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TAVŞANLI ZONE: THE NORTHERN SUBDUCTED MARGIN OF THE ANATOLIDE-TAURIDE BLOCK

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ABSTRACT. - The Tavşanlı Zone constitutes the northern margin of the Anatolide-Tauride Block that has undergone high pressure-low temperature metamorphism during the Cretaceous. It is bounded in the north by the İzmir-Ankara suture and in the south by the rocks of the Afyon Zone. The Tavşanlı Zone is subdivided into four tectonic units. At the base there is the Orhaneli Group, which shows a regular stratigraphic succession that has underdone metamorphism at ~24 kbar pressure and 430-500 °C temperature during the Late Cretaceous (~80 Ma). From the base upward the Orhaneli Group consists of micaschist, marble and metabasite-metachert-phyllite, and is tectonically overlain by ophiolitic mélange or directly by ophiolite. The ophiolitic mélange consists of basalt, chert, pelagic shale and limestone, and has undergone an incipient blueschist facies metamorphism. The ophiolite constitutes the topmost member of the tectonic stack. It consists mainly of peridotite (>%90) with minor gabbro and pyroxenite, and is cut by isolated diabase dykes. In the western part of the Tavşanlı Zone all these tectonic units are intruded by Lower to Middle Eocene granodiorites, and in the eastern part of the Tavşanlı Zone the blueschists and ophiolite are overlain by Lower Eocene marine limestones. The northern margin of the Anatolide-Tauride Block was buried in an intra-oceanic subduction zone during the Campanian and Paleocene underwent HP/LT metamorphism. The blueschists were exhumed during ongoing subduction and prior to continental collision through a thrust fault at the base and a normal fault at the top. In terms of tectonic setting and the timing of the geological events, the Tavşanlı Zone exhibits close similarities to the Semail ophiolite and the underlying blueschists.

Key words: Tavşanlı Zone, blueschist, ophiolite, northwest Turkey, subduction.

INTRODUCTION

The Tavşanlı Zone constitutes the northern margin of the Anatolide-Tauride Block, which has undergone high pressure/low temperature (HP/LT) metamorphism during the Cretaceous (Figure 1). It extends for 280 km from Mustafakemalpaşa in the west to Mihaliçcık - Yunak in the east, the extension of the Tavşanlı Zone farther southeast is difficult to follow because of the extensive Neogene cover in central Anatolia (Figure 2). Isolated exposures of blueschists within the Neogene of the central Anatolia suggest that the Tavşanlı Zone extends towards the Bolkar Mountains following the southern margin of the Haymana-Ulukışla basin. The Tavşanlı Zone is in contact in the north with the Sakarya Zone along the İzmir-Ankara suture, in the west with the Bornova Flysch and in the south with the Afyon zones.

Stratigraphic, petrologic and geochronological arguments to be discussed below indicate that the Tavşanlı Zone represents a promontory of the Anatolide-Tauride Block that was subducted and exhumed during the Late Cretaceous. In this respect the Tavşanlı Zone can be compared with the continental HP/LT metamorphic belts such as Oman (e.g., Lippard et al., 1986; El-Shazly et al., 1990; Warren et al., 2005), Cyclades in the Aegean (e.g., Okrusch and Bröcker, 1990) and Alaska (Forbes et al., 1984;

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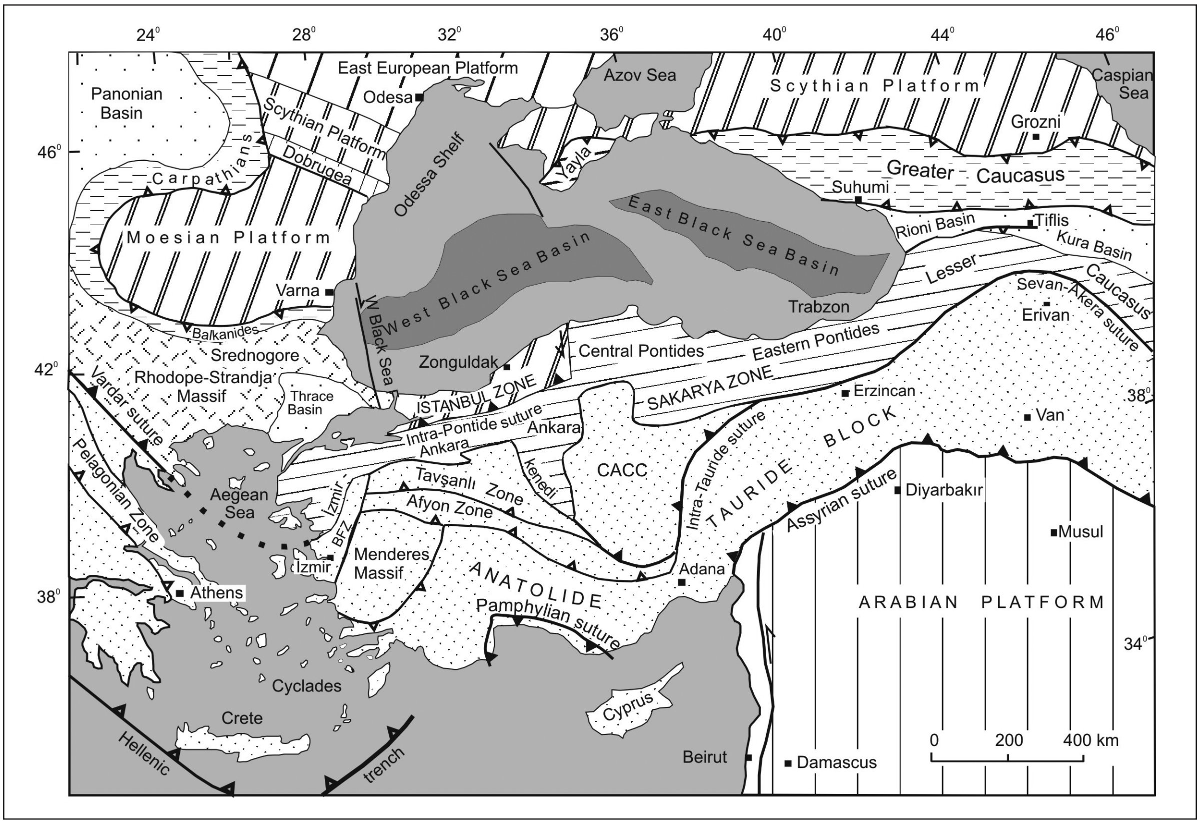

Figure 1 - Tectonic map of Turkey (modified from Okay and Tüysüz, 1999). CACC, Central Anatolian Crystalline Complex; BF, Bornova Flysch Zone.

Patrick and Evans, 1989). In terms of its size and the preservation of the HP/LT mineral assemblages, the Tavşanlı Zone is one of the largest and best preserved blueschists belts in the world (Okay, 1989).

TECTONOSTRATIGRAPHY

The Tavşanlı Zone is subdivided into four tectonostratigraphic units (Figure 3) (Okay, 1984). These are from base upwards: 1) the Orhaneli Group made up of a coherent continental upper crustal stratigraphic sequence, 2) ophiolitic mélange, 3) ophiolite, 4) Eocene sedimentary rocks and Eocene granitoids (Figures 4 and 5). These units are described below.

ORHANELİ GROUP

The Orhaneli Group constitutes a coherent stratigraphic section made up predominantly of metasedimentary rocks (Okay, 1985). It is particularly well described from the western part of the Tavşanlı Zone and is subdivided into three formations. These are from base upwards the Kocasu formation consisting of micaschists, İnönü Marble and the Devlez formation made up mainly of metabasites (Figure 3). Apart from these three formations, the micaschists and marbles, which crop out at around Sivrihisar, are known as the Sivrihisar formation. The stratigraphic base of the Orhaneli Group is not observed, only in a small area around Orhaneli an Ordovician metagranitoid crops out, which

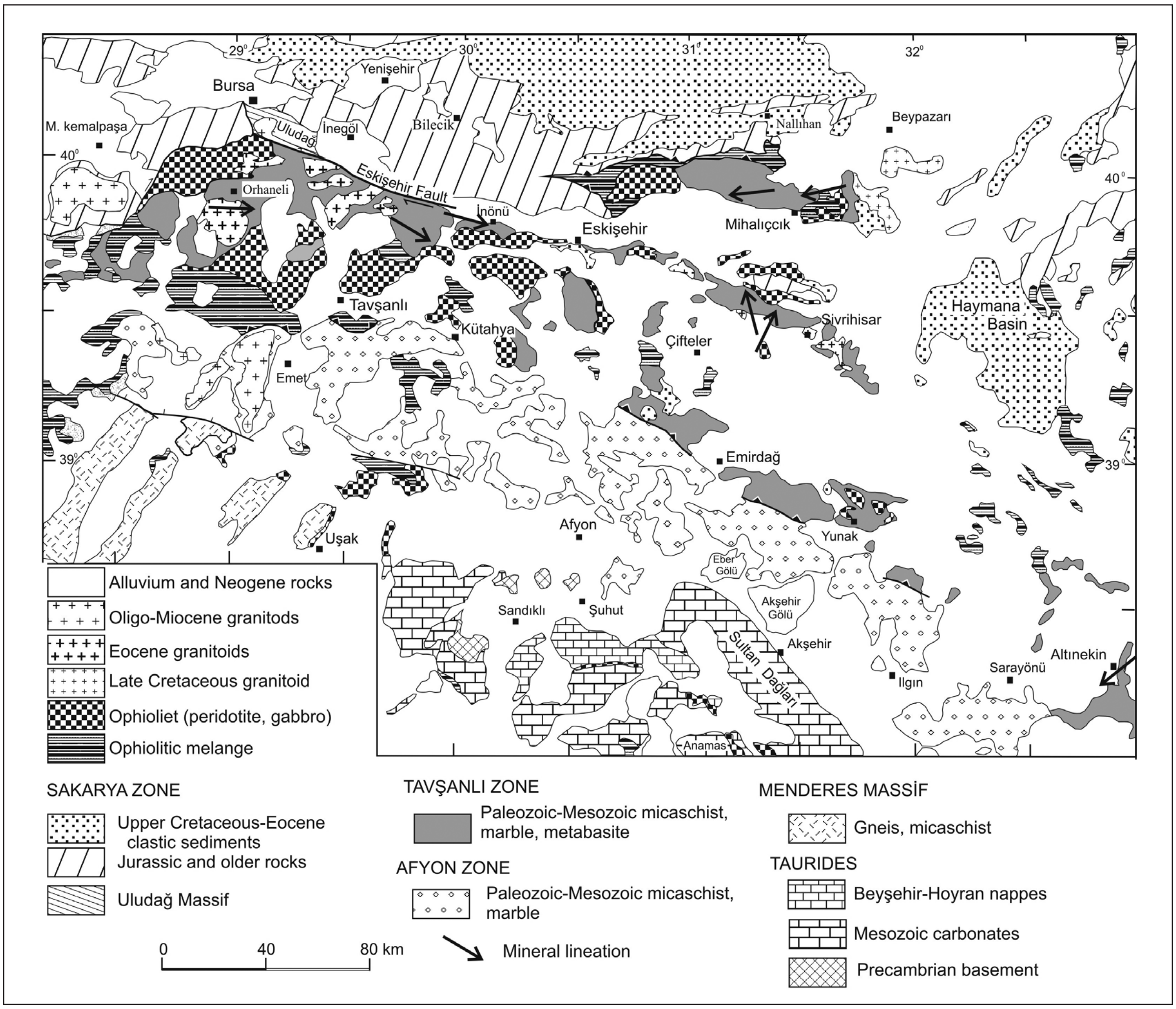

Figure 2- Geological map of the Tavşanlı Zone and the surrounding region. The map is based on Konak (2002) and Turhan (2002).

may represent a tectonic slice from the basement.

