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This paper is dedicated to
Prof. Dr. RER. NAT. İHSAN KETİN
on the occasion of his seventy-fifth birthday

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GEOLOGY AND TECTONIC EVOLUTION OF THE BIGA PENINSULA, NORTHWEST TURKEY

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Abstract: Four NE-SW trending zones are recognised in the Biga and Gelibolu peninsulas, which are from northwest to southeast: the Gelibolu, the Ezine, the Ayvacık-Karabiga and the Sakarya zones. The Gelibolu and the Ayvacık - Karabiga zones are made up of an Upper Cretaceous/Paleocene ophiolitic melange called the Çetmi Ophiolitic Melange consists of spilite, limestone, pelagic shale, turbiditic sandstone, blueschist/eclogite and minor amounts of serpentinite and dariolarian chert. The large Norian limestone and eclogite blocks are the characteristic features of the Çetmi Ophiolitic Melange.

The Ezine Zone consists of a slightly metamorphosed epicontinental Permo-Carboniferous sedimentary sequence (the Karadağ Unit) that is tectonically overlain by a Permo-Triassic ophiolite (the Denizgören Ophiolite); both are in fault contact with high-grade metasedimentary rocks (the Çamlıca Micaschists).

The Sakarya Zone, that occurs east of the Çetmi Ophiolitic Melange of the Ayvacık - Karabiga Zone, is made up of the Triassic Karakaya Complex overlain unconformably by the Jurassic-Cretaceous sedimentary rocks. In the west, the gneisses, amphibolites and marbles of the Kazdağ Group occur tectonically below the Karakaya Complex while in the east low grade metamorphic rocks intruded by a granite form the stratigraphic basement to one of the Karakaya units (the Hodul Unit). Four tectonostratigraphic units are distinguished in the Karakaya Complex. The Nilüfer Unit made up largely of metatuffs and metavolcanic rocks with intercalations of marble and phyllite constitutes the lowest of the Karakaya units. The Hodul Unit consists of a thick sequence of arkosic sandstones overlain by Norian shales, siltstones and olistostromes with Permian limestone olistoliths. The Orhanlar Greywacke is made up of monotonous greywackes with subordinate shale and small Lower Carboniferous limestone olistoliths. The Çal Unit, forming the uppermost of the Karakaya units, consists of basic volcanic and pyroclastic flows, olistostromes with spilite and Upper Permian limestone fragments and olistoliths, volcanogenic sandstone and minor amounts of red radiolarian chert, calc-arenite and pelagic limestone. Large Middle Triassic limestone blocks (the Camialan Limestone) are associated with the Çal Unit.

All the four Karakaya units are strongly deformed during the Late Triassic Karakaya orogeny and are later unconformably overlain by the Jurassic sandstone, marn and conglomerate (the Bayırköy Formation) and by a thick sequence of Late Jurassic-Early Cretaceous limestones (the Bilecik Limestone). The Bilecik Limestone is unconformably overlain by a thin sequence of Mid-Cretaceous pelagic limestones (the Vezirhan Formation).

The juxtaposition of the four zones in the Biga and Gelibolu peninsulas occurred during the Late Paleocene/Early Eocene following the closure of the Intra-Pontide Suture along the Gelibolu Zone. Following the deposition of a thick clastic sequence during the Middle Eocene-Early Oligocene there was major uplift and erosion in the Middle-Late Oligocene. This was followed by an extensive calc-alkaline magmatism of Early to Middle Miocene age.

CONTENTS

1. INTRODUCTION

The Biga Peninsula constitutes the western end of the Sakarya Zone of the Pontides in Turkey; it is located in a critical region between the Rhodope and Serbo-Macedonian massifs in Greece in the west and the Thrace Basin in the north (Fig. 1).

The Sakarya Zone extending from the Biga Peninsula eastwards towards Ankara and farther east is characterised by the lack of Lower Paleozoic and in situ Upper Paleozoic sedimentary rocks in contrast to the Istanbul Zone farther north (Fig. 1), where there is a well developed Paleozoic sequence [1, 2]. The basement of the Jurassic and younger sediments of the Sakarya Zone is constituted by a widely exposed but poorly known Triassic orogenic rock complex, named as the Karakaya Complex, that was first described from the Biga Peninsula [3]. Although the Karakaya Complex is widely mentioned in recent papers, there are little data on its lithology, stratigraphy, structure and metamorphism. One of the principal aims of our work in the Biga Peninsula was to deliniate, describe and understand the Karakaya Complex. For this objective the whole of the Biga Peninsula and the area to the east was mapped on a 1/25.000 scale during the years of 1986 to 1989 to establish the major tectonostratigraphic units [4, 5, 6, 7]. The regional mapping unexpectedly led to the discovery of a major Late Cretaceous ophiolitic melange trending through the centre of the Biga Peninsula and to the recognition of an obducted Permo-Triassic ophiolite over a Permian carbonate platform [8].

Over the four years between 1986 and 1989 our work involved over 400 days in the field and the study of over 2000 paleontological and petrographic thin sections. Reference sections, and fossil contents determined

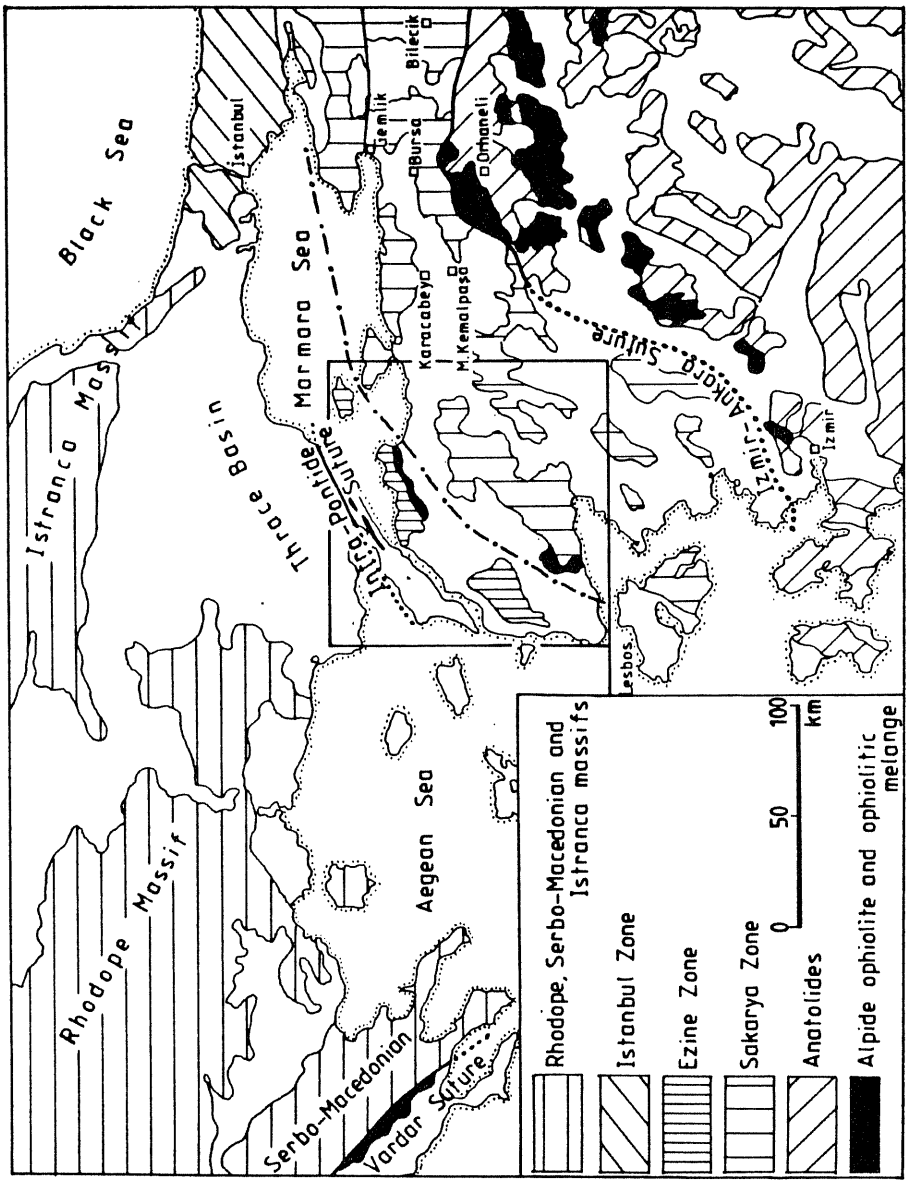

Fig. 1. Geotectonic map of the region around the Marmara Sea; the studied region is outlined. The blank regions are post-tectonic Tertiary deposits. The dash-dot line indicates the possible trace of the Paleo-Tethyan suture.

during this study for the units described for the first time are given to remedy the vagueness pervading the early studies on the Karakaya Complex.

The earliest regional studies in the Biga Peninsula were by Kaaden [9] and Kalafatçioğlu [10] who provided reconnaiscance maps for the southeastern and northwestern parts of the Biga Peninsula respectively. Aygen [11] published a similar study for the region east of the Biga Peninsula. Later Gümüş [12], Aslaner [13], Bingöl [14] and Blanc [15] mapped small areas in the southeastern part of the Biga Peninsula for their thesis work. The regional mapping by the MTA geologists during the late 1960's and early 1970's in the Biga Peninsula were synthesized and published by Bingöl et al. [3] who also introduced the term of the Karakaya Formation. A similar but unpublished synthesis for the region east of the Biga Peninsula was provided by Gözler et al. [16].

2. THE TECTONIC FRAMEWORK OF THE BIGA AND GELIBOLU PENINSULAS

Four major NE-SW trending tectonic belts are recognised in the Gelibolu and Biga peninsulas, which are from northwest: the Gelibolu, the Ezine, the Ayvacık-Karabiga, and the Sakarya zones (Figs. 1, 2). The Gelibolu and Ayvacık-Karabiga zones are made up of a Late Cretaceous/Paleocene ophiolitic melange. The Ezine Zone is characterised by a Permo-Triassic ophiolite obduction while the Sakarya Zone comprises the units of the Karakaya Complex unconformably overlain by the Jurassic-Cretaceous sedimentary rocks. The lithological, stratigraphic features and the internal structure of these tectonic belts are described below.

3. THE GELIBOLU ZONE

A Late Cretaceous/Paleocene ophiolitic melange, called the Çetmi Ophiolitic Melange, constitutes the basement of the Tertiary sedimentary rocks in the Gelibolu Peninsula and in the Thrace basin south of the Ganos Fault (Figs. 2, 3) and represents the Intra-Pontide Suture of Şengör and Yılmaz [17] that separates their Rhodope-Pontide Fragment from the Sakarya Zone. The Çetmi Ophiolitic Melange outcrops in the cores of the faulted anticlines north of Şarköy [18, 19], and is encountered below the Middle Eocene limestones in the petroleum wells opened in the Gelibolu Peninsula, around Mürefte and in the Marmara Sea (Fig. 2). The southernmost outcrop of the Çetmi Ophiolitic Melange in the Gelibolu Zone occurs at the northwestern margin of the Marmara island, where small ser-

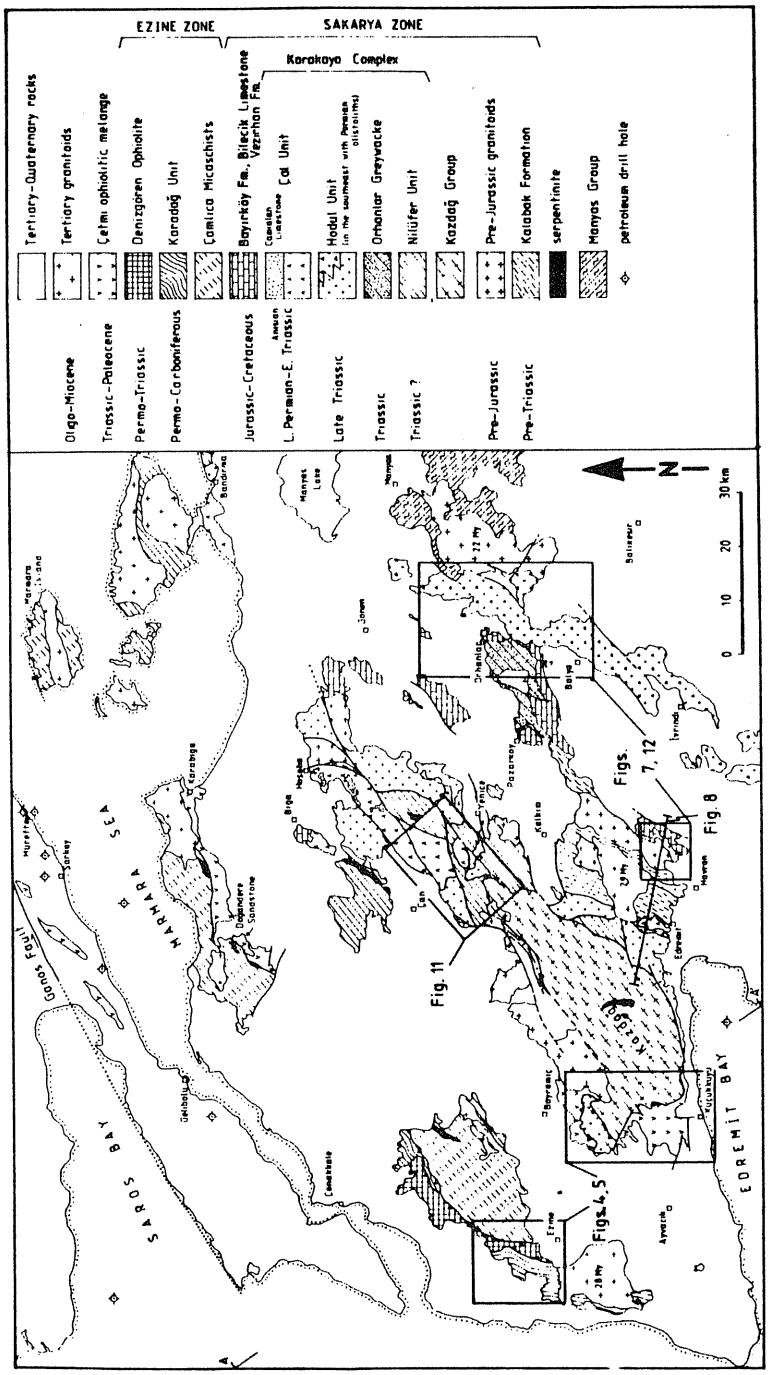

Fig. 2. Geotectonic map of the Gelibolu and Biga peninsulas; the locations of the geological maps in Figs. 4,5, 7, 11 and 12, and the cross-sections in Figs. 3 and 8 are indicated.

pentinite lenses are in steep tectonic contact with the micaschists [20] (Fig. 2).

The Çetmi Ophiolitic Melange in the Gelibolu Zone is made up mainly of serpentinite, radiolarian chert, red and grey pelagic limestone, spilite and dolerite; the basic magmatic rocks locally show blueschist metamorphism [18, 19]. These various lithologies occur as tectonically juxtaposed blocks without any obvious overall matrix. The pelagic limestones in the Çetmi Ophiolitic Melange north of Şarköy yield Late Cretaceous [18] and Mid-Paleocene (Okay 1988 pers. obs.) foraminifera. Neritic Middle Eocene limestones overlie the Çetmi Ophiolitic Melange north of Şarköy with a pronounced angular unconformity and with a few metres thick basal conglomerate. The base of the Çetmi Ophiolitic Melange in the Gelibolu Zone is not exposed.

With its lithology, internal structure and blueschist metamorphism, the Çetmi Ophiolitic Melange in the Gelibolu Zone shows the characteristic features of a sediment-starved accretionary prism.

4. THE EZINE ZONE

The Ezine Zone which is largely constituted of rocks of continental affinity, lies to the southeast of the Gelibolu Zone (Figs. 2, 3). The contact

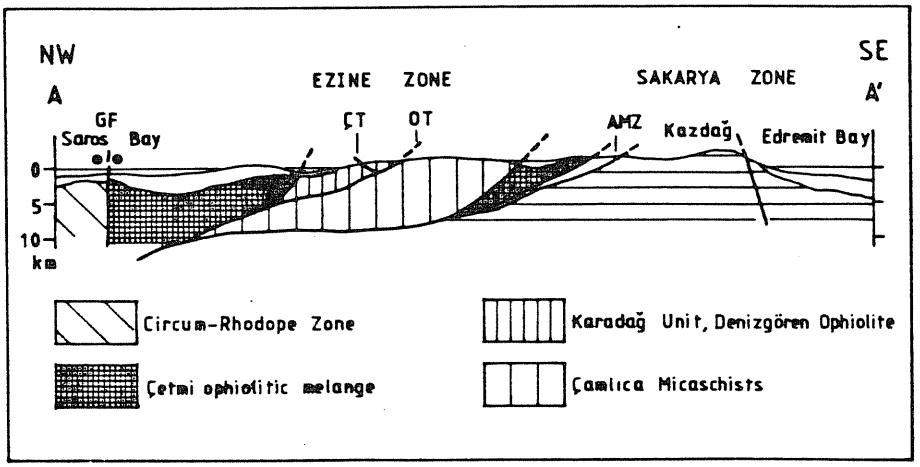

Fig. 3. Simplified interpretative cross-section across the Biga Peninsula. For the location of the cross-section see Fig. 2. The blank areas in the section represent the Tertiary and Quaternary deposits; GF, Ganos Strike-Slip Fault; ÇT, Çamlıca Thrust; OT, Ovacık Fault; AMZ, Alakeçi Mylonite Zone.

between these two belts is largely covered by the Late Tertiary deposits except on the Marmara Island where a steeply northward dipping fault separates the serpentinites of the Çetmi Ophiolitic Melange from the mica – schists of the Marmara Island [20].

The Ezine Zone is constituted of three SW-NE trending units: the Karadağ Unit, the Denizgören Ophiolite and the Çamlıca Micaschists (Figs. 1, 2, 4).

4.1. The Karadağ Unit

The slightly metamorphosed Late Paleozoic-Triassic (?) epicontinental sedimentary sequence that outcrops between Ezine and Çanakkale is named as the Karadağ Unit. The name of the unit comes from the Karadağ village north of Ezine. The reference section for the unit is along the road between Geyikli and Karadağ villages (Fig. 4).

At the base of the Karadağ sequence there are silvery grey, brownish green metashale, fine to medium grained, light pink metasandstone with quartz pebbles, white metaquartzite and calcschist which outcrop around the village of Geyikli (Fig. 4). These metaclastics pass upwards through recrystallised limestone - metashale intercalation to grey, black, thickly bedded/massive recrystallised limestones. This conformable stratigraphic contact between the metaclastics and carbonates can be observed in the rock quarries north of the Gökçebayır village. The apprx. 1600 m thick recrystallised limestone sequence is subdivided into three sections that show vertical and lateral transitions (Fig. 4). At the base there are 650 m thick massive/thickly bedded, dark unfossiliferous limestones that overlie the metaclastics. These dark limestones are conformably overlain by 600 m thick thin to medium bedded, dark grey, black, beige recrystallised limestones locally with fusulinids. A specimen collected from south of the Taptepe village has yielded *Neoschwagerina* sp. and *Stafella* sp. (det. Demir Altıner), characteristic foraminifera for the Late Permian. A similar Late Permian fauna has been described from these limestones by Kalafatçıoğlu [10] and Gözler et al. [16]. These fusulinid-bearing limestones are overlain by 350 m thick white, thickly bedded/massive limestones (Fig. 4) that in upper parts contain traces of the Late Permian alg *Mizzia* sp.

This thick neritic limestone sequence passes upwards through calciturbidite horizons to an apprx. 350 m thick synorogenic metaclastic sequence (Fig. 4), that is made up of slightly metamorphosed fine-grained green shale, siltstone, calciturbidite, pelagic cherty limestone, and limestone and basic volcanic rock olistoliths. It has undergone a greenschist facies metamorphism along with the rest of the Karadağ sequence with the develop-

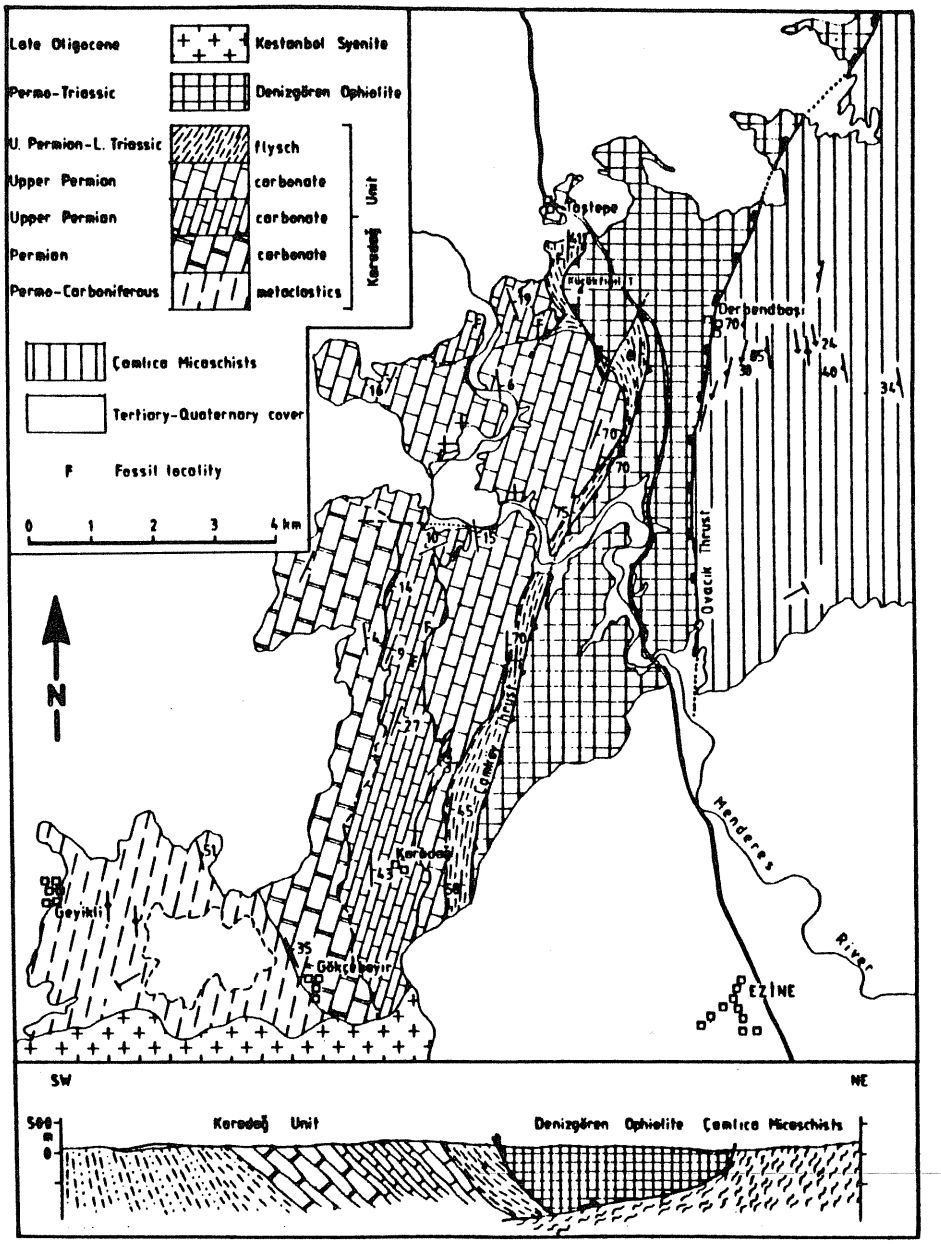

Fig. 4. The geological map and cross-section of the Ezine region.

ment of hornblend/actinolite + epidote + chlorite + albite + sphene paragenesis in the metabasic rocks. However, calciturbidites sampled from south of the village of Taştepe (Fig. 4) still retain recognisable transported Late Permian foraminifera, *Kahlerina* sp. and *Globivolvulina* sp. (det. Demir Altıner), most probably derived from the underlying Late Permian carbonate platform. The metaclastics are tectonically overlain by the Denizgören Ophiolite.

