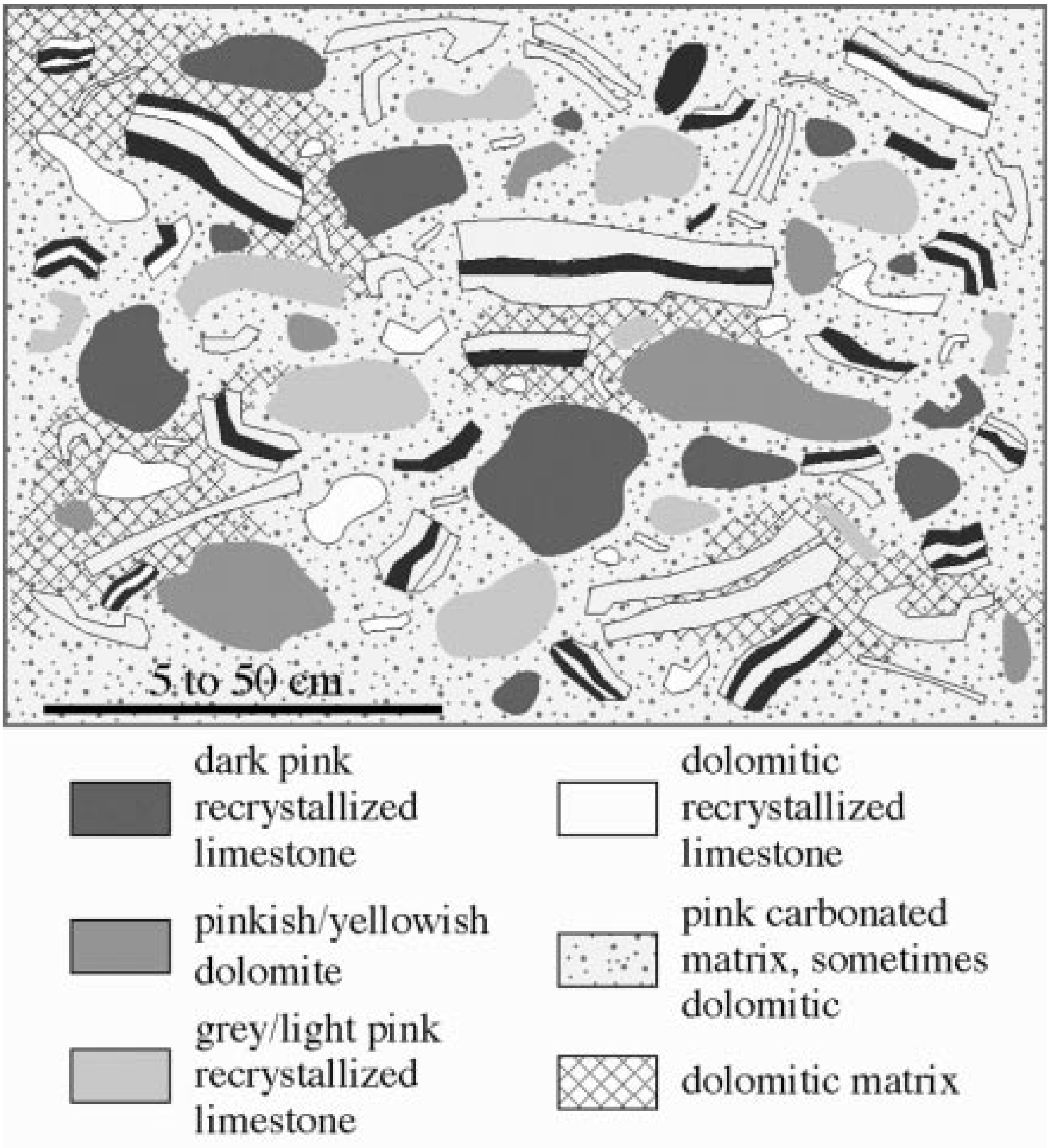


Figure 6. Schematic drawing of the light-pink debris-flows.

Structure of the Çamköy Formation

The contact between the more massive lithologies (light pink debris flows and karstic massive grey limestone) and the other lithologies (mainly the silty to sandy carbonate turbidites) is generally obliterated by recent strike-slip faulting. However, the original contacts are observable in places, where they are clearly conformable. Therefore, the whole Çamköy formation has recorded a continuum of sedimentation, and despite its chaotic aspect, it has not been deposited as a mélange-like formation.

Age of the Çamköy Formation

Only one sample, coming from a red pelagic recrystallised limestone layer, has yielded the conodont *Gladigondollela* sp. (sample E34, location in Figures 3 & 4, and photograph in Plate 1), whose age ranges between late Scythian (Spathian) to middle Carnian (det. H. Kozur, Budapest). As indicated by other facies characteristics, this conodont is typical of an open sea, deep pelagic environment.

The red limestones are in stratigraphic contact with the underlying pink debris flows and are overlain stratigraphically by carbonate turbidites (Figure 7). Actually, the whole section shows stratigraphic continuity, which implies an age for the section which should not be too different from the age of the red pelagic limestones. By inference, the whole Çamköy sequence is considered to have a Spathian–Carnian age, on the basis of facies similarities and continuities. However, it is a broad time interval, and the real age of Çamköy formation is suspected to be closer to the Spathian than to the Carnian, because it is in stratigraphic continuity with the Late Permian–earliest Triassic (?) Karadağ formation. Moreover, calciturbidites from the Çamköy formation retain transported Upper Permian foraminifers, most probably derived from the underlying Upper Permian Karadağ formation (Okay *et al.* 1991).

Depositional Environment of the Çamköy Formation

The Çamköy formation records a dramatic increase in energy, marked by the arrival of erosional products from the carbonate platform-type deposits: possible olistoliths of karstified limestones, debris flows with dolomitic and carbonate pebbles (or fragments of layers), and carbonate turbidites. The debris flows were emplaced onto pelagic red limestones, implying a strong deepening of the depositional environment, confirmed by the occurrence of re-sedimented carbonates. This deepening and strong coeval erosion may be due to landward fault activity, suggesting an extensive regime. The scarce green tuffites, green sandstones and green shales suggest that there was volcanic activity in the region at the time of deposition of the Çamköy formation.

The Ezine Group as a Permian–Triassic Syn-rift Sequence

In summary, very few age markers are available from the Ezine Group. The Geyikli formation is considered to be (Middle)–Late Permian, the Karadağ formation to be Late Permian (Djulfian), and the Çamköy formation to be Spathian to Carnian. This is a major limitation in the precise understanding of the evolution of the Ezine Group. For example, these very few ages prevent determination of possible hiatuses in the sedimentary sequence. However, from a structural point of view, the Ezine Group is a homogeneous sequence, as its various members and formations are in stratigraphic contact and the bedding is generally dipping uniformly toward the east.

Another characteristic of the Ezine Group is its great thickness (c. 3500 m max), most of it due to the Geyikli and Karadağ formations. Independent of eustatic variations, this observation implies continuous and regular subsidence in the (Middle)–Late Permian. The Geyikli formation is the only unit which shows erosion of continental-type material. As for the Çamköy formation, it marks a rapid change in conditions of sedimentation, with a deepening and the coeval erosion of landward rocks, and with the presence of rare volcanogenic facies (e.g., green tuffites). The Ezine Group is also characterised by typical lateral variations in facies and thickness, which are signs of changes in local depositional conditions. All these features are typically found in rift-related environments (tilted block margin), and it is possible to make two hypotheses (Figure 8):

1. A simple one would consider the Ezine Group as a part of the infill of a single tilted block, whose sedimentation is controlled by normal fault activity. In this case, the Geyikli and Karadağ formations record regular subsidence at the beginning of the rifting, with limestone olistoliths (lM2 of Geyikli formation) and two conglomeratic events (middle member of Karadağ formation), suggesting landward uplift and erosion of tilted blocks. Because the Karadağ formation is characterised by more quiet carbonate sedimentation, it may represent a slowing down of the fault (rift ?) activity. The tectonic activity recorded in the Çamköy formation may accommodate a rise in the extensional regime following the previous subsidence, resulting in an increase of erosional processes in the landward domains. The scarcity of lithologies of continental origin ("basement") may be explained by a distal position of the Ezine Group with respect to the rift shoulders. Pre-rift deposits, as well as post-rift sedimentation, are unknown in the Ezine area.