Kapanca Metagranitoid - an old granitic basement of Ordovician age

Rocks of the Orhaneli Group must have been deposited on a continental granitic-metamorphic basement; however this basement does not crop out in the Tavşanlı Zone. Only a small metagranitoid, interpreted as a tectonic slice from the basement, crops out in the core of a synform south of Orhaneli (Figure 4, Okay et al., 2008). This Kapanca metagranitoid has a thickness of about 400 meters and takes up an area of 1.5 km^2 (Figure 6). Despite complete recrystallization, the granitic texture is generally well preserved (Figure 7). The granitoid is underlain by the Triassic micaschists and marbles of the Kocasu formation. The Kapanca metagranitoid is made up essentially of quartz and jadeite with minor chloritoid, lawsonite, glaucophane and phengite. Similar HP/LT paragenesis observed in the surrounding micaschists and the subparallel

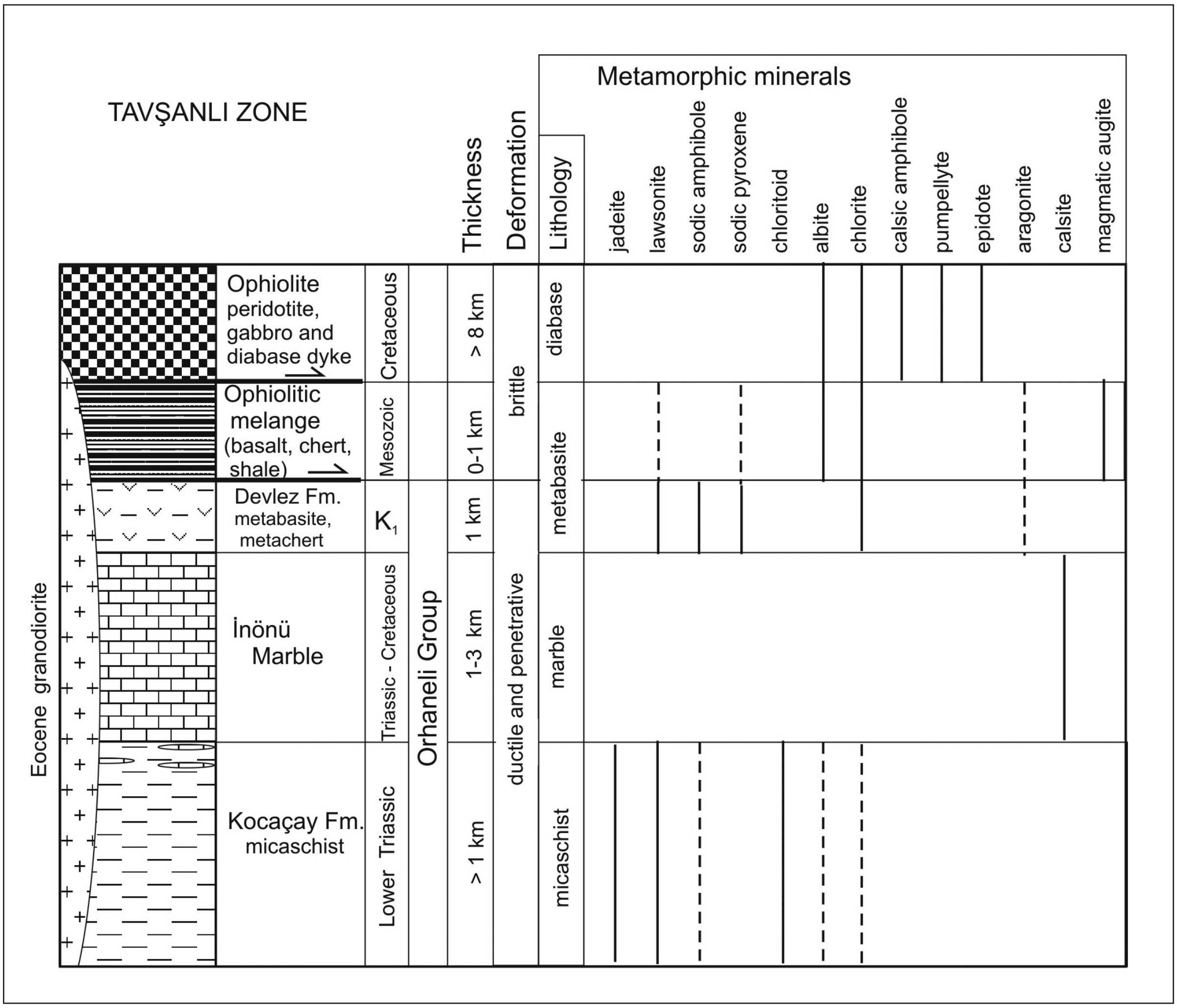

Figure 3- Tectonostratigraphy of the western part of the Tavşanlı Zone.

attitude of the foliation indicate that both units share a common metamorphic and deformational history. The micaschists surrounding the metagranitoid has yielded clastic zircons as young as Permo-Carboniferous showing that the granitoid cannot have intruded into the micaschists. It must have been tectonically emplaced in the Kocasu Formation before the HP/LT metamorphism. Single zircon U-Pb evaporation analysis on zircons from two metagranitoid samples have yielded Middle Ordovician (467.0 ± 4.5 ma) ages (Okay et al., 2008*a*). These ages are interpreted as the crystallization age of the granitic magma.

The crystalline basement of the Anatolide-Tauride Block is made up generally of Pan-African (570-520 ma) granitoids (Satır and Friedrichsen, 1986; Kröner and Şengör, 1990; Hetzel and Reischmann, 1996; Loos and Reischmann, 1999; Gürsü and Göncüoğlu, 2006). These granitoids of Late Proterozoic-Early Cambrian ages crop out over large areas in the Menderes Massif. Granitoids of similar age cover large areas in the northern parts of Africa

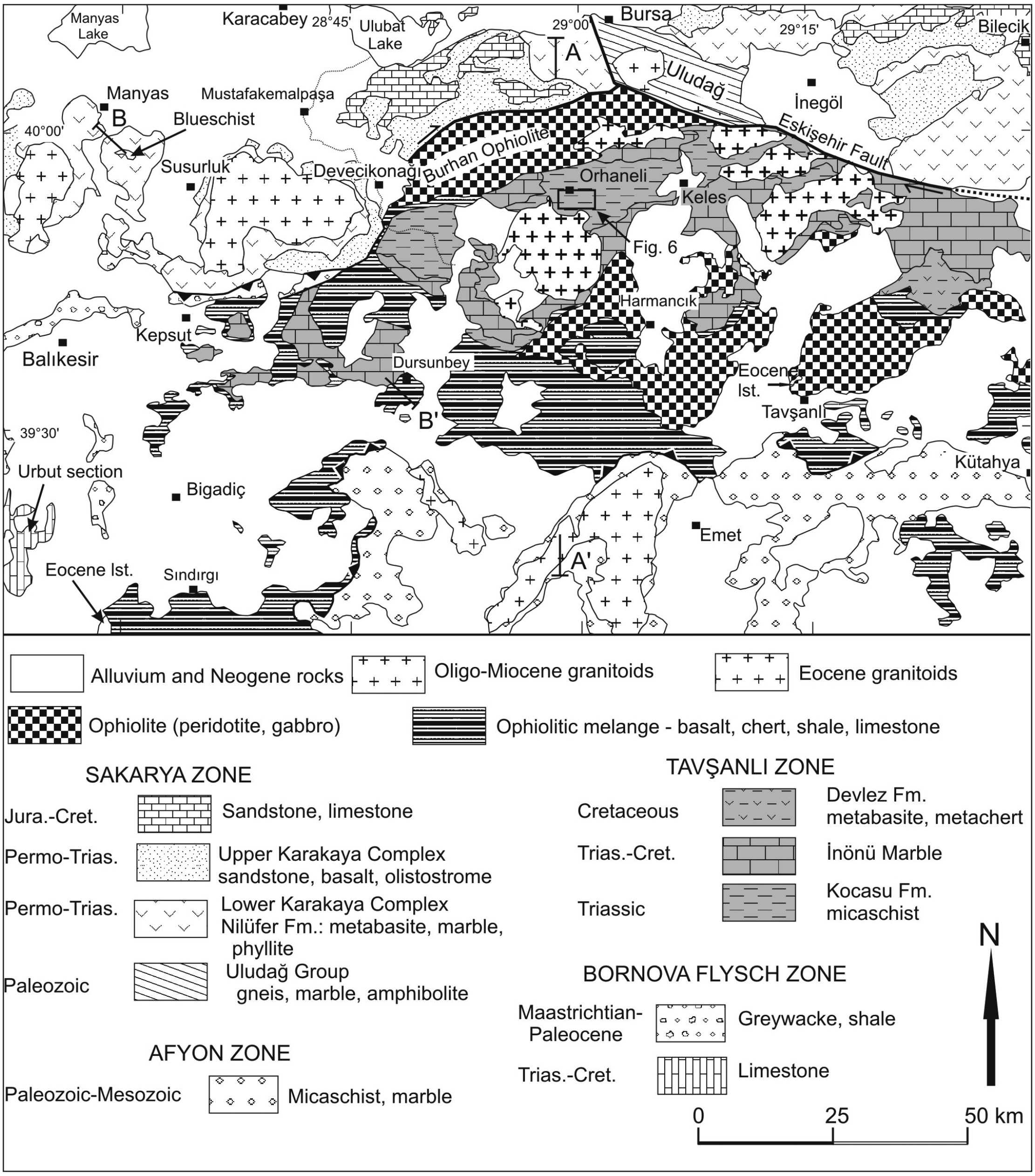

Figure 4- Geological map of the western part of the Tavşanlı Zone.

and Arabia. On the other hand, Ordovician magmatic rocks are described from Western Europe in small continental plates, which have rifted off from the northern margin of Gondwana during the Early Palaezoic (e.g., von Raumer et al., 2002). The Ordovician granitoid in the Tavşanlı Zone represents the eastward extension of this Ordovician magmatism. The Ordovician acidic magmatism is probably related to the rifting of continental terranes, such as the İstanbul Zone, from the northern margin of Gondwana (Okay et al., 2008*a*).

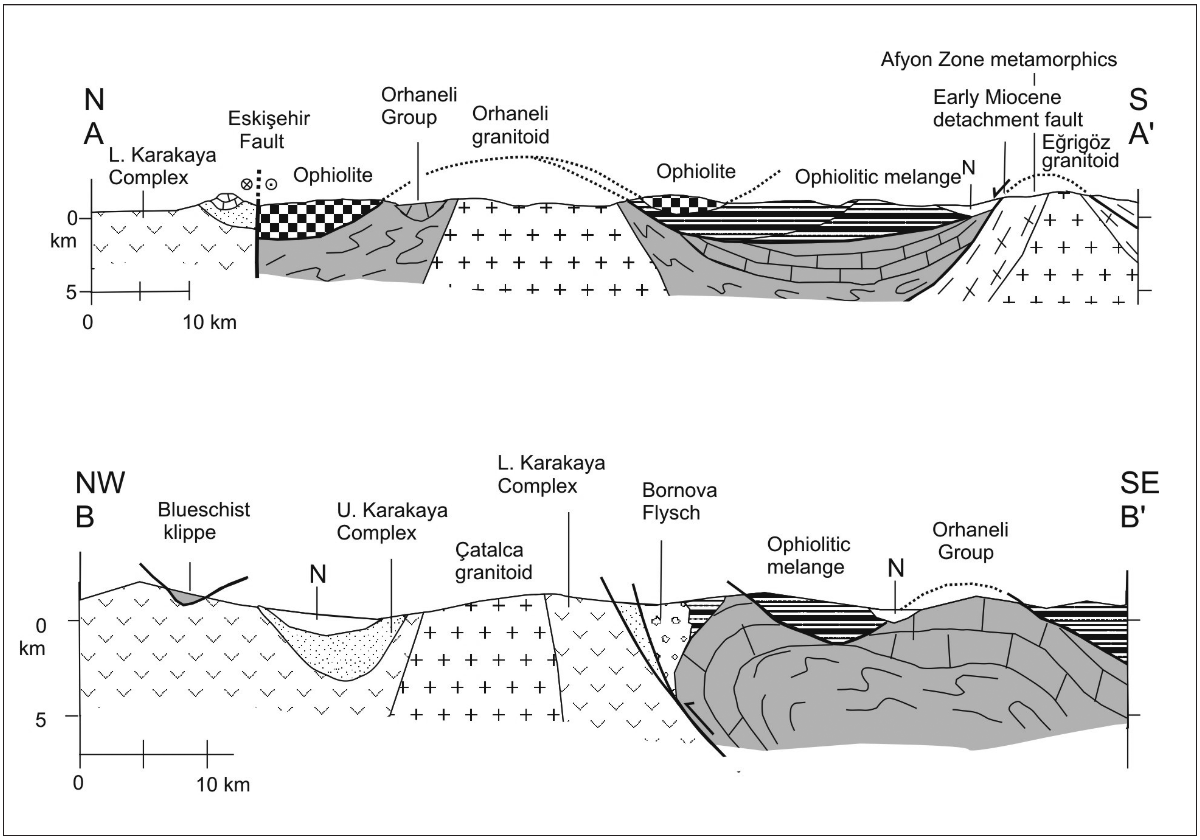

Figure 5- Geological cross-sections from the western part of the Tavşanlı Zone. For location see figure 4.