The age of the metaclastic sequence that represents rapid clastic sedimentation on a Late Permian carbonate platform in front of an advancing ophiolite nappe, is not known. However, similar synorogenic clastics, such as at the top of the Menderes Massif in southwest Turkey (e.g. Dürr [21], Gutnic et al. [22]) or in the Appalachians (e.g. Bradley and Kusky [23]) represent rapid sedimentation in a narrow time interval. Thus, the age of the synorogenic clastics at the top of the Karadağ Unit is therefore believed to be uppermost Permian to early Triassic.

4.2. Denizgören Ophiolite

The metaclastics at the top of the Karadağ Unit are tectonically overlain by the Denizgören ophiolite (Figs. 2, 4), that consists predominantly of ultramafic rocks. The name of the ophiolite comes from the Denizgören village. The Denizgören Ophiolite is made up mainly of partially serpentinised harzburgite (> 95 %). The harzburgite shows locally a distinct tectonite fabric defined by the parallel alignment of the orthopyroxenes. A good reference section of the Denizgören Ophiolite is along the new Çanakkale-İzmir highway between Troy and Ezine (Fig. 4).

The Çamköy thrust that forms the tectonic boundary between the Karadağ Unit and the Denizgören Ophiolite has an easterly dip of 70° - 80° which however decreases towards the north to 20° - 30°, west of the Küçükfiğıl Tepe (Fig. 4). In the northeast near the Armutalan village, the synorogenic clastics of the Karadağ Unit outcrop also to the east of the Denizgören Ophiolite (Fig. 2) and make a direct tectonic contact with the Çamlıca Micaschists. In the east the Denizgören Ophiolite overlies tectonically the Çamlıca Micaschists, and thus forms a 2 - 3 km wide outcrop band bounded on both sides by faults and extending for 25 - 30 km in a SSW-NNE direction (Fig. 2).

4.3. The Çamlıca Micaschists

The medium-grade metasedimentary rocks that outcrop over wide areas north of Ezine and west of Karabiga are named as the Çamlıca Mi-

caschists. The metamorphic rocks of the Marmara Island (Fig. 2) are also tentatively included in the Çamlıca Micaschists. The name of the unit comes from the village of Çamlıca northeast of Ezine. The reference section is the road between the Derbendbaşı and Çamlıca villages. The Çamlıca Micaschists outcrop in two large areas separated by an extensive Miocene volcanic cover (Fig. 2). As these two regions exhibit some lithological differences they will be described separately below.

Çamlıca Micaschists north of Ezine. The Çamlıca Micaschists that outcrop in an area of over 300 km^2 north and northeast of Ezine (Fig. 2) have a very monotonous lithology. Over 80% of the Çamlıca Micaschists in this region are made up of grey, brown, greenish brown, well-foliated, micaceous quartz-micaschists with the common mineral assemblage of quartz + muscovite + carbonate + albite ± chlorite ± clinozoisite ±garnet. Apart from these monotonous quartz-micaschists, there are yellowish calcschist, white, yellow or black marble, white metaquartzite and albite-chlorite schist which occur as one to ten metre thick horizons within the quartz-micaschists. Metabasic rocks have been encountered in only one locality west of the village of Çamlıca; they show complex polymetamorphic textures and consist of resorbing garnet associated with hornblend/actinolite, chlorite, epidote, calcite, carbonate and albite. In one specimen blue sodic amphiboles are preserved in the cores of the large hornblende grains.

The Çamlıca Micaschists represent a thick, monotonous epicontinental clastic sequence that is now however completely recrystallised and has lost all of its primary features. The very rare metabasic rocks indicate that the Çamlıca Micaschists have probably undergone an early high pressure - low temperature (HP/LT) metamorphism which was later almost completely obliterated by a greenschist facies metamorphism.

The Çamlıca Micaschists north of Ezine have a relatively simple internal structure. The foliation surfaces in the metamorphic rocks trend generally N-S with westerly dips of 20° to 50° (Fig. 4). Large number of mesoscopic isoclinal folds with axial surfaces parallel to the foliation occur in the micaschists; possibly through such folding the Çamlıca Micaschists in the region have an apparent thickness of over seven kilometres.

The Çamlıca Micaschists tectonically underlie both the Karadağ Unit and the Denizgören Ophiolite along the over 30 km long Ovacık Fault that has a west to northwesterly dip of 30° to 80° (Figs. 2, 3, 4). The dip of the Ovacık Fault increases from north to south and reaches 70° - 80° north of Ezine; in this latter region the Ovacık Fault is probably a rejuvanated structure used by a normal fault defining the western boundary of the Bayramiç Neogene Basin (Fig. 4). A 5 - 6 m thick, strongly foliated, white protomylonite occurs in the Çamlıca Micaschists immediately beneath the Ovacık

Fault. A N-S trending southward dipping strong mineral lineation has also developed in the Çamlıca Micaschists near the Ovacık Thrust; the lineation dies out gradually over a distance of two kilometers away from the thrust (Fig. 4). The lineation, that is subparallel to the trace of the Ovacık Fault, suggests either that the Ovacık Fault has a large strike-slip component or that the thrusting was N-S directed.

In the southwest the Çamlıca Micaschists are in steep tectonic contact, marked by small serpentinite slivers, with green, brownish green foliated metashale and metasiltstones that are tentatively assigned to the Nilüfer Unit of the Karakaya Complex (Fig. 2). These metashale and metasiltstones contain several serpentinite slivers; similar serpentinite slivers occur in the northeastern part of the Çamlıca Micaschists (Fig. 2). The contact relations of these serpentinite slivers indicate that the emplacement of the serpentinite post-dates the metamorphism and the development of the foliation in the Çamlıca Micaschists.

The Çamlıca Micaschists west of Karabiga. In this region the Çamlıca Micaschists occupy an area of apprx. 200 km^2 north and west of the ophiolitic melange of the Ayvacık-Karabiga belt (Fig. 2). A major part of the Çamlıca Micaschists in this region is made up of micaceous, well-foliated, grey, dark grey, red, brown, silvery grey quartz-micaschists and phyllites that also include 1 to 100 m thick calcschist, metaquartzite and marble horizons. Serpentinite tectonic lenses aligned parallel to the foliation and ranging in size from a few ten metres to 2 - 3 kilometres occur in the metamorphic sequence (Fig. 2). Apart from the serpentinite lenses, small tectonic slices of the Çetmi Ophiolitic Melange are also observed in the metamorphic sequence.

The internal structure of the Çamlıca Micaschists west of Karabiga is difficult to evaluate because of the very poor exposure in this region. However, the structure in the Karabiga region does not appear to be as simple as that north of Ezine; the strike and dip of the foliation in the metamorphic rocks varies over short distances although a general east-west strike is the most common.

The Çamlıca Micaschists west of Karabiga are intruded by two large granodioritic bodies of probable Late Tertiary age (Fig. 2), and are unconformably overlain by the Middle Eocene and younger sedimentary and volcanic rocks. In the south they are in tectonic contact with the ophiolitic melange of the Ayvacık - Karabiga belt along steeply dipping faults (Fig.2).

5. THE AYVACIK - KARABIGA ZONE

The Ayvacık-Karabiga Zone is constituted like the Gelibolu Zone by the Çetmi Ophiolitic Melange but is situated between the Ezine and the Sakarya zones. It has two large outcrop areas separated by an extensive Miocene volcanic cover (Fig. 2).

5.1. The Çetmi Ophiolitic Melange between Küçükkuyu and Bayramiç

The Çetmi Ophiolitic Melange that outcrops between the Küçükkuyu and Bayramiç lies tectonically over the high-grade metamorphic rocks of the Kazdağ Group with an intervening two kilometre thick mylonite zone in the north called the Alakeçi Mylonite Zone (Fig. 5). The Çetmi Ophiolitic Melange in this region also includes large tectonic slices of eclogite and garnet-micaschist named as the Elliayak Eclogite.

5.1.1. The Alakeçi Mylonite Zone

The name of the mylonate zone comes from the Alakeçi village and its reference sections are along the forest roads going south and east from the village of Çaldağ (Fig. 5).

The Alakeçi Mylonate Zone is constituted mainly of two lithologies, mylonated gneiss and metaserpentinite. Sheared and mylonated gneisses form brown, grey, yellow, friable rocks with a strong N-S trending and northward dipping lineation (Fig. 5).

Petrographically the mylonates are made up of finely granulated, foliated and partly recrystallised quartz, sericite, opaque and biotite, and of plagioclase porphyroclasts that are aligned parallel to the lineation. Within the mylonated gneisses there are black amphibolites and strongly boudinaged marble lenses.

Metaserpentinite lenses ranging in size from 10 cm to 3 - 4 km occur in the mylonated gneisses of the Alakeçi Mylonite Zone (Fig. 5). The metaserpentinite is dark green, bluish green, generally fine-grained, massive and hard. Petrographically it has completely lost its primary ultramafic texture and consists mainly of antigorite with minor antophyllite, talc and diopside. Rare, fine-grained microgabbro lenses made up of hornblend and plagioclase occur in the metaserpentinite.

The lower contact of the Alakeçi Mylonite Zone with the Kazdağ Group, which dips at 30° - 40° to the northwest, is transitional over a distance of a few hundred metres; in contrast its upper tectonic contact with

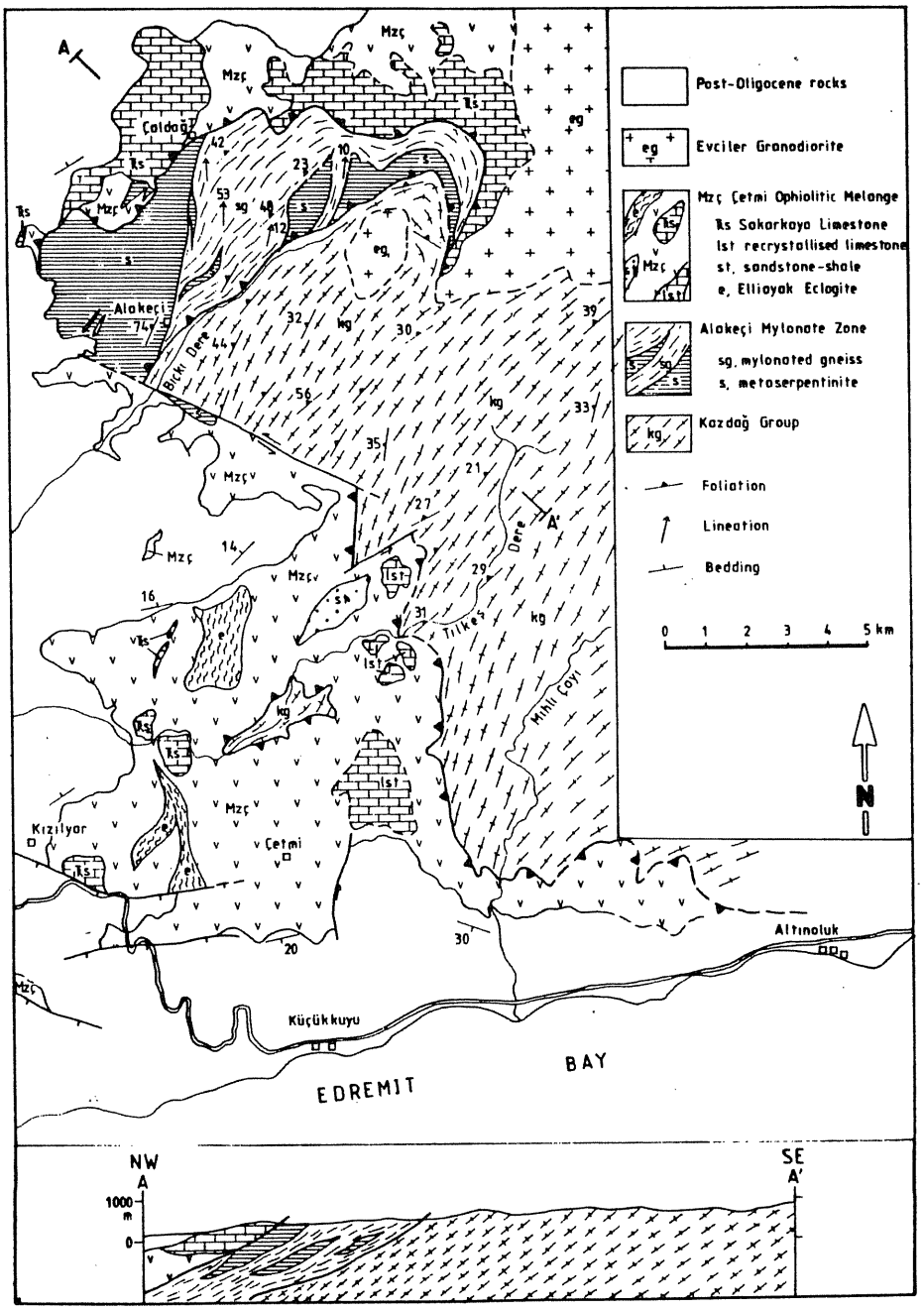

Fig. 5. The geological map and cross-section of the western flank of the Kazdağ between Küçükkuyu and Bayramiç.

the Çetmi Ophiolitic Melange is sharp. Spilite and recrystallised limestone of the Çetmi Ophiolitic Melange lie over the metaserpentinite and mylonated gneisses of the Alakeçi Mylonite Zone with dips ranging between 10° and 80°. The structural thickness of the Alakeçi Mylonite Zone is about two kilometres (Fig. 5).

The Alakeçi Mylonite Zone is not observed south of a steeply dipping sinistral strike slip fault with a minimum displacement of nine kilometres (Fig. 5). South of this fault the Çetmi Ophiolitic Melange lies directly over the Kazdağ Group. However, as discussed later this latter tectonic contact could be a Tertiary normal fault that would have cut out the Alakeçi Mylonite Zone in this region.

The Alakeçi Mylonite Zone probably extended all along the northwestern margin of the Kazdağ Group before the intrusion of the Evciler Granodiorite. Remnants of the Alakeçi Mylonite Zone occur south of Çan (Fig. 2) where they consist mainly of metaserpentinite with tectonic lenses of sheared gneiss, metatuff, spilite, recrystallised limestone and radiolarian chert.

5.1.2. The Çetmi Ophiolitic Melange

The Çetmi Ophiolitic Melange that outcrops over a large area west of the Kazdağ Group is made up largely of spilitised basic volcanic and pyroclastic rocks, Upper Triassic, Upper Jurassic-Lower Cretaceous and Upper Cretaceous limestone blocks, shale and greywacke. Apart from these lithologies, that make up of over 90% of the melange, there are minor serpentinite and radiolarian chert. In addition large tectonic slices of garnet-micaschist and eclogite occur in the Melange (Fig. 5).

The spilitised basic volcanic rocks are dark green, blackish green, generally fine-grained with sparse amygdoils; locally as in the west of the Sakarkaya Hill, pillow structures are observed in the volcanic rocks. Spilites generally do not show any foliation, and consist of albite, pink Ti-augite and chlorite; only those around the eclogite tectonic blocks show a distinct foliation and a greenschist facies mineral assemblage with actinolite and epidote.

There are several types of limestone blocks in the Çetmi Ophiolitic Melange. The most common variety is a cream coloured, fine-grained, thinly-bedded to massive, locally cherty, Late Triassic limestone that are generally embedded in spilitised basic volcanic rocks and range in size from a few metres to two kilometres (Fig. 5). This limestone, named as the Sakarkaya Limestone, can best be observed in Sakarkaya and Beşik Hills. The Late Triassic limestone blocks vary in lithology from thinly bedded, pelagic

micrite with radiolaria to thickly bedded/massive biorudites with abundant Late Triassic bivalve *Megaladont* and represent lagoon, reef and fore-reef facies. *Involutina* forms, characteristic for the Late Triassic, are frequently found in the thinly bedded pelagic limestone blocks. Specimens collected from various such blocks have yielded *Trochammina* sp.; *Agathammina austroalpina, Galeanella* cf. *panticae; Nodosaria* sp., *Nodosaria ordinata, Austrocolomia* sp.; *Aulotortus* spp., *Aulotortus gaschei, Aulotortus communis, Aulotortus* gr. *sinousus, Spiroamphorella carpathica* (det. Demir Altıner and Murat Köylüoğlu), that are characteristic for Norian. These pelagic limestone blocks also contain the characteristic Late Norian bivalve *Monotis salinaria* (det. Leopold Krystyn). Gözler [24] also assigns a Middle-Late Triassic age to the Sakarkaya Limestone. Large recrystallised limestone blocks in the Çetmi Ophiolitic Melange near its contact with the Kazdağ Group are probably also of Triassic (Fig. 5). Similar late Triassic limestone blocks with megalodonts associated with Triassic volcanic rocks are described from the Haybi Complex of the Hawasina nappes in oman [25, 26] and from the Zagros Mountains in south Iran [27, 28]. In Oman they are described as having primary contacts with the underlying basic volcanic rocks and are regarded as carbonate build-ups on rift volcanics [26].

Apart from these Late Triassic limestones, small, red Upper Cretaceous limestone blocks occur in the Çetmi Ophiolitic Melange southeast of the Kızılyar village (Fig. 5). They form 0.2 - 1 metre large, red, silty biomicrite blocks of Couches-Rouges facies embedded in a greywacke-shale matrix. Specimens from these blocks yield Turonian-Santonian pelagic foraminifera: *Marginotruncata* sp., *M. coranata, M. marginata, M.* cf. *pseudolinneiana* (det. İzver Tansel). From the same region Brinkmann et al. [29] describe similar pelagec foraminifera of Late Turonian-Coniacian age from a similar limestone, which however, they wrongly interpret as unconformably overlying the greywackes and spilites. A very informative section in the Çetmi Ophiolitic Melange west of Karabiga, which is described below, indicate that these Upper Cretaceous red limestone blocks originally had probable stratigraphic relation with the Norian limestones. Small neritic limestone blocks of Late Jurassic-Early Cretaceous age with *Pseudocyclammina* sp., *Conicospirillina* sp., *Trocholina* sp. (det. M. Baykal), reddish nodular Hallstatt limestone blocks with ammonites and blocks of red radiolarian chert occur in close association with the above described Upper Cretaceous limestones southeast of the Kızılyar.

Black, dark grey greywacke and intercalated siliceous shale are relatively common in the melange; their contacts with the spilite are tectonic. A large tectonic slice of light beige, grey, medium bedded feldspathic sandstone and intercalated laminated shale occurs in the Çetmi Ophiolitic

Melange forming the Gelinmezarı ridge west of the Kapıkaya Hill (Fig. 5), it probably represents a ponded basin developed on the accretionary complex.

Red, pink and rarely green, thinly bedded radiolarian chert form a few ten metres large tectonic blocks in the spilites. Serpentinite is a rare rock type in the melange and occurs as a few small (< 10 m) tectonic lenses.

The Çetmi Ophiolitic Melange north of Küçükkuyu has a complexly imbricated internal structure. Although spilitised basic volcanic rocks and greywacke are the most common lithology, they do not form an obvious matrix for the other rock types; rather the Çetmi Ophiolitic Melange represent a rock complex cut by a dense network of steeply dipping, and generally N-S trending faults and shear zones along hich the various lithology of the melange are juxtaposed. The very heterogeneous distribution of strain in the Çetmi Ophiolitic Melange is related to these complex array of shear zones which result in close association of undeformed and chaotically deformed and foliated rocks over short distances. With its lithological and structural features the Çetmi Ophiolitic Melange represents an accretionary complex with minor trench fan and axial channel deposits [30]; it probably also includes fragments of a Mesozoic passive continental margin.

The age of the rocks of the Çetmi Ophiolitic Melange north of Küçükkuyu range from Late Triassic to Late Cretaceous. The melange is unconformably overlain by the Miocene sediments and is intruded by the Evciler Granodiorite, most probably of Late Oligocene-Early Miocene age (Fig. 5), thus constraining the age of the emplacement of the Çetmi Ophiolitic Melange over the Kazdağ Group between the latest Cretaceous and Late Oligocene.

5.1.3. Elliayak Eclogite

The Elliayak Eclogite consists of garnet-micaschists and metabasic rocks metamorphosed in the eclogite facies; it occurs as large tectonic lenses in the Çetmi Ophiolitic Melange north of Küçükkuyu (Fig. 5). The unit was named after the Elliayak Hill north of Küçükkuyu which is made up of these rocks.

The Elliayak Eclogite is made up mainly of silvery grey, micaceous, foliated, coarse grained garnet-micaschists that have the mineral assemblage of quartz + white mica + garnet + calcite. The eclogites occur as 0.2 to 20 m thick horizons between the garnet-micaschists. They form dark bluish green, massive, hard, banded, medium to coarse grained rocks with the common mineral assemblage of garnet + omphacite + glaucophane + epidote + white mica.

5.2. The Çetmi Ophiolitic Melange in the west of Karabiga

The ophiolitic melange that outcrops westwards from Karabiga as a 3 - 4 km wide and 35 - 40 km long belt (Fig. 2) closely resembles in its lithology and structure the Çetmi Ophiolitic Melange in the Gelibolu Zone and that in the north of Küçükkuyu, and is assigned to this unit. In the Karabiga region the Çetmi Ophiolitic Melange is in tectonic contact with the Çamlıca Micaschists and is intruded by a large granodiorite pluton (Fig. 2).

The Çetmi Ophiolitic Melange west of Karabiga consists, in order of abundance, of spilite, various types of limestone, shale, sandstone, serpentinite and radiolarite. Spilites represent submarine flows and tuffs and have largely preserved their original features only infrequently show foliation; they display stratigraphic contacts with radiolarian cherts and red micrites along the Kemer Stream.

Large, white, generally thickly bedded to massive Late Triassic limestone blocks also occur in the Çetmi Ophiolitic Melange west of Karabiga. Specimens from these Sakarkaya Limestone blocks have yielded a very similar Late Triassic fauna to that north of the Küçükkuyu with *Aulotortus* cf. *gaschei*, Dasycladacea, *Trocholina* sp (det. Murat Köylüoğlu). A very important section involving the Sakarkaya Limestone is found 1.5 km north of the Karapürçek Village. At the base of this Karapürçek section there is an over 50 metre thick sequence of thickly bedded grey to white partly recrystallised Sakarkaya Limestone (Fig. 6). Specimens from this neritic limestone have yielded a Norian to Rhaetian fauna of *Trochammina* sp., *Frondicularia* sp., *Aulotortus* sp., *Aulotortus* cf. *gaschei, Trocholina* sp., Nodosariidae, *Miliopora* sp., Solenoporacea, *Cayeuxia* sp. (det. Murat Köylüoğlu and İsmet Sezgin). These neritic Upper Triassic limestones are overlain sharply, through a disconformity, by a 25 metre thick pelagic sequence of red, laminated, thinly bedded limestone with calciturbidite intercalations overlain by thinly bedded silty micrites that yield a mid-Cretaceous (Cenomanian-Turonian) fauna of *Hedbergella* sp., *Hedbergella* cf. *delrioensis, Praeglobotruncana* sp., *Heterohelix* sp (det. Murat Köylüoğlu and İsmet Sezgin). The mid-Cretaceous silty micrites are in turn overlain by volcanogenic sandstones and spilitised basic volcanic rocks (Fig. 6). Thus this small section preserves a stratigraphic record between the Late Triassic and Late Cretaceous with a major disconformity probably encompassing the whole of the Jurassic, and the Early Cretaceous.

