Field Trip Guide Book - P01

Volume n° 3 - from D01 to P13

32nd INTERNATIONAL GEOLOGICAL CONGRESS

TECTONICS AND HIGH-PRESSURE METAMORPHISM IN NORTHWEST TURKEY

Leader: A.I. Okay

Florence - Italy
August 20-28, 2004

Post-Congress

P01

The scientific content of this guide is under the total responsibility of the Authors

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Front Cover:
View of the Uludag range in northwest Turkey from south. The white mountains in the background are made up of Paleozoic marble, the grey mountainous area to the south consists of a foliated granodiorite emplaced along the Izmir-Ankara suture. The foreground is made up of peridotites representing the Neo-Tethyan oceanic mantle

Leader: A. I Okay

Introduction

This guidebook has been prepared for the field excursion to northwest Turkey following the 32nd International Geological Congress in Florence. The aim is to show the well-preserved and widespread high pressure - low temperature metamorphic rocks of northwest Turkey, as well as other pre-Neogene formations in their regional tectonic context. This guidebook is divided into two sections. The first section gives the general background information on the tectonics of northwest Turkey. The second part deals specifically with the field trip sites.

The guidebook summarises geological data of a large region, where I have been working on and off for the last 25 years. I tried to make it a self-contained independent guidebook for the pre-Neogene geology of northwest Turkey by trying to give precise information on the locations of the key outcrops.

The guidebook also includes many optional stops, which we will have most probably no time to visit.

Independent geologists with this guidebook at hand should be able to visit all the sites mentioned in the text. Most stops described in the guidebook are reachable by a normal car. Some of the stops involve extended walks, where field boots are necessary.

In writing the guidebook I tried to include social, economic, and geographic information, as well as geological data, on the regions that will be visited.

One of the pleasures of a field trip is to see the countryside and the people, as well as the geology of the region. Especially for a relatively isolated country like Turkey, such information might be interesting and gives colour to the generally dry geological descriptions.

There are no restrictions on collecting samples during the field trip. In terms of mineral assemblage, lack of retrograde metamorphism and freshness, the blueschists of the Tavsanli Zone are one of the best in the world and are highly suitable as samples for metamorphic petrography classes.

Unfortunately, systematic detailed geological maps of northwest Turkey (on scales 1/100,000 or larger) are still not available. The only geological maps, which cover the whole country, are the 1/500,000 scale sheets published by the MTA Institute during the early 1960s. They are highly out-dated but are still useful for general purposes. The lack of geological maps means that every field study in northwest Turkey has to start by making a geological map.

The itinerary of the field trip is summarised below, and the route of the field trip is shown on the back of the guidebook.

29th August 2004. Drive from Istanbul to Bursa. Start the section across the Izmir-Ankara Tethyan suture on the Bursa-Orhaneli road. Triassic metabasites with high-pressure greenschist-facies metamorphism and the overlying Triassic greywackes, Jurassic sandstones and limestones, Izmir-Ankara suture fault, peridotite, banded gabbros, diabase dykes in peridotite. Night in Bursa.

30th August 2004. Continue the section across the Izmir-Ankara suture on the Bursa-Orhaneli-Keles road. Peridotite and the underlying subophiolite metamorphic rocks and Cretaceous blueschists, blueschist metapelites with jadeite, lawsonite, glaucophane and chloritoid; jadeite-fels; blueschist facies marbles; accretionary complex with incipient blueschist facies metamorphism. Night in Bursa.

31st August 2004. Bursa - Harmancik - Tavsanli -Bozüyük - Bursa road. Jadeite + K-feldspar rocks (“purple jades”), aragonitised limestone in the accretionary complex; lawsonite-zone blueschists; glaucophane-lawsonite blueschist facies metabasites and marbles. Triassic blueschists north of Eskisehir. Night in Bursa.

1st September 2004. Bursa - Bandirma - Biga -Edremit - Kücükkuyu. Paleo-Tethyan accretionary complex near Bandirma: Permo-Triassic metabasites; Triassic clastic rocks; Triassic eclogite in the metabasites. Cretaceous accretionary complex near Kücükkuyu; exotic eclogite blocks in the melange.
Night near Kücükkuyu.

2nd September 2004. Kücükkuyu - Canakkale - Istanbul. Kazdag: a late Oligocene core complex: high-grade gneisses, amphibolites and marbles with Early Miocene cooling ages and the overlying mylonitic shear zone. Denizgören ophiolite and the underlying Permian carbonate platform. Visit to Troy.
Glaucophane-lawsonite schists in an accretionary complex in Thrace. Arrival in Istanbul.

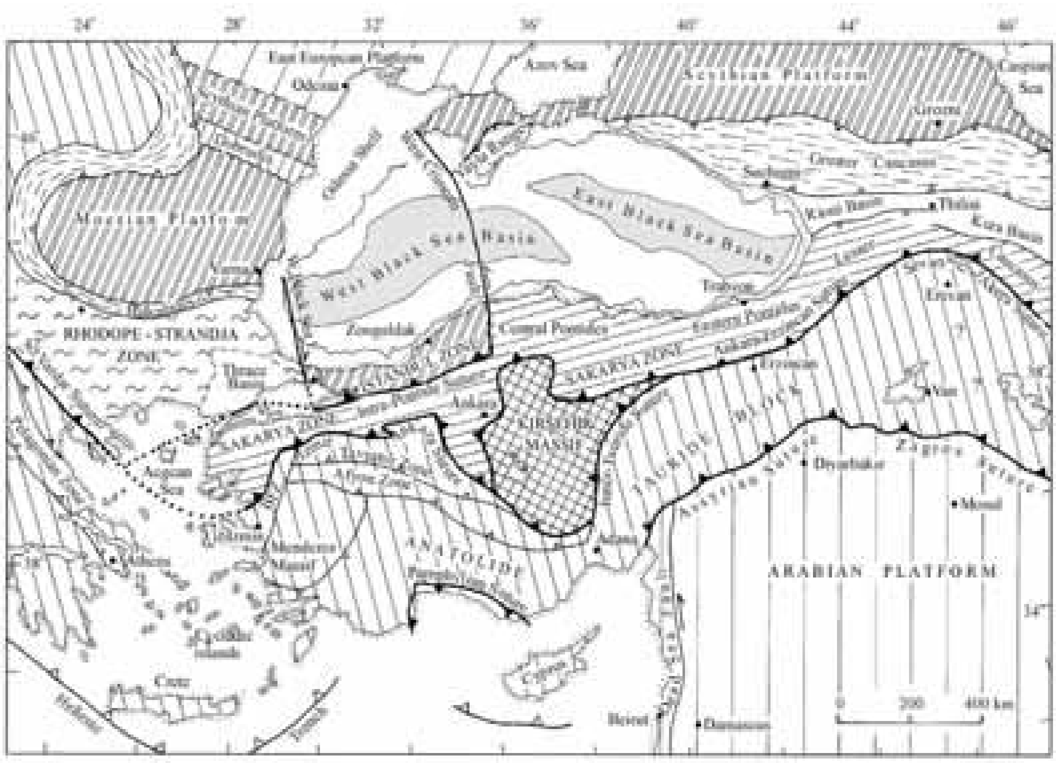

Figure 1 - Tectonic map of the northeastern Mediterranean showing the major sutures and continental blocks. Sutures are shown by heavy lines with the polarity of the former subduction zones indicated by filled triangles. Heavy lines with open triangles represent active subduction zones. Small open triangles indicate the vergence of the major fold and thrust belts. BFZ is the Bornova Flysch Zone (Okay and Tüysüz, 1999).

Regional geologic setting

Turkey, forming an east-west bridge between Europe and Asia, also straddles the geological boundary between Gondwana and Laurasia along a north-south transect. It was not a single entity until the Early Tertiary, when several continental fragments with independent Palaeozoic and Mesozoic geological histories were assembled during a complex sequence of events leading to the collision of Gondwana and Laurasia.

Figure 1 shows the sutures and major continental fragments in Turkey and the surrounding regions. There are six major lithospheric fragments in Turkey: the Strandja, the Istanbul and the Sakarya Zones, the Anatolide-Tauride Block, the Kirsehir Massif and the Arabian Platform (Sengör and Yilmaz, 1981; Sengör et al., 1982; Okay and Tüysüz, 1999). The first three zones, which show Laurasian affinities, are classically referred to as the Pontides. They are separated by the Izmir-Ankara-Erzincan suture from the Kirsehir Massif and the Anatolide-Tauride Block. The Intra-Pontide suture represents the former plate boundary between the Sakarya and Istanbul zones. For the purposes of the field trip we will be chiefly interested in the Sakarya zone and the Anatolide-Tauride Block, and will be crossing the Istanbul Zone. The major geological features of these lithospheric fragments are summarised below.

The Istanbul Zone

The Istanbul Zone is a small continental fragment, about 400 km long and 70 km wide, located on the southwestern margin of the Black Sea (Figure 1). It is made up of a late Proterozoic crystalline basement overlain by a continuous, well-developed transgressive sedimentary sequence extending from Ordovician to Carboniferous, which was mildly deformed during the Carboniferous Hercynian orogeny (Görür et al., 1997; Dean et al., 2000). The stratigraphy of the Istanbul Zone is shown in Figure 2. In the Zonguldak area the Carboniferous sequence of the Istanbul Zone includes coal measures (Kerey et al., 1986). The

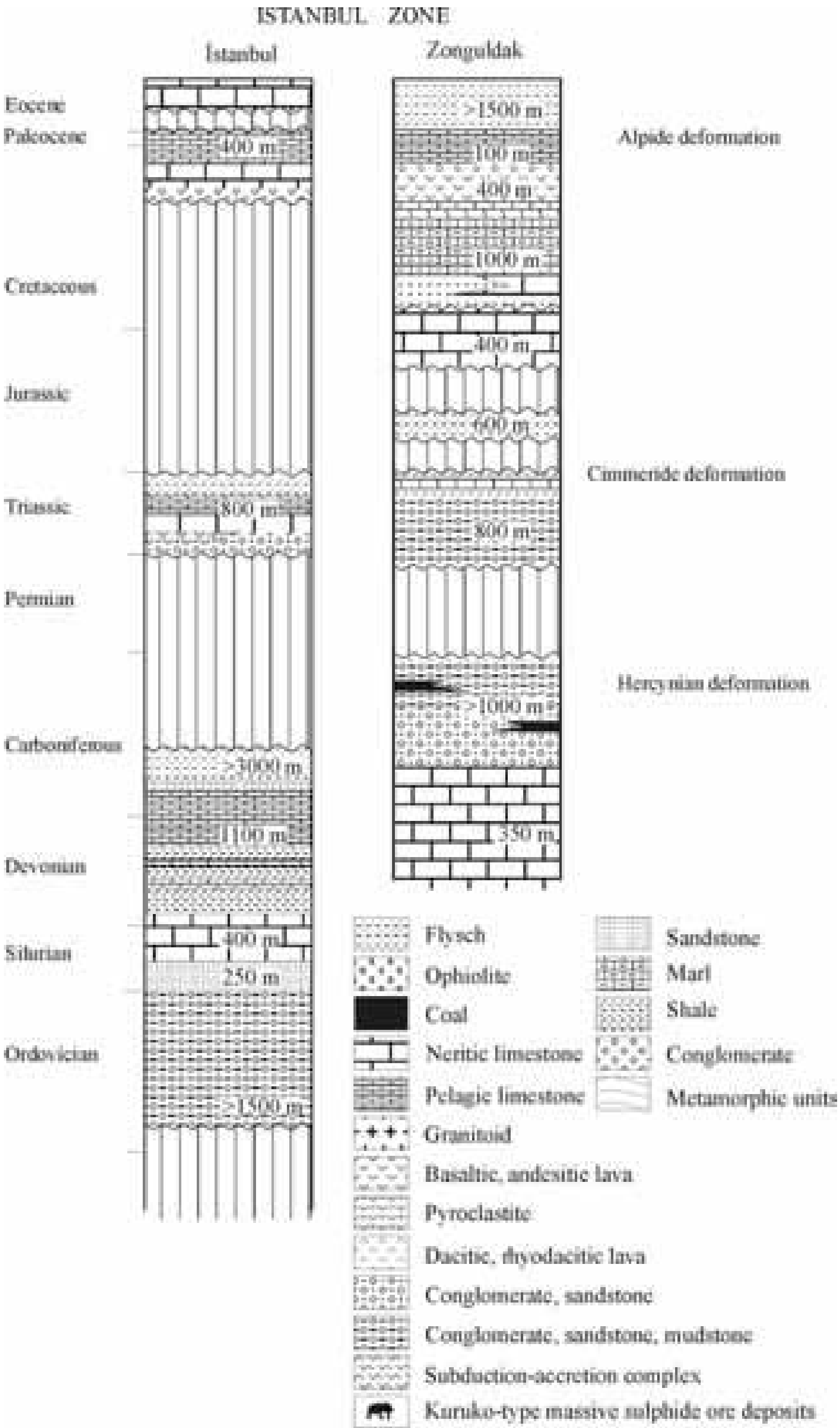

Figure 2 - Stratigraphy of the Istanbul Zone in the west (Istanbul region) and east (Zonguldak region) (Okay and Tüysüz, 1999).

deformed but unmetamorphosed Palaeozoic sequence of the Istanbul Zone is unconformably overlain by the earliest Triassic sedimentary rocks (Figure 2). The Triassic sequence is well developed in the Istanbul region and comprises an ~800 m thick sequence of Scythian to Norian age (Assereto, 1972; Gedik, 1975). It ends with a flysch-like sequence of sandstone and shale with *Halobia* sp. marking the onset of the Late Triassic Cimmeride deformation, which is particularly strong in the Sakarya Zone to the south. In the Istanbul region the Triassic rocks are unconformably overlain by Upper Cretaceous-Palaeocene clastic, carbonate and andesitic volcanic rocks (Dizer and Meric, 1983; Tansel, 1989). Senonian andesitic lavas, dykes and small acidic intrusions, which are widespread in the northern part of the Istanbul Zone, were produced during the northward subduction of the Tethys ocean.
The palaeomagnetic results from the Palaeozoic and Triassic rocks of the Istanbul Zone indicate its affinity to Laurasia during these periods (Saribudak et al., 1989; Evans et al., 1991; Theveniaut, 1993). The Istanbul Zone shows a similar Mesozoic-Mesozoic stratigraphy to that of Moesian Platform, and prior to the late Cretaceous opening of the West Black Sea Basin it was situated south of the Odessa shelf (Okay et al., 1994). With the inception of back-arc spreading in the Black Sea, the Istanbul Zone was rifted off from the Odessa shelf and was translated southward, bounded by two transform faults, the West Black Sea fault to the west and the West Crimean fault to the east (Figure 1, Okay et al., 1994). The southward translation of the Istanbul Zone led to the gradual closure of the Intra-Pontide Ocean by north-dipping subduction.
During the Cretaceous the Istanbul Zone collided with the Sakarya Zone, leading to the formation of Intra-Pontide suture.

The Sakarya Zone

The Sakarya Zone is an east-west oriented continental fragment, about 1500 km long and 120 km wide, between the Anatolide-Tauride Block to the south and the Istanbul and Strandja zones and the eastern Black Sea to the north (Figure 1). A distinctive geological feature of the Sakarya Zone is the widespread presence of Triassic subduction-accretion complexes, which form a strongly deformed and partly metamorphosed basement to the overlying, unmetamorphosed Lower Jurassic-Eocene sequence (Tekeli, 1981). The Triassic subduction-accretion units, called the Karakaya Complex, comprise a lower unit of Permo-Triassic metabasite-marble-phyllite series (Nilüfer Formation), over three kilometres in thickness, with exotic Triassic eclogite (Okay and Monie, 1997) and blueschist lenses (Okay et al., 2002). The Nilüfer Formation is tectonically overlain by chaotically deformed, but unmetamorphosed, clastic and basic volcanic rocks of Triassic age with exotic blocks of Carboniferous and Permian neritic limestone, basalt, Carboniferous and Permian radiolarian chert (Bingöl et al. 1975; Okay and Mostler, 1994; Kozur and Kaya, 1994; Leven and Okay, 1996; Okay et al., 1996). The final phase of deformation and metamorphism of the subduction-accretionary complexes occurred during the latest Triassic, and the various units of the Karakaya Complex are unconformably overlain by Lower Jurassic terrigeneous- to shallow-marine, clastic sedimentary rocks. The Sakarya Zone also includes rare Upper Palaeozoic granites and associated metamorphic rocks, which are in tectonic contact with the Karakaya Complex, and, which probably represent fragments of the Laurasian margin (Figure 3, Yilmaz, 1990; Yilmaz et al., 1994; Okay et al., 1996). As we will be studying many of the tectonostratigraphic units of the Sakarya Zone during the fieldtrip, they are described below in more detail.

Palaeozoic Continental Rocks of the Sakarya Zone

The continental basement of the Sakarya Zone is represented by Palaeozoic (Devonian and Carboniferous) granites and metamorphic rocks. The metamorphic rocks, mainly felsic gneiss, quartzofeldspathic micaschist intercalated with banded amphibolite and marble, are mainly exposed in the tectonic windows of the Uludag and Kazdag ranges, where they are overlain by the Karakaya Complex (Figure 3). Zircon $^{207}Pb/^{206}Pb$ step ages of two gneiss samples from Kazdag gave a mean of 308 ± 16 Ma (Okay et al., 1996), whereas K/Ar and Rb/Sr muscovite and biotite ages are 19-22 Ma (Okay and Satir, 2000).

Paleo-Tethyan active margin units - the Karakaya Complex

The Karakaya Complex represents Triassic subduction-accretion units, which include possible fragments of a Triassic oceanic plateau (Tekeli, 1981; Okay et al., 1996; Okay, 2000). The Karakaya Complex extends from the Biga peninsula eastwards for over 1000 km in the Sakarya Zone, and northward to the southern Crimea (e.g. Kotanski, 1978; Tekeli, 1981; Tüysüz, 1990; Ustaömer and Robertson, 1994). Studies in northwest Turkey have led to the

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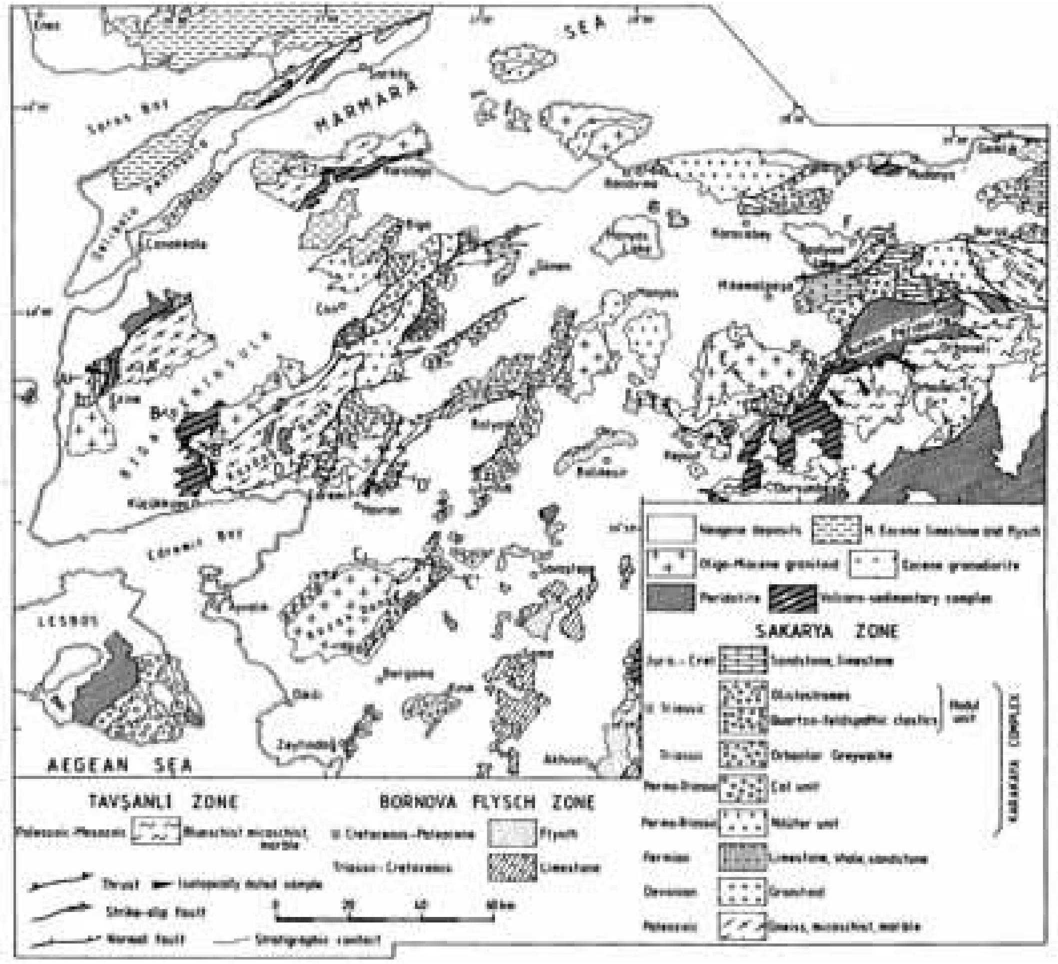

Figure 3 - Geological map of northwestern Turkey south of the Marmara Sea (Okay et al., 1996).

subdivision of the Karakaya Complex into four major tectonostratigraphic units (Figure 4), which are described below.

Fragments of a Triassic oceanic plateau?
The Nilüfer Formation.

This is an over 3-km-thick, semi-coherent sequence of mafic tuffs, pyroclastic rocks, and pillow lavas that are interstratified with up to 50-m-thick carbonate and shale bands (Figure 4). The stratigraphic base of the Nilüfer Formation is not known. In the Kazdag and Uludag ranges it rests with a tectonic contact over the high-grade gneisses, amphibolites and marbles (Figure 3). The Nilüfer Formation is overlain generally through tectonic contacts by the Upper Triassic clastic sequences of the Karakaya Complex (Figure 4).

The Nilüfer Formation has undergone a high-pressure greenschist facies metamorphism with the development of albite + chlorite + epidote + actinolite + sphene in the fine-grained mafic tuffs. Sodic amphibole occurs rarely in iron-rich tuffs, while the massive coarse-grained pyroclastic flows retain most of their igneous texture and the igneous clinopyroxene. The greenschist facies metabasites of the Nilüfer Formation include very rare, generally a few ten meters large tectonic lenses of ultramafic rock. A 40-m-large lens of glaucophane-eclogite has been described in the Nilüfer Formation east of Bandirma (Okay and Monie, 1997), and a large blueschist-eclogite thrust sheet north of Eskisehir (Okay et al., 2002). The deformation in the Nilüfer Formation is characterized by the development of cleavage in the phyllites and fine-grained metatuffs, and mesoscopic upright isoclinal folds. The more massive marble bands have boudinaged, giving a "broken formation" character to the Nilüfer Formation. Lower and Middle Triassic conodonts are described from the carbonates interstratified with the metabasites from the Nilüfer Formation south of Bursa (Kozur et al., 2002) and the Kozak range (Kaya and Möstler, 1992), respectively, indicating a Middle Triassic and earlier age for the sequence. This, together with the unconformably-overlying Liassic clastic rocks, and isotopic data indicate a latest Triassic age for the regional metamorphism in the Nilüfer Formation. Ar-Ar phengite and amphibole ages from the Nilüfer Formation also give latest Triassic ages (Okay and Monie, 1997, Okay et al., 2002).

Various tectonic settings have been proposed for the Nilüfer Formation. These include accreted oceanic plateau (Okay, 2000), oceanic seamount (Pickett and Robertson, 1996) and ensimatic fore-arc (Göncüoglu et al., 2000). For more extensive discussions of the tectonic setting of the Nilüfer Formation see Picket and Robertson (1996), Okay (2000) and Göncüoglu et al. (2000).

Karakaya Clastics - Hodul Formation and the Orhanlar Greywacke.

The basaltic rocks of the Nilüfer Formation are associated with several-kilometre- thick, highly disrupted, turbiditic clastic sequences, probably representing Triassic accretionary complexes. The contacts between the two are almost always tectonic, only in the eastern part of the Kozak Range the metavolcanic rocks of the Nilüfer Formation are probably stratigraphically overlain by Late Triassic quarzo-feldspathic sandstones and shales (Akyürek and Soysal, 1983). The coherence of the clastic sequences is largely destroyed; they range from broken formation to melange, and locally show a dynamo-thermal metamorphism and cleavage development. Two major types of clastic sequences can be distinguished in the Karakaya Complex. One is a quartzo-feldspathic sandstone-shale sequence (Hodul Formation) with a continental granitic source; the other is a greywacke-shale sequence (Orhanlar Greywacke) (Figure 4; Okay et al., 1991).

The quartzo-feldspathic clastic sequence (the Hodul Formation) ranges from proximal to distal turbidites and, in regions near the Izmir-Ankara suture, passes up to extensive Late Triassic debris flows with exotic Carboniferous-Permian limestone blocks in a greywacke matrix. This olistostromal belt can be traced from the mainland to the island of Lesbos in the Aegean (Figure 3). The neritic Carboniferous and Permian limestone blocks, that may reach up to several kilometres in size, make up over 95% of the olistoliths and are characterised by rich fusulinid faunas (Leven and Okay, 1996). Rarer blocks of fine-grained aphyric mafic volcanic and pelagic sedimentary rock also occur in the olistostromes. A two-meter-wide block of intercalated red pelagic limestone and radiolarian chert in the greywackes northeast of Balya has yielded Middle Carboniferous (Bashkirian) conodonts: *Idiognathoides* cf. *optimus*, *Ozarkodina* sp. and *Hindeodus* sp. (Okay and Mostler, 1994).

The clastic rocks of the Orhanlar Greywacke are homogeneous greywackes with poorly -orted, angular quartz, plagioclase, opaque, lydite, radiolarian chert, mafic volcanic rock and phyllite fragments in an argillaceous matrix. They contain small blocks of Lower Carboniferous dark limestone, rich in corals, brachiopods and foraminifera (Leven and Okay, 1996).

The Cal Formation.

The Cal Formation consists of mafic volcanic flows and pyroclastic rocks, sheet-like debris flow conglomerates, volcanogenic sandstone and shale, and Middle Triassic limestone (Figure 4). It exhibits generally steeply-dipping fault contacts with the other Karakaya Complex units, and is unconformably overlain by Late Liassic basal conglomerates (Okay et al., 1991, 1996).