THE KOCASU FORMATION

The Kocasu Formation is a coherent sequence of quartz-micaschists, with a minimum thickness of 800 meters, at the base of the Orhaneli Group (Okay, 2004). Micaschists form medium-grained, hard, finely banded, grey to light grey rocks. Quartz-rich micaschist bands with a gneissic texture, 0.1 to 2 m in thickness, alternate with finer grained and more mica-rich micaschists (Figure 8, Okay and Kelley, 1994; Okay, 2002). Metaconglomerates with quartz clasts occur rarely within the micaschists. The percentage of mica increases upwards in the metamorphic sequence. South of the town of Devecikonağı there are metaaplitic sills and dykes, 0.5 to 3 m in thickness, within the micaschists (Figure 9). These acidic vein rocks, which were emplaced prior to the HP/LT metamorphism consists of jadeite, quartz and secondary albite (Okay and Kelley, 1994).

The lithological characteristics of the Kocasu formation indicate that before the metamorphism the sequence consisted of an alternation of sandstone and shale, however, the rocks are now completely recrystallized and have lost their primary lithological features. The Kocasu formation passes upwards gradually to the İnönü Marble. The transition zone consists of micaschists intercalated with marble layers.

The Kocasu formation crops out over a large area between Devecikonağı in the west and south of Uludağ in the east (Figure 4). It also crops out northwest of Mihaliççık under the İnönü

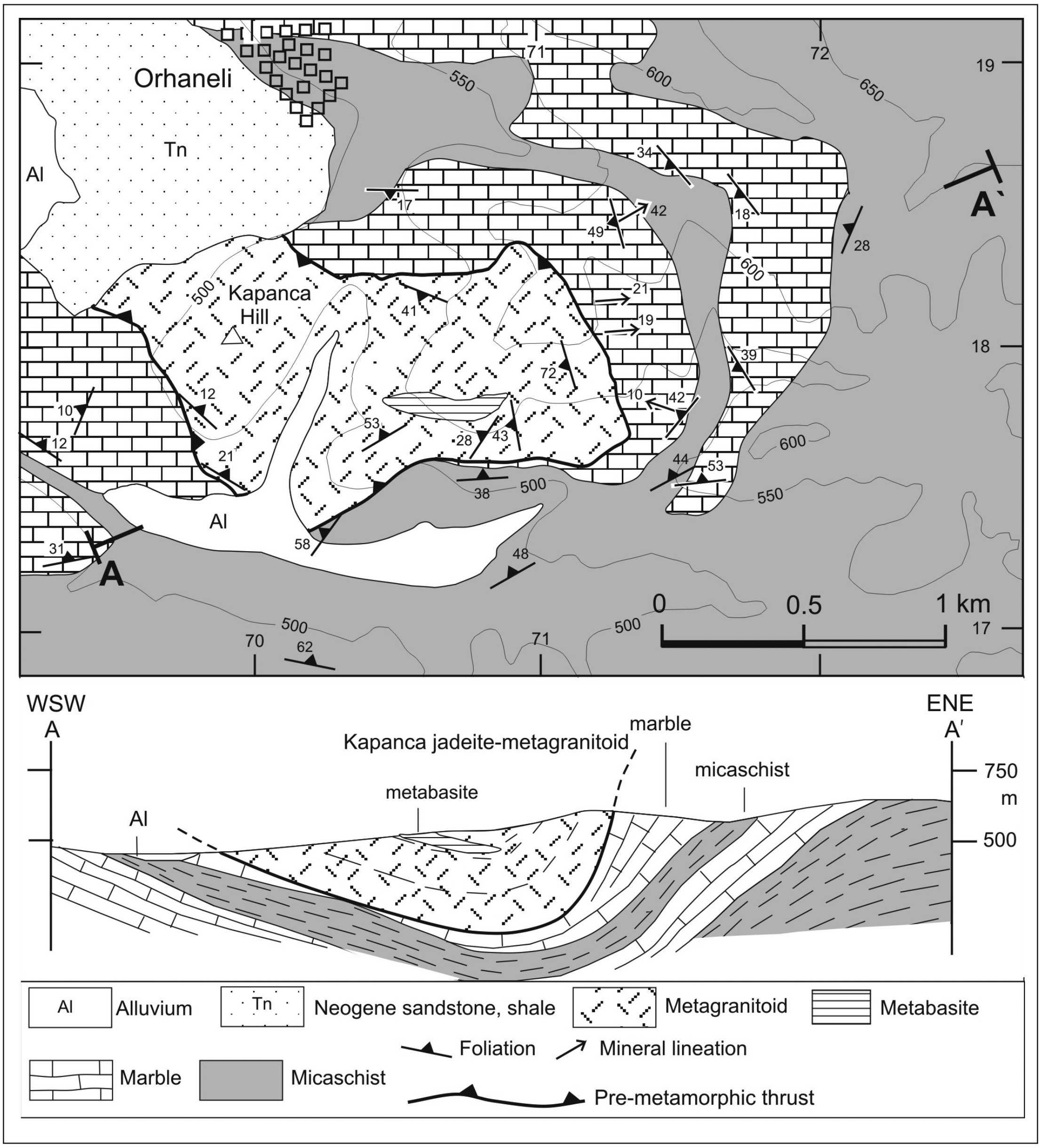

Figure 6- Geological map and cross-section of the Orhaneli region showing the setting of the Kapanca metagranitoid (Okay et al., 2008). For location see figure 4.

Marble. In this latter region, the metaclastic sequence has been called as the Göktepe metamorphics by Göncüoğlu et al. (2000). The stratigraphic base of the Kocasu formation is not exposed; however, as discussed above it is probably underlain by a Lower Palaezoic granitic basement. In order to constrain the depositional age of the Kocasu formation clastic zircons from the micaschists have been dated in the regions of Orhaneli and Keles. The clastic zircons give Ordovician and Permo-Carboniferous age peaks (Okay et al., 2008*a*), which indicate that the

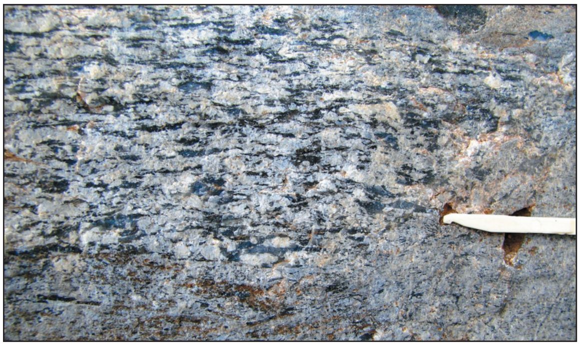

Figure 7- Kapanca metagranitoid. The dark regions are quartz and the white ones jadeite.

Figure 8- Isoclinally folded micaschists of the Kocasu Formation. The thick horizon in the upper part of the photograph is quartz-micaschist of psammatic origin, the lower horizon is finer grained metapelitic micaschist. The jadeite + chloritoid + quartz paragenesis in these rocks show that they were metamorphosed at 80 km depth. East of Orhaneli, the road between Orhaneli and Kabaklar.

Kocasu formation is younger than Carboniferous. A comparison with the general stratigraphy of the Taurides (e.g. Gutnic et al., 1979; Özgül, 1976) suggests a Permo-Triassic, and probably Early to Mid-Triassic age for the Kocasu formation.

The micaschists of the Kocasu formation consists essentially of quartz and phengite. South of Bursa these minerals are accompanied by chlorite, jadeite, chloritoid, lawsonite and albite. The critical HP/LT mineral paragenesis in the micaschists is quartz + phengite + jadeite + chloritoid + glaucophane + lawsonite. Jadeite, locally pseudomorphed by sericite and albite, is common in the Orhaneli region, which possibly is the most jadeite-rich area in the world.

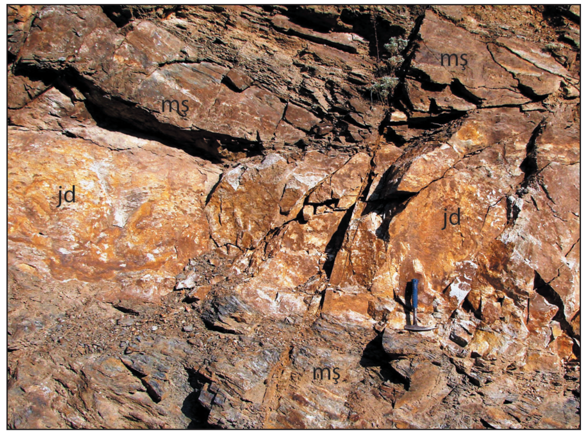

Figure 9- Metaacidic vein rock (jd) within the micaschists (mş) of the Kocasu Formation. The rock is composed of jadeite and quartz. The shaft of the hammer marks the contact between the two rock types. South of Devecikonağı along the Kocasu valley.

İNÖNÜ MARBLE

The marble series with a structural thickness of several kilometers, which overlie the Kocasu formation, is called as the İnönü Marble (Servais, 1982). The İnönü Marble crops out over large areas in the western part of the Tavşanlı Zone in the regions of Dodurga, Tahtaköprü and İnönü (Figure 4, Konak, 2002). İnönü Marble is made up of white, light grey, massif locally banded marble with occasional chert bands. A characteristic microstructural feature of the İnönü Marble is a strong mineral lineation defined by the parallel alignment of elongate calcite grains. The İnönü Marble consists of calcite, although it must have been made up of aragonite during the metamorphism.

The İnönü Marble represents the metamorphosed equivalent of the Tauride Mesozoic carbonate platform. This is supported by the description of Late Triassic (Late Norian) conodonts from the lower parts of the İnönü Marble from east of Orhaneli (Kaya et al., 2001). The upper parts of the İnönü Marble probably extends into the Cretaceous.

DEVLEZ FORMATION

The sequence of metabasite, metachert and phyllite, which lie over the İnönü Marble, is called as the Devlez formation (Okay, 1981; 2004). Metabasites constitute the bulk (more than 80%) of the Devlez formation. They are represented by submarine lavas, pyroclastic rocks and tuffs, which are, however, completely recrystallized with the development of a penetrative metamorphic fabric and new minerals. The typical mine-ral paragenesis in the metabasites is sodic amphibole + lawsonite + chlorite + sodic pyroxene + phengite. Relict magmatic augite is occasionally found in the metabasites. In the metacherts the HP mineral paragenesis is quartz + sodic amphibole + lawsonite + spessartine-rich garnet + phengite + hematite (Okay, 1980*a*). The structural thickness of the Devlez Formation in the region northeast of Tavşanlı is one kilometers. Metabasites and metacherts of the Devlez formation show a strong foliation and a strong mineral lineation defined through the parallel alignment of the sodic amphibole grains. The Devlez formation shares a common metamorphic and deformational history with the underlying İnönü Marble, however, it is possible that it represents an exotic tectonic slice emplaced on the Mesozoic limestones of the İnönü Marble prior to regional metamorphism.