In the Çetmi Ophiolitic Melange west of Karabiga there are, apart from the neritic Late Triassic limestones, blocks of medium to thickly bedded calciturbidite, radiolarian chert with red thinly bedded pelagic limestone intercalations and thinly bedded grey limestone with abundant pela-

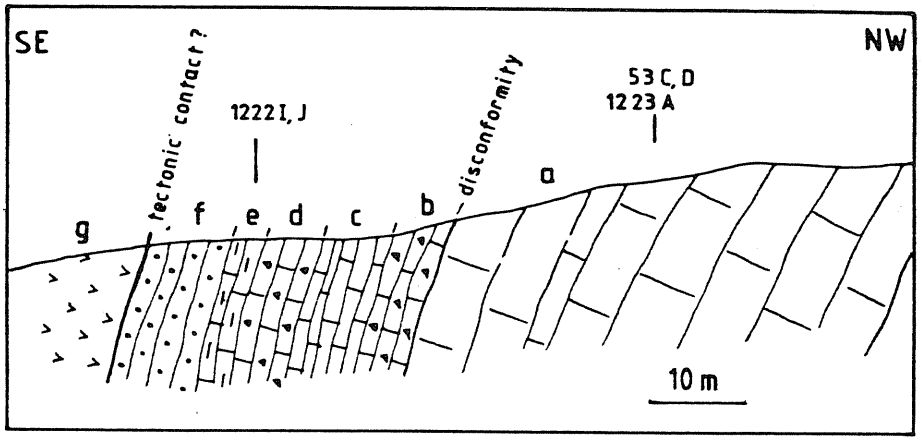

Fig. 6. The Karapürçek section in the Çetmi Ophiolitic Melange west of Karabiga showing the Cretaceous disconformity above the Norian limestones. a. thickly bedded to massive, partly recrystallised, neritic, grey Norian limestone. Sample 53C, 53D and 1223A, *Trochammina* sp., *Frondicularia* sp., *Aulotortus* cf. *gaschei, Trocholina* sp., Nodosariidae, Miliolidae b. brecciated, thinly bedded, red limestone, c. finely laminated thinly bedded, red micrite, d. thinly bedded, red intramicrite with abundant intraclasts and volcanic fragments, e. yellowish brown, thinly bedded, silty, fossilifereous Cretaceous micrite. Sample 1222I, J, *Hedbergella* sp., *Hedbergella* cf. *delrioensis*. f. dark grey, volcanogenic greywacke, g. brownish green spilitised basic volcanic rock.

gic lamellibranchs; these have not yielded any ages but are probably late Mesozoic. One small, white micritic limestone block in the spilites contains Tintinidae? and is probably of Late Jurassic age. A very infrequent limestone type is a dark grey small neritic limestone with *Calcisphaera* sp., probably of Permian age.

A large, internally homogeneous tectonic slice of sandstone and shale occurs in the Çetmi Ophiolitic Melange around the village Doğandere (Fig. 2). The slice has a minimum thickness of a few hundred metres and is sandwiched through low angle tectonic contacts by the other lithologies of the Çetmi Ophiolitic Melange. It consists of greenish grey, light grey, medium to thickly bedded sandstones intercalated with thin, fine grained dark shales; petrographically the sandstones consist of poorly sorted, angular quartz, plagioclase, shale, opaque, white mica and chert grains in a siliceous matrix. The lithological features of the Doğandere Sandstone can be observed along the roads trending west and northwest from the Doğandere village. Doğandere Sandstone also includes small amounts (< 5%) of limestone, radiolarian chert and spilite blocks as olistoliths. One such one metre large limestone olistolith has yielded *Hedbergella* gr. *planispira, Hedbergella*

gella gr. trochospira? (det.Demir Altıner), foraminifera characteristic for the Apsian-Albian. Elongate tectonic slices of sheared serpentinite occur in the Doğandere Sandstone near its contact with the Çamlıca Micaschists (Fig. 2).

The Doğandere Sandstone represents a local turbidite fan deposited on a growing accretionary prism and forms a good ancient example of a small ponded basin developed on the trench wall [31]. It is of post-Albian and most probably of Paleocene age.

Two steeply dipping faults locally marked by serpentinite slivers and trending E-W and NE-SW respectively separate the Çetmi Ophiolitic Melange from the Çamlıca Micaschists in the north (Fig. 2); these faults are most probably Late Tertiary structures. In a small region between these two faults the Çamlıca Micaschists are observed to lie tectonically over the Çetmi Ophiolitic Melange (Fig. 3).

6. THE SAKARYA ZONE

The general absence of the Paleozoic rocks in northwest Anatolia in stark contrast to the well developed Paleozoic sequence in the Istanbul region, seems to have been first noticed by Brinkmann [32, 33] who named this zone as the Mysisch-Galatische Scholle [32] or as the North Anatolian Welt [33] and regarded the absence of the Paleozoic rocks in this region due to erosion at the end of the Paleozoic. Şengör and Yılmaz [17] called this region as the Sakarya Continent and established its boundaries as the Intra-Pontide suture in the north and the İzmir - Ankara suture in the south. Both Brinkmann [32, 33] and Şengör and Yılmaz [17] terminate the Sakarya Continent east of Ankara by joining the northern and the southern sutures. Okay [1, 34] extended the Sakarya Zone to include the Eastern Pontides that displays a very similar stratigraphy and tectonic development to that of northwestern Turkey.

Throughout the Sakarya Zone a clear distinction can be made between the complexly deformed, commonly metamorphosed pre-Jurassic basement and the little deformed and not regionally metamorphosed Jurassic-Tertiary cover. The pre-Jurassic basement of the Sakarya Zone in the eastern part of the Biga Peninsula can be subdivided into three units: the pre-Karakaya units, the Kazdağ Group and the units of the Karakaya Complex.

6.1. The Pre-Karakaya Units

The definite pre-Karakaya units in the Biga Peninsula occur to the north of Edremit and Havran, and comprise low-grade metasediments, cal-

led the Kalabak Formation, and an intrusive granodiorite, the Çamlık Metagranodiorite (Figs. 2, 7).

6.1.1. The Kalabak Formation

The low-grade metasedimentary rocks, that constitute part of the pre-Triassic basement, outcrop in a zone extending from Edremit and Havran northwards towards Pazarköy (Fig. 2). The reference section for these metamorphic rocks, called the Kalabak metamorphic sequence by Krushensky et al. [35] is along the ridge trending northward from the village of Kalabak, north of Havran (Fig. 7). In this section the Kalabak Formation consists of fine-grained, yellowish grey, silvery grey, dark grey phyllite, medium-grained yellowish grey quartzo-felspathic schist that shows distinct compositional lamination, and a few metres thick infrequent marble and green metabasite horizons, while dark to bluish grey, brown, micaceous phyllites make up the Kalabak Formation in the north of Edremit.

Petrographically the phyllites consist mainly of quartz, albite, muscovite and biotite. The rare metabasic horizons contain the greenschist facies mineral assemblage of actinolite + epidote + chlorite + albite.

The Kalabak Formation is intruded in the east by the pre-Late Triassic Çamlık and in the west by the Oligo-Miocene Eybek granodiorites (Figs. 2, 7). In the north of Edremit the Kalabak Formation is thrust over the distal turbidites of the Hodul Unit of the Karakaya Complex and is tectonically overlain by a klippe of spilite, shale and Permian limestone olistoliths of the Çal Unit again of the Karakaya Complex (Fig. 8). In the northeast south of Pazarköy the Kalabak Formation lies tectonically over the Orhanlar Greywacke of the Karakaya Complex in an imbricate tectonic zone (Figs. 2, 9). In this latter region the Kalabak Formation is unconformably overlain by the Jurassic clastics of the Bayırköy Formation (Fig. 9).

6.1.2. The Çamlık Metagranodiorite

The pre-Upper Triassic metagranodiorite that extends in a 4 - 5 km wide zone northeastward from Havran is named as the Çamlık metagranodiorite (Fig. 2). The name of the unit comes from the village of Çamlık in this region (Fig. 7).

The Çamlık Metagranodiorite consists essentially of quartz, plagioclase and chlorite; it is leucocratic and is frequently cut by aplite and quartz veins; it has a medium-grained aphyric texture that frequently shows a distinct tectonic foliation; the foliation is especially strongly developed near its contact with the Kalabak Formation where it is parallel to the foliation in

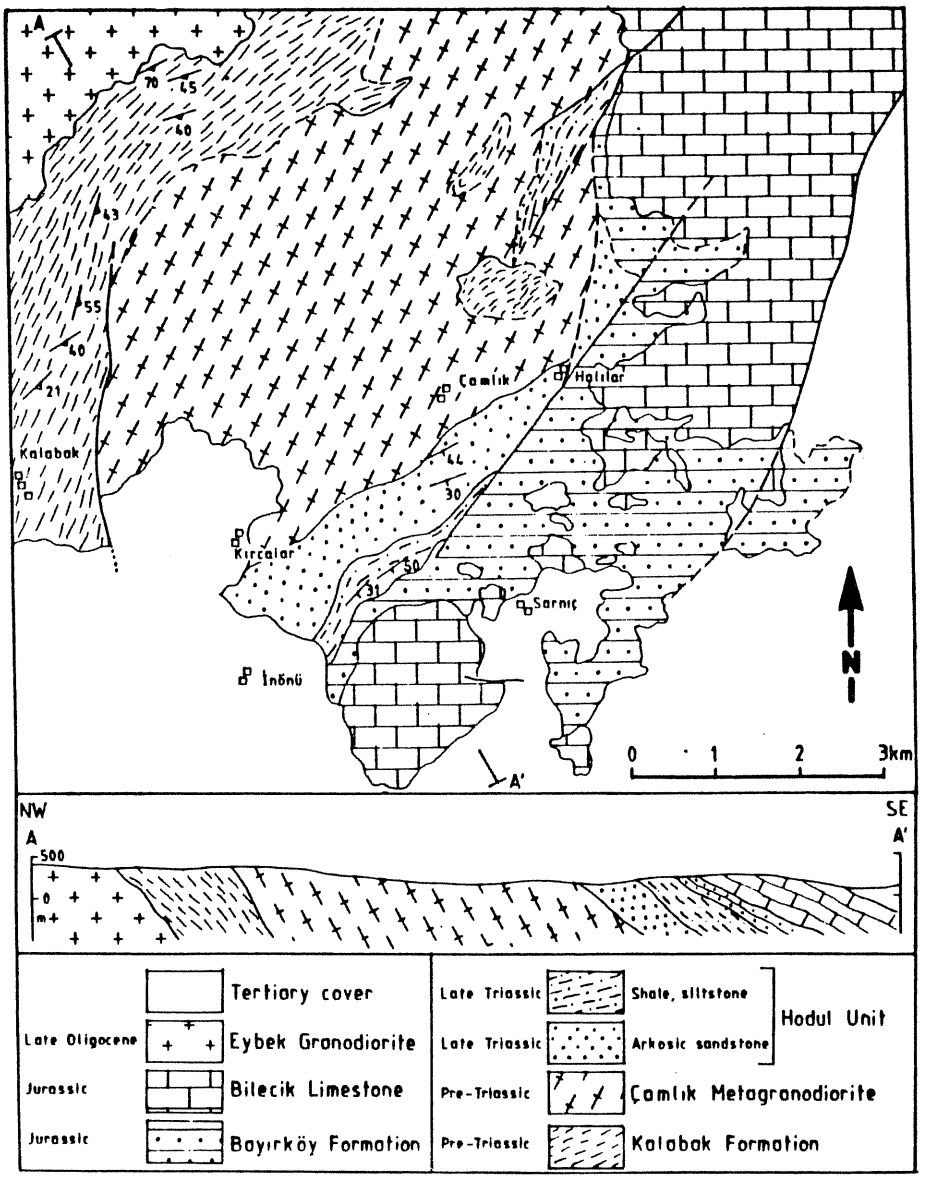

Fig. 7. The geological map and cross-section of the region northeast of Havran. Modified from Gümüş [12], Aslaner [13] and Krushensky et al [35].

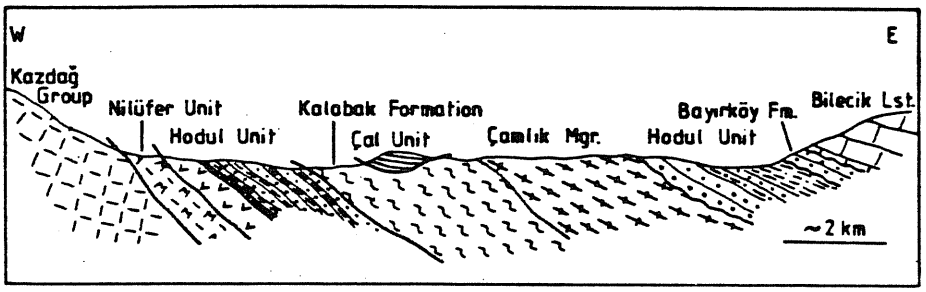

Fig. 8. E-W trending simplified sketch cross-section passing from north of Edremit showing the tectonic relations between the Kazdağ Group, the Karakaya units, the Kalabak Formation and the Çamlık metagranodiorite. The Hodul Unit tectonically overlying the Nilüfer Unit in the west is strongly tectonised in contrast to the little deformed Hodul Unit in the east.

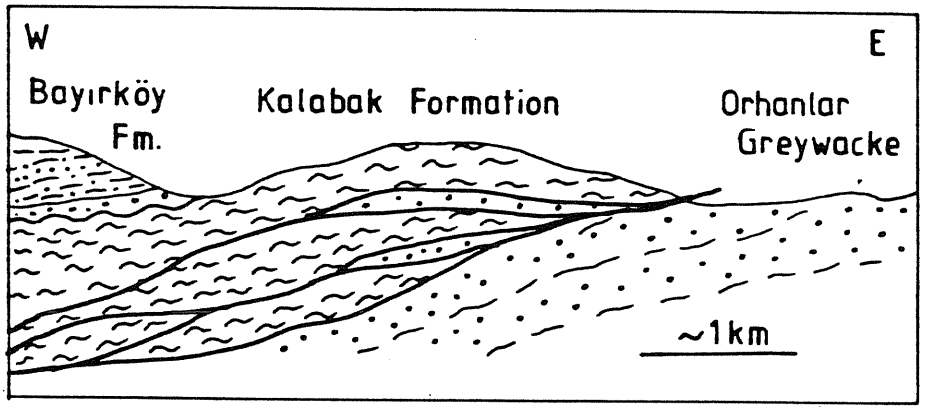

Fig. 9. Schematic cross-section from south of Pazarköy showing the imbricate thrust zone between the Kalabak Formation and the Orhanlar Greywacke and the unconformably overlying Jurassic Bayırköy Formation.

the phyllites, and gradually dies out towards the inner parts of the granodiorite. The field relations, especially the presence of contact metamorphic rocks in the Kalabak Formation at the margin of the Çamlık Metagranodiorite suggest that the Çamlık Metagranodiorite intruded the Kalabak Formation prior to the regional greenschist facies metamorphism that affected both units. A second large outcrop of the Çamlık Metagranodiorite occurs north of the Eybek Mountain (Fig. 2).

In the vicinity of the Çamlık village the Çamlık Metagranodiorite is overlain with a clear discordance by the Upper Triassic coarse arkosic sandstones of the Hodul Unit, which include 3 - 4 cm large granodiorite

and phyllite pebbles (Fig. 7). Krushensky et al. [35] for reasons difficult to comprehend, denie the existence of the Çamlık Metagranodiorite altogether and show it as sandstone on their maps, while Gümüş [12] and Aslaner [13] have regarded the Çamlık Metagranodiorite and the Oligo-Miocene Eybek Granodiorite as part of the same pluton and assigned both a pre-Late Triassic age.

The scanty evidence suggests that the pre-Permian basement of the Sakarya Zone was made up mainly of granitoids and low grade metasedimentary rocks. The Gümüşhane granite in the eastern part of the Sakarya Zone [36], the Söğüt granite southeast of Bilecik [37], the Karacabey granodiorite north of Karacabey and the metasedimentary rocks associated with this granitic rocks are part of this pre-Permian basement of the Sakarya Zone. Saner [38] also describes from south of Geyve, Lower Permian carbonates and basal clastics that are overlying a metamorphic and granitic basement. The isotopic age of only one of these pre-Jurassic granitoids, namely the Söğüt granite, is known; a single biotite K/Ar age from this granodiorite gives 272 ± 3 Ma (Early Permian) [39] suggesting a Late Paleozoic (Variscan ?) age for the consolidation of this basement.

The pre-Alpine crystalline basement of the Istanbul Zone and of the Taurides is known to be of Precambrian age; a Late Paleozoic crystalline basement is described from the Pelagonian Zone in Greece where low-grade metasedimentary rocks are associated with granitoids of late Carbonifereous ages [40, 41]; this basement is overlain by a thick and predominantly clastic sequence of Permo-Carbonifereous age [42] which interestingly includes olistoliths and turbidites in the Late Permian deposits on the island of Salamis [43]. It is here suggested, that in terms of the pre-Triassic history, the Sakarya Zone forms the eastern continuation of the Pelagonian Zone in Greece.

6.2. Pre-Jurassic Granitoids

Apart from the Çamlık Metagranodiorite there are two other large pre-Jurassic granitic bodies in the Biga Peninsula southeast of Biga (Fig. 2). These are the Yolindi Metagranodiorite and the Sarıoluk Granodiorite. However, unlike the Çamlık Metagranodiorite their present relation to the units of the Karakaya Complex are either tectonic or intrusive.

6.2.1. The Yolindi Metagranodiorite

The Yolindi Metagranodiorite occupies an area of 30 km^2 southeast of Biga (Fig. 2) and consists of deformed, medium grained, homogeneous granodiorite with a gneissic texture; it is cut locally by aplite veins. Its name

comes from the village of Yolindi located on the metagranodiorite. The Yolindi Metagranodiorite has a equigranular, foliated texture and consists of plagioclase, quartz, biotite and hornblende. The foliation is marked by the parallel aligned biotite and hornblende and rotated plagioclase crystals; however, only the quartz grains are recrystallised. Although it is clearly of granitic origin, the Yolindi Metagranodiorite is shown on the map of Bingöl et al. [3] as part of the Kazdağ Group.

A 750 m thick and 5 km long slice of the Kabalak Formation made up of dark phyllite, micaschist and marble occurs in steep tectonic contact with the Yolindi Metagranodiorite in the southwest around the village of Kazıklı (Fig. 2). Both the Yolindi Metagranodiorite and the Kalabak Formation are separated in the west from the Çal Unit of the Karakaya Complex, and in the east from the Hodul Unit of the same complex by very steeply dipping Tertiary strike-slip faults that formed a compressive segment leading to the uplift of this piece of the Pre-Karakaya basement (Fig. 2).

6.2.2. The Sarıoluk Granodiorite

The Sarıoluk Granodiorite is located immediately southwest of the Yolindi Metagranodiorite (Fig. 2) but shows no foliation; its name comes from the Sarıoluk village located on the granodiorite. It has an equigranular, homogeneous magmatic texture. In the east it is overlain by a clear unconformity by the Jurassic Bayırköy Formation. Again a Tertiary strike-slip fault separates the Sarıoluk Granodiorite from the Hodul Unit in the north while a probable intrusive contact with the Hodul Unit is observed in the west (Fig. 2).

6.3. The Kazdağ Group

The gneiss, amphibolite and marble that make up the core of the Kazdağ Mountain (the ancient Ida) are named by Bingöl et al. [3] as the Kazdağ Group. The Kazdağ Group forms a 50 km long SW-NE trending complex anticlinorium cut by several, most probably Late Tertiary, granodiorites (Fig. 2). In the east the Kazdağ Group is tectonically overlain by the metatuffs (Nilüfer Unit) and arkosic sandstones (Hodul Unit) of the Karakaya Complex, and in the west and north by the late Cretaceous Çetmi Ophiolitic Melange (Figs. 2, 5). The base of the Kazdağ Group is not exposed.

Medium to coarse-grained, generally banded, grey, light grey gneisses are the most common lithology in the Kazdağ Group. Schuiling [44] notes a widespread N-S trending lineation in the gneisses over the whole of the

Kazdağ Group. Petrographically the gneisses consist of quartz + plagioclase + biotite + hornblende ±diopside ± scapolite ± garnet ± opaque ± sphene. Bingöl [14] and Gözler [24] also record staurolite, kyanite and sillimanite in the gneisses. Marble forms 1 - 20 metre thick white, massive, coarse-grained, locally laminated horizons in the gneiss and amphibolite. Medium to coarse-grained, dark green amphibolites consist of plagioclase + horblende ± diopside ± opaque. Apart from these common rock types there is a metaophiolite sequence of metadunite, metaharzburgite and metagabbro, which give splendid outcrops at the summit of the Kazdağ (Fig. 2) [14]. This metaophiolite sequence overlies a thick marble horizon and has undergone the same deformation and metamorphism along with the rest of the Kazdağ Group. The total structural thickness of the Kazdağ Group is over 10 km. Good reference sections for the Kazdağ Group exist in the western part along the Tilkeş and Bıçkı valleys (Fig. 5).

Amphibolite and marble intercalations are predominant in the Kazdağ Group near its eastern contact with the tectonically overlying Nilüfer Unit of the Karakaya Complex which also consists of metabasite and marble (Fig. 11). However, the metamorphic grade is always lower in the metabasites of the of the Nilüfer Unit, where diopside, common in the amphibolites of the Kazdağ Group, is absent.

Isotopic age dating by Bingöl [45] on the Kazdağ Group has given controversial results: The K/Ar mineral ages in the gneisses are 23 to 27 Ma, while the Rb/Sr mineral ages range from 29 Ma to 253 Ma; the isochron age is 233 ± 24 Ma. The young ages are reset ages caused by the strong Oligo-Miocene magmatism. Geologically the most reasonable age for the regional metamorphism is the late Triassic isochron age.

Geomorphological data [46] and the presence of Miocene siltstones and shales immediately south of the Kazdağ Mountain [47] that rises sharply to over 1700 metres indicates that the uplift of the Kazdağ Group is of post-Miocene and most probably of Pliocene age. The Oligo-Miocene mineral ages obtained from the Kazdağ Group also testify that these rocks were deeply buried during this time. The Pliocene uplift of the Kazdağ Mountain is achieved in the south by the normal faults now bounding the northern margin of the bay of Edremit, and in the east and west by the steeply dipping tectonic contacts that in the east separate the Kazdağ Group from the overlying metatuffs of the Karakaya Complex. This suggest that the Kazdağ Group originally formed the lower parts of the now tectonically overlying metatuff-marble unit of the Karakaya Complex and constitutes a core complex [48, 49] of Pliocene age. The difficulty encountered in some parts such as west of the Susuzdağ, in placing a contact between these two units is explicable in this model involving a major normal fault

between these two units (Figs. 8, 11). Thus, it is here suggested that the upper parts of the Kazdağ Group constitute the deeply buried parts of the Nilüfer Unit of the Karakaya Complex, while its lower parts may represent the stratigraphic or the tectonic basement of the Karakaya Complex. This is also suggested by the Late Triassic isochron age obtained from the Kazdağ Group [45]. Papanikolaou and Demirtaşlı [50] correlate the Kazdağ Group with the Rhodope Massif and the tectonically overlying Nilüfer Unit with the Circum-Rhodope Belt in Greece.

6.4. The Karakaya Complex

This pre-Jurassic orogenic complex, that has a wide distribution in the Sakarya Zone, is first described from the Biga Peninsula by Bingöl et al. [3]. They described the Karakaya Formation as consisting of slightly metamorphosed, spilitic basalt with exotic Upper Permian limestone blocks, mudstone, radiolarite, feldspathic sandstone, quartzite, conglomerate and siltstone which overlie unconformably the gneisses of the Kazdağ Group. The Karakaya Formation was ascribed an Early Triassic age based on the presence of exotic Upper Permian limestone blocks and the Middle Triassic limestones that were regarded as lying unconformable on the Karakaya Formation. Bingöl et al. [3] also pointed out to the wide distribution of the Karakaya Formation in the Pontides and traced it from the Biga Peninsula eastward to Ankara. Apart from the Biga Peninsula the Karakaya Complex has been studied under various names in the Soma-Bergama [51, 52], Bursa-Bilecik [53, 54, 55, 56, 57] and Ankara [58, 59, 60, 61, 62, 63, 64] regions and farther east in The Sakarya Zone [65, 66, 67, 68].