2. A second hypothesis would consider the Geyikli and Karadağ formations as post-rift (transgressive)

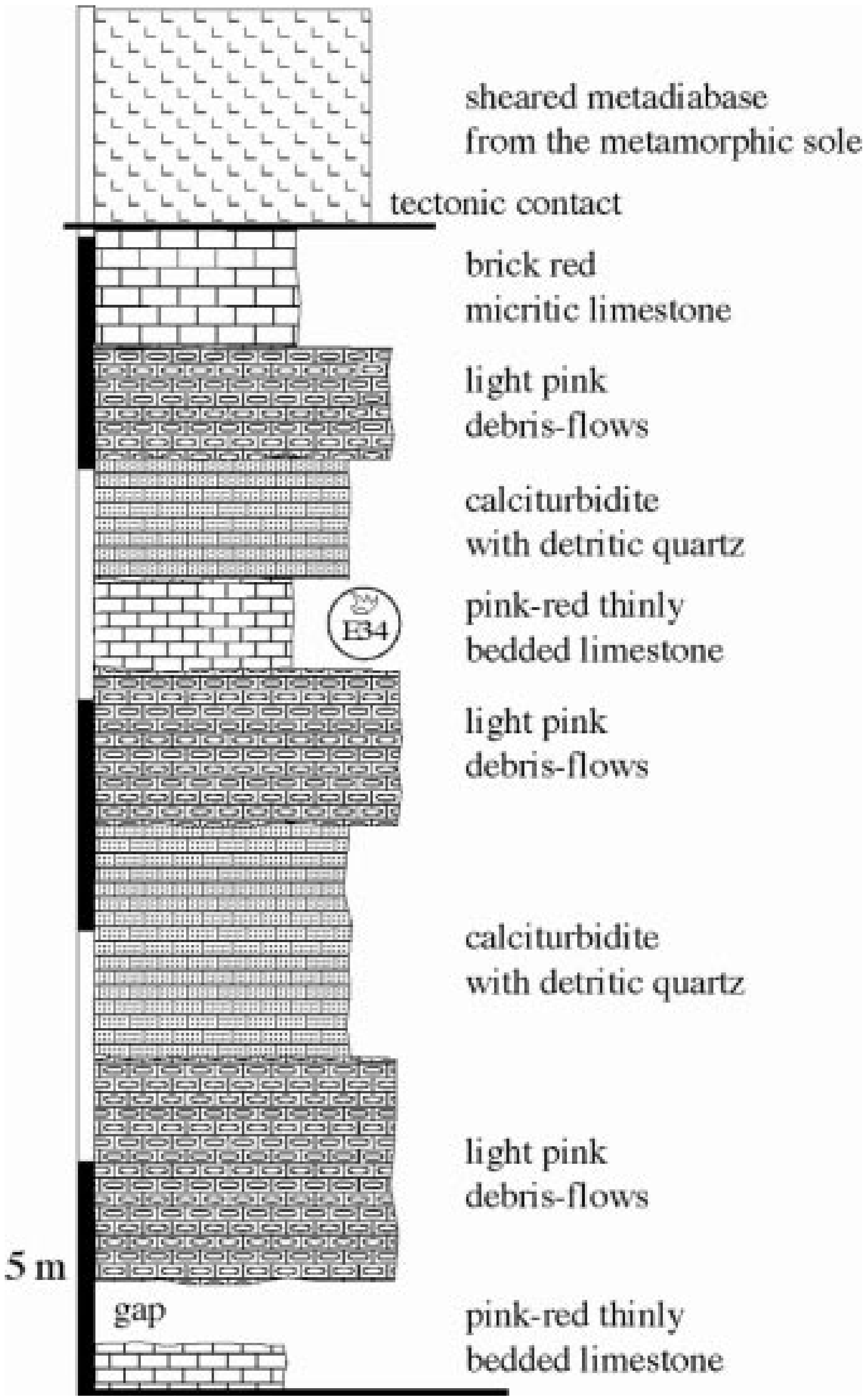


Figure 7. Stratigraphic column in the Çamköy formation, with the location of sample E34 of Late Scythian–Middle Carnian age; location of sample given in Figure 2.

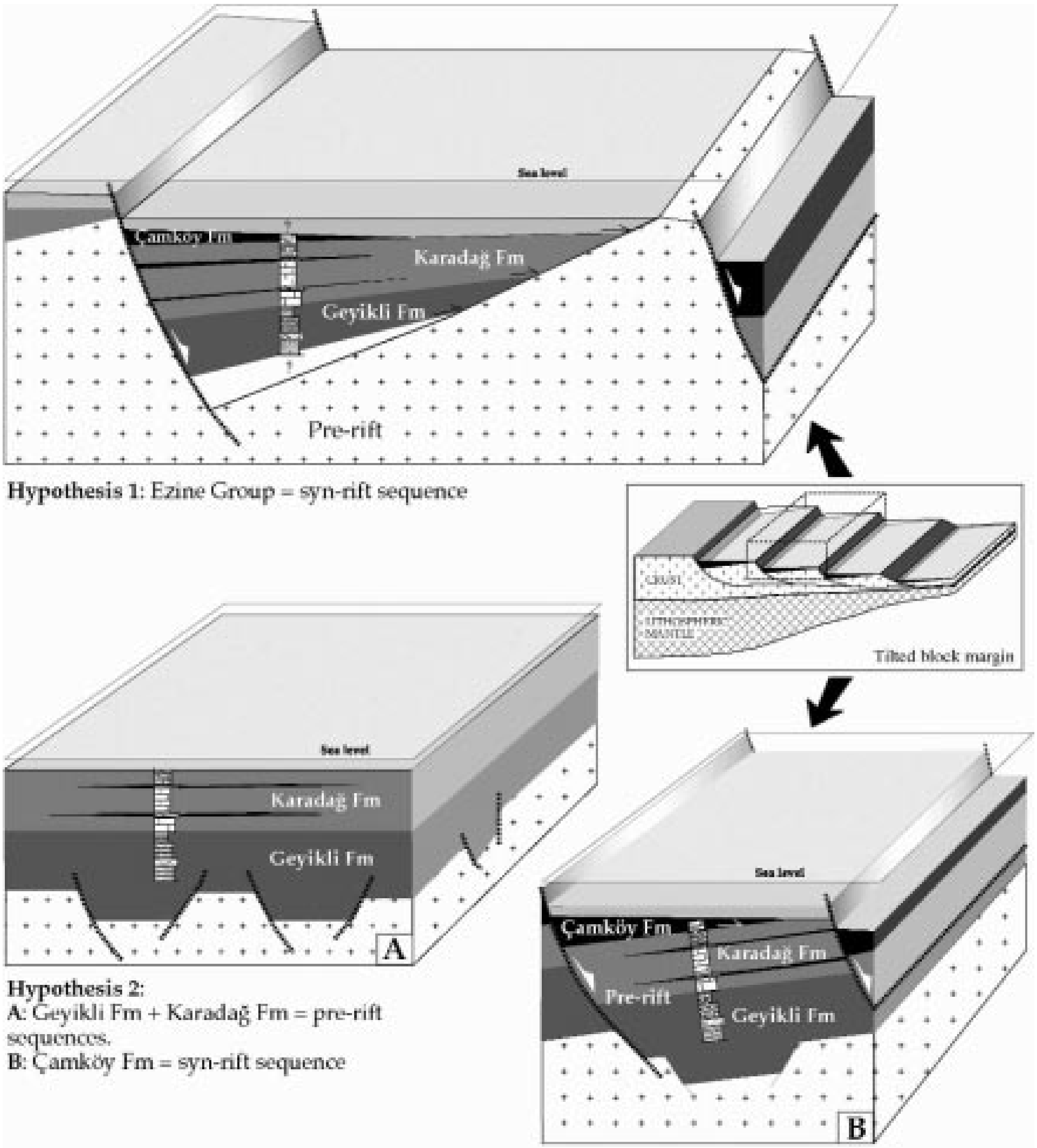


Figure 8. Schematic diagrams showing two hypotheses for the genesis of the Ezine Group.

sedimentation following a previous phase of extensional tectonics in Early–Middle Permian times (unknown in the Ezine area). The tectonic activity may have continued, but it remained limited. The Triassic Çamköy formation represents, then, the real, significant rifting phase. In this case, the Geyikli and Karadağ formations are the pre-rift sequences with respect to the syn-rift Çamköy formation.

The Low-grade Metamorphism of the Ezine Group-Illite Crystallinity

The whole Ezine Group is characterised by recrystallised lithologies, well revealed by micro- and macro-facies observations. A well-known cause of metamorphism is the Upper Oligocene–Lower Miocene Kestanbol granodiorite (Fytikas *et al.* 1976; Birkle & Satır 1995), which intrudes the Geyikli formation at its southern border (see Figure 3). The contact metamorphism of this intrusion has already been studied in detail (Birkle & Satır 1992; Karacık & Yılmaz 1998); the Geyikli formation displays quartz veins crossing the bedding and quartz pebbles reworked in the olive tree fields, both possibly related to silica-rich fluid circulation accompanying the pluton emplacement. Moreover, scarce neoformed quartz, albite, muscovite and graphite, indicating low greenschist conditions (200–300°C), have been found in detrital limestones of intermediate member n°2. However, the intrusion affects only its immediate surroundings, but cannot be responsible for the metamorphism farther north. Six samples from along an E–W transect through the various limestones of the Karadağ formation have been processed for illite crystallinity determinations in an effort to constrain metamorphic grade.