SİVRİHİSAR AND HALİLBAĞI FORMATIONS

In the eastern part of the Tavşanlı Zone, especially in the region of Sivrihisar, The Orhaneli Group is represented by an intercalation of marble and micaschist (Figure 10). These metasedimentary rocks, called as the Sivrihisar formation, have a structural thickness of over three kilometers (Kulaksız, 1981; Gautier, 1984; Monod et al., 1991). Marbles form bands within the micaschists, whose thickness ranges from a few meters to several hundred meters. There are approximately equal amounts of marble and micaschist in the Sivrihisar formation. Apart from these two dominant rock types, there are rare metabasite layers within the micaschists. The Sivrihisar formation probably represents a lateral facies variation of the Kocasu and İnönü formations.

Unlike the western part of the Tavşanlı Zone, HP/LT mineral paragenesis is not well preserved in the Sivrihisar formation. The common mineral assemblage in the micaschists is quartz + albite + chlorite + phengite, and in the metabasites albite + chlorite + actinolite + epidote (Gautier, 1984). However, the occasional presence of lawsonite in the metabasites and in the calcium-rich micaschists and relict sodic amphibole in the metabasites indicates that the Sivrihisar formation has undergone a regional HP/LT metamorphism (Monod et al., 1991), which was subsequently overprinted by a greenschist facies metamorphism.

South of the village of Halilbağı, the Sivrihisar formation is overlain by metabasite, metachert, marble and metaserpentinite, called the Halilbağı formation (Figure 10). The HP/LT mineral paragenesis including lawsonite-eclogites are well preserved in the Halilbağı region, which has been the subject of several detailed petrological studies (Kulaksız, 1978; Monod et al., 1991; Davis and Whitney, 2006, 2008; Whitney and Davis, 2006; Çetinkaplan et al., 2008). In the Halilbağı region, the metabasic rocks consist of an interesting intercalation of blueschist, garnet-blueschist and lawsonite-eclogite. The Halilbağı Formation passes downwards into the Sivrihisar Formation. The nature of the contact between the two formations is difficult to map, as petrologically uninformative marbles crop out at the contact zone. The Halilbağı formation can be correlated with the Devlez formation from the western part of the Tavşanlı Zone.

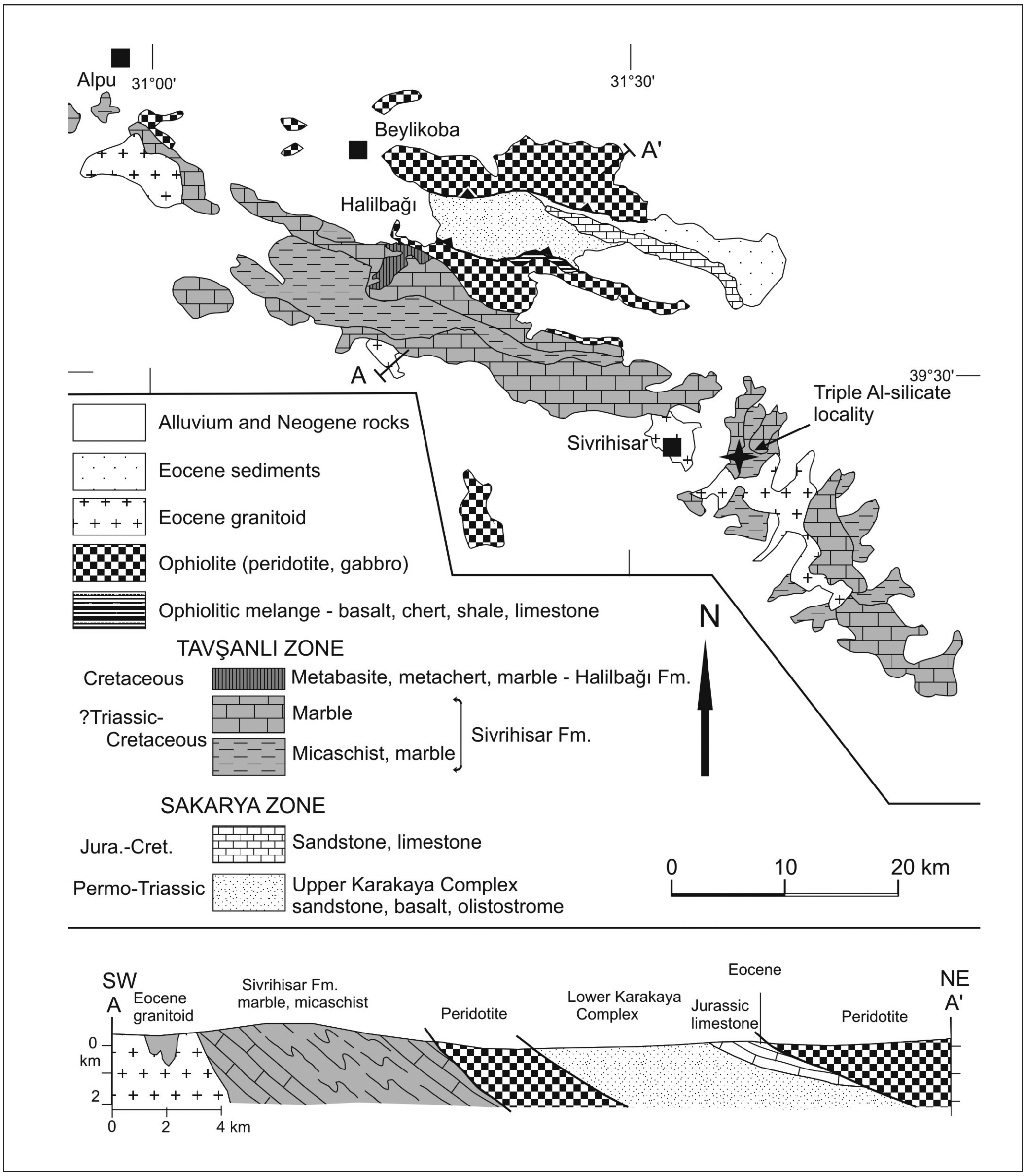

Figure 10- Geological map and cross-section of the Sivrihisar region modified from Monod et al., 1991).

Tectonostratigraphy of the southeastern part of the Tavşanlı Zone

Because of the extensive Neogene cover, rocks metamorphosed in blueschist facies form small isolated outcrops south of the Haymana basin. Within this large area blueschists of the Altınekin region northeast of Konya and those from Yunak have been studied in detail. A metamorphic sequence consisting of marble and phyllite with subordinate metabasite, similar to the Sivrihisar Formation, crops out in the Yunak region (Yeniyol, 1979). Sodic amphibole + lawsonite paragenesis is widely described from the metabasites. This sequence is tectonically overlain by an ophiolitic mélange.

A metamorphic sequence of marble, calcschist, phyllite and metaquartzite, probably Permian to Mesozoic in age, crops out in the Altınekin region northeast of Konya (Karaman, 1986; Özgül and Göncüoğlu, 1999; Eren, 2000; Droop et al., 2005). This sequence metamorphosed in blueschist facies is tectonically overlain by an ophiolitic mélange and ophiolite. The ophiolitic mélange in the Altınekin region shows a distinct blueschist facies metamorphism and associated deformation. The grade of metamorphism and intensity of deformation in the Altınekin region increases upwards in the sequence and from south to north. The typical paragenesis in the metabasites of the ophiolitic mélange is sodic amphibole + epidote ± lawsonite + albite + chlorite + phengite.

Sodic amphibole-bearing metamorphic rocks in the Bolkardağ region south of the Ulukışla basin (Blumenthal, 1956; Çalapkulu, 1980) may represent the eastward extension of the Tavşanlı Zone. Information on the tectonic setting and mineral paragenesis of these rocks are limited.

OVACIK COMPLEX - OPHIOLITIC MELANGE

Slices of ophiolitic mélange rest with tectonic contacts on the Orhaneli Group. The ophiolitic mélange, called as the Ovacık Complex (Kaya, 1972*a, b*), crops out over large areas and consists mainly of basalt, radiolarian chert, pelagic shale and limestone with lesser amounts of serpentinite, talc, greywacke and bedded manganese deposits. The basaltic rocks, which make up at least 60% of the Ovacık Complex, consist generally of pyroclastic rocks and agglomerates; pillow lavas are rare. All the basaltic rocks are spilitized and locally show an incipient high pressure metamorphism. Radiolarian cherts are red, thinly to medium bedded and are intercalated with thin black shale layers; rarely do they show stratigraphic contacts with the basalts. The carbonate rocks are found as clasts and olistoliths in the basalts, 2 cm to several hundred meters across, and as thinly bedded pelagic limestones intercalated with the basalts. The metaphonolites, which today occur as clasts and blocks in the Neogene deposits south of Bursa, were probably once part of the Ovacık Complex (Okay, 1997). They have an interesting mineralogy of jadeite, quartz and K-feldspar and are marketed as a semi-precious stone under the name of purple jade.

The Ovacık Complex and equivalent ophiolitic mélanges crop out widely outside the Tavşanlı Zone within the Afyon Zone, in the Menderes Massif and in the Taurides (Figure 2). As discussed below the Ovacık Complex and the Anatolian Ophiolite probably formed once a continuous tectonic cover over the Anatolide-Tauride Block.

Although the Ovacık Complex is generally known as a mélange, it lacks an easily definable matrix and instead consists of strongly deformed rock types juxtaposed along tectonic contacts. Stratigraphic relation between the different rock types are generally not preserved and it is difficult to follow bedding for more than ten meters without encountering a fault or shear zone. With its lithological features, internal structure and with its incipient HP metamorphism, the Ovacık Complex represents a Tethyan subduction-accretion complex.

Radiolaria from the cherts within the Ovacık Complex from the Tavşanlı and Bornova Flysch zones have given Late Triassic (late Carnian, late Norian), Jurassic, Early Cretaceous (Berriasian-Hauterivian) and Late Cretaceous (Cenomanian, Turonian) ages (Bragin and Tekin, 1996; Tekin et al., 2002; Göncüoğlu et al., 2006). These radiolarian ages indicate that the Neo-Tethyan oceanic crust north of the Anatolide-Tauride Block has a minimum age range from Late Triassic to Late Cretaceous. A 179 ± 15 Ma zircon U-Pb age from a plagiogranite from an ophiolitic mélange near Ankara also indicates the presence of an Early Jurassic oceanic crust in the northern Neo-Tethys (Dilek and Thy, 2006). The geochemistry of the basaltic rocks in the Ovacık Complex shows the presence of several magma types with a dominance of oceanic island and mid-ocean ridge type basalts (Tankut et al., 1998; Rojay et al., 2004; Göncüoğlu et al., 2006; Gökten and Floyd, 2007).

ANATOLIAN OPHIOLITE

Large ophiolite massifs lie tectonically over the Ovacık Complex or directly on the blueschists of the Orhaneli Group. Over 90% of the ophiolitic masses in the Tavşanlı Zone are made up of peridotites; the rest is represented by pyroxenite, gabbro, chromite and diabase dykes. Sub-ophiolitic metamorphic rocks are described from the base of the ophiolites.

The peridotites mainly consist of harzburgite and dunite; lenticular chromite deposits occur within the dunites. The best studied ophiolite is the Burhan ophiolite north of Orhaneli; it consists predominantly (> 90%) of harzburgite and dunite (Figure 4), the rest is made up of gabbro, pyroxenite, chromite and diabase dykes (Lisenbee, 1971; 1972; Tankut, 1980). The harzburgites and dunites form bands, ~2 km thick, intercalated with thinner bands of gabbro and pyroxenite. The bands are transitional over a width of 50 m. The peridotites show a tectonic foliation subparallel to the lithological layering. The thickness of the Burhan ophiolite, measured perpendicular to lithological layering, is over 13 kilometers. The lithological and structural features of the Burhan ophiolite show it to be a deformed cumulate sequence.