In a regional synthesis of the pre-Jurassic formations of the Pontides, Tekeli [69] and following him Şengör and Yılmaz [17], and Şengör et al. [70] included the widespread ophiolitic melanges and blueschists in northwest Turkey within the pre-Liassic Karakaya Complex (cf.the map in Tekeli [69]). This shift in the description of the Karakaya Complex from a largely sediment dominated unit to a complex consisting "dominantly of blueschist, greenschist and amphibolite facies rocks and a deformed ophiolitic melange" [70], is caused by the mistaken allocation of the Cretaceous Alpide blueschist and ophiolitic melanges to the Karakaya Complex. In fact, as the original description of Bingöl et al. [3] and other detailed regional studies [e.g. 62, 64] indicate, the Karakaya Complex is dominated by clastic sedimentary rocks; blueschists, except a few grains of incipient sodic amphibole in the Nilüfer Unit of the Karakaya Complex, are absent and ophiolitic melanges are rare. The later regional studies of Kaya et al. [56, 57] in the Bursa region, on the other hand, take the other extreme view and claim that all

the clastic sedimentary rocks of the Karakaya Complex represent an authochthonous slope sequence deposited on a basement of greenschist facies metamorphic rocks (the Nilüfer Unit of the Karakaya Complex of this study) and relate virtually all the deformation observed in the clastic sediments to soft-sediment deformation. However, even a cursory examination reveals a strong pre-Liassic tectonism affecting the units of the Karakaya Complex in the Biga Peninsula. Both Bingöl et al. [3] and Kaya et al. [56, 57] regard the sedimentary rocks of the Karakaya Complex as a single stratigraphic unit.

Our studies in northwest Turkey have shown the Karakaya Complex consists of several, probably coeval, pre-Jurassic tectonostratigraphic units; In the Biga Peninsula four such major units are recognised in the Karakaya Complex: the Nilüfer Unit, the Hodul Unit, the Orhanlar Greywacke and the Çal Unit (Fig. 10). These units are described below.

6.4.1. The Nilüfer Unit

The thick sequence of metabasic rocks with subordinate amounts of phyllite and marble that form the lowest tectonic unit of the Karakaya Complex is named as the Nilüfer Unit (Fig. 10). A good reference section for the Nilüfer Unit is along the forest road between Derenti and Yukarı Çavuş south of Çan (Fig. 11). Another easly accessible reference section outside the field area is along the Bursa-Keles road that follows the Nilüfer valley.

The bulk of the Nilüfer Unit in the Biga Peninsula is constituted by green, dark green, fine-rained, generally foliated, monotonous greenschist metabasites called the Sazak Metatuffs after the village of Sazak south of Yenice (Fig. 11). In rare cases one can observe primary bedding in the metabasites; this and the presence of green, grey volcanogenic metashales indicate that the sequence represents largely distal submarine tuffs. The rare presence of relict Ti-augite in the metatuffs suggests that at least part of the sequence has alkaline affinity. In the region south of Çan the metatuffs make up an over 3 km thick uniformly northward dipping sequence with a few thin (< 50 m) horizons of graphitic phyllite, calcschist and marble (Fig. 11). No carbonate olistoliths are observed in the metatuffs. These thin clastic horizons probably represent the locations of syn-metamorphic thrust planes through which the metatuffs have attained a thickness of over 3 km (Figs. 11, 13). In the same region, south of the village of Çal the metatuffs pass laterally and structurally upwards to a sequence of grey, silvery grey, graphitic phyllites and micaschists with infrequent marble intercalations and rare serpentinite lenses (Figs. 11, 13). A 10 km long elongate slice of ser-

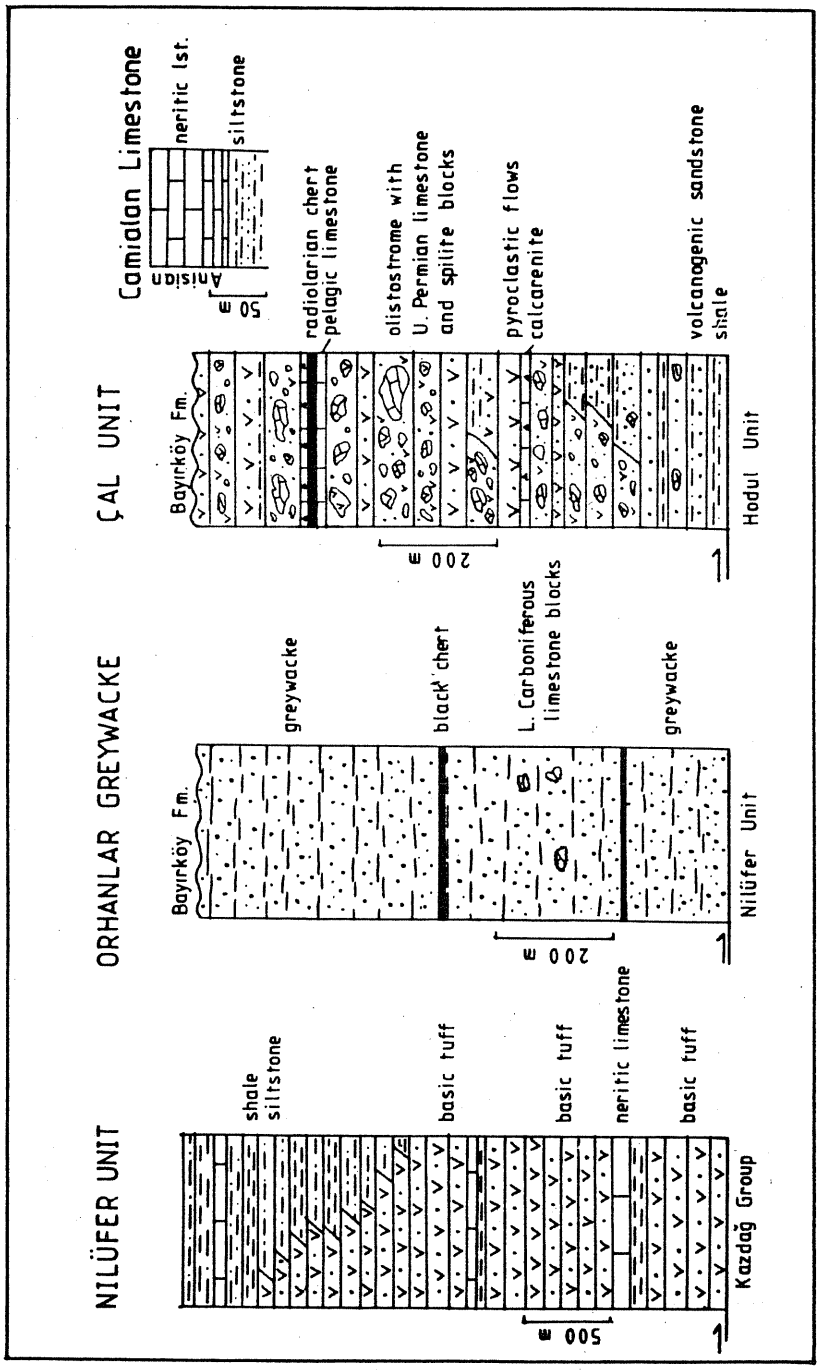

Fig. 10. Stratigraphic sections of the Karakaya Complex units with the exception of the Hodul Unit which is shown in Fig. 14. The thicknesses, apart of that of the Camialan Limestone, are highly approximate.

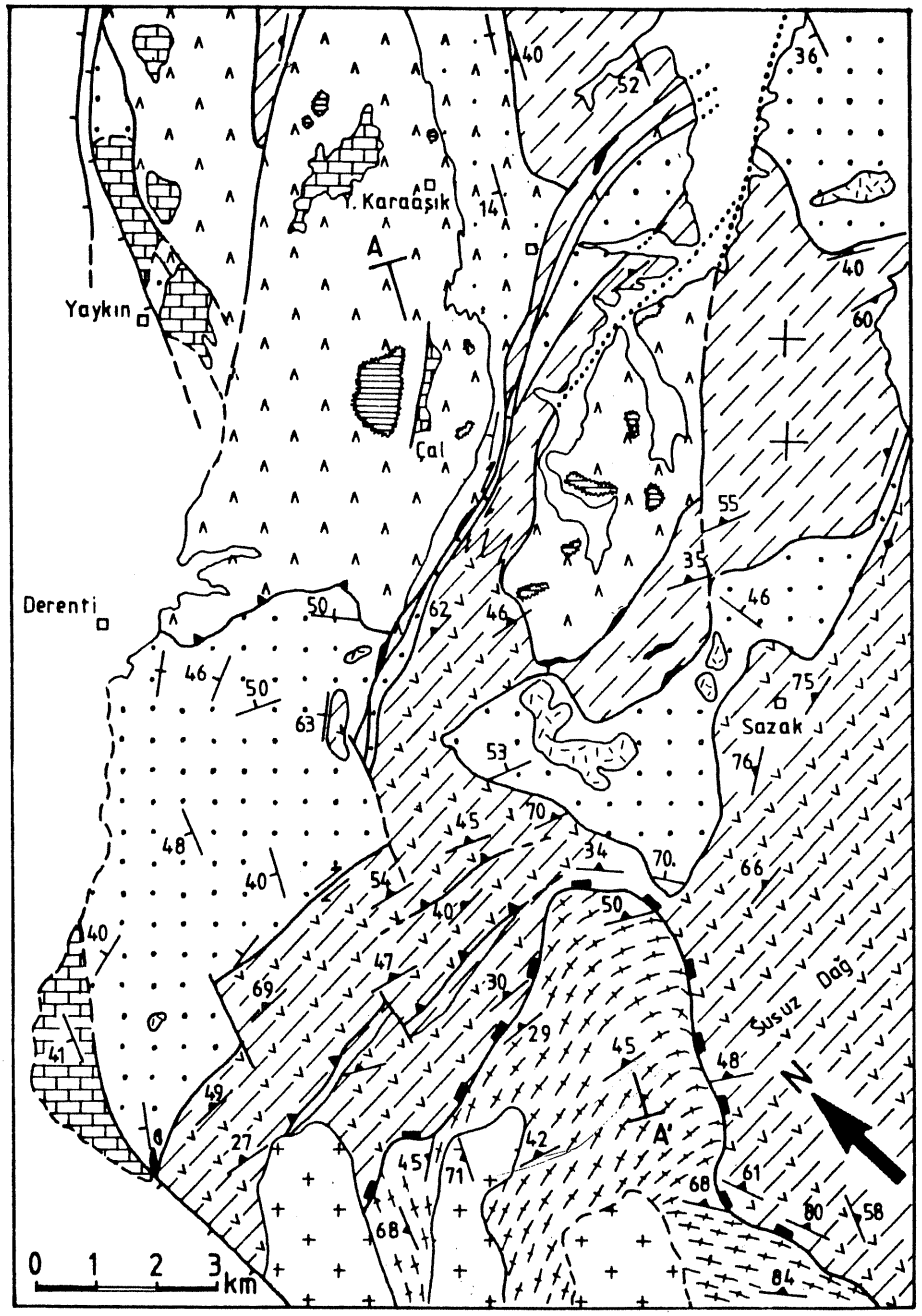

Fig. 11. The geological map of the region between Çan and Yenice. For legend see Fig. 12.

pentinite associated with metagabbro and metadiabase southwest of Biga (Fig. 2) may represent a dismembered ophiolite in the Nilüfer Unit.

In some regions, such as west of the Susuz Dağ (Fig. 11), the lower parts of the metatuff sequence, which tectonically lies over the Kazdağ Group, contains increasing amounts of white marble intercalations and as stated above, lithologically resembles the upper parts of the Kazdağ Group.

The Nilüfer Unit has undergone a greenschist facies regional metamorphism in the Biga Peninsula with the development of actinolite/hornblende + albite + epidote + chlorite + leucoxene + opaque mineral assemblage in the metabasic rocks, which are generally completely recrystallised and show a penetrative micro-scale foliation. The micaschists and the phyllites have the mineral assemblage of quartz + muscovite + biotite + plagioclase + opaque. The Nilüfer Unit has undergone an intense shortening with isoclinal and tight folds with steeply and generally northward dipping axial planes well displayed along the Nilüfer Valley between Bursa and Keles. In regions where the metamorphic grade is low, the deformation has imparted a broken formation character to the Nilüfer Unit.

The Nilüfer Unit is well exposed outside the Biga Peninsula on the Bursa-Keles road along the Nilüfer valley. In this section it includes thick basaltic volcanic and pyroclastic flows that retain most of the igneous texture and are characterised by the presence of pink Ti-augite and locally kaersutite revealing an alkaline character. In some specimens from this region incipient blue sodic amphibole is observed replacing the kaersutite crystalls. Recently small (< 100 m) tectonic lenses of sodic amphibole bearing eclogites are reported in the metabasic rocks of the Nilüfer Unit east of Bandırma outside the area studied (A. Özgül pers. comm. 19900. However, no sodic amphibole is observed in the more recrystallised basic volcanic rocks of the Nilüfer Unit from the Biga Peninsula.

In the Biga Peninsula the Nilüfer unit rests with a steep tectonic contact, probably a normal fault of Late Tertiary age, on the Kazdağ Group (Fig. 11). The pre-Tertiary contacts with the other units of the Karakaya Complex is difficult to decipher because of the effects of the late Tertiary strike-slip faulting. However, in the region south of Çal it includes kilometre size tectonic blocks of the Hodul and Çal units of the Karakaya Complex (Fig. 11).

No fossils have been found in the Nilüfer Unit. Thus the Triassic age assigned to the Nilüfer Unit is based on regional tectonic considerations. The Nilüfer Unit has a wide distribution in the Sakarya Zone and is described from south of Bursa [71, 72] north of Söğüt [54, 73, 74], from the Ankara region [62, 64], from the Tokat [65, 67] and Ağvanis [68] massifs.

Pelagic sedimentary rocks such as radiolarian cherts or pelagic limestones, and intrusive magmatic rocks or dykes are absent in the Nilüfer Unit that consists essentially in its lower parts of voluminous basaltic, pyroclastic and volcanic rocks interbedded with neritic limestones; Clastics derived from a continental source are scarce. In terms of its stratigraphy and lithology the Nilüfer Unit resembles the deposits of intra-arc and/or fore-arc basins (cf. [75]) developed on oceanic or transitional crust. A better known example of a similar intra-arc basin is the Cretaceous-Eocene sequence of the eastern outer Pontides, which consists, like the Nilüfer unit, of basic and intermediate volcanic rock and limestone intercalations [76, 77].

6.4.2. The Hodul Unit

The Hodul Unit, which is the most widespread of the Karakaya Complex units in the Biga Peninsula (Fig. 2), consists largely of Late Triassic white, pale grey arkose and intercalated dark grey, black shale and siltstone (Fig. 14). Tectonic blocks of spilite and rarely of recrystallised limestone occur within these clastics. In the region between İvrindi and Manyas, the thick arkosic clastics pass upwards to olistostromes with Permo-Carboniferous limestone olistoliths (Figs. 2, 12, 14). The Hodul Unit is also widespread east of the studied region and occurs north of Bursa ([55], pers. obs. 1989).

The Hodul Unit, that occurs over very wide areas in the Biga Peninsula, will be described separately in four regions that show some lithological and stratigraphic differences (Fig. 14).

Northeast of Havran. The Havran region in the southeast of the Biga Peninsula is the only locality in the Peninsula where the stratigraphic base of the Hodul Unit and thus of the Karakaya Complex is clearly recognised. In the northeast of Havran the Çamlık Metagranodiorite, described above, is unconformably overlain by a 350 m thick sequence of largely white arkosic sandstones (Figs. 7, 14) [12, 13]. The unconformity can be observed clearly south of the village of Çamlık. The thickly to medium bedded arkosic sandstones contain rare greenish siltstone intercalations with wood fragments and discontinuous white conglomerate lenses. The conglomerate includes well rounded micro-granitoid, aplite, black phyllite and quartz pebbles that may reach up to 20 cm in diametre and which are derived from the underlying Çamlık Metagranodiorite and the Kalabak Formation. The arkosic sandstone sequence passes upwards to a 150 - 200 m thick black shale-siltstone sequence with infrequent arkosic sandstone intercalations (Figs. 7, 14). In the transition zone there are fossilifereous grey siltstone

rizons with lamellibranch, brachiopod, gastropod forms characteristic of Norian (Fig. 14) [12, 13, 35], Dr. Leopold Krystyn 1988 pers. comm.). The overlying 150 - 200 m thick black shale sequence is not very fossilifereous; only Kaaden [9] describes Late Triassic lamellibranchs, such as *Halobia, Daonella* and *Posidonomya* from this shale sequence. The shales are overlain sharply with a parallel unconformity, by the yellowish brown, medium to thickly bedded, porous, calcareous sandstones of the Jurassic Bayırköy Formation (Fig. 14).

Gümüş [12], Aslaner [13], Krushensky et al. [35] and Altıner et al. [78] regard the contact between the dark Norian shales and the overlying calcareous sandstones as conformable, and Altıner et al. [78] suggest a continous deposition in the Havran region from Norian to the Late Jurassic. However, the age of the 200 m thick calcareous sandstones overlying the shales is not known and no precise intermediate ages between Norian and Oxfordian has ever been determined in this region. Here, we argue for the presence of a major disconformity encompassing probable Rhaetian and early Lias between the two clastic sequences; this is based firstly on the sharp lithological change from the dark shales to porous calcareous shallow water sandstones, and secondly on the presence of a clear unconformity in the Balya region 40 km to the northeast (Fig. 12) between the Norian olistostromal sequence and the overlying calcareous sandstones of the Bayırköy Formation lithologically very similar to those in the Havran region.

Region between İvrindi and Manyas. In this region the Hodul Unit forms a NNE-SSW trending, 70 km long and 5 - 6 km wide belt bounded by the Orhanlar Greywacke in the west and by the metamorphic rocks of the Manyas Group in the east (Figs. 2, 12). In the northern section of this belt the basal parts of the Hodul Unit, as exposed in the area north of the village of Karlık, consist of hundreds of metres thick white arkosic sandstones locally with conglomerate beds with quartzite, dacite, lydite pebbles and infrequent grey, black siltstone/shale intercalations. It is likely that this clastic sequence unconformably overlies a crystalline basement similar to the situation north of Havran (Fig. 13). In regions farther north this clastic sequence has a more distal character and consists of thinly to medium bedded arkosic sandstones intercalated with black shales.

In the northern part of the İvrindi-Manyas belt, the thick arkosic sandstones pass upwards through generally only a few ten metres thick sequence of brown, greenish brown, micaceous greywacke, siltstone, shale, black chert and calciturbidite with Upper Permian limestone fragments to olistostromes; the olistostromes contain abundant Permo-Carbonifereous limestone and rare spilite olistoliths that range in size from a few metres to few kilometres (Figs. 12, 13, 14) and which are embedded in a dirty

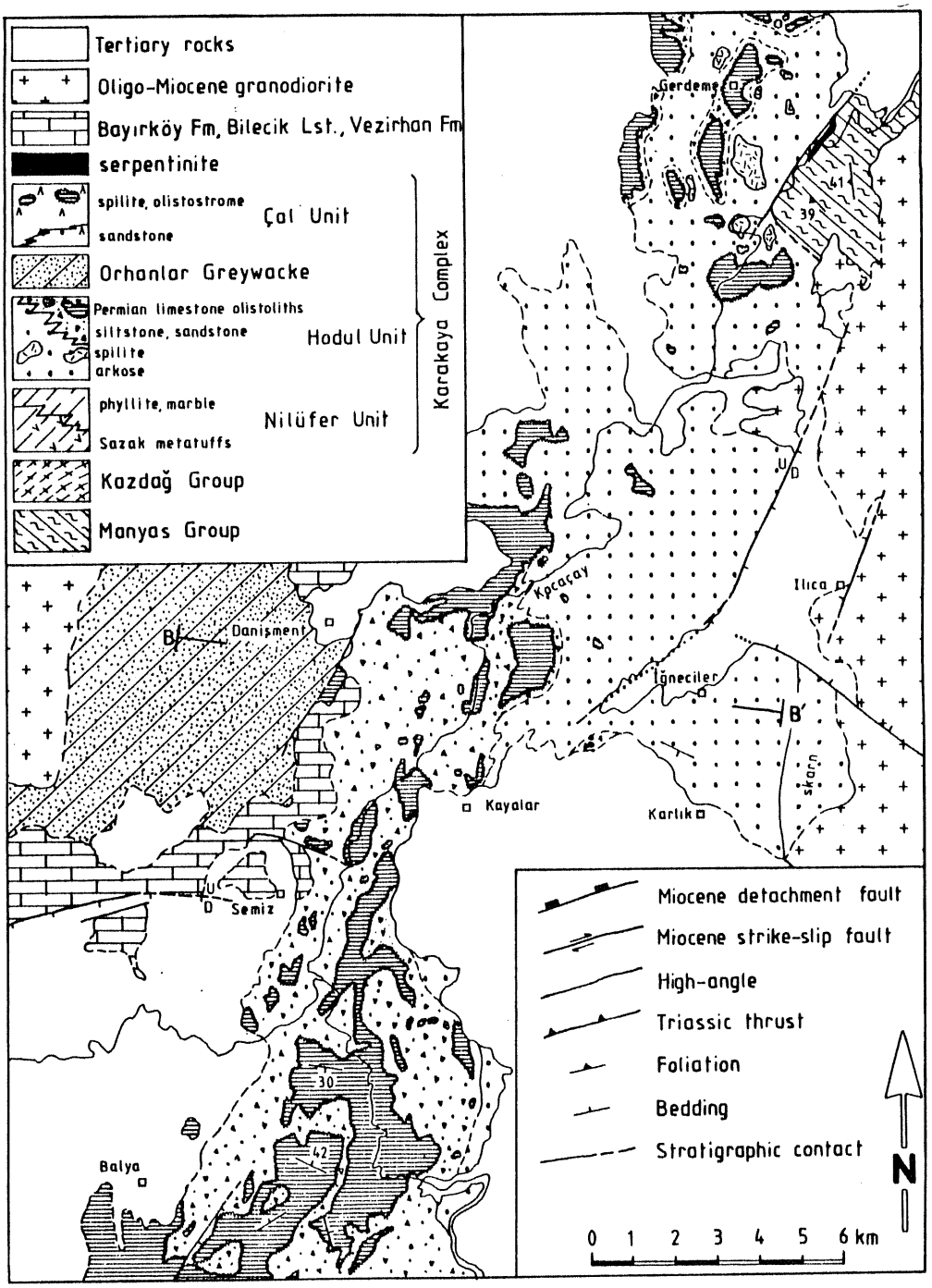

Fig. 12. The geological map of the region between İvrindi and Manyas.

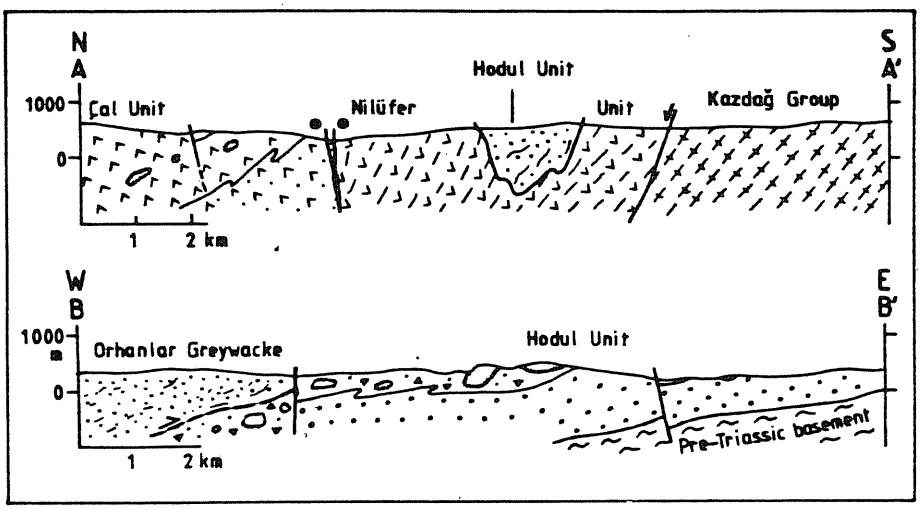

Fig. 13. Cross-sections for the geological maps in Fig. 11 (above) and Fig. 12 (below).

sandstone and siltstone matrix. This transition from the arkosic sandstones to the olistostromes can be beautifully observed around the village of Gerdeme southwest of Gönen (Figs. 12, 15). The limestone olistoliths are generally white, thickly bedded to massive and frequently contain fusulinids, alg, bivalve, gastropoda and corals which give ages ranging from the Middle Carbonifereous to Late Permian. Apart from these neritic Permo-Carboniferous limestone olistoliths which make up well over 95% of all the olistoliths in the Hodul Unit, there are a few spilite olistoliths and one two metre large olistolith of intercalated red pelagic limestone and radiolarite with a thin volcanic envelope, exposed two kilometres southwest of the village of İgneciler (Fig. 12); conodonts from the red pelagic limestone from this block indicate an Early Carbonifereous age (Dr. L. Krystyn pers. comm. 1990).