Sample preparation and illite crystallinity determinations were done at the Institute of Mineralogy and Geochemistry of Lausanne University, according to the method developed by Jaboyedoff & Thélin (1996). The method is based on the direct relation between the width of the first illite peak (Scherrer width), measured by X-ray diffractometry, and the temperature at the time of the crystallisation of the illite mineral. Because (1) the measurements have been done on the fraction smaller than 2 μm, (2) the lithology (limestone) is particularly favourable, and (3) the Scherrer widths are homogeneous, the illite is considered a neoformed mineral, whose crystallisation is due to the increasing temperature (burial). The Scherrer Width of the six samples ranges from 0.15 to 0.21 $\Delta 2\theta°$(CuKα), with no significant metamorphic gradient along the transect (Figure 9). These values indicate that the illites crystallised under epizonal conditions, at a temperature above 300°C, corresponding to a burial of more than 10 km with a temperature gradient of 30°C/km (Figure 10). Moreover, secondary clay minerals, such as kaolinite and smectite, possibly as late phases, are present on the diffractogram of some samples (Figure 11). All these results are confirmed by the mineral assemblage of the very fine-grain green metatuffs found in the Çamköy formation, characterised by the incipient crystallisation of chlorite, epidote and albite, all typical of the lower greenschist facies.

Because the contacts between the three formations of the Ezine Group are stratigraphic, the previous results from the Karadağ and Çamköy formations are extrapolated to the whole Ezine Group; hence the latter was buried to about 10 km depth before being eroded. This erosional process may have been related to various events, such as the emplacement of the ophiolite, or most probably to the exhumation of the underlying Çamlıca mica schists (Beccaletto 2003).

As for the secondary phases, the smectite crystallisation temperature is less than 150°C, and that of the kaolinite is less than 200°C, indicating that a second lower-temperature event, responsible for their formation, postdates the crystallisation of illite, which was formed at a minimum of 300°C. If the illite is assumed to have formed before the doming process (Early Tertiary), the secondary phases may be related to Late Oligocene–Miocene magmatic activity that occurred in the Biga Peninsula, particularly around Ezine (e.g., Kestanbol pluton and associated volcanic products).

The Denizgören Ophiolite and its Metamorphic Sole

The Denizgören Ophiolite

The Denizgören ophiolite (from the village of the same name) is almost totally made up of partially serpentinized harzburgite (Okay *et al.* 1991), whereas the crustal components of the typical ophiolitic suite are absent (various types of gabbros, sheeted dykes, basalts, pelagic sediments). Geochemical analyses from the peridotite suggest a supra-subduction zone (SSZ) tectonic setting (Pickett & Robertson 1996).

The Metamorphic Sole

Metamorphosed basic rocks occur systematically between the Çamköy formation and the Denizgören ophiolite. Mylonitised metabasalts in the greenschist facies (prasinite) represent the most common lithology, with a thickness of about 100–300 m. Scarce foliated

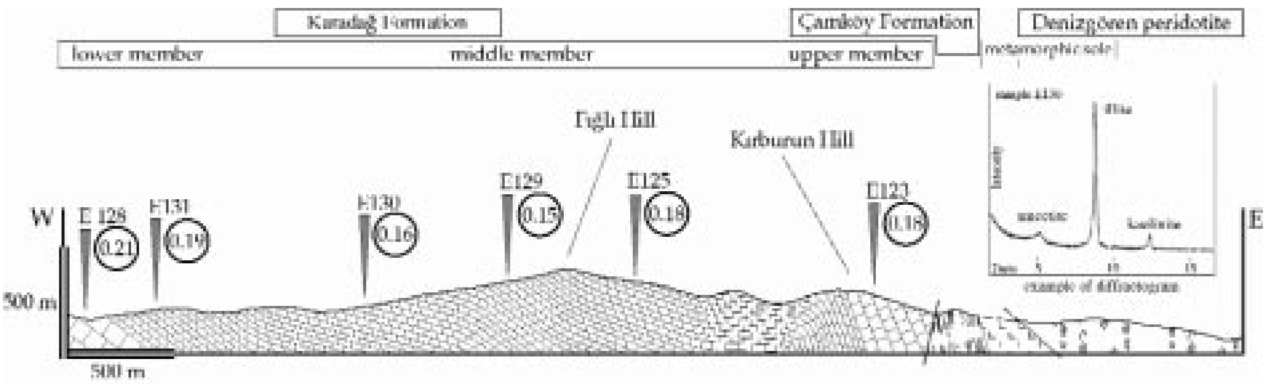


Figure 9. Distribution of samples used for determination of illite crystallinity along an E–W transect through the Karadağ formation; the numbers in the circles correspond to the Scherrer Width; location of cross-section given in Figure 2.

amphibolite lenses also occur locally, between the peridotite body and the prasinites; their maximum thickness is about 50 m. The transition from prasinites to amphibolites is not continuous, but occurs along late tectonic strike-slip faults parallel to the general foliation.

Structure and Petrography

The prasinites consist of green, strongly foliated, very fine-grained rocks with mylonitic textures, characterised by numerous small-scale brittle shear bands; they are in tectonic contact with both the Çamköy formation and the ophiolite body, or with the amphibolites where present. Their foliation is homogeneous and parallel to the contact toward which they dip (Figure 11). Only in one place, a small deformed metabasalt block has been found. The common mineral assemblage in the prasinites is chlorite + epidote + albite + amphibole ± graphite ± calcite ± titanite ± serpentine (?), and suggests medium- to high-grade greenschist conditions. The mylonitic texture is clearly visible in thin section, where all the grains have undergone grain-size reduction. The minerals are oriented along mm-thick shear bands parallel to the main foliation, and amphiboles underlie the schistosity in some samples, which suggests that the greenschist-facies metamorphism was syn-deformational.

Dark green foliated amphibolites occur only locally as coarse-grained massive rocks between the peridotite body and the prasinites. The foliation is parallel to that of both the prasinites and the contact with the peridotite (Figure 11). Their typical paragenesis is hornblende + plagioclase ± quartz ± epidote ± titanite. The schistosity is particularly marked by the amphibole minerals. The presence or absence of epidote is related to variations in the temperature of the amphibolite facies. Some later veins of calcite, quartz, albite and chlorite suggest a greenschist overprint.

Whole-Rock Geochemistry

Five samples from the prasinites and four samples from the amphibolites have been processed for whole-rock geochemistry. The analyses were done at the Centre d'Analyse Minérale of Lausanne University. The sample locations are shown in Figure 3 and the analytical results are given in Table 2. Immobile elements have been plotted on various geochemical diagrams in Figure 12.

The geochemical analyses were used to test the hypothesis of an oceanic origin for the samples. The chondrite-normalised diagram (normalising values from Boynton 1984) shows typical MORB patterns for E84 and E90, and enriched-MORB patterns for the other samples. These observations are confirmed by the MORB-normalised diagram (normalising values from Pearce 1983). These discrimination diagrams confirm the MORB signature of most of the samples, as only E84, E90 and E14 are outside of the MORB field; for the two amphibolite samples (E84 and E90), remobilization of the elements during metamorphism may have caused this scatter; as for E14, it is the most enriched sample as observed from the chondrite-normalised diagram, and hence suggests a within-plate basalt setting. The whole-rock geochemical analyses, therefore, confirm the oceanic origin of the metabasite samples (with a MORB signature), in agreement with the results of Pickett & Robertson (1996).