The mineral paragenesis in the peridotites of the Tavşanlı Zone is olivine + orthopyroxene + clinopyroxene + chrome-spinel (Lisenbee, 1971; Okay, 1985, Lünel, 1986; Asutay et al., 1989; Önen, 2003). This mineral assemblage is stable at pressures of less than 14 kbar; garnets start to form at higher pressures (Perkins et al., 1981). The paragenesis in the gabbros is plagioclase (An_{89-100}) + clinopyroxene + orthopyroxene + spinel (Önen, 2003). Based on the petrography and geochemistry of the ophiolitic rocks around Kütahya, Önen (2003) argues that they are similar to those formed in the oceans and in the back-arc basins.

Between the İzmir-Ankara suture and the Mediterranean there are several ophiolitic massifs. The ophiolites in this large region show many common lithological and structural features: a) they are generally made up of harzburgite and dunite, b) the peridotites are cut by diabase dykes, c) all of the isotopically dated sub-ophiolite metamorphic rocks in Anatolia are Albian in age, d) the sub-ophiolite metamorphic rocks show a low-grade HP/LT metamorphism that overprints the earlier HT metamorphism (Dilek and Whitney, 1997; Okay et al., 1998; Önen and Hall, 2000). These common features suggest that these ophiolitic massifs formed part of a very large ophiolite obducted over the Anatolide-Tauride Block during the Late Cretaceous (Dilek et al., 1999; Önen 2003). In terms of its size and its association with the HP/LT metamorphic rocks this Anatolian ophiolite nappe can be compared with the Semail ophiolite in Oman.

SUB-OPHIOLITE METAMORPHIC ROCKS

Most ophiolites have a metamorphic sole produced during the intra-oceanic thrusting stage (e.g., Williams and Smyth, 1973; Woodcock and Robertson, 1977). The sub-ophiolite metamorphism forms during the intra-oceanic thrusting through frictional heating and through the downward convection of the heat from the overlying ophiolite body. As the heat is conducted downward, the sub-ophiolite metamorphic rocks show an inverted metamorphic zonation with the metamorphic grade increasing upwards in the sequence. As the sub-ophiolite metamorphism occurs in the oceanic lithosphere, the metamorphic rocks are naturally of oceanic crustal origin.

Sub-ophiolite metamorphic rocks are described from several localities in the Tavşanlı

Zone (Gautier, 1984; Monod et al., 1991; Önen and Hall, 1993, 2000; Okay et al., 1998). The garnet-amphibolites at the base of the Burhan ophiolite have peak P-T values of 8.5 ± 3.5 kbar and ~700 °C (Okay et al., 1998). The pressure values indicate an initial ophiolite thickness of 25 ± 10 km. The amphibolites at the base of the Burhan ophiolite also exhibit a second phase of low-grade HP/LT metamorphism marked by the development of sodic amphibole and very fine-grained aggregates of lawsonite. A similar case has been described from the sub-ophiolite metamorphic rocks in the Central Taurides (Dilek and Whitney, 1997). Hornblende Ar-Ar cooling ages of the sub-ophiolite metamorphic rocks at the base of the Burhan ophiolite are 101.1 ± 3.8 Ma (Harris et al., 1994), and those from the Kütahya region 93 ± 2 Ma (Önen, 2003). These ages are similar to the 95-90 Ma Ar-Ar hornblende and mica ages from the sub-ophiolite metamorphic rocks of the Lycian, Beyşehir, Aladağ, Kızıltepe and Mersin ophiolites in the Taurides (Dilek et al., 1999; Parlak and Delaloye, 1999; Çelik et al., 2006).

DIABASE DYKES

The ophiolites in the Tavşanlı Zone are cut by generally east-west trending diabase dykes. The diabase dykes, which have an average thickness of 1-2 meters, cannot generally be followed along strike for more than 100 meters. The dyke frequency is quite variable and ranges from a single dyke within a stretch of several hundred meters of peridotite to 10 dykes within 30 m of peridotite. The dyke-peridotite contacts are generally faulted due to later brittle deformation, however, in some localities the original intrusive contact are preserved and the dykes can be seen to have narrow chilled margins. This observation indicates that the dykes intruded into cold peridotite (Okay, 1981). The mineral assemblage in the diabase dykes is augite, partly replaced by magmatic hornblende, and altered plagioclase. Plagioclase has commonly altered into very fine grained aggregates of pumpellyite and albite. The mineral assemblage in the diabase dykes indicates that they and by implication the ophiolitic rocks have not undergone the HP/LT metamorphism observed in the underlying Orhaneli Group.

Diabase dykes very similar to those described above occur in the peridotites of the Lycian nappes (Whitechurch et al., 1984) and of the Central Taurides (Lytwyn and Casey, 1995; Parlak, 2000). Whole rock Ar-Ar ages of the diabase dykes cutting the Mersin ophiolite and the sub-ophiolitic metamorphic rocks of the Mersin ophiolite range between 90 Ma and 64 Ma (Parlak and Delaloye, 1996). Considering the large errors associated with the whole rock Ar-Ar dating, and that the emplacement of the ophiolite over the Anatolide-Tauride Block occurred during the Campanian, the crystallization ages of the diabase dykes are expected to be at around 90 Ma.

LOWER EOCENE SEDIMENTARY ROCKS AND EOCENE PLUTONS

In the eastern part of the Tavşanlı Zone ophiolitic rocks, ophiolitic mélange and the blueschists of the Orhaneli Group are unconformably overlain by the Lower Eocene marine sedimentary rocks. The westernmost exposure of the Eocene sediments is found north of Tavşanlı, where the peridotites are unconformably overlain by a 60-m-thick shallow marine sequence of Lower Eocene (Cuisian) sandy and pebbly limestones (Figure 4, Baş, 1986). Farther east, south Eskişehir a Lower Eocene (Cuisian) marine sequence of conglomerate, sandstone, shale and shaley limestone with abundant nummulites, ~300-m-thick, lies unconformably over the ophiolitic gabbros (Figure 2, Gözler et al., 1985). South and west of Çifteler a 300-m-thick sequence of limestone, shaley limestone and marn of Early Eocene age (early Ilerdian-middle Cuisian) lies uncomformably over the metamorphic and ophiolitic rocks (Göncüoğlu et al., 1992; Özgen-Erdem et al., 2007). The stratigraphic data indicate that the Tavşanlı Zone was covered by a shallow sea at the beginning of the Early Eocene (50 Ma).

Apart from the marine Eocene sedimentation, a series of plutons have intruded into the Tavşanlı Zone during the Eocene. These intrusions form a WNW-ESE trending linear belt between Sivrihisar and Bursa (Figure 2, Okay and Satır, 2006). The plutons have generally a granodioritic composition and comprise hornblende and biotite; their ages range from 53 Ma and 45 Ma (Early-Middle Eocene) (Table 1). The 48-Ma-old Topuk pluton farthest west cuts the blueschists of the Orhaneli Group as well as the overlying peridotites indicating that the tectonic contact between these units is pre-Eocene in age (Okay et al., 1998).

The Eocene plutons in the Tavşanlı Zone have a metaaluminous composition and the amount of SiO_2 varies between 63 and 69 %. Enrichment in the LIL elements in the granodiorites indicates a calc-alkaline magma. Relatively low Y and HREE ratios suggest that garnet was not an important restite phase in the region of magma generation and hence the magma was generated at depths of less than 30 kilometers (10 kbar). The Eocene granodiorites have formed by fractionation of mantle-derived magmas in shallow magma chambers and through crustal melting induced by mantle derived basic magmas (Harris et al., 1994; Altunkaynak, 2007; Karacık et al., 2008).

METAMORPHISM AND METAMORPHIC AGES IN THE TAVŞANLI ZONE

The three tectonostratigraphic units of the Tavşanlı Zone show different metamorphic characteristics. The Orhaneli Group has undergone a regional blueschist facies metamorphism (Çoğulu, 1965; 1967; van der Kaaden, 1966; Lünel, 1967; Okay, 1980*a, b*, 1981, 1984, 2002; Servais, 1981; Kaya, 1981; Gautier, 1984; Monod et al., 1991; Davis and Whitney, 2006; Çetinkaplan et al., 2008). The minerals of the blueschist metamorphism are particularly well preserved in the western part of the Tavşanlı Zone. The characteristic HP/LT mineral para-

Table 1- Isotopic ages of the Eocene granitoids in northwest Anatolia

Sivrihisar	53.0 ± 3.0[1]		
Gürgenyayla	45.0[2]		
Tepeldağ	44.7 ± 0.4[3]	45.0 ± 0.2[4]	
Topuk	47.8 ± 0.4[5]		
Orhaneli	52.6 ± 0.4[6]	52.4 ± 1.4[7]	49.8 ± 1.3[8]
Karabiga	52.7 ± 1.9[9]	45.3 ± 0.9[10]	
Kuzey Kapıdağ	39.9 ± 0.8[10]	38.3 ± 0.8[11]	35.5 ± 0.3[11]
Güney Kapıdağ	36.1 ± 0.8[10]	38.2 ± 0.8[10]	35.3 ± 0.3[11]
Avşa	40.9 ± 1.1[12]	44.4 ± 0.4[12]	
Fıstıklı	48.2 ± 1.0[10]	35.4 ± 0.8[10]	

1) Ar-Ar hornblende, Sherlock et al. (1999); 2) Rb-Sr biotite, Ataman (1973 *a,b*);
3) Rb-Sr biotite, Okay and Satır, 2006; 4) U-Pb zircon, Okay and Satır, 2006;
5) Ar-Ar hornblende, Harris et al. (1994); 6) Ar-Ar biotite, Harris et al. (1994);
7) Ar-Ar biotite - in hornfels, Harris et al. (1994);
8) Rb-Sr biotite, Ataman (1972); 9) U-Pb xenotime, Beccaletto et al. (2007);
10) K-Ar hornblende, biotite, Delaloye and Bingöl (2000);
11) Rb-Sr biotite, M. Satır (unpublihed data);
12) K-Ar biotite, Karacık et al. (2008).

genesis in the metabasites is sodic amphibole + lawsonite + chlorite ± sodic pyroxene + phengite + sphene (Çoğulu, 1967; Okay, 1980*a*). Apart from these minerals some metabasites contain garnet. In the metabasites the sodic amphibole is generally of glaucophane and crossite in composition and the sodic pyroxene is chloromelanite. The common mineral paragenesis is the metacherts is quartz + garnet + sodic amphibole + lawsonite + phengite + hematite. In the metacherts the garnet is rich in spessartine and sodic amphibole is magnesio-riebeckite and crossite in composition.

The characteristic HP/LT mineral paragenesis in the micaschists of the Kocasu Formation and of the Kapanca metagranitoid is: jadeite + chloritoid + lawsonite + glaucophane + quartz + phengite (Okay and Kelley, 1994; Okay, 2002; Okay and Satır, 2006; Okay et al., 2008). This mineral assemblage in the metapelitic rocks shows that the peak pressure and temperature values of the metamorphism in the western part of the Tavşanlı Zone is 24±3 kbar and 430 ± 30 C° (Okay, 2002).

In the Halilbağı region, where the temperature during the metamorphism was slightly higher, the metabasic rocks contain the mineral assemblages characteristic for the lawsonite-eclogite: sodic pyroxene + garnet + sodic amphibole + lawsonite (Kulaksız, 1981; Monod et al., 1991; Davis and Whitney, 2006, 2008; Whitney and Davis, 2006; Çetinkaplan et al., 2008). The lawsonite eclogites in the Halilbağı region are intercalated with blueschists and garnet-bearing blueschists. The peak P-T conditions in the Halilbağı region have been estimated as 22-24 kbar pressure and 520 C° temperature (Davis and Whitney, 2008).

The P-T conditions of the HP/LT metamorphism in the Sivrihisar Formation is not well constrained because of the strong overprint by the greenschist facies metamorphism. In the southeastern part of the Tavşanlı Zone in the Konya-Altınekin region the peak P-T conditions of the blueschist facies metamorphism has been estimated as 9-11 kbar pressure and 375-400 °C temperature (Droop et al., 2005).