The debris flow conglomerates, which make up the bulk of the Cal Formation, consist of poorly-sorted Upper Permian neritic limestone clasts in a mafic volcanic or volcanogenic sandstone matrix. The Upper Permian limestones range from a few millimetres to a maximum of a few hundred meters in size. Well-bedded calciturbidites with transported Upper Permian limestone clasts, pelagic limestone, radiolarian chert and Middle Triassic shallow marine limestone also occur in minor amounts in the Cal Formation (Okay et al., 1991, 1996). Like most units in the Karakaya Complex, the Cal Formation also has a highly disrupted internal structure that ranges from broken formation to melange. In most cases it is not clear whether the more competent lithologies are exotic blocks or represent an original part of the now disrupted stratigraphic sequence. Such a few-meters-big "block" of radiolarian chert in siliceous shales from southeast of Can (Figure 3) yielded a Permian radiolarian fauna (Okay and Möstler,

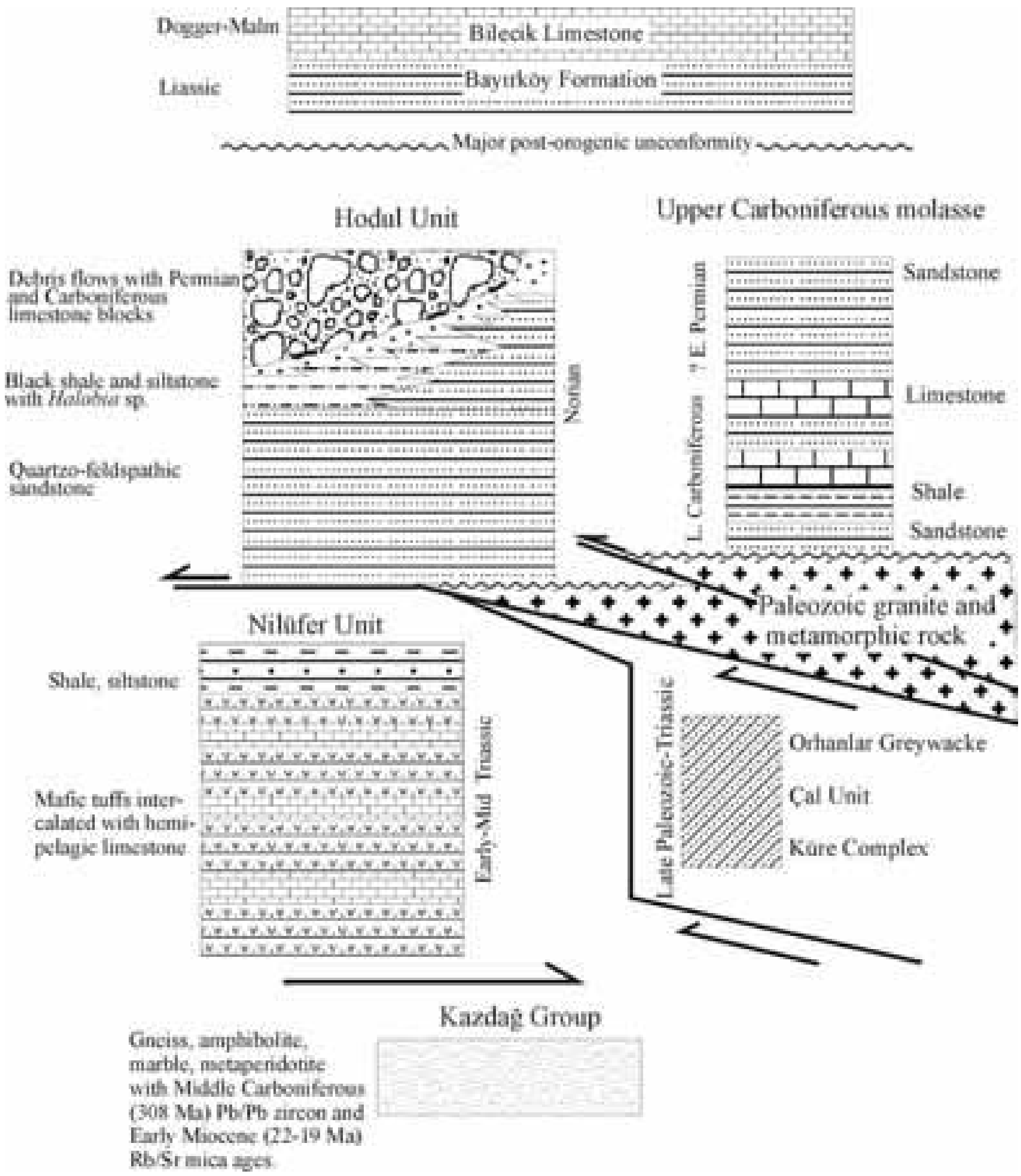

Figure 4 - Generalized tectono-stratigraphy of the Karakaya Complex in northwest Turkey (Okay, 2000).

1994; Kozur, 1997), providing the first evidence of pelagic Permian facies in Turkey.

The intermingling of mafic volcanic rocks and Upper Permian limestone clasts suggests that the limestone deposition was penecontemporaneous with the mafic volcanism, indicating an Upper Permian age for part of the sequence. The Middle Triassic limestones may represent an interval of carbonate deposition following the cessation of the volcanism. The Liassic clastic rocks that unconformably overly the Cal Formation constrain its age to Permo-Triassic.

Jurassic and younger cover rocks of the Sakarya Zone

Following the latest Triassic Karakaya orogeny molasse-type continental- to shallow-marine Liassic clastic rocks were deposited over the entire

Sakarya Zone (e.g. Altiner et al., 1991). They lie unconformably over various Karakaya Complex units, as well as on the Palaeozoic granitic rocks. The Liassic clastic rocks are disconformably succeeded by the Middle Jurassic to Lower Cretaceous neritic carbonates, that are in turn unconformably overlain by the Albian-Cenomanian pelagic limestones. In northwest Turkey the rest of the Cretaceous and Palaeocene sedimentary rocks are missing, and Middle Eocene neritic limestones unconformably overlie units as old as the Karakaya Complex (Figure 3; Siyako et al., 1989). However, farther east, in the region east of Bursa, the mid-Cretaceous pelagic limestones are succeeded by an over 1000-m-thick Upper Cretaceous tuffaceous flysch sequence with serpentinite, blueschist and Jurassic limestone olistoliths, which passes up to the continental to fluviatile Palaeocene clastic rocks (Saner, 1980). The first compressive movements were in the Palaeocene, when Jurassic limestones were thrust south over the Palaeocene terrigeneous sandstones (Yilmaz, 1981). The passage from flysch to molasse sedimentation, and subsequent thrusting, reflect the Palaeocene continent-continent collision between the Sakarya Zone and the Anatolide-Tauride block (Okay and Tüysüz, 1999).

The Anatolide-Tauride Block

The Anatolide-Tauride Block forms the bulk of southern Turkey and, in contrast to the Pontide continental fragments, shows a Mesozoic stratigraphy similar to the Arabian Platform, and hence to that of Gondwana (Sengör and Yilmaz, 1981). During the obduction, subduction and continental collision episodes in the Late Cretaceous-Palaeocene, the Anatolide-Tauride Block was in the footwall position, and underwent much stronger deformation and regional metamorphism than that observed in the Pontide zones. During the Senonian, a massive body of ophiolite and accretionary complex was emplaced over the Anatolide-Tauride Block. The northern margin of the Anatolide-Tauride Block underwent high pressure/low temperature (HP/LT) metamorphism at depths of over 70 km. Erosional remnants of this ophiolite thrust sheet occur throughout the Anatolide-Tauride Block. With the inception of continental collision in the Palaeocene the Anatolide-Tauride Block was internally sliced, and formed a south to southeast vergent thrust pile. The compression continued until the Early to Mid-Miocene in western Turkey, and is still continuing in eastern Anatolia. The lower parts of the thrust pile in the north were regionally metamorphosed, while the upper parts to the south form large cover nappes. This leads to subdivision of the Anatolide-Tauride Block into zones with different metamorphic and structural features, in a similar manner to the subdivision of the Western Alps into Helvetics and Penninics albeit with a different polarity. There are three main regional metamorphic complexes: A Cretaceous blueschist belt, the Tavsanli Zone, in the north, a poorly-known metamorphic belt, the Afyon Zone in the centre, and an Eocene Barrovian-type metamorphic zone, the Menderes Massif, in the south (Figure 1). To the northwest of the Menderes massif there is a belt of chaotically-deformed uppermost Cretaceous-Palaeocene flysch with Triassic to Cretaceous limestone blocks. This Bornova Flysch Zone has an anomalous position between the Izmir-Ankara suture and the Menderes Massif (Figure 1). The Taurides, which lie south of the metamorphic regions, consist of a stack of thrust sheets of Mesozoic sedimentary rocks (e.g., Gutnic et al., 1979; Özgül, 1984).

Although the Anatolide-Tauride Block shows a variety of metamorphic, structural and stratigraphic features, there are some elements of stratigraphy common to all of these zones, and which classify the Anatolide-Tauride Block as a single tectonic entity. These are a Pan-African crystalline basement, a discontinuous Cambrian to Devonian succession dominated by siliciclastic rocks, a Permo-Carboniferous sequence of intercalated limestone, shale and quartzite, and a thick Upper Triassic to Upper Cretaceous carbonate sequence. On the other hand, Hercynian deformation or metamorphism, and Triassic subduction-accretion units, characteristic features of the Sakarya Zone, are not observed in the Anatolide-Tauride Block.

The geology of the Tavsanli Zone, the Anatolide-Tauride zone that will be visited during the field trip, is described below.

Tavsanli Zone - A subducted passive continental margin

Tavsanli Zone is a 50-60-km-wide and about 250-km-long east-west trending belt of regional blueschists tectonically overlain by oceanic accretionary complexes and large peridotite slabs (Figs. 5 and 6). Undeformed Early to Middle Eocene granodiorites (50 Ma $^{40}Ar/^{39}Ar$ isochron ages), intrude the

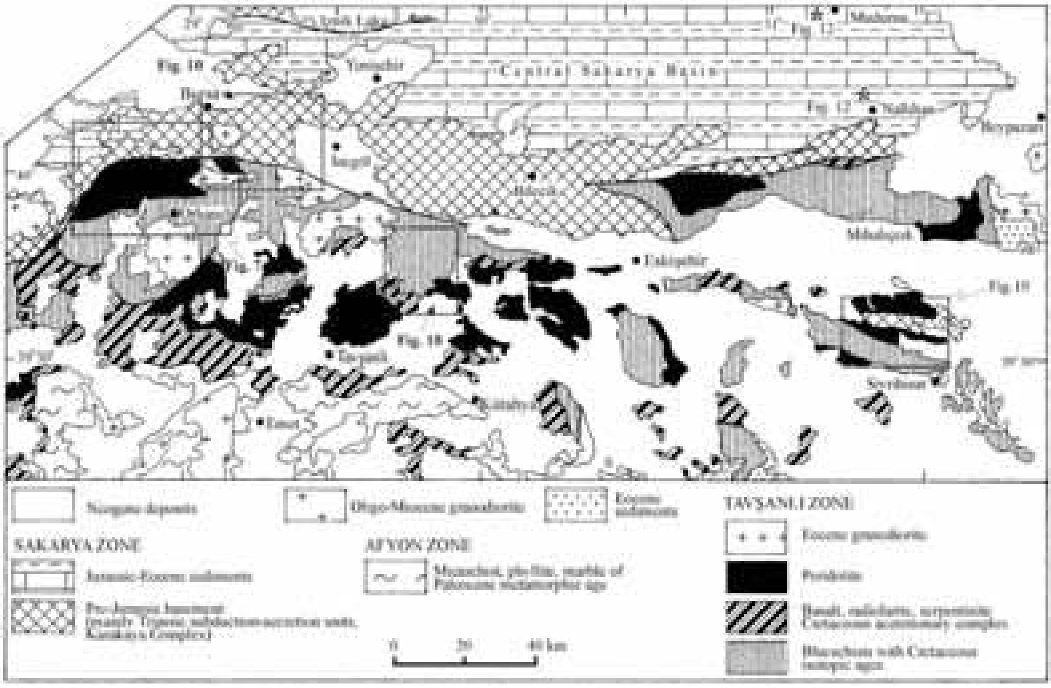

Figure 5 - Geological map of the Tavsanli Zone (Okay and Tüysüz, 1999).

blueschists and the overlying peridotite (Figure 5). The blueschists of the Tavsanli Zone represent the subducted north-facing passive continental margin of the Anatolide-Tauride block, and show a similar tectonic evolution to those from Oman (e.g., Goffe et al., 1988; Searle et al., 1994). They were partly exposed by, or were at high crustal levels during, the latest Cretaceous, prior to the continent-continent collision, as evidenced by blueschist detritus in latest Cretaceous clastic sequences in the Sakarya Zone north of the Tavsanli Zone. The continental collision between the Sakarya Zone and the Anatolide-Tauride block was of Palaeocene age. Thus, continent-continent collision had little role in the exhumation of the blueschists in the Tavsanli Zone. Below I describe briefly the four units, namely the regional blueschists, the Cretaceous accretionary complex, the ophiolite, and the Eocene granodiorites, which make up the Tavsanli Zone.

The coherent blueschist sequence - Orhaneli Group

The coherent blueschist sequence consists of over 1-km-thick basal metaclastics overlain by several-kilometres-thick marbles, which pass up to a metabasite-metachert-metashale sequence, with well-preserved blueschist facies minerals (Figure 6). Based on a stratigraphic comparison with the Tauride-Anatolide units, the depositional age of the blueschist metaclastics is probably Mesozoic, and that of the marbles is Mesozoic. The age of the blueschist metamorphism, based on Rb/Sr phengite dating, is Campanian (~80 Ma, Sherlock et al., 1999).

The Blueschist Facies Metaclastics (The Kocasu Formation).

This formation consists of alternating sodic metapelites and metapsammites, and has a thickness of over 1000 metres. It outcrops over large areas around Orhaneli and Keles (Okay and Kelley, 1994; Okay 2002) and is overlain by the Inönü Marble (Figure 6). The metaclastic rocks have lost all their primary lithological features and show a penetrative foliation. All contain quartz and phengite and, additionally, many metaclastic rocks comprise lawsonite, jadeite, glaucophane and chloritoid. They include unique mineral assemblages, such as jadeite + chloritoid + glaucophane + lawsonite. Garnet is conspicuously absent due to the low metamorphic temperatures. The mineral assemblages in the metaclastic rocks tightly constrain the P-T conditions in the Tavsanli Zone and indicate a pressure of about 24 kbar and a temperature of about 430° C (Okay and Kelley, 1994; Okay, 2002). The petrology of these rocks is described in detail by Okay and Kelley (1994) and Okay (2002).

The Blueschist Facies Carbonates (The Inönü Marble).
The metaclastic rocks of the Kocasu Formation are stratigraphically overlain by a thick sequence of marbles (Figure 6). The Inönü marble, which has a thickness of several kilometres, consists of white, massive calcite-marble. Its depositional age is most probably Middle Triassic to Early Cretaceous, based on similar but unmetamorphosed sequences in the Anatolide-Tauride Block. P-T conditions of the blueschist facies metamorphism indicate that the carbonates must have been composed of aragonite, which must have been retrograded to calcite during the exhumation of the blueschists.

The Blueschist Facies Metabasites and Metacherts (The Devlez Formation).
The metabasites with rare bands of metachert and siliceous phyllite lie stratigraphically over the carbonates of the Inönü Marble (Figure 6). The metabasites are characterized by sodic amphibole and lawsonite with minor sodic pyroxene, chlorite, leucoxene and phengite (Okay, 1980a). These are the classical "blue" blueschists. The metacherts include quartz, spessartine-rich garnet, hematite, lawsonite and sodic pyroxene.

Petrological Evolution of the Blueschists.
An important feature of the blueschists in the western part of the Tavsanli Zone is that they commonly contain prograde mineral assemblages. This is most apparent in the metabasites (Okay, 1980b). The initial metabasite assemblage consisted of sodic pyroxene + lawsonite + chlorite + quartz, where sodic pyroxene often pseudomorphs the igneous augite. Sodic pyroxene in these metabasites is of an aegerine-jadeite composition with high aegerine content. At this metamorphic stage, called the lawsonite zone, there is no penetrative deformation, and the original igneous texture of the basalt is discernable (Okay, 1980b). In the second stage associated, with the inception of penetrative deformation, sodic amphibole forms at the expense of sodic pyroxene, chlorite and quartz. The metamorphic reaction can be written as:

Sodic pyroxene + chlorite + quartz = sodic amphibole + lawsonite

Structure of the Blueschists.
Regional blueschists in the Tavsanli Zone show a well-developed foliation, and in many cases a strong mineral lineation, generally defined by sodic amphibole and/or by calcite (Okay et al., 1998). They are strongly folded with the axis of the tight to isoclinal folds trending parallel to that of the mineral stretching lineation. The regional mineral lineation in the blueschists trends approximately east-west, parallel to the trend of the Izmir-Ankara suture north of the Tavsanli Zone. This is unexpected, as the mineral lineation is generally regarded as showing the direction of transport, which in this case should be perpendicular to the trend of the suture. A possible model explaining this unusual trend of the mineral lineation, as well as an exhumation mechanism for the blueschists is given in Okay et al. (1998).

The Cretaceous Accretionary Complex

(The Ovacik Complex)
In many regions in the Tavsanli Zone a tectonic unit of basalt, radiolarian chert, pelagic shale, pelagic limestone and serpentinite occurs above the regional blueschists. This Cretaceous unit, called the Ovacik Complex, is interpreted as an accretionary complex (Okay and Kelley, 1994; Okay et al., 1998). Most of the Ovacik Complex is constituted by basaltic agglomerates with lesser amounts of red radiolarian chert and pelagic shale. Serpentinite, pelagic limestone and greywacke make up less than 10 % of the Ovacik Complex. Basaltic agglomerates commonly contain blocks of recrystallized limestone up to several hundred metres wide. The Ovacik Complex differs from the Franciscan or Makran type accretionary complexes in the scarcity of sandstones and siltstones.
The scarce palaeontological data from the Ovacik Complex suggest a Jurassic and Cretaceous depositional age for some of the radiolarian cherts and limestones (Servais, 1981; Okay and Kelley, 1994; Tekin et al., 2002).
The Ovacik Complex is cut by a large number of shear zones with tens to hundreds of metres spacing. Apart from local development of foliation along these shear zones, the rocks in the volcano-sedimentary sequence are generally free of penetrative deformation. Rocks of the Ovacik Complex also generally appear unmetamorphosed, except for

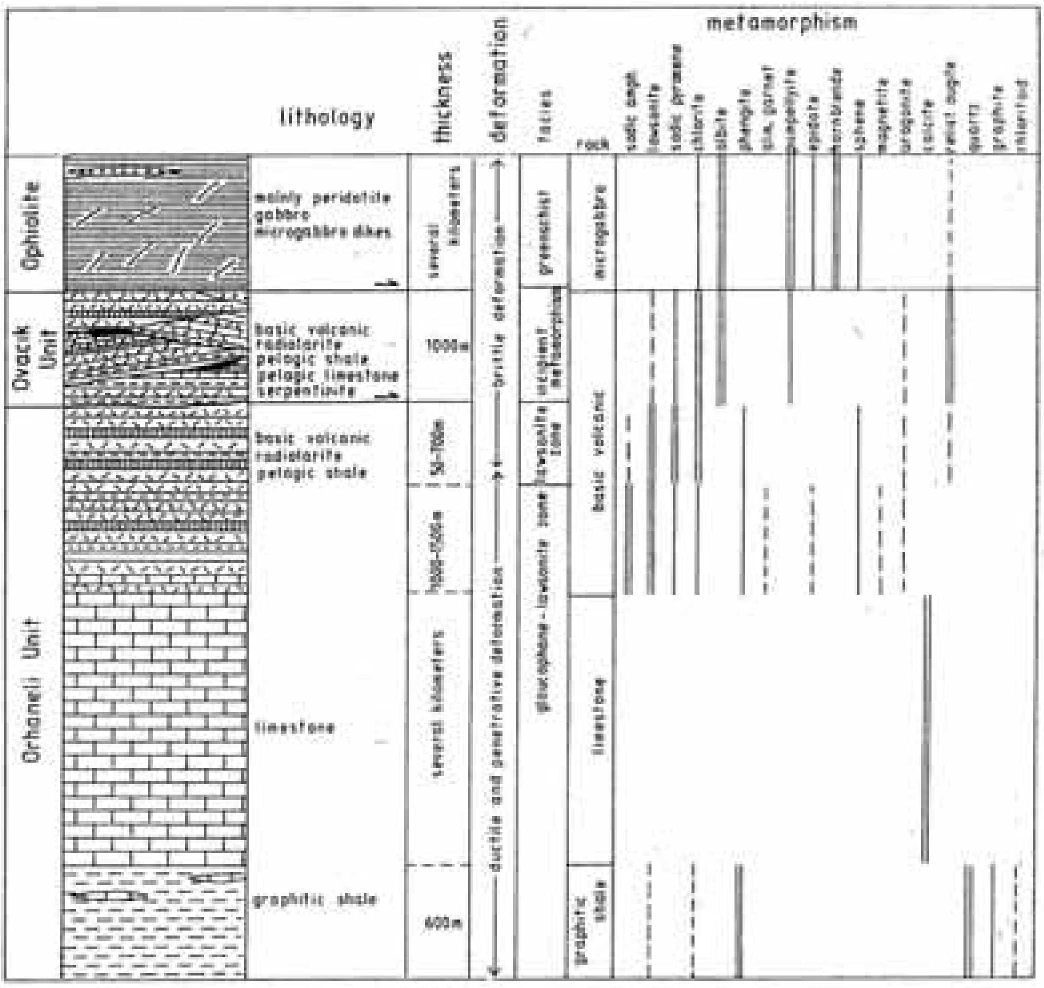

Figure 6 - Stratigraphy, lithology, structural features and mineral paragenesis of the Tavsanli Zone (Okay, 1986).

the ubiquitous spilitization, which imparts a green colour to the basalts. However, this is deceptive, as almost all the Ovacik Complex has undergone an incipient blueschist facies metamorphism (Okay, 1982). This is most apparent in the basalts, which commonly consist of augite partially to completely replaced by sodic pyroxene, chlorite, albite and lawsonite. Blueschist facies minerals such as aragonite, sodic pyroxene and lawsonite commonly occur in the veins and amygdales of the basalts (Okay, 1982; Okay et al., 1998). Associated with the incipient metamorphism, there has been sodium metasomatism producing basalts with up to 8 wt. % Na_2O (Okay, 1982). In rare cases the Ovacik Complex has undergone a stronger deformation and metamorphism, producing a sequence similar to the upper parts of the regional blueschist sequence.

Ophiolite

Large slabs of ultramafic rock lie tectonically over the accretionary complex or directly over the blueschists. They are generally believed to be parts of an ophiolite, although the extrusive upper parts of an ophiolite have never been identified in northwest Turkey. It is probable that the various ultramafic fragments in the Tavsanli Zone (Figure 5) initially formed part of a very large ophiolite, comparable in size to the Semail ophiolite in Oman.

Most of the ophiolite in the Tavsanli Zone consists of peridotite (mainly dunite and harzburgite), which shows only minor serpentinization. Gabbros occur but are rare (Lisenbee, 1971; Önen and Hall, 1993). An enigmatic feature of the ultramafic rocks is the diabase dykes, which intrude the peridotite. Chilled contacts indicate that the dykes have intruded into already cold oceanic lithosphere. The petrology of the diabase dykes, as well as the gabbros, indicate that the ophiolite has not undergone the HP/LT metamorphism observed in the underlying regional blueschists.

Eocene Granodiorites

Several large granodiorite plutons intrude the regional blueschists, as well as the overlying accretionary complex and peridotite. They are all undeformed biotite-hornblende-bearing plutons with a calc-alkaline affinity (Harris et al., 1994). The geochemistry of the plutons in the western part of the Tavsanli Zone has been studied by Harris et al., (1994). Although the plutons are separated by 250 km (Figure 5), they give closely spaced Ar-Ar biotite ages of around 50 Ma (Early to Mid-Eocene) (Ataman, 1972, 1973; Harris et al., 1994; Sherlock et al., 1999). This observation, as well as the absence of Eocene plutons outside the Tavsanli Zone, suggests a genetic link between the granodiorite genesis and exhumation of the blueschists (Okay et al., 1998). One possible mechanism is the rupturing of the subducting oceanic lithospheric slab, which is thought to produce magmatism by the upflow of the asthenosphere through the lithospheric fracture created by the slab break off (Davies and Blackenberg, 1995).

Tertiary cover rocks

All the tectonostratigraphic units of the Tavsanli Zone are unconformably overlain by the Neogene terrigeneous deposits, which are of Miocene to Pliocene age. The pre-Miocene Tertiary history of the Tavsanli Zone is poorly documented. The only known sequence of this age is a small outcrop of Middle Eocene neritic limestones, which lie unconformably over the peridotite north of Tavsanli (Bas, 1986).

Field trip itinerary

DAY 1

Sunday, August 29th, 2004
Road description between Istanbul and Bursa

We leave Istanbul early in the morning, passing to Asia using the Fatih Bridge built in 1988. The first Bosphorus Bridge, built in 1973, can be seen farther south. We take the new motorway to Ankara. The hills around the motorway are made up of Ordovician quartzites of the Istanbul Zone. Along the motorway one gets a feeling as to how the city of Istanbul is growing with unfinished red brick buildings extending in every direction. In 1960, Istanbul had a population of 1.5 million, now it boasts a population of over 10 million people.

We leave the motorway near Gebze and head for the ferry station in Eskihisar, a small village on the Izmit Bay. The crossing by ferry saves a detour around the Izmit Bay. If we are lucky we will not queue for the ferry. The white cliffs around the ferry station are made up of Upper Cretaceous marly limestone, similar in age to those in southern England. In the east, above the village, is a ruined castle, which gives its name to the village of Eskihisar (literally “old castle”). The castle rests on the Middle Triassic carbonates of the Istanbul Zone. One of the substages of the Triassic (Bithynian Substage of the Anisian Stage) was named in this region (Assereto, 1974). Eskihisar was also the home of the first Turkish archaeologist and museum director, Hamdi Bey, whose quaint house is now a museum.

The ferry across the Izmit Bay takes about an hour. The Izmit Bay, as well as the Marmara Sea, was formed as a result of the activity of the North Anatolian fault. The North Anatolian fault is a post-Early Miocene dextral transform fault, along which the Anatolian plate moves west. It consists essentially of a single fault zone along most of its 1500-km-long course; however, as it nears the Marmara Sea it splits into several branches. The main branch is responsible for the formation of the Marmara Sea. Despite its small size, the Marmara Sea is deep; 20 km west of the route of the ferry the sea is more than 1200 m deep. The main branch of the Anatolian Fault passes through the centre of the Izmit Bay, a subparallel fault with a major normal fault component bounds the southern side of the Bay. As the ferry approaches Topcular on the south side of the Bay, you will be able to see the sharp break in the steep slope of the east-west aligned hills, which marks the location of the North Anatolian Fault. The hills are made up of red continental sandstones of earliest Triassic age.