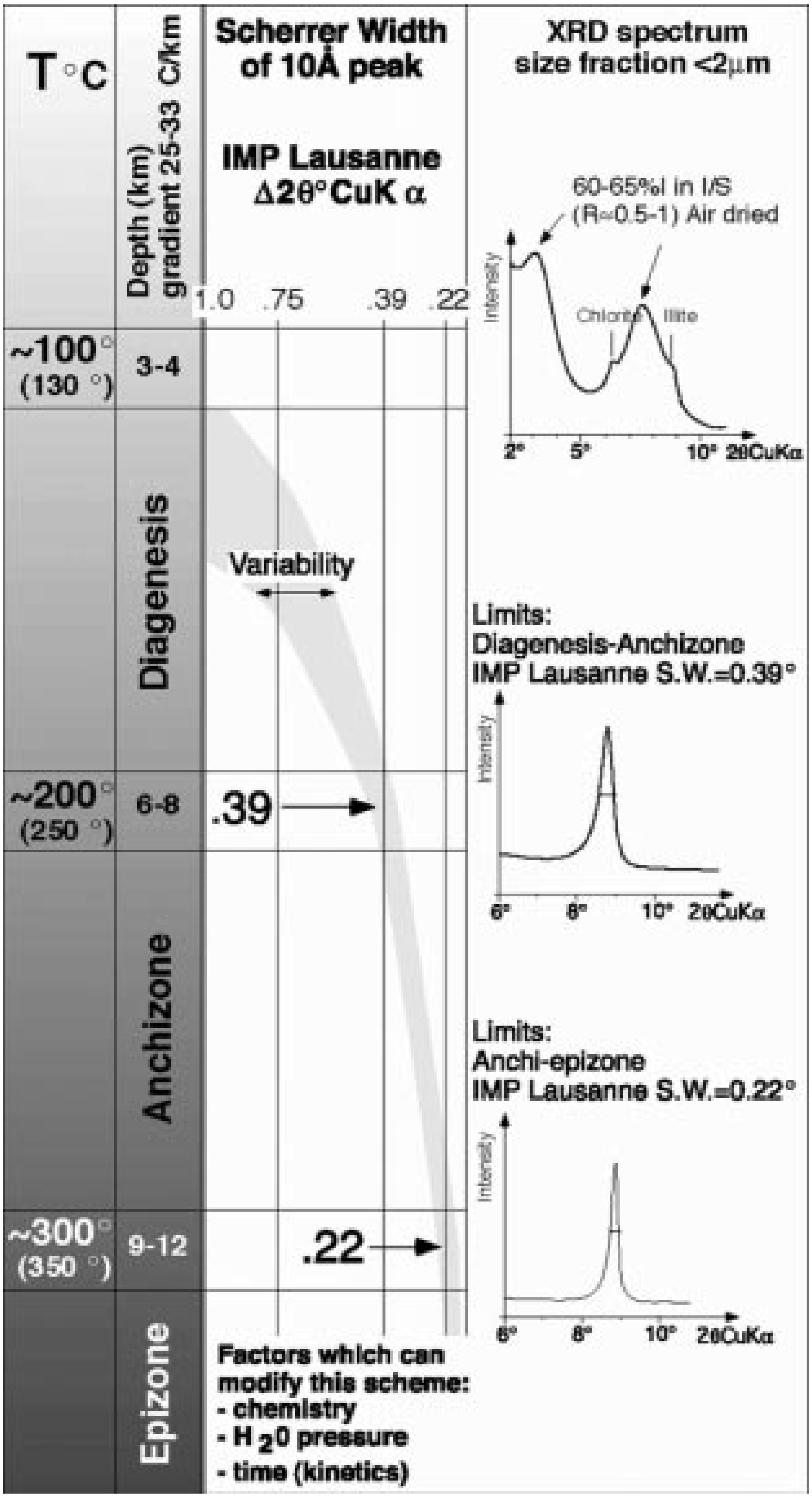


Figure 10. Scherrer Width ideal evolution with respect to depth and temperature, Jaboyedoff & Thélin (1996).

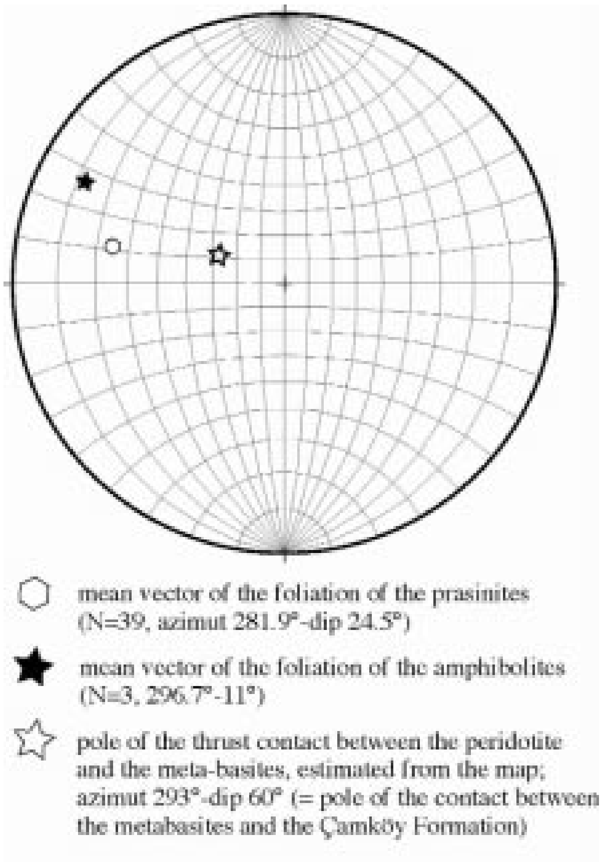


Figure 11. Foliation of the metabasites from the metamorphic sole; equal area, lower hemisphere projection.

The Metabasites in the Metamorphic Sole

The metabasic rocks at the base of the Denizgören ophiolite represent a coherent sequence, characterised by a strong inverted metamorphic gradient, from the amphibolite facies close to the contact to the greenschist facies farther away. Moreover, they have MORB geochemical signatures. We therefore interpret these rocks as a metamorphic sole (or a part of it), recording the initial thrusting of the ophiolite at or near the oceanic ridge. The existence of the metamorphic sole, which implies high-temperatures at the inception of obduction, rules out the hypothesis of an unroofed peridotite body, with no ophiolitic suite, and typical of passive-margin environments.

Timing of Amphibolite-Facies Metamorphism

Two amphibolite samples have been processed for $^{40}Ar/^{39}Ar$ dating to obtain the age of the amphibolite-facies metamorphism. The age determination has been performed by P. Monié in the Ar/Ar laboratory of the University of Montpellier. The analytical methods used were the same as those described in Monié *et al.* (1997). The locations of the samples are shown in Figure 3, and the analytical results are tabulated in Table 3. Figure 13 shows the age spectra and isochron ages for two hornblende separates from samples E84 and E94.

Results from sample E84 are preferred to those of sample E94 because they are more homogeneous. Moreover, because the plateau and isochron ages are different, the latter was chosen as reference in so far as this age is independent of the hypothesis on the original atmospheric Ar value used in the calculation of the plateau age. Therefore, the age of the amphibolite-facies metamorphism is considered to be 125 ± 2 Ma. This age is interpreted as the age of inception of the obduction process at or near the ridge. It is comparable but slightly older than the $^{40}Ar/^{39}Ar$ ages found by Okay *et al.* (1996) for amphibolite samples from the same area (117 ± 1.5 Ma and 118.3 ± 3.1 Ma).

Structural Relations between the Ezine Group and the Denizgören Ophiolite

The time gap of about 100 Ma between the Ezine Group (Carnian age of the Çamköy formation) and the Denizgören ophiolite (Barremian age of the metamorphic sole) raises the crucial question of the structural relationship between the two units. It is clear from field observations that the peridotite overlies the sedimentary sequence. However, some observations, such as the disturbed aspect of the Çamköy formation and the silicification of the harzburgite near the contact with the Ezine Group, suggest a remobilisation of the initial contact. Despite this local evidence of late tectonic activity, the thrust contact currently observed is regarded as a witness of the original emplacement of the peridotite slice over the margin. Moreover, the time gap remains compatible with this view, and two reasons may account for it: (1) the ophiolite may have been emplaced directly on the Ezine Group as situated today (after erosion or non-deposition of the younger lithologies); (2) the younger lithologies may have been transported farther away from the present-day position during ophiolite emplacement.

Table 2. Major- and trace-element analytical data of metabasite samples from the metamorphic sole of the Denizgören ophiolite.

	Sample	E14	E15	E28	E78	E115	E66	E70	E84	E90
SiO_2	wt-%	48.49	48.73	47.59	45.84	48.97	48.27	49.12	43.79	48.35
TiO_2	wt-%	2.41	1.58	1.83	2.20	1.43	1.07	1.16	0.39	0.52
Al_2O_3	wt-%	13.77	14.20	15.79	13.76	14.82	15.98	14.75	15.21	18.73
Fe_2O_3	wt-%	9.15	6.05	5.86	7.51	4.97	9.78	10.18	7.68	7.28
FeO	wt-%	4.34	5.63	5.37	6.56	4.79	0.00	0.00	0.00	0.00
MnO	wt-%	0.18	0.21	0.17	0.23	0.15	0.16	0.21	0.14	0.13
MgO	wt-%	4.82	7.59	6.05	5.81	5.82	7.69	7.85	11.40	7.90
CaO	wt-%	7.73	8.72	9.50	12.46	12.60	10.99	9.95	16.55	10.77
Na_2O	wt-%	4.17	3.62	3.53	2.19	3.58	3.20	2.52	0.95	3.03
K_2O	wt-%	0.15	0.11	0.26	0.16	0.08	0.65	1.71	0.08	1.12
P_2O_5	wt-%	0.34	0.15	0.19	0.23	0.17	0.11	0.12	0.03	0.03
H_2O	wt-%	3.43	3.12	3.21	2.68	2.02	1.98	2.05	3.69	2.01
CO_2	wt-%	0.22	0.20	0.19	0.25	0.47	0.00	0.00	0.00	0.00
Cr_2O_3	wt-%	0.02	0.02	0.04	0.02	0.04	0.05	0.05	0.13	0.07
NiO	wt-%	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03
Total	wt-%	99.22	99.93	99.6	99.91	99.92	99.94	99.67	100.07	99.95
Nb	ppm	14.7	3.8	7.5	7	6.6	4.1	3.2	<1.0<	1.2
Zr	ppm	261	103	154	154	115	62	72	19	41
Sr	ppm	149	118	179	163	289	177	199	102	142
Rb	ppm	1.7	<1.0<	4	1.5	1.1	11	35.5	1.1	24.6
Pb	ppm	<2<	<2<	<2<	<2<	<2<	<2<	3	<2<	<2<
Ga	ppm	21	18	20	23	19	18	17	14	15
Zn	ppm	137	99	100	117	73	70	123	49	53
Ni	ppm	38	62	73	62	72	121	120	235	206
Cr	ppm	105	96	240	83	245	289	327	902	496
V	ppm	258	284	238	390	241	249	259	188	143
Ce	ppm	16	<3<	7	<3<	5	<3<	3	<3<	<3<
Ba	ppm	35	<9<	43	14	9	91	282	<9<	38
Ce	ppm	34.9	10.8	20.1	18.4	15.7	9.2	7.2	1.6	1.4
Dy	ppm	10.8	5.82	6.7	8.83	4.78	4.15	4.14	1.76	1.85
Er	ppm	6.54	3.56	4.3	5.61	2.88	2.61	2.7	1.32	1.27
Eu	ppm	2.47	1.34	1.13	1.94	1.33	1.04	0.91	0.4	0.34
Gd	ppm	9.84	5	5.6	7.23	4.23	3.47	3.45	1.29	1.28
Ho	ppm	2.39	1.26	1.5	2	1.01	0.97	0.97	0.45	0.4
La	ppm	14.3	3.6	8.3	6.3	6.2	4	2.6	0.5	0.4
Lu	ppm	0.93	0.56	0.71	0.8	0.39	0.39	0.4	0.18	0.2
Nd	ppm	25.9	10.6	15.1	15.9	11.1	7.3	6.8	1.6	1.5
Pr	ppm	5.6	1.88	3.3	3.23	2.45	1.48	1.25	0.27	0.22
Sm	ppm	7.9	3.5	4.4	5.5	3.4	2.5	2.5	0.8	0.7
Tb	ppm	1.65	0.92	1.1	1.36	0.76	0.64	0.67	0.28	0.24
Th	ppm	1.3	0.2	1.9	0.6	0.8	0.3	0.2	<0.1	<0.1
Tm	ppm	0.93	0.56	0.7	0.82	0.41	0.43	0.43	0.19	0.2
U	ppm	0.37	0.58	0.2	0.45	0.21	0.09	0.52	<0.05	<0.05
Y	ppm	57.4	31.6	36	49.2	26.4	22.3	24.5	10.4	10.7
Yb	ppm	6	3.3	4.3	5.8	2.6	2.5	2.6	1.2	1.3