Metamorphism, in terms of recrystallization and associated deformation, is not apparent in the field in the rocks of the Ovacık Complex. However, close petrographic examination of the basalts usually reveals HP minerals such as lawsonite, sodic pyroxene and aragonite in the veins and amygdales of the rock (Okay, 1982). The magmatic clinopyroxene in the basalts has commonly been partly or totally pseudomorphed by aegerine-rich sodic pyroxene. Another interesting feature of the Ovacık Complex is the replacement of primary micrite in the pelagic limestones by several centimeters large aragonite crystals (Topuz et al., 2006). This case of prograde aragonitization from northeast of Tavşanlı, unique in the world, points to the very low temperature and relatively high pressure values in the subduction-accretion complex.

The Ovacık Complex is made up of numerous tectonic slices buried to different depths; therefore it is not possible to give a single peak P-T value for the unit. The general absence of recrystallization indicates that the temperatures were below 200 C°. The HP minerals in the basalts and their composition suggest that the pressure was in the range of 4 to 7 kbar (Okay, 1982; Topuz et al., 2006).

In some parts of the Ovacık Complex metamorphism is more apparent, foliation has started to develop in finer grained rocks and the colour of the red cherts has become pale as a result of recrystallization. In such basaltic rocks the magmatic texture is still largely preserved, however the magmatic mineral assemblage is replaced by sodic pyroxene + lawsonite + chlorite + sphene. With an increase in penetrative deformation and in the intensity of foliation, sodic amphibole forms at the rims of the sodic pyroxenes through the reaction: sodic pyroxene + chlorite + quartz = sodic amphibole + lawsonite (Okay, 1980 *b*).

The Anatolian Ophiolite does not show any regional metamorphism. The magmatic mineral assemblage of plagioclase and pyroxene is well preserved in the ophiolitic gabbros (Önen, 2003). The diabase dykes in the peridotites consists of magmatic hornblende, which has partly or totally replaced augite, and altered plagioclase. The plagioclase in the diabase dykes is altered to fine grained aggregates of pumpellyite and albite. The secondary mineral assemblage in the diabase dykes is indicative for very low-grade metamorphism and shows that the Anatolian Ophiolite has not been affected by the HP/LT metamorphism observed in the Orhaneli Group.

The tectonic contact between the Orhaneli Group and the overlying ophiolitic mélange-ophiolite represents a major jump in the metamorphic grade. Rocks below the contact have undergone metamorphism at pressures of ca. 24 kbar and those above at pressures below 8 kbar; this difference in metamorphic pressures indicates that a rock column of 50 km in thickness has been excised along the contact.

Some regions in the Tavşanlı Zone show an Eocene high temperature - low pressure metamorphism related to the granitic magmatism. Such metamorphism has developed in the margins of the Eocene granodiorites at around Uludağ, and is characterized by the formation of andalusite + cordierite + biotite + muscovite + K-feldspar + plagioclase mineral assemblage in the micaschists of the Kocasu formation (Okay and Satır, 2006). In this region the development of a new foliation defined by biotite, cordierite and muscovite shows that the metamorphism is not just static contact metamorphism. The peak P-T conditions of this metamorphism overprinting the blueschist facies metamorphism is estimated as 2 ±1 kbar and 575 ± 50 °C Rb-Sr muscovite and biotite isotopic analyses from a single specimen gave cooling ages of 46 ± 3 Ma and 39 ±1 Ma, respectively (Okay and Satır, 2006).

A different type of metamorphism in the Orhaneli Group has been described from southeast of Sivrihisar. The metamorphic belt extending southeastward from Sivrihisar is made up of an intercalation of marble, calc-schist and mica-schist (Figure 10, Türkay and Kuşçu, 1992). Lithostratigraphically the sequence resembles the Sivrihisar formation, however, Whitney (2002) has described from this region micaschists and quartzites with andalusite, kyanite, sillimanite, staurolite and garnet. The relation of this amphibolite facies metamorphism with the blueschist facies one is not known. However, considering the widespread presence of Eocene granitoids in this region, it is likely that the amphibolite facies metamorphism is of Eocene age.

K-Ar and Ar-Ar isotopic determinations in HP/LT metamorphic rocks give frequently incompatible and contradicting ages due excess argon and incomplete equilibration at these low temperatures (e.g., Arnaud and Kelley, 1995; Scaillet, 1996; Sherlock and Kelley, 2001; Warren et al., 2005). The K-Ar and Ar-Ar ages from the blueschists of the Tavşanlı Zone range between 175 Ma and 60 Ma (Çoğulu and Krummenacher, 1967; Okay and Kelley, 1994; Harris et al., 1994; Sherlock et al., 1999). A detailed study by Sherlock (1998) on this topic has shown that this spread in Ar-Ar ages has no geological meaning but is due to excess argon. In contrast Rb-Sr phengite ages from four blueschists sampled between Tavşanlı and Sivrihisar are coherent and range between 78.5 ± 1.6 Ma and 82.8 ± 1.7 Ma (Sherlock et al., 1999). The relatively low peak metamorphic temperatures in the Orhaneli Group (430-450 °C) imply that the Rb-Sr ages reflect the age of the HP/LT metamorphism. Similar Rb-Sr phengite ages from the blueschists of the Tavşanlı and Sivrihisar regions, separated by a distance of 130 km, indicates that the Orhaneli Group has undergone the HP/LT metamorphism during the Campanian (80 ± 2 my). The isotopic ages from the blueschists of the Konya-Altıntekin region also correspond to Campanian (Giles Droop, oral communication).

A firm upper age limit for the HP/LT metamorphism is given by the 53 Ma Sivrihisar (Sherlock et al., 1999) and Orhaneli granodiorites (Harris et al., 1994), which are intrusive in the blueschists and shows that the Orhaneli Group has reached upper crustal levels during the Early Eocene.

The Ovacık Complex has undergone a low-grade HP/LT metamorphism. The age of this metamorphism is not known. Furthermore, as the Ovacık Complex represents an accretionary complex, one is not dealing with a single age of metamorphism. Considering that the northward subduction of the Neo-Tethys has started in the Albian, the metamorphism in the Ovacık Complex could have encompassed the whole of the Late Cretaceous.

STRUCTURAL FEATURES OF THE TAVŞANLI ZONE

The metamorphic rocks of the Orhaneli Group show penetrative foliation and isoclinal folding, and have lost all traces of their primary sedimentary protolith. The foliation is gently dipping except at some fault zones. A mineral stretching lineation has developed in marble, metachert and metabasites defined mainly by calcite and sodic amphibole (Monod et al., 1991; Okay et al., 1998; Masuda et al., 2004). The mineral lineation trends approximately east-west in the Orhaneli, Tavşanlı and Mihaliçcık regions subparallel to the İzmir-Ankara suture (Figure 2), and N-S and NE-SW in the Sivrihisar (Monod et al., 1991) and Konya-Altınekin regions (Eren, 2000), respectively. The axis of the isoclinals folds are subparallel to the mineral lineation. These observations indicate a very strong stretching subparallel to the present trend of the İzmir-Ankara suture. The shapes of the clasts in the metaconglomerates of the Orhaneli Group also indicate that the finite strain ellipsoid is of constrictional type (Figure 11). An analysis of the crystallographic orientation of the quartz crystals in the blueschists of the Halilbağı Formation also produced a finite strain ellipsoid that falls in the field of apparent constriction ($0.2 < k < 0.8$, Monod et al., 1991). This deformation is coeval with the HP/LT metamorphism.

REGIONAL CONTACTS OF THE TAVŞANLI ZONE

TAVŞANLI ZONE - BORNOVA FLYSCH ZONE

The Tavşanlı Zone is in contact with the Bornova Flysch Zone south of Mustafakemalpaşa. The Bornova Flysch Zone consists of blocks and tectonic slices in a highly deformed Maastrichtian - Paleocene clastic matrix. In the western part of the Bornova Flysch Zone these blocks and slices are mainly tectonized Mesozoic limestone olistoliths, and in the eastern part mainly basalt, radiolarian chert and rare serpentinite. The Early Eocene (Cuisian, Akdeniz, 1980) marine limestones, which lie unconformably over the Bornova Flysch Zone indicate that the deformation is Paleocene in age (Figures 4 and 12). In contrast, the HP/LT metamorphism and the associated deformation in the Tavşanlı Zone are of Campanian age (~80 Ma), and the blueschists of the Tavşanlı Zone were on or near the surface before the Early Eocene and probably by Maastrichtian.

South of Susurluk and Mustafakemalpaşa three important tectonic belts - Bornova Flysch Zone, Tavşanlı Zone and Sakarya Zone are in contact (Figure 4, Akyüz and Okay, 1996). South of Çataldağ the ophiolitic mélange passes westward into the greywacke and shale of the Bornova Flysch Zone. Both the ophiolitic mélange and the greywackes of the Bornova Flysch Zone are underlain by the İnönü Marble of the Tavşanlı Zone in the Kepsut-Dursunbey region, and by the Nilüfer Formation of the Sakarya Zone in the Çataldağ area (Figures 4 and 5). Blueschist metabasites and greywacke crop out as a klippe over the Nilüfer Formation in the region south of Manyas (Akyüz and Okay, 1999). This relation indicate that the Orhaneli Group is thrust northwestward over the Sakarya Zone during the Late Paleocene-Eocene.

TAVŞANLI ZONE - SAKARYA ZONE

The Tavşanlı Zone is in contact with the Sakarya Zone along the İzmir-Ankara suture. In

Figure 11- Metaconglomerate with quartz clasts in the Kocasu Formation. The photographs are taken parallel (a) and at right angles to the finite axis of elongation and define a prolate finite strain ellipse.

the west the suture is represented by the dextral Göktepe and Eskişehir faults. The Eskişehir Fault, with a total dextral strike-slip displacement of over 100 km, constitutes the İzmir-Ankara suture and the northern boundary of the Tavşanlı Zone between south of Bursa and Eskişehir (Figure 2). Most of the displacement along the Eskişehir Fault occurred during the Oligocene (Okay et al., 2008 *b*). East of Eskişehir the contact between the Tavşanlı and Sakarya zones jumps to the north. In this region and around Sivrihisar the ophiolitic mélange of the Tavşanlı Zone and the Karakaya Complex of the Sakarya Zone form south-vergent imbricate tectonic slices (Figures 10 and 13, Göncüoğlu et al., 2000; Okay et al., 2002). Farther east in the region south of Nallıhan the Nilüfer Formation (Lower Karakaya Complex) has been thrust southward over the ophiolitic mélange. These thrusts affect Middle Eocene rocks and hence their latest movements are younger than Middle Eocene (Yıkılmaz, 2002).

The İzmir-Ankara suture, which trends east-west between Bursa and Mihaliççık, makes a sharp southward bend east of Mihaliççık and extends south-southeastwards towards Konya. In this region the Sakarya Zone is represented by the Haymana basin, the contact of the Haymana basin and the blueschists of the Tavşanlı Zone lies under the Neogene sediments.

TAVŞANLI ZONE - AFYON ZONE

The Tavşanlı Zone is in contact in the south with the Afyon Zone (Figure 2). The Afyon Zone, which is also part of the Anatolide-Tauride Block, is constituted mainly of metasedimentary rocks that have undergone low grade regional HP/LT metamorphism characterized by the common presence of carpholite (Candan et al., 2005). The rocks in the Afyon Zone commonly contain greenschist facies mineral paragenesis, the typical mineral assemblage in the metabasites is "actinolite + chlorite + albite + epidote; sodic amphibole is found rarely and lawsonite has not been described from the metabasites of the Afyon Zone (Candan et al., 2005). Carpholite, which is not described from the Tavşanlı Zone, has widely developed in the phyllites of the Afyon Zone. The peak P-T conditions of metamorphism in the Afyon Zone is 6-9 kbar and 350 °C, whereas in the Tavşanlı Zone they are 24 kbar and 440 °C.

Marble crops out in the contact zones between the Tavşanlı and Afyon zones, as the carbonate rocks are insensitive to metamorphic pressures it is difficult to map a contact between the two tectonic zones in such areas. An exception to this occurs in the Altınekin region north of Konya. Here the blueschists are thrust over low-grade metamorphic rocks of the Afyon Zone known as the Ladik metamorphics (Eren, 1996; Eren et al., 2004; Droop et al., 2005). The contact between the Ovacık Complex and the Afyon Zone in the region south of Tavşanlı has been reworked by the Early Miocene extensional tectonics (Figures 4 and 5, Işık and Tekeli, 2001; Işık et al., 2004).