In the southern part of the İvrindi-Manyas belt, in the area immediately east of Balya, the argillaceous sequence above the arkosic sandstones, which is generally only a few ten metres thick in the north, is correlated with a much thicker, regressive, upward coarsening clastic sequence (Figs. 12, 14), studied in detail by several geologists including Neumayr [79], Bittner [80], Bukowski [81] and more recently by Aygen [11]. In this Bahçecik region east of Balya, there are at the base black shales and siltstones of Norian age with abundant *Halobia neumayeri*, which pass upwards to medium bedded yellowish brown sandstones and siltstones with plant fragments, brachiopod, lamellibranch and ammonites. Bittner [80] and Aygen [11] des-

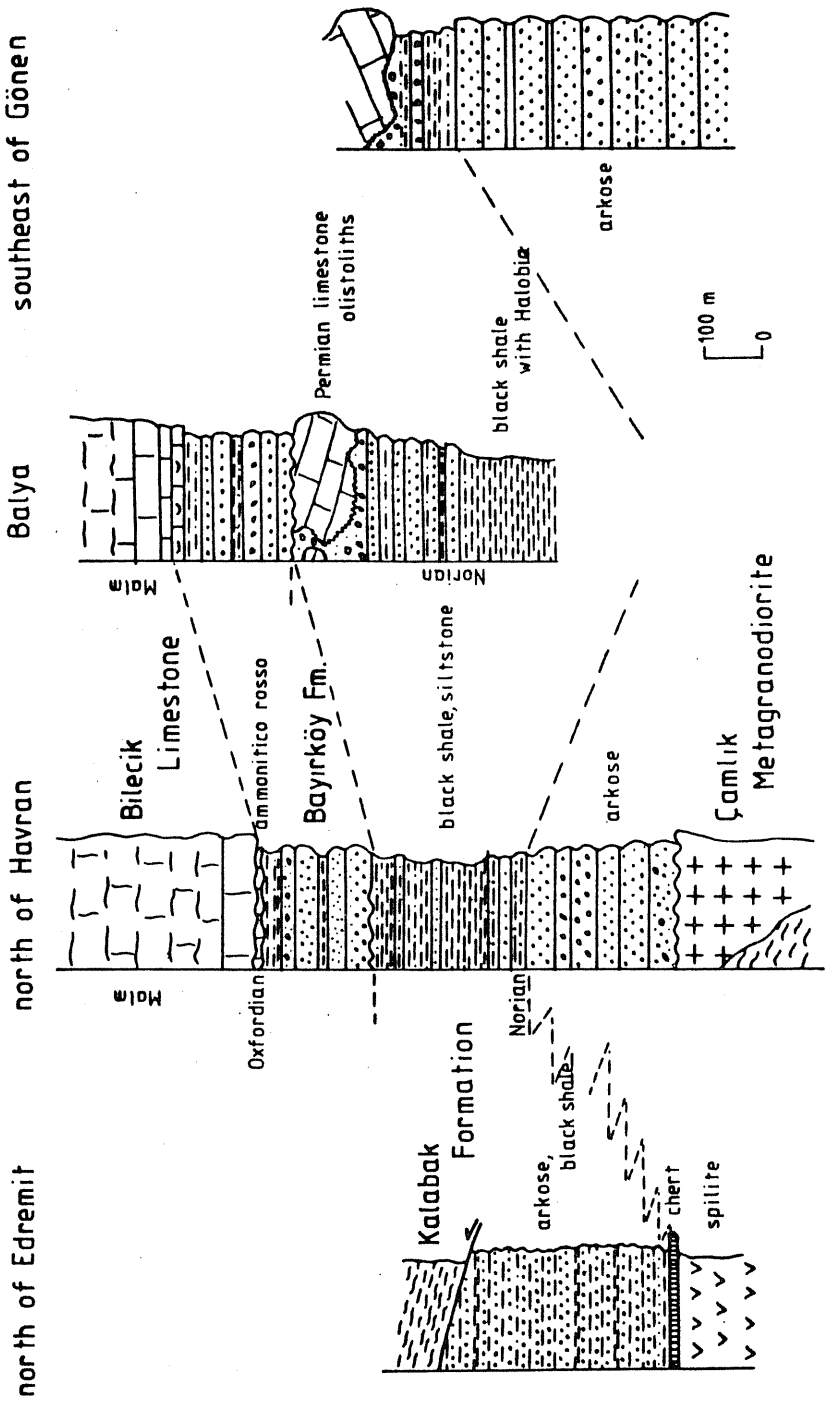

Fig. 14. Generalised stratigraphic sections of the Hodul Unit for four different regions in the Biga Peninsula.

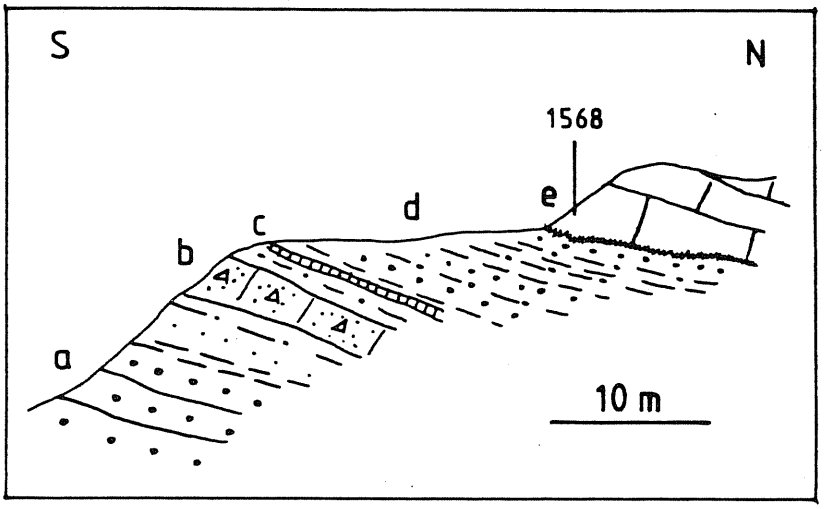

Fig. 15. The upper part of the Hodul Unit around the village of Gerdeme south of Manyas showing the transition from the arkosic sandstones to the olistoliths, a. white arkosic sandstone, b. two metres thick grain flow with around 10 cm large Permian limestone fragments, c. black chert, d. brown, greenish brown, micaceous siltstones, shale and sandstone. e. Middle-Late Carboniferous limestone olistolith. Sample 1568, *Monotaxionoides* sp., *Paleotextularia* sp., *Tuberitina* sp., *Pachysphaerina* sp., Fusulinidae, Endothyriridae (det. M. Baykal).

cribe a Late Triassic fauna from these sandstones. The apprx. 100 m thick sandstone-siltstone sequence is overlain by a few metres thick conglomerate with well rounded, poorly sorted, 1 to 10 cm large Upper Permian limestone and quartz pebbles (Figs. 12, 14). This conglomerate is overlain by the Permian limestone olistoliths generally of a few ten to few hundred metres in size, which clearly belong to the same olistostromal unit described from farther north of the belt. The Hodul Unit extending southward from Balya consists dominantly of this olistostromal unit with hundreds of Permo-Carboniferous limestone blocks embedded in a matrix of yellowish brown, pale grey, thinly to medium bedded sandstone and siltstone. The olistoliths consist largely of thickly bedded to massive, white limestone, however, locally shale interbedded or thinly to medium bedded, dark grey limestones are also found as olistoliths. The olistoliths reach in size to over several kilometers (Fig. 12) and in thickness of over 100 metres. In one, several metres large Upper Permian limestone olistolith east of Balya a brecciated base with a sandy, silty matrix passes gradually upwards to massive unbrecciated limestone indicating rock sliding in a shallow clastic basin.

The great density and large size of the limestone olistoliths in the İvrindi-Manyas belt (Fig. 12) suggest that the source area was not distant. The medium to thickly bedded sandstones and conglomerates with well rounded and moderately to poorly sorted quartz and limestone pebbles associated with the olistoliths indicates that the Upper Permian limestone olistoliths of the Hodul Unit were transported in shallow water conditions, unlike the poorly sorted more typical olistostromes of the Çal Unit, and represent the frontal parts of a relief-überschiebung (surface thrust) [82]. The olistoliths of the Hodul Unit have formed by processes of rock fall or sliding in a compressive regime while those of the Çal Unit by mass or debris flow processes in much deeper basinal conditions and in a tensional tectonic regime.

The samples collected from various limestone olistoliths in the Hodul Unit in the belt between İvrindi and Manyas have yielded Early Carboniferous, Middle-Late Carboniferous, Late Carboniferous-Early Permian and Late Permian ages with the Upper Permian limestone olistoliths being by far the most common type (90%). The Upper Permian limestones (nine samples) have yielded a fauna especially rich in Endothyracea and Fusulinacae: *Glomospira* sp., *Pseudoglomospira* sp., *Tuberitina* sp., *Tuberitina reitlingerae, Lunucammina* (syn. *Geinitzina*) sp., *Pachyphloia* sp., *Paleotextularia* sp., *Climacammina* sp., *Cribrogenerina* sp., *Cribrogenerina sumatrana, Tetrataxis* sp., *Globivalvulina* sp., *Globivalvulina* cf. *biserialis, Lasiodiscus* cf. *tenuis; Reichelina* sp., *Stafella* sp., *Codonofusiella* sp., *Dunbarula* sp., *Pseudofusulina* sp., *Verbeekina* sp., *Neoschwagerina* sp.; *Agathammina* sp., *Hemigordius* sp.; *Pseudovermiporella* sp., *Gymnacodium* sp., *Mizzia* sp., *Girvanella* cf. *media, Epimastapora* (det. M. Baykal). Only one, small, medium bedded black limestone olistolith east of Balya (1863) has yielded an Early Carboniferous fauna of *Globivalvulina* sp., *Endothyra* sp., *Archaediscus* sp., *Monotaxinoides transitorius, Girvanella* sp., Calcisphaera (det. M. Baykal). A limestone olistolith from west of Manyas (1968) has yielded a Middle-Late Carboniferous fauna of *Monotaxionoides* sp., ? *Eostafella* sp., *Paleotextularia* sp., *Tuberitina* sp., *Pachysphaerina* sp., Fusulinidae, Endothyridae, Beresellinae (det. M. Baykal). Another limestone olistolith from the same region (1503) contains a Late Carboniferous-Early Permian fauna of *Ammodiacella* sp., *Eotuberitina* sp., *Globivalvulina* cf. *bulloides, Bradyina* sp., *Schubertella* sp., *Hemigordius* sp., *Permocalculus* sp. (det. M. Baykal). Aygen [11] who made a detailed paleontological study of the limestone olistoliths around Balya mentions the frequent presence of the fusulinids *Neoschwagerina craticulifera, Verbeekina verbeeki, Sumatrina* aff. *pesuliensis* and *Sumatrina annae,* which are characteristic for the middle Late Permian. Foraminifera for the upper Late Permian (Dorashamian) are not

present in the limestone olistoliths. Erk [47] who studied the micropaleontology of the late Permian limestone olistoliths in the Karakaya Complex in the Gemlik region east of the studied area (Fig. 1) describe a very similar fusulinid fauna to that of the İvrindi-Manyas area; here again the latest Permian (Dorashamian) fusulinids are absent.

In the area north of Balya the olistostromal facies of the Hodul Unit is unconformably overlain by the brown calcareous sandstones of the Jurassic Bayırköy Formation (Fig. 12), which can be observed clearly two kilometers northeast of the village of Semiz.

The stratigraphy of the Hodul Unit in the İvrindi-Manyas belt clearly reflects the initial deepening and later shallowing of a fore-land basin due to elastic rebound related to the approach of a nappe of Late Permian limestones during the Norian.

North of Edremit. A strongly tectonised sequence of thinly bedded arkosic sandstone and black shale, which shows turbidite features such as graded bedding and flame structures, occurs north of Edremit (Fig. 2). This turbiditic sequence is cut by a dense (every 5 - 10 metres) network of shear zones, however, at several locations north of the Karadağ Hamlet, the sandstones and shales can be observed to lie stratigraphically over fine-grained non-vesicular spilitised basic volcanic rocks with a few metres thick intervening zone of thinly to medium bedded grey chert (Fig. 14); the lower contact of the spilites is invariably tectonic suggesting that the spilite forms the basement of the turbidite sequence rather than being basaltic flows within the sequence. The Karakaya Hill north of Edremit, from which the name Karakaya Complex has originated [14], consists of these fine grained spilites that are overlain by the turbidites in the east of the Hill.

The sandstone-shale sequence north of Edremit is tectonically overlain by the Kalabak Formation (Fig. 8).

The region between Yenice and Biga. In this large region the Hodul Unit consists of arkosic sandstones and intercalated laminated black shales, and frequently shows turbidite features such as graded bedding, convolute lamination, slumping, sliding and scour, and is in places quite similar to the Hodul Unit north of Edremit. In this thick turbidite sequence there are proximal parts consisting of up to 2 m thick arkosic sandstone beds, and distal parts made up of regular intercalations of a few centimetre thick sandstone and shale beds. The turbidite sequence can best be observed east of the Hodul Mountain, where the unit derives its name, in the south of the Derenti Village (Fig. 11) and west of the Karadoru Village.

In the region between Yenice and Biga the Hodul Unit is strongly tectonised with large number of anastamosing shear zones, as in the region of

Edremit, and includes tectonic blocks of fine-grained green spilitised basic volcanic rock generally of more than a few hundred metres in size. The basic volcanic rocks consist of fine-grained pale pink Ti-augite, altered and albitised plagioclase, chlorite and leucoxene. These spilite blocks are believed to represent fragments of the basement of the Hodul Unit in this region. Very infrequently, dark, thickly bedded recrystallised limestone and thinly bedded black cherts occur as intercalations in the arkosic sandstones. The olistostromal upper part of the Hodul Unit, so well developed in the region of Balya, is not present here, there are only very infrequent grain flows with limestone, shale, sandstone and quartz pebbles ranging in size from one to 40 centimetres. Limestone fragments from one such grain flow west of Karadoru have yielded the probable Late Permian foraminifer *Lunucammina* (syn. *Geinitzina*) sp. (det. Mustafa Esenler).

In the region between Yenice and Biga the deformation is distributed very heterogeneously in the Hodul Unit and is related to the complex anastamosing, generally steeply dipping shear zones that result in close juxtaposition of undeformed and chaotically deformed turbidite sequences giving locally a melange like character to the unit. Local, very low-grade metamorphism is also observed in the clastics in the strongly deformed areas.

As in the other areas, the Hodul Unit in this region is unconformably overlain by the Jurassic sandstones of the Bayırköy Formation as observed in the vicinity of the Yaykın Village (Fig. 11).

The arkosic sandstones of the Hodul Unit in all the four regions show common petrographic features. Quartz and altered feldspar make up the bulk of the sandstone that invariably shows strong diagenetic alteration. Staining techniques have revealed that most of the feldspar present is K-feldspar. Thus the Hodul Unit represents a thick clastic Late Triassic apron that was fed from a continental source.

In regions west of the İvrindi-Manyas belt the Hodul Unit frequently shows a slight metamorphism especially apparent in the fine-grained arkosic sandstones and foliated shales; however no recrystallisation is observed in the spilite tectonic blocks or in the coarse, thickly-bedded arkosic sandstones.

6.4.3. Orhanlar Greywacke

A thick monotonous clastic sequence largely made up of greywackes outcrop over a wide region south of Orhanlar (Figs. 2, 12). This clastic sequence, which is readily distinguished in the field from the Hodul Unit, is called as the Orhanlar Greywacke [83] after the village of Orhanlar north of Balya. The Orhanlar Beds and the Dışkaya Formation as used by Brink-

mann [83] and Kaya et al. [56, 57] respectively includes both the Orhanlar Greywacke and the Hodul Unit. The reference section of the Orhanlar Greywacke is along the forest road between Orhanlar and Danişment villages, which follows the İğnecik valley (Fig. 12).

The bulk of the Orhanlar Greywacke (> 80%) is made up of yellowish green, yellowish brown, highly fractured, generally strongly altered greywacke that rarely shows recognisable bedding (Fig. 10). Petrographically the greywacke consists of very poorly sorted, angular quartz, plagioclase, opaque, lidide, radiolarian chert and volcanic and metamorphic rock fragments in an argillaceous matrix. Bluish grey shale, siltstone and very infrequently conglomerate occur in the greywackes. A characteristic feature of the Orhanlar Greywacke is the presence of infrequent, thinly bedded, black chert and white siliceous shale intercalations that form a few metres thick horizons in the greywacke sequence. Such chert horizons are observed north of the Darıalan and south of the Karamustafa villages. Small olistoliths of Lower Carbonifereous black limestone, generally 0.3 to 2 metres in size with algs, brachipods, corals and foraminifera, are sporadically found in the Orhanlar Greywacke. Such olistoliths are particularly abundant along the forest road between Orhanlar and Danişment (Fig. 12). The Early Carbonifereous fauna, especially rich in the Endothyracea, determined in over ten olistolith samples are *Glomispira* sp.; *Archaesphaera* sp., ? *Bisphaera* sp., *Earlandia* sp., *Pseudoglomispira* sp., *Turrispiroides* sp.; *Tuberitina* sp., *Tuberitina* cf. *conili, Tuberitina reitlingerae*, *Stacheoides* sp., *Climacammina* sp., *Cribrogenerina* sp., *Tetrataxis* sp., ? *Globivalvulina* sp., *Forschia* sp., *Endothyra* sp., *Endothyra bowmani, Paraendothyra* sp., *Bradyina* sp., *Archaediscus* sp., ? *Brunsia* sp., *Howchinia* sp., *Monotaxinoides* sp.; *Paramillerella* (syn. *Mediocris*) sp., ? *Stafella* sp.; *Girvanella* sp. (det. M. Baykal). Outside the studied area southwest of Bursa the Orhanlar Greywacke also contains Upper Permian limestone olistoliths and very infrequent small (< 10 m) serpentinite lenses.

The thickness of the Orhanlar Greywacke is difficult to estimate because of the difficulty in locating bedding, however, based on the topography the Orhanlar Greywacke has a minimum thickness of a few hundred metres and probably has a thickness of over 1000 metres. The Orhanlar Greywacke is unconformably overlain by the sandstones and shales of the Jurassic Bayırköy Formation (Figs. 10, 12), while its base is not exposed in the studied region. In the east the Orhanlar Greywacke is in tectonic contact with the Hodul Unit; this tectonic contact between the two Karakaya Complex units is marked by a late Tertiary fault and is largely covered by the Jurassic and younger deposits (Fig. 12); however, it is likely that the Orhanlar Greywacke is thrust over the Hodul Unit of the İvrindi-Manyas

belt (Fig. 13). In the west the Orhanlar Greywacke is tectonically overlain by the Kalabak Formation in an imbricate tectonic zone south of Pazarköy (Figs. 2, 9) The Orhanlar Greywacke is intruded by a granodiorite, most probably of late Tertiary age, which has a wide contact metamorphic aureole (Fig. 12). Outside the studied area south of Bursa the Orhanlar Greywacke rests with a steep tectonic contact on the Nilüfer Unit.

The internal structure of the Orhanlar Greywacke is difficult to establish due to the lack of marker horizons and general poor outcrops. However, shear zones are frequent while folding or foliation are not observed. The Orhanlar Greywacke is not affected by regional metamorphism.

With its monotonous greywackes, frequent shear zones and absence of any recognisable stratigraphic basement the Orhanlar Greywacke may represent an accretionary complex dominated by trench fan and axial channel deposits (cf. [30]).

Although the Orhanlar Greywacke shows no regional metamorphism, Radelli [84] shows most of the Orhanlar Greywacke as metamorphic basement on his map (see Fig. 2 of [84]). Radelli [84]'s paper on Balya is characterised by a great confusion of units. He mistakenly correlates the upper parts of the Hodul Unit (the Balya section) with the Jurassic Bayırköy Formation both of which he assigns a Late Triassic age. Thus, the Late Triassic Bayırköy Formation is regarded as unconformably overlying a metamorphic basement, which in reality is the Orhanlar Greywacke. The small part of the Orhanlar Greywacke shown of his map, is regarded as of Permo-Carboniferous age, similarly he regards the Hodul Unit as of Permian age.

6.4.4. The Çal Unit

The Çal Unit consists of spilitised basic volcanic and pyroclastic rocks, olistostromes with spilite and Upper Permian limestone olistoliths, greywacke, shale and rare calciturbidite, radiolarian chert and pelagic shale (Fig. 10). A Middle Triassic limestone sequence called as the Camialan Limestone, is closely associated with the Çal Unit (Fig. 10). A characteristic and distinguishing feature of the Çal Unit is the presence of thousands of fossilifereous Upper Permian limestone fragments and olistoliths ranging in size from a few centimetres to one kilometre, in a basic volcanic or rarely sandstone matrix. The great majority of the Upper Permian limestone olistoliths in the Çal Unit are less than 100 metre in size, and have a thickness of less than a few ten metres; they are much smaller and thinner than the Upper Permian Limestone olistoliths in the Hodul Unit. The olistostromes of the Çal Unit are also readily distinguished from those of the Hodul Unit by the abundant presence of spilitised basic volcanic rocks in the former.

The Çal Unit was first described as the Çal Köy Series by Blanc [15, 85]. The name of the unit comes from the village of Çal on the Çan-Yenice highway (Fig. 11). Two easly accessible reference sections for the Çal Unit are the highway between Derenti and Yenice, and the village road between Aşaği Karaaşık and Yukarı Karaaşık (Fig. 11).

At the base of the Çal Unit there are medium to thickly bedded, micaceous, greenish brown greywackes and intercalated shales, which in places contain small Upper Permian limestone olistoliths (Fig. 11). This clastic sequence, that outcrops around the Çal Village, passes upwards and laterally to olistostromes and spilitised basic volcanic and pyroclastic rocks that make up around 70 % of the Çal Unit (Fig. 10). Discontinuous greywacke-shale horizons also occur within the olistostromes and basic volcanics. Olistostromes make up irregular horizons ranging from one metre to several metres in thickness and contain abundant Upper Permian limestone and basic volcanic rock fragments in a volcanic or more rarely sandstone matrix. Dark green spilitic tuff, pyroclastic and lava flows occur between the olistostromes. The basic volcanic rocks often have a glomeroporphyritic texture and consists of tightly clustered augite phenocrysts in a glassy or very-fine grained groundmass with plagioclase laths. The olistoliths are monolithic and consist of white, thickly bedded to massive Upper Permian limestone with corals, brachiopods, gastropods, ostracods and echinoids. Samples from a large number of olistoliths yielded a Late Permian fauna of *Ammodiscus* sp., *Glomospira* sp.; *Archaesphaera* sp., *Bisphaera* ? sp.; *Tuberitina* sp., *Pachyphloia* sp., *Paleotextularia* sp., *Cribrogenerina* sp., *Globivalvulina* sp.; *Reichelina* ? sp., *Codonofusiella* ? sp., *Yangchienia* ? sp., *Schwagerina* sp., *Neoschwagerina* sp.; *Pseudovermiporella* sp. (det. Mustafa Esenler and Ismet Sezgin).

Important but infrequent rocks in the Çal Unit are red, black, thinly bedded pelagic limestone and shale, thin to medium bedded, red, green radiolarian chert and medium bedded calciturbidite intercalations, which form a few ten metre thick horizons between the olistostromes and spilites (Fig. 16). Calciturbides consist completely of transported Late Permian limestone and fossil fragments.

The Çal Unit is unconformably overlain by the basal conglomerates of the Jurassic Bayırköy Formation, as can be clearly observed in the Çal Village (Fig. 17).