Correlations of the Ezine Group and Denizgören Ophiolite

The Ezine Group

In northwestern Turkey, the only sedimentary rocks of Permian age are found as olistoliths in the Hodul and Çal units of the Karakaya Complex (Bingöl *et al.* 1975; Okay *et al.* 1991; Leven & Okay 1996). In the Hodul Unit, the Permian blocks are white, thickly bedded to massive limestones, which in many cases contain fusulinids, algae, bivalves, gastropods and corals. The most common olistoliths are of Late Permian age. In the Çal Unit, the olistoliths also consist of white, thickly bedded to massive Upper Permian limestones with corals, brachiopods, gastropods, ostracods and echinoids. These typical neritic blocks can reach sizes of several km^2. The origin of the

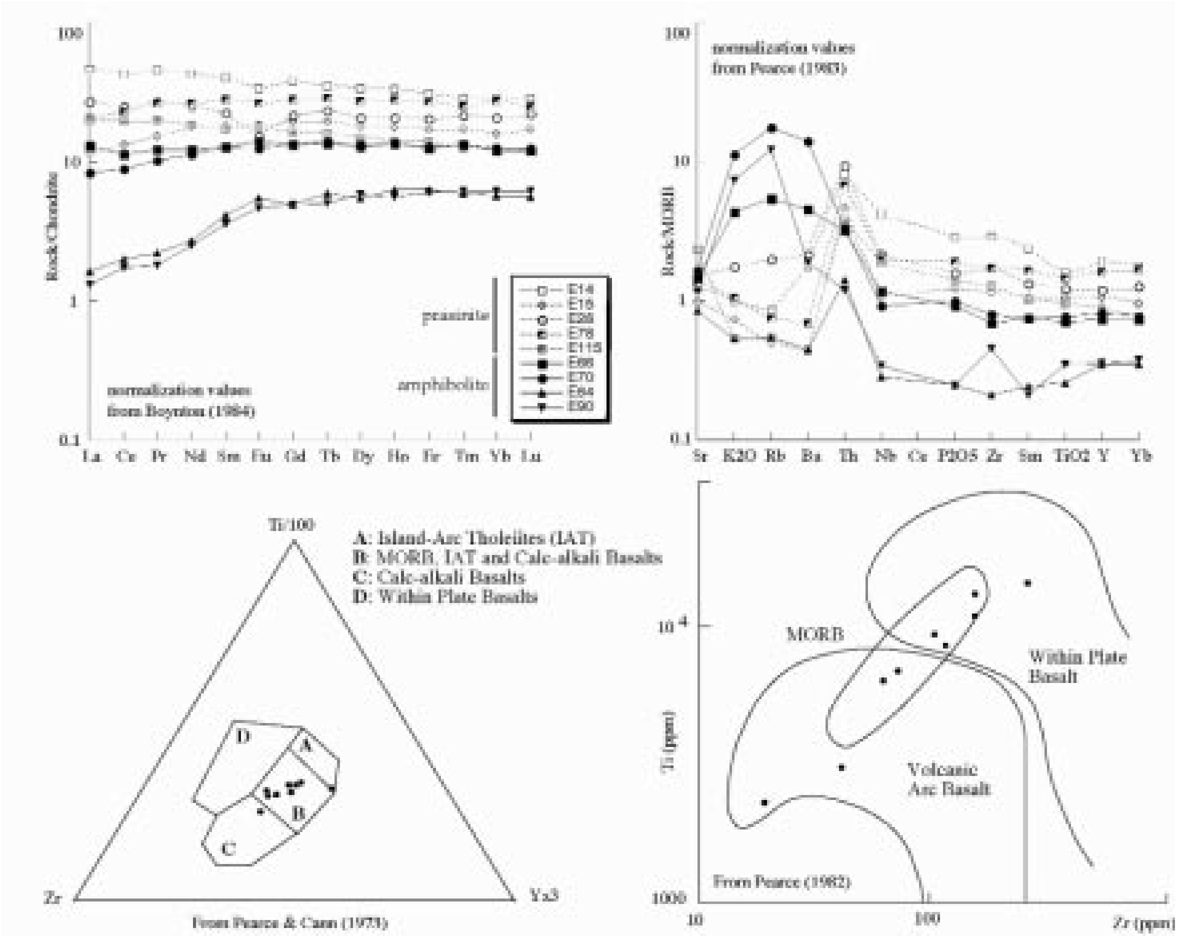


Figure 12. Normalisation and discrimination diagrams for the metabasites from the metamorphic sole of the Denizgören ophiolite.

Karakaya Complex remains open to discussion (Okay & Göncüoğlu 2004), even if the occurrence of Carboniferous and Permian radiolarites, as well as eclogite and blueschist lenses, points toward a subduction-accretion origin. Moreover, this hypothesis fits well with other regional geological data (Stampfli *et al.* 2003). In any case, a compelling hypothesis for the origin of the shallow-water Permian carbonates found in the Karakaya Complex is that they belonged to the cover of the Variscan Sakarya terrane before being involved later in the Karakaya Complex in Late Permian–Triassic times (e.g., Kozur & Mock 1997). Therefore, these olistoliths may be considered as lateral time equivalents of the Ezine Group, but bear no relation to its geological evolution. A correlation between the Ezine Group and the Karakaya Complex would be acceptable only in the weak hypothesis of the Karakaya Complex interpreted as a rift-related basin (Genç & Yılmaz 1995); in that case, the Ezine Group would represent an isolated fragment of the Karakaya Complex at the western end of the Sakarya Zone.

In the Eastern Rhodope, a short distance northwest of the study area, there is no sequence similar to that observed in the Ezine area; only reworked siliceous Upper Permian rocks in mélange-like units belonging to the allochthonous nappes of the Rhodope are known (Trifanova & Boyanov 1986).

On the other hand and at a regional scale, Permian–Lower Middle Triassic syn-rift deposits have been described in the Pelagonia terrane of Greece (Hydra and Evia islands, Figure 14). On Hydra Island, the Permian evolution is characterised by four main stratigraphic events, reflecting extensional tectonism with

Table 3. Ar isotope analytical data for amphibolite samples E84 and E94 from the metamorphic sole of the Denizgören ophiolite.