GEOLOGICAL EVOLUTION

EARLY CRETACEOUS - BEGINNING OF SUBDUCTION AND FORMATION OF THE BACK-ARC OCEANIC CRUST

In the Early Cretaceous the northern part of the Anatolide-Tauride Block was a passive margin facing north to the İzmir-Ankara Neo-Tethyan ocean (Figure 14a). The Pontides, consisting of the Sakarya and İstanbul zones, lay north of the İzmir-Ankara ocean. Paleontological data from the radiolarian cherts from the ophiolitic mélange show that the age of the İzmir-Ankara ocean extends from Mid Triassic to Cretaceous (Bragin and Tekin, 1996; Tekin et al., 2002).

Data on the age of the initiation of northward subduction of the İzmir-Ankara Neo-Tethyan ocean are not clear. The arc magmatism in the Pontides has started in the Turonian, however, isotopic ages of the Elekdağ blueschists and eclogites in the Central Pontides indicate ongoing subduction during the Albian (~105 ma, Okay et al., 2006). The geochemical features of the Pontide arc magmatism (Keskin et al., 2003) and the observation that the magmatism was wholly submarine are indicative of an extensional tectonic regime. This extensional tectonic setting might have resulted in the development of an oceanic back-arc basin over the northward subducting Neo-Tethyan ocean (Figure 14c-d). The Anatolian ophiolite represents not the İzmir-Ankara Neo-Tethyan ocean but rather this back-arc oceanic lithosphere formed during the Cretaceous. There is no isotopic or paleontological data on the age of this back-arc type Anatolian ophiolite. However, studies in the ophiolites worldwide have shown that the age of the sub-ophiolite metamorphism is close to the age of the ophiolite (e.g., Spray et al., 1984; Hacker et al., 1996). The 95-90 Ma ages from the sole of the Anatolian Ophiolite (Dilek et al., 1999; Parlak and Delaloye, 1999; Çelik et al., 2006) suggest that the Anatolian Ophiolite is of Cenomanian age.

LATE CRETACEOUS (CAMPANIAN) - CONTINENTAL SUBDUCTION AND METAMORPHISM

Following the complete subduction of the İzmir-Ankara Neo-Tethyan oceanic lithosphere, the northern margin of the Anatolide-Tauride Block entered in an intra-oceanic subduction zone and was metamorphosed at HP/LT conditions (Figure 14e-f). The Rb-Sr ages from the Orhaneli Group blueschists indicate that the continental crust was subducted to a depth of 80 km at 80 Ma (Campanian). The obduction of the ophiolite over the continental crust must have started with an intra-oceanic slicing (Figure 14e). The 90-95 Ma isotopic ages from the sub-ophiolite metamorphic rocks shows that the intra-oceanic thrusting began in the Cenomanian-Turonian. Biostratigraphic data from the blocks of the Bornova Flysch Zone also indicate that the foundering of the Anatolide-Tauride carbonate platform as a result of compression started at the late Cenomanian (Figure 12, Okay and Altıner, 2007).

The lithostratigraphic features of the Orhaneli Group imply that these rocks were not deposited on a continental margin but rather on a shelf or on a shallow-marine platform. This suggests that during the continental subduction the continental margin deposits were detached from their substratum and thrust southward (Figure 14f-g). These continental margin sequences are probably represented by the Lycian Nappes in the Taurides. The Mesozoic carbonate stratigraphy within the blocks of the Bornova Flysch Zone shows great similarity to some of the units in the Lycian Nappes (Okay and Altıner, 2007).

LATE CRETACEOUS (MAASTRICHTIAN) - PALEOCENE - EXHUMATION

The Lower Eocene marine deposits in the Tavşanlı Zone show that by the end of the Paleocene the Orhaneli Group was on the surface or very close to the surface. The marine character of the Early Eocene sediments indicates that the crust was of normal thickness in the Tavşanlı Zone at this time. The post-tectonic Eocene granodiorites, which intrude the Orhaneli Group, the ophiolitic mélange and the ophiolite in the Tavşanlı Zone also indicate that the main tectonism in the Tavşanlı Zone was completed by the end of the Paleocene.

Stratigraphic and sedimentological data from the Sakarya Zone indicate that the blueschists of the Orhaneli Group were locally on the surface by the Maastrichtian. In the southern part of the Sakarya Zone and in the Haymana basin the Maastrichtian deposits are represented by thick flysch-type clastics (Figure 12). In contrast, in the northern parts of the Sakarya Zone and in the İstanbul Zone the Maastrichtian-Paleocene interval is represented by deposition of marine limestone and marl. This shows that the source of the Maastrichtian clastics lay south of the Sakarya Zone. Although continental collision between the Sakarya Zone and the Anatolide-Tauride Platform had not started by the Maastrichtian, the two terranes must have been in close proximity. During the Maastrichtian the Sakarya Zone was receiving detritus from the uplifted and eroding Tavşanlı Zone. Upper Campanian - lower Maastrichtian debris flows with glaucophane-lawsonite pebbles have been described within the 5000-m-thick flysch sequence of the Haymana basin, (Batman, 1978), furthermore, serpentinite and blueschist clasts are common in the Paleocene-Eocene sandstones and conglomerates (Norman and Rad, 1971). Maastrichtian sandstones of the Gölpazarı Group from the region of Nallıhan contain clastic glaucophane grains (Yıkılmaz, 2002).

Two coeval tectonic processes were responsible for the exhumation of the Orhaneli Group blueschists that were buried to 80 km depth (Okay et al., 1998). The first one is the detachment of the Orhaneli Group from its crystalline basement and its exhumation within the subduction channel bounded by a thrust at the base and a normal fault at the top (Figure 14g). The other process is the rupture of the subducting oceanic lithosphere from the continental one.

PALEOCENE - CONTINENTAL COLLISION

The continental crust thickens in the region of continental collision, undergoes uplift and erosion. Consequently an upward coarsening and regressive clastic sedimentation is observed in such regions, which is followed by uplift and erosion. The first clastic sedimentation on top of pelagic carbonates in the southern parts of the

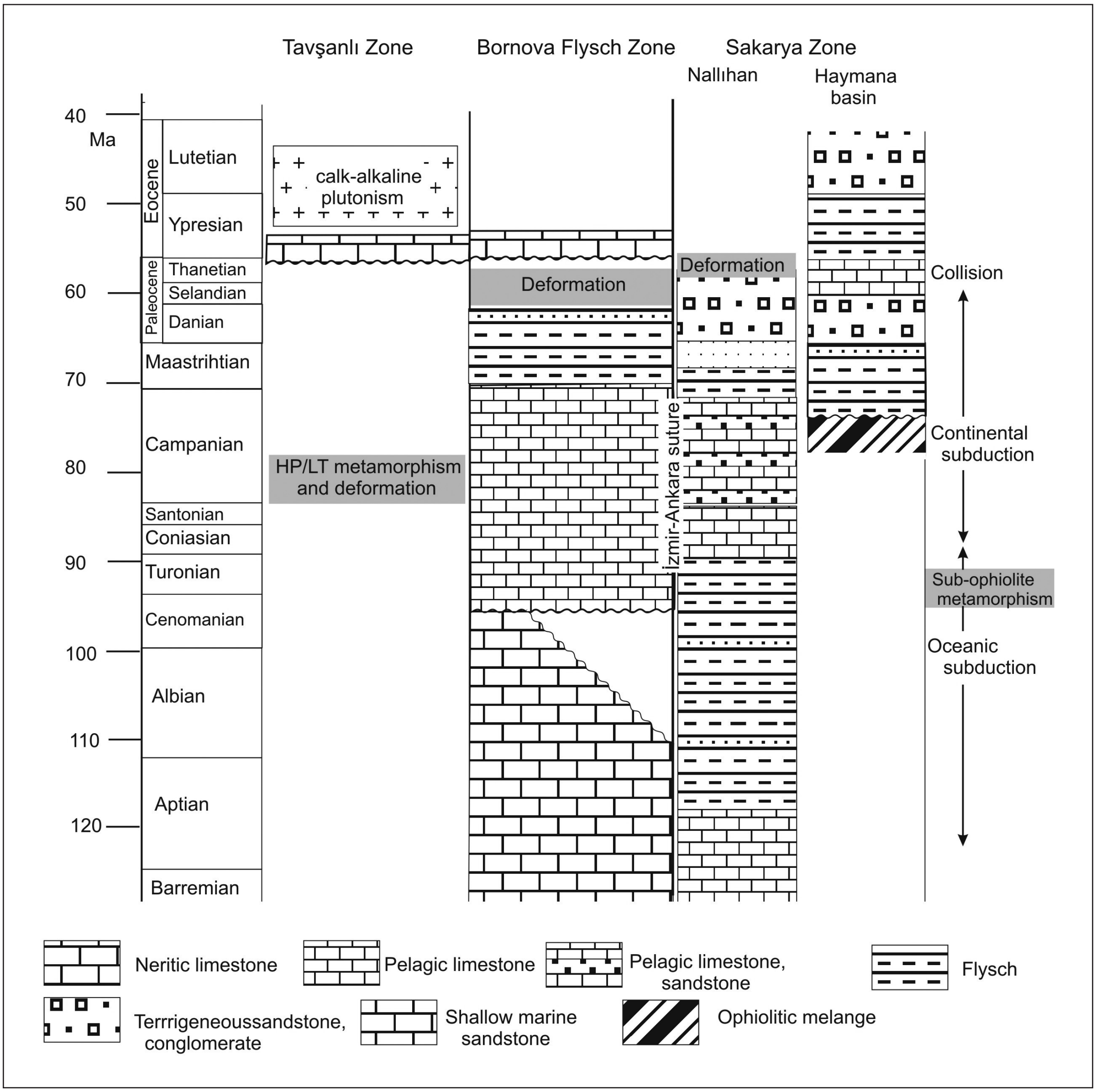

Figure 12- Stratigraphic and tectonic evolution of the Tavşanlı, Sakarya and Bornova Flysch zones.

Sakarya Zone starts in the Middle to Late Albian, and the siliciclastic turbidites intercalated with pelagic carbonates continue into the Campanian and Maastrichtian. In the late Maastrichtian the flysch deposition gives way to sedimentation of shallow marine sandstone, and in the Paleocene fluviatile sandstone and conglomerate are deposited (Tansel, 1980; Yılmaz, 2008). The sedimentary data suggests that the collision between the Tavşanlı and Sakarya zones started in the Paleocene. A transition from the deep sea Maastrichtian turbidites to Paleocene continental clastics is also observed in the Haymana basin (Ünalan et al., 1976).