We drive from Topcular to Yalova along the alluvial coastal strip. The low-lying hills south of the road consist of Neogene sediments. The coastal area between Topcular and Yalova was badly affected by the 17th August 1999 Izmit earthquake. The traffic is always heavy along this road. We will not enter the town of Yalova, famous for its spa, but instead take the road to Bursa. The road climbs up hills amidst heavy traffic and passes through the unremarkable town of Orhangazi. A few kilometres after Orhangazi we will see the Iznik Lake and the mountains rising along its southern margin. A branch of the North Anatolian Fault follows the southern slope of the Iznik Lake. At Orhangazi, a road sign points to Iznik, the ancient Nicae, and a picturesque and unspoilt town on the eastern margin of the Lake. Iznik was famous for its Ottoman tiles and is historically important as the place of the first (325 A.D.) and seventh (787 A.D.) ecumenical councils of the Christian church. On the way to Gemlik you might be able to see on the road sections' white marbles intercalated with greenish grey metabasites, and grey phyllites. They form part of the Nilüfer unit of the Karakaya Complex and indicate that we have entered the Sakarya Zone. There is a small diabase quarry on the roadside, which works a thick dolerite flow with a striking ophitic texture. The quarry produces diabase slabs for small decorative purposes. The contact between the Istanbul and Sakarya zones, the so-called Intra-Pontide suture, passes through the Armutlu Peninsula (Göncüoglu and Erendil, 1990; Yilmaz et al., 1994).

Gemlik is a small port on the Marmara Sea. The region is also well known for its olives. The olive trees line both sides of the road towards Bursa. Here we are near the northern limit of the olive habitat. Olive trees grow in the southern part of Istanbul, but most of Istanbul and the northern Bosphorus are too cold for olive trees. The flat-lying sediments on the left (east) as the road climbs up from Gemlik are Oligocene-Miocene deposits. Farther on we pass south-dipping, thickly-bedded red sandstone conglomerates, these are fluvial deposits of Early to Mid-Eocene age. Then the road descends into the Bursa plain. If the sky is clear we will see in front of us the mighty mountain Uludag, the ancient Bithynian Olympus, rising from the Bursa plain.

Uludag rises from near sea level to a height of above 2500 metres. It is the most popular ski resort in Turkey. The top part of the mountain is a national park with wild bears, boars and wolfs. A paved road reaches the ski resort; from there there is a dirt road to a disused tungsten mine near the peak of the mountain. The tungsten was produced from the skarn deposits between Mesozoic marbles and Miocene granite. The mine was run by the state mining company, Etibank, the more it produced the more it lost moneywise. At the end someone decided to shut down the mine.

On the road to Bursa we will stop in a large market (Özdilek) to buy food for a picnic lunch, as well as other provisions. This will be the only large and well-stocked market we will see during the trip; therefore, it is a good idea to buy here whatever is necessary for the next five days.

We will not enter the city of Bursa but will take the by-pass to Canakkale/Izmir. The road to Orhaneli branches off from the main highway. It skirts the western margin of the Uludag following the Nilüfer valley. The Uludag forms a major topographic and geological dome; the core of this dome is made up of Palaeozoic marble, gneiss and amphibolite pierced by a Miocene granite (Figure 10, Ketin, 1947). The mantle of the dome consists of the metabasite-phyllite-marble sequence of the Nilüfer Formation of the Karakaya Complex, named after the Nilüfer valley. Nilüfer was also the name of the Greek wife of the second Ottoman Sultan, Orhan, whose grave is in Bursa. The road to Orhaneli is a reference section for the Nilüfer Formation (Okay et al., 1991). Our first stop will be in this unit.

The meter is set to zero at the Bursa-Orhaneli-Canakkkale junction.

Stop 1.1:

Triassic metabasite-marble-phyllite of the Nilüfer Formation of the Karakaya Complex

Locality: opposite the Misi village on the Bursa-Orhaneli road, 4.6 km from the junction (2557, 5348), (Figure 7).

The road to Orhaneli follows the Nilüfer valley, the type locality of the Nilüfer unit. Here, on the east side of the road, opposite the village of Misi, there are outcrops of intercalated metabasite, marble and calcschist of the Nilüfer Formation. The metabasites are mostly fine-grained tuffs. Lamination in some marbles and calcschists suggests a pelagic environment of deposition. Conodonts from the marbles in the Nilüfer valley have been dated as earliest Triassic (Kozur, personal comm.). The metamorphic sequence dips steeply northwest and is folded with the fold axis showing variable plunge but generally trending 60-70°. On the tectonic discrimination diagrams involving (Ti, Y, Zr, Nb, Cr) the metabasites from this area (as well as from other areas of the Nilüfer Formation) plot in the "within plate basalt" field (Pickett, 1994).

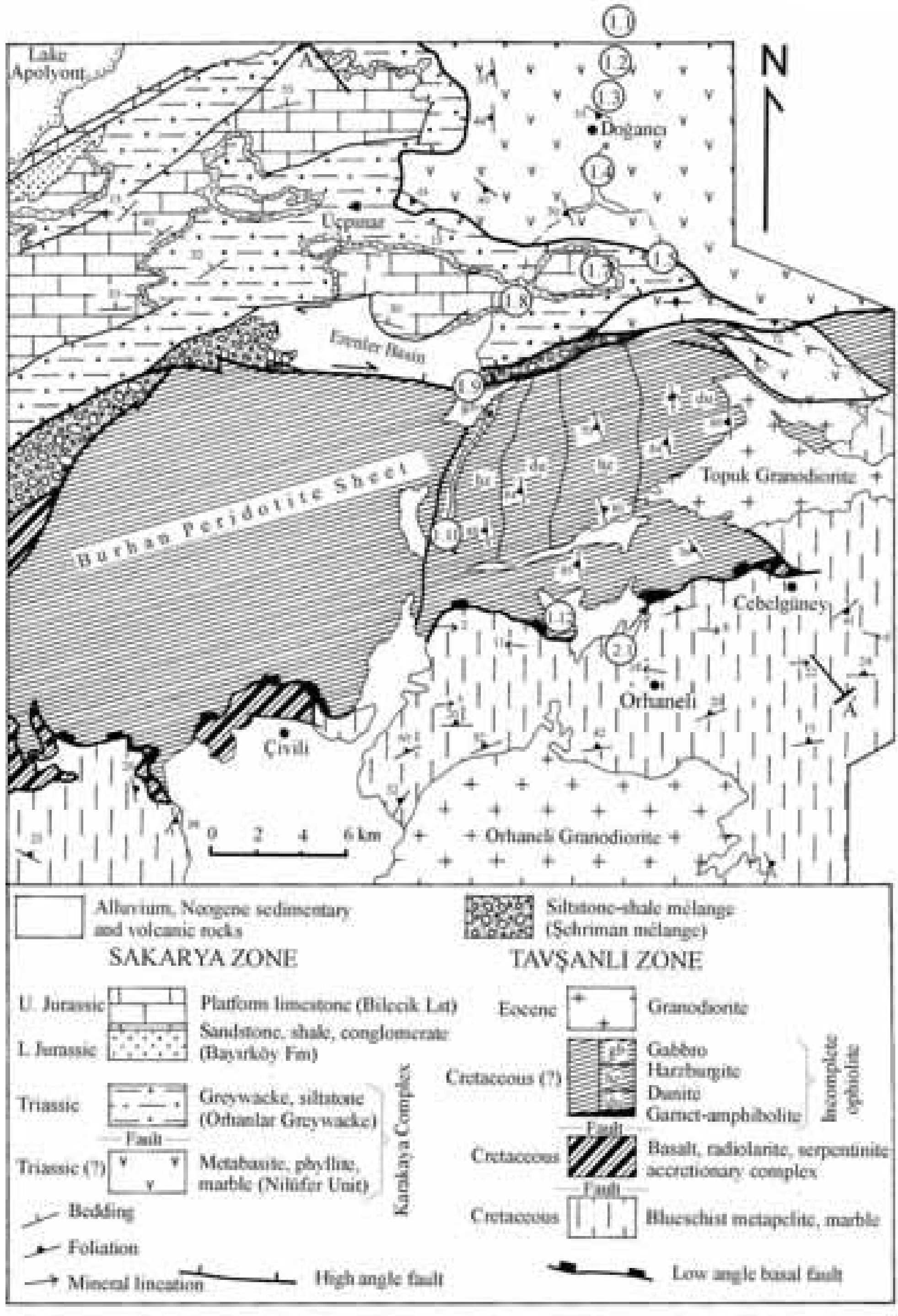

Figure 7 - Simplified geological map of the Orhaneli region showing the stop locations. For location see Figure 5 (Okay and Tüysüz, 1999).

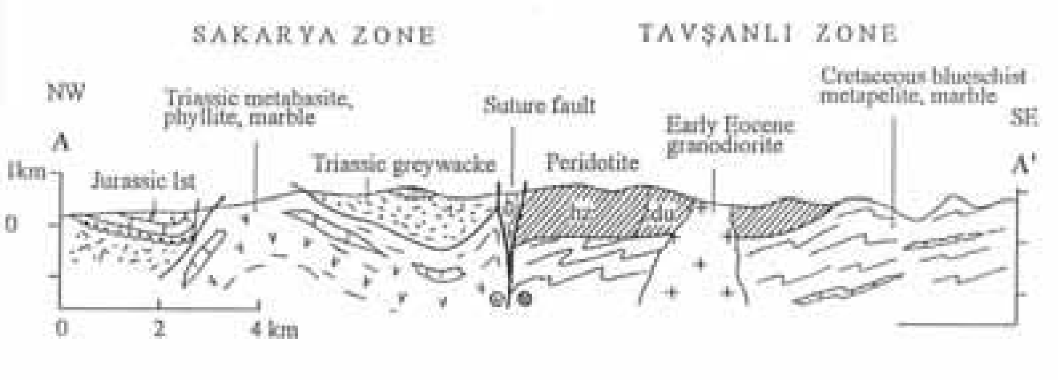

Figure 8 - Geological cross-section of the Orhaneli area. See Figure 7 for location.

The metamorphism in the Nilüfer unit in this valley is in the high-pressure greenschist facies. The mineral assemblage in the metabasites is actinolite/barroisite + epidote + chlorite + albite + leucoxene. Within the green metabasites there is a blue siliceous band repeated by folding. It is an epidote-blueschist with the mineral assemblage of quartz + sodic amphibole + epidote + albite. Sodic amphibole is a Fe^{3+} rich-crossite with blue to lavender blue pleochroism. As there is no evidence for poly-metamorphism in these rocks, we have a clear case of cogenetic blueschists and greenschists, which is to be expected in the P-T region of transition between the greenschist and blueschist facies metamorphism. Sodic amphibole also occurs in some coarse metabasites as rims around relict igneous augite or kaersutite. Phengites in similar blueschists and greenschists in the Nilüfer Formation north of Eskisehir have been dated by Ar/Ar method as latest Triassic (Okay et al., 2002).

Optional Stop 1.2:

Deformational features of the Nilüfer Formation

Locality: Bursa-Orhaneli road, 11 km after the Orhaneli junction, before the Dogancilar dam (2562, 5349) (Figure 7).

On the quarry face on the opposite side of the Nilüfer valley we can observe an upright isoclinal antiform, well characterised by a marble bed. The core of the fold is made up of marble flanked by metabasites. Through such folding the structural thickness of the Nilüfer Formation exceeds 7 km.

Optional Stop 1.3:

Deformational features of the Nilüfer Formation

Locality: Bursa-Orhaneli road, 12 km after the Orhaneli junction, before the Dogancilar dam (2563, 5350), (Figure 7).

On the opposite side of the Nilüfer valley we can see a succession of pyroclastic flow, marble, pyroclastic flow and tuff. The more massive marble band has been boudinaged and has partly lost its continuity. This often gives a “broken-formation” character to the Nilüfer Formation. The normal faulting observed in the marble band suggests an earlier episode of brittle stretching, prior to isoclinal folding. There is as yet no detailed study of the structure of the Nilüfer Formation.

Stop 1.4:

Metabasites of the Nilüfer Formation and the panorama to the south

Locality: On the Bursa-Orhaneli road above the axis of the Dogancilar Dam, 13 km after the Orhaneli junction, at the Orhaneli-Keles road junction (2564, 5351) (Figure 7).

On the well-exposed road cut (careful of the passing vehicles!) one can see the metabasites of the Nilüfer Formation. Over 80% of the metabasites in the Nilüfer Formation have a pyroclastic origin, and pillow lavas are relatively rare. However, here we have a tectonic slice of deformed pillow lavas. Pillow lavas are identifiable by their amygdaloidal rims. The pillow lava sequence forms an about 35-m-thick section and is bounded by two faults, probably thrust faults. The one in the south dips north (105/53N) and the one in the north dips southeast (40/53E).

From this locality there is also a good panoramic view towards the south. The flat top of the hills on the horizon is made up of the Upper Jurassic – Lower Cretaceous limestones (Bilecik Limestone) of the Sakarya Zone. Below the limestones there

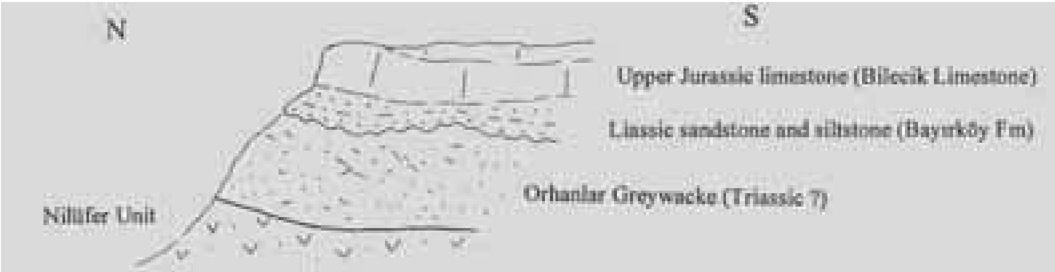

Figure 9 - Relationships between the Nilüfer Formation, Orhanlar Greywacke, the Bayirköy Formation and the Jurassic limestones.

is a Liassic basal clastic unit of sandstone and conglomerate (the Bayirköy Formation), although this is not apparent from this point (Figure 9). These two formations are typical of the Jurassic and Lower Cretaceous of the Sakarya Zone. Between the Nilüfer Formation and the Liassic basal clastics there is a strongly deformed greywacke unit, which we will be seeing in the next Stop.

Stop 1.5:

The Nilüfer Formation and the overlying Orhanlar Greywacke

Locality: On the Bursa-Keles road, the dirt road to the village Dagakca, 19.8 km from the Orhaneli junction. (2808-2810) (Figure 7).

In northwest Turkey the Nilüfer Formation is overlain by a strongly deformed but generally unmetamorphosed clastic series, which often bear exotic blocks of Permian and Carboniferous limestone. The contact is invariably tectonic, although originally it could have been stratigraphic.

Here on the road to the village of Dagakca we will see the contact between the Nilüfer Formation and the overlying greywackes of the Orhanlar Greywacke. We will walk down to the contact after observing the lithological features of the Orhanlar Greywacke.

On the side of the road there are fine-grained brownish weathering (the fresh colour is dark grey) sandstones and siltstones. Siltstones show a rough foliation. Bedding in the Orhanlar Greywacke is rarely observed, due to strong deformation. Lithologically, the sandstones of the Orhanlar Greywacke are homogeneous greywackes. They consist of angular and poorly sorted fragments of quartz, feldspar, basalt, shale, and mica grains in a clay matrix. Strong shear and incipient recrystallisation of quartz grains is evident under the microscope.

Walking down the road we see the contact between the Nilüfer Formation and the Orhanlar Greywacke. About 40 metres above the contact there are black, dark grey slates and metasiltstones, just above the contact there is a several-metres-thick red, silty chert. The contact is sheared and is tectonic.

Stop 1.6:

Panoramic view towards Uludag and Orhanlar Greywacke

Locality: The side road to Dagakca village branching from the Bursa-Keles road, 23.9 km away from the Orhaneli junction. Just below Dagakca village (5353) (Figs. 7 and 10).

The road climbs up through the monotonous greywacke towards Dagakca village. Just before the village there is a magnificent view towards the Uludag to the north. The snow-white layers, which dip steeply towards us, are Mesozoic marbles of the Uludag sequence; they overlie gneisses with Carboniferous zircon ages (Figure 10). South of the marble horizon, there is foliated granitoid, which forms a tabular body 17 km wide and only 1.5 km thick. It was emplaced, probably in the Eocene, in the suture zone, which at that time was a major strike-slip fault. The entire region between the granitoid and the Nilüfer valley is made up of the metabasite-marble-phyllite of the Nilüfer Formation. The Miocene granite, which cuts the Uludag series, can be observed as greyish-white crags west of the marble sequence.

Stop 1.7:

Liassic sandstones and Upper Jurassic limestones of the Sakarya Zone

Locality: The side road to Dagakca village branching from the Bursa-Keles road, 28.2 km away from the Orhaneli junction. Pass through Dagakca and take the side road at 27.9 km (3122, 5354) (Figure 7).

The road passes through Dagakca and continues southeast. Above the village we can see the flat-lying carbonates of the Bilecik Limestone. Here we are near the top of the hill that we saw from a distance

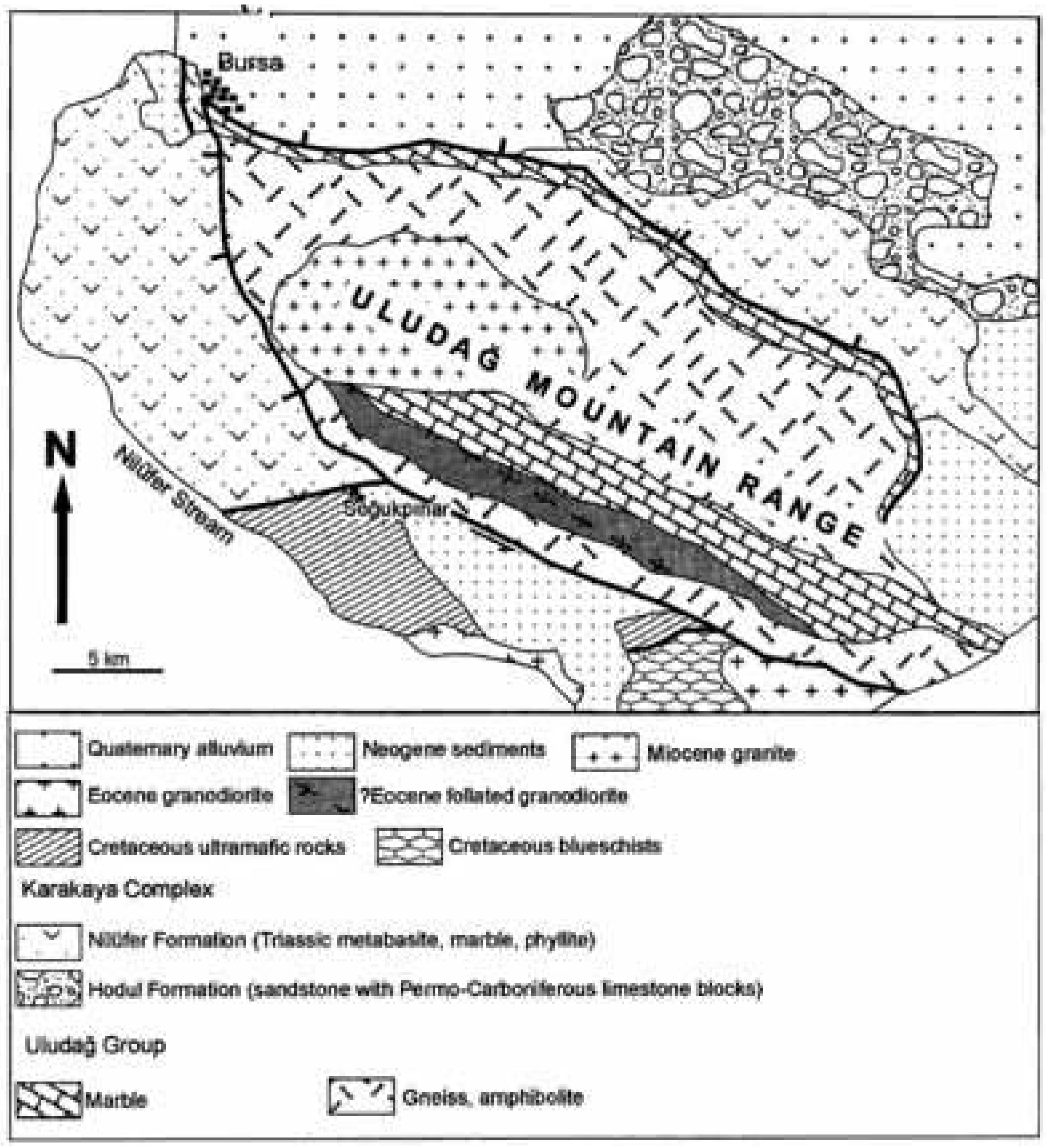

Figure 10 - Simplified geological map of the Uludag range, southeast of Bursa. For location see Figure 5 (modified from Ketin, 1947).

at Stop 1.4. On a side road we can observe the shales and sandstones of the Liassic Bayirköy Formation. They are little deformed and contain plant fragments, lamellibranches and belemnites. The strong contrast in the deformation between the Orhanlar Greywacke and the Bayirköy Formation is obvious. This hiatus of the latest Triassic (Rhaetian) - earliest Jurassic (Hettangian) age marks the Cimmeride orogeny in the Sakarya Zone, associated with the closure of the Paleo-Tethys.

Immediately above the clastics of the Bayirköy Formation one can see the Bilecik Limestone, which forms a flat lying ledge at the top. This was the table mountain topography we observed from Stop 1.4 at the Dogancilar Dam.

We turn back to the Orhaneli-Keles junction on the Dogancilar Dam, and take the road to Orhaneli. Good roadside exposures of the dark green metabasites of the Nilüfer Formation can be seen along the road. After a while we enter the Orhanlar Greywacke; it is the westward continuation of the same large outcrop seen in the previous stops (cf. Figure 7). Then the road climbs up to the Bilecik Limestone, which forms the core of a broad syncline. In this particular spot the northern contact of the Bilecik Limestone is faulted against the Orhanlar Greywacke, and the Bayirköy Formation is only exposed on the southern limb of the syncline.

Altiner et al. (1991) measured a section in the Bayirköy Formation and Bilecik limestone one kilometre east of the present road. According to their data the Bayirköy Formation is 136 m thick and consists chiefly of conglomerate, sandstone and siltstone deposited in a fluviatile environment. The overlying Bilecik Limestone has a minimum thickness of 750 metres and is of Callovian to Tithonian age (Mid- and Late Jurassic). The basal part of the Bilecik Limestone, a few tens of metres thick, is largely dolomitic, with lenses of ammonitico rosso-type red nodular limestone of Callovian age. The rest of the neritic carbonate sequence consists of bioturbated cherty limestone, packstone and grainstone.

Optional Stop 1.8:

The unconformity between the Orhanlar Greywacke and the Bayirköy Formation.

Locality:

On the Bursa-Orhaneli road (5362) (Figure 7).

In the northern limb of the Dagakca syncline along the Orhaneli road, the Bayirköy Formation consists of siltstone, sandstone with conglomerate lenses. The clasts in the conglomerates include quartz, metamorphic rock, diabase and Permian limestone. The contact between the Orhanlar Greywacke and the overlying Bayirköy Formation can be located within a few metres along the road section. Here, the Orhanlar Greywacke consists of sandstone and shale with a 5 m long and about 0.5 m thick lens of coal. It is overlain by little deformed sandstones and microconglomerates of the Bayirköy Formation.

Stop 1.9:

The Göktepe fault - the post-Miocene expression of the Izmir-Ankara suture

Locality: On the Bursa-Orhaneli road, 15.9 km away from the Orhaneli-Keles junction. Just past the village of Erenler, opposite the petrol station. The eastern wall of a large harvest field (3046, 3047) (Figure 7).

Here we are at the southern limit of the Sakarya Zone at the Izmir-Ankara Neo-Tethyan suture. The suture, represented by a major steeply-dipping fault, the Göktepe fault, separates the Sakarya Zone from the ophiolite and blueschists of the Tavsanli Zone. It corresponds to a profound tectonic break. On one side of the suture there are unmetamorphosed, little-deformed, Upper Jurassic limestones, on the other side are rocks metamorphosed at 70-km-depth during the Late Cretaceous. Before the days of plate tectonics contacts such as this must have been bewildering. Yet, for all its profoundness, the Izmir-Ankara suture is represented here by a sharp strike-slip fault, which has been active as late as post-Miocene.

The Erenler basin is a small Miocene pull-apart basin nested on the suture (Figure 7). It consists of poorly-sorted, terrigeneous, monomict conglomerates, over 300 m in thickness. The generally well-rounded clasts in the conglomerates consist mostly of diabase and minor ultramafic rock, derived from the Burhanlar peridotite in the south. The conglomerates are overlain by white tuffs, which can be seen in the village of Erenler that we have just passed. There is no independent evidence for the age of the Erenler basin. However, such basins abound in northwest Turkey, and the isotopic and palaeontological data indicate a Miocene age for the basin infill. For example, biotites from the crystal-tuffs at the base of the Civili basin, 15 km to the south, have yielded Ar-Ar ages of 18 Ma (Early Miocene, Okay et al., 1998). Thus, one can reasonably be sure that the conglomerates and tuffs of the Erenler basin are of Miocene age.

On the wall of the harvest field the Miocene conglomerates are cut by a steeply dipping fault. The steep dip of the fault plane suggests strike-slip movement along the fault. The geometry of the Erenler basin implies a dextral strike-slip movement, which is also compatible with the sense of movement of the North Anatolian fault. This Göktepe fault can be followed for 60 km along strike (Figure 5) and was probably reactivated as a dextral strike-slip fault during the late Miocene with the inception of the North Anatolian fault. The Göktepe fault may also be presently active and may join another major fault in the east, the Eskisehir fault; the fast uplift of the Uludag Mountain may be partly related to the activity along these faults (Figure 5).

Obviously the activity along the Göktepe fault dates back to the Palaeocene-Eocene, when continental collision between the Sakarya Zone and the Anatolide-Tauride Block took place, or even earlier, to the Late Cretaceous. The east-west elongation of the Topuk granodiorite implies that the Göktepe fault controlled the intrusion of this pluton during the Mid-Eocene (Figure 5). The Göktepe fault can be compared to the Insubric line in the Western Alps, which, although a post-collisional structure, constitutes the Alpine suture in some segments.

Optional Stop 1.10:

Burhan peridotite: ultramafic rocks

Locality: Bursa-Orhaneli road, after Akcabük village (60) (Figure 7).

After passing through the Göktepe fault we are in the Tavsanli Zone of the Anatolide-Tauride Block. Initially we pass through a major peridotite massif, the Burhan peridotite sheet, which probably represents the lower parts of an ophiolite (Figure 7). It consists mainly of dunite and harzburgite with minor gabbro, pyroxenite and chromite. The eastern part of the Burhan peridotite, mapped by Lisenbee (1971), consists of north-south trending, subvertical bands, and a few kilometres in thickness. The peridotite shows a distinct tectonic foliation, parallel to the compositional layering, and defined by the preferred orientation of olivine and elongate crystals of enstatite. According to Lisenbee (1972) the contacts between the bands are gradational. The peridotite gets younger towards the west and is bounded by a poorly defined fault zone marked by serpentinite slivers, small Neogene basins and Miocene dacite intrusions (Figure 7). The internal structure of the western part of the Burhan peridotite is poorly known.