Sample	$^{40}Ar^{*}/^{39}Ar$	$^{36}Ar/^{40}Ar$ x 1000	$^{39}Ar/^{40}Ar$	$^{37}Ar/^{39}Ar$	% ^{39}Ar	% Atm.
E84 (amphibolite)						
1	18,460	3,252	0,0021	15,626	2,1	96,1
2	9,212	2,879	0,0161	58,154	3,7	85,1
3	3,439	2,347	0,0890	16,692	22,1	69,3
4	3,074	1,484	0,1825	13,287	29,3	43,8
5	4,088	2,212	0,0846	28,800	32,6	65,3
6	4,196	2,017	0,0961	48,267	38,1	59,6
7	4,762	1,650	0,1075	59,658	57,5	48,7
8	4,882	1,057	0,1408	49,331	66,4	31,2
9	4,955	1,089	0,1367	49,582	72,9	32,1
10	4,844	1,531	0,1130	48,021	78,0	45,2
11	4,501	2,216	0,0766	52,580	83,8	65,4
12	4,511	1,603	0,1166	50,975	100,0	47,3
E94 (amphiblolite)						
1	5,660	2,574	0,0422	1,562	5,5	76,0
2	4,149	2,104	0,0911	9,329	13,7	62,1
3	3,618	0,557	0,2308	1,673	31,3	16,4
4	3,162	0,350	0,2834	2,113	39,8	10,3
5	3,296	0,548	0,2541	5,080	46,3	16,2
6	4,468	0,710	0,1768	14,935	55,0	21,0
7	4,916	0,855	0,1518	25,636	66,0	25,2
8	5,335	0,641	0,1518	27,224	71,1	18,9
9	4,975	0,702	0,1592	28,897	75,3	20,7
10	4,478	0,405	0,1965	15,318	100,0	11,9

% Atm.: proportion of atmospheric argon

block faulting and tilting (Baud *et al.* 1990; Grant *et al.* 1991). On Evia Island, the presence of carbonate breccias, slight angular unconformity and olistoliths are interpreted as the result of syn-sedimentary extensional tectonics (Angiolini *et al.* 1992; de Bono 1998; de Bono *et al.* 2001; Vavassis 2001). Therefore, despite its poor age constraints, the Ezine Group may be related to the middle Late Permian–early Middle Triassic rifting phase observed in Greece. In Greece, the Early Permian is transgressive onto the Variscan granitic basement, implying large-scale extensional events, recorded there by the cooling of Late Carboniferous granites and their erosion at the surface in the Early Permian (Vavassis *et al.* 2000). This observation may favour the second hypothesis, in which the Geyikli and Karadağ formations record syn-extensional transgressive sedimentation.

From a geodynamic point of view, the extensional event could be related to continuous rifting of the future Maliac/Meliata oceanic domain, triggering the southward drift of a piece of the Eurasian margin, the Pelagonia terrane (Stampfli 2000). The Hydra and Evia sequences record syn-rift sedimentation at the southern margin of this Maliac/Meliata oceanic domain (de Bono 1998). As for the northern margin of this oceanic domain, it is poorly known, but its eastern part may be represented by the Rhodope domain (Stampfli 2000). The remnants of this Maliac/Meliata Triassic oceanic domain are known as ophiolitic obducted nappes and/or tectonic mélanges located in Austria, Slovak and Czech republics, Hungary and Romania (Kozur 1991, and references therein; Kozur & Mock 1996; Mello *et al.* 1998); they are also found *in situ* in Greece (Ferrière 1982), and also possibly as olistoliths in the obducted Late Jurassic–Early Cretaceous mélanges of the Vardar Ocean (Simantov & Bertrand 1987; Pe-Piper 1998; Vavassis 2001; de Bono 1998). Sea-floor spreading began in the early Middle Triassic, whereas subduction began during the Jurassic, and closure was within the Late Jurassic (Kozur 1991; de Bono *et al.* 2001). The Maliac/Meliata oceanic basin may be correlated (at least in time) with the Küre Ocean (Kozur & Mock 1997; Ustaömer & Robertson 1994, 1997).

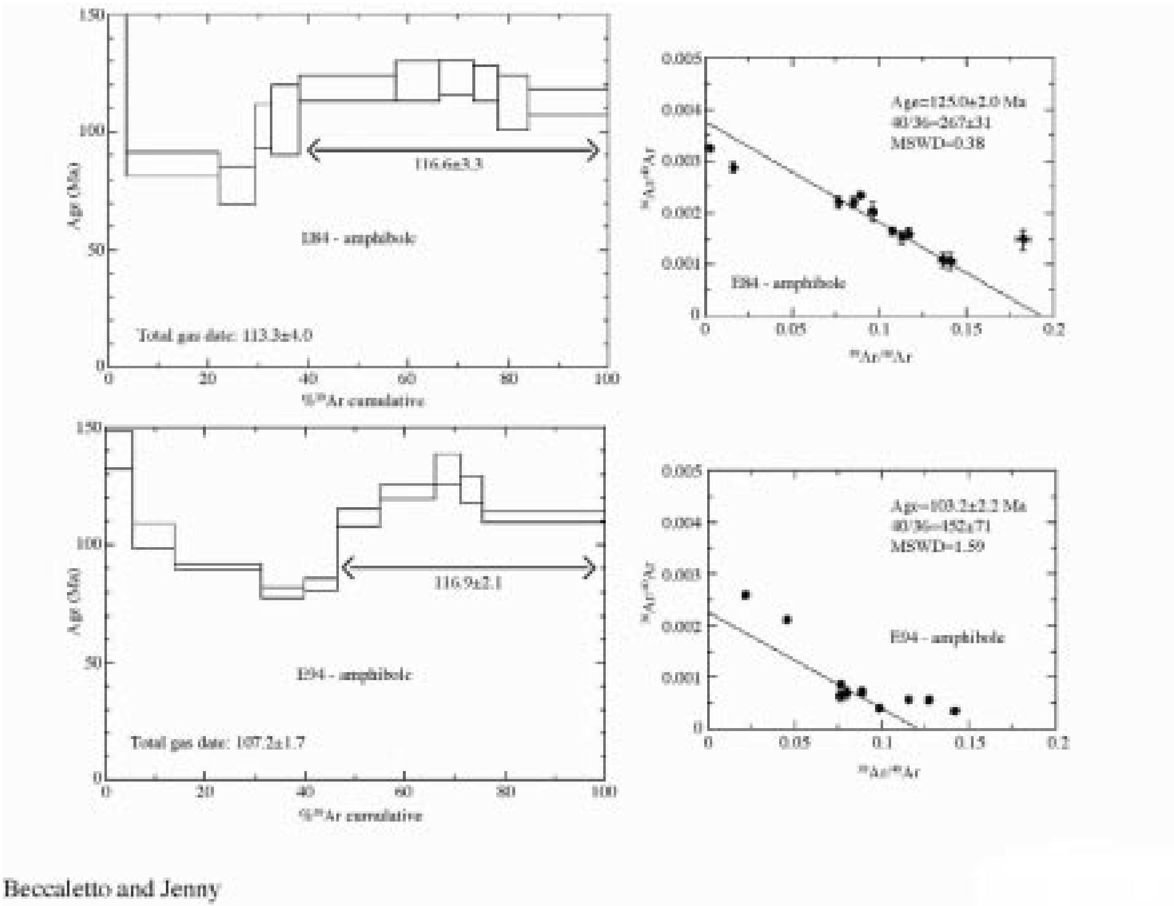


Figure 13. $^{39}Ar/^{40}Ar$ age spectra and isochron ages for amphibolite samples E84 and E94 from the metamorphic sole of the Denizgören ophiolite.

Based only on these stratigraphic data, it is not possible to discuss the position of the Ezine Group at the northern or southern margin of the Maliac/Meliata Ocean (Pelagonian or Rhodopian origin) and, in any case, both margins were close to one another during the rifting event. The comparison of the age of the metamorphic sole of the overlying Denizgören ophiolite with that of the Aegean ophiolites, as well as its structural position, may be helpful in this regard.

The Denizgören Ophiolite

The age of the metamorphic sole of the Denizgören ophiolite (125 Ma, Barremian) is quite surprising if compared with the ages of the metamorphic soles of ophiolites in the Aegean region (Figure 15); all the ophiolites from western Turkey have Late Cretaceous ages (Cenomanian–Turonian), whereas those from Greece have a Middle Jurassic age (Eo-Hellenic phase, Aalenian-Bajocian obduction over the Pelagonian platform, e.g., Bernoulli & Laubscher 1972). In Greece, only the Lesvos ophiolite gives a younger age, its metamorphic sole being dated at 155 Ma (Hatzipanagiotou & Pe-Piper 1995). Moreover, dikes related to three ophiolitic complexes of northern Greece have also been dated: (1) the Guevgueli complex of central Macedonia, belonging to the Vardar Zone, has yielded Late Jurassic radiometric ages (163–149 Ma, Spray *et al.* 1984); (2) diorite dikes from the Samothraki ophiolite yielded Oxfordian ages (155 Ma, Tsikouras *et al.*