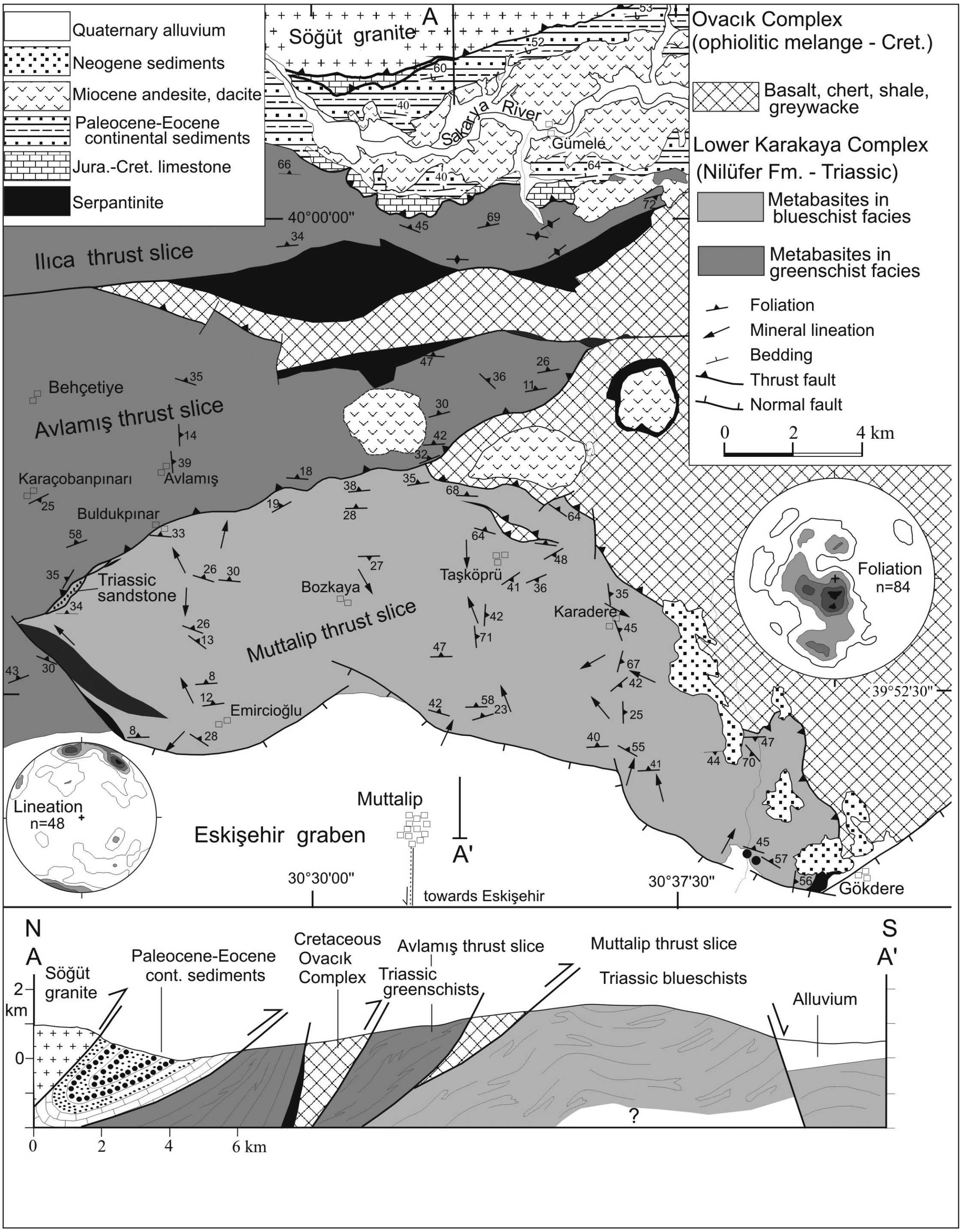

Figure 13- Geological map and cross-section of the region north of Eskişehir illustrating the imbricate tectonic contacts between the Tavşanlı and Sakarya zones (modified from Okay et al., 2002).

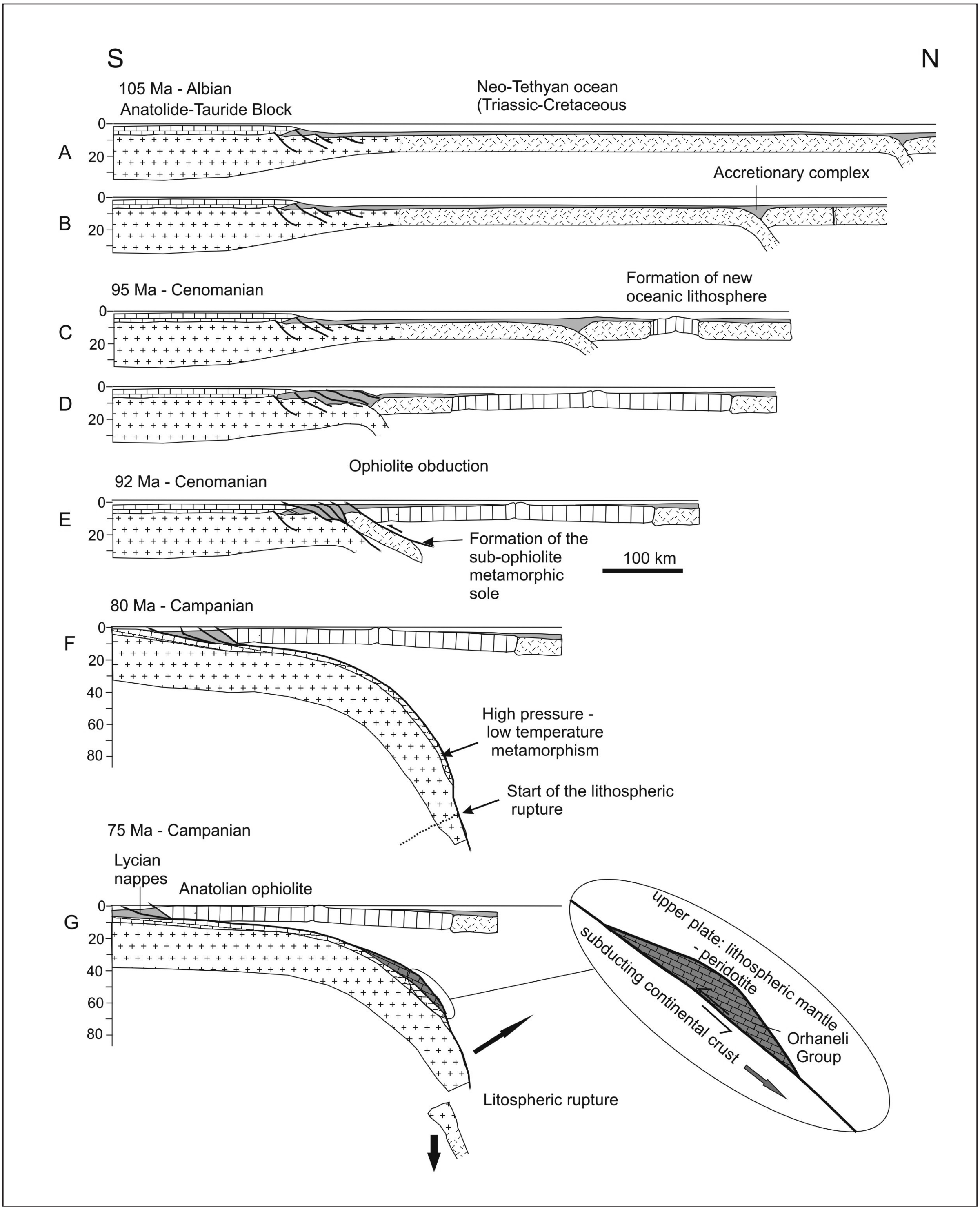

Figure 14- Gelogical evolution of the Tavşanlı Zone. For explanation see the text. The Figure is inspired from Lippard et al. (1986).

Sedimentary sequences on both sides of a suture are expected to show features of deposition on continental margins. However, such sequences are not recognized north and south of the İzmir-Ankara suture in northwest Turkey. Shallow marine Jurassic limestones crop out within 1.5 km of the İzmir-Ankara suture south of Bursa (Figure 4). In contrast in the Eastern Pontides the Jurassic-Cretaceous sediments show an increasingly deeper marine character towards the İzmir-Ankara-Erzincan suture. The absence of such deep marine Jurassic-Cretaceous sequences in the western part of the Sakarya Zone suggests major strike-slip faulting following continental collision (e.g. Okay et al., 2008).

EOCENE - CALK-ALKALINE MAGMATISM AND ASSOCIATED LOW-PRESSURE METAMORPHISM

Rocks of the Tavşanlı Zone are unconformably overlain by the Lower Eocene shallow marine limestones. This provides an upper age limit for the deformation related to continental collision in the Tavşanlı Zone. Furthermore, several Early to Mid-Eocene calc-alkaline plutons have intruded the Tavşanlı Zone between 53 and 45 Ma. These Eocene plutons are of post-tectonic character and intrude the Orhaneli Group, ophiolitic mélange and the ophiolite and cut the tectonic contacts between these units. A low pressure dynamo-thermal metamorphism has developed around the Eocene plutons south of Uludağ characterized by the andalusite + cordierite + biotite + muscovite + K-feldspar + plagioclase paragenesis in the metapelitic rocks (Okay and Satır, 2006).

Two hypotheses have been suggested for the genesis of Eocene magmatism: slab-break off (Altunkaynak, 2007; Karacık et al., 2008) and arc magmatism (Okay and Satır, 2006). In the slab-break off hypothesis asthenospheric mantle intrudes into the rupture between the oceanic and continental lithosphere and the additional heat brought by the asthenospheric mantle leads to partial melting and magmatism. Both hypotheses result in the generation of magmas with similar geochemical and petrographic features. Nevertheless, the extension of the Eocene plutonic belt 140 km northwest of the İzmir-Ankara suture to the Marmara island and Karabiga makes the magmatic arc hypothesis more probable. Furthermore, as discussed above, the rupture between the oceanic and continental lithosphere most probably occurred during the Maastrichtian and not in the Eocene.

DISCUSSION AND CONCLUSIONS

The Tavşanlı Zone provides one of the best examples of continental crust subducted to a depth of 80 km and exhumed, while preserving to a large extent the HP/LT mineral assemblages. Most probably a major part of the subducted continental crust, including the lower crust, will never be exhumed. This has major implications in terms of the heterogeneity of the mantle and magma genesis.

The deformation and metamorphism in the Tavşanlı Zone is of Campanian age and constitutes the beginning Alpide orogeny in the western Anatolia. The deformation migrated southward and affected the Menderes Massif and most of the Taurides during the Mid Eocene; during the Miocene the Lycian nappes were thrust over the Tauride autochthon (e.g. Gutnic et al., 1979).

The Tavşanlı Zone shows strong similarities to the Semail ophiolite and the underlying HP/LT metamorphic rocks in terms of tectonic setting, geological evolution and in the timing of the deformational and metamorphic events. The Semail ophiolite has a length of over 400 km and a width of 150 km, its thickness prior to emplacement is thought to be 15-20 km (Lippard et al., 1986; Hacker et al., 1996); the thickest part of the ophiolitic sequence (8-12 km) is made up of peridotites (Boudier and Coleman, 1981; Lippard et al., 1986). The zircon ages from the plagiogranites of the Semail ophiolite (95.4-

94.5 my) and the radiolarian ages from the cherts overlying the ophiolite show that the Semail ophiolite is Cenomanian in age. The ~93.5 Ma hornblende Ar-Ar ages from the subophiolite metamorphic rocks show that within 2 ma following the formation of the Semail ophiolite at a mid-ocean ridge, it was emplaced, probably along a transform fault, over the neighbouring oceanic crust (Hacker et al., 1996; Warren et al., 2005). The Ar-Ar ages from the base of the Anatolian Ophiolite are also in the range of 95-90 Ma. The Semail ophiolite was first emplaced over an oceanic crust and then over the continental margin of Arabia. During its emplacement over the Arabia margin, it bulldozed the continental margin sequences in its front. These continental margin sequences, which crop out southwest of the Semail ophiolite, are known as the Hawasina nappes and show close similarities to the Lycian Nappes in the Taurides. The Arabian continental crust under the Semail ophiolite underwent HP/LT metamorphism during the Campanian (82-79 my, e.g. Warren et al., 2005), which is of the same age as the HP/LT metamorphism in the Tavşanlı Zone. The blueschists and eclogites under the Semail ophiolite are unconformably overlain by the marine Eocene deposits, as in the Tavşanlı Zone (Poupeau et al., 1998). The main difference between the Tavşanlı Zone and Oman is that in the Tavşanlı Zone the ophiolite emplacement was followed by the continent-continent collision, whereas Indian ocean lies north of the Semail ophiolite. Another difference is that the Semail ophiolite is thrust over the Arabian platform, whereas the Anatolian ophiolite over the Anatolide-Tauride Block. The northern and southern branches of the Neo-Tethys, which bound the Anatolide-Tauride Block, join up in Iran and continue southeastward as the Zagros Neo-Tethyan ocean. The Anatolian ophiolite is derived from the İzmir-Ankara Neo-Tethyan ocean (the northern branch of the Neo-Tethys), and the Semail ophiolite from the Zagros ocean.

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