Out of all the Karakaya Complex units the Çal Unit is the one least affected by the Triassic deformation and metamorphism. No regional metamorphism or schistosity are observed in the rocks of the Çal Unit. Shear zones although present are not so common as in the Hodul Unit or in the Orhanlar Greywacke.

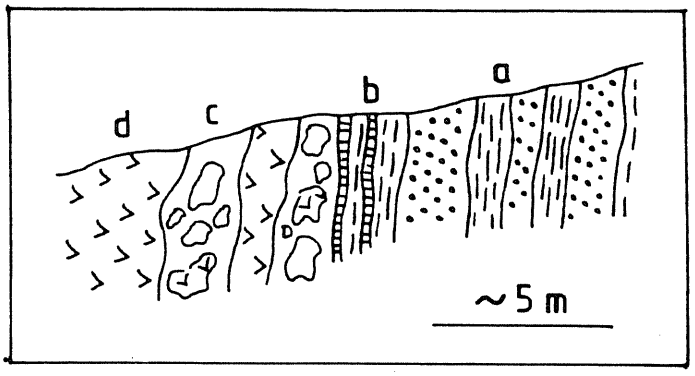

Fig. 16. Â field section of the Çal Unit with radiolarian chert, a. greenish brown, micaceous sandstone and shale, b. intercalation of red radiolarian chert and shale, c. olistostrome with Late Permian limestone and spilite fragments, d. spilitised volcanic flow.

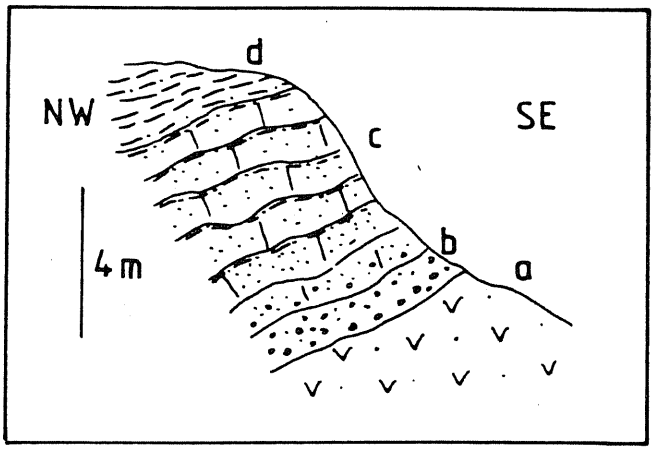

Fig. 17. The unconformity between the Çal Unit and the Jurassic Bayırköy Formation in the village of Çal (cf. Fig. 8), a. spilitised fine-grained pyroclastic rocks of the Çal Unit with small (< 10 cm) Late Permian limestone fragments, b. basal conglomerate of the Bayırköy Formation with well rounded 0.2 - 5 cm large spilite fragments, c. lenticular sandy limestone with thin siltstone horizons and with krinoid, lamellibranch, gastropod, hydrozoa and belemnite, and spilite grains. The clastic content decreases upwards in the section, d. well-bedded, greenish brown, reddish siltstone and shale with *Bositra (syn. Posidonia) bronni* (det. L. Krystyn).

A Karakaya unit, variously named as the Döşemedere Formation [59, 64], Dilarkaç member [86] or the Ortaköy Formation [62], lithologically similar to the Çal Unit, occurs in the Ankara region. It consists of spilitised basic volcanic rock, volcanogenic siltstone, shale, olistostrome and radiolarian chert. The olistostromes are however scarcer and more polygenic in the Ankara region and include recrystallised limestone, Triassic limestone, phyllite as well as Permian limestone blocks [59, 62, 64, 86].

The abundant olistostromes, pyroclastic and lava flows in the Çal Unit suggest an origin in a (back-arc) rift that developed to maturity indicated by the presence of pelagic sediments probably in the upper parts of the sequence. The Camialan Limestone that probably constitutes the top part of the Çal Unit represents the basin inactivity stage (cf. [87]).

6.4.4.1. The Camialan Limestone

The Middle Triassic limestones that occur as up to several kilometres large tectonic blocks in the Çal Unit in the southeast of Biga are named as the Camialan Limestone (Fig. 2); the name of the unit comes from the Camialan village in this region. The reference section for the unit is along the road between the villages of Hoşoba and Camialan. Here, a 100 metre thick, sequence is exposed (Fig. 18) which starts at the base by yellowish pink marn and siltstones (Scythian ?) that pass upwards to pink, grey, thinly bedded micritic limestones with chert lenses in the transition zone (Fig. 18). These thinly bedded limestones are overlain by a minimum 50 m thick thickly bedded/massive grey, partly recrystallised Anisian limestones with mollusc, alg and echinoderm fragments. Samples from these limestones have yielded *Meandrospira dinarica, Glomospirella grandis, Glomospira densa, Ammobaculites,* Duartaminadae, *Endothyra* or *Endothyranella* sp. (det. Demir Altıner) indicating an Anisian age. No age diagnostic fossils are found in the structurally lower part of the sequence. Gözler et al. [16] also describe Middle-Late Triassic fossils from another block of the Camialan Limestone farther southeast which they interpret as unconformably overlying the Çal Unit (their Karakaya Complex s. 1.) and thus assign an Early Triassic age to the Karakaya Complex.

The contacts of the Camialan Limestone blocks with the surrounding lithologies of the Çal Unit are not well exposed. In some regions the Camialan Limestone seems to tectonically overlie the spilites and the olistostromes of the Çal Unit, in other regions, such as in the type locality, Camialan Limestone blocks are embedded in the Çal Unit. Here it is tentatively suggested that the Camialan Limestone represents stratigraphically the upper parts of the Çal Unit.

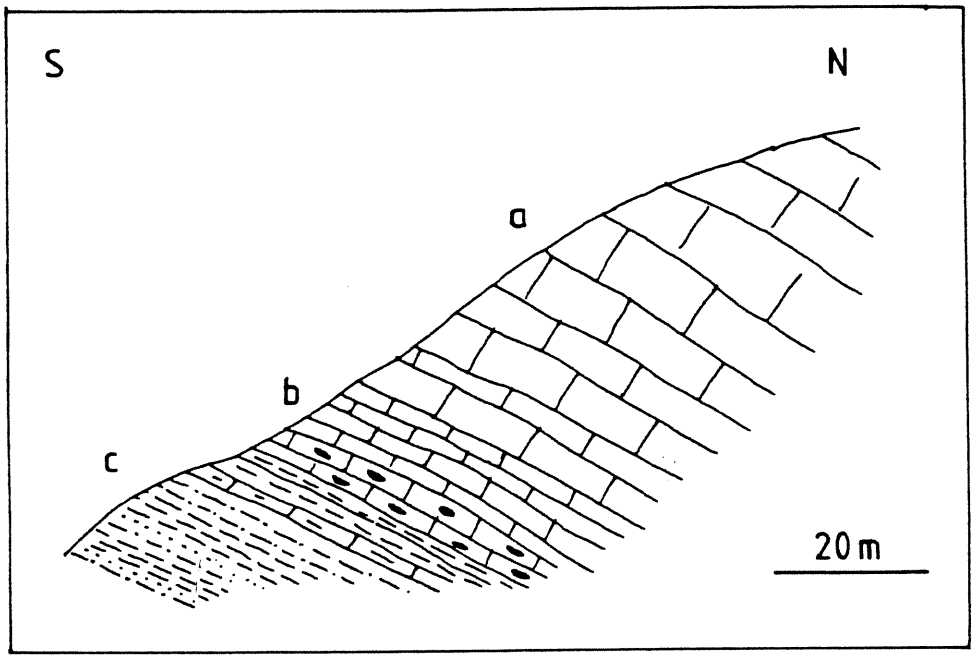

Fig. 18. Field section of the Middle Triassic Camialan limestone sequence southeast of Biga, a. grey, thickly bedded-massive, partially recrystallised Anisinian limestone, b. grey, pink, thinly bedded limestone with chert nodules, c. yellowish red marn, siltstone and sandstone

An Anisian limestone block, lithologically and faunally similar to the Camialan Limestone is described by Altıner and Koçyiğit [88] and by Koçyiğit [64] (the Yazılıkaya Formation) from the Ankara region. The limestone is stratigraphically under and overlain by basic volcanic pillow lavas and is closely associated with the equivalent of the Çal Unit in the Ankara region.

6.5. The Manyas Group

A thick sequence of white marble overlain by calc-schist, amphibolite and quartz-micaschist occur in a small region in the extreme east of the studied area south of Manyas (Fig. 2). This group of metamorphic rocks, called the Manyas Group, make a steep tectonic contact marked with serpentinite slivers with the arkosic sandstones of the Hodul Unit (Fig. 2) and is tectonically overlain by the blueschists of the Tavşanlı Zone [34]. The metamorphic rocks of the Manyas Group are also intruded by the Oligo-Miocene Ilıca-Şamlı Granodiorite. The blueschists and probably also the Manyas Group belong to the Anatolides.

6.6. Post-Karakaya Units

Like everywhere else in the Sakarya Zone, the units of the Karakaya Complex in the Biga Peninsula are unconformably overlain by a Jurassic and younger sedimentary sequence (Fig. 19) that shows no regional metamorphism or major deformation. This sedimentary sequence is best known from the Bursa-Bilecik region where it is studied by large number of geologist [89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 38, 99, 100]. A recent detailed paleontological and stratigraphic study by Altıner et al. [78] is also devoted to the Jurassic-Early Cretaceous evolution of the western part of the Sakarya Zone. In the Biga Peninsula the Mesozoic part of this sedimentary se-

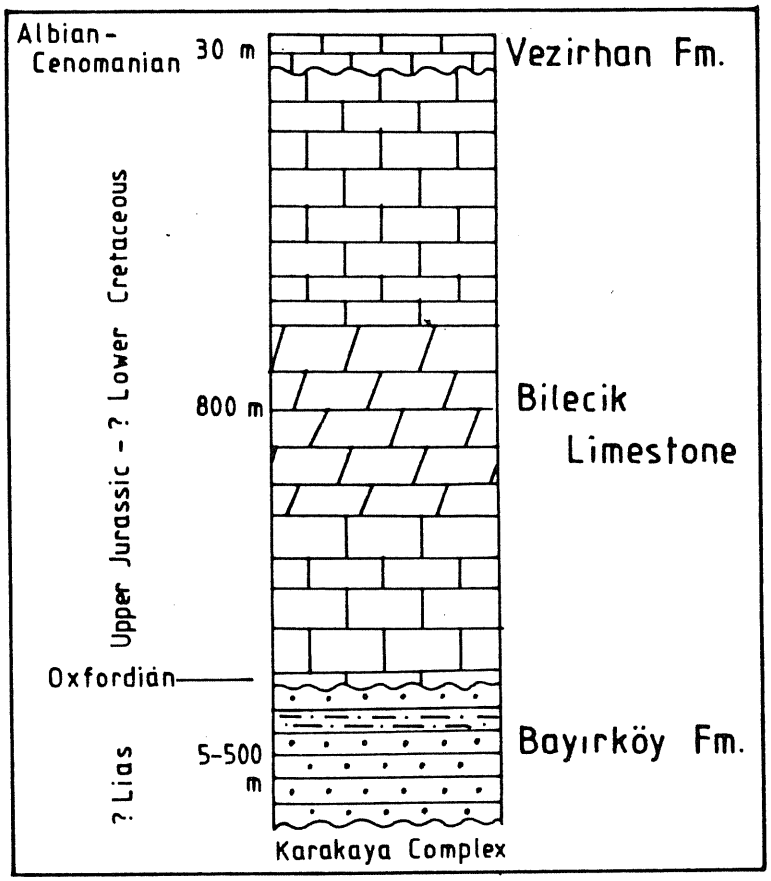

Fig. 19. The Jurassic-Cretaceous stratigraphy of the Sakarya Zone in the Biga Peninsula.

quence is subdivided into three formations named after their counterparts in the Bursa-Bilecik region: the Bayırköy Formation, the Bilecik Limestone and the Vezirhan Formation (Fig. 19).

6.6.1. The Bayırköy Formation

In the Biga Peninsula the Bayırköy Formation consists mainly of yellowish brown sandstone, siltstone, marn and conglomerate. It unconformably overlies the Hodul, Orhanlar and Çal units of the Karakaya Complex (Fig. 17) and the Sarıoluk Granodiorite. It has a very variable thickness ranging from a few metres to 500 metres, and is overlain disconformaby the Bilecik Limestone.

In the Biga Peninsula the clastics overlying the Çal Unit contain *Bositra* (syn. *Posidonia*) *bronni* of Late Liassic age (det. L. Krystyn). In the Bursa-Bilecik region the Bayırköy Formation is assigned a Hettangian-Early Pliensbachian (Lias) age based on the fossils from the red nodular ammonitico rosso limestones intercalated within the clastics of the Bayırköy Formation. Such ammonitico rosso horizons are absent within the Bayırköy clastics and only occur at the base of the overlying Bilecik Limestone.

6.6.2. The Bilecik Limestone

The Bilecik Limestone is a light to dark coloured medium to thickly bedded limestone that disconformably overlies the Bayırköy Formation; in some areas such as east of the village of Yaykın, east of Çan, the Bilecik Limestone overlies the Karakaya Complex directly without the intervening Bayırköy Formation. Detailed paleontological studies by Granit and Tintant [89] and Altıner et al. [78] in the Bursa-Bilecik region have shown the presence of a disconformity between the Bayırköy Formation and the Bilecik Limestone encompassing Late Pliensbachian-Bathonian (late Lias-early Dogger). Contrary to the views of Altıner et al. [78] a similar disconformity most probably exists in the Biga Peninsula although, as stated above, the age of the Bayırköy Formation has not been determined independently in this region.

A few metres thick, nodular, light pink to cream coloured limestone in the ammonitico rosso facies, occurs at the base of the Bilecik Limestone in the Yenice-Havran region, while in the area north of Balya a few metres thick, yellowish grey, pink, marly limestone with abundant pelagic lamellibranchs constitutes its base (Fig. 19). The base of the Bilecik Limestone is well dated through the presence of the basal ammonitico rosso limestone.

Blanc [15] assigns a Bathonian-Oxfordian (Late Dogger-Early Malm) age to the ammonites collected from around the Yaykın Village north of Yenice. Ammonites collected by us from the base of the Bilecik Limestone from the vicinity of the Village of Aşağı Çavuş west of Kalkım indicate a Callovian-Oxfordian age: *Sowerbyceras tortisulcatum, Callephylloceras* sp., *Partschiceras flabellatum, Perisphinctes* sp., *Perisphinctes gregoryceras* ? (det. Leopold Krystyn). Aslaner [13] and Krushensky et al. [35] report ammonite faunas from the base of the Bilecik Limestone similarly characteristic for the Dogger-Malm boundary (Callovian-Oxfordian).Point samples from the Bilecik Limestone give a Late Jurassic fauna: *Glomispira* sp., ? *Reophax* sp., *Mesoendothyra* sp., *Pseudocyclammina* sp., *Labyrinthina* sp., *Textularia* sp., *Trochommina* sp., *Valvulina* sp., *Haplophragmoides* sp., *Nautilocolina* ? sp., *Opthalmidium* sp., *Spirillina* sp., *Conincospirillina basiliensis* sp., *Protopeneroplis striata, Trocholina* sp., *Bachinella irregularis, Cladocoropsis mirabilis, Lithocodium aggregatum, Cayeuxia,* Tintinidae, Dasycladacea (det. Mustafa Esenler and M. Baykal). The upper age limit of the Bilecik Limestone in the Biga Peninsula is not well known. In the Havran region the upper parts of the incomplete Bilecik Limestone sequence give Kimmeridgian-Tithonian (uppermost Jurassic) ages [78], while no age diagnostic fossils are as yet determined in the upper parts of the more complete Kalkım-Balya Bilecik Limestone sequence. In the Bursa-Bilecik region the age of the Bilecik Limestone reaches into the Early Cretaceous.

In the Biga Peninsula the Bilecik Limestone has generally been eroded from the top; only in the region between Kalkım and Balya both the basal and top contacts of the Bilecik Limestone are exposed and in this region the Bilecik Limestone has a thickness of approximately 800 m (Naci Görür, pers. comm.). The Bilecik Limestone is overlain disconformably by the pelagic argillaceous limestones of the Vezirhan Formation.

6.6.3. The Vezirhan Formation

The Vezirhan Formation consists of thinly to medium bedded, white, pink, pelagic argillaceous limestones that overlie the Bilecik Limestone with disconformity (Fig. 19). The Vezirhan Formation has an observed maximum thickness of about 30 metres and has small outcrops in several parts of the Biga Peninsula, such as south of Biga, around the Hamdibey-Kalkım Neogene basin, on the Kalkım-Balya road and north of Balya. Samples collected from these localities contain radiolaria and *Hedbergella* sp. that is characteristic for the Apsian-Maastrichtian time interval. Only one sample collected from the vicinity of the Semiz Village around Balya contains *Banetocardiella conoidea* (det. M. Baykal) characteristic for Albian-Cenomanian.

7. THE TERTIARY DEPOSITS OF THE BIGA PENINSULA

In the Sakarya Zone in the Biga Peninsula rocks of Late Cretaceous to early Eocene age are not known. Farther east in the Middle Sakarya region the Vezirhan Formation of mid-Cretaceous age is succeeded by a over 1000 m thick Upper Cretaceous tuffaceous flysch sequence with olistoliths of serpentinite and Bilecik Limestone, and argillaceous pelagic limestone intercalations [90, 98]. This turbiditic flysch sequence, called the Gölpazarı Group, shows a regressive development and passes upwards to the fluvial sediments of Paleocene age. In the Biga Peninsula this sequence is probably eroded during the Late Paleocene.

The Tertiary deposits of the Biga and Gelibolu Peninsulas are recently reviewed by Siyako et al. [47]. The Tertiary history of the Biga Peninsula begins essentially with the Middle Eocene neritic limestones that are overlain conformably by the Upper Eocene turbidites with andesite and andesitic tuff intercalations. At the end of the Oligocene there was widespread uplift in the Biga Peninsula which led to the erosion of most of the Eocene-Oligocene sequence. This major uplift and erosion phase was followed by an extensive latest Oligocene-Middle Miocene calc-alkaline magmatism. All the isotopically dated granitoids in the Biga Peninsula have given latest Oligocene-Early Miocene ages: Eybek Granodiorite, 23 - 31 Ma [101, 102]; Kestanbol Syenite, 28 Ma [103]; Ilıca-Şamlı Granodiorite, 20 - 23 Ma [104, 105]; Nevruz-Çakıroba Granodiorite, 24 Ma [106]. The intrusion of these granitoids were accompanied by the extrusion of large volumes andesite, dacite, rhyolite and acidic tuffs during the Early to Mid-Miocene (e.g. [107]). Limnic sequences frequently with lignite occur locally within the volcanic rocks. In the Late Miocene the volcanism ceased and fluvial to shallow marine clastics were deposited in the Gelibolu Peninsula and in the northern parts of the Biga Peninsula. During the Pliocene-Quaternary there were local fluvial and limnic sedimentation and small scale alkali basaltic volcanism.

8. THE STRUCTURE OF THE BIGA PENINSULA

The large scale structures in the Biga Peninsula belong to three successive periods; a) Triassic Karakaya orogeny, b) Tertiary Alpide orogeny, c) Late Tertiary strike-slip faulting.

8.1. Structures related to the Karakaya orogeny

Triassic structures in the Ezine and Sakarya Zones show different structural styles. In the Ezine Zone the Triassic structures are characterised

by shallow to medium dipping thrusts that can be traced for over long distances and separate internally coherent nappes; a good example is the Çamköy Thrust that separates the Denizgören Ophiolite from the underlying Karadağ Unit. Similarly the over 35 km long Ovacık Fault is probably also a Triassic structure reactivated during the Early Tertiary (Fig. 3).

Thrust bound flat-lying internally coherent nappe packages are rare in the Karakaya units. The different Karakaya units are often bound by steeply dipping faults that outline megablocks of several kilometres in size. Shear zones are very frequent and strongly disrupt the internal continuity of the strata. A representative example of such structures occurs southeast of Çan (Figs. 11, 13) where two blocks of Hodul and Çal units respectively, each seven kilometers across occur in the metatuffs and phyllites of the Nilüfer Unit. The steeply dipping faults, locally marked by small serpentinite slivers, which bound these blocks cross-cut the consistent E-W foliation in the Nilüfer Unit (Figs. 11, 13). The internal structure of the megablocks is also highly complex with frequent shear zones; the block with the Hodul Unit itself contains large tectonic blocks of spilite (Fig. 11). Observed on a very large scale, the Karakaya Complex in the central part of the Biga Peninsula has a melange like structure which makes it difficult to establish the early structural succession of the Karakaya units. However, the Kazdağ Group and the Nilüfer Unit are clearly at the base of the tectonic stack. Higher up in the stack come the Hodul Unit and the Orhanlar Greywacke; the relationship between these two units is not clear. They occur in contact in the studied region only in the north of Balya where a steeply diping fault that has been reactivated during the Tertiary separates the two units. In this region the Orhanlar Greywacke probably tectonically overlies the Hodul Unit at depth (Fig. 13). The Çal Unit, the least deformed of all the Karakaya units, occurs at the top of the tectonic stack. East of the village of Derenti the Çal Unit lies tectonically over the Hodul Unit along a shallowly dipping probably Triassic fault (Fig. 11).

The structures in the Karakaya Complex suggest two major stages of deformation. The first stage comprises the tectonic stacking of the Karakaya units and the metamorphism and folding of the lower Karakaya units such as the Nilüfer Unit. The second stage involves the disruption of the tectonic stack by steeply dipping anastomosing shear zones probably related to strike-slip faulting.

8.2. Early Tertiary Alpide structures

As no Mesozoic rocks are present in the Ezine Zone, virtually nothing is known on the Alpide history of this belt. In the Sakarya Zone the Late

Jurassis-Early Cretaceous limestones are generally only gently folded; only in the region south of Biga near the Çetmi Ophiolitic Melange, the Late Jurassic-Cretaceous succession occurs locally in an overturned position.

The major Early Tertiary Alpide event in the Biga Peninsula was the emplacement of the ophiolitic melange units on the continental rocks. Most of the thrust contacts between the ophiolitic melanges and the continental rocks are covered by the Neogene deposits or reactivated as Late Tertiary steeply dipping faults; the Alakeçi Mylonite Zone is probably the only example of these major Early Tertiary thrusts.

8.3. Late Tertiary Strike-Slip Faulting

In the Biga Peninsula the strike-slip faulting started as early as Early Miocene. The small lacustrine Early Miocene basins, such as Çan or Kalkım basins, that lie over the voluminous calc-alkaline volcanic rocks, are controlled by the strike-slip faults. The strike-slip faulting was particularly intense along a NE-SW trending zone between the Küçükkuyu and Bandırma (Fig. 2); this zone contains many strike-slip faults some with minimum lateral off-sets of eight kilometers [47] and can be regarded as an Early Miocene to Recent strike-slip fault zone. The region of Kazdağ Group in the southwest and the Yolindi Metagranodiorite in the northeast are compressive segments within this strike-slip fault zone. The Kazdağ Range bounded in the north and south by major strike-slip faults is still undergoing fast uplift as a pressure ridge.

9. TECTONIC EVOLUTION

9.1. The Cimmeride Evolution

The lack of precise age data for many of the Karakaya units, and the strong effects of the later Alpide compressive and recent strike-slip fault movements make any schema on the Permo-Triassic tectonic evolution of the Biga Peninsula highly speculative. Especially, strong lateral movements may have occurred between the Ezine and the Sakarya zones for which there are very little data. Thus, the proposed tectonic evolution model will be strongly modified with new data from the Biga Peninsula and elsewhere from the Sakarya Zone.