Gravity profiles across the Burhan peridotite, as well as geological cross-sections, indicate that the maximum vertical thickness of the peridotite is 1.5 km. This contrasts with the actual thickness of over 13 km, measured perpendicular to the compositional layering.

Stop 1.11:

Burhan peridotite: banded, two-pyroxene gabbros

Locality: Bursa-Orhaneli road, 24.9 km away from the Orhaneli-Keles junction, road cut on the side road to the village of Yörücekler (towards the lignite power-station) (57).

The gabbro in the Burhan peridotite forms a north-south striking and steeply west-dipping band, less than 100 m thick (Figure 7). Here on the road cut we see a section from these banded two-pyroxene gabbros. Banding is a primary igneous feature. The gabbros are strongly melanocratic with little plagioclase. The black, irregularly-shaped minerals are spinels, which appear green to dark green under the microscope. The rest is largely colourless clinopyroxene and pleochroic orthopyroxene with minor olivine, amphibole and plagioclase. Plagioclase is strongly altered and consists of very fine-grained aggregates of a high relief mineral (clinozoisite? pumpellyite?) and albite. There is no evidence for blueschist facies metamorphism in the gabbros. Interestingly, the rocks also show no effects of hydration; they must have stayed dry during their long history.

The long chimneys on the west belong to a lignite power plant. The small Neogene basins west and northwest of Orhaneli contain lignite, which is used for generating electricity.

Stop 1.12:

Diabase dykes in the Burhan peridotite

Locality: Bursa-Orhaneli road, 5.2 km north of Orhaneli, at the junction with the road to the village of Cöreler (5361) (Figure 7).

The Burhan peridotite slab, like the other peridotite bodies in the Tavsanli Zone, is cut by east-west trending, subvertical diabase dykes with chilled margins against the peridotite. The dykes are generally a few meters thick, and vary in abundance from one dyke over several hundred meters to ten dykes over 30 m. They do not extend down to the accretionary complex, and they are cut by the basal fault. The chilled margins of the dykes indicate that they were injected into an already cold oceanic lithosphere. One speculation is that their formation is related to the subduction of a spreading centre, which would produce magmatism in the overlying oceanic lithosphere.

The mineral assemblage in the dykes is altered plagioclase and augite, partly replaced by igneous hornblende. Plagioclase is represented by albite with very small turbid aggregates of pumpellyite. This observation is critical since it indicates that the dykes, and by inference the Burhan peridotite slab, have not undergone the regional blueschist metamorphism that is observed in the immediately underlying rocks.

Here on the road cut we see three microgabbro dykes in the sheared and fractured, partially serpentinized, black peridotite. They are boudinaged and form one-to-three-metre long lenses.

DAY 2

Monday, August 30th, 2004

Bursa-Orhaneli-Keles-Bursa

From Bursa we drive towards Orhaneli passing through the yesterday's stop localitions. Just before entering the town of Orhanli, we take a side road to the village of Delibalar to see the blueschists and the overlying peridotite.

Stop 2.1:

The Burhan peridotite and the underlying blueschist sequence (Figure 11).

Locality: On the Bursa-Orhaneli road, just before entering Orhaneli, along the village road to Deliballar (62, 4414, 4415) (Figure 7).

Just before entering the town of Orhaneli, we take the small dirt road on the left, which leads to the village of Deliballar. We disembark the minibus next to a large barracks, and go on foot for about one hour. The aim of this small excursion is to study the blueschist marbles and metabasites, subophiolite metamorphic rocks, and the overlying ultramafic rocks.

The barracks, now in disuse, was a collecting ground for manganese ore, used in making the tips of matchsticks. As people no longer use matches, the mine, which lies several kilometres away, has been abandoned. Exposed on the road cuts around the barracks are marbles. Some primary brecciation structures are still recognisable in some marble horizons, which can speculatively be ascribed to the collapse of the Mesozoic carbonate platform of the Anatolide-Tauride Block.

Farther on along the road there are some calcschist horizons (calcite + phengite ± sodic amphibole) and rare metabasites. Along the small path leading to the hilltop, the calcschists and marbles are intercalated with the blue metabasites. This shows that the marbles must also have been metamorphosed in the blueschist facies. Initially they must have been composed of aragonite, but now they are all calcite-marbles. As we will see later, marbles make up an important part of the Tavsanli Zone blueschists.

As we start climbing up the hill we commonly encounter blocks of blue metabasite. The few-millimetre-large laths of greyish- white lawsonite can easily be observed with the naked eye. Lawsonite crystals are commonly shaped as rectangles or as wedges (in two dimensions), and are invariably idioblastic. They are set on a blue matrix of sodic amphibole, commonly of crossite in composition. This is the characteristic blueschist metabasite of the Tavsanli Zone. The mineral assemblage is sodic amphibole + lawsonite + chlorite + sodic pyroxene + phengite + leucoxene ± garnet ± opaque. Sodic amphibole and lawsonite together make up over 80% of the rock. In metabasites sodic amphibole is almost always crossite, reflecting the composition of the parent rock. Phengite, chlorite, sodic pyroxene (chloromelanite in composition) and leucoxene are commonly present in small amounts. Garnet is rare in the metabasites of the Tavsanli Zone; metamorphic temperatures in these rocks were generally not high enough to generate garnet. However, in this locality I have found at least one

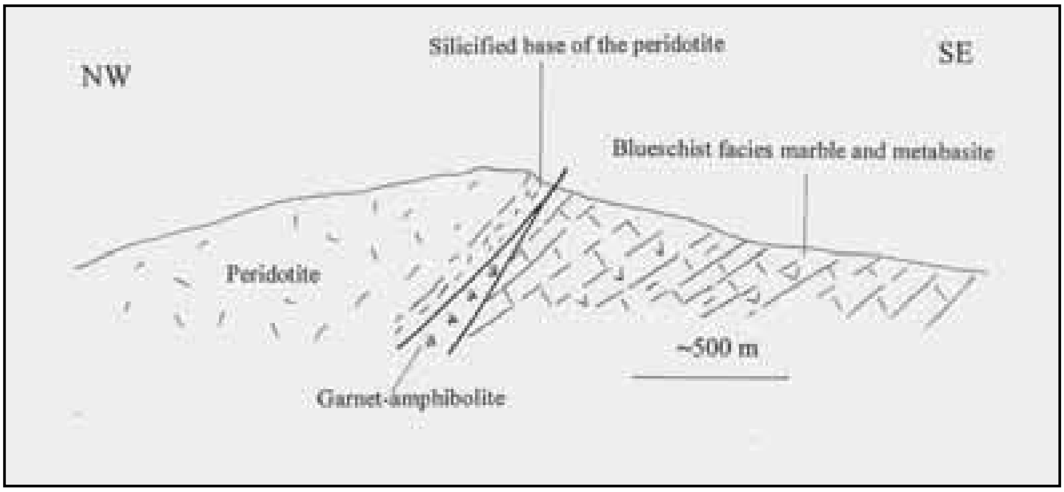

Figure 11 - Cross-section of the southern margin of the Burhan peridotite showing the relationship between the blueschists, the subophiolite metamorphic rocks, and the peridotite. For location of this section see Figure 7.

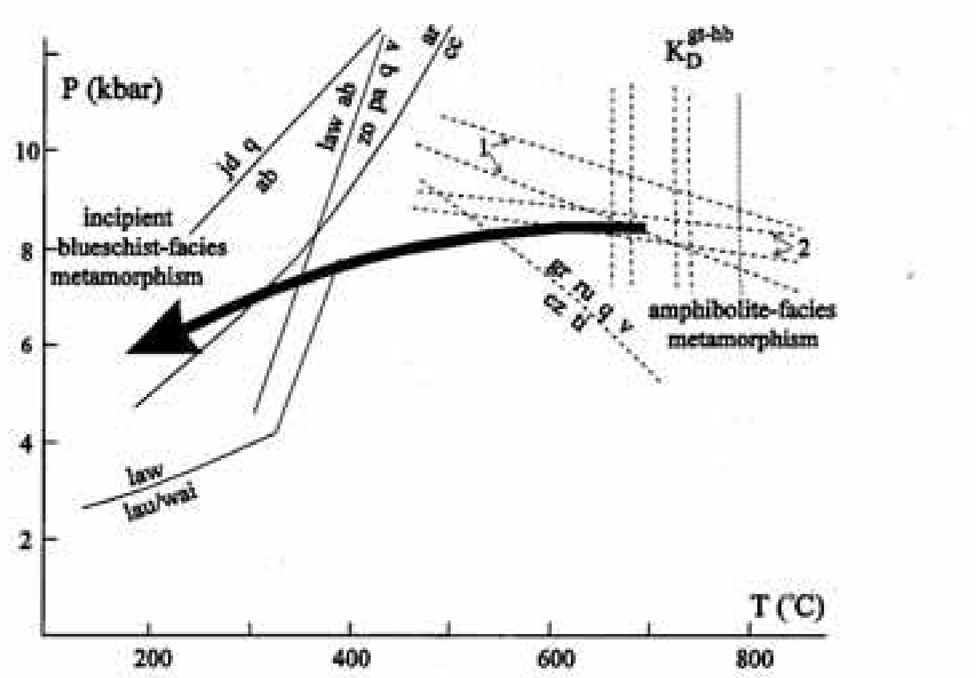

Figure 12 - Pressure-temperature path of garnet-amphibolites from the base of the peridotite. P-T conditions of the amphibolite facies metamorphism at 8.5 ± 3 kbar and 700°C are constrained by the Graham and Powell's (1984) garnet-hornblende geothermometer (K^{gt-hb}, vertical dashed lines) and by reactions (1) pargasite + hornblende + ferrohornblende = edenite + grossular + almandine + quartz + H_2O and (2) pargasite + ferrohornblende + pyrope = edenite + grossular + almandine + quartz + H_2O, for minerals in the two analyzed samples. Conditions of incipient blueschist-facies metamorphism at 6 ± 2 kbar and 200 ± 100° C are constrained by the lawsonite + albite stability. Other reactions are calculated using Holland and Powell's (1990) THERMOCALC . ab, albite; ar, aragonite; cc, calcite, cz, clinozoisite; gr, grossular; jd, jadeite; lau, laumantite; law, lawsonite; pa, paragonite; sph, titanite; q, quartz; ru, rutile, v; H_2O; wai, wairakite; zo, zoisite. (Okay et al., 1998).

metabasite with red garnets, a few millimetres wide, coexisting with lawsonite and crossite.
The top of the hill is made up of silicified serpentinite. The mesh-texture of the serpentinite can be seen as a ghost texture in some of these silica-rocks. Serpentininization and silicification are commonly observed along the basal tectonic contact of the Burhan peridotite body. The silicification is probably a late, post-tectonic feature, due to fluid circulation along the fault contact. Silicification of the ultramafic rocks is an active surfacial process under the present climatic conditions.
In this locality the contact between the silicified peridotite and the underlying blueschists can be located to within a few meters. This tectonic contact juxtaposes blueschists, metamorphosed at 70-km--depth, over the ultramafic rocks, which have not been buried deeper than 20 km. Considering this major omission of strata, what is striking about this contact is the lack of any major brittle structures in the underlying blueschist marble and calcschist). The structures in the blueschists, such as foliation, mineral lineation, and isoclinal folding is largely syn-metamorphic. Thick sequences of mylonites, the retrogression of blueschist facies mineral assemblages, and brittle structures overprinting ductile extensional structures -- all features present in extensional core complexes -- are not observed here. Instead we see a late, upper-crustal, brittle fault. This is a characteristic and enigmatic feature of the Tavsanli Zone.
We descend the hill on the opposite side from which we climbed up. Notice the black mineral trails of chromium-spinel, which stand out in the yellowish-brown silicified serpentinite. When we reach the bottom of the valley, turn left and follow the small path. Farther along the path are poor exposures of garnet-amphibolites. This is a small slice between

the Burhan peridotite and the blueschists (Figure 7 and 11).

There is another larger, and better-exposed, slice of garnet-amphibolite farther west. The mineral assemblage in the garnet-amphibolite is hornblende + plagioclase + garnet + epidote + rutile ± opaque (Okay et al., 1998). The garnet-amphibolite shows locally an incipient high-pressure metamorphic overprint, characterised by tiny laths of lawsonite in the albitized plagioclase, and thin rims of blue sodic amphibole around hornblende. However, it has certainly not undergone the same blueschist metamorphism observed in the marbles, calcschists and metabasites of the Tavsanli Zone. Rather, its metamorphism can be compared to that of the Ovacik Complex (an accretionary complex).

The mineral compositions of the garnet amphibolite from this locality is given in Table 2 of Okay et al. (1998). Geothermobarometry of the garnet-amphibolite assemblage indicates P-T conditions of about 8 kbar and 700°C. The metamorphic conditions of the incipient blueschist facies metamorphism is around 6 kbar and 200°C. This gives an unusual isobaric cooling path for the garnet-amphibolites (Figure 12). One way to explain this P-T path is through the gradual cooling of the garnet-amphibolite at a subduction zone; the garnet-amphibolite having been formed initially through intra-oceanic slicing at the inception of subduction (see Figure 9 of Okay et al., 1998).

Optional Stop 2.2:

Blueschist metacherts near Orhaneli

Locality: Bursa-Orhaneli road. Just before entering Orhaneli turn left 300 m after passing a petrol station (Petrol Ofisi). Follow the small dirt road for about one kilometre (passable by car). Stop near the house and walk up the bush-covered hill. On foot it takes about 15 minutes from the petrol station (61, 5356) (Figure 7).

The banded, quartz-rich rocks sticking out in the bush-covered small hill are blueschist facies metacherts. The metacherts are distinctly banded, isoclinally folded and have the quartz + hematite + phengite + sodic amphibole + garnet + lawsonite ± epidote mineral assemblage. Quartz makes up over 80% of the mode. Phengite is visible as tiny shiny flakes. The small black laths are hematite, which alters to reddish goethite (?). Thus, the red mineral is not piemontite! Other minerals are not recognisable by the naked eye. It is interesting to note that the sodic amphibole, which is a magnesium-riebeckite, is completely colourless in thin section. Because of the high oxygen fugacity during the metamorphism of this rock, no Fe^{2+} was available for the sodic amphibole. In fact, there is hardly any Fe^{2+} in these rocks; almost all the iron is represented by Fe^{3+}.

Garnet in these metacherts forms submilimetric idioblastic grains and is rich in spessartine end-member. In such highly oxidised rocks lawsonite, epidote and hematite coexist peacefully!

Sodic amphiboles contain independently variable $Fe^{2+}/(Fe^{2+}+Mg)$ and $Fe^{3+}/(Fe^{3+}+Al)$ ratios; therefore, their composition is highly dependent on the prevailing oxygen fugacities (effective oxygen partial pressure) during the metamorphism. In fact, it is possible to deduce the oxygen fugacity during the metamorphism from the composition of sodic amphiboles. For a detailed discussion of this interesting question see Okay (1980c).

In the late afternoon there is a good view from this Stop towards the peridotite-blueschist contact visited at the locality 2.1.

Stop 2.3:

Jadeite - quartz fels (Metagranite)

Locality: A few hundred metres east of Orhaneli, near the rubbish dump (5254, 5256) (Figure 13).

Blueschists in the Orhaneli-Keles region form a predominantly metaclastic sequence; metabasites and other magmatic rocks are conspicuously absent. An exception is this unusual outcrop of jadeite-quartz rocks, which might have an acidic magmatic origin.

The jadeite-quartz fels forms massive, very hard (in 1997 I broke my glasses on this outcrop!), pale grey bands, up to one metre thick, in the micaschists. It is a lens, about 200 metres thick, trending southwest. The rock consists mainly of several-millimetres-large jadeite grains and quartz with minor glaucophane, chloritoid, white mica and lawsonite. In these rocks the jadeite is snow-white, similar to feldspar; the greyish blue grains are sodic amphibole. The texture of the rock is reminiscent of that of a microgranite. It could be a small acidic intrusion, but why it is so rich in Na and devoid of K is not clear. In this outcrop there is also a metagabbro, 2 m thick, associated with the jadeite-quartz fels.

Stop 2.4:

Blueschist facies sodic metasediments east

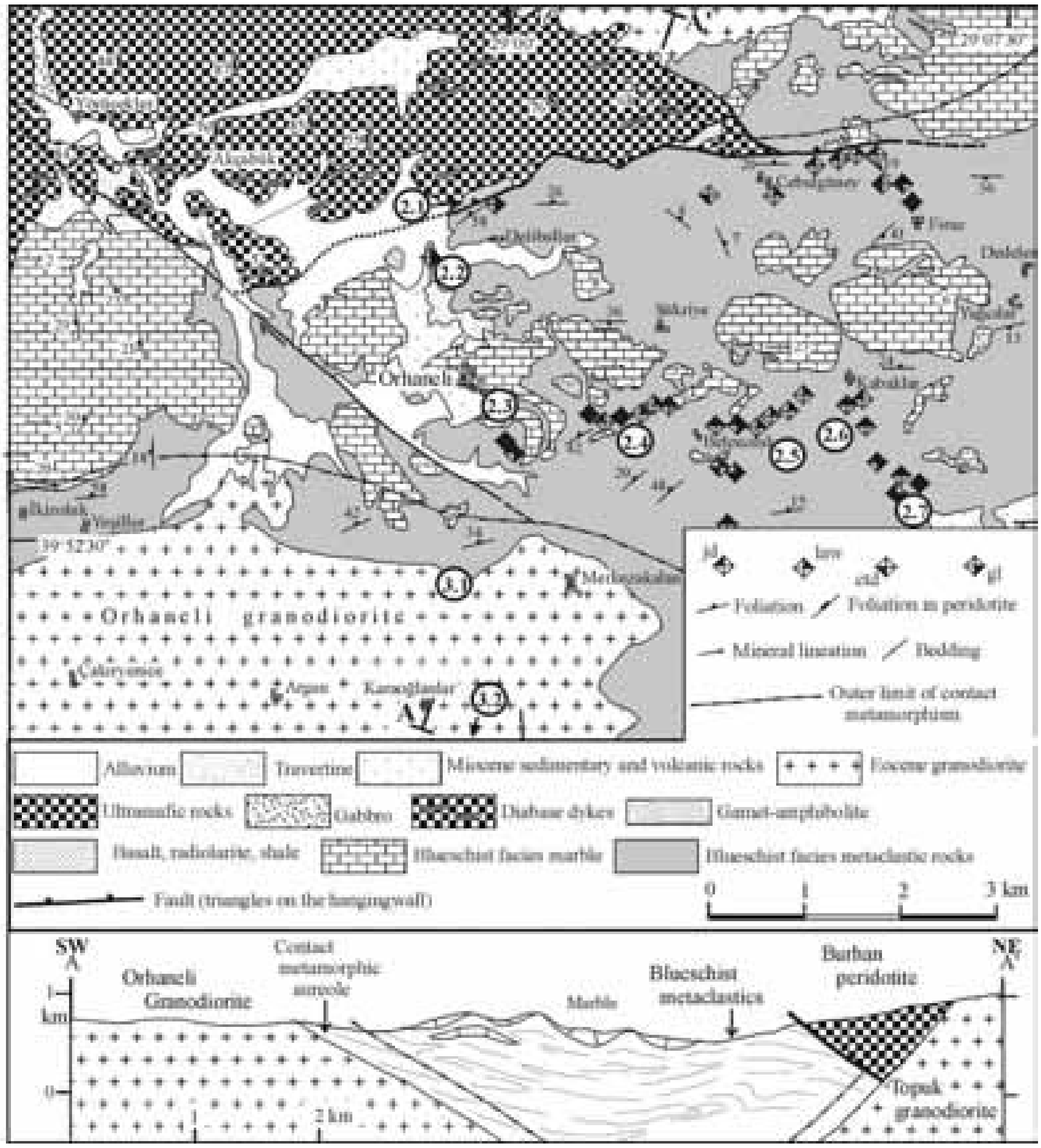

Figure 13 - Geological map and cross-section of the Orhaneli region with stop 2.1-2.7 and 3.1-3.2 locations. For orientation see Figure 5 (Okay, 2002).

of Orhaneli

Locality: The road between Orhaneli and the village of Belenoluk. Less than one kilometre after leaving Orhaneli, in the direction of Harmancik, turn left and follow the road signs to the villages of Belenoluk and Agachisar. Pass the ugly rubbish dump of Orhaneli, take a right turn at the junction at 4.1 km. The section starts at 4.7 km, next to a small spring; we will walk till 5.9 km (4891-4901) (Figure 13).

This road section exposes a sequence of blueschist-facies metasedimentary rocks, remarkable for the excellent preservation of the unstable blueschist minerals jadeite, lawsonite, and glaucophane, as well as for the presence of unique mineral paragenesis involving jadeite + chloritoid + lawsonite + glaucophane. We will walk for about one kilometre along the road studying this interesting series.

The metamorphic rocks in this section are fully recrystallized and exhibit a penetrative foliation locally modified by a later crenulation cleavage. The rocks show complex folding and a weak east-west-trending lineation. They can be broadly divided into two lithologies. The first is a grey to black, strongly schistose phyllite/micaschist, originally a pelite, and the second is a light grey to black, massive and hard rock, informally called "greyfels". The greyfels occurs as bands, 2-200 cm thick, in the grey micaschists, and probably represent calcareous sandstone beds in shale. The whole sequence was initially a sandstone-shale sequence, probably with a Palaeozoic depositional age.

The micaschists consist essentially of phengite and quartz, locally with minor lawsonite, chloritoid, chlorite and graphite. The greyfels shows two different mineral assemblages; the common variety consists mainly of lawsonite and quartz, with minor jadeite, carbonate, phengite and chlorite. The rare, but more significant, mineral assemblage in the greyfels is jadeite + chloritoid + glaucophane + lawsonite + phengite + quartz. The jadeite + chloritoid subassemblage in this location is apparently unique in the world and tightly constrains the P-T conditions of the blueschist-facies metamorphism.

Unfortunately, it is not easy to identify the minerals in these rocks by hand lens. A few clues: the black (rarely pinkish) spots in the greyfels, which might be mistaken for chloritoid, are in fact lawsonite. The common rusty red spots in the greyfels are either the reddish brown alteration products of a carbonate (ankerite?) or reddish brown oxychlorite. Chloritoid may occasionally be recognised in the micaschists as splaying aggregates of long prismatic crystals. The greyfels' layers, with jadeite + chloritoid + glaucophane + lawsonite subassemblages (4892, 4893), will be pointed out in the road section.

Mineral compositions, phase relationships and P-T conditions in the Kocasu sequence

The petrology of the blueschist metasediments east of Orhaneli is described in Okay (2002). Okay and Kelley (1994) have described the western part of the blueschist metaclastic belt around the Kocasu Valley in the west, which shows slight lithological and petrologic differences from that of the Orhaneli area.

Mineral compositions and P-T conditions

All the analysed jadeites contain over 85-mol% jadeite component, the rest is largely aegerine (1-7%). Sodic amphiboles from greyschists are glaucophane-ferroglaucophane solid solutions, with very minor ferric iron and calcium, as shown by the Ca/(Ca+Na) ratios less than 0.01. There is very little zoning in the sodic amphiboles. Lawsonite compositions are close to the ideal structural formula, with only minor substitution of Al by Fe^{3+}. Chloritoids are Fe^{2+}-rich, with $Fe^{2+}/(Fe^{2+}+Mg)$ ratios of over 0.84. They show no zoning and contain minor Mn and Fe^{3+}. The maximum Si content of the analysed phengites is 3.56 per formula unit (on the basis of 11 oxygens). Chlorite shows a range of Fe/(Fe+Mg) ratios (0.45 to 0.75), and is richer in Fe and Al compared to the chlorite from the metabasites of the same metamorphic grade.

The jadeite + paragonite + quartz assemblage in the Orhaneli region constrains the pressure between 12 and 25 kbars by the reactions (Figure 14)

Albite = jadeite + quartz
Paragonite = jadeite + kyanite + H_2O
Quartz = coesite

Phengites with up to 3.56 Si f.u. in the greyschists indicate minimum pressures of 14 kbar, according to Massone & Schreyer's (1987) phengite geobarometer. The jadeite + chloritoid + glaucophane + quartz mineral assemblage places tight constraints on the metamorphic pressure, pointing to a pressure of about 24 kbar (Figure 14). A similar pressure estimate is obtained from the chloritoid + glaucophane + paragonite + chlorite + quartz mineral assemblage, through the pressure sensitive equilibrium reaction (cf. Theye & Seidel, 1991):

Chloritoid + glaucophane + H_2O = paragonite + chlorite + quartz.

The stability of lawsonite and jadeite, a paragenesis observed in some greyschists in the Orhaneli area, gives a maximum temperature of 560°C at 20 kbar (Figure 13). Minimum temperatures of 420°C at 22 kbar are given by the stable coexistence of chloritoid and glaucophane (Figure 14):

Chloritoid + glaucophane + H_2O = jadeite + quartz + chlorite.