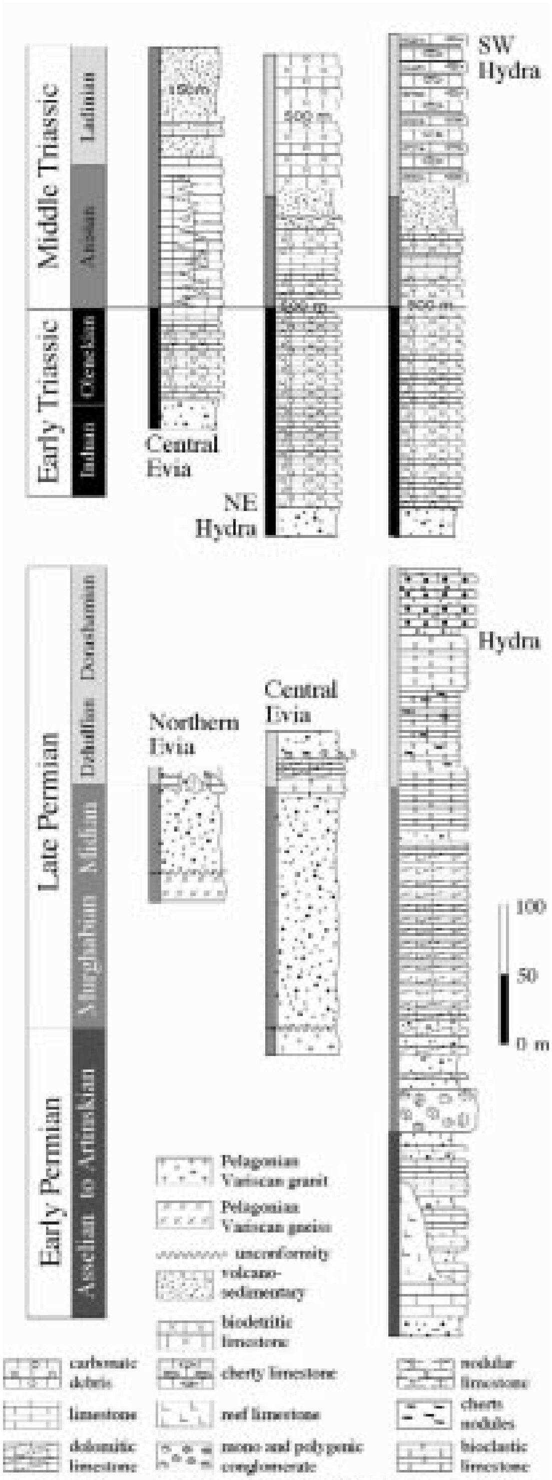


Figure 14. Stratigraphic columns of the syn-rift sequences of northern Pelagonia: northern Evia (Vavassis 2001), Central Evia (de Bono 1998), Hydra (Baud *et al.* 1990; Grant *et al.* 1991).

1990); and (3) in northern Greece, the basic and ultrabasic rocks of the Makri and Drimos-Melia Units (Bigazzi *et al.* 1989; Boyanov & Russeva 1989; Braun 1993) are closely associated in space and time and are considered to be dispersed fragments of an incomplete supra-subduction zone ophiolite (Evros ophiolite, Magganas *et al.* 1991; Magganas 2002). Dikes associated with the Evros ophiolite has yielded Late Jurassic–Early Cretaceous ages (160–140 Ma, Bigazzi *et al.* 1989), and northward shear senses, interpreted as recording ophiolite emplacement, have been described locally (Bonev & Stampfli 2003). Therefore, the metamorphic sole of the Denizgören ophiolite has no time equivalent in Greece and Turkey.

A first possibility would be to allow an Intra-Pontide origin to the Denizgören ophiolite (Göncüoğlu *et al.* 2000); the Intra-Pontide suture separates the İstanbul Zone from the Sakarya Zone (Şengör & Yılmaz 1981; Figure 1). The major problem here concerns the structural complexity of the suture's exposures, and scarce field data for the existence of such (Okay & Tüysüz 1999). As a consequence, the evolution of the Intra-Pontide Ocean remains highly speculative. For instance, there are no reliable data for the age of its opening, and there is still debate concerning the age of its closure; generally, based on the age of the first unconformable cover sediments, the latter is placed in the Late Cretaceous (Yılmaz *et al.* 1995; Göncuoğlu *et al.* 2000), Palaeocene–Eocene (Şengör & Yılmaz 1981), Early Eocene (Okay *et al.* 1994; Wong *et al.* 1995), or Early Eocene to Oligocene (Monod & Okay 1999). These discrepancies seem actually related to disagreements about the true location of the suture. Even the existence of the Intra-Pontide Ocean has been recently challenged (Yiğitbaş *et al.* 1999). Moreover, the Barremian age of the metamorphic sole is difficult to explain compared to the possible Cretaceous to Oligocene age for closure of the Intra-Pontide oceanic domain. All these uncertainties lead us to search for another solution to the genesis of the Denizgören ophiolite.

The Barremian age of the metamorphic sole excludes a typical Eo-Hellenic origin for the obduction of the Denizgören ophiolite. Consequently, in the hypothesis of the Ezine Group as recording the Malic/Meliata rifting, it cannot be considered a typical Pelagonian substratum, as the latter has only been seen in Jurassic ophiolites. It most probably suggests a genesis of the Ezine Group at

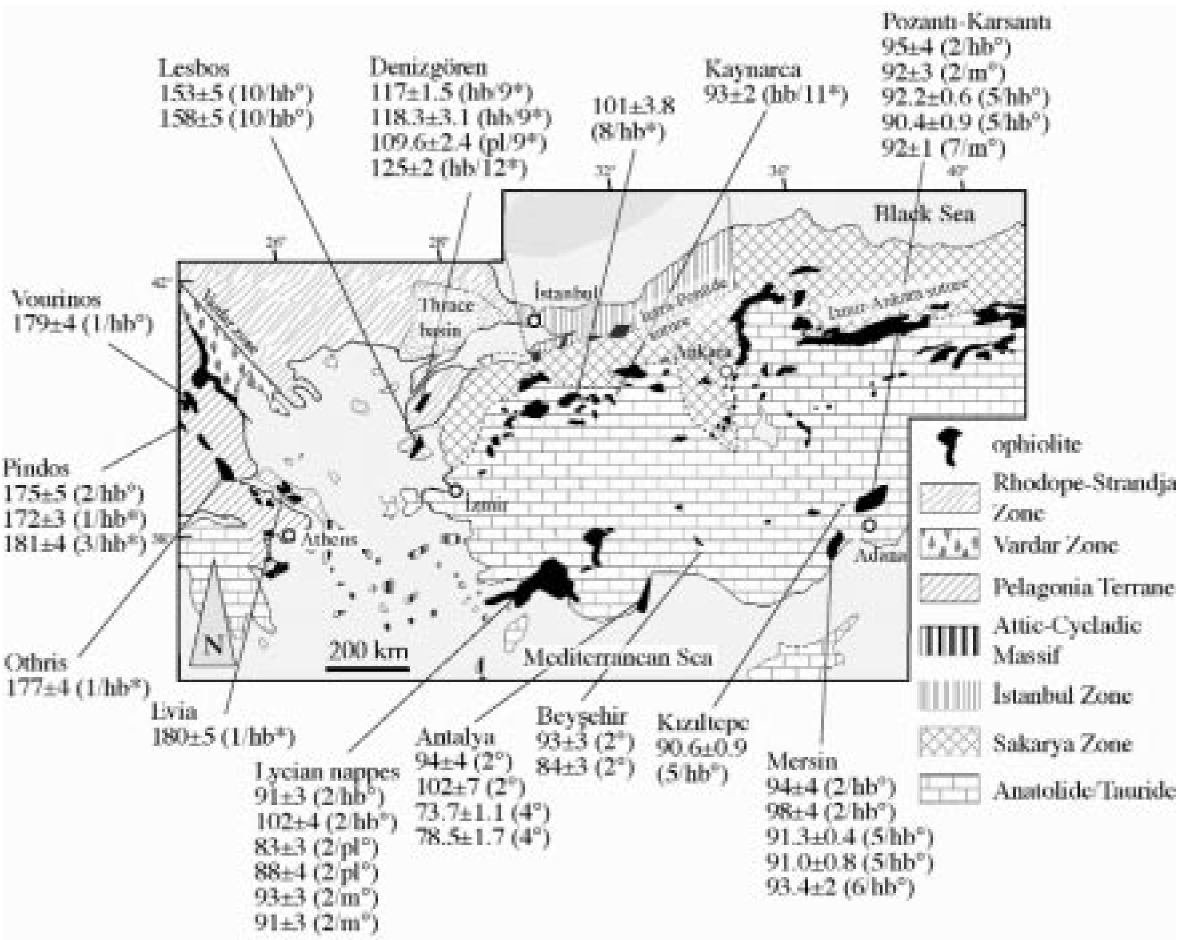


Figure 15. Age (Ma) of the metamorphic soles from ophiolites from the Aegean region, modified from Robertson (2002); hb– hornblende; pl– plagioclase; m– mica; *– Ar/Ar; °– K-Ar; 1– Spray & Roddick (1980); 2– Thuizat *et al.* 1981; 3– Roddick *et al.* 1979; 4– Yılmaz & Maxwell 1982; 5– Dilek *et al.* 1999; 6– Parlak *et al.* 1995; 7– Thuizat *et al.* 1978; 8– Harris *et al.* 1994; 9– Okay *et al.* 1996; 10– Hatzipanagiotou & Pe-Piper 1995; 11– Önen & Hall 2000; 12– this work.

the northern margin of the oceanic domain (i.e., Rhodope margin). This is supported by the southward occurrence of the Lesvos ophiolite, which has an Eo-Hellenic signature, and lies over a Pelagonian sequence (Katsikatsos *et al.* 1986, and personal observations). Another argument comes from the accretion-related Çetmi mélange, which crops out on the Biga Peninsula, SE and NE of the Ezine Group (Figure 2). The regional correlations of the mélange, plus its tectonic history, suggest a Rhodopian affinity for some of its components (Beccaletto 2003), which shows the possibility of finding rocks with a Rhodopian origin very close to the Ezine Group.