The presence of the Permo-Triassic ophiolite in the Ezine Zone and the pelagic Late Paleozoic blocks in the Karakaya Complex indicate that an oceanic basin, corresponding to the Paleo-Tethys of Şengör et al. [70], was in existence during the Late Paleozoic near the studied region. As no pelagic Late Paleozoic rocks or pre-Jurassic ophiolite are known from the

area between the Biga Peninsula and the İzmir-Ankara suture, the Paleo-Tethyan ocean must have been located north or northwest of the Sakarya Zone. There are two possibilities; the Paleo-Tethyan suture may lie between the Ezine and Sakarya zones following the trend of the Late Cretaceous Çetmi Ophiolitic Melange of the Ayvacık-Karabiga belt (Fig. 20a) or it may be located farther northwest of the Ezine Zone [70]. We tend to subscribe to the first hypothesis based on the absence of the Karakaya units in the Ezine Zone, and farther northwest in the Rhodope and Serbo-Macedonian massifs in Greece.

The scenary during the Late Permian (Murghabian) is shown in Fig. 20A. In the northwest there was a passive continental margin bordered in the north by a carbonate platform where over 1000 metres of shallow water carbonates were deposited during the Permo-Carbonifereous (Karadağ Unit of the Ezine Zone). In the southwest there was a magmatic arc build on transitional crust. The Nilüfer Unit and probably the upper parts of the Kazdağ Group represent the intra-arc and probably the fore-arc deposits, while the Orhanlar Greywacke may represent accreted trench deposits characterised by abundant sediment supply similar to the Franciscan Complex in the western United States [30]. The magmatic arc was bordered in the southeast by an extensive shallow water carbonate platform extending to the Taurides (Fig. 20A). In contrast to the Ezine Zone, the Permian carbonates in the Sakarya Zone were thinner and were deposited on a Variscan (?) crystalline basement.

During the latest Permian a part of the carbonate platform in the back-arc setting began rifting (Fig. 20B). Preceeding the rifting there was widespread uplift in the Sakarya Zone and probably also in the northern part of the Anatolide-Tauride platform. The age of the rifting is indicated by the absence of the latest Permian (Dorashamian) and Triassic olistoliths in the rift deposits represented by the Çal Unit. The rifting was accompanied by extensive basic volcanism and deposition of olistostromes derived from the rift shoulders made up of Upper Permian carbonates. The rift axis was located, within the present day geography, between the Kazdağ and Bandırma (Fig. 20B). The presence of rocks similar to the Çal Unit on the island of Lesbos [108] and pelagic Lower Triassic rocks in the Chios and Karaburun [109] west of İzmir suggests that the rift axis trended southward from Kazdağ and probably joined a triple rift junction in the Chios-Karaburun region (Fig. 20B); the eastern arm of the rift was to become the İzmir-Ankara ocean, the western arm the Pindos ocean while the Karakaya rift was to close at the end of the Triassic.

During the latest Permian/Early Triassic an ophiolite obduction occurred over the passive northwestern continental margin of the Paleo-Tethys

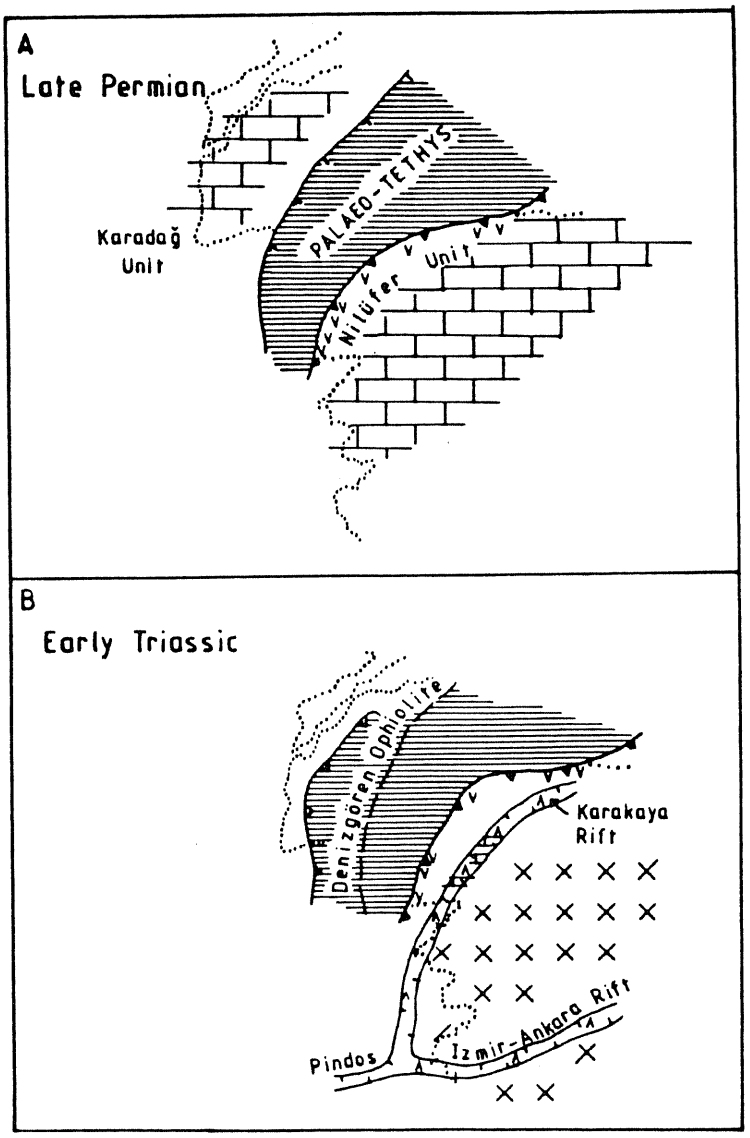

Fig. 20. Paleotectonic maps showing the Permo-Triassic tectonic evolution of the Biga Peninsula and the surrounding regions. Maps show oceans (vertical and horizontal rulings, widths are not to scale) and the predominant lithofacies on the continents (widely spaced carbonate pattern = neritic carbonates, closely spaced carbonate pattern = pelagic carbonates, dots = clastics, crosses = land or erosional area, v = arc volcanics, Λ = rift volcanics, m = regional Barrovian metamorphism). Thin lines with hachures are passive continental margins, heavier lines with black triangles are subduction zones, lines with open triangles show major intra-continental thrust faults.

(Fig. 20B). The reason for this latest Permian-Early Triassic ophiolite obduction is not clear. It could be due to the partial subduction of a Late Permian continental margin under a northwest dipping subduction zone as in the case of Oman. The absence of any continental margin assemblages between the Late Permian carbonate platform (Karadağ Unit) and the Denizgören Ophiolite is striking, and suggests either that there were initially present but were later cut out through a normal fault or that the ophiolite was a far-travelled nappe as in the case of some Late Cretaceous ophiolite bodies in the Taurides, such as the Aladağ Ophiolite, that similarly rest directly on the Mesozoic platform carbonates [110, 111].

The presence of radiolarian cherts, pelagic limestones and calciturbidites probably in the upper parts of the Çal Unit indicate that the Karakaya rift reached a mature stage probable towards the end of the Scythian; however, the complete absence of the ophiolite in this unit suggests that the rift never developed oceanic crust. During the Middle Triassic rift volcanism died out and limestones were deposited (Camialan Limestone) (Fig. 21A). However, evidence from the Ankara region [64] indicate that the rift volcanism continued at least in the Ankara region during the Late Anisian.

During most of the Early and probably Middle Triassic the region southeast of the Karakaya rift was an erosional area which in places was stripped down to the crystalline basement. In the Late Triassic high-standing regions with exposed basement of granitic (Çamlık Metagranodiorite) and metamorphic rocks (the Kalabak Formation), was supplying detritus to the west (Fig. 21A). The distal parts of this thick clastic apron (the Hodul Unit) rest of rift volcanics in the north of Edremit (Fig. 21A).

Compression leading to the closure of the Karakaya rift basin started during the latest Triassic as a response of the continental collision between the Ezine and the Sakarya zones following the closure of the Paleo-Tethys (Fig. 21B). The vergence of the orogen in the Biga Peninsula was southeastward as suggested by the general decrease in deformation and metamorphism towards that direction. The N-S directed lineations under the Ovacık Fault in the Ezine Zone, assuming that they are related to thrusting, indicate a southward vergence suggesting that the present SW-NE tectonic grain of the central and eastern Biga Peninsula is the result of the Late Tertiary strike slip faulting. In the region between Bursa and Orhaneli the mesoscopic folds in the Nilüfer Unit also show a southward vergence. Thus the thrusting was antithetic to the dip of the subduction zone.

The only definite evidence for the age of the compressive movements in the Karakaya Complex is the arrival, probable from the northwest, of

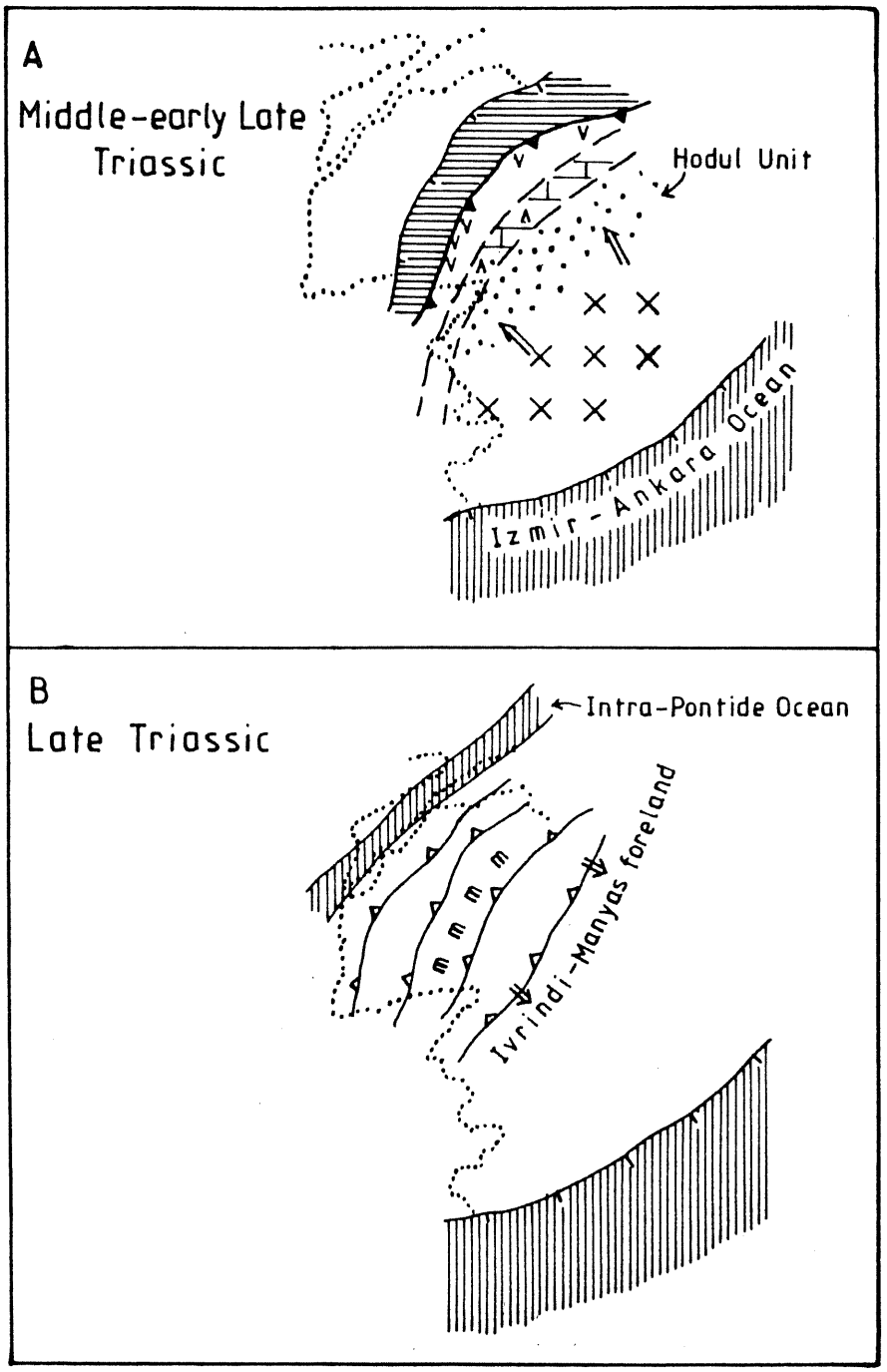

Fig. 21. Paleotectonic maps depicting the Middle-Late Triassic tectonic evolution of the Biga Peninsula and the surrounding regions. For explanations see Fig. 20.

large number of Permian limestone olistoliths during the Norian into the Hodul Unit along the 70 km long İvrindi-Manyas belt (Fig. 2) which was forming the peripheral foreland basin of the Karakaya orogen during this time (Fig. 21B). The absence of Early or Middle Triassic olistoliths in the Norian deposits indicates that the region southeast of the Karakaya rift was largely a land area between the Late Permian and the Late Triassic as suggested above. The deformation must have started earlier in the more internal northwestern parts of the Karakaya orogen. In this internal part two distinct stages of deformation can be recognised. During the first stage the different facies belts were telescoped by thrusting and the deeply buried parts, such as the Nilüfer Unit and the Kazdağ Group, underwent regional metamorphism (Fig. 21B). The section north of Edremit (Fig. 8) illustrates the thrust stacking of the Karakaya units and the involvement of the basement. This stage was followed by major Triassic strike-slip faulting that disrupted the initial nappe stack and created the structural style outlined in the previous section.

The Intra-Pontide ocean opened north of the Ezine Zone probably in the Norian associated with strike-slip faulting after the continental collision. The pronounced disconformity above the neritic Norian limestones in the Çetmi ophiolitic melange in the Karabiga region (Fig. 6) is probably a reflection of this rifting event. The pelagic Late Jurassic, Mid- and Late Cretaceous and Mid-Paleocene limestone blocks in the Çetmi Ophiolitic Melange indicate the persistence of the Intra-Pontide ocean throughout the Late Mesozoic.

Following the Late Triassic Karakaya orogeny there was uplift and erosion during the latest Triassic and earliest Jurassic and the whole region was first transgressed by the molasse type clastics during the Early Jurassic. During the Late Jurassic to mid-Cretaceous the Biga Peninsula was part of a wide continental shelf in the northern margin of the Neo-Tethys with passive continental margins in the north facing the Intra-Pontide ocean and in the south the İzmir - Ankara ocean.

The schema proposed here for the Cimmeride evolution of the northwest Turkey is broadly in agreement with the schemas proposed by Şengör and Yılmaz [17], Şengör et al. [70] and Şengör [112] in involving a Permian Paleo-Tethys with a south-dipping subduction zone, and in the opening of the Karakaya rift as a back-arc south of the Paleo-Tethys. However, there are some significant differences. The data from the Biga Peninsula indicate that the Paleo-Tethys was not situated north of the Istranca Massif (the Kırklareli Nappe of Şengör et al [70]) but probably was located between the Sakarya and Istanbul zones. Another less likely possibility is that the Paleo-Tethyan suture may pass between the Istranca Massif and the Istan-

bul Zone and then follow the northern border of that zone. Another difference from the schema of Şengör et al. [70] is that, at least in the Biga Peninsula, the Karakaya rift never developed oceanic crust.

9.2. Alpide Evolution

There are two ophiolitic melange belts in the studied region, namely the Ayvacık-Karabiga and Gelibolu zones, each of which can be regarded as a separate suture representing individual Mesozoic oceans. However, the rock types, their ages and the internal structure of both of these melange belts are quite similar, including the presence of the HP/LT metamorphic rocks. Furthermore it is difficult to envisage two, and if one includes the İzmir-Ankara ocean, three major Mesozoic oceans with important subduction histories that would generate blueschists and eclogite, in close proximity. Here it is suggested that the two ophiolitic melange belts are products of the Mesozoic Intra-Pontide ocean [17] which separated the Sakarya and Ezine zones from the Rhodope-Istranca massifs. The suture of this ocean is represented by the Gelibolu Zone while the ophiolitic melanges of the Ayvacık-Karabiga Zone represent imbricated outliers that were thrust southeastward from the Intra-Pontide suture.

The Intra-Pontide ocean was closed by northwest dipping subduction between the Middle Paleocene and Middle Eocene; this is indicated by the presence of pelagic Mid-Paleocene limestones in the Çetmi Ophiolitic Melange and the transgressive cover of the Middle Eocene neritic carbonates. During the initial late Paleocene collision between the Rhodope-Istranca and Ezine-Sakarya zones the accretionary complex represented by the Çetmi Ophiolitic Melange was thrust southeastward covering the Ezine and part of the Sakarya zones. Following further compression the Late Triassic Paleo-Tethyan suture was reactivated as a major out of sequence thrust and resulted in the emplacement of the Ezine Zone over the Çetmi Ophiolitic Melange. This major crustal restacking and consequent increase in the crustal thickness in the Biga Peninsula during the Early Eocene, was responsible for the Late Oligocene uplift and voluminous Oligo-Miocene calc-alkaline magmatism observed in the Biga Peninsula. Major strike-slip faulting related to the North Anatolian Fault Zone has affected the Biga Peninsula since the Early Miocene [47].

10. CONCLUSION

Detailed studies in the Biga Peninsula have shown that the Karakaya Complex consists of various Permo-Triassic active margin tectonostratigraphic units representing accretionary complex (the Orhanlar Greywacke), intra-arc, fore-arc (the Nilüfer Unit and the upper parts of the Kazdağ Group) and rift (the Çal Unit) deposits, and a thick Late Triassic clastic apron (the Hodul Unit). Thus, it is not correct to think of the Karakaya Complex as a single stratigraphic unit, as has been done by most previous workers (e.g. 3, 16, 52, 56, 62]), or to regard it as a formation or as a group. The ophiolitic melanges in the Biga Peninsula that were considered as part of the Karakaya Complex [3, 16, 24, 69] are shown to be of Late Cretaceous/Paleocene ages. This close spatial association of the Alpide and Cimmeride orogenic rock units has led in the past to misleading conclusions on the nature of the Karakaya Complex.

Our studies have established the western boundary of the Karakaya Complex and thus of the Sakarya Zone in the Biga Peninsula; this explains the difficulty in tracing the Sakarya Zone westwards to the northeastern Greece, where units equivalent to the Karakaya Complex or the major Liassic transgression, which is a very typical feature of the Sakarya Zone, are absent. This western boundary of the Sakarya Zone probably corresponds to the Paleo-Tethyan suture that juxtaposes a Permo-Triassic passive continental margin characterised by an ophiolite obduction, with the active margin deposits of the Karakaya Complex.

Major Alpide thrusting related to the emplacement of the ophiolitic melanges are recorded for the first time in this study from the Biga Peninsula. This Early Tertiary Alpide thrusts related to the closure of the Intra-Pontide ocean, thickened the continental crust of the Biga Peninsula and probably resulted in the Late Tertiary partial melting and in extensive Late Oligocene-Early Miocene calc-alkaline magmatism.

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REFERENCES

[1]. OKAY, A.I., High-pressure/low-temperature metamorphic rocks of Turkey, Geol. Soc. Am. Memoir No. **164**, 333 - 348 (1986).

[2]. OKAY, A.I., Tectonic units and sutures in the Pontides, northern Turkey, Tectonic Evolution of the Tethyan Region, ed. A.M.C. Şengör. 109 - 115 (1989).

[3]. BİNGÖL, E., B. AKYÜREK and B. KORKMAZER, Biga Yarımadası'nın Jeolojisi ve Karakaya Formasyonu'nun bazı özellikleri, Cümhuriyetin 50. Yılı Yerbilimleri Kongresi Tebliğleri, MTA Enstitüsü, Ankara, 70 - 77 (1975).

[4]. OKAY,. A.I., Biga Yarımadası'nın batı kesiminin jeolojisi ve tektoniği, TPAO Report No. 2374 (1987).

[5]. OKAY, A.I., Çan-Yenice-Biga arasının jeolojisi ve tektoniği, TPAO Report No. 2544 (1988).

[6]. OKAY, A.I., Edremit-Balya-Manyas arasının jeolojisi ve tektoniği, TPAO Report No. (1989).

[7]. OKAY, A.I., Bandırma-Bursa arasının jeolojisi ve tektoniği, TPAO Report No. 2703 (1990).

[8]. OKAY, A.I., Ophiolite obduction on a Permian carbonate platform in northwest Turkey, Fourth Meeting of the European Union of Geosciences (EUG IV), Terra Cognita, **7**, 100 (1987).

[9]. KAADEN, G. v.d., Age relations of magmatic activity and of metamorphic processes in the northwestern part of Anatolia-Turkey. Bull. Min. Res. Expl. Ins. Turkey. **52**, 15 - 33 (1959).

[10]. KALAFATÇIOĞLU, A., Geology around Ezine and Bozcaada and the age of the limestones and serpentines, Bull. Min. Res. Expl. Ins. Turkey, **60**, 61 - 70 (1963).

[11]. AYGEN, T., Balya bölgesi jeolojisinin incelenmesi, Publ. Min. Res. Expl. Ins. No. D11, 1 - 95 (1956).

[12]. GÜMÜŞ, A., Contribution a l'etude geologique de secteur septentrional de Kalabak Köy-Eymir Köy region d'Edremit Turquie, Publ. Min. Res. Expl. Ins. No. **117**, 1 - 109 (1964).

[13]. ASLANER, M., Etude geologique et petrographique de la region d'Edremit-Havran (Turquie), Publ. Min. Res. Expl. Ins. no. 119 (1965).

[14]. BİNGÖL, E., Contribution a l'etude geologique de la partie centrale et SE du massif de Kazdağ (Turquie), Ph. D. Thesis, University of Nancy, France (1968).

[15]. BLANC, M.P. Etude petrographique de la granidiorite de Yenice, Peninsula de Çanakkale, Ph. D. Thesis, University of Paris, France (1969).

[16]. GÖZLER, M.Z., E. ERGÜL, F. AKÇAÖREN, Ş. GENÇ, Ü. AKAT and Ş. ACAR, Çanakkale Boğazı doğusu-Marmara Denizi güneyi-Bandırma-Balıkesir-Edremit ve Ege Denizi arasındaki alanın jeolojisi ve kompilasyonu. MTA Report No. (1984).

[17]. ŞENGÖR, A.M.C. and Y. YILMAZ, Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics, **75**, 181 - 241 (1981).

[18]. KOPP, K., N. PAVONI and C. SCHINDLER, Geologie Thrakiens V: Das Ergene-Becken. Beihefte Geologischen Jahrbuch, **76**, 1 - 136 (1969).

[19]. ŞENTÜRK, K. and A.I. OKAY, Blueschists discovered east of Saros Bay in Thrace, Bull. Min. Res. Expl. Ins. Turkey, **97/98**, 152 - 155 (1984).

[20]. YÜZER, E., Marmara Adası mermerlerinin mühendislik jeolojisi ve anizotropik özelliklerinin araştırılması, Thesis, Istanbul Technical University, 1 - 128 (1971).

[21]. DÜRR, S., Über alter und geotektonische Stellung des Menderes Kristallins SW-Anatolien und seine Aequivalente in der mittleren Aegaeis, Thesis. Marburg, West Germany, (1975).

[22]. GUTNIC, M., O. MONOD, A. POISSON, and J.F. DUMONT, Geologie des Taurides Occidental (Turquie), Mem. Soc. Geol. France, No. **137**, 1 - 112 (1979).

[23]. BRADLEY, D.C. and T.M. KUSKY, Geological evidence for rate of plate convergence during the Taconic arc-continent collision, J. Geology, **94**, 667 - 681 (1986).

[24]. GÖZLER, Z., Kazdağ batısı Mıhlı Dere vadisinin jeolojik ve petrografik incelenmesi, Türkiye Jeol. Kur. Bült., **29**, 133 - 142 (1986).

[25]. GLENNIE, K.W., M.G.A. BOEUF, M.W.H. CLARKE, M. MOODY-STUART, W.F.H. PILAAR, and B.M. REINHARDT, Geology of the Oman Mountains, Verh. K. Geol. Mijnbou. Genoot, **31**, 1 - 423 (1974).

[26]. LIPPARD, S.J., A.W. SHELTON, and I.G. GASS, The ophiolite of northern Oman, Geol. Soc. London Memoir No. **11**, 1 - 178 (1986).

[27]. STÖCKLIN, J., Possible ancient continental margins in Iran, The Geology of the Continental Margins, ed. C.A. Burke and C.L. Drake, 873 - 887 (1974).

[28]. HALLAM, A., Geology and plate tectonic interpretation of the sediments of the Mesozoic radiolarite-ophiolite complex in the Neyriz region, southern Iran, Geol. soc. Am. Bull., **87**, 47 - 52 (1976).

[29]. BRINKMANN, R., A. GÜMÜŞ, F. PLUMHOFF, and A.A. SALAH, Höhere Oberkreide in Nordwest Anatolien und Thrakien, N. Jb. Geol. Paleon. Abh., **154**, 1 - 20 (1977).

[30]. THORNBURG, T.M. and L.D. KULM, Sedimentation in the Chile Trench: depositional morphologies, lithologies, lithofacies and stratigraphy, Geol. Soc. Am. Bull., **98**, 33 - 52, (1987).

[31]. MOORE, G.F. and D.E. KARIG, Development of sedimentary basins on the lower trench slope, Geology, **4**, 693 - 697 (1976).

[32]. BRINKMANN, R., Geotektonische Gliederung von Westanatolian, N. Jb. Geol. Paleon. Monatshefte, 603 - 619 (1966).

[33]. BRINKMANN, R., The geology of western Anatolia, The Geology and History of Turkey, ed. Campbell, 171 - 190 (1971).

[34]. OKAY, A.I., Distribution and characteristics of the northwest Turkish blueschists, Geol. Soc. London, Spec. Publ. No. **17**, 455 - 466 (1984).

[35]. KRUSHENSKY, R., Y. AKÇAY, and E. KARAEGE, Geology of the Karalar-Yeşiller area, northwest Anatolia, Turkey, Bull. U. S. Geol. Survey, **1461**, 1 - 72 (1980).

[36]. YILMAZ, Y., Petrology and structure of the Gümüşhane granite and the surrounding rocks, northeast Anatolia, Ph. D. Thesis, University College London (1972).

[37]. YILMAZ, Y., Sakarya Kıtası güney kenarının tektonik evrimi, İstanbul Yerbilimleri, **1**, 33 - 52 (1981).

[38]. SANER, S., Geology and the environment of deposition of Geyve-Osmaneli-Gölpazarı-Taraklı area, İst. Univ. Fen. Fak. Mecm., Ser. B, **43**, 63 - 91 (1978).

[39]. ÇOĞULU, E. and D. KRUMMENACHER, Problemes geochronometriques dans la partie NW de l'Anatolie Centrale (Turquie), Schweiz. Mineral. Petrogr. Mitt., **47**, 825 - 833 (1967).

[40]. YARWOOD, G.A. and M. AFTALION, Field relations and U-Pb geochronology of a granite from the Pelagonian Zone of the Hellenides (High Pieria, Greece), Bull. Soc. Geol. France, **18**, 259 - 265 (1976).

[41]. MOUNTRAKIS, D., Structural evolution of the Pelagonian zone in northwestern Macedonia, Greece, Geol. Soc. London, Spec. Publ. No. **17**, 581 - 590 (1984).

[42]. JACOBSHAGEN, V., Geologie von Griechenland, Gebrüder Borntraeger, Berlin-Stuttgart, 1 - 363 (1986).

[43]. PAPANIKOLAOU, D.J. and C. SIDERIS, Contribution to the Paleozoic of the Aegean area, IGCP Project No. 5, Newsletter No. **5**, 138 - 145 (1983).

[44]. SCHUILING, R.D., Über eine pra-herzynische Faltungsphase im Kazdağ Kristallin, Bull. Min. Res. Expl. Ins. Turkey, **53**, 89 - 93 (1959).

[45]. BİNGÖL, E., Fiziksel yaş tayini metodlarını sınıflama denemesi ve Rb-Sr ve K-Ar metodlarının Kazdağ'da bir uygulaması, Türkiye Jeol. Kur. Bült., **14**, 1 - 16 (1971).

[46]. BİLGİN, T., Biga Yarımadası'nın güneybatı kısmının jeomorfolojisi, İst. Üni. Coğr. Enst. Yayın No. 55 (1433), 1 - 273 (1969).

[47]. SİYAKO, M., K.A. BÜRKAN, and A.I. OKAY, Biga ve Gelibolu yarımadalarının Tersiyer jeolojisi ve hidrokarbon olanakları, Türk. Petr. Jeolog. Dern. Bült., **1**, 183 - 199 (1989).

[48]. ARMSTRONG, R.L., Cordilleran metamorphic core complexes - from Arizona to southern Canada, Ann. Rev. Earth Planet. Sci., **10**, 129 - 154 (1982).

[49]. DAVIS, G.H., Shear-zone model for the origin of metamorphic core complexes, Geology, **11**, 342 - 347 (1983).

[50]. PAPANIKOLAOU, D.J. and E. DEMİRTAŞLI, Geological correlations between the Alpine segments of the Hellenides-Balkanides and Taurides-Pontides, Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts, ed. H.W. Flügel, F.P. Sassi and P. Grecula, Alfa Publishers Bratislava, 387 - 396 (1987).

[51]. BRINKMANN, R., R. FEIST, W.U. MARR, E. NICKEL, W. SCHLIMM and H.R. WALTER, Geologie der Soma Dağları, Bull. Min. Res. Expl. Inst. Turkey, **74**, 7 - 21 (1970).

[52]. AKYÜREK, B. and Y. SOYSAL, Biga Yarımadası güneyinin (Savaştepe-Kirkağaç-Bergama-Ayvalık) temel jeoloji özellikleri, Mad. Tetk. Arama Enst. Dergisi, **95/96**, 1 - 13 (1983).

[53]. ERK, A.S., Etude geologique de la region entre Gemlik et Bursa (Turquie), Publ. Min. Res. Expl. Inst. Ser. B, No. **9**, 1 - 293 (1942).

[54]. YILMAZ, Y., Bilecik-Söğüt dolayındaki eski temel karmaşığının petrojenetik evrimi, Thesis, İstanbul Üniversity (1977).

[55]. GENÇ, Ş., Geology of the region between Uludağ and the İznik Lake, Guide Book for the field excursion along western Anatolia, Turkey, M.T.A. Inst., 19 - 25 (1987).

[56]. KAYA, O., J. WIEDMANN, and H. KOZUR, Preliminary report on the stratigraphy, age and structure of the so-called Late Paleozoic and/or Triassic Melange or Suture Zone Complex of northwestern and western Turkey, Yerbilimleri, **13**, 1 - 16 (1986).

[57]. KAYA, O., O. ÖZKOÇAK and A. LISENBEE, Stratigraphy of the pre-Jurassic blocky sedimentary rocks to the south of Bursa, NW Turkey, Bull. Min. Res. Expl., **109**, 15 - 24 (1989).

[58]. EROL, O., A study of the geology and geomorphology of the region SE of Ankara in Elmadağ and its surroundings. Publ. Min. Res. Expl. Inst. Turkey, Ser. D No. **9**, 1 - 99 (1956).

[59]. BİLGÜTAY, U., Geology of the Hasanoğlan-Ankara region, Bull. Min. Res. Expl. Inst. Turkey, 54, 44 - 51 (1960).

[60]. BATMAN, B., Haymana kuzeyinin jeolojik evrimi ve yöredeki melanjin incelenmesi I: stratigrafi birimleri, Yerbilimleri, 4, 95 - 124 (1978).

[61]. OKAN, Y., Elmadağ Formasyonu'nun (Ankara) yaşı ve alt bölümleri, Türkiye Jeol. Kur. Bülteni, **25**, 95 - 104 (1982).

[62]. AKYÜREK, B., E. BİLGİNER, B. AKTAŞ, N. HEPŞEN, Ş. PEHLİVAN, O. SUNU, Y. SOYSAL, Z. DAĞER, E. ÇATAL, B. SÖZERİ, H. YILDIRIM and Y. HAKYEMEZ, Ankara-Elmadağ-Kalecik dolayının temel jeolojik özellikleri, Jeoloji Mühendisliği, **20**, 31 - 46 (1984).

[63]. GAUTIER, Y., Deformations et metamorphismes associes a la fermeture Tethysienne en Anatolie Centrale (region de Sivrihisar, Turquie), Thesis, University Paris-Sud, Centre d'Orsay, 1 - 235 (1984).

[64]. KOÇYİĞİT, A., Hasanoğlan (Ankara) yöresinin tektono-stratigrafisi: Karakaya orojenik kuşağının evrimi, Yerbilimleri, 14, 269 - 294 (1989).

[65]. BLUMENTHAL, M., Orta ve Aşağı Yeşilırmak bölgelerinin jeolojisi hakkında, Publ. Min. Res. Expl. Ins. Turkey, Ser. D No. 4 (1950).

[66]. ALP, D., Amasya yöresinin jeolojisi, İst. Uni. Fen. Fak. Monograf. No. 22 (1972).

[67]. ÖZCAN, A., A. ERKAN, A. KESKİN, A. ORAL, S. ÖZER, M. SÜMENGEN and O. TEKELİ, Kuzey Anadolu Fayı - Kırşehir Masifi arasının temel jeolojisi, Min. Res. Expl. Inst. Turkey Report No. 6722 (1980).

[68]. OKAY, A.I., The geology of the Ağvanis metamorphic rocks and neighbouring formations, Bull. Min. Res. Expl. Inst. Turkey, **99/100**, 16 - 36 (1984).

[69]. TEKELİ, O., Subduction complex of pre-Jurassic age, northern Anatolia, Turkey, Geology, **9**, 68 - 72 (1981).

[70]. ŞENGÖR, A.M.C., Y. YILMAZ and O. SUNGURLU, Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Paleo-Tethys, Geol. Soc. London Spec. Bubl. **17**, 77 - 112 (1984).

[71]. ÖZKOÇAK, O., Etude geologique du massif ultrabasic d'Orhaneli et de sa proche bordure, Thesis, University of Paris, 1 - 181 (1969).

[72]. LISENBEE, A., The Orhaneli ultramafic-gabbro thrust sheet and its surroundings, Geology and History of Turkey, ed. A.S. Campbell, 349 - 368 (1971).

[73]. AYAROĞLU, H., Bozüyük metamorfitlerinin petrokimyasal özellikleri, Türkiye Jeol. Kur. Bülteni, **22**, 101 - 107 (1979).

[74]. SERVAIS, M., Collision et suture tethysienne en Anatolie Centrale etude structurale et metamorphique (HP-BT) de la zone Nord Kütahya, Ph. D. Thesis,University of Paris (1982).

[75]. INGERSOLL, R.V., Tectonics of sedimentary basins, Geol. Soc. Am. Bull., **100**, 1704 - 1719 (1988).

[76]. ZANKL, H., Magmatismus und Bauplan des ost-pontischen Gebirges im Querprofil des Harşit Tales, NE Anatolien, Geol. Rundschau, **51**, 218 - 235 (1961).

[77]. SCHULTZE-WESTRUM, H.H., Das geologische Profil des Aksudere bei Giresun (nordost Anatolien), Bayerische Akad. Wissen. Abh. Neue Folge, **109**, 25 - 58 (1962).

[78]. ALTINER, D., A. KOÇYİGİT, A. FARINACCI, U. NICOSIA and M.A. CONTI, Kuzeybatı Anadolu'nun Kuzey Anadolu Fay Zonu güneyindeki Rosso Ammonitiko'lu Jura-Alt Kretase stratigrafisi, bölgenin paleocoğrafik ve tektonik evrimi, TÜBİTAK Report 1 - 270 (1989).

[79]. NEUMAYER, M., Über Trias und Kohlenkalkversteinerungen aus dem westlichen Kleinasien, Anz. Kais. Akad. Wiss. Wien, 241 - 243 (1887).

[80]. BITTNER, A., Triaspetrefakten von Balia in Kleinasien, Jahrb. K. K. geol. Reichanstalt XLI (1891).

[81]. von BUKOWSKY, G., Die geologischen Verhaltnisse der Umgebung von Balia Maden, Sitzber. Kaiserl. Akad. Wiss. Wien, math.-naturw. Kl., 101, 214 - 235 (1892).

[82]. TOLLMANN, A., Grundprincipien der Alpinen Decken-Tektonik, Franz Deuticke, Wien, 1 - 404 (1973).

[83]. BRINKMANN, R., Jungpalaozoikum und alteres Mesozoikum in NW-Anatolien, Bull. Min. Res. Expl. Inst. Turkey, **76**, 56 - 67 (1971).

[84]. RADELLI, L., La nappe de Balya - La Zone des polis eggens et l'extension du Vardar en Turquie occidentale, Geologie Alpine, **46**, 169 - 175 (1970).

[85]. BLANC, P., Serie stratigraphique de Çal Köy (Anatolie Occidentale, Turquie): presence de spilites dans le Permien, C. R. Soc. Geol. France, **3**, 100 - 102 (1965).

[86]. ERK, S., Ankara civarında Genç Palezoyikin Kulm fliş formasyonu, Bull. Min. Res. Expl. Ins. Turkey, **88**, 73 - 94 (1977).

[87]. CAREY, S., H. SIGURDSSON, A model of volcanogenic sedimentation in marginal basins, Geol. Soc. London, Spec. Publ. **16**, 37 - 58 (1984).

[88]. ALTINER, D. and A. KOÇYİĞİT, Micropaleontological study of a megablock within the Karakaya Nappe (Hasanoğlan region, Ankara): paleogeographic and tectonic implications, Melih Tokay Symposium 87, Abstracts, 138 - 139 (1987).

[89]. GRANİT, Y. and H. TINTANT, Observation preliminaires sur le Jurassique de la region de Bilecik (Turquie), C. R. Acad. Scien. Paris, **251**, 1801 - 1803 (1960).

[90]. ALTINLI, İ.E., Orta Sakarya Jeolojisi, Cumhuriyet'in 50. Yılı Yerbilimleri Kongresi Tebliğleri, 159 - 191 (1975).

[91]. ALTINLI, İ.E., Geology of the northern portion of the Middle Sakarya River, İst. Üniver. Fen Fak. Mecm., ser. B, **41**, 35 - 56 (1976).

[92]. ALTINLI, İ.E., Geology of the eastern territory of Nallıhan (Ankara Province), İst. Üniver. Fen Fak. Mecm., ser. B, **42**, 29 - 44 (1977).

[93]. ALTINLI, İ.E., O. GÜRPINAR, S. ERŞEN, Erenköy-Dedesakarı (Bilecik İli) alanının jeolojisi, İst. Üniver. Fen Fak. Mecm., Ser. B, **35**, 77 - 83 (1970).

[94]. ALTINLI, İ.E., and S. SANER, Bilecik yakın dolayının jeoloji incelemesi, İst. Üniver. Fen Fak. Mecm., Ser. B, **36**, 9 - 21 (1971).

[95]. ALTINLI, İ.E. and C. YETİŞ, Bayırköy-Osmaneli alanının jeoloji incelemesi, İst. Üniver. Fen Fak. Mecm., Ser. B, **37**, 1 - 18 (1972).

[96]. EROSKAY, O., Geology of the Paşalar gorge Gölpazarı area, İst. Üniver. Fen Fak. Mecm., Ser. B, **30**, 133 - 170 (1965).

[97]. GÜRPINAR, O., Geological investigation of the Bilecik-İnegöl-Yenişehir territories together with a study of engineering properties of the Bilecik Limestone, İst. Üniver. Fen Fak. Mecm., ser. B, **40**, 83 - 113 (1976).

[98]. SANER, S., The depositional associations of Upper Cretaceous-Paleocene-Eocene times in central Sakarya and petroleum exploration possibilities, Proc. 4th Petr. Congr. Turkey, 95 - 115 (1978).

[99]. SANER, S., Mudurnu-Göynük havzasının Jura ve sonrası çökelim nitelikleriyle paleocoğrafya yorumlaması, Türkiye Jeol. Kurumu Bült., **23**, 39 - 52 (1980).

[100]. GENÇ, Ş., Uludağ-İznik arasının jeolojisi, Min. Res. Expl. Inst. Report No. 1 - 122 (1986).

[101]. KRUSHENSKY, R.D., Neogene calc-alkaline extrusive and intrusive rocks of the Karalar-Yeşiller area, northwest Anatolia, Bull. Volcan., **40**, 336 - 360 (1976).

[102]. AYAN, M., Geochronological and petrological studies of the Eybek granodiorite pluton (Edremit), Comm. Fac. Scien. Univ. Ankara, **22**, 19 - 31 (1979).

[103]. FYTIKAS, M., O. GIULIANI, F. INNOCENTI, G. MARINELLI and R. MAZZUOLI, Geochronological data on recent magmatism of the Aegean Sea, Tectonophysics, **31**, 29 - 34 (1976).

[104]. ATAMAN, G., Plutonisme calc-alkalin d'age Alpin en anatolie du nordquest, C. R. Acad. Sc. Paris, D **280**, 2065 - 2068 (1975).

[105]. BİNGÖL, E., M. DELALOYE and G. ATAMAN, Granitic intrusions in western Anatolia: a contribution to the geodynamic study of this area, Eclogae Geol. Helv., **75**, 437 - 446 (1982).

[106]. ZIMMERMANN, J.L., F. SAUPE, S. ÖNGEN and M. ANIL, Oligocene-Miocene K-Ar ages of the quartz-monzonite stocks from Nevruz-Çakıroba (Yenice, Çanakkale, northwest Turkey), Fifth Meeting of the European Union of Geosciences (EUG V), Terra Cognito, 354 - 355 (1989).

[107]. ERCAN, T., Batı Anadolu, Trakya ve Ege adalarındaki Senozoyik volkanizması, Jeoloji Mühendisliği, **10**, 117 - 137 (1979).

[108]. HECHT, J., Zur Geologie von Südost-Lesbos (Griechenland). Zeit. Deutsch. Geol. Ges., **123**, 423 - 432 (1972).

[109]. JACOBSHAGEN, V., Die Trias der mittleren Ost-Agaeis und ihre palaeogeographische Beziehungen innerhalb der Helleniden, Zeit. Deutsch. Geol. Ges., **123**, 445 - 454 (1972).

[110]. BLUMENTHAL, M.M., Das taurische Hochgebirge des Aladağ, neuere Forschungen zu seiner Geographie, Stratigraphie und Tektonik, Publ. Min. Res. Expl. Inst. Turkey, Ser. D, **6**, 1 - 136 (1952).

[111]. TEKELI, O., A. AKSAY, B.M. ÜRGÜN and A. IŞIK. Geology of the Aladağ Mountains. In Geology of the Taurus Belt, MTA Pub., 143 - 158 (1984).

[112]. ŞENGÖR, A.M.C., The Cimmeride orogenic system and the tectonics of Eurasia, Geol. Soc. America Special Paper No. **195**, 1 - 77 (1984).

BİGA YARIMADASI'NIN JEOLOJİSİ VE TEKTONİK EVRİMİ

Özet: Gelibolu ve Biga Yarımadalarında SW-NE yönünde uzanan Tersiyer öncesi dört tektonik zon ayırt edilmiştir. Bunlar kuzeybatıdan itibaren, Gelibolu, Ezine, Ayvacık-Karabiga ve Sakarya zonlarıdır.

Gelibolu Zonu, Geç Kretase/Paleosen yaşta pelajik kireçtaşı, radyolarit, serpantinit, gabro, mavişist gibi kayalardan meydana gelmiş, yığışım prizması niteliğinde bir ofiyolitli melanjdır. Çetmi Ofiyolit Melanjı ismi verilen bu birim Gelibolu Yarımadası'nın Eosen ile başlayan sedimentar istifinin temelini oluşturur.

Gelibolu Zonu'nun güneydoğusunda kıtasal kökenli kayalardan oluşan Ezine Zone yer alır. Ezine Zonu batı kesiminde yeşilşist fasiyesinde metamorfizma geçirmiş. Permo-Karbonifer yaşta sedimenter bir istiften ve bu istifi Triyas'ta üzerlemiş olan bir ofiyolitten, doğuda ise sedimenter kökenli, yüksek dereceli metamorfik kayalardan oluşur.

Ezine Zonu'un güneydoğusunda yer alan Ayvacık-Karabiga Zonu, Gelibolu Zonu gibi, Çetmi Ofiyolit Melanjı'ndan oluşur. Bu melanj içerisinde yer alan eklojit ve Geç Triyas yaşta kireçtaşı blokları Ayvacık-Karabiga Zonu için tipiktir.

Sakarya Zonu başlıca Kazdağ metamorfitlerinden, bu metamorfitleri tektonik olarak üzerleyen Karakaya Kompleksi birimlerinden ve Triyas sonrası çökellerden oluşur. Biga Yarımadası'nda Karakaya Kompleksi benzer yaşta fakat değişik havza koşulları ve tektonik ortamları yansıtan dört tektonostratigrafik birimden meydana gelmiştir: Nilüfer Birimi, Hodul Birimi, Orhanlar Grovakı ve Çal Birimi.

Nilüfer Birimi başlıca yeşil metatüflerden ve bu metatüflerle ardalanmalı mermer ve fillatlardan meydana gelmiştir. En alt Karakaya birimini oluşturan Nilüfer Birimi genellikle doğrudan Kazdağ Grubu gnaysları üzerinde tektonik bir dokanakla yer alır. Hodul Birimi beyaz arkozik kumtaşları ve bunların üzerine gelen değişik boyda Permo-Karbonifer yaşta kireçtaşı olistolitleri içeren kirli kumtaşı ve şeyllerden yapılmıştır. Bazı bölgelerde arkozik kumtaşları içinde spilit tektonik blokları bulunur. Hodul Birimi'nin üst kesiminin yaşı Noriyen'dir. Orhanlar Grovakı sarımsı kahve, monoton grovak ve şeyllerden meydana gelmiştir; grovaklar içerisinde seyrek araseviyeler halinde siyah çörtler ve ufak bloklar şeklinde Alt Karbonifer yaşta siyah kireçtaşları bulunur. Çal Birimi başlıca spilit, grovak, şeyl ve değişik boyda yaygın Permiyen ve spilit blokları içeren olistostromlardan yapılmıştır. Ayrıca Çal Birimi içinde seyrek araseviyeler halinde radyolaryalı çört ve pelajik kireçtaşları bulunur.

Karakaya Kompleksi birimleri karmaşık ve yoğun bir deformasyon geçirmiştir. Yer yer melanj tipi yapıların oluşmasına yol açan bu deformasyondan en fazla Nilüfer ve Hodul birimleri etkilenmiştir. Karakaya Kompleksi birimlerinin stratigrafik temeli genellikle gözlenmez, yalnızca Havran'ın kuzeyinde Hodul Birimi'ne ait arkozik kumtaşları düşük dereceli bir metamorfizma geçirmiş ve deforme olmuş bir granitoid üzerinde uyumsuzlukla yer alır. Triyas öncesi bu granit batı sınırı boyunca düşük dereceli metamorfizma geçirmiş sedimenter kökenli kayaları kesmektedir.

Biga Yarımadası'nda Karakaya birimleri Jura yaşındaki Bayırköy Formasyonu tarafından uyumsuzlukla örtülür. Bayırköy Formasyonu Karakaya birimlerinde gözlenen deformasyon ve metamorfizmadan etkilenmemiştir. Başlıca kumtaşı, silttaşı ve marndan oluşan Bayırköy Formasyonu, genellikle arada bir ammonitico rosso seviyesi ile, Geç Jura-Erken Kretase yaşta Bilecik Kireçtaşı'na geçer. Bilecik Kireçtaşı üzerinde ise parallel bir uyumsuzlukla ince tabakalı marnlı pelajik kireçtaşlarından oluşan Üst Kretase yaşta Vezirhan Formasyonu yer alır. Biga Yarımadası'nda Üst Kretase ile Miyosen arasındaki çökeller, Oligosen sonundaki rejyonal yükselme sonucu, büyük ölçüde aşınmıştır. Alt Miyosen'de yaygın bir kalk-alkalen magmatizma bölgede egemen olmuş ve buna bağlı olarak birçok granodiyorit bileşimli pluton bölgeye yerleşmiş ve geniş alanlar andezit, dasit bileşimli volkanik kayalarla kaplanmıştır.