The transition from lawsonite-blueschist facies to epidote-blueschist and eclogite facies occurs between 450 and 500°C. The P-T conditions for

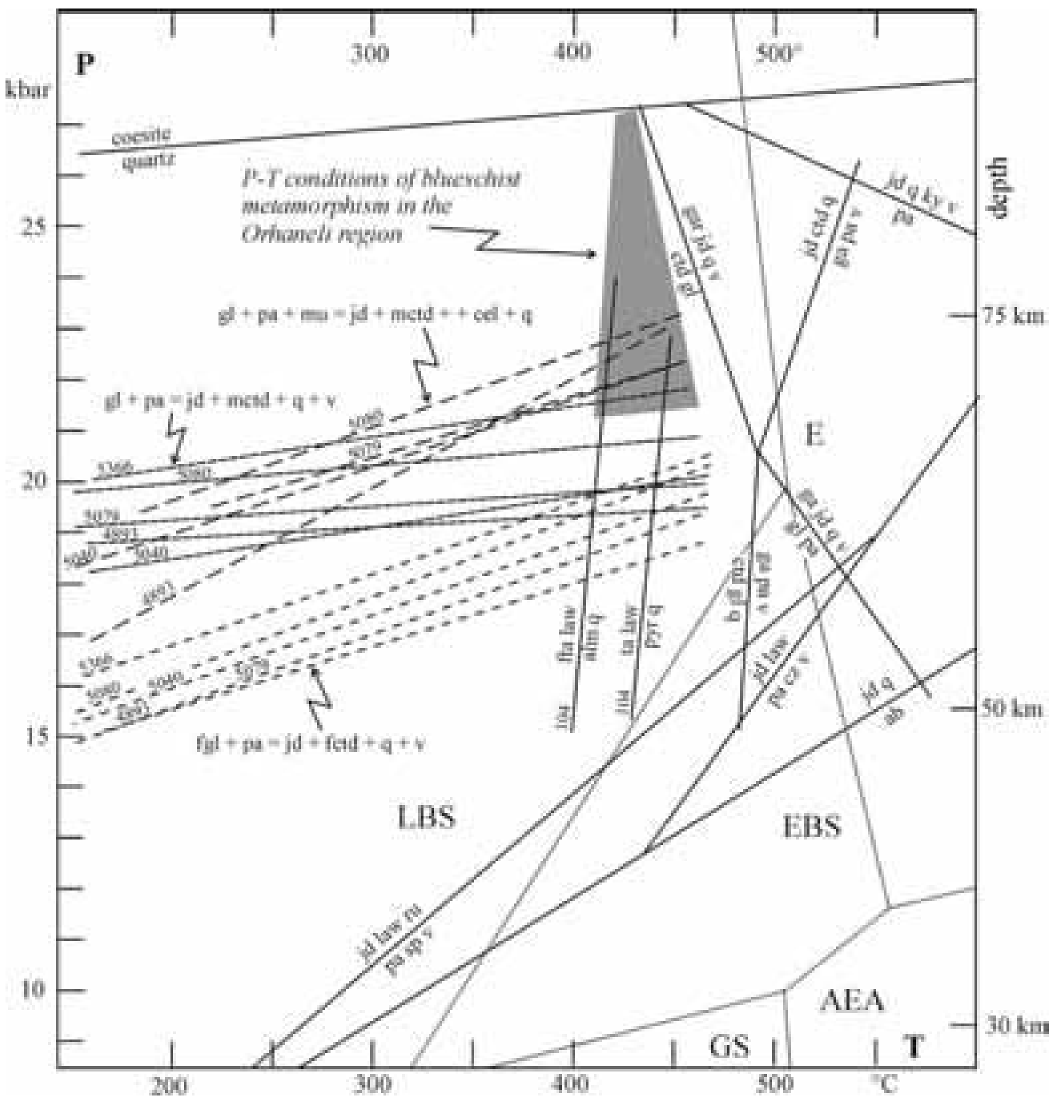

Figure 14 - Pressure-temperature diagram showing equilibria relevant to the estimation of the P-T conditions of the Orhaneli greyschists. Facies boundaries are after Evans (1990); LBS, lawsonite blueschist; EPS, epidote blueschist; E, eclogite; AEA, albite-epidote amphibolite; GS, greenschist facies. All reactions were calculated using Powell and Holland's (1988) and Holland & Powell's (1998) THERMOCALC. The garnet-forming equilibria represent an average of the ferrous and magnesian end member reactions for almandine, and pyrope activities of 0.26 and 0.00061, respectively, and the data from sample 5080. As paragonite does not occur with the jadeite-chloritoid-sodic amphibole subassemblage, the dashed reaction lines in the Figure involving these minerals provide minimum pressure estimates. Abbreviations: ab, albite; clin, clinochlore; coe, coesite; ctd, chloritoid; cz, clinozoisite; di, diopside; fctd, Fe-chloritoid; fgl, ferroglaucophane; fta, ferrotalc; ga, garnet; gl, glaucophane; jd, jadeite; ky, kyanite; law, lawsonite; mctd, Mg-chloritoid pa, paragonite; q, quartz; ru, rutile; sa, sodic amphibole; sp, sphene; ta, talc; v, H_2O.

eclogite- and epidote-blueschist facies rocks from the Cyclades with garnet, omphacite and epidote paragenesis in metabasites, were 470 ± 30°C and 15 ± 3 kbar (e.g. Schliestedt, 1986; Okrusch & Bröcker, 1990). The temperatures in the Orhaneli region, where the metabasic mineral paragenesis is sodic amphibole + lawsonite generally without epidote, must therefore have been less than 450°C. Epidote is a rare and probably secondary mineral in the Orhaneli region, and it is generally found in altered greyschists associated with albite and chlorite.

Taking these factors into account, I estimate that P-T conditions of blueschist metamorphism in the Orhaneli area were 430 ± 30°C and 24 ± 3 kbar (Figure 14).

Stop 2.5:

Panoramic view: Blueschist metasediments and the overlying blueschist marbles

Locality: On the road between Orhaneli and Keles, near the village of Kabaklar. 11.2 km after Orhaneli (Figure 13).

After seeing the road section we board the minibus at 5.9 km and drive eastward. The road section exposes further blueschist micaschists; eastward there are also marble bands and boudins surrounded by schists, starting at 6.5 km. These marble bands were probably original limestone intercalations in the upper parts of the Kocasu sequence. However, because of the deformation and the competence contrast between the schist and marble, most marble horizons are boudinaged and show sheared contacts with the micaschists. Most of this shearing is post-metamorphic. At the junction at the 7th km, we take the road on the left and pass through Belenoluk at 7.6 km. After the village there is another junction at 8.2 km; we again take the road on the left, which climbs up a hill. Then we drive down a small valley with springs and, invariably, with sheep herds and sheep dogs. This small spring leads to the major Kocasu River.

At 11.2 km there is a good view of the deeply-incised Kocasu valley. The northern part of the Kocasu Valley is made up of massive blueschist marbles, several hundred meters thick; the blueschist metasedimentary sequence, which we have been crossing, dips under the marbles. The marble occupies the core of a major east-west trending syncline (Figure 13). Below us there is the village of Kabaklar. We will stop briefly to look at this view.

Stop 2.6:

Jadeitite

Locality: On the road between Orhaneli and the village of Belenoluk, east of Orhaneli; immediately south of the village of Kabaklar. Between 12.4 and 12.5 km after Orhaneli (5074, 5251, 5359) (Figure 12).

Immediately after the village of Kabaklar we will stop and study the road cut on the right. The dark grey phyllites are made up essentially of phengite (80% of the mode) with minor chloritoid and graphite (5073). 100 m farther on we come to an interesting outcrop. In this outcrop there are two types of rock. The first one is composed mainly of jadeite (over 80 % of the mode) with minor quartz, phengite and oxychlorite. Jadeite forms splaying crystals, 2-3 mm large, and can be recognized by a hand lens. The second type has a granular texture and is composed of jadeite + lawsonite + quartz. The 2 mm long greenish grey crystals in the rock are altered jadeite. The origin of these rocks is enigmatic.

Stop 2.7:

Jadeite - Chloritoid - Glaucophane schists

Locality: On the road between Orhaneli and the village of Belenviran, east of Orhaneli. 17.0 km after Orhaneli (5080, 5252, 5360) (Figure 13).

After the jadeitite stop the road continues southward, descending into the Kocasu valley and passing through poorly exposed metasediments and marble. After crossing the Kocasu valley at 15.5 km, the road starts climbing up towards Keles. Along this section of the road there are micaschists and jadeite-chloritoid-glaucophane felses. We will stop briefly near the top of the hill to look at the metasediments. One very fresh jadeite-chloritoid-glaucophane fels occurs as a 15-cm-thick, hard band amidst schistose black micaschists. The elongated black crystals of glaucophane, defining a strong lineation, are visible to the naked eye. The mineral assemblage in this rock is jadeite + chloritoid + glaucophane + lawsonite + phengite + quartz. 30 m farther on there are dark to light schists of jadeite, lawsonite and quartz, with minor phengite and graphite. Lawsonite forms the dark equant grains visible through a hand lens.

We drive towards Keles for about two kilometres more. When we reach the top of the plateau we can observe the gently undulating Neogene topography extending eastward towards Keles. This bears a testimony to the strong post-Miocene uplift, which affected the region of Orhaneli.

Optional Stop 2.8:

Jadeite - Fels

Locality: On the road between Orhaneli and Keles, 700 m north of the village of Dedeler (5693).

Folded, light grey micaschists with fresh jadeite porphyroblasts, up to 4 mm across, occur in the road-section. Jadeite is accompanied by quartz and phengite, with minor lawsonite and secondary chlorite.

Optional Stop 2.9:
Jadeite-chloritoid-glaucophane schist and jadeite - Fels

Locality: On the road between Orhaneli and Keles, 1 km west of the village of Harmanalani (5681).

Just before we enter the Neogene cover near Keles, there are good roadside exposures of greyschists and jadeite fels. The greyschists consist of jadeite, quartz, pale blue glaucophane, pale green chloritoid, phengite, secondary chlorite and albite, whereas the jadeite-fels is made up by jadeite, quartz and phengite, with minor glaucophane and lawsonite.

After this stop we cross into the Neogene, made up of lacustrine to fluviatile sandstone, shale, limestone, conglomerate, tuff and volcanic rocks. East of the village of Harmanalani there is a large lignite coal mine. From the village of Harmanalani we drive within the Neogene to Keles, and then take the road to Bursa.

Optional Stop 2.10:
Chloritoid schist

Locality: On the road between Keles and Bursa, 1.5 km south of the village of Barakli (5510).

In regions east of Keles the jadeite- and glaucophane-bearing greyschists are overprinted by a second phase of regional metamorphism, this time of low pressure - high temperature type. High-pressure minerals, such as jadeite, lawsonite and glaucophane, have been destroyed. The grade of LP/HT metamorphism increases eastward, and 10 km northeast of Keles andalusite and cordierite have formed in the greyschists. This second phase of regional metamorphism is probably of Eocene age. I am currently working on this problem.

In this stop, we see the same greyschists which we have been driving through since Orhaneli. But in this locality none of the HP/LT minerals are extant. Chloritoid accompanied by quartz, white mica and chlorite are the main minerals. There are only pseudomorphs after glaucophane and, possibly, also after jadeite.

On the road from Keles to Bursa there are magnificent views of the Uludag range to the north, with the Mesozoic marbles forming an imposing, steeply dipping, tabular body (Figure 10). The marbles are intruded by an elongated granitoid with magmatic foliation, aligned parallel to the suture zone. Farther on we cross a small peridotite body forming the eastern elongation of the Burhanlar peridotite. Then we are back in the Nilüfer Formation, and reach the Orhaneli-Bursa road near the water reservoir.

DAY 3

Tuesday, August 31st, 2004
Bursa-Orhaneli-Harmancik-Tavsanli-Bozüyük-Bursa

In the morning we drive directly south from Bursa, passing through Orhaneli in the direction of Harmancik. The road south of Orhaneli passes through the poorly-exposed blueschist facies metasediments and marble. Our first stop in this stretch will be at the contact of the Orhaneli granodiorite, one of the Eocene granodiorites, which intrudes the blueschist sequence.

Stop 3.1:
The northern contact of the Orhaneli granodiorite

Locality: On the Orhaneli-Harmancik road, road-cut 5.8 km south of Orhaneli (3876) (Figure 13).

Here on the road cut we can study the northern contact of the Orhaneli granodiorite, which has intruded the blueschist metaclastic rocks. None of the blueschist mineralogy survives in the hornfelses, which at this locality consist mainly of biotite, quartz and plagioclase.

Orhaneli Granodiorite – One of the Eocene Plutons of the Tavsanli Zone

An unusual feature of the Tavsanli Zone is a number of Early Eocene granodiorites, which intrude the blueschists, as well as the overlying ultramafic sheets. There are six such plutons ranging from the Orhaneli granodiorite in the west to the Sivrihisar granodiorite 250 km to the east. They have a similar geochemistry and similar ages. Obviously their formation is related to the thermal perturbations in the upper mantle and crust during the exhumation of the blueschists. One possibility is that they were formed due to slab-break off during the transition from subduction to collision, a mechanism introduced to explain post-tectonic intrusions near suture zones, such as the Bergell granodiorite in the Alps (Davies and Blanckenberg, 1995).

Like the other Eocene granodiorites, the Orhaneli granodiorite is undeformed and post-dates the Palaeocene-Eocene continental collision between the Sakarya Zone and the Anatolide-Tauride Block. The circular Orhaneli intrusion occupies the centre of a major dome, possibly produced during the intrusion. Before the intrusion the Burhan and Harmancik peridotites probably formed a single body (Figure 5). The petrology and geochemistry of the Orhaneli

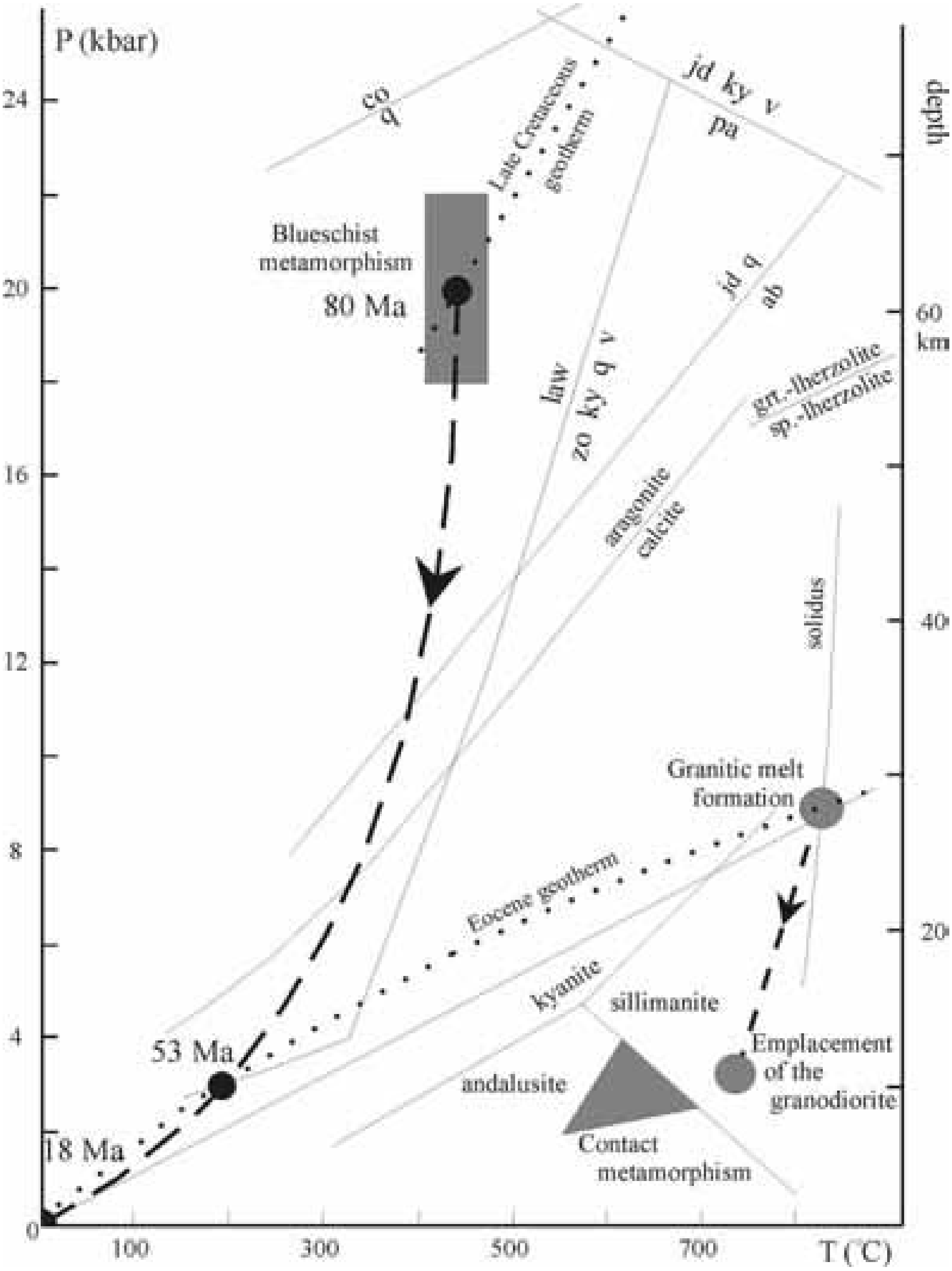

Figure 15 - Pressure-temperature diagram showing the P-T-t path followed by the blueschists in the Orhaneli-Keles area, the P-T conditions of emplacement of the Orhaneli granodiorite, and relevant equilibria. The two dotted lines show possible isotherms in the continental crust of the Orhaneli area for 80 and 53 Ma (modified from Okay et al., 1998).

pluton have been investigated by Harris et al. (1994). It is a homogeneous, medium-grained granodiorite made up of plagioclase, quartz, biotite, alkali feldspar and hornblende. It has a uniform, metaluminous composition with silica contents of 63-69%. Selective LIL trace-element enrichment in the granodiorites suggests a typical calc-alkaline affinity. The absence of Y and HREE depletion precludes garnet as a significant restite phase, thus indicating melt formation at pressures less than 10 kbar. Mantle-derived melts are required in the petrogenesis of these magmas, either as parental magmas -- for the granodiorites to evolve by fractionation processes in shallow magma chambers, or as a convective heat source for crustal anatexis.

The Orhaneli pluton has a contact aureole marked by the destruction of the blueschist mineral assemblages and by the formation of andalusite and cordierite in the inner contact aureole. The contact aureole mineral assemblages, as well as the Al-content of the hornblende in the granodiorite, indicate that the Orhaneli granodiorite was emplaced at a pressure of 3 ± 1 kbar (Harris et al., 1994).

Ar/Ar laser spot analysis on biotite from the Orhaneli granodiorite (4419A) yielded a good isochron age of 52.6 ± 0.4 Ma, which is compatible with a biotite isochron of 52.4 ± 1.4 Ma from a hornfels (4410) two meters from the granodiorite contact. These ages suggest rapid cooling after intrusion at a high level in the crust in the Early Eocene. A slightly younger isochron age of 47.8 ± 0.4 Ma was obtained from biotite and hornblende grains from the higher-level Topuk granodiorite (4427A).

The age and contact relations of the Eocene granodiorites put tight restrictions on the exhumation of the blueschists, and show that the blueschists were at or near the earth’s surface by the Eocene (Figure 15).

Optional Stop 3.2:

Orhaneli granodiorite

Locality: Orhaneli-Harmancik road, 9.3 km away from Orhaneli (Figure 13).

In this stop we can study the lithological and petrographical features of the Orhaneli granodiorite. It consists of quartz, feldspar (largely plagioclase), biotite and hornblende. The granodiorite does not show any significant macroscopic or microscopic deformation. It is cut by aplite veins and contains rare xenoliths.

The road continues for several kilometres more in the granodiorite. On the left (east) one can make out the contact between the granodiorite, which forms the low-lying ground, and the blueschist marbles, which make up the hills on the horizon. The road eventually cuts this southeastern contact south of Emirköy. At the granodiorite-marble contact there are diopside-garnet-wollastonite skarns. If there is a general demand (and time) we can stop and look at these skarn deposits in the marble. The contact here is steep; the granodiorite dips at 70-80° under the marbles. The marbles are also thin in this locality, and are faulted against a sliver of accretionary complex and a major body of peridotite (Figure 5). The road enters the Harmancik peridotite at 20.5 km and continues in these monotonous mantle rocks until 33.0 km. The peridotite is made up of massive dunite and harzburgite; the Harmancik chromite mines are located in this peridotite body, mainly in the dunites. There are also several magnesite mines in the region; the white dumps of magnesite can be seen on the right at 24.7 km. The chromite mining activity is dying out, mainly due to the exhaustion of the known reserves.

33.0 km after Orhaneli we reach a major road junction with the road between Tavsanli and Balikesir. We take the road to the right -- towards Balikesir. Along this road the Cretaceous accretionary complex extends for miles (Figure 7). We will investigate only the first 5-6 km of this road.

Optional Stop 3.3:

Accretionary complex with incipient blueschist-facies metamorphism

Locality: Balikesir-Tavsanli road; 35.1 km after Orhaneli (4660) (Figure 16).

After about one kilometre from the Balikesir-Orhaneli-Tavsanli junction the peridotite is truncated by a steeply dipping post-Miocene fault and we enter the accretionary complex (Figure 16). This Cretaceous accretionary complex, named the Ovacik Complex, is a very widespread and typical tectonostratigraphic unit in the Tavsanli Zone. Unlike most other accretionary complexes in the world, the Ovacik Complex contains little clastic sedimentary rock, but is mainly composed of basalt, radiolarian chert and pelagic shale.

In this Stop we see a typical outcrop of the accretionary complex, consisting of red and green shale with thin limestone beds, tuff and basalt. The shales and tuffs, on account of their fine grain size,

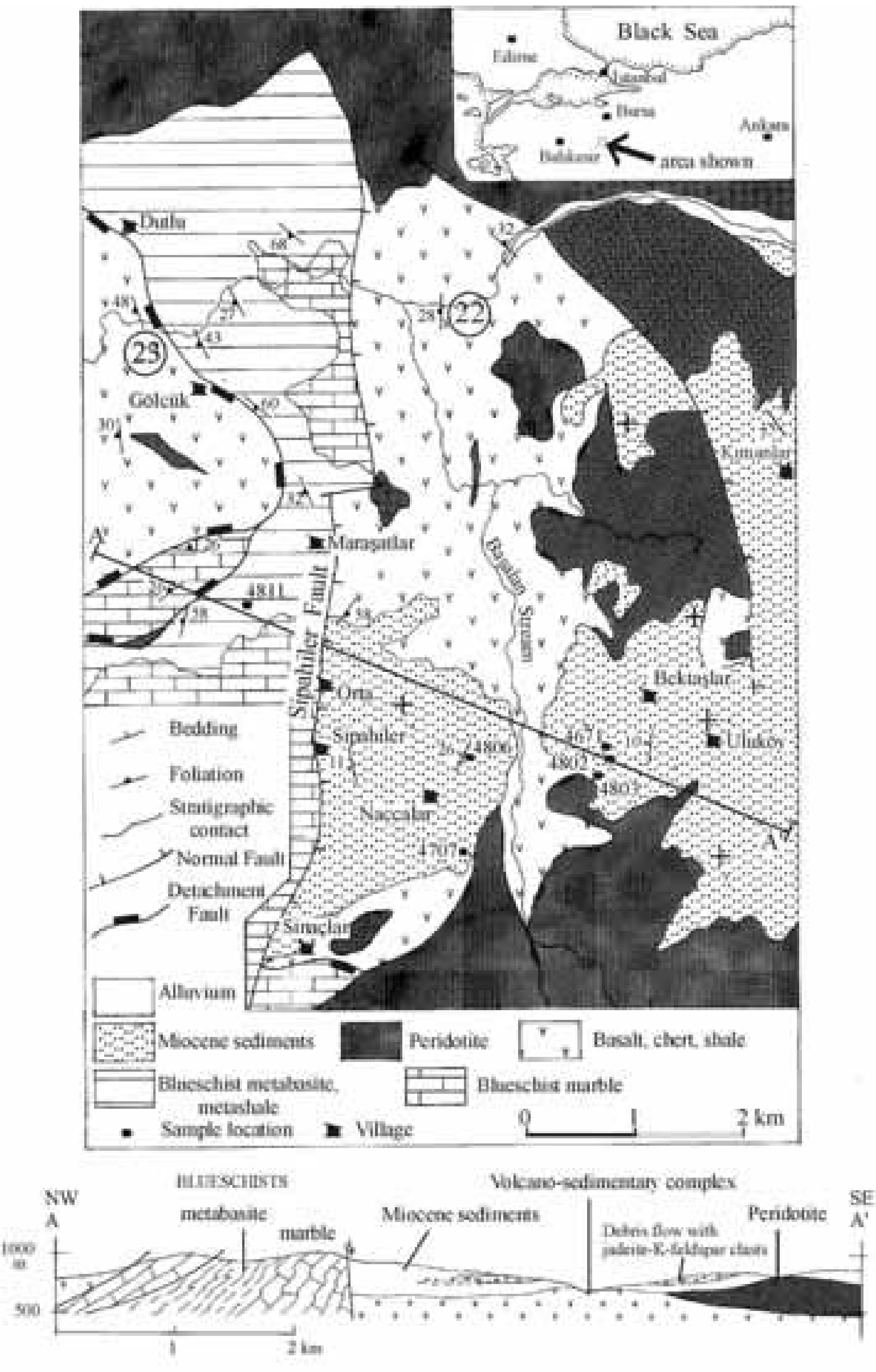

Figure 16 - Geological map and cross-section of the region west of Harmancik (after Okay, 1997).

show a strong foliation; in contrast, the basalt is not penetratively deformed. Except for spilitization, which imparts a green colour, the basalt also appears unmetamorphosed. But this is deceptive; in thin section the basalt is seen to consist of lawsonite, sodic pyroxene pseudomorphs after augite, chlorite, quartz and leucoxene (4660). The basalt is cut by narrow veins of aragonite and albite.

On the opposite side of the road there is a 100-m- long recrystallized limestone block. Such blocks occur as olistoliths in the basaltic agglomerates, possibly large slide blocks from seamounts.

Stop 3.4:

The Accretionary Complex and the blueschists

Locality: Balikesir-Tavsanli road, 37.9 km after Orhaneli (4775, 4889, 5357) (Figure 16).

After stop 3.3. we board the minibus and drive west, initially among the basalts of the accretionary complex, about one kilometre later another post-Miocene normal fault (Sipahiler Fault), trending north-south, has juxtaposed the accretionary complex with the blueschist marbles (Figure 16). We will drive through a well-exposed road section and stop at a particularly good outcrop of the accretionary complex. This road cut is particularly instructive as it shows the lithological and structural features of the accretionary complex (Figure 17). The centrepiece is a 20-m-thick red radiolarian chert. The radiolaria, deformed into ellipses, is visible through a hand lens. The age of the chert is not known, but is probably in the range of Late Triassic (Norian)-Early Cretaceous. It is stratigraphically underlain by foliated fine-grained basalt, about 2 m thick. The foliated basalt includes boudins of less-deformed, coarser-grained basalt. A sample from one boudin (5357B) contains sodic pyroxene pseudomorphs after augite, lawsonite, albite and chlorite. The basalt is tectonically underlain by schistose serpentinite, about one metre thick. Below the serpentinite there are several sheets of basalt separated by southwest-dipping shear zones. They also consist of sodic pyroxene, lawsonite, albite and chlorite with minor sodic amphibole (5357C, D). One of the basalt sheets contains a recrystallized limestone block, about 0.5 m long On the northwestern side the radiolarian chert is faulted against an amphibole- rock, of actinolite, partially to completely replaced by sodic amphibole with minor lawsonite (5357A).

This intense faulting and juxtaposition of different lithologies are the characteristic structural feature of the Ovacik Complex.

In this outcrop we have tectonic slices of the Neo-Tethyan ocean floor. In the Ankara region radiolarian cherts in the accretionary complex range in age from Late Triassic (Norian) to mid-Cretaceous (Baragin and Tekin, 1996), reflecting the age span of the Neo-Tethyan ocean.

After this stop if there is time, we will walk back about one kilometre along the road towards the east. Along

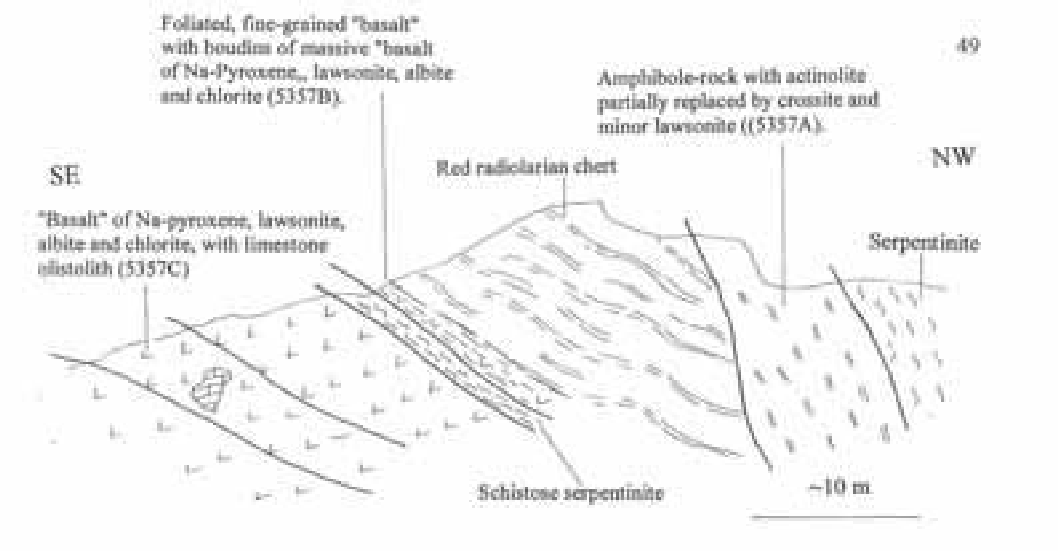

Figure 17 - Field sketch of the incipiently metamorphosed accretionary complex on the road between Harmancik and Dursunbey (Stop 3.4).

this road section the accretionary complex, showing various degrees of blueschist-facies metamorphism and penetrative deformation, has been tectonically intercalated with grey-quartz micaschists, possibly equivalent to those we saw east of Orhaneli. Most of the faults along this section dip at intermediate angles (40-50°) to the west and emplace lower grade, less recrystallized blueschists over higher-grade, more strongly recrystallized blueschists. In this respect they resemble normal faults.

The grey micaschists in this section consist mainly of quartz, phengite and chlorite with minor lawsonite (4782A). The more massive bands in the micaschists are made up of lawsonite and quartz, locally with sodic pyroxene (4782B, C). The metabasites in the more recrystallized accretionary complex contain sodic amphibole and lawsonite, with minor chlorite, quartz and aragonite (4783). Aragonite is partly replaced by calcite. The metabasites appear blue on account of crossite, which makes up nearly half of the mode. The blueschist marbles, which occur at the base of this tectonic stack, underlie the grey micaschists.

After stop 3.4 we board the bus and turn back in the direction of Tavsanli. After a few kilometres on this road, but before reaching the Orhaneli-Balikesir-Tavsanli junction, we turn south and take the village road to Marasatlar. The meter is set to zero on the junction to the village road.
The village road climbs through the accretionary complex, which consists mainly of basalt (80%) with minor red and green shale, red radiolarian chert, limestone and serpentinite (Figure 16). After the village of Marasatlar the road runs close to the Sipahiler fault and we see the marbles and calcschists (4663), which we observed in stop 23. After about one kilometre from the village of Marasatlar the road enters the poorly exposed Neogene sequence and passes through the villages of Orta and Sipahiler. The three small villages of Marasatlar, Orta and Sipahiler are aligned parallel to the Sipahiler fault, which forms the western boundary of the Neogene sequence (Figure 20). After the village of Orta (at 4.9 km) there is a good view of the Neogene basin to the east.

Optional Stop 3.5:
the Neogene sequence

Locality: A few hundred meters south of the village of Sipahiler; 5.8 km after the road junction (4666, 4693) (Figure 16).

If time allows we might look at the Neogene limnic sandy limestone exposed in a small outcrop south of the village of Sipahiler. The significance of this optional stop is to illustrate a common Neogene lithology, which contrasts starkly with the underlying Neogene debris flows of the next stop. The terrigeneous Neogene sediments, mainly sandstone, limestone, marl, acidic tuff, shale and lignite, cover large areas east of Orhaneli. They have been dated paleontologically as Middle Miocene (Kavusan, 1984).

Stop 3.6:
Neogene limnic debris flows with blueschist, ophiolite and jade clasts

Locality: On the road between the villages of Sipahiler and Bektaslar;, between 7.0 and 7.9 km after the road junction (4667-4668, 4807-4806 (Figure 16).

After Sipahiler we turn left and follow a small side creek, which joins the Basalan stream to the east. After driving for 0.7 km we leave the minibus and walk downhill for about 900 metres, studying the road section, which exposes a remarkable sequence of Miocene breccias, several hundred metres thick. The poorly consolidated breccia consists of very poorly sorted, matrix-supported blocks of blueschist, peridotite, marble and “jade” in a mudstone/sandstone matrix. The size of the clasts ranges from three metres down to a few millimetres, with “jade” forming the largest blocks. The very poor sorting and chaotic mixing of the blocks, and lack of internal layering, suggest that the breccias represent debris flows (Okay, 1997). The deformation in the debris flows must be syn-sedimentary.
The white “jade” blocks, well exposed in one debris flow outcrop, consists essentially of jadeite, albite and magmatic aegerine with minor lawsonite and phengite (4806C). This is the only rock I know in which jadeite and albite are in apparent equilibrium. This constrains the upper limit of the metamorphic pressure by the albite = jadeite + quartz reaction line (Okay, 1997).

Origin of the Miocene debris flows

Two lines of evidence indicate that the debris flow, and hence the jadeite-K-feldspar blocks, came from west of the Sipahiler fault, which forms the contact between the Miocene rocks and the blueschists (Figure 16). First, all the different block rock types, with the exception of “jades”, can be foundd in the region west of the Sipahiler fault, whereas the blueschists are not exposed to the east of the fault. Second, the breccias are restricted to within three kilometres of the Sipahiler fault, and are not reported in the extensive Miocene deposits from farther east. The debris flows may have been triggered by Miocene earthquake activity along the Sipahiler fault. Similar earthquake-generated debris flows have been described in active faults. However, a careful search for *in situ* “jades” to the west of the Sipahiler fault was fruitless, suggesting that such rocks are completely eroded.

We will board the minibus at the Basalan stream and drive towards the village of Bektaslar. The road passes through the Neogene limestone and conglomerate (4670). Near the Bektaslar village there are good views towards Uludag in the north (9.3 km).

Stop 3.7:

Jadeite-K-feldspar “jades”

Locality. On the road between Bektaslar and Uluköy; 9.7 km after the road junction. (4671, 4802, 5358) (Figure 16).

We will park the minibus 400 m after Bektaslar and walk southwest to find the “jades”. Neogene sandy and pebbly limestones and microconglomerates with clasts of blueschist and peridotite are exposed along this path. We will walk for about 700 m among the Neogene sediments. In this area, like everywhere else in northwest Turkey, Neogene sediments form a relatively flat-lying area suitable for farming. The farmers have cleared the Neogene fields by carrying large blocks to the margins of their fields to form stone walls. In these stone walls, as well as in the fields, there are blocks of red radiolarian chert, microgabbro, basalt, blueschist, and listvenite, as well as purple to white “jade”. Although there are no outcrops there is little doubt (at least in my mind) that these blocks are derived from the same or a similar debris flow to that we saw in the last stop. The close association of these blocks with the Neogene pebbly limestones is the main argument for a Miocene age of the debris flows. The “jade” forms very tough, white, pale green to purple rocks with a very fine-grained, homogeneous texture. The “jade” blocks from this locality are petrologically different from those we saw in stop 3.6, in that they consist essentially of jadeite + K-feldspar rather than jadeite + albite. A petrographic study of 30 individual “jade” blocks from this locality has indicated a fairly consistent mineral assemblage of jadeite, K-feldspar, lawsonite and aegerine, which together make up over 80 % of the mode with very minor amounts of monazite, phengite and secondary sericite. Because of the extremely fine grain size, the constituent minerals are only visible through a high power microscope.

Jadeite in these rocks contains over 90% jadeite end-member and many crystals are essentially pure end-member jadeite (Okay, 1997). The striking pink colour of many jadeite-K-feldspar rocks comes from jadeite, which is commonly pale brownish-pink in thin-section. The origin of the colour of jadeite is unclear, but may be related to its trace elements. Aegerine, which is partly replaced by jadeite, has over 90 % aegerine end-member; pyroxenes with intermediate jadeite contents appear not to have formed during the HP/LT metamorphism. K-feldspar always forms cryptocrytalline aggregates and is locally replaced by sericite. Compositionally it is also very pure, with very minor (<1 %) albite and anorthite components. Albite and lawsonite are also close to their ideal end-member compositions. The composition of the sericitic white micas with low Si pfu (per formula unit) indicates that, in contrast to the phengite with 3.45 Si pfu, they formed during the low-pressure alteration of K-feldspar.

I could not find out who first discovered the ornamental value of these purple blocks, which lie in such an isolated spot. Whoever it was that discovered it, two lorry loads of “jade” blocks have been taken from this locality and exported to Western Europe and USA. Little “jade” is left behind and soon this “jade” will be an extinct rock species to be found in some mineralogical museums or encountered as ornamental artefacts. Considering that it started life as a phonolite, its transformation to “jade” must have required a set of extraordinary circumstances not likely to be encountered again in the earth’s history.

The origin of “jade” and the significance of the jadeite-K-feldspar mineral assemblage

The strongest clue for the origin of these rocks lies in their texture, which was inherited from a volcanic protolith. This is beautifully illustrated in Figure 4a in Okay (1997), where former nepheline micro-phenocrysts, recognised by their square and hexagonal shapes, are set in a groundmass of jadeite and very fine-grained aggregates (< 0.02 mm) of K-feldspar. Nepheline is also pseudomorphed by jadeite and cryptocrytalline aggregates of K-feldspar. Reddish-brown to green aegerine is the sole surviving magmatic mineral. The association of nepheline with aegerine suggests a phonolitic parentage. This is supported by the whole rock and trace element chemistry (Okay, 1997), which is similar to that of phonolites (e.g., Le Maitre, 1976; Cox et al., 1979). Thus, the geochemistry and petrography of the rock both suggest that it must have initially consisted mainly of aegerine, nepheline and sanidine/anorthoclase. The following metamorphic reactions are inferred:

Sanidine/anorthoclase + H_2O = K-feldspar + jadeite + lawsonite + quartz

Nepheline + quartz = jadeite + K-feldspar

The initial K-feldspar must have been sanidine or anorthoclase. The recrystallisation of K-feldspar to cryptocrytalline aggregates may have been due to conversion of sanidine to microcline. The close association of K-feldspar, jadeite and lawsonite indicates that this mineral paragenesis is stable in blueschist-facies conditions. The rarity of K-feldspar in blueschist-facies rocks is due to the unusual rock compositions required to form this mineral. Unlike albite, K-feldspar is stable at crustal temperatures up to 25 kbar (Seki and Kennedy, 1964; Huang and Wyllie, 1974), at which point it reacts with H_2O to form K-feldspar-hydrate.

The P-T conditions of the metamorphism of the “jades” are poorly constrained. A reasonable estimate is 8 ± 2 kbar and 300 ± 50°C based on the presence of jadeite, albite and Si-content of phengite (Okay, 1997).

After seeing the “jades” we will return to the minibus and drive back to the main Balikesir-Tavsanli road.

The Harmacik-Tavsanli-Gümüsyeniköy road

From Stop 3.7 there will be a long drive of about 80 km to Stop 3.8 in the village of Gümüsyeniköy, northeast of Tavsanli (Figure 5). We set the meter to zero at the Orhaneli-Balikesir-Tavsanli triple junction. After 2.5 km we enter the town of Harmancik. Flat-lying Neogene sandstones, conglomerates and limestones form a ledge at the exit of Harmancik. Over the next ten kilometres we’re crossing the Harmancik Neogene basin (Figure 5). The only outcrops along the road are the white acitic tuffs of Miocene age. Peridotite emerges under the Neogene cover at 12.4 km, and for the next ten kilometres the road crosses monotonous harzburgites. At 23.2 km we enter another Neogene basin (Figure 5). This basin contains large lignite deposits; some lignite mines can be seen at 26.2 km. There are good Neogene sections, mainly of white acidic tuffs, farther along the road. At the 40th km we come to the town of Tavsanli, driving past it in the direction of Kütahya, and passing good road cuts in the Neogene sediments. At 57.4 km we leave the main asphalt and turn left (north), taking a village road, signed as Cobanköy-Gümüsgölcük-Senlik. The road passes through the Neogene deposits with small lignite mines along the road. At 66.0 km we enter the village of Senlik and take the road to Egriöz, which is the road on the left at the village fountain. After about one kilometre from Senlik there are isolated outcrops of accretionary complex and peridotite, surrounded by Neogene sediments; however, the road passes mainly through Neogene conglomerate and sandstone. At 74.5 km there is a road junction; we follow the road to the left, which leads to the village of Gümüsyeniköy. Peridotite emerges under the Neogene cover at 77.2 km as the road descends to the Kocasu valley, the same river we saw on Stop 2.5. At 81.2 km we enter the village of Gümüsyeniköy, our base for Stop 3.8. There are remarkable outcrops of blueschists in the region between Gümüsyeniköy and Bozüyük, which, hopefully, will justify this long drive.

Stop 3.8:

Aragonitised limestones in the accretionary complex

Locality: One kilometre south of the village of Gümüsyeniköy, Tavsanli; 81.2 km after the Orhaneli-Balikesir-Tavsanli triple junction (475) (Figure 18).

We park the minibus near the village mosque of Gümüsyeniköy, and walk about a kilometre south of the village.

The village of Gümüsyeniköy sits in a large region of accretionary complex of basalt, red radiolarian chert, shale, bedded manganese deposits, serpentinite, talc and rare limestone, which show an incipient blueschist-facies metamorphism (Figure 18, Okay, 1982). Medium to thickly bedded, red limestones outcrop in small village quarries. In one of these quarries basaltic pillow lavas are seen to stratigraphically overlie the red limestones. These limestone beds are traceable for a few hundred meters along strike. A remarkable feature of these rocks is the prograde aragonitisation observed in the limestone beds. Aragonite appears to have nucleated in the centre of the limestone beds and has been growing towards its lower and upper surfaces, eating away the original micrite. In thin section the individual aragonite crystals are several centimetres across; commonly a single aragonite crystal occupies the whole of the thin section. Aragonitization appears to postdate the stylolites, which are subparallel to the bedding in the limestones. To the best of my knowledge this is the only locality of prograde aragonitization in the world; in all other occurrences aragonite has partially transformed back into calcite. The prograde aragonitization indicates very low metamorphic temperatures, possibly below 200°C, at pressures of above 7 kbar!

Optional Stop 3.9:

Lawsonite Zone blueschists and the accretionary complex

Locality: Between the villages of Ketenlik and Göynücek, Tavsanli; 500 m after the village of Ketenlik. 92.7 *km after the Orhaneli-Balikesir-Tavsanli triple junction. (507-509) (Figure 18).*

From Gümüsyeniköy we drive north, initially in the accretionary complex, recognisable from the red colour of the soil. At 83.8 km we enter proper blueschists, which structurally underlie the accretionary complex (Figure 18). The blueschists in this northeastern Tavsanli region consist of a sequence of intercalated metabasite, metachert, metashale and metagabbro bodies, of over two kilometres in thickness, named the Devlez Formation. Blue metabasites, consisting mainly of sodic amphibole and lawsonite, are the dominant lithology. This sequence rests on white, massive marbles (Inönü Marble), several kilometres in thickness. The large-scale structure in this region is a large, southward plunging synform, whose core is made up by the Devlez Formation (Figure 18). The blueschist-facies metaclastic rocks (the Kocasu Formation), which underlie the marble sequence in the Orhaneli area, are not exposed northeast of Tavsanli.

The road from Gümüsyeniköy continues for several kilometres among poorly exposed blueschists. At 89.6 km we come to a junction and take the road on the right. Farther on, at km 92.2, there is another junction; this time we follow the road to the left, towards the village of Ketenlik. A few hundred metres after the village of Ketenlik, we stop and walk for about 1.5 km along the road, studying the road section. In this section we will see the northern contact of a klippe of the accretionary complex, which lies over the blueschists of the Devlez Formation.

Immediately outside the village of Ketenlik the contact between the Devlez Formation and the accretionary complex is exposed. The village lies in the glaucophane-lawsonite blueschists of the Devlez Formation. These rocks give much better outcrops in the following stop. Here they are tectonically overlain by the accretionary complex consisting of basalt, red radiolarian chert and red shale, which show a foliation and a beginning of blueschist metamorphism. At the contact there is a small lens of serpentinite. The basalt consists mainly of lawsonite, sodic pyroxene, chlorite and leucoxene. Sodic pyroxene is pseudomorphous after igneous augite. The sodic amphibole, found here as blue stringers, is just starting to form. Such metabasites I have termed “lawsonite zone metabasites” and they constitute a stage in the prograde blueschist metamorphism in the Tavsanli Zone.

If time allows we can walk to the northern contact of the klippe of the accretionary complex at 94.5 km, and see the strikingly blue metabasites of the Devlez Formation under the klippe.

Stop 3.10:

The Blueschists of the Devlez Formation

Locality: Between the village of Göynücek and Dodurga, Tavsanli (Figure 18).

After driving for about 600 metres among the blueschists we enter white massive marbles at the base of the blueschists; he road passes through the marble for about one kilometre. There is a road junction at 96.1 km; we take the road to the left, and after driving through poorly exposed blueschists, enter the village of Göynücek at 98.7 km. There are good outcrops of the blueschists of the Devlez Formation after the village of Göynücek. At 100.8 km we can see from a distance the blueschist facies marbles, which cover a very large area and extend for 15 km northwards, right up to the Izmir-Ankara suture (Figure 5). There are good road sections of Devlez blueschists between 101.6-102.3 km, 103.2-103.5 km and at around 104.3 and 104.6 km. We will walk along at least one of these sections to see the petrological and structural aspects of the Devlez Formation. The mineralogy and petrology of the blueschists in this region is described in detail in Okay (1980a).

Stop 3.11:

The contact between the Devlez blueschists and the Inönü Marble

Locality: Between the villages of Göynücek and Dodurga; 107.4 km after the Orhaneli -Balikesir - Tavsanli triple junction (234) (Figure 18).

The road from Göynücek to Dodurga continues eastward in Devlez blueschists, crossing the core of a complex syncline (Figure 18). At 104.9 km we enter the underlying Inönü marbles and drive for about 2.5 km amidst the white marble. We reenter the overlying Devlez blueschists at 107.4 km. If there is time we can study the contact between the Devlez Formation and the Inönü Marble. At the contact there is a metaquartzite horizon, about 50 m thick. There is a common lineation and foliation

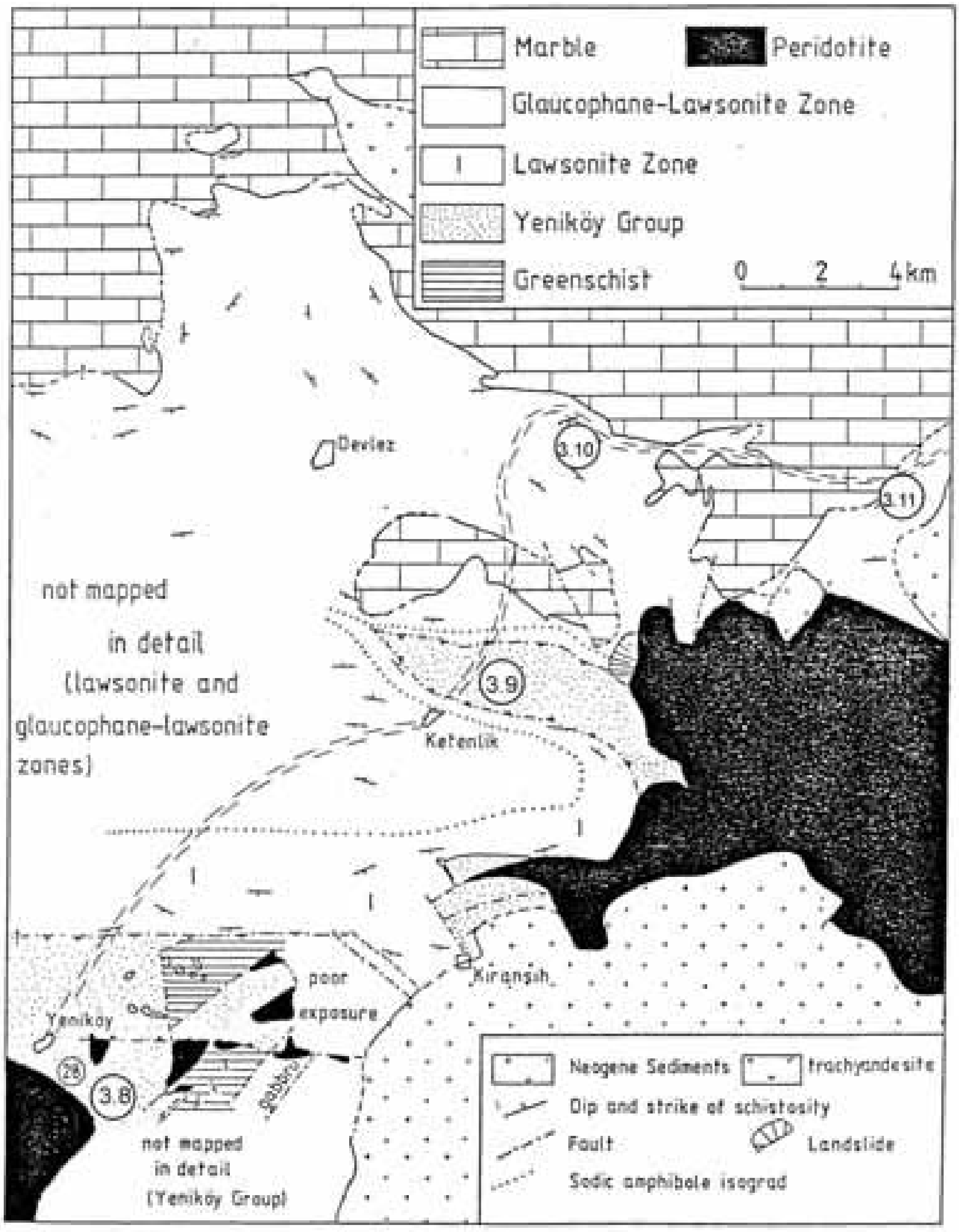

Figure 18 - Geological map of the region northeast of Tavsanli showing the location of Stops 3.8 to 3.11. For location see Figure 5 (Okay, 1981).

in the Devlez Formation and the underlying Inönü Marble. It is clear that the limestones were metamorphosed and deformed together with the overlying sequence of basic tuff, radiolarian chert and pelagic shale. It is also probable that the primary contact between these two formations was stratigraphic. One evidence for this is the presence of the quartzite horizon on top of the marbles, which can be traced for several kilometres along the contact.
From this contact eastward the overlying Devlez blueschists are well exposed until the 108th km, when the road enters the overlying Neogene sediments.

Optional Stop 3.12:

Tectonostratigraphy of the Tavsanli Zone.

Locality: Dodurga dam, between Dodurga and Bozüyük; 119.6 km after the Orhaneli-Balikesir-Tavsanli triple junction.

At 111.5 km the village road from Göynücek joins the main Dodurga road; there is a new fountain decorated with tiles at this junction. We turn left (north) and reach Dodurga at 116.4 km. There are Neogene sediments exposed along this road.
The Dodurga region is of historical interest, in that this area was the cradle of the Ottomans. In the 13th Century they started as a nomadic tribe grazing their sheep in the pastures of Dodurga and Domanic (20 km farther west) before forming an Empire. At this time this was a frontier region between the Byzantines in the west and the Anatolian Seljuks in the east. The region has changed little in terms of landscape or people's habitat.
The blueschist marbles extend behind Dodurga. After a few miles from Dodurga, at 119.6 km, there is a side road towards a small irrigation dam. The outcrops around the dam reveal in miniature the tectonostratigraphy of the Tavsanli Zone. Along the road towards the dam, there is a good section of blueschist metabasites, metatuffs and phyllites. These rocks are tectonically overlain by the accretionary complex of basalt, radiolarian chert and pelagic shale exposed on the eastern wall of the dam. Above the accretionary complex lies tectonically a peridotite body with a basal horizon of yellowish-brown silicified serpentinite.

The road between Dodurga and Bursa

From the Dodurga Dam there is a drive of about 15 km northwards towards Bozüyük. The first part of the road is in poorly exposed blueschist marble, schist and peridotite, and the second part in the Neogene. This region was studied by Servais (1982). One of the battles of the 1920-23 Turkish-Greek war took place near this road and there is a war cemetery for the fallen Turkish soldiers along the road (Intikam Tepe Sehitligi). Eleven kilometres after the Dodurga dam we pass through the large village of Saraycik; one kilometre before Bozüyük there is a good panoramic view to the north. Here we are on the northern margin of the Tavsanli Zone, and Bozüyük lies at the contact between the Sakarya and Tavsanli zones (Figure 5). The Izmir-Ankara suture in this region is marked by a post-Miocene fault, the Eskisehir fault, which forms the eastward extension of the suture fault we saw in the Stop 1. 9.

The hills behind Bozüyük are made up of a Carboniferous granitoid, which is thrust over the metabasite-marble-phyllite sequence of the Nilüfer Formation. Liassic Bayirköy Formation and the Late Jurassic Bilecik Limestone lie unconformably over the granite. Bilecik Limestone makes a ledge and is easily recognisable from this point. The Permo-Triassic metabasite-marble-phyllite sequence (Nilüfer Formation) crops out over large areas north of Bozüyük and north of Eskisehir.

At Bozüyük we join the main Eskisehir-Bursa road. From here Bursa is about 100 km away. The first 40 km of the road from Bozüyük to Bursa follows the valley created by the Eskisehir fault. Then the road turns northwest and crosses the Neogene basin of Inegöl, before reaching Bursa.

DAY 4

Wednesday, September 1st, 2004

In the morning we will pack our cases, say farewell to Bursa and drive west towards Bandirma. The road towards Bandirma follows a monotonous, rather featureless Neogene plain. In northwest Turkey virtually all major roads pass through Neogene landscapes, hiding the interesting geology.
After about 36 km along the Bandirma road we can glimpse Lake Apolyont on the left (south); it is only a few metres deep! There is a deteriorating bird sanctuary in Manyas Lake farther west (not visible from the main road). 57 km after Bursa we come to the Balikesir-Canakkale junction and take the road towards Canakkale. A few kilometres farther on we pass through the town of Karacabey. The region around Karacabey is famous for its red

onions, a delightful side dish when eaten with fish in autumn and winter. The stalls along the road near Karacabey sell these onions and other local produce.

The hilly coastal region north of Karacabey is made up of the metabasite-marble-phyllite sequence of the Nilüfer Formation (Figs. 3 and 19), wherein lies the eclogite lens that has yielded Late Triassic ages. To visit this locality we take the road to Bandirma and, about two kilometres after the second Balikesir-Canakkale junction, take a side road (next to Banvit) towards the villages of Ömerli and Erikli.

Stop 4.1:

Metabasites of the Nilüfer Formation

Locality: The road between the villages of Erikli and Yenice, Bandirma; between 11.0 km and 11.8 km after the exit from the main Bursa-Bandirma road (2054-2058) (Figure 19).

The Nilüfer Formation outcrops from beneath the Neogene cover around the village of Erikli. On the road between Erikli and Yenice there are several good sections of the Nilüfer Formation. We will walk part of one section. In this stretch, like everywhere else, the Nilüfer Formation is dominated by metatuffs, which range from green phylitic rocks to more massive metapyroclastic rocks. The mineral assemblage in the metabasic rocks is barroisite + albite + epidote + chlorite + leucoxene (2057, 2059). The rocks show a strong foliation, which dips generally southwest (Figure 19). The metabasites are cut by frequent shear zones and comprise rare horizons of marble.

Stop 4.2:

Triassic eclogite

Locality: About one kilometre south of the village of Yenice (4176). To reach the eclogite walk inland from the village square next to the teahouse. Turn left at the Mustafa Can fountain. The path curves right and climbs up; turn left at the next fountain. It's about a 15-minute walk from the tea-house (Figure 19).

We will leave the minibus in the village of Yenice on the Marmara Sea and walk south, climbing a hill along a rough road. There is little exposure along this road, except for large blocks of massive metabasite and serpentinite. The eclogite makes a small knocker on the side of the hill.

The eclogite is about 15 m thick and 40 m long, aligned parallel to the east-northeast-trending foliation in the metabasites, and is enclosed by a 2-10-m-thick envelope of antigorite serpentinite. It is massive and has a homogeneous texture. Most of the lens consists of pink garnets set on dark blue sodic amphibole and pale green omphacite. Metabasite samples collected adjacent to the eclogite show no evidence of high-pressure metamorphism, but they contain greenschist-facies assemblages. In the vicinity of the eclogite, there are also tectonic lenses of greenschist-facies metagabbro and antigorite serpentinite (Figure 19).

The mineral assemblage in the eclogite is garnet + omphacite + glaucophane ± barroisite + epidote + quartz ± phengite + rutile. The red garnets and dark blue sodic amphibole is readily recognisable; apple green omphacite is less common.

Petrography, mineralogy, P-T conditions and isotopic age of the eclogite

The mineral assemblage in the eclogite is garnet + omphacite + glaucophane ± barroisite + epidote + quartz ± phengite + rutile. Garnet, omphacite and glaucophane make up over 70% of the rock. Garnet forms subidioblastic crystals, 2-4 mm in size, with quartz, rutile, and glaucophane inclusions, and is essentially an almandine-grossular solid solution with minor pyrope (3-11 mol%) and spessartine (0-4 mol%) Okay and Monie (1997). Sodic amphibole occurs as prismatic, lavender blue crystals as much as 4 mm in size. It has rims and patches of bluish-green barroisite but otherwise is compositionally homogeneous and plots in the glaucophane and crossite fields. Apple-green omphacite crystals as much as 2 mm long commonly occur as inclusions in glaucophane as well as in the matrix of the rock. Omphacite contains up to 36 mol% jadeite and 15-25 mol% aegerine. Epidote is found as aggregates of grains 0.2 mm in size. Phengite, with 3.30-3.45 Si per formula unit, is a rare mineral. The greenschist-facies overprint in the eclogite is characterized by barroisite rims around glaucophane, the development of interstitial albite, and by the partial replacement of garnet by chlorite.

Ellis and Green's (1979) Garnet-clinopyroxene Fe-Mg geothermometry indicates temperatures of 480 ± 50 °C at a pressure of 10 kbar for adjoining omphacite-garnet pairs from the eclogite samples, whereas a minimum pressure of 10 kbar can be estimated from the jadeite content of the sodic pyroxene (Holland, 1990). In terms of its petrology

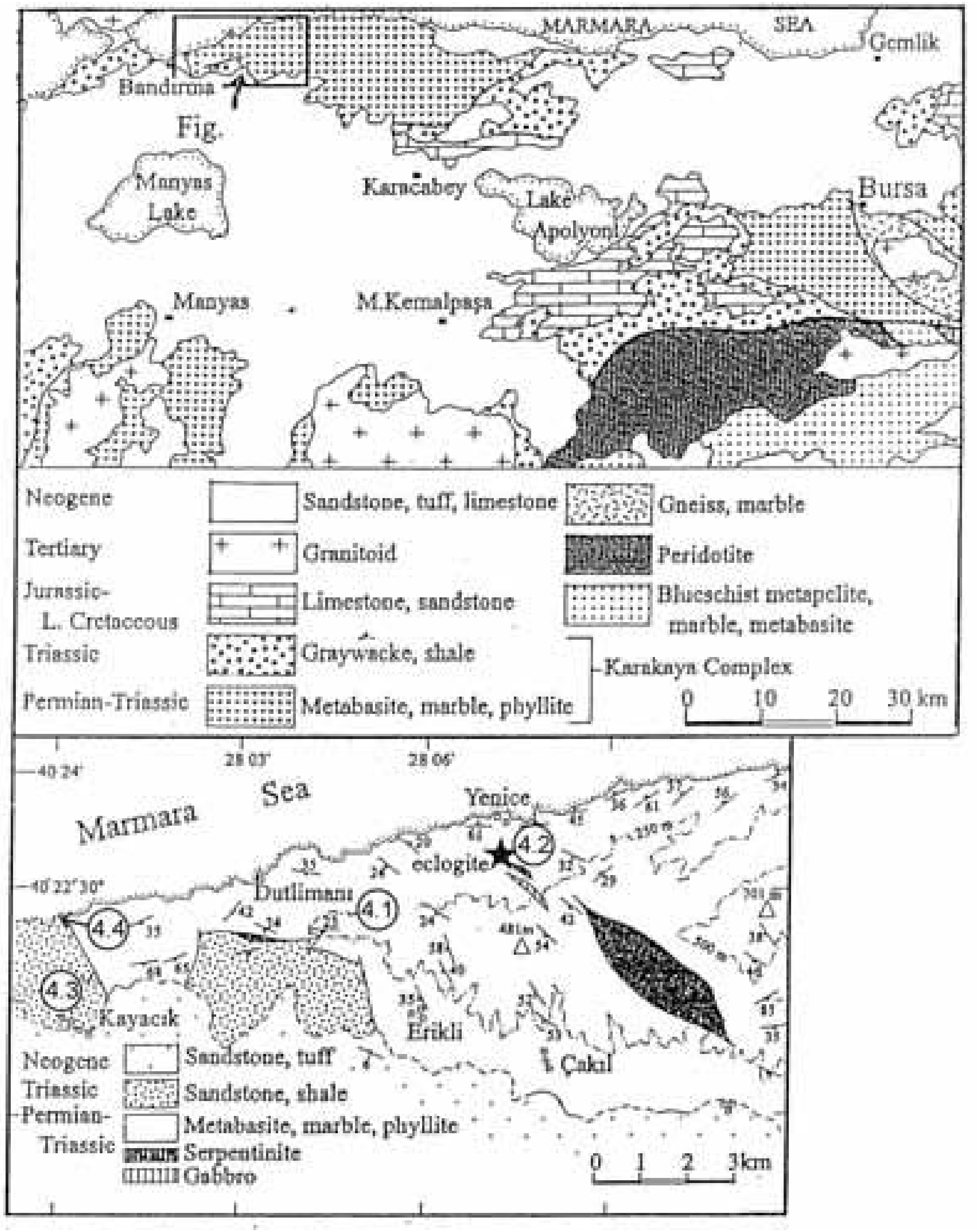

Figure 19 - Geological map of the region east of Bandirma showing Stopns 4.1 to 4.4. For location see Figure 3 (Okay and Monie 1997).

and tectonic setting, the eclogite lens is a typical Group C eclogite (Coleman et al., 1965) and is similar to both the exotic eclogite blocks in the Franciscan Complex in California (e.g., Moore and Blake, 1989) and that of the Besshi district of the Sanbagawa metamorphic belt in Japan (Banno and Nakajima,

1992; Takasu et al., 1994).
Two eclogite samples from this lens were dated with step-heating and spot-fusion $^{40}Ar/^{39}Ar$ laser-probe methods on single grains (Okay and Monie, 1997). The step-heating and spot-fusion $^{40}Ar/^{39}Ar$ laser-probe ages from the phengites from the first sample range from 208 to 203 Ma, corresponding to the Triassic-Jurassic boundary.

Stop 4.3:
The Hodul Formation
Locality: Abandoned quarries near Bandirma (2044-2049) (Figure 19).
From Yenice we take the coastal road, which passes through the metabasites of the Nilüfer Formation. After the village of Dutyenice on the Marmara Sea the road bends landward and, after a while, enters the sedimentary rocks of the Hodul Formation of the Karakaya Complex (Figure 19). The contact between the Nilüfer and Hodul formations is not exposed along this road. The road leads to a series of quarries north of Kavacik near Bandirma.
A good section of the upper parts of the Hodul Formation is exposed in these abandoned quarries. The lower part of the section in the quarries is made up of white, thickly-bedded to massive, arkosic sandstones, which also crops out around the dam to the east. The arkosic sandstones pass up into a sequence of slates with thin sandstone, siltstone, calciturbidite beds and blocks of recrystallized limestone. The sequence here is recrystallized and has not yielded any fossils. However, similar sequences in the Balya and Ivrindi regions contain Norian fossils.

Stop 4.4:
The tectonic contact between the Hodul and Nilüfer formations, and the debris flows in the upper parts of the Hodul Formation.
Locality: The coastal section east of Bandirma (2049-2050). To get to this Stop follow the ugly dirt road leading north from the quarries. The dirt road intersects a tarmac road; turn right and head towards the concrete high-rise flats near the coast. Drive to the end of the tarmac road (Büyük Levent Caddesi, next to the Kafkas Market) and then follow a dirt road, which leads towards the axis of the dam. A footpath descends to the shore just in front of the dam's axis (Figure 19).
The coastal section east of Bandirma is probably the best locality in northwest Turkey to see the contact between the Nilüfer and Hodul formations (Figure 19). The coastal section also exposes very good examples of debris and grain flows in the Hodul Formation, and some of the limestone blocks in the debris flows contain Permian fusulinids.
Initially we will walk east and see the contact between the Nilüfer and Hodul formations. The metabasites of the Nilüfer Formation are overlain by melange-like, highly sheared slates with clasts of arkosic siltstone. The contact is folded. I interpret the contact as a deep-seated tectonic contact. At present there is a controversy in the geological community in Turkey regarding the contact between the Nilüfer and Hodul formations. Some geologists consider the arkosic sandstones of the Hodul Formation as being deposited unconformably (post-metamorphic unconformity!) over the metabasites of the Nilüfer Formation. This outcrop, at least, shows the impossibility of a post-metamorphic unconformity between these two formations.

After seeing this outcrop we will walk west to see the exposures of the upper parts of the Hodul Formation. The well-exposed sequence along the coast consists of black, greyish brown slate intercalated with thinly bedded siltstone and debris and grain flows with abundant limestone blocks, 0.3 to 30 m in size. Many of the limestone blocks are fossiliferous and some contain fusulinids, indicating a Permo-Carboniferous age. Such blocks are very widespread in the upper parts of the Hodul Formation in northwest Turkey, and the microfauna in these blocks have been the subject of a recent study (Leven and Okay, 1996). The whole sedimentary section is strongly tectonized with the partial to complete loss of the stratigraphic continuity.
After this stop we will have a long drive to Kücükkuyu, on Edremit Bay. The road from Bandirma follows the main Istanbul-Izmir highway through Balikesir, Ivrindi and Havran, and passes largely through Neogene volcanic and sedimentary rocks. At Havran we leave the main Izmir highway and take the road that follows the northern margin of the Gulf of Edremit. Rising abruptly from the Gulf of Edremit is the mountain of Kazdag, which is a metamorphic core complex of Oligocene age.

Here on the Aegean coast we are in the realm of the Aegean extension. The north-south extension, which started in about the Late Oligocene, has overprinted the complex orogenic geology of western Turkey. The early Late Oligocene-Miocene extension in the

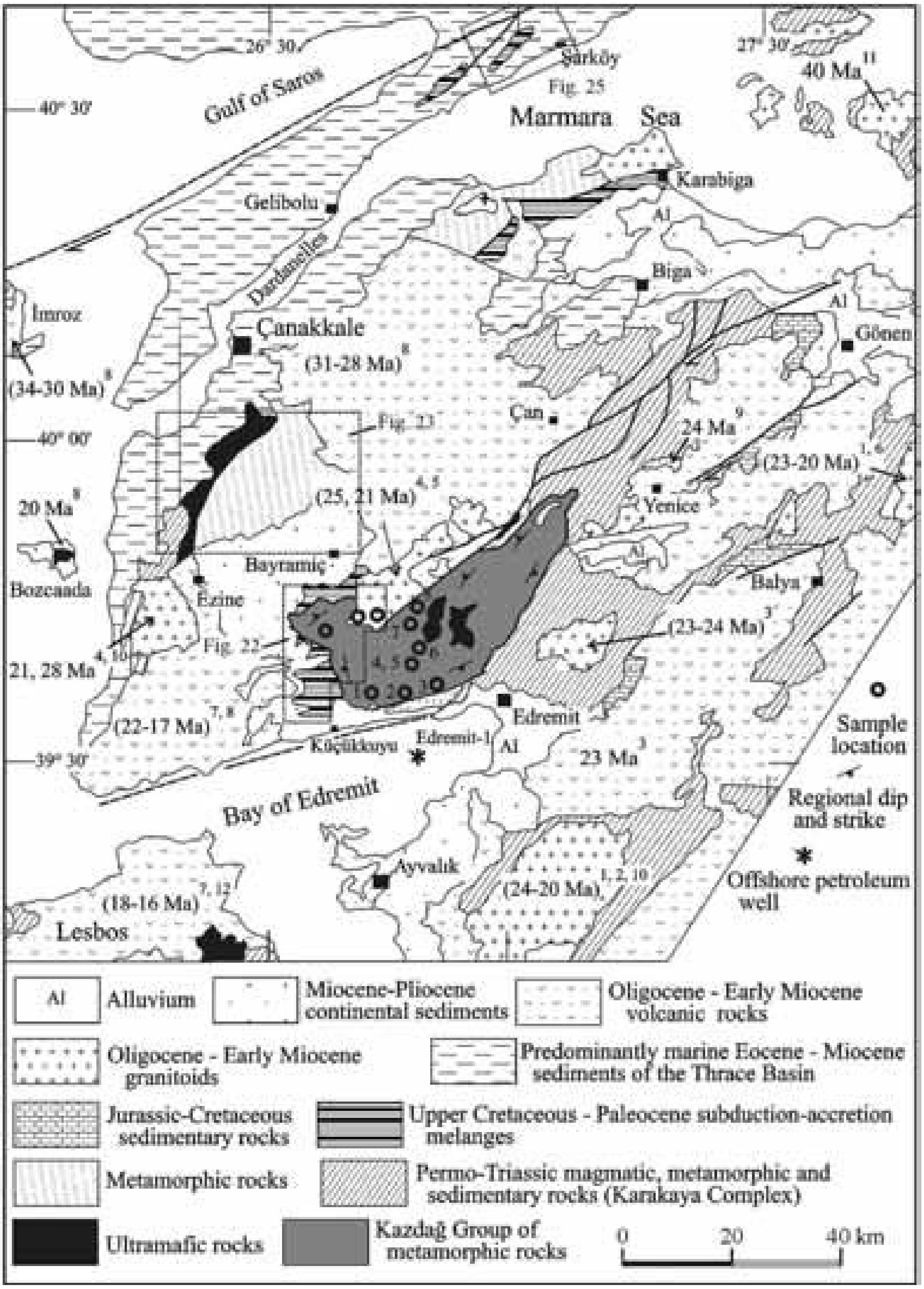

Figure 20 - Geological map of northwestern Turkey illustrating the tectonic setting of the Kazdag Massif and the isotopic ages of the Oligo-Miocene calc-alkaline magmatic province (Okay and Satir, 2000)

Aegean is characterized by several metamorphic core complexes (Figure 20). One of these metamorphic core complexes is the Kazdag mountain range on the Biga peninsula which exposes high-grade metamorphic rocks under an unmetamorphosed ophiolitic melange. The Kazdag range consists of gneiss, amphibolite, marble and meta-ultramafic rock. Zircon Pb/Pb ages from the gneisses are about 308 Ma, whereas the Rb/Sr mica and amphibole ages are 20-19 Ma, reflecting the metamorphism associated

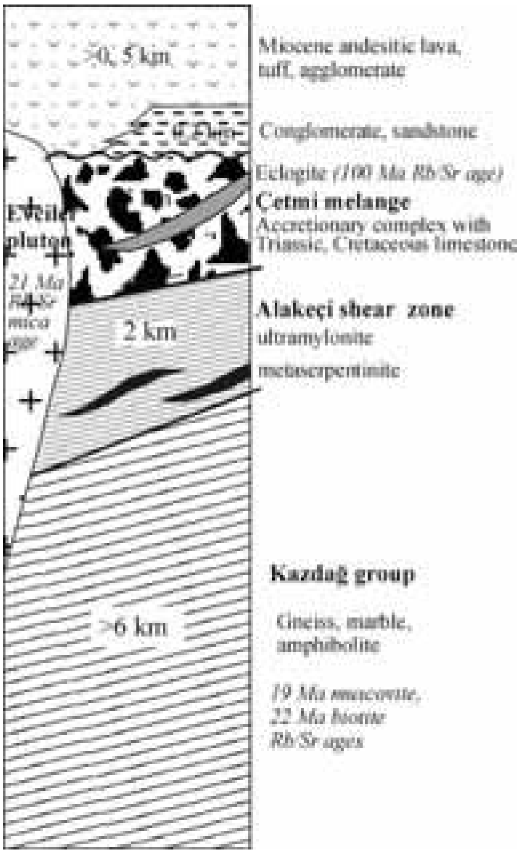

Figure 21 - Columnar section showing the tectonostratigraphic units in the western Kazdag region (Okay and Satir, 2000).

with the Late Oligocene extension. A major shear zone constituted by ultramylonites forms the contact between the Kazdag metamorphic rocks and the overlying unmetamorphosed melange (Figure 21).

We will start by studying the ophiolitic melange, which includes Cretaceous eclogite lenses, and then will go down through the sequence to see the ultramylonites of the Alakeci shear zone and, finally, the metamorphic rocks of the Kazdag Group.

Stop 4.5:

Cetmi Ophiolitic Melange.

Locality: Near the village of Kizilyar, just off the Ayvacik-Kücükkuyu highway (Figure 22).

In the Biga Peninsula we are near the northern margin of the Sakarya Zone (Figure 1). In this region there are outcrops of the Cretaceous-Palaeocene accretionary complex, which is believed to have formed during the closure of the Intra-Pontide ocean between the Sakarya and Rhodope-Strandzha Zone (Figs. 3 and 20). They have a more melange-like internal structure compared with the Ovacik Complex and are richer in the clastic component. A good outcrop of this Cetmi Ophiolitic. This locality illustrates the various lithologies which make up the Cetmi Ophiolitic Melange. They include basalts, green and red radiolarian cherts, white micritic limestone of Late Triassic age (Norian), red pelagic limestone of Senonian age, greywacke, shale, siltstone, debris flows with basalt and limestone clasts. All these lithologies occur without any order, in a chaotic jumble. It is difficult to define an all-encompassing matrix; greywacke and siltstone are the best candidates. Unlike the Ovacik Complex, though, no high-pressure metamorphic minerals have been identified in the basalts of the Cetmi Ophiolitic Melange.

The pelagic Triassic limestone blocks, which range up to one kilometre in size, consist of thinly-bedded radiolarian micrites with the characteristic Upper Triassic Norian pelagic bivalve *Monotis salinaria.* They also contain a Norian foraminiferal assemblage of *Trochommina* sp., *Agathammina austroalpina*, *Galeanella* cf. *panticae*, *Nodosaria* sp., *N. ordinata*, *Austrocolomia* sp., *Aulotortus* sp, *A. gaschei*, *A. communis*, *A.* gr. *sinousus*, and *Spiroamphorella carpathica*. There are also massive limestone blocks with the characteristic Norian bivalve *Megalodon* s; Beccaletto (2003) has also discovered Anisian pelagic limestones and Upper Jurassic - Lower Cretaceous radiolarian cherts in the melange.

Fossiliferous Upper-Cretaceous limestones are rare. A few-meters long red silty biomicrites in Couches-Rouges facies embedded in greywacke-shale matrix in this locality has yielded Turonian-Santonian pelagic foraminifera *Marginotruncana* sp., *M. coranata*, *M. marginata*, *M.* cf. *pseudolineiana* (see also Brinkmann et al., 1977). The Cretaceous limestone provides a lower age limit of the Turonian for the final phase of subduction-accretion leading to

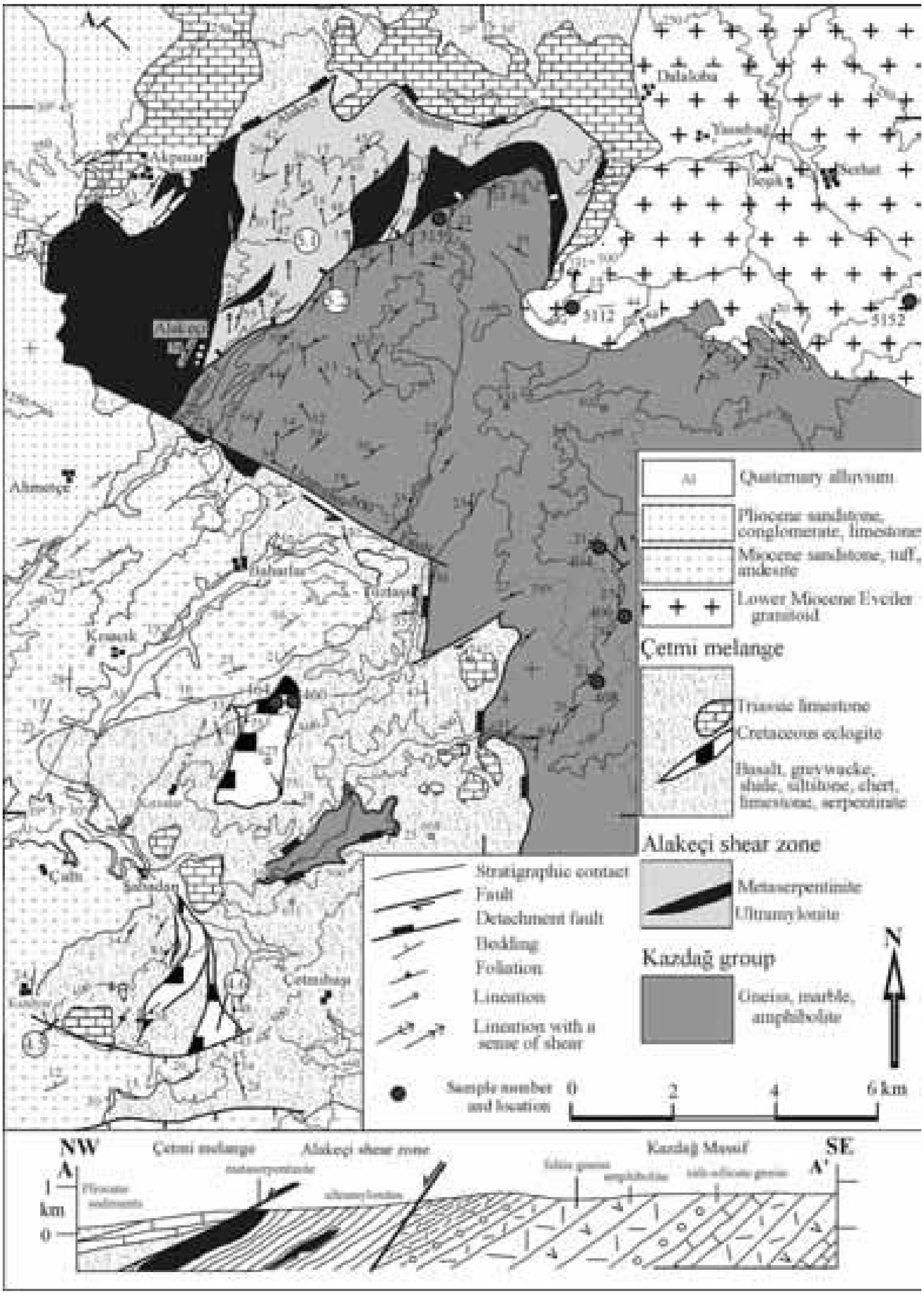

Figure 22 - Geological map and cross-section of the western part of the Kazdag range showing Stops 4.5, 4.6 and 5.1, 5.2. For location see Figure 20 (Okay and Satir, 2000a).

the formation of the Cetmi Ophiolitic Melange.

Stop 4.6:

The eclogite lens in the Cetmi ophiolitic melange

Locality: From Kocalan on the Kücükkuyu-Ayvacik highway take the dirt road to the village of Kizilyar. There is a road junction 150 metres after the highway; take the road on the right. The road curves up towards the hills and forks about 300 m before the hut on the Dikili Tepe. Take the road on the right, and then the second on the left, which descends towards a stream. The eclogite locality is on the northern side of this dirt road (609-610) (Figure 22).

From Stop 4.5 we take a forest road, which climbs up towards the hills. There are good outcrops of the Cetmi Melange along the first part of this road. Farther along the road there is good panoramic view of the Melange with the Norian limestone blocks sticking out from the landscape as white mounts. The Cetmi Melange also includes Cretaceous eclogite lenses. We will stop in a well-exposed section to see the banded eclogites and associated garnet-micaschists.

The eclogites make a 15-m-thick section on the side of the small valley. They are beautifully-banded fresh rocks. The bands are composed of alternating glaucophane + garnet, and omphacite + garnet layers. Towards the top of the section there are local zones of retrogression into amphibolites. Amphibolitisation has occurred parallel to the banding. The eclogites are overlain by silvery white garnet-micaschists with large, conspicuous garnets.

Eclogitic garnet-micaschist and eclogite form two large exotic slices in the Cetmi Melange (Figure 22). They are surrounded by unmetamorphosed basalt, greywacke and shale, which only near the eclogite contacts show any foliation. The garnet-micaschists form silvery grey, well-foliated, homogeneous rocks with mesoscopic garnet porphyroblasts. The mineral assemblage in the garnet-micaschists is garnet + quartz + phengite + paragonite. The garnet micaschists comprise 0.2-20-m-thick horizons of eclogites, which are variably altered to blueschists. The eclogites are massive, dense, greenish, banded rocks with the garnet + omphacite + sodic amphibole + epidote + phengite + rutile ± quartz mineral assemblage. There is a continuous petrographic range from essentially anhydrous eclogite to a blueschist metabasite with garnet and sodic amphibole but no omphacite. Rb/Sr isotopic dating of the eclogites have given Cretaceous ages (Okay and Satir, 2000).

DAY 5

Thursday, September 2nd, 2004

In the morning we pack our cases and leave Kücükkuyu in the direction of Canakkale passing through Ayvacik. The road passes through Neogene volcanic rocks and sediments. There are good road sections of Miocene lahars (volcanic debris flows) around Ayvacik. At the town of Ezine we take the road to Bayramic, which follows the Plio-Quaternary sediments of the Bayramic basin north of Kazdag. From Bayramic we will take the road to the village of Kutluoba. After Kutluoba the road climbs up and enters the altered basalts belonging to the Cetmi Melange. The two large limestone blocks in the east and west are similar to the Norian limestones we saw yesterday. In the eastern limestone block I have found *Megalodon* s; these are large bivalves of Norian age (Okay et al., 1991). On top of the western limestone block there are ruins of the ancient Greek city Kebrene.

The Cetmi Melange is underlain by the high-grade metamorphic rocks of the Kazdag Group. South of Bayramic there is a two-kmthick mylonite zone, called the Alakeci Mylonite Zone, between the Melange and the Kazdag Group. After the village of Caldag we enter into the mylonites; our first stop will be in the mylonites which form a shear zone between the Kazdag metamorphic rocks and the overlying Cetmi Ophiolitic Melange.

Stop 5.1:

The Alakeci Mylonite Zone

Locality: The road between the villages of Caldag and Alakeci, Bayramic. About half-way between these two villages there is a junction; take the road on the left, which leads to the village of Dalaloba (5205-5207) (Figure 22).

The Alakeci Mylonite Zone between the Kazdag Group and the Cetmi Ophiolitic Melange has a thickness of about two kilometres. It consists mainly of ultramylonites with tectonic lenses of serpentinite. The protoliths of the mylonites were the felsic gneiss, amphibolite and marble of the Kazdag Group. The mylonites show a NNE plunging mineral lineation. The foliation, which is deflected around the large serpentinite bodies is more scattered but shows a general northward dip. Antigorite-serpentinite occurs as 10-cm- to 3-4-km-wide tectonic lenses in the mylonite. Locally the serpentinite consists of small diabase lenses of hornblende and plagioclase.

The lower contact of the Alakeci Mylonite Zone with the Kazdag Group is transitional over a few hundred meters and dips 30-40° to the northwest. Its upper contact with the Cetmi Melange is sharp, and the dip of the contact ranges from 10° to 80°. The microstructures in the mylonites, such as C-S fabrics, rotated porphyroclasts, mica fish, indicate

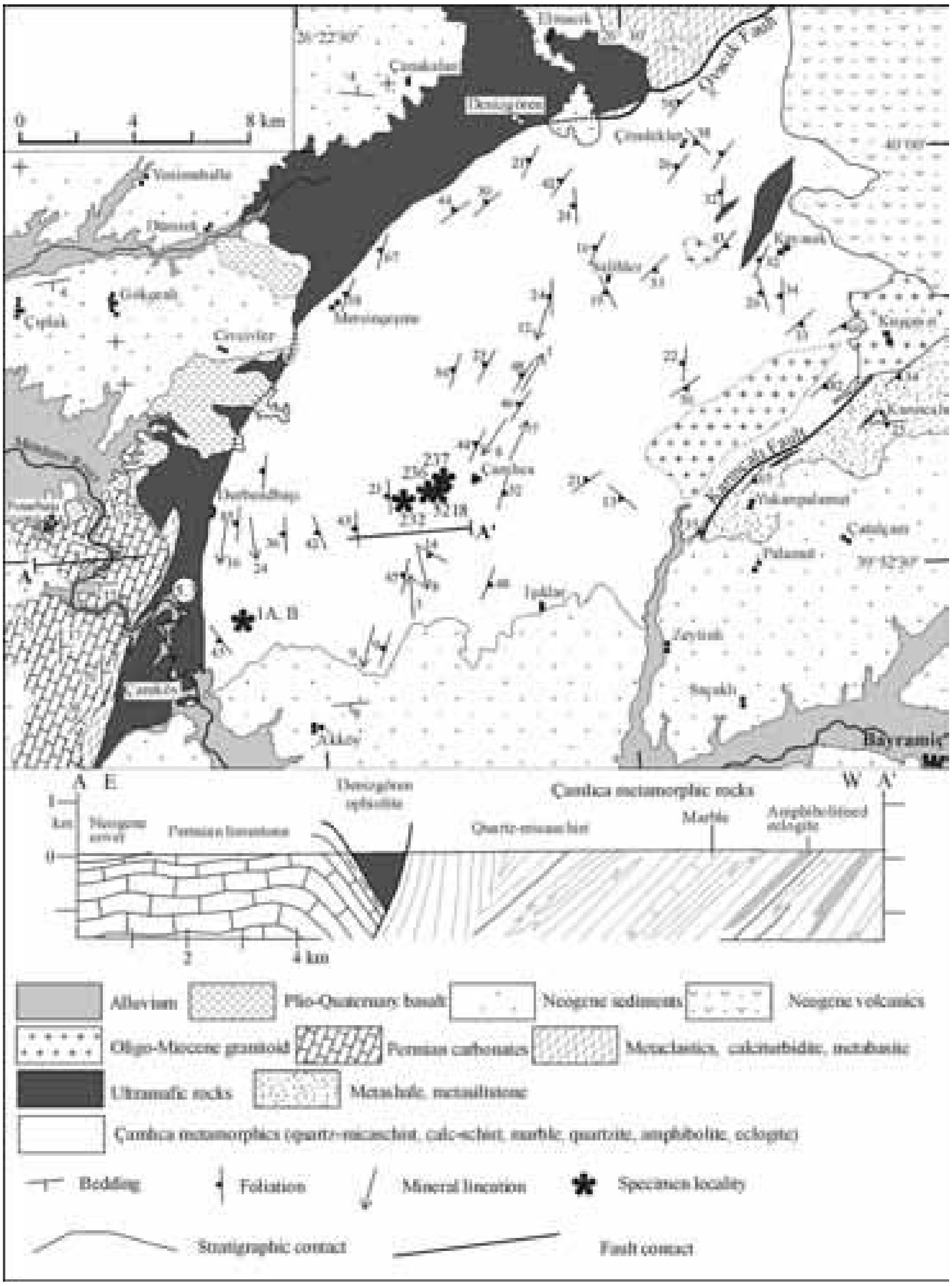

Figure 23 - Geological map and cross-section of the region north of Ezine showing Stop 5.3 (Okay and Satir 2000b).

generally top-to-the-north movement, which is consistent with the extensional exhumation of the Kazdag Group during the Miocene (Okay and Satir, 2000).

After the village of Alakeci, which gives its name to the mylonite zone, we take a side road that runs parallel to the Bickidere stream; we'll enter into the metamorphic rocks of the Kazdag Group. We will stop at the upper reaches of the Bickidere stream and walk back up section (5164-5173), studying the lithology and structure of the Kazdag Group. First, though, some background information on the high-grade metamorphic rocks of the Kazdag Group.

The Kazdag Group - High-grade metamorphic rocks with Carboniferous zircon and Miocene Rb-Sr ages

The Kazdag Group forms a 55-km-long, NE-trending antiform of gneiss, amphibolite and marble (Figure 4). In the northwest part of the region we will visit it consists of an intercalation of paragneiss, amphibolite and marble. The medium-grained gneisses, which show compositional banding, are the most common lithology (60 %). The mineral assemblage in the gneiss is quartz + plagioclase + biotite + hornblende + diopside ± garnet + opaque + sphene. The marble forms one- to 20-m-thick horizons in the gneiss. Amphibolites of hornblende + plagioclase ± diopside occur as bands in the gneiss and marble. Migmatites are locally developed in the gneisses. Strong folding observed in the migmatites suggest that migmatization was synchronous with deformation.

The dominant structure in the Kazdag Group is a high-temperature metamorphic foliation, which dips consistently northwest. There is also a north-trending mineral lineation, which becomes stronger towards the overlying mylonite zone. Folds are rare and are largely restricted to the migmatites. The fold axial planes lie in the plane of the foliation and the fold axis plunges to the north. The folds show a consistent northeastward vergence.

Zircons from the Kazdag gneisses, dated using the single-zircon, step-wise, Pb-evaporation technique, have given a mid-Carboniferous (308 ± 16 Ma) age (Okay et al., 1996). Eight gneiss samples, including the two previously dated by zircons, were dated using the Rb/Sr technique (Okay and Satir, 2000). The biotite/whole rock Rb/Sr ages cluster tightly between 18 and 20 Ma, while the muscovite/whole rock ages are between 20 and 24 Ma. These Early Miocene cooling ages are similar to those previously-reported, K/Ar and Rb/Sr mineral ages (23 to 27 Ma) from the Kazdag Group (Bingöl, 1971), and indicate that, by the Early Miocene, the Kazdag gneisses were situated several kilometres below surface. This inference, together with the observation that the unmetamorphosed Cretaceous-Palaeocene melange lies tectonically over the Kazdag Group, suggest that the Kazdag Group represents a Miocene extensional core complex (Okay et al., 1991). This interpretation is further supported by the presence of a thick mylonite zone between the Kazdag Group and the Cetmi Melange, with the stretching lineations in the mylonite zone indicating top-to-the-north movement (Okay and Satir, 2000).

Stop 5.2:

The high-grade metamorphic rocks of the Kazdag Group and the overlying Alakeci Mylonite Zone

Locality: The section along the Bickidere stream, northeast of the village of Alakeci, south of Bayramic. From Bayramic drive south to Kutluoba; from there a village road leads to Caldag and Alakeci.

The Kazdag Group along the Bickidere consists of biotite-sillimanite-garnet gneiss, diopside-plagioclase-garnet calcsilicate rock, marble, quartzo-feldspathic gneiss, and, farther up-section, banded amphibolite. These lithologies are closely intercalated. Geothermobarometry indicates regional metamorphism at 5 ± 1 kbar, and 640º ± 50 ºC (Okay and Satir, 2000). The metamorphic rocks are cut by undeformed granitic veins and aplite dykes. The metamorphic rocks show a consistent northwest-dipping foliation and a weak NNW-trending mineral lineation. At a few localities they show strong folding, which post-dates the formation of the strong metamorphic banding. The folds are recumbent with strongly attenuated limbs. There are also rare normal faults with approx. N-S striking fault planes. The mineral assemblage in the common gneiss is quartz + plagioclase + biotite + hornblende + diopside ± garnet + opaque + sphene. The high-grade metamorphic sequence is truncated by a semi-brittle fault zone about 20 metres thick (5170). The fault zone consists of cataclastically-deformed, microbrecciated, altered gneiss and amphibolite with a metaserpentinite lens.

Here we see the contact between the Kazdag Group and the overlying Alakeci Mylonite Zone. Walking farther up-section we will see gneisses and micaschists

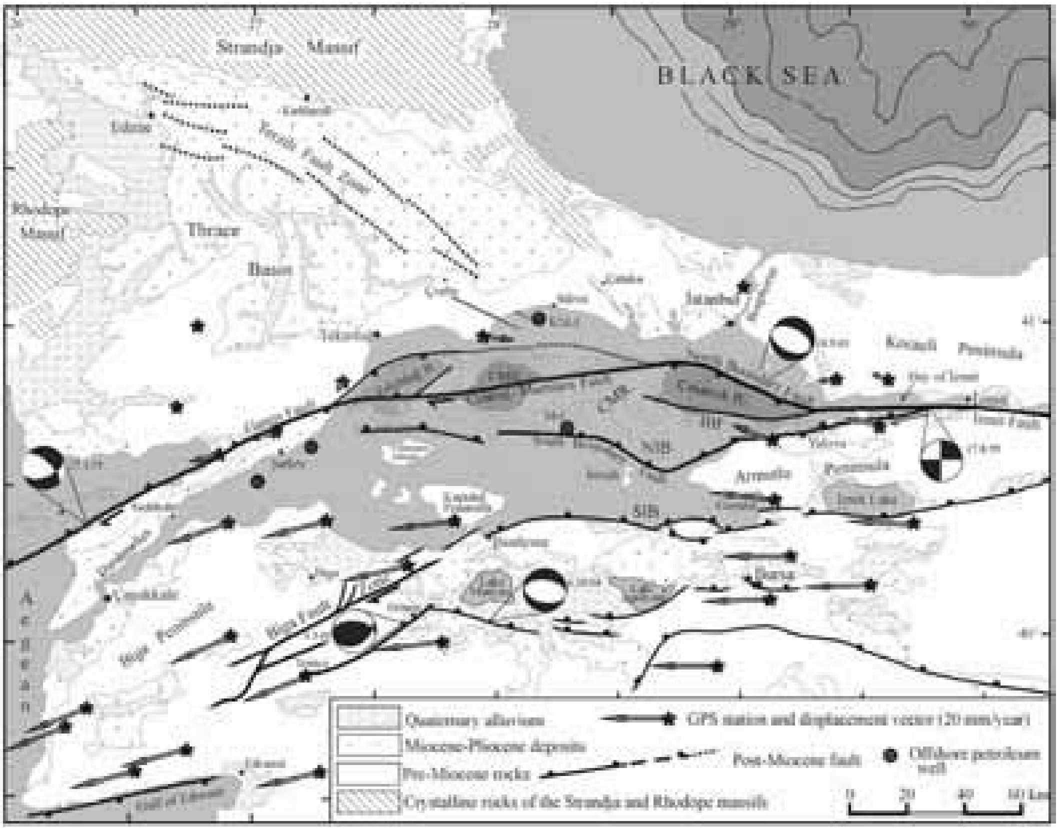

Figure 24 - Active tectonic map of the Marmara region. The fault plane solutions of the major earthquakes (M_s> 5) are from Taymaz et al. (1991) and USGS (1999). The stars and arrows indicate Global Positioning System (GPS) station localities and displacement vectors, respectively, with respect to a fixed station in Istanbul (Straub et al. 1997). CMR, Central Marmara Ridge; CMB, Central Marmara Basin; IBF, Inner Boundary Fault; NIB, Northern Imrali Basin; SIB, Southern Imrali Basin; KM-1, Kuzey Marmara-1 well; M-1, Marmara-1 well. (Okay et al., 2000).

with a strong NNE-trending lineation.

From Stop 5.2 we return to Bayramic and then to Ezine, where we join the Canakkale highway. North of Ezine the highway crosses a large peridotite (the Denizgören ophiolite), which lies tectonically over slightly-metamorphosed Permian carbonates.

Stop 5.3:

Panoramic view of the Denizgören ophiolite and the underlying Permian limestones.

Locality: On the highway between Ezine and Canakkkale; about ten kilometres after Ezine (Figure 23).

As seen from this stop the peridotites lie tectonically over the white, slightly recrystallized limestones with rare Upper Permian fusulinids (Figure 25, Okay et al., 1991, 1996). In between the peridotite and Permian limestone there is a flysch-like sequence with rare Permian and Triassic limestone blocks (Beccaletto, 2003). The Permian limestones as well as the flysch sequence have been metamorphosed into low-grade greenschist facies. This tectonic sequence was logically interpreted as a Permo-Triassic ophiolite obduction over an Upper Permian carbonate platform (Okay, 1987). However, subsequent dating of amphibolites at the base of the Denizgören Ophiolite gave a Cretaceous age (~117 Ma, Okay et al., 1996; Beccaletto, 2003). But why and how did a Cretaceous ophiolite overthrust an Upper Permian carbonate platform?

At the northern end of the peridotite there is a young basaltic flow, which lies directly over the peridotite near the village of Tastepe. After Tastepe we will drive through a featureless Neogene landscape (Figure 23). The ancient city of Troy, which we might pay a short visit to, is situated on

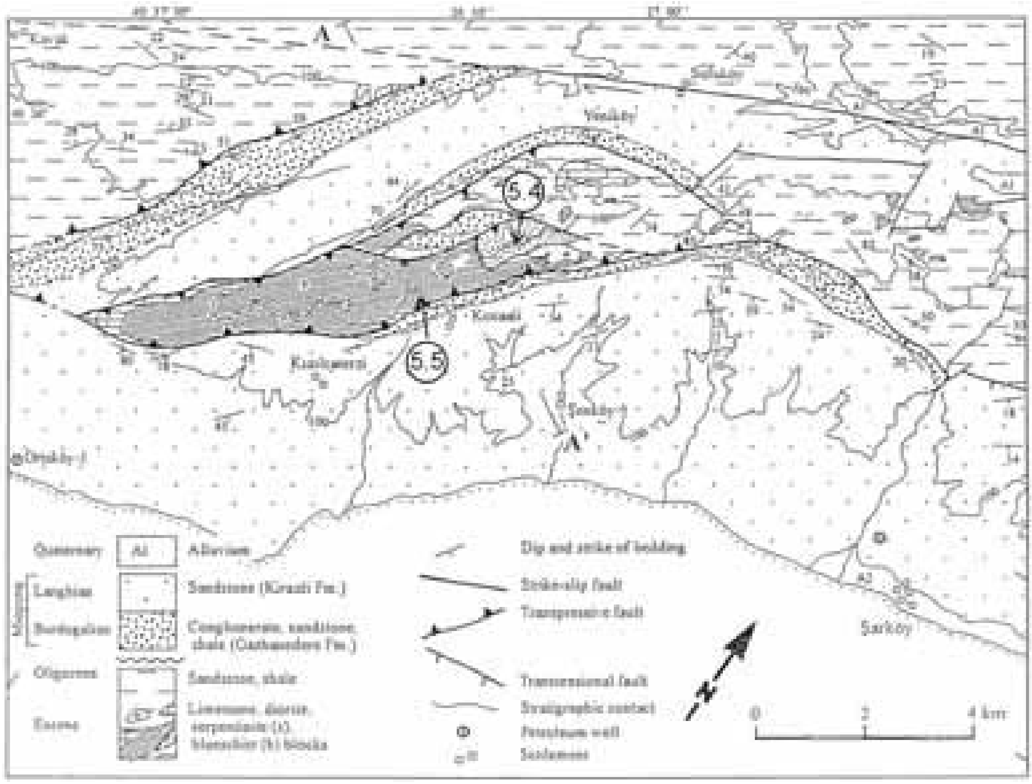

Figure 25 - Geological map of the region northwest of Sarköy showing Stops 5.4 and 5.5. For location see Figure 20 (Okay et al., 1999).

this Neogene plateau. A good section of flat-lying Neogene sediments can be seen on the road cut after the Troy junction. Farther on, near the Dardanelles, there are good road sections of white, marly, lagoonal limestone and sandstone of Miocene age. There is a good panoramic view of the Straits of Dardanelles from near these outcrops.

We will cross the Dardanelles by ferry and drive through the southern margin of the Gelibolu Peninsula. The southwestern tip of the Gelibolu Peninsula is today a National Park with war cemeteries for the British, Australian-New Zealand (ANZAC), French and Turkish soldiers who died during the Gelibolu (Galipoli) Campaign of 1915.

We drive pass the picturesque town of Gelibolu and, after about 25 km, leave the main highway for a road signd to Sarköy. The road runs over low-lying hills from where one can glimpse both the Saros Bay in the west and the Marmara Sea in the east. The road also follows the northern branch of the North Anatolian Fault, which extends for 50 km from Gaziköy to the Bay of Saros (Figure 24). An earthquake in 1912 along this Ganos Fault destroyed almost all the villages and towns in this region.

About one kilometre after the village of Yeniköy we take a side road which climbs the hills to the south; our first stop will be on this dirt road.

Stop 5.4:

Blueschists north of the village of Kocaali, northwest of Sarköy

Locality: On the dirt road between the villages of Yeniköy and Kocaali (356) (Figure 25).

All the way from Gelibolu we have driven in poorly-exposed Tertiary sedimentary rocks of the Thrace Basin. The Thrace basin is a largely siliciclastic basin of Mid-Eocene-Early Miocene age. The thickness of the Eocene-Oligocene sandstone-shale sequence in the centre of the basin exceeds eight kilometres. There are several gas fields and one oil field in the Thrace Basin. It is most unexpected to find blueschists in such a basin. We owe the exposure of the blueschists to the recent activity of the North Anatolian Fault.

The Ganos fault in the region northwest of Sarköy is transpressional and has formed positive flower structures and thrusts (Okay et al., 1999). One such flower structure has exposed blueschists and associated serpentinites (Figure 25).

The dirt road south of Yeniköy passes through an olistostromal sandstone-shale sequence of Mid-Eocene age. The sandstones contain blocks of serpentinite, diabase, microgranite, greenschist, pelagic Upper Cretaceous and Palaeocene limestone as well as reefal Upper Eocene limestone (Okay and Tansel, 1994). The blocks must have been derived from an accretionary complex of Late Cretaceous-Palaeocene age.

After the olistostromal Eocene sequence the road enters the blueschists. The blueschists north of Sarköy form an outcrop about one kilometre across (Figure 25). They are in tectonic contact with the serpentinite in the south and are probably intruded, along with the serpentinite, by a microgranite in the southeast (Figure 25). Their geological setting is not clear; it is possible that they form a large block in the Eocene sequence.

Blueschists north of Sarköy are represented mainly by metabasites with rare marble and phyllite horizons. Most metabasites show a strong foliation; however, there is at least one outcrop where the pillow structures in the metabasites are well preserved. In some of the metabasites sodic amphibole crystals are recognisable as forming long, nearly acicular crystals. The mineral assemblage in the metabasites is sodic amphibole + lawsonite + sodic pyroxene + chlorite + leucoxene (Sentürk and Okay, 1984). Sodic amphibole and lawsonite make up over 80 modal percent of the rock. In terms of mineral assemblage and texture these blueschists are similar to those of the Tavsanli Zone.

Stop 5.5:

Diabase dykes in serpentinite with low-grade blueschist facies assemblages

Locality: The upper reaches of the Kongu stream, about 400 metres west of the village of Kocaali (Figure 25).

A steep dirt road descends from the blueschist outcrop to the village of Kocaali at the base of the hills. If our minibus cannot make this road we will have to drive through Sarköy to Kocaali.

We will park our minibus on the road between the villages of Kocaali and Kizilcaterzi and walk up the Kongu stream. At the start of the section there are subvertical beds of multi-coloured sandstone, conglomerate, siltstone and rare limestone. This is the Gazhanedere Formation of Early to Mid-Miocene age. In the beginning of the century oil was obtained from this formation! Walking northwest we come up to a reverse fault, which has emplaced highly sheared serpentinite over the Miocene beds. This forms the southern limb of the flower structure related to the North Anatolian Fault (Figure 25).

The serpentinite forms a ridge, about eight kilometres long and 1.5 km wide, trending parallel to the active (main) strand of the Ganos Fault in the north (Figure 25). It is bounded both in the north and south by reverse faults. The serpentinite includes large number of diabase blocks. The diabase forms dark grey to black, extremely hard, homogeneous rocks. Originally they might have been dykes, but at present all the serpentinite-diabase contacts are sheared. The diabase appears unmetamorphosed in the field; however, when studied petrographically,it can be seen to contain a number of blueschist facies minerals, including sodic amphibole and lawsonite. The green hornblende crystals in the diabase are partially to completely replaced by sodic amphibole, while the former plagioclase is represented by aggregates of tiny prisms of lawsonite and sheets of colourless to pale green pumpellyite.

A good exposure of diabase occurs at the end of the path in the Kongu stream. It is dark grey, very hard and has a homogeneous texture. This particular diabase (332) consists of magmatic augite and hornblende, which are partially replaced by sodic pyroxene and sodic amphibole, respectively. The place of the former plagioclase is taken up by very fine-grained aggregates of colourless pumpellyite and interlocking prismatic crystals of lawsonite. Ilmenite in the rock is partially replaced by leucoxene.

After this last outcrop of the field trip we board the minibus, say farewell to the blueschists of northwest Turkey and drive back to Istanbul.

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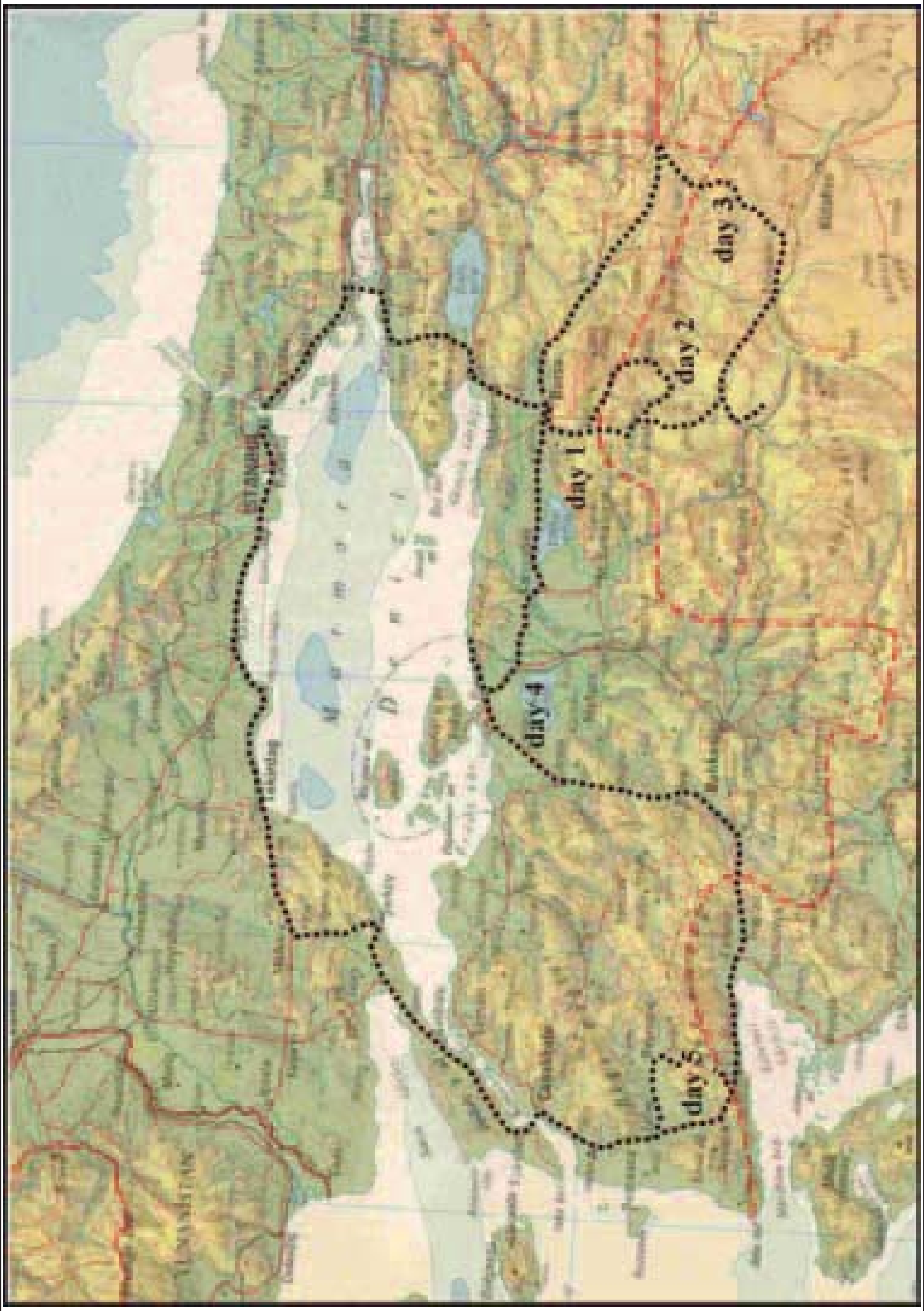
Back Cover:
field trip itinerary

FIELD TRIP MAP

32nd INTERNATIONAL GEOLOGICAL CONGRESS



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