The Late Jurassic–Early Cretaceous is a period of an important compressional deformational regime involving the whole Rhodope area, characterised by a greenschist-facies metamorphism and northward thrusting (Georgiev *et al.* 2001). This Balkanic orogen, sealed by a regional Cenomanian transgression over the Rhodope margin, may be responsible for the inception of obduction, and the northward emplacement of the Denizgören ophiolite over the Ezine Group. From a geodynamic point of view, the Balkanic orogen may be related to the final closure of the southward subducting Maliac/Meliata Ocean and the consecutive collision of the Vardar intra-oceanic arc with the Rhodope margin (Stampfli 2000).

Unlike its age, the structural position of the Denizgören ophiolite north of the (Vardar) İzmir-Ankara suture is not unusual. In Turkey, the dated ophiolites were emplaced southward over the Anatolide-Tauride

Block (e.g., Şengör & Yılmaz 1981; Bozkurt & Mittwede 2001); nevertheless, there are also some local north-directed obduction events in eastern Turkey, where peridotite bodies are emplaced over typical Sakarya units (Bergougnan 1975; Okay & Şahintürk 1997). The ages of these ophiolites are poorly constrained, but the obduction is younger than in the Ezine area (Cenomanian–Campanian). As noted above, the main obduction in Greece is related to Jurassic emplacement of the Vardar ophiolites over the Pelagonia terrane (Eo-Hellenic phase, south of the Vardar suture). But a poorly known obduction event is recorded slightly later in the Rhodope area (Guevgueli, Samothraki and Evros ophiolites); consequently, it looks as if the Denizgören ophiolite was emplaced northward (with respect to the (Vardar)-İzmir-Ankara suture), between this northward obduction event found in Greece over the Rhodope margin, and in Turkey over the Sakarya Zone.

Conclusion

The sedimentary Ezine Group and the overlying Denizgören ophiolite of the Biga Peninsula have been studied with the aim of determining their geological significance in the frame of the regional (north Aegean) tectonic evolution.

The sedimentary Ezine Group has been subdivided into three new successive formations, forming a coherent stratigraphic sequence. It records either syn-rift sedimentation of Middle–Late Permian to Middle Triassic age, or most probably pre-rift transgressive sedimentation in the Early–Middle Permian, followed by syn-rift sedimentation in the Early–Middle Triassic. A Karakaya origin seems unlikely for the Ezine Group, and we prefer to correlate it with contemporaneous units in Greece, which are interpreted to record the Maliac/Meliata opening. The overlying Denizgören ophiolite has no time equivalent in the Aegean region, neither in Greece nor in Turkey. Nevertheless, the age of its metamorphic sole, compared with regional geological data, suggests northward emplacement over the Rhodope margin, represented by the Ezine Group. The origin of the compressive regime responsible for the obduction may be found in the context of the Balkanic orogen.

Moreover, these results provide two new constraints for the regional palaeotectonic framework: (1) as the Rhodope margin has also undergone local obduction in the Late Jurassic, the Ezine Group must represent a segment of the margin preserved until the Mid-Cretaceous obduction of the Denizgören ophiolite. The uniqueness of an ophiolite of this age, and the preservation of the sedimentary sequence (together with the ophiolite), suggest a strong strike-slip component for the general tectonic regime during and after the emplacement process; (2) if the Ezine Group and the Denizgören ophiolite represent fragments of the Rhodope domain, they must have been juxtaposed with the western end of the Sakarya Zone in post-Barremian times.

Acknowledgements

The authors thank G.M. Stampfli for his support at Lausanne University. The authors are indebted to A.İ. Okay and E. Bozkurt for their constructive scientific and editorial comments, and thank M.C. Göncüoğlu and C. Yaltırak for their helpful remarks. This work has been supported by the Swiss National Science Foundation, grants n°2049114-96 and n°2061885-00.

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Received 18 January 2004; revised typescript accepted 11 March 2004

Plate 1

Age-diagnostic taxa from the Ezine Group;

1- *Hemigordius* sp., Sample E96, middle member of the Karadağ formation

2- *Gyroporella* sp., E96, middle member of the Karadağ formation

3- *Staffella* sp., E96, middle member of the Karadağ formation

4- A: *Agathammina* sp., B: *Globivalvulina* sp., E96, middle member of the Karadağ formation

5- *Geinitzina* sp., E96, middle member of the Karadağ formation

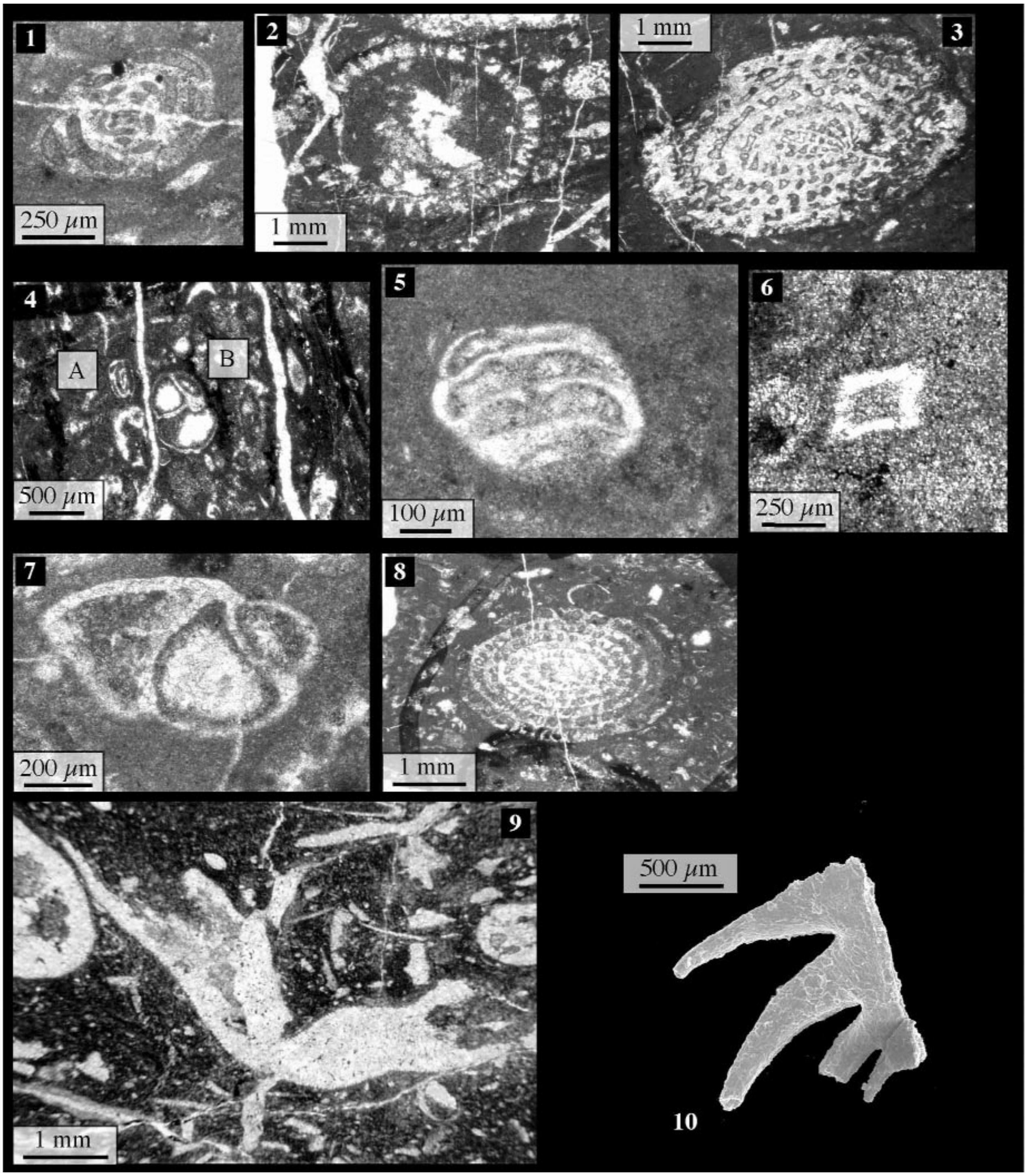
6- *Rectostipulina quadrata* JENNY-DESHUSSES, E95, middle member of the Karadağ formation

7- *Globivalvulina* sp., E96, middle member of the Karadağ formation

8- *Staffella* aff. *sphaerica* (ABICH), E96, middle member of the Karadağ formation

9- *Permocalculus* sp., E148, intermediate member n°2 of the Geyikli formation

10- *Gladigondollela* sp., E34, Çamköy